Fisheries New Zealand

Tini a Tangaroa

Fisheries Science and Information

Fisheries Assessment Plenary

November 2019

Stock Assessments and Stock Status

ISBN (print): 978-1-99-001723-0
ISBN (online): 978-1-99-001721-6

Compiled and published by
Fisheries New Zealand
Fisheries Science and Information
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PO Box 2526, Wellinton 6011
New Zealand

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Facsimile: 04-894 0300

This publication is also available on the Ministry for Primary Industries website

Or at

fs.fish.govt.nz under document library and stock assessment plenary.

Cover images: Red gurnard and sea perch – Fisheries New Zealand Observer Programme

Printed by: Graphic Press & Packaging, Levin

Preferred citation
Fisheries New Zealand (2019). Fisheries Assessment Plenary, November 2019: stock assessments and stock status. Compiled by the Fisheries Science and Information Group, Fisheries New Zealand, Wellington, New Zealand. 579p

PREFACE

Fisheries Assessment Plenary reports have represented a significant annual output of Fisheries New Zealand (FNZ) and its predecessors for the last 35 years. The Plenary is now more than 2200 pages long and is split into four volumes, three of which are produced in May and one in November of each year. The Plenary reports provide summaries of the available information and are in turn supported by 70–100 more detailed reports published on-line each year.

The November 2019 Fisheries Plenary Report summarises fisheries, biological, environmental, stock assessment and stock status information for New Zealand's commercial fish species or species groups in a series of Science Working Group (SWG) or Plenary reports. Each species or species group is split into 1–10 stocks for management purposes. The November Plenary includes SWG and Plenary summaries for species that operate on different management cycles to those summarised in the May Plenary Report (which in 2019 included 83 species or species groups). It includes Highly Migratory Species (HMS), rock lobster, scallops and dredge oysters, covering 18 species in total.

Over time, continual improvements have been made in data acquisition, stock assessment techniques, the development of reference points to guide fisheries management decisions, and the provision of increasingly comprehensive and meaningful information from a range of sources, and peer review processes. SWG and Plenary meetings have continued the effort to populate the Status of the Stocks summary tables, which are used to provide comprehensive summary information about current stock status and the prognosis for these stocks, to evaluate fisheries performance relative to the 2008 Harvest Strategy Standard for New Zealand Fisheries and other management measures, and to rank the quality of assessment inputs and outputs based on the 2011 Research and Science Information Standard for New Zealand Fisheries.

Over the past few years, sections on environmental and ecosystem considerations have also been developed for some species by the SWGs that oversee aquatic environment and biodiversity. Sections on how ocean warming, ocean acidification and other ecosystem trends affect, for example, productivity and fish distributions will be incorporated as new information becomes available. Fisheries New Zealand (FNZ) recognises the need to increase our knowledge of the impacts of important environmental factors.

The Plenary reports take into account the most recent data and analyses available to SWGs and Fisheries Assessment Plenary meetings, and also incorporate relevant analyses undertaken in previous years. Due to time and resource constraints, recent data for some stocks may not yet have been fully analysed by the SWGs or the Plenary.

I would like to recognise and thank the large number of research providers and scientists from research organisations, academia, the seafood industry, marine amateur fisheries, environmental NGOs, customary non-commercial interests and FNZ; along with all other technical and non-technical participants in present and past SWG and Plenary meetings for their substantial contributions to this report. My sincere thanks to each and all who have contributed.

I would also like to pay particular tribute to FNZ's past and present Science Officers who put tireless effort into checking and collating each Plenary report. The Science Officer for this report was Josh van Lier.

I am pleased to endorse this document as representing the best available scientific information relevant to stock and fishery status, as at 30 November 2019.

Pamela Mace
Principal Science Advisor Fisheries, Fisheries New Zealand

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November 2019: Introductory section to Yellowfin tuna

Introduction

This report summarises the conclusions and recommendations from the meetings of the Fisheries Assessment Working Groups and the Fisheries Assessment Plenary held since last year's Plenary report was published. The meetings were convened to assess the fisheries managed within the Quota Management System, as well as other important fisheries in the New Zealand EEZ, and to discuss various matters that pertain to fisheries assessments.

In addition, summaries of environmental effects of fishing from research presented to the Aquatic Environment Working Group (AEWG) that have relevance to fishery management have been incorporated for selected species. Paragraph 11 (page 14) of the Terms of Reference for Fisheries Assessment Working Groups (FAWGs) includes "…information and advice on other management considerations (e.g., …by-catch issues, effects of fishing on habitat…)", and states that "Sections of the Working Group reports related to bycatch and other environmental effects of fishing will be reviewed by the Aquatic Environment Working Group although the relevant FAWG is encouraged to identify to the AEWG Chair any major discrepancies between these sections and their understanding of the operation of relevant fisheries". In addition, the Terms of Reference for the AEWG (Paragraph 9, page 17) specifies the need "to review and revise existing environmental and ecosystem consideration sections of Fisheries Assessment Plenary report text based on new data or analyses, or other relevant information".

The report addresses, for each species, relevant aspects of the Fisheries Act 1996 and related considerations, as defined in the Terms of Reference for Fisheries Assessment Working Groups for 2019. In all cases, consideration has been based on and limited by the best available information. The purpose has been to provide objective, independent assessments of the current status of the fish stocks.

There are two types of catch limits used in this document – total allowable catch (TAC) and total allowable commercial catch (TACC). The current definition is that a TAC is a limit on the total removals from the stock, including those taken by the commercial, recreational and customary non-commercial sectors, illegal removals and all other mortality to a stock caused by fishing. A TACC is a limit on the catch taken by the commercial sector only. The definition of TAC was changed in the 1990 Fisheries Amendment Act when the term TACC was introduced. Before 1990, the term TAC applied only to commercial fishing. In the Landings and TAC tables in this report, the TAC figures equate to the TACC unless otherwise specified.

Only actual TACCs are provided. The actual TACCs are the values as of the last day of the fishing year; e.g., 30 September.

In considering customary non-commercial, and recreational interests, the focus has been on current interests and activities rather than historical activities. In most cases, there is little information available on the nature and extent of non-commercial interests, although estimates of recreational harvest are available in some instances. Information on illegal catches and other sources of mortality is provided where available.

Yield Benchmarks
The biological reference points, Maximum Constant Yield (*MCY*) and Current Annual Yield (*CAY*) first used in the 1988 assessment continue to be used in a small number of stock assessments. This approach is described in the section of this report titled "Guide to Biological Reference Points for Fisheries Assessment Meetings".

Sources of Data
A major source of information for these assessments is the fisheries statistics system. It is important to maintain and develop this system to provide adequate and timely data for stock assessments.

Other Information
For some assessments, draft Fisheries Assessment Reports that more fully describe the data and the analyses have been prepared in time for the Working Group or Plenary process. Once finalised, these documents are placed on the Fisheries New Zealand website in a searchable database.

Environmental Effects of Fishing
The scientific information to assess the environmental effects of fishing and enable this outcome comes primarily from research commissioned by Fisheries New Zealand and, for protected species only, the Department of Conservation (DOC). The work is reviewed by the Aquatic Environment Working Group (AEWG) (or a similar DOC technical working group) or by the Biodiversity Research Advisory Group (BRAG). Fisheries New Zealand has developed an “Aquatic Environment and Biodiversity Annual Review”, which summarises the current state of knowledge on the environmental interactions between fisheries and the aquatic environment. The Aquatic Environment and Biodiversity Annual Review assesses the various known and potential effects of fishing on an issue-by-issue basis (e.g., the total impact of all bottom trawl and dredge fisheries on benthic habitat), whereas relatively brief fishery-specific summaries have been progressively included in this report since 2005, starting with hoki. These fishery-specific sections are reviewed by AEWG rather than by the FAWGs responsible for the stock assessment sections in each Working Group report.

Status of Stocks Summary Tables
Since 2009, the key information relevant to providing more comprehensive and meaningful information for fisheries managers, stakeholders and other interested parties has been summarised at the end of each chapter in a table format using the Guidelines for Status of the Stocks Summary Tables on pages 33–38. Beginning in 2012, Status of Stocks tables have incorporated a new science information quality ranking system, as specified in the Research and Science Information Standard for New Zealand Fisheries (2011). Beginning in 2013, Status of Stocks tables have incorporated explicit statements regarding the status of fisheries relative to overfishing thresholds.

Glossary of Common Technical Terms

Abundance Index: A quantitative measure of fish density or abundance, usually as a relative time series. An abundance index can be specific to an area or to a segment of the **stock** (e.g., mature fish), or it can refer to abundance stock-wide; the index can reflect abundance in numbers or in weight (**biomass**).

AEWG: The Aquatic Environment (Science) Working Group.

Age frequency: The proportions of fish of different ages in the **stock,** or in the **catch** taken by either the commercial fishery or research fishing. This is often estimated based on a sample. Sometimes called an age composition.

Age-length key: The proportion of fish of each age in each length-group in a sample of fish.

Age-structured stock assessment: An assessment that uses a model to estimate how the numbers at age in the stock vary over time in order to determine the past and present **status** of a fish **stock**.

a_{50}: Either the age at which 50% of fish are mature (= A_M) or 50% are recruited to the fishery (=A_R).

AIC: The Akaike Information Criterion is a measure of the relative quality of a statistical model for a given set of data. As such, AIC provides a means for model selection; the preferred model is the one with the minimum AIC value.

A_M: *Age at maturity* is the age at which fish, of a given sex, are considered to be reproductively mature. See **a_{50}**.

AMP: ***Adaptive Management Programme***. This involves increased **TACC's** (for a limited period, usually 5 years) in exchange for which the industry is required to provide data that will improve understanding of **stock status**. The industry is also required to collect additional information (biological data and detailed catch and effort) and perform the analyses (e.g. **CPUE** standardisation or age structure) necessary for monitoring the **stock.**

ANTWG: Antarctic (Science) Working Group.

A_R : *Age of recruitment* is the age when fish are considered to be **recruited** to the fishery. In **stock assessments**, this is usually the youngest age group considered in the analyses. See **a_{50}**.

a_{to95} : The number of ages between the age at which 50% of a stock is mature (or recruited) and the age at which 95% of the stock is mature (or recruited).

B_o: *Virgin biomass, unfished biomass*. This is the theoretical **carrying capacity** of the **recruited** or **vulnerable** or **spawning biomass** of a fish **stock**. In some cases, it refers to the average **biomass** of the **stock** in the years before fishing started. More generally, it is the average over recent years of the biomass that theoretically would have occurred if the stock had never been fished. B_0 is often estimated from stock modelling and various percentages of it (e.g. 40% B_0) are used as **biological reference points (BRPs)** to assess the relative status of a **stock**.

B_{AV} : The average historical **recruited biomass**.

Bayesian stock assessment: an approach to stock assessment that provides estimates of uncertainty (**posterior distributions**) of the quantities of interest in the assessment. The method allows the initial uncertainty (that before the data are considered) to be described in the form of **priors**. If the data are informative, they will determine the posterior distributions; if they are uninformative, the posteriors will resemble the **priors**. The initial model runs are called **MPD** (mode of the posterior distribution) runs, and provide point estimates only, with no uncertainty. Final runs (Markov Chain Monte Carlo runs or **MCMCs)**, which are often very time consuming, provide both point estimates and estimates of uncertainty.

B_{BEG}**:** The estimated **stock biomass** at the beginning of the fishing year.

$B_{CURRENT}$**:** Current **biomass** in the year of the assessment (usually a **mid-year biomass**).

Benthic - the ecological region at the lowest level of a body of water, including the sediment surface and some sub-surface layers

Biological Reference Point (BRP): A benchmark against which the **biomass** or abundance of the **stock,** or the **fishing mortality rate** (or **exploitation rate**), or **catch** itself can be measured in order to determine **stock status**. These reference points can be **targets**, **thresholds** or **limits** depending on their intended use.

Biomass: Biomass refers to the size of the **stock** in units of weight. Often, biomass refers to only one part of the **stock** (e.g., **spawning biomass, vulnerable biomass** or **recruited biomass**, the latter two of which are essentially equivalent).

B_{MSY}**:** The average **stock biomass** that results from taking an average catch of ***MSY*** under various types of harvest strategies. Often expressed in terms of spawning **biomass**, but may also be expressed as **recruited** or **vulnerable biomass.**

Bootstrap: A statistical methodology used to quantify the uncertainty associated with estimates obtained from a **model**. The bootstrap is often based on **Monte Carlo** re-sampling of residuals from the initial **model** fit.

BRAG – Biodiversity Research Advisory Group

B_{REF}**:** A reference average biomass usually treated as a management target.

Bycatch: Refers to fish species, or size classes of those species, caught in association with key target species.

B_{YEAR}**:** Estimated or predicted **biomass** in the named year (usually a **mid-year biomass**).

Carrying capacity: The average **stock** size expected in the absence of **fishing**. Even without fishing the **stock** size varies through time in response to stochastic environmental conditions. See B_o**: virgin biomass**.

Catch (C): The total weight (or sometimes number) of fish caught by fishing operations.

***CAY*: Current annual yield** is the one year **catch** calculated by applying a reference **fishing mortality**, F_{REF}, to an estimate of the fishable **biomass** at the beginning of the fishing year. Also see *MAY*.

CELR: Catch-Effort Landing Return.

CLR: Catch Landing Return.

Cohort: Those individuals of a **stock** born in the same spawning season. For annual spawners, a year's **recruitment** of new individuals to a **stock** is a single cohort or **year-class**.

Collapsed: Stocks that are below the **hard limit** are deemed to be **collapsed**.

Convergence: In reference to **MCMC** results from a **Bayesian stock assessment**, convergence means that the average and the variability of the parameter estimates are not changing as the **MCMC** chain gets longer.

CPUE: Catch per unit effort is the quantity of fish caught with one standard unit of fishing effort; e.g., the number of fish taken per 1000 hooks per day or the weight of fish taken per hour of trawling. CPUE is often assumed to be a relative **abundance index**.

Customary catch: Catch taken by tangata whenua to meet their customary needs.

CV: Coefficient of variation. A statistic commonly used to represent variability or uncertainty. For example, if a biomass estimate has a CV of 0.2 (or 20%), this means that the error in this estimate (the difference between the estimate and the true biomass) will typically be about 20% of the estimate.

Density-dependence: Fish populations are thought to self-regulate: as population biomass increases, growth may slow down, mortality may increase, recruitment may decrease or maturity may occur later. Growth is density-dependent if it slows down as biomass increases.

Depleted: Stocks that are below the **soft limit** are deemed to be **depleted**. Stocks can become **depleted** through **overfishing**, or environmental factors, or a combination of the two.

Discards – the portion of the catch thrown away at sea

DWWG: The Deepwater (Science) Working Group.

ECER: Eel Catch-Effort Return.

ECLR: Eel Catch Landing Return.

Ecosystem –a biological community of interacting organisms and their physical environment.

EEZ: An **Exclusive Economic Zone** is a maritime zone beyond the **Territorial Sea** over which the coastal state has sovereign rights over the exploration and use of marine resources. Usually, a state's EEZ extends to a distance of 200 nautical miles (370 km) out from its coast, except where resulting points would be closer to another country.

Equilibrium: A theoretical model state that arises when the **fishing mortality**, **exploitation pattern** and other fishery or **stock** characteristics (growth, natural mortality, **recruitment**) do not change from year to year.

Exploitable biomass: Refers to that portion of a **stock's biomass** that is available to the fishery. Also called **recruited biomass** or **vulnerable biomass**.

Exploitation pattern: The relative proportion of each age or size class of a **stock** that is vulnerable to fishing. See **selectivity ogive.**

Exploitation rate: The proportion of the **recruited** or **vulnerable biomass** that is caught during a certain period, usually a fishing year.

***F*:** The **fishing intensity** or **fishing mortality rate** is that part of the total mortality rate applying to a fish **stock** that is caused by fishing. Usually expressed as an instantaneous rate.

$F_{0.1}$: The **fishing mortality rate** at which the increase in **equilibrium yield per recruit** in weight per unit of effort is 10% of the **yield per recruit** produced by the first unit of effort on the unexploited **stock** (i.e., the slope of the **yield per recruit** curve for the $F_{0.1}$ rate is only 1/10th of the slope of the **yield per recruit** curve at its origin).

$F_{40\%B0}$*:** The **fishing mortality rate** associated with a biomass of 40% ***B_0 at **equilibrium** or on average.

***$F_{40\%SPR}$*:** The **fishing mortality rate** associated with a spawning biomass per recruit (**SPR**) (or equivalently a spawning potential ratio) of 40% B_0 at equilibrium or on average.

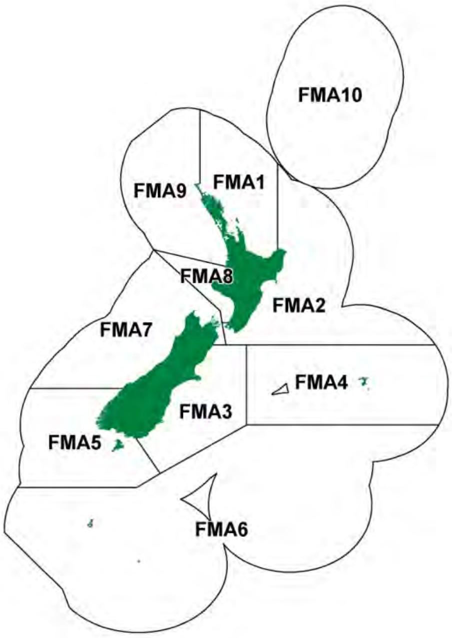
FAWGs: Fisheries Assessment (Science) Working Groups.

Fishing intensity: A general term that encompasses the related concepts of **fishing mortality** and **exploitation rate**.

Fishing mortality: That part of the total mortality rate applying to a fish **stock** that is caused by fishing. Usually expressed as an instantaneous rate.

Fishing year: For most fish stocks, the fishing year runs from 1 October in one year to 30 September in the next. The second year is often used as shorthand for the split years. For example, 2015 is shorthand for 2014–15.

FMA: Fishery Management Area. The New Zealand **EEZ** is divided into 10 fisheries management units:



F_{MAX}*:** The **fishing mortality rate** that maximises **equilibrium yield per recruit**. ***F_{MAX} is the **fishing mortality** level that defines **growth overfishing**. In general, F_{MAX} is different from ***F_{MSY}*** (the **fishing mortality** that maximises **sustainable yield**), and is always greater than or equal to ***F_{MSY}***, depending on the **stock-recruitment relationship**.

***F_{MEY}*:** The fishing mortality corresponding to the maximum (**sustainable**) economic yield.

F_{MSY}*:** The **fishing mortality rate** that, if applied constantly, would result in an average catch corresponding to the **Maximum Sustainable Yield** (MSY***) and an average biomass corresponding to ***B_{MSY}***. Usually expressed as an instantaneous rate.

F_{REF}*:** The **fishing mortality** that is associated with an average biomass of ***B_{REF}.

FRML – Fisheries Related Mortality Limit.

Growth overfishing: Growth overfishing occurs when the **fishing mortality rate** is above F_{MAX}. This means that on average fish are caught before they have a chance to reach their maximum growth potential.

Hard Limit: A biomass limit below which fisheries should be considered for closure.

Harvest Strategy: For the purpose of the Harvest Strategy Standard, a harvest strategy simply specifies **target** and **limit reference points** and management actions associated with achieving the **targets** and avoiding the **limits**.

HMS: Highly Migratory Species.

HMSWG: Highly Migratory Species (Science) Working Group.

Hyperdepletion: The situation where an abundance index, such as **CPUE**, decreases faster than the true abundance.

Hyperstability: The situation where an abundance index, such as **CPUE**, decreases more slowly than the true abundance.

Incidental capture: Refers to non-fish and protected species which were not targeted, but were caught.

Index: Same as an **abundance index**.

LCER: Longline Catch-Effort Return.

Length frequency: The distribution of numbers at length from a sample of the **catch** taken by either the commercial fishery or research fishing. This is sometimes called a length composition.

Length-Structured Stock Assessment: An assessment that uses a model to estimate how the numbers at length in the stock vary over time in order to determine the past and present **status** of a fish **stock**.

Limit: a **biomass** or fishing mortality **reference point** that should be avoided with high probability. The Harvest Strategy Standard defines both **soft limit**s and **hard limit**s.

***M*:** The (instantaneous) **natural mortality rate** is that part of the total mortality rate applying to a fish **stock** that is caused by predation and other natural events.

MAFWG: Marine Amateur Fisheries (Science) Working Group.

MALFIRM: Maximum Allowable Limit of Fishing Related Mortality.

Maturity: Refers to the ability of fish to reproduce.

Maturity ogive: A curve describing the proportion of fish of different ages or sizes that are mature.

***MAY*: Maximum average yield** is the average **maximum sustainable yield** that can be produced over the long term under a constant fishing mortality strategy, with little risk of **stock** collapse. A constant fishing mortality strategy means catching a constant percentage of the biomass present at the beginning of each fishing year. *MAY* is the long-term average annual catch when the catch each year is the *CAY*. Also see *CAY*.

MCMC: Markov Chain Monte Carlo. See **Bayesian stock assessment**.

***MCY*: Maximum constant yield** is the maximum sustainable yield that can be produced over the long term by taking the same catch year after year, with little risk of stock collapse.

MIDWG: Middle-depths (Science) Working Group.

Mid-year biomass: The biomass after half the year's catch has been taken.

MLS: Minimum Legal Size. Fish above the MLS can be retained while those below it must be returned to the sea.

Model: A set of equations that represents the population dynamics of a fish stock.

Monte Carlo Simulation: is an approach whereby the inputs that are used for a calculation are re-sampled many times assuming that the inputs follow known statistical distributions. The Monte Carlo method is used in many applications such as **Bayesian stock assessments**, parametric bootstraps and stochastic **projections**.

MPD: ***Mode of the (joint) posterior distribution*.** See **Bayesian stock assessment**.

***MSY*: Maximum sustainable yield** is the largest long-term average catch or yield that can be taken from a **stock** under prevailing ecological and environmental conditions, and the current selectivity patterns exhibited by the fishery.

MSY*-compatible reference points:** *MSY*-compatible references points include B_{MSY}, F_{MSY} and ***MSY itself, as well as analytical and conceptual **proxies** for each of these three quantities.

Natural mortality (rate): That part of the total mortality rate applying to a fish **stock** that is caused by predation and other natural events. Usually expressed as an instantaneous rate.

NCELR: Set Net Catch-Effort Landing Return.

NINS: Northern Inshore (Science) Working Group.

Objective function: An equation to be optimised (minimised or maximised) given certain constraints using non-linear programming techniques.

Otolith: One of the small bones or particles of calcareous substance in the internal ear of teleosts (bony fishes) that are used to determine their age.

Overexploitation: A situation where observed **exploitation** (or **fishing mortality**) rates are higher than **target levels**.

Overfishing: A situation where observed **fishing mortality** (or **exploitation**) rates are higher than **target** or **threshold** levels.

Partition: The way in which a fish stock or population is characterised, or split, in a stock assessment model; for example, by sex, age and maturity.

PCELR: Paua Catch Effort and Landing Return.

Population: A group of fish of one species that shares common ecological and genetic features. The **stocks** defined for the purposes of **stock assessment** and management do not necessarily coincide with self-contained populations.

Population dynamics: In general, refers to the biological and fishing processes that result in changes in fish **stock** abundance over time.

Posterior: a mathematical description of the uncertainty in some quantity (e.g., **biomass**) estimated in a **Bayesian stock assessment**. This is generally depicted as a frequency distribution (often plotted along with the **prior** distribution to show how much the two diverge).

Potential Biological Removal (PBR) - an estimate of the number of seabirds that may be killed without causing the population to decline below half the carrying capacity.

Pre-recruit: An individual that has not yet entered the fished component of the **stock** (because it is either too young or too small to be vulnerable to the fishery).

Prior: available information (often in the form of expert opinion) regarding the potential range of values of a parameter in a **Bayesian stock assessment**. Uninformative priors are used where there is no such information.

Production Model: A **stock model** that describes how the **stock biomass** changes from year to year (or, how **biomass** changes in **equilibrium** as a function of **fishing mortality**), but which does not keep track of the age or length frequency of the stock. The simplest production functions aggregate all of the biological characteristics of growth, **natural mortality** and reproduction into a simple, deterministic **model** using three or four parameters. Production models are primarily used in simple data situations, where total catch and effort data are available but age-structured information is either unavailable or deemed to be less reliable (although some versions of production models allow the use of age-structured data).

Productivity: Productivity is a function of the biology of a species and the environment in which it lives. It depends on growth rates, **natural mortality**, **age at maturity**, maximum average age and other relevant life history characteristics. Species with high **productivity** are able to sustain higher rates of **fishing mortality** than species with lower **productivity**. Generally, species with high productivity are more resilient and take less time to rebuild from a **depleted** state.

Projection: Predictions about trends in stock size and fishery dynamics in the future. Projections are made to address "what-if" questions of relevance to management. Short-term (1–5 years) projections are typically used in support of decision-making. Longer term projections become much more uncertain in terms of absolute quantities, because the results are strongly dependent on **recruitment,** which is very difficult to predict. For this reason, long-term projections are more useful for evaluating overall management strategies than for making short-term decisions.

Proxy: A surrogate for B_{MSY}, F_{MSY} or ***MSY*** that has been demonstrated to approximate one of these three metrics through theoretical or empirical studies.

***q*: Catchability** is the proportion of fish that are caught by a defined unit of fishing effort. The constant relating an **abundance index** to the true biomass (the **abundance index** is approximately equal to the true biomass multiplied by the catchability).

Quota Management Areas (QMA): QMAs are geographic areas within which fish stocks are managed in the **TS** and **EEZ**.

Quota Management System (QMS): The **QMS** is the name given to the system by which the total commercial catch from all the main fish **stocks** found within New Zealand's 200 nautical mile **EEZ** is regulated.

Recruit: An individual that has entered the fished component of the **stock**. Fish that are not recruited are either not catchable by the gear used (e.g., because they are too small) or live in areas that are not fished.

Recruited biomass: Refers to that portion of a **stock's biomass** that is available to the fishery; also called **exploitable biomass** or **vulnerable biomass**.

Recruitment: The addition of new individuals to the fished component of a **stock**. This is determined by the size and age at which fish are first caught.

Reference Point: A benchmark against which the biomass or abundance of the **stock** or the **fishing mortality rate** (or **exploitation rate**) can be measured in order to determine its **status**. These reference points can be targets, thresholds or limits depending on their intended use.

RLWG: Rock Lobster (Science) Working Group.

SAMWG: Stock Assessment Methods (Science) Working Group.

S_{AV} **:** The average historical **spawning biomass**.

Selectivity ogive: Curve describing the relative vulnerability of fish of different ages or sizes to the fishing gear used.

SFWG: The Shellfish (Science) Working Group.

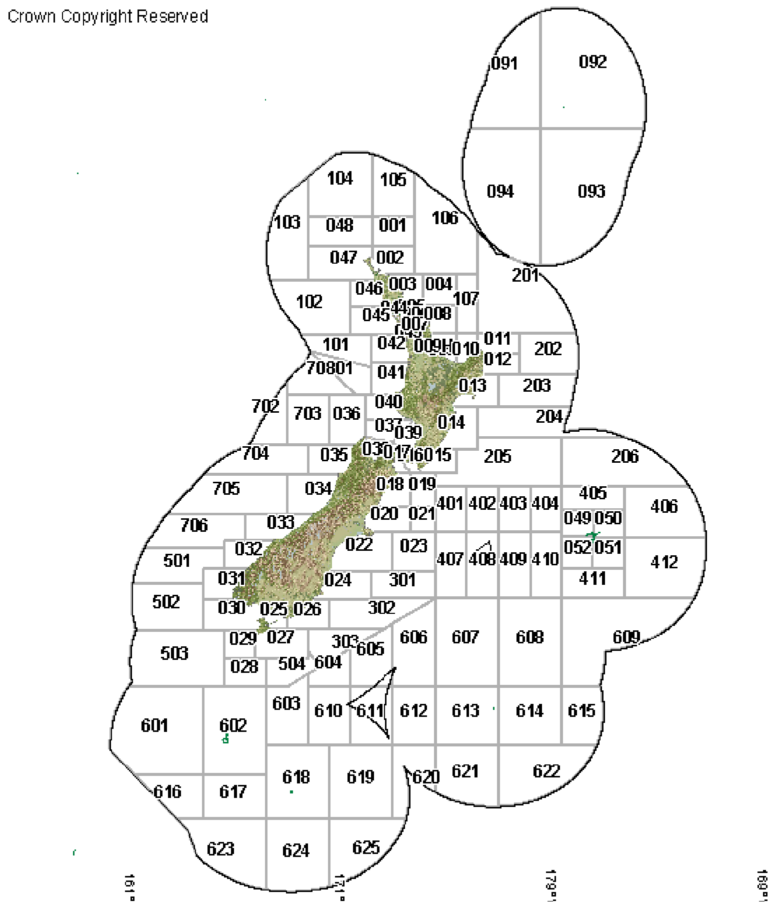
SINS: Southern Inshore (Science) Working Group.

Soft Limit: A **biomass** limit below which the requirement for a formal, time-constrained **rebuilding plan** is triggered.

Spawning biomass: The total weight of sexually mature fish in the **stock**. This quantity depends on the abundance of **year classes**, the **exploitation** pattern, the rate of growth, both fishing and **natural mortality rates**, the onset of sexual maturity, and environmental conditions. Same as **mature biomass**.

Spawning (biomass) Per Recruit or Spawning Potential Ratio (SPR): The expected lifetime contribution to the **spawning biomass** for the average recruit to the fishery. For a given exploitation pattern, rate of growth, maturity schedule and **natural mortality**, an **equilibrium** value of SPR can be calculated for any level of fishing mortality. SPR decreases monotonically with increasing fishing mortality.

Statistical area: See the map below for the official **Territorial Sea** and Exclusive Economic Zone (**EEZ**) statistical areas.



Steepness: A parameter of **stock-recruitment relationships** that determines how rapidly, or steeply, it rises from the origin, and therefore how resilient a stock is to rebounding from a depleted state. It equates to the proportion of virgin recruitment that corresponds to 20% $\boldsymbol{B_0}$. A steepness value greater than about 0.9 is considered to be high, while one less than about 0.6 is considered to be low. The minimum value is 0.2.

Stock: The term has different meanings. Under the Fisheries Act, it is defined with reference to units for the purpose of fisheries management (Fishstock). On the other hand, a biological stock is a population of a given species that forms a reproductive unit and spawns little if at all with other units. However, there are many uncertainties in defining spatial and temporal geographical boundaries for such biological units that are compatible with established data collection systems. For this reason, the term "stock" is often synonymous with an assessment / management unit, even if there is migration or mixing of some components of the assessment/management unit between areas.

Stock assessment: The analysis of available data to determine stock status, usually through application of statistical and mathematical tools to relevant data in order to obtain a quantitative understanding of the **status** of the **stock** relative to defined management benchmarks or **reference points** (e.g. $\boldsymbol{B_{MSY}}$ and/or $\boldsymbol{F_{MSY}}$).

Stock-recruitment relationship: An equation describing how the expected number of recruits to a stock varies as the **spawning biomass** changes. The most frequently used stock-recruitment relationship is the asymptotic Beverton-Holt equation, in which the expected number of recruits changes very slowly at high levels of spawning biomass.

Stock status: Refers to a determination made, on the basis of **stock assessment** results, about the current condition of the **stock**. Stock status is often expressed relative to management benchmarks and **biological reference points** such as $\boldsymbol{B_{MSY}}$ or $\boldsymbol{B_0}$ or $\boldsymbol{F_{MSY}}$ or $\boldsymbol{F_{\%SPR}}$. For example, the current biomass may be said to be above or below $\boldsymbol{B_{MSY}}$ or to be at some percentage of $\boldsymbol{B_0}$. Similarly, fishing mortality may be above or below $\boldsymbol{F_{MSY}}$ or $\boldsymbol{F_{\%SPR}}$.

Stock structure: (1) Refers to the geographical boundaries of the **stocks** assumed for assessment and management purposes (e.g., albacore tuna may be assumed to be comprised of two separate **stocks** in the North Pacific and South Pacific), (2) Refers to boundaries that define self-contained **stocks** in a genetic sense, (3) refers to known, inferred or assumed patterns of residence and migration for stocks that mix with one another.

Surplus production: The amount of **biomass** produced by the **stock** (through growth and **recruitment**) over and above that which is required to maintain the [total stock] **biomass** at its current level. If the catch in each year is equal to the surplus production then the biomass will not change.

Sustainability: Pertains to the ability of a fish **stock** to persist in the long-term. Because fish **populations** exhibit natural variability, it is not possible to keep all fishery and **stock** attributes at a constant level simultaneously, thus sustainable fishing does not imply that the fishery and **stock** will persist in a constant **equilibrium** state. Because of natural variability, even if $\boldsymbol{F_{MSY}}$ could be achieved exactly each year, **catches** and **stock biomass** will oscillate around their average ***MSY*** and $\boldsymbol{B_{MSY}}$ levels, respectively. In a more general sense, sustainability refers to providing for the needs of the present generation while not compromising the ability of future generations to meet theirs.

TAC: Total Allowable Catch is the sum of the Total Allowable Commercial Catch (**TACC**) and the allowances for customary Maori interests, recreational fishery interests and other sources of fishing-related mortality that can be taken in a given period, usually a year.

TACC: Total Allowable Commercial Catch is the total regulated commercial catch from a **stock** in a given time period, usually a fishing year.

Target: Generally, a **biomass**, **fishing mortality** or **exploitation rate** level that management actions are designed to achieve with at least a 50% probability.

Threshold: Generally, a **biological reference point** that raises a "red flag" indicating that **biomass** has fallen below the **target**, or **fishing mortality** or **exploitation rate** has increased above its **target**, to the extent that additional management action may be required in order to prevent the stock from declining further and possibly breaching the **soft limit**.

TCEPR: Trawl Catch-Effort Processing Return.

TCER: Trawl Catch-Effort Return.

TLCER: Tuna Longline Catch-Effort Return.

TS: Territorial Sea: a belt of coastal waters extending at most 12 nautical miles (22.2 km; 13.8 mi) from the baseline (usually the mean low-water mark) of a coastal state.

$\boldsymbol{U_{MSY}}$**:** The **exploitation rate** associated with the maximum sustainable yield.

$\boldsymbol{U_{40\%B0}}$**:** The **exploitation rate** associated with a biomass of 40% $\boldsymbol{B_0}$ at equilibrium or on average.

von Bertalanffy equation: An equation describing how fish increase in length as they grow older. The mean length (L) at age a is

$$L = L_\infty(1 - e^{-k(a-t_0)})$$

where L_∞ is the average length of the oldest fish, k is the average growth rate (Brody coefficient) and t_0 is a constant.

Vulnerable biomass: Refers to that portion of a **stock's biomass** that is available to the fishery. Also called **exploitable biomass** or **recruited biomass**.

Year class (cohort): Fish in a **stock** that were born in the same year. Occasionally, a **stock** produces a very small or very large year class which can be pivotal in determining **stock** abundance in later years.

Yield: Catch expressed in terms of weight.

Yield per Recruit (YPR): The expected lifetime **yield** for the average recruit. For a given **exploitation pattern**, rate of growth, and **natural mortality**, an **equilibrium** value of YPR can be calculated for each level of **fishing mortality**. YPR analyses may play an important role in advice for management, particularly as they relate to minimum size controls.

Z**:** Total mortality rate. The sum of **natural** and **fishing mortality rates**.

Terms of Reference for Fisheries Assessment Working Groups (FAWGs) in 2019

Overall purpose

The purpose of the FAWGs is to assess the status of fish stocks managed within the Quota Management System, as well as other important species of interest to New Zealand. Based on scientific information the FAWGs assess the current status of fish stocks or species relative to MSY-compatible reference points and other relevant indicators of stock status, conduct projections of stock size and status under alternative management scenarios, and review results from relevant research projects. They do not make management recommendations or decisions (this responsibility lies with Fisheries New Zealand fisheries managers and the Minister responsible for fisheries).

Preparatory tasks

1. Prior to the beginning of the main sessions of FAWG meetings (January to May and September to November), Fisheries New Zealand fisheries scientists will produce a list of stocks and issues for which new stock assessments or evaluations are likely to become available prior to the next scheduled sustainability rounds. This list will include stocks for which the fishing industry and others intend to directly purchase scientific analyses. It is therefore incumbent on those purchasing research to inform the relevant FAWG chair of their intentions at least three months prior to the start of the sustainability round. FAWG Chairs will determine the final timetables and agendas for each Working Group.

2. At least six months prior to the main sessions of FAWG meetings, Fisheries New Zealand fisheries managers will alert Fisheries New Zealand science managers and the Fisheries New Zealand Principal Science Advisor to unscheduled special cases for which assessments or evaluations are urgently needed.

Technical objectives

3. To review new research information on stock structure, productivity, abundance and related topics for each fish stock/issue under the purview of individual FAWGs.

4. Where possible, to derive appropriate MSY-compatible reference points[1] for use as reference points for determining stock status, based on the Harvest Strategy Standard for New Zealand Fisheries[2] (the Harvest Strategy Standard).

5. To conduct stock assessments or evaluations for selected fish stocks in order to determine the status of the stocks relative to MSY-compatible reference points[1] and associated limits, based on the "Guide to Biological Reference Points for Fisheries Assessment Meetings", the Harvest Strategy Standard, and relevant management reference points and performance measures set by fisheries managers.

6. For stocks where the status is unknown, FAWGs should use existing data and analyses to draw logical conclusions about likely future trends in biomass levels and/or fishing mortality (or exploitation) rates if current catches and/or TACs/TACCs are maintained, or if fishers or fisheries managers are considering modifying them in other ways.

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[1] MSY-compatible reference points include those related to stock biomass (i.e. B_{MSY}), fishing mortality (i.e. F_{MSY}) and catch (i.e. MSY itself), as well as analytical and conceptual proxies for each of the three of these quantities.

[2] Link to the Harvest Strategy Standard: http://fs.fish.govt.nz/Page.aspx?pk=104

7. Where appropriate and practical, to conduct projections of likely future stock status using alternative fishing mortality (or exploitation) rates or catches and other relevant management actions, based on the Harvest Strategy Standard and input from the FAWG and fisheries managers.

8. For stocks that are deemed to be depleted or collapsed, to develop alternative rebuilding scenarios based on the Harvest Strategy Standard and input from the FAWG and fisheries managers.

9. For fish stocks for which new stock assessments or analyses are not conducted in the current year, to review the existing Fisheries Assessment Plenary report text on the "Status of the Stocks" in order to determine whether the latest reported stock status summary is still relevant; else to revise the evaluations of stock status based on new data or analyses, or other relevant information.

Working Group reports

10. To include in the Working Group report information on commercial, Māori customary, non-commercial and recreational interests in the stock; as well as all other mortality to that stock caused by fishing, which might need to be allowed for in setting a TAC or TACC. Estimates of recreational harvest will normally be provided by the Marine Amateur Fisheries Working Group (MAFWG).

11. To provide information and advice on other management considerations (e.g. area boundaries, by-catch issues, effects of fishing on habitat, other sources of mortality, and input controls such as mesh sizes and minimum legal sizes) required for specifying sustainability measures. Sections of the Working Group reports related to bycatch and other environmental effects of fishing will be reviewed by the Aquatic Environment Working Group (AEWG) although the relevant FAWG is encouraged to identify to the AEWG Chair any major discrepancies between these sections and their understanding of the operation of relevant fisheries.

12. To summarise the stock assessment methods and results, along with estimates of MSY-compatible references points and other metrics that may be used as benchmarks for assessing stock status.

13. To review, and update if necessary, the "Status of the Stocks" tables in the Fisheries Assessment Plenary report for all stocks under the purview of individual FAWGs (including those for which a full assessment has not been conducted in the current year) based on new data or analyses, or other relevant information.

14. For all important stocks, to complete (and/or update) the Status of Stocks tables using the template provided in the Introductory chapter of the most recent May and November Plenary reports.

15. It is desirable that full agreement amongst technical experts is achieved on the text of the FAWG reports, particularly the "Status of the Stocks" sections, noting that the AEWG will review sections on bycatch and other environmental effects of fishing, and the MAFWG will provide text on recreational harvests. If full agreement amongst technical experts cannot be reached, the Chair will determine how this will be depicted in the FAWG report, will document the extent to which agreement or consensus was achieved, and record and attribute any residual disagreement in the meeting notes.

Working Group input to the Plenary

16. To advise the Fisheries New Zealand Principal Science Advisor about stocks requiring review by the Fisheries Assessment Plenary and those stocks that are not believed to warrant review by the Plenary. The general criteria for determining which stocks should be discussed by the

Plenary are that (i) the assessment is controversial and Working Group members have had difficulty reaching consensus on one or more base cases, or (ii) the assessment is the first for a particular stock or the methodology has been substantially altered since the last assessment, or (iii) new data or analyses have become available that alter the previous assessment, particularly assessments of recent or current sto

ck status, or projections of likely future stock status. Such information could include:

- new or revised estimates of MSY-compatible reference points, recent or current biomass, productivity or yield projections;
- the development of a major trend in the catch or catch per unit effort; or
- any new studies or data that extend understanding of stock structure, fishing patterns, or non-commercial activities, and result in a substantial effect on assessments of stock status.

Membership and Protocols for all Science Working Groups

17. FAWG members are bound by the Membership and Protocols required for all Science Working Group members (see separate document).

Terms of Reference for the Aquatic Environment Working Group (AEWG) in 2019

Overall purpose
For all New Zealand fisheries in the New Zealand TS and EEZ as well as other important fisheries in which New Zealand engages:

to assess, based on scientific information, the effects of (and risks posed by) fishing on the aquatic environment, including:

- bycatch and unobserved mortality of protected species (e.g. seabirds and marine mammals), fish, and other marine life, and consequent impacts on populations;
- effects on benthic ecosystems, species, and habitat;
- effects on biodiversity, including genetic diversity; and
- changes to ecosystem structure and function from fishing, including trophic effects

Where appropriate and feasible, such assessments should explore the implications of the effect, including with respect to government standards, other agreed reference points, or other relevant indicators of population or environmental status. Where possible, projections of future status under alternative management scenarios should be made.

AEWG does not make management recommendations or decisions (this responsibility lies with Fisheries New Zealand fisheries managers and the Minister responsible for Fisheries).

Fisheries New Zealand also convenes a Biodiversity Research Advisory Group (BRAG) which has a similar review function to the AEWG. Projects reviewed by BRAG and AEWG have some commonalities in that they relate to aspects of the marine environment. However, the key focus of projects considered by BRAG is on the functionality of the marine ecosystem and its productivity, whereas projects considered by AEWG more commonly focus on the direct effects of fishing.

Preparatory tasks
1. Prior to the beginning of AEWG meetings each year, Fisheries New Zealand fisheries scientists will produce a list of issues for which new assessments or evaluations are likely to become available that year.

2. Fisheries New Zealand's research planning processes should identify most information needs well in advance but, if urgent issues arise, Fisheries New Zealand staff will alert the relevant AEWG chair prior to the required meeting of items that could be added to the agenda. AEWG Chairs will determine the final timetables and agendas for meetings.

Technical objectives
3. To review any new research information on fisheries, including risks of impacts, and the relative or absolute sensitivity or susceptibility of potentially affected species, populations, habitats, and systems.

4. To estimate appropriate reference points for determining population, system, or environmental status, noting any draft or published Standards.

5. To conduct environmental assessments or evaluations for selected species, populations, habitats, or systems in order to determine their status relative to appropriate reference points and Standards, where such exist.
6. In addition to determining the status of the species, populations, habitats, and systems relative to reference points, and particularly where the status is unknown, AEWG should explore the potential for using existing data and analyses to draw conclusions about likely future trends in

fishing effects or status if current fishing methods, effort, catches, and catch limits are maintained, or if fishers or fisheries managers are considering modifying them in other ways.

7. Where appropriate and practical, to conduct or request projections of likely future status using alternative management actions, based on input from AEWG, fisheries plan advisers and fisheries and standards managers, noting any draft or published Standards.

8. For species or populations deemed to be depleted or endangered, to develop ideas for alternative rebuilding scenarios to levels that are likely to ensure long-term viability based on input from AEWG, fisheries managers, noting any draft or published Standards.

9. To review and revise existing environmental and ecosystem consideration sections of Fisheries Assessment Plenary report text based on new data or analyses, or other relevant information.

Working Group input to annual Aquatic Environment and Biodiversity Review

10. To include in contributions to the Aquatic Environment and Biodiversity Review (AEBAR) summaries of information on selected issues that may relate to species, populations, habitats, or systems that may be affected by fishing. These contributions are analogous to Working Group reports from the Fisheries Assessment Working Groups.

11. To provide information and scientific advice on management considerations (e.g. area boundaries, by-catch issues, effects of fishing on habitat, other sources of mortality, and input controls such as mesh sizes and minimum legal sizes) that may be relevant for setting sustainability measures.

12. To summarise the assessment methods and results, along with estimates of relevant standards, references points, or other metrics that may be used as benchmarks or to identify risks to the aquatic environment.

13. It is desirable that full agreement among technical experts is achieved on the text of contributions to the AEBAR. If full agreement among technical experts cannot be reached, the Chair will determine how this will be depicted in the AEBAR, will document the extent to which agreement or consensus was achieved, and record and attribute any residual disagreement in the meeting notes.

14. To advise the Fisheries New Zealand Principal Science Advisor and Aquatic Environment manager about issues of particular importance that may require independent review or updating in the AEBAR. The general criterion for determining which issues should be discussed by a wider group or text changed in the AEBAR is that new data or analyses have become available that alter the previous assessment of an issue, particularly assessments of population status or projection results. Such information could include:

    - New or revised estimates of environmental reference points, recent or current population status, trend, or projections;
    - The development of a major trend in bycatch rates or amount;
    - Any new studies or data that extend understanding of population, system, or environmental susceptibility to an effect or its recoverability, fishing patterns, or mitigation measures that have a substantial implications for a population, system, or environment or identify risks associated with fishing activity; and
    - Consistent performance outside accepted reference points or Standards.

Membership and Protocols for all Science Working Groups

15. The AEWG is bound by the same membership and protocols as other Science Working Groups (see separate document).

Terms of Reference for the Marine Amateur Fisheries Working Group (MAFWG) in 2019

Overall purpose

The purpose of the MAFWG is to assess the harvest of marine amateur fishers from fish stocks managed within or outside the Quota Management System and to review other scientific or research information relevant to the management of marine amateur fisheries. MAFWG does not make management recommendations or decisions; this responsibility lies with Fisheries New Zealand fisheries managers and the Minister responsible for fisheries.

Preparatory tasks

1. It is anticipated that marine amateur fisheries research will focus primarily on the estimation of amateur harvests of fish stocks based on corroborated off-site national surveys conducted about every 5 years. At least six months before any such survey is conducted, Fisheries New Zealand fisheries managers will alert Fisheries New Zealand science managers and the Fisheries New Zealand Principal Science Advisor to their priority stocks for harvest estimation to facilitate good survey design. In years when national surveys are not being conducted, Fisheries New Zealand fisheries managers and fisheries scientists will work closely together to prioritise the meeting of other key information needs in relation to marine amateur fisheries.

Technical objectives

2. To review new research information on the harvest and harvesting patterns of marine amateur fishers using off-site and/or on-site methods, focussing primarily on priority non-commercial and shared stocks or fisheries identified by fisheries managers.

3. To develop methods for making reliable estimates of total catch by fish stock (finfish and shellfish); catch per unit of effort (CPUE); fish lengths and weights within the harvest; daily bag sizes in relation to limits; the spatial and temporal variability of fishing, CPUE, or harvest; and other information likely to inform fisheries management decisions, the development of environmental standards, or the formulation of relevant policy.

Working Group reports

4. In collaboration with relevant Stock Assessment Working Group Chairs, to provide timely and current information on marine amateur harvest for Working Group reports for non-commercial and shared stocks. MAFWG will also periodically review information on marine amateur harvest in Working Group reports to ensure accuracy and currency.

5. As necessary, provide information and advice on other management considerations for marine amateur fisheries (e.g. effects of fishing on habitat, other sources of mortality, and potential input controls such as bag limits, mesh sizes, and minimum legal sizes) required for specifying sustainability measures.

6. It is desirable that full agreement amongst technical experts is achieved on the information provided for Working Group reports on the harvest and other aspects of marine amateur fisheries. If full agreement amongst technical experts cannot be reached, the Chair will determine how this will be depicted in the Working Group report, will document the extent to which agreement or consensus was achieved, and record and attribute any residual disagreement in the meeting notes.

Membership and Protocols for all Science Working Groups

7. MAFWG members are bound by the Membership and Protocols required for all Science Working Group members (see separate document).

Membership and Protocols for all Science Working Groups in 2019

This document summarises the protocols for membership and participation in all Science Working Groups including Fisheries Assessment Working Groups (FAWGs), the Aquaculture Working Group (AQWG), the Aquatic Environment Working Group (AEWG), the Biodiversity Research Advisory Group (BRAG), the Highly Migratory Species Working Group (HMS), the South Pacific Working Group (SPACWG), the Antarctic Working Group (ANTWG), and the Marine Amateur Fisheries Working Group (MAFWG).

Working Group chairs

1. Fisheries New Zealand will select and appoint the Chairs for Science Working Groups. The Chair will be a Fisheries New Zealand fisheries or marine scientist who is an active participant in the Working Group, providing technical input, rather than simply being a facilitator. Working Group Chairs will be responsible for:

* ensuring that Working Group participants are aware of the Terms of Reference for the Working Group, and that the Terms of Reference are adhered to by all participants;

    * setting the rules of engagement, facilitating constructive questioning, and focussing on relevant issues;

    * ensuring that all peer review processes are conducted in accordance with the Research and Science Information Standard for New Zealand Fisheries[3] (the Research Standard), and that research and science information is reviewed by the relevant Working Group against the *P R I O R* principles for science information quality (page 6 in the Research Standard) and the criteria for peer review (pages 12–16 in the Research Standard);

    * requesting and documenting the names and affiliations of participants at each Working Group meeting and ensuring that these are noted in the Working Group meeting notes. Chairs are responsible for managing conflicts of interest (refer to page 15 of the Research Standard), and ensuring that fisheries management or aquaculture implications do not jeopardise the objectivity of the review or result in biased interpretation of results;

    * ensuring that the quality of information that is intended or likely to inform fisheries management or aquaculture decisions, the development of environmental standards or the formulation of relevant fisheries policy is ranked in accordance with the information ranking guidelines in the Research Standard (page 21–23), and that resulting information quality ranks are appropriately documented in the Fisheries Assessment Plenary and the Aquatic Environment and Biodiversity Annual Review (AEBAR);

    * striving for consensus while ensuring the transparency and integrity of research analyses, results, conclusions and final reports; and

    * reporting on Working Group recommendations, conclusions and action items; and ensuring follow-up and communication with the Fisheries New Zealand Principal Science Advisor, relevant Fisheries New Zealand fisheries management or aquaculture staff, and other key stakeholders.

Working Group members

2. Membership of Science Working groups will be open to any participant with the agreement of the Working Group Chair.

3. Working Groups will consist of the following participants:

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[3] Link to the Research Standard: http://www.fish.govt.nz/en-nz/Publications/Research+and+Science+Information+Standard.htm

* Fisheries New Zealand science chair – required;
* research providers – required (may be the primary researcher, or a designated substitute capable of presenting and discussing the agenda item);
* other scientists not conducting the presented research to act in a peer review capacity;
* representatives of relevant Fisheries New Zealand fisheries management or aquaculture teams; and
* any interested party who agrees to the standards of participation below.

4. Working Group participants must commit to:
   * participating appropriately in the discussion;
   * resolving issues;
   * following up on agreements and tasks;
   * maintaining confidentiality of Working Group discussions and deliberations (unless otherwise agreed in advance, and subject to the constraints of the Official Information Act);
   * adopting a constructive approach;
   * avoiding repetition of earlier deliberations, particularly where agreement has already been reached;
   * facilitating an atmosphere of honesty, openness and trust;
   * respecting the role of the Chair; and
   * listening to the views of others, and treating them with respect.

5. Participants in Working Group meetings will be expected to declare their sector affiliations and contractual relationships to the research under review, and to declare any substantial conflicts of interest related to any particular issue or scientific conclusion.

6. Working Group participants must adhere to the requirements of independence, impartiality and objectivity listed under the Peer Review Criteria in the Research Standard (pages 12–16). It is understood that Working Group participants will often be representing particular sectors and interest groups, and may be expressing the views of those groups. However, when participating in the review of science information, representatives are expected to step aside from their sector affiliations, and to ensure that individual and sector views do not result in bias in the science information and conclusions.

7. Participants in each Working Group will have access to the corresponding sections of the Science Working Group website including the Working Group papers and other information provided in those sections. Access to Science Working Group websites will generally be restricted to those who have a reasonable expectation of attending at least one meeting of a given Science Working Group each year.

8. Working Group members who do not adhere to the standards of participation (paragraph 4), or who use Working Group papers and related information inappropriately (see paragraph 10), may be requested by the Chair to leave a particular meeting or to refrain from attending one or more future meetings. In more serious instances, members may be removed from the Working Group membership and denied access to the Working Group website for a specified period of time.

Working Group papers and related information

9. Working Group papers will be posted on the Fisheries New Zealand website prior to meetings if they are available. As a general guide, PowerPoint presentations and draft or discussion papers should be available at least two working days before a meeting, and near-final papers should be available at least five working days before a meeting if the Working Group is expected to agree to the paper. However, it is also likely that some papers will be made available for the first time during the meeting due to time constraints. If a paper is not available for sufficient time before the meeting, the Chair may provide for additional time following the meeting for additional comments from Working Group members.

10. Working Group papers are "works in progress" intended to facilitate the discussion of analyses by the Working Groups. They often contain preliminary results that are receiving peer review for the first time and, as such, may contain errors or preliminary analyses that will be superseded by more rigorous work. **For these reasons, no-one may release the papers or any information contained in these papers to external parties. In general, Working Group papers should not be cited.** Exceptions may be made in rare instances by obtaining permission in writing from the Principal Advisor Fisheries Science, and the authors of the paper. It is also anticipated that Working Group participants who are representing others at a particular Working Group meeting or series of such meetings may wish to communicate preliminary results to the people they are representing. Participants, along with recipients of the information, are required to exercise discretion in doing this, and to guard against preliminary results being made public.

11. From time to time, Fisheries New Zealand commissions external reviews of analyses, models or issues. Terms of Reference for these reviews and the names of external reviewers may be provided to the Working Group for information or feedback. It is extremely important to the proper conduct of these reviews that all contact with the reviewers is through the Chair of the Working Group or the Principal Advisor Fisheries Science. Under no circumstances should Working Group members approach reviewers directly until after the final report of the review has been published.

Working Group meetings

12. Meetings will take place as required, generally January–April and July–November for FAWGs and throughout the year for other Working Groups (AEWG, AQWG, BRAG, HMSWG, SPACWG, ANTWG and MAFWG).

13. A quorum will be reached when the Chair, the designated presenter, and at least three other technical experts are present. In the absence of a quorum, the Chair may decide to proceed as a sub-group, with outcomes being discussed with the wider Working group via email or taken forward to the next meeting at which a quorum is formed.

14. The Chair is responsible for deciding, with input from the entire Working Group, but focussing primarily on the technical discussion and the views of technical expert members:

    * the quality and acceptability of the information and analyses under review;
    * the way forward to address any deficiencies;
    * the need for any additional analyses;
    * contents of research reports, Working Group reports and AEBAR chapters;
    * choice of best models and sensitivity analyses to be presented; and
    * the status of the stocks, or the status/performance in relation to any relevant environmental standards or targets.

15. The Chair is responsible for facilitating a consultative and collaborative discussion.

15. Working Group meetings will be run formally, with agendas pre-circulated, and formal records kept of recommendations, conclusions and action items.

16. A record of recommendations, conclusions and action items will be posted on the Fisheries New Zealand website after each meeting has taken place.

17. Data upon which analyses presented to the Working Groups are based must be provided to Fisheries New Zealand in the appropriate format and level of detail in a timely manner (i.e. the data must be available and accessible to Fisheries New Zealand; however, data confidentiality concerns mean that some data may not necessarily be made available to Working Group members).

18. Working Group processes will be evaluated periodically, with a view to identifying opportunities for improvement. Terms of Reference and the Membership and Protocols may be updated as part of this review.

19. Fisheries New Zealand scientists and science officers will provide administrative support to the Working Groups.

Information Quality Ranking

20. Science Working Groups are required to rank the quality of research and science information that is intended or likely to inform fisheries management or aquaculture decisions, in accordance with the science information quality ranking guidelines in the Research Standard (pages 21–23). Information quality rankings should be documented in Working Group reports and, where appropriate, in Status of Stock summary tables. Note that:

- Working Groups are not required to rank all research projects and analyses, but key pieces of information that are expected or likely to inform fisheries management or aquaculture decisions, the development of environmental decisions or the formulation of relevant policy should receive a quality ranking;
- explanations substantiating the quality rankings will be included in Working Group reports. In particular, the quality shortcomings and concerns for moderate/mixed and low quality information should be documented; and
- the Chair, working with participants, will determine which pieces of information require a quality ranking. Not all information resulting from a particular research project would be expected to achieve the same quality rank, and different quality ranks may be assigned to different components, conclusions or pieces of information resulting from a particular piece of research.

Record-keeping

21. The overall responsibility for record-keeping rests with the Chair of the Working Group, and includes:

- keeping notes on recommendations, conclusions and follow-up actions for all Working Group meetings, and to ensure that these are available to all members of the Working Group and the Principal Advisor Fisheries Science in a timely manner. If full agreement on the recommendations or conclusions cannot readily be reached amongst technical experts, then the Chair will document the extent to which agreement or consensus was achieved, and record and attribute any residual disagreement in the meeting notes; and
- compiling a list of generic assessment issues and specific research needs for each stock, species or environmental issue under the purview of the Working Group, for use in subsequent research planning processes.

Fisheries Assessment Working Groups: Membership 2019

<u>Highly Migratory Species Working Group</u>

Convenor: **John Annala**

Members: Hilary Ayrton, Peter Ballantyne, Joshua Barclay, Tom Clark, Bubba Cook, Samik Datta, Charles Edwards, Toni Ferdinands, Brit Finucci, Malcolm Francis, Lynda Griggs, John Holdsworth, Arthur Hore, Charles Hufflet, Terese Kendrick, Jo Lambie, Adam Langley, Kath Large, Jeremy McKenzie, David Middleton, Alison Undorf-Lay, Dominic Vallieres, Peter van Kampen, Oliver Wilson

Species: Albacore, bigeye tuna, blue shark, hammerhead shark, mako shark, Pacific bluefin tuna, porbeagle shark, Ray's bream, skipjack tuna, southern bluefin tuna, striped marlin, swordfish, yellowfin tuna

<u>Rock Lobster Working Group</u>

Convenor: **Marine Pomarède and Kevin Sullivan**

Members: John Annala, Josh Barclay, Paul Breen, Mark Edwards, Jeff Forman, Debbie Freeman, Sonja Hempel, Julie Hills, John Holdsworth, Monique Holmes, Kath Large, Pamela Mace, Alison MacDiarmid, Andy McKenzie, Alicia McKinnon, Phil Neubauer, Jim Roberts, Merrill Rudd, Paul Starr, Daryl Sykes, Peter van Kampen, Nathan Walker, Te Aomihia Walker, Darcy Webber.

Species: Red rock lobster, packhorse rock lobster

<u>Shellfish Working Group</u>

Convenors: **Julie Hills and Marine Pomarède**

Members: John Annala, Michael Arbuckle, Josh Barclay, Mike Beentjes, Roger Belton, Katrin Berkenbusch, Des Boyce, Anthony Brett, Andrew Caddie, Willie Calder, Hannah Charan-Dixon, Damian Cloeter, Mike Connolly, Jeremy Cooper, Martin Cryer, Alistair Dunn, Buzz Falconer, Jack Fenaughty, Rich Ford, Allen Frazer, Laura Furneaux, Mark Geytenbeek, Sean Handley, Michael Hawke, Steven Hawke, Tim Healy, Eric Jorgensen, Daniel Kerrigan, Doug Loder, Pamela Mace, Craig Marsh, Tom McCowan, Greg Mead, Jon Mears, Keith Michael, David Middleton, Bryony Miller, Reyn Naylor, Phil Neubauer, Tracy Osborne, Isaac Piper, Mathieu Poot, Daniel Pritchard, Richardt Prosch, Tanith Robb, David Skeggs, Storm Stanley, Josh Tarrent, Fred Te Miha, Laura Tremblay-Boyer, Ian Tuck, Peter van Kampen, Josh van Lier, Gordon Wade, D'Arcy Webber, Chris West, Lindsey White, James Williams, Graeme Wright, Tom Wright.

Species: Scallops, dredge oysters

<u>Aquatic Environment Working Group</u>

Convenors: Rich Ford, Ben Sharp and Nathan Walker

Members: Ed Abraham, Owen Anderson, Sonja Austin, Hilary Ayrton, Karen Baird, Suze Baird, Barry Baker, Scott Baker, Sira Ballara, Joshua Baller, Josh Barclay, Steve Beatson, Katrin Berkenbusch, Tiffany Bock, Lesley Bolton-Ritchie, Laura Boren, Erin Breen, Anthony Brett, Niall Broekhuizen, Ian Brown, Paul Breen, Tania Cameron, Simon Childerhouse, Bill Chisholm, Malcolm Clark, Tom Clark, Katie Clemens-Seely, Deanna Clement, George Clement, Justin Cooke, Igor Debski, Peter Dillingham, Matt

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Guide to Biological Reference Points for Fisheries Assessment Meetings

The Guide to Biological Reference Points was originally developed by a Stock Assessment Methods Working Group in 1988, with the aim of defining commonly used terms, explaining underlying assumptions, and describing the biological reference points used in fisheries assessment meetings and associated reports. However, this document has not been substantially revised since 1992 and the methods described herein, while still used in several assessments, have been replaced with other approaches in a number of cases. Some of the latter approaches are described in the Harvest Strategy Standard for New Zealand Fisheries and the associated Operational Guidelines, and are being further developed in various Fisheries Assessment Working Groups and the current Stock Assessment Methods Working Group.

Here, methods of estimation appropriate to various circumstances are given for two levels of yield: Maximum Constant Yield (***MCY***) and Current Annual Yield (***CAY***), both of which represent different forms of maximum sustainable yield (***MSY***). The relevance of these to the setting of Total Allowable Catches (TACs) is discussed.

Definitions of *MCY* and *CAY*

The Fisheries Act 1996 defines Total Allowable Catch in terms of maximum sustainable yield (***MSY***). The definitions of the biological reference points, ***MCY*** and ***CAY***, derive from two ways of viewing ***MSY***: a static interpretation and a dynamic interpretation. The former, associated with ***MCY***, is based on the idea of taking the same catch from the fishery year after year. The latter interpretation, from which ***CAY*** is derived, recognises that fish populations fluctuate in size from year to year (for environmental and biological, as well as fishery, reasons) so that to get the best yield from a fishery it is necessary to alter the catch every year. This leads to the idea of maximum average yield (***MAY***) which is how fisheries scientists generally interpret ***MSY*** (Ricker 1975).

The definitions are:

> ***MCY*** – Maximum Constant Yield
> The maximum constant catch that is estimated to be sustainable, with an acceptable level of risk, at all probable future levels of biomass.

and

> ***CAY*** – Current Annual Yield
> The one-year catch calculated by applying a reference fishing mortality, F_{REF}, to an estimate of the fishable biomass present during the next fishing year. F_{REF} is the level of (instantaneous) fishing mortality that, if applied every year, would, within an acceptable level of risk, maximise the average catch from the fishery.

Note that ***MCY*** is dependent to a certain extent on the current state of the fish stock. If a stock is fished at the ***MCY*** level from a virgin state then over the years its biomass will fluctuate over a range of levels depending on environmental conditions, abundance of predators and prey, etc. For stock sizes within this range the ***MCY*** remains unchanged (though our estimates of it may well be refined). If the current state of the stock is below this range the ***MCY*** will be lower.

The strategy of applying a constant fishing mortality, F_{REF}, from which the ***CAY*** is derived each year is an approximation to a strategy which maximises the average yield over time. For the purposes of this document the ***MAY*** is the long-term average annual catch when the catch each year is the ***CAY***. With perfect knowledge it would be possible to do better by varying the fishing mortality from year to year. Without perfect knowledge, adjusting catch levels by a ***CAY*** strategy as stock size varies is probably the best practical method of maximising average yield. Appropriate values for F_{REF} are discussed below.

What is meant by an "acceptable level of risk" for ***MCY***s and ***CAY***s is intentionally left undefined here. For most stocks our level of knowledge is inadequate to allow a meaningful quantitative assessment of risk. However, we have two qualitative sources of information on risk levels: the experience of fisheries scientists and managers throughout the world, and the results of simulation exercises such as those of Mace (1988a). Information from these sources is incorporated, as much as is possible, in the methods given below for calculating ***MCY*** and ***CAY***.

It is now well known that ***MCY*** is generally less than ***MAY*** (see, e.g., Doubleday 1976, Sissenwine 1978, Mace 1988a). This is because ***CAY*** will be larger than ***MCY*** in the majority of years. However, when fishable biomass becomes low (through overfishing, poor environmental conditions, or a combination of both), ***CAY*** will be less than ***MCY***. This is true even if the estimates of ***CAY*** and ***MCY*** are exact. The following diagram shows the relationships between ***CAY***, ***MCY*** and ***MAY***.

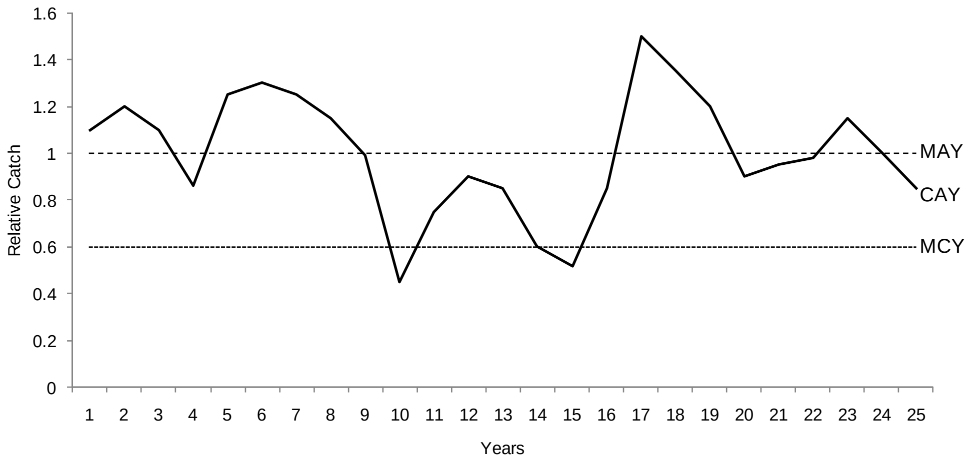

Figure 1: Relationship between *CAY*, *MCY* and *MAY*.

In this example ***CAY*** represents a constant fraction of the fishable biomass, and so (if it is estimated and applied exactly) it will track the fish population exactly. ***MAY*** is the average over time of ***CAY***. The reason ***MCY*** is less than ***MAY*** is that ***MCY*** must be low enough so that the fraction of the population removed does not constitute an unacceptable risk to the future viability of the population. With an ***MCY*** strategy, the fraction of a population that is removed by fishing increases with decreasing stock size. With a ***CAY*** strategy, the fraction removed remains constant. A constant catch strategy at a level equal to the ***MAY***, would involve a high risk at low stock sizes.

Relationship Between *MCY, CAY,* TAC and Total Allowable Commercial Catch (TACC)

The TAC covers all mortality to a fish stock caused by human activity, whereas the TACC includes only commercial catch. ***MCY*** and ***CAY*** are reference points used to evaluate whether the current stock size can support the current TAC and/or TACC. It should not be assumed that the TAC and/or TACC will be equal to either one of these yields. There are both legal and practical reasons for this.

Legally, we are bound by the Fisheries Act 1996. In setting or varying any TACC for any quota management stock, 'the Minister shall have regard to the total allowable catch for that stock and shall allow for –

(a) The following non-commercial fishing interests in that stock, namely –
  (i) Maori customary non-commercial fishing interests; and
  (ii) Recreational interests; and
(b) All other mortality to that stock caused by fishing.

From a practical point of view it must be acknowledged that the concepts of ***MCY*** and ***CAY*** are directly applicable only in idealised management regimes. The ***MCY*** could be used in a regime where a catch level was to be set for once and for all; our system allows changes to be made if, the level is found to be too low or too high.

With a ***CAY*** strategy the yield would probably change every year. Even if there were no legal impediments to following a ***CAY*** strategy, the fishing industry's desire for stability may be a sufficient reason to make TACC changes only when the need is pressing.

Natural and Fishing Mortality

Before describing how to calculate ***MCY*** and ***CAY*** we must discuss natural and fishing mortality, which are used in these calculations. Both types of mortality are expressed as instantaneous rates (thus, over n years a total mortality Z will reduce a population of size B to size Be^{-nZ}, ignoring recruitment and growth). Units for mortalities are 1/year.

Natural mortality

Methods of estimating natural mortality, M, are reviewed by Vetter (1988). When a lack of data rules out more sophisticated methods, M may be estimated by the formula,

$$M = \frac{\log_e(p)}{A}$$

where p is the proportion of the population that reaches age A (or older) in an unexploited stock. p is often set to 0.01, when A is the "maximum age" observed. Other values for p may be chosen dependent on the fishing history of the stock. For example, in an exploited stock the maximum observed age may correspond to a value of p = 0.05, or higher. For a discussion of the method see Hoenig (1983).

Reference Fishing Mortalities

Reference fishing mortalities in widespread use include $F_{0.1}$, F_{MSY}, F_{MAX}, F_{MEY}, and M.

The most common reference fishing mortality used in the calculation of ***CAY*** (and, in some cases, ***MCY***) is $F_{0.1}$ (pronounced `F zero point one'). This is used as a basis for fisheries management decisions throughout the world and is widely believed to produce a high level of yield on a sustainable basis (Mace 1988b). It is estimated from a yield per recruit analysis as the level of fishing mortality at which the slope of the yield-per-recruit curve is 0.1 times the slope at F = 0. If an estimate of $F_{0.1}$ is not available an estimate of M may be substituted.

F_{MAX} , the fishing mortality that produces the maximum yield per recruit. It may be too high as a target fishing mortality because it does not account for recruitment effects (e.g. recruitment declining as stock size is reduced). However, it may be a valid reference point for those fisheries that have histories of sustainable fishing at this level.

F_{MSY}, the fishing mortality corresponding to the deterministic ***MSY***, is another appropriate reference point. F_{MSY} may be estimated from a surplus production model, or a combination of yield per recruit and stock recruitment models.

When economic data are available it may be possible to calculate F_{MEY} the fishing mortality corresponding to the maximum (sustainable) economic yield.

Every reference fishing mortality corresponds to an equilibrium or long-run average stock biomass. This is the biomass which the stock will tend towards or randomly fluctuate around, when the reference fishing mortality is applied constantly. The fluctuations will be caused primarily by variable recruitment. It is necessary to examine the equilibrium stock biomass corresponding to any candidate reference fishing mortality.

A reference fishing mortality which corresponds to a low stock biomass may be undesirable if the low biomass would lead to an unacceptable risk of stock collapse. For fisheries where this applies a lower reference fishing mortality may be appropriate.

Natural Variability Factor

Fish populations are naturally variable in size because of environmental variability and associated fluctuations in the abundance of predators and food. Computer simulations (e.g., Mace 1988a) have shown that, all other things being equal, the ***MCY*** for a stock is inversely related to the degree of natural variability in its abundance. That is, the higher the natural variability, the lower the ***MCY***.

The natural variability factor, ***c***, provides a way of incorporating the natural variability of a stock's biomass into the calculation of ***MCY***. It is used as a multiplying factor in method 5 below. The greater the variability in the stock, the lower is the value of ***c***. Values for ***c*** should be taken from the table below and are based on the estimated mean natural mortality rate of the stock. It is assumed that because a stock with a higher natural mortality will have fewer age-classes it will also suffer greater fluctuations in biomass. The only stocks for which the table should be deviated from are those where there is evidence that recruitment variability is unusually high or unusually low.

Natural mortality rate	**Natural variability factor**
M	***c***
<0.05	1.0
0.05-0.15	0.9
0.16-0.25	0.8
0.26-0.35	0.7
>0.35	0.6

Methods of Estimating *MCY*

It should be possible to estimate ***MCY*** for most fish stocks (with varying degrees of confidence). For some stocks, only conservative estimates for ***MCY*** will be obtainable (e.g., some applications of Method 4) and this should be stated. For other stocks it may be impossible to estimate ***MCY***. These stocks include situations in which: the fishery is very new; catch or effort data are unreliable; strong upwards or downwards trends in catch are not able to be explained by available data (e.g., by trawl survey data or by catch per unit effort data).

When catch data are used in estimating ***MCY*** all catches (commercial, illegal, and non-commercial) should be included if possible. If this is not possible and the excluded catch is thought to be a significant quantity, then this should be stated.

The following examples define ***MCY*** in an operational context with respect to the type, quality and quantity of data available. Knowledge about the accuracy or applicability of the data (e.g., reporting anomalies, atypical catches in anticipation of the introduction of the Quota Management System) should play a part in determining which data sets are to be included in the analysis.

As a general rule it is preferable to apply subjective judgements to input data rather than to the calculated ***MCY***s. For example, rather than saying "with the official catch statistics the ***MCY*** is ***X*** tonnes, but we think this is too high because the catch statistics are wrong" it would be better to say "we believe (for reasons given) that the official statistics are wrong and the true catches were probably such and such, and the ***MCY*** based on these catches is ***Y*** tonnes".

Background information on the rationale behind the following calculation methods can be found in Mace (1988a) and other scientific papers listed at the end of this document.

New fisheries

$$MCY = 0.25F_{0.1}B_0$$

where $\boldsymbol{B_0}$ is an estimate of virgin recruited biomass. If there are insufficient data to conduct a yield per recruit analysis $\boldsymbol{F_{0.1}}$ should be replaced with an estimate of natural mortality ($\boldsymbol{M}$). Tables 1–3 in Mace (1988b) show that $\boldsymbol{F_{0.1}}$ is usually similar to (or sometimes slightly greater than) $\boldsymbol{M}$.

It may appear that the estimate of ***MCY*** for new fisheries is overly conservative, particularly when compared to the common approximation to MSY of $\mathbf{0.5}\boldsymbol{MB_0}$ (Gulland 1971). However various authors (including Beddington & Cooke 1983; Getz et al 1987; Mace 1988a) have shown that $\mathbf{0.5}\boldsymbol{MB_0}$ often overestimates ***MSY***, particularly for a constant catch strategy or when recruitment declines with stock size. Moreover it has often been observed that the development of new fisheries (or the rapid expansion of existing fisheries) occurs when stock size is unusually large, and that catches plummet as the accumulated biomass is fished down.

It is preferable to estimate ***MCY*** from a stochastic population model (Method 5), if this is possible. The simulations of Mace (1988a) and Francis (1992) indicate that the appropriate factor to multiply $\boldsymbol{F_{0.1}B_0}$ may be somewhat higher or somewhat lower than **0.25**. This depends primarily on the steepness of the assumed stock recruitment relationship (*see* Mace & Doonan 1988 for a definition of steepness).

New fisheries become developed fisheries once ***F*** has approximated or exceeded ***M*** for several successive years, depending on the lifespan of the species.

2. Developed fisheries with historical estimates of biomass

$$MCY = 0.5F_{0.1}B_{AV}$$

where $\boldsymbol{B_{AV}}$ is the average historical recruited biomass, and the fishery is believed to have been fully exploited (i.e., fishing mortality has been near the level that would produce ***MAY***). This formulation assumes that $\boldsymbol{F_{0.1}}$ approximates the average productivity of a stock.

As in the previous method an estimate of ***M*** can be substituted for $\boldsymbol{F_{0.1}}$ if estimates of $\boldsymbol{F_{0.1}}$ are not available.

3. Developed fisheries with adequate data to fit a population model

$$MCY = {}^{2}/_{3}\,MSY$$

where ***MSY*** is the deterministic maximum equilibrium yield.

This reference point is slightly more conservative than that adopted by several other stock assessment agencies (e.g. ICES, CAFSAC) that use as a reference point the equilibrium yield corresponding to 2/3 of the fishing effort (fishing mortality) associated with the deterministic equilibrium ***MSY***.

If it is possible to estimate ***MSY*** then it is generally possible to estimate ***MCY*** from a stochastic population model (Method 5), which is the preferable method. The simulations of Mace (1988a) and Francis (1992) indicate that the appropriate factor to multiply ***MSY*** varies between about **0.6** and **0.9**. This depends on various parameters of which the steepness of the assumed stock recruitment relationship is the most important.

If the current biomass is less than the level required to sustain a yield of 2/3 ***MSY*** then

$$MCY = {}^{2}/_{3}\,CSP$$

where ***CSP*** is the deterministic current surplus production.

4. Catch data and information about fishing effort (and/or fishing mortality), either qualitative or quantitative, without a surplus production model

$$MCY = cY_{AV}$$

where ***c*** is the natural variability factor (defined above) and $\boldsymbol{Y_{AV}}$ is the average catch over an appropriate period.

If the catch data are from a period when the stock was fully exploited (i.e. fishing mortality near the level that would produce ***MAY***), then the method should provide a good estimate of ***MCY***. In this case, $\boldsymbol{Y_{AV}}$ = ***MAY***. If the population was under-exploited the method gives a conservative estimate of ***MCY***.

Familiarity with stock demographics and the history of the fishery is necessary for the determination of an appropriate period on which to base estimates of $\boldsymbol{Y_{AV}}$. The period chosen to perform the averaging will depend on the behaviour of the fishing mortality or fishing effort time series, the prevailing management regime, the behaviour of the catch time series, and the lifespan of the species.

The period should be selected so that it contains no systematic changes in fishing mortality (or fishing effort, if this can be assumed to be proportional to fishing mortality). Note that for species such as orange roughy, where relatively static aggregations are fished, fishing mortality cannot be assumed to be proportional to effort. If catches during the period are constrained by a TACC then it is particularly important that the assumption of no systematic change in fishing mortality be adhered to. The existence of a TACC does not necessarily mean that the catch is constrained by it.

The period chosen should also contain no systematic changes in catch. If the period shows a systematic upward (or downward) trend in catches then the ***MCY*** will be under-estimated (over-estimated). It is desirable that the period be equal to at least half the exploited life span of the fish.

5. Sufficient information for a stochastic population model

This is the preferred method for estimating ***MCY*** but it is the method requiring the most information. It is the only method that allows some specification of the risk associated with an ***MCY***.

The simulations in Mace (1988a) and Breen (1989) provide examples of the type of calculations necessary for this method. A trial and error procedure can be used to find the maximum constant catch that can be taken for a given level of risk. The level of risk may be expressed as the probability of stock collapse within a specified time period. At the moment Fisheries New Zealand has no standards as to how stock collapse should be defined for this purpose, what time period to use, and what probability of collapse is acceptable. These will be developed as experience is gained with this method.

Methods of Estimating *CAY*

It is possible to estimate ***CAY*** only when there is adequate stock biomass data. In some instances relative stock biomass indices (e.g., catch per unit effort data) and relative fishing mortality data (e.g., effort data) may be sufficient. ***CAY*** calculated by method 1 includes non-commercial catch.

If method 2 is used and it is not possible to include a significant non-commercial catch, then this should be stated.

1. Where there is an estimate of current recruited stock biomass, ***CAY*** may be calculated from the appropriate catch equation. Which form of the catch equation should be used will depend on the way fishing mortality occurs during the year. For many fisheries it will be a reasonable

approximation to assume that fishing is spread evenly throughout the year so that the Baranov catch equation is appropriate and ***CAY*** is given by

$$CAY = \frac{F_{ref}}{F_{ref} + M}(1 - e^{-(F_{ref}+M)})B_{beg}$$

Where $\boldsymbol{B_{BEG}}$ is the projected stock biomass at the beginning of the fishing year for which the ***CAY*** is to be calculated and $\boldsymbol{F_{REF}}$ is the reference fishing mortality described above.

If most of the fishing mortality occurs over a short period each year it may be better to use one of the following equations:

$$CAY = (1 - e^{-F_{ref}})B_{beg}$$

$$CAY = (1 - e^{-F_{ref}})e^{-\frac{M}{2}}B_{beg}$$

$$CAY = (1 - e^{-F_{ref}})e^{-M}B_{beg}$$

where the first equation is used when fishing occurs at the beginning of the fishing year, the second equation when fishing is in the middle of the year, and the third when fishing is at the end of the year.

It is important that the catch equation used to calculate ***CAY*** and the associated assumptions are the same as those used in any model employed to estimate stock biomass or to carry out yield per recruit analyses. Serious bias may result if this criterion is not adhered to. The assumptions and catch equations given here are by no means the only possibilities.

The risk associated with the use of a particular $\boldsymbol{F_{REF}}$ may be estimated using simulations.

2. Where information is limited but the current (possibly unknown) fishing mortality is thought to be near the optimum, there are various "status quo" methods which may be applied. Details are available in Shepherd (1984, 1991) and Pope (1983).

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Guidelines for Status of the Stocks Summary Tables

A new format for Status of the Stocks summaries was developed by the Stock Assessment Methods Working Group over the period February-April 2009. The purpose of this project was to provide more comprehensive and meaningful information for fisheries managers, stakeholders and other interested parties. Previously, Status of the Stocks summary sections had not reflected the full range of information of relevance to fisheries management contained in the earlier sections of Plenary reports, and were of variable utility for evaluating stock status and informing fisheries management decisions.

Status of the Stocks summary tables should be constructed for all stocks except those designated as "nominal"; e.g. those with administrative TACs or TACCs (generally less than 10–20 t) or those for which a commercial or non-commercial development potential has not currently been demonstrated. As of November 2014, there were a total of 292 stocks in this classification. The list of nominal stocks can be found at: https://www.fisheries.govt.nz/dmsdocument/19331-nz-nominal-fish-stocks-2018-report.

In 2012 a number of changes were made to the format for the Status of the Stocks summary tables, primarily for the purpose of implementing the science information quality rankings required by the Research and Science Information Standard for New Zealand Fisheries that was approved in April 2011 (New Zealand Ministry of Fisheries 2011a). At the time, these changes were only applied for Status of Stocks tables updated in 2012. Subsequently, an attempt has been made to revise some of the older tables as well.

In 2013, the format was further modified to require Science Working Groups to make a determination about whether overfishing is occurring, and to further standardise and clarify the requirements for other parts of the table.

It is anticipated that the format of the Status of the Stocks tables will continue to be reviewed, standardised and modified in the future so that it remains relevant to fisheries management and other needs. New formats will be implemented each time stocks are reviewed and as time allows.

The table below provides a template for the Status of the Stocks summaries. The text following the template gives guidance on the contents of most of the fields in the table. Superscript numbers refer to the corresponding numbered paragraph in the following text. Light blue text provides an example of how the table might be completed.

STATUS OF THE STOCKS TEMPLATE[1]

Stock Structure Assumptions[2]
<insert relevant text>

- **Fishstock name**[3]

Stock Status	
Year of Most Recent Assessment	2019
Assessment Runs Presented	Base case model only
Reference Points	Target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: $F_{40\%B0}$
Status in relation to Target	B_{2019} was estimated to be 50% B_0; Very Likely (> 90%) to be at or above the target
Status in relation to Limits	B_{2019} is Very Unlikely (< 10%) to be below both the soft and hard limits

Status in relation to Overfishing	The fishing intensity in 2014 was Very Unlikely (< 10%) to be above the overfishing threshold [or, Overfishing is Very Unlikely (<10%) to be occurring]

Historical Stock Status Trajectory and Current Status
<insert relevant graphs>

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass reached its lowest point in 2001 and has since consistently increased.
Recent Trend in Fishing Intensity or Proxy	Fishing intensity reached a peak of F=0.54 in 1999, subsequently declining to less than F=0.2 since 2006.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	Recent recruitment (2005–2017) is estimated to be near the long-term average.

Projections and Prognosis	
Stock Projections or Prognosis	Biomass is expected to stay steady over the next 5 years assuming current (2016–17) catch levels.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Very Unlikely (< 10%) Hard Limit: Very Unlikely (< 10%)
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Very Unlikely (< 10%)

Assessment Methodology and Evaluation		
Assessment Type	Level 1 - Full Quantitative Stock Assessment	
Assessment Method	Age-structured CASAL model with Bayesian estimation of posterior distributions	
Assessment Dates	Latest assessment: 2019	Next assessment: 2020
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Research time series of abundance indices (trawl and acoustic surveys) - Proportions at age data from the commercial fisheries and trawl surveys - Estimates of biological parameters	1 – High Quality 1 – High Quality 1 – High Quality
Data not used (rank)	Commercial CPUE	3 – Low Quality: does not track stock biomass
Changes to Model Structure and Assumptions	None since the 2012 assessment	

Major sources of Uncertainty	- The base case model deals with the lack of older fish in commercial catches and surveys by estimating natural mortality at age which results in older fish suffering high natural mortality. However, there is no evidence to validate this outside the model estimates. - Aside from natural mortality, other major sources of uncertainty include stock structure and migration patterns, stock-recruit steepness and natal fidelity assumptions. Uncertainty about the size of recent year classes affects the reliability of stock projections.

Qualifying Comments
The impact of the current young age structure of the population on spawning success is unknown.

Environmental and Ecosystem Considerations	
Observer coverage	Highly variable year to year (from 1.6 to 11.1%), but higher from 2008 onwards.
Non-target fish and invertebrate catch	Blue shark, lancetfish and porbeagle shark are the most commonly non-target fish species caught by the longline fleet (by number), but are rarely retained. Other species, like Rays bream and moonfish are caught more rarely, but are more frequently retained.
Incidental catch of seabirds	Observed capture rates of seabirds was highly variable prior to 2008 due to low levels of observer coverage. This fishery contributes primarily to the risk to Black petrel, Northern Buller's albatross and Gibson's albatross, among other species.
Incidental catch of cetaceans	Between 2002 and 2018, observers recorded one unidentified cetacean, two common dolphin, and one long finned pilot whale captured in this fishery. All of these cetaceans were released alive.
Incidental catch of pinnipeds	Between 2002 and 2018, there were two observed captures of New Zealand fur seals in this fishery. Both were released alive.
Incidental catch of other protected species	Between 2002 and 2018 incidental captures of 17 sea turtles were observed, these were leatherback turtles (10), unidentified turtles (5), green (1) and loggerhead (1) turtles.
Benthic interactions	There are no known benthic interactions for this fishery.

Guidance on preparing the Status of the Stocks summary tables

1. Everything included in the Status of the Stocks summary table should be derived from earlier sections in the Working Group or Plenary report. No new information should be presented in the summary that was not encompassed in the main text of the Working Group or Plenary report.

Stock Structure Assumptions

2. The current assumptions regarding the stock structure and distribution of the stocks being reported on should be briefly summarised. Where the assessed stock distribution differs from the relevant QMA fishstock(s), an explanation must be provided of how the stock relates to the QMA fishstock(s) it includes.

Stock Status

3. One Status of the Stocks summary table should be completed for each assessed stock or stock complex.

4. Management targets for each stock will be established by fisheries managers. Where management targets have not been established, it is suggested that an interim target of 40% B_0, or a related B_{MSY}-compatible target (or $F_{40\%}$, or a related target) should be assumed. In most cases, the soft and hard limits should be set at the default levels specified in the Harvest Strategy Standard (20% B_0 for the soft limit and 10% B_0 for the hard limit). Similarly, the overfishing threshold should be set at F_{MSY}, or a related F_{MSY}-compatible threshold. Overfishing thresholds can be expressed in terms of fishing mortality, exploitation rates, or other valid measures of fishing intensity. When agreed reference points have not been established, stock status may be reported against interim reference points.

5. Reporting stock status against reference points requires Working Group agreement on the model run to use as a base case for the assessment. The preference, wherever possible, is to report on the best estimates from a single base case, or to make a single statement that covers the results from a range of cases. In general, ranges or confidence intervals should not be included in the table. Only where more than one equally plausible model run exists, and agreement cannot be reached on a single base case, should multiple runs be reported. This should still be done simply and concisely (e.g. median results only).

6. Where probabilities are used in qualifying a statement regarding the status of the stock in relation to target, limit, or threshold reference levels, the following probability categories and associated verbal descriptions are to be used (IPCC, 2007):

Probability	**Description**
> 99 %	Virtually Certain
> 90 %	Very Likely
> 60 %	Likely
40–60 %	About as Likely as Not
< 40 %	Unlikely
< 10 %	Very Unlikely
< 1 %	Exceptionally Unlikely

Probability categories and associated descriptions should relate to the probability of being “at or above” biomass targets (or “at or below” fishing intensity targets if these are used), below biomass limits, and above overfishing thresholds. Note, however, that the descriptions and associated probabilities adopted need not correspond exactly to model outputs; rather they should be superimposed with the Working Group’s belief about the extent to which the model fully specifies the probabilities. This is particularly relevant for the “Virtually Certain” and “Exceptionally Unlikely” categories, which should be used sparingly.

7. The status in relation to overfishing can be expressed in terms of an explicit overfishing threshold, or it can simply be a statement about the Working Group’s belief, based on the evidence at hand, about the likelihood that overfishing is occurring (based on, for example, a stock abundance index exhibiting a pronounced recent increase or decline). The probability rankings in the IPCC (2007) table above should be used. Overfishing thresholds can be considered in terms of fishing mortality rates, exploitation rates, or other valid measures of fishing intensity.

Historical Stock Status Trajectory and Current Status

8. This heading should be changed to reflect the graphs that are available to illustrate trends in biomass or fishing intensity (or proxies) and the current stock or fishery status.

Recent Fishery and Stock Trends

9. Recent stock or fishery trends should be reported in terms of stock size and fishing intensity (or proxies for these), respectively. For full quantitative (Level 1) assessments, median results should be used when reporting biomass. Observed trends should be reported using descriptors

such as increasing, decreasing, stable, or fluctuating without trend. Where it is considered relevant and important to fisheries management, mention could be made of whether the indicator is moving towards or away from a target, limit, threshold, or long term average.

10. Other Abundance Indices: This section is primarily intended for reporting of trends where a Level 2 (partial quantitative) evaluation has been conducted, and appropriate abundance indices (such as standardised CPUE or survey biomass) are available.

11. Other Relevant Indicators or Variables: This section is primarily intended for reporting of trends where only a Level 3 (qualitative) evaluation has been conducted. Potentially useful indicators might include trends in mean size, size or age composition, or recruitment indices. Catch trends vs TACC may be relevant here, provided these are qualified when other factors are known to have influenced the trends.

Projections and Prognosis

12. These sections should be used to report available information on likely future trends in biomass or fishing intensity or related variables under current (or a range of) catch levels over a period of approximately 3–5 years following the last year in the assessment. If a longer period is used, this must be stated.

13. When reporting probabilities of current catches or TACC levels causing declines below limits, the probability rankings in the IPCC (2007) table above should be used. Results should be reported separately (i.e. split into two rows) if the catch and TACC differ appreciably, resulting in differing conclusions for each level of removals, with the level of each specified. The timeframe for the projections should be approximately 3–5 years following the last year in the assessment unless a longer period of time is required by fisheries managers.

Assessment Methodology and Evaluation

14. Assessment type: the envisaged Assessment Levels are:

1 – Full Quantitative Stock assessment: There is a reliable index of abundance and an assessment indicating status in relation to targets and limits.
2 – Partial Quantitative Stock Assessment: An evaluation of agreed abundance indices (e.g. standardised CPUE) or other appropriate fishery indicators (e.g. estimates of *F* (*Z*) based on catch-at-age) is available. Indices of abundance or fishing intensity have not been used in a full quantitative stock assessment to estimate stock or fishery status in relation to reference points.
3 – Qualitative Evaluation: A fishery characterisation with evaluation of fishery trends (e.g. catch, effort, unstandardised CPUE, or length-frequency information) has been conducted but there is no agreed index of abundance.
4 – Low Information Evaluation: There are only data on catch and TACC, with no other fishery indicators.

Management Procedure (MP) updates should be presented in a separate table. In years when an actual assessment is conducted for stocks under MPs, the MP update table should be preceded by a Status of the Stocks summary table.

Table content will vary for these different assessment levels.

Ranking of Science Information Quality

15. The Research and Science Information Standard for New Zealand Fisheries (2011a) specifies (pages 21–23) that the processes that rank the quality of research and science information used in support of fisheries management decisions will be implemented. The quality ranking system is:

1 – High Quality: information that has been subjected to rigorous science quality assurance and peer review processes as required by this Standard, and substantially meets the key principles for science information quality. Such information can confidently be accorded a high weight in fisheries management decisions. An explanation is not required in the table for high quality information.

2 – Medium or Mixed Quality: information that has been subjected to some level of peer review against the requirements of the Standard and has been found to have some shortcomings with regard to the key principles for science information quality, but is still useful for informing management decisions. Such information should be accompanied by a description of its shortcomings.

3 – Low Quality: information that has been subjected to peer review against the requirements of the Standard but has substantially failed to meet the key principles for science information quality. Such information should be accompanied by a description of its shortcomings and should not be used to inform management decisions.

One of the key purposes of the science information quality ranking system is to inform fisheries managers and stakeholders of those datasets, analyses or models that are of such poor quality that they should not be used to make fisheries management decisions (i.e. those ranked as "3"). Most other datasets, analyses or models that have been subjected to peer review or staged technical guidance in the Fisheries New Zealand's Science Working Group processes and have been accepted by these processes should be given the highest score (ranked as "1"). Uncertainty, which is inherent in all fisheries science outputs, should not by itself be used as a reason to score down a research output, unless it has not been properly considered or analysed, or if the uncertainty is so large as to render the results and conclusions meaningless (in which case, the Working Group should consider rejecting the output altogether). A ranking of 2 (medium or mixed quality) should only be used where there has been limited or inadequate peer review or the Working Group has mixed views on the validity of the outputs, but believes they are nevertheless of some use to fisheries management.

16. In most cases, the "Data not used" row can be filled in with "N/A"; it is primarily useful for specifying particular datasets that the Working Group considered but did not use in an assessment because they were of low quality and should not be used to inform fisheries management decisions.

Changes to Model Assumptions and Structure

17. The primary purpose of this section is to briefly identify only the most significant model changes that directly resulted in significant changes to results on the status of the stock concerned, and to briefly indicate the main effect of these changes. Details on model changes should be left in the main text of the report.

Qualifying Comments

18. The purpose of the "Qualifying Comments" section is to provide for any necessary explanations to avoid misinterpretation of information presented in the sections above. This section may also be used for brief further explanation considered important to understanding the status of the stock.

Fishery Interactions

19. The "Fishery Interactions" section should be used to simply list QMS by-catch species, non-QMS by-catch species and protected / endangered species interactions.

FOR FURTHER INFORMATION

IPCC (2007) Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. [Core Writing Team, Pachauri, R K; Reisinger, A (eds.)]. IPCC, Geneva, Switzerland, 104 p.

New Zealand Ministry of Fisheries (2008) Harvest Strategy Standard for New Zealand fisheries. 25 p. Available at http://fs.fish.govt.nz/Page.aspx?pk=61&tk=208&se=&sd=Asc&filSC=&filAny=False&filSrc=False&filLoaded=False&filDCG=9&filDC=0&filST=&filYr=0&filAutoRun=1.

New Zealand Ministry of Fisheries (2011a) Research and Science Information Standard for New Zealand Fisheries. 31 p. Available at http://www.fish.govt.nz/en-nz/Publications/Research+and+Science+Information+Standard.htm.

New Zealand Ministry of Fisheries (2011b) Operational Guidelines for New Zealand's Harvest Strategy Standard Revision 1. 78 p. Available at http://fs.fish.govt.nz/Doc/22847/Operational_Guidelines_for_HSS_rev_1_Jun_2011.pdf.ashx.

Fisheries New Zealand

Tini a Tangaroa

New Zealand Government

FNZ management teams and primary species managed

FISHERIES MANAGEMENT - INSHORE

Common name	Code	Stock
Anchovy	ANC	All
Barracouta	BAR	BAR1
Bladder kelp	KBB	All
Blue cod	BCO	All
Blue moki	MOK	All
Blue warehou	WAR	All
Bluenose	BNS	All
Butterfish	BUT	All
Cockle	COC	All
Deepwater (king) clam	PZL	All
Dredge oyster	OYS, OYU	All
Elephantfish	ELE	All
English mackerel	EMA	EMA1, 2
Flatfish	FLA	All
Freshwater eels (NI and SI)	ANG, LFE, SFE	All
Frostfish	FRO	FRO1, 2
Garfish	GAR	All
Gemfish	SKI	SKI1, 2
Ghost shark, dark	GSH	GSH1-3, 7-9
Greenlipped mussel	GLM	All
Grey mullet	GMU	All
Gurnard	GUR	All
Hapuka / bass	HPB	All
Horse mussel	HOR	All
Jack mackerel	JMA	JMA1
John dory	JDO	All
Kahawai	KAH	All
Kina	SUR	All
Kingfish	KIN	All
Knobbed whelk	KWH	All

Common name	Code	Stock
Leatherjacket	LEA	All
Ling	LIN	LIN1, 2
Paddle crab	PAD	All
Parore	PAR	All
Paua	PAU	All
Pilchard	PIL	All
Pipi	PPI	All
Porae	POR	All
Queen scallop	QSC	All
Red cod	RCO	All
Red snapper	RSN	All
Ribaldo	RIB	RIB1, 2, 9
Rig	SPO	All
Rock lobsters (incl. PHC)	CRA, PHC	All
Scallop	SCA	All
School shark	SCH	All
Sea cucumber	SCC	All
Sea perch	SPE	SPE1, 2, 8, 9
Skate, rough and smooth	RSK, SSK	All
Snapper	SNA	All
Spiny dogfish	SPD	SPD1, 3, 7, 8
Sprat	SPR	All
Stargazer	STA	All
Surf clams (all species)	DAN, DSU, MMI, MDI, SAE, PDO, BYA	All
Tarakihi	TAR	All
Trevally	TRE	All
Trumpeter	TRU	All
Tuatua	TUA	All
Yelloweyed mullet	YEM	All

FISHERIES MANAGEMENT - DEEPWATER

Common name	Code	Stock
Alfonsino	BYX	All
Barracouta	BAR	BAR4, 5, 7
Cardinalfish	CDL	All
Deepwater crabs (red crab, king crab, giant spider crab)	CHC, KIC, GSC	All
English mackerel	EMA	EMA3, 7
Frostfish	FRO	FRO3-9
Gemfish	SKI	SKI3, 7
Ghost shark, dark	GSH	GSH4-6
Ghost shark, pale	GSP	All
Hake	HAK	All
Hoki	HOK	All
Jack mackerel	JMA	JMA3, 7
Ling	LIN	LIN3-7
Lookdown dory	LDO	All
Orange roughy	ORH	All
Oreos	SSO, BOE, SOR, WOE, OEO	All
Patagonian toothfish	PTO	All
Prawnkiller	PRK	All
Redbait	RBT	All
Ribaldo	RIB	RIB3-8
Rubyfish	RBY	All
Scampi	SCI	All
Sea perch	SPE	SPE3-7
Silver warehou	SWA	All
Southern blue whiting	SBW	All
Spiny dogfish	SPD	SPD4, 5
Squid	SQU	All
White warehou	WWA	All

FISHERIES MANAGEMENT - HMS

Common name	Code	Stock
*Albacore tuna **	*ALB*	*All*
Bigeye tuna	BIG	All
Blue shark	BWS	All
Mako shark	MAK	All
Moonfish	MOO	All
Pacific bluefin tuna	TOR	All
Porbeagle shark	POS	All
Ray's bream	RBM	All
*Skipjack tuna **	*SKJ*	*All*
Southern bluefin tuna	STN	All
Swordfish	SWO	All
Yellowfin tuna	YFN	All

** non-QMS species*

INTL POLICY - FISHERIES MGMT

Common name	RFMO
Antarctic toothfish, Patagonian toothfish	CCAMLR
Orange roughy	SPRFMO
Pacific HMS species *	WCPFC
Southern bluefin tuna	CCSBT

Regional Fisheries Management Organisations (RFMOs)

CCAMLR - *Commission for the Conservation of Antarctic Marine Living Resources*

SPRFMO - *South Pacific Regional Fisheries Management Organisation*

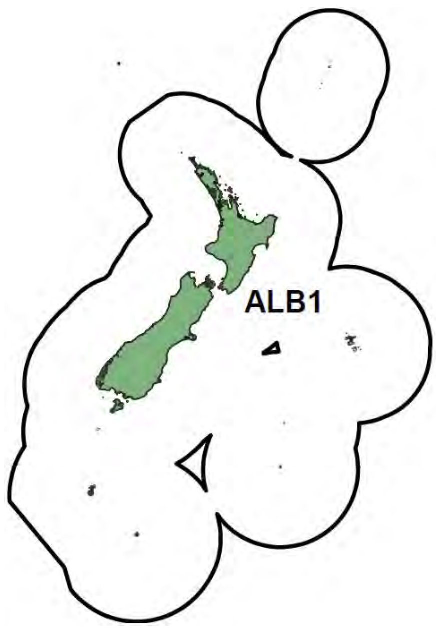
WCPFC - *Western and Central Pacific Fisheries Commission*

CCSBT - *Commission for the Conservation of Southern Bluefin Tuna*

** primarily ALB, BIG, SKJ, SWO and YFN*

ALBACORE (ALB)

(*Thunnus alalunga)*
Ahipataha



1. FISHERY SUMMARY

Albacore is currently outside the Quota Management System.

Management of albacore stock throughout the South Pacific is the responsibility of the Western and Central Pacific Fisheries Commission (WCPFC). Under this regional convention New Zealand is responsible for ensuring that the management measures applied within New Zealand fisheries waters are compatible with those of the Commission.

At its seventh annual meeting in 2011 the WCPFC passed a Conservation and Management Measure (CMM) (this is a binding measure that all parties must abide by), CMM2010-05, relating to conservation and management measures for South Pacific albacore tuna. Key aspects of this CMM are below:

1. Commission Members, Cooperating Non-Members, and participating Territories (CCMs) shall not increase the number of their fishing vessels actively fishing for South Pacific albacore in the Convention Area south of 20°S above current (2005) levels or recent historical (2000–04) levels.
2. The provisions of paragraph 1 shall not prejudice the legitimate rights and obligations under international law of small island developing State and Territory CCMs in the Convention Area for whom South Pacific albacore is an important component of the domestic tuna fishery in waters under their national jurisdiction, and who may wish to pursue a responsible level of development of their fisheries for South Pacific albacore.
3. CCMs that actively fish for South Pacific albacore in the Convention Area south of the equator shall cooperate to ensure the long-term sustainability and economic viability of the fishery for South Pacific albacore, including cooperation and collaboration on research to reduce uncertainty with regard to the status of this stock.

4. This measure will be reviewed annually on the basis of advice from the Scientific Committee on South Pacific albacore.

In 2015 the WCPFC passed CMM2015-02, which reaffirmed CMM2010-05 and added an additional clause as follows:

> ‘CCMs shall report annually to the Commission the annual catch levels taken by each of their fishing vessels that has taken South Pacific albacore, as well as the number of vessels actively fishing for South Pacific albacore, in the Convention area south of 20°S. Catch by vessel shall be reported according to the following species groups: albacore tuna, bigeye tuna, yellowfin tuna, swordfish, other billfish, and sharks. Initially this information will be provided for the period 2006–2014 and then updated annually. CCMs are encouraged to provide data from periods prior to these dates.’

1.1 Commercial fisheries

The South Pacific albacore catch in 2014 (83 033 t) was the second highest on record. Catches from within New Zealand fisheries waters in 2014 (2466 t) were about 4% of the South Pacific albacore catch. The South Pacific albacore catch increased to 93 290 t in 2018 and the New Zealand catch declined to 2514 t.

In New Zealand, albacore form the basis of a summer troll fishery, primarily on the west coasts of the North and South Islands. The New Zealand albacore fishery, especially the troll fishery, has been characterised by periodic poor years that have been linked to poor weather or colder than average summer seasons. In 2013 about 55% of the albacore catch was taken by troll (see Figure 2). Albacore are also caught throughout the year by longline. Total annual landings between 2000 and 2018 ranged between 2092 and 6744 t (Table 1). Figure 1 shows the historical landings and fishing effort for albacore stocks.

The earliest known commercial catch of tuna (species unknown but probably skipjack tuna) was by trolling and was landed in Auckland in the year ending March 1943. Regular commercial catches of tuna, however, were not reported until 1961. Prior to 1973 the albacore troll fishery was centred off the North Island (Bay of Plenty to Napier and New Plymouth) with the first commercial catches off Greymouth and Westport (54% of the total catch) in 1973. The expansion of albacore trolling to the west coast of the South Island immediately followed experimental fishing by the *W. J. Scott*, which showed substantial quantities of albacore off the Hokitika Canyon and albacore as far south as Doubtful Sound. Tuna longlining was not established as a fishing method in the domestic industry until the early 1990s.

Table 1: Reported total New Zealand landings (t) and landings (t) from the South Pacific Ocean (SPO) of albacore tuna from 1972 to 2018 (continued over page).

Source: LFRR and MHR and SC11-ST-IP-01.

Year	NZ fisheries waters	SPO	Year	NZ fisheries waters	SPO	Year	NZ fisheries waters	SPO
1972	240	39 521	1988	672	37 867	2004	4 459	61 871
1973	432	47 330	1989	4 884	49 076	2005	3 459	62 566
1974	898	34 049	1990	3 011	36 062	2006	2 542	62 444
1975	646	23 600	1991	2 450	35 600	2007	2 092	58 591
1976	25	29 082	1992	3 481	38 668	2008	3 720	62 740
1977	621	38 740	1993	3 327	35 438	2009	2 216	82 901
1978	1 686	34 676	1994	5 255	42 318	2010	2 292	88 942
1979	814	27 076	1995	6 159	38 467	2011	3 205	66 476
1980	1 468	32 541	1996	6 320	34 359	2012	2 990	87 752
1981	2 085	34 784	1997	3 628	39 490	2013	3 142	84 698
1982	2 434	30 788	1998	6 525	50 371	2014	2 466	83 033
1983	720	25 092	1999	3 903	39 614	2015	2 537	68 594
1984	2 534	24 704	2000	4 428	47 338	2016	2 274	68 601
1985	2 941	32 328	2001	5 349	58 344	2017	2 141	93 290
1986	2 044	36 590	2002	5 566	73.240	2018	2 514	68 454
1987	1 236	25 052	2003	6 744	62.477			

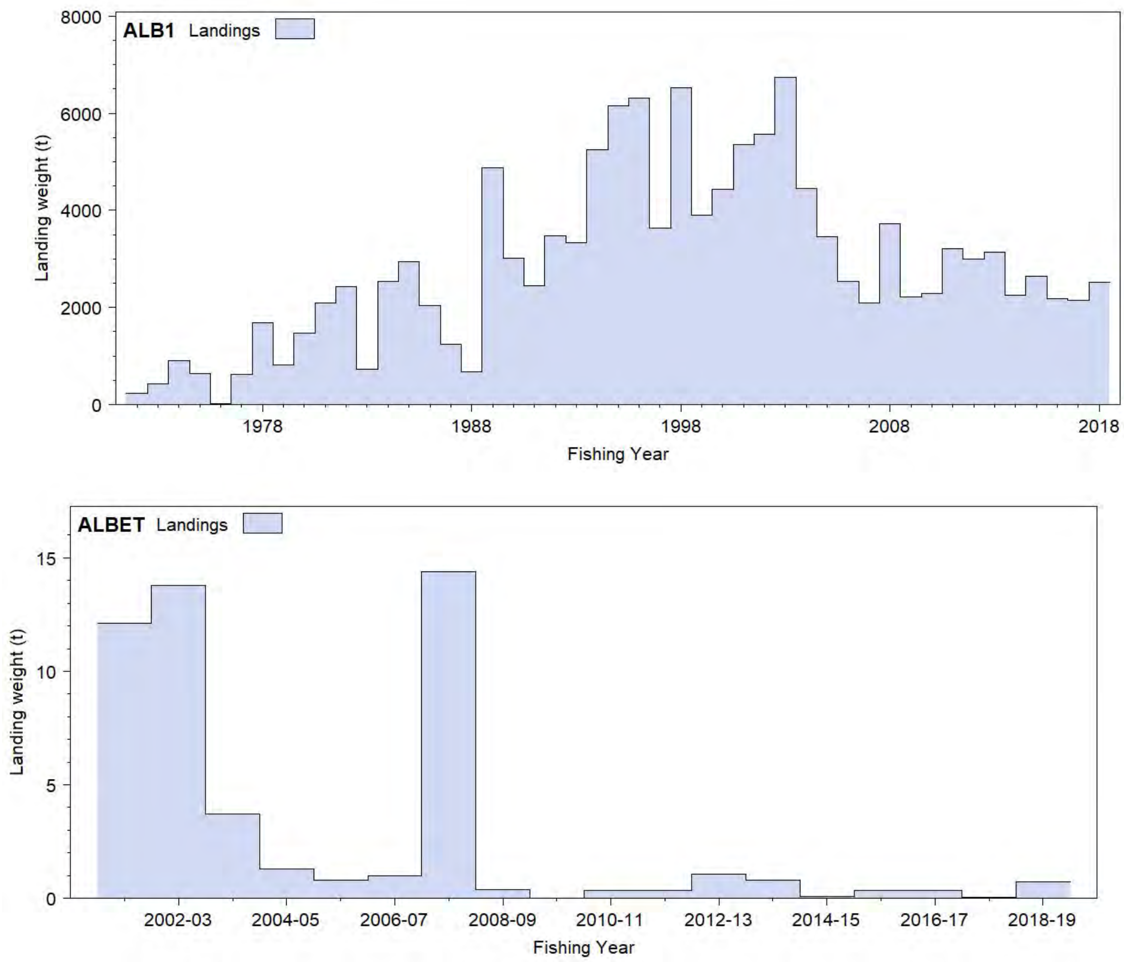


Figure 1: [Top] Albacore catch from 1972 to 2018 within New Zealand waters (ALB 1) and (bottom) 2001–02 to 2018–19 on the high seas (ALB ET).

Most albacore troll fishery catches are in the first and second quarters of the calendar year, with the fourth quarter important in some years. Most of the troll fishery catch comes from FMA 7 off the west coast of the South Island although FMAs 1, 2, 8 and 9 have substantial catches in some years. High seas troll catches have been infrequent and a minor component (maximum catch of 42.2 t in 1991) of the New Zealand fishery over the 1991 to 2018 period. Albacore are caught by longline throughout the year as a bycatch on sets targeting bigeye and southern bluefin tuna. Most of the longline albacore catch is reported from FMAs 1 and 2 with lesser amounts caught in FMA 9. While albacore are caught regularly by longline in high seas areas, New Zealand effort and therefore catches are small.

The majority of albacore caught in New Zealand waters is by troll fishing, which accounts for 55% of the overall effort in the surface lining fisheries (troll, surface longline, pole-and-line) and 91% of the albacore catch. In the surface-longline fisheries in 2012–13, 65% of fishing effort was directed at bigeye tuna, while for all surface lining fisheries combined, 55% of fishing effort was directed at albacore (Figure 2). Albacore made up 6% of the catch in the surface-longline fisheries in 2017–18 (Figure 3).

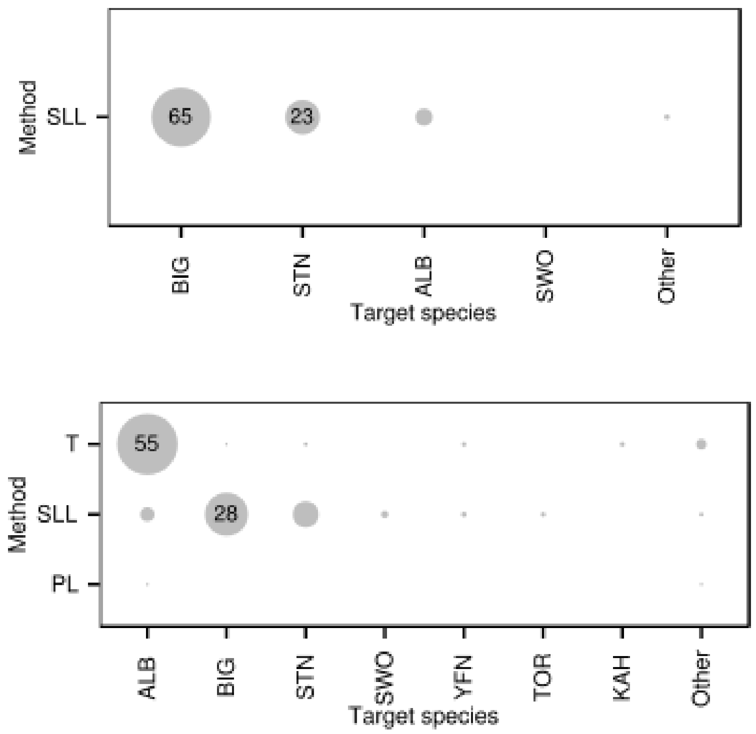


Figure 2: The proportion of effort in each of New Zealand's surface-longline fisheries (top) and in all surface lining fisheries for 2012–13 (bottom), (T – troll; SLL – surface longline; PL – pole-and-line). The area of each circle is proportional to the percentage of overall effort and the number in the circle is the percentage (Bentley et al. 2013).

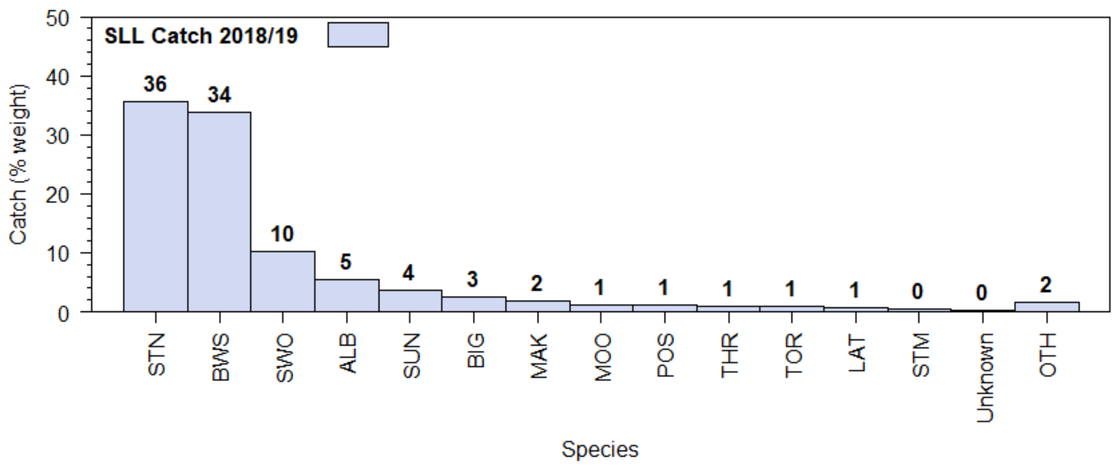


Figure 3: A summary of species composition by weight of the surface-longline estimated catch for 2018–19.

Across all fleets in the 2014–15 longline fishery, 35.4% of albacore tuna were alive when brought to the side of the vessel (Table 2). The domestic fleets retained around 96–98% of their albacore tuna catch, while the foreign charter fleet retained almost all the albacore (98–100%). The Australian fleet that fished in New Zealand waters in 2006–07 also retained most of the albacore catch (92.4%) (Table 3).

Table 2: Percentage of albacore (including discards) that were alive or dead when arriving at the longline vessel and observed from 2006–07 to 2014–15, by fishing year, fleet and region. Small sample sizes (number observed < 20) were omitted (Griggs & Baird 2013, Griggs et al. 2018).

Year	Fleet	Region	% Alive	% Dead	Number
2006–07	Australia	North	21.5	78.5	79
	Charter	North	61.2	38.8	784
		South	77.3	22.7	587
	Domestic	North	28.1	71.9	1 880
	Total		**44.4**	**55.6**	**3 330**
2007–08	Charter	South	71.3	28.7	167
	Domestic	North	22.7	77.3	1 765
	Total		**26.9**	**73.1**	**1 932**
2008–09	Charter	North	84.6	15.4	410
		South	79.5	20.5	112
	Domestic	North	33.7	66.3	1 986
	Total		**44.0**	**56.0**	**2 511**
2009–10	Charter	South	82.1	17.9	78
	Domestic	North	28.8	71.2	1 766
		South	42.9	57.1	42
	Total		**31.3**	**68.7**	**1 886**
2010–11	Charter	South	87.0	13.0	54
	Domestic	North	25.8	74.2	3 717
	Total		**26.8**	**73.2**	**3 781**
2011–12	Charter	North	70.8	29.2	48
		South	78.0	22.0	91
	Domestic	North	33.8	66.2	942
		South	42.2	57.8	211
	Total		**39.6**	**60.4**	**1 292**
2012–13	Charter	North	61.8	38.2	408
		South	84.0	16.0	100
	Domestic	North	27.8	72.2	905
	Total		**41.4**	**58.6**	**1 419**
2013–14	Charter	South	85.7	14.3	482
	Domestic	North	16.7	83.3	1464
		South	28.3	71.7	205
	Total		**33.2**	**66.8**	**2 151**
2014–15	Charter	South	81.9	18.1	216
	Domestic	North	19.1	80.9	435
		South	8.9	91.1	112
	Total		**35.4**	**64.6**	**763**

Table 3: Percentage albacore that were retained, or discarded or lost, when observed on a longline vessel from 2006–07 to 2014–15, by fishing year and fleet. Small sample sizes (number observed < 20) omitted (Griggs & Baird 2013, Griggs et al. 2018).

Year	Fleet	% retained	% discarded or lost	Number
2006–07	Australia	92.4	7.6	79
	Charter	97.7	2.3	1 448
	Domestic	96.1	3.9	1 882
	Total	**96.7**	**3.3**	**3 409**
2007–08	Charter	98.8	1.2	170
	Domestic	95.9	4.1	1 769
	Total	**96.1**	**3.9**	**1 939**
2008–09	Charter	99.7	0.3	605
	Domestic	97.8	2.2	1 993
	Total	**98.2**	**1.8**	**2 598**
2009–10	Charter	100.0	0.0	89
	Domestic	97.2	2.8	1 814
	Total	**97.3**	**2.7**	**1 903**
2010–11	Charter	100.0	0.0	68
	Domestic	96.6	3.4	3 755
	Total	**96.7**	**3.3**	**3 823**
2011–12	Charter	100.0	0.0	151
	Domestic	95.8	4.2	1 175
	Total	**96.3**	**3.7**	**1 326**
2012–13	Charter	97.6	2.4	509
	Domestic	96.1	3.9	925
	Total	**96.7**	**3.3**	**1 434**
2013–14	Charter	98.5	1.5	532
	Domestic	87.0	13.0	1 739
	Total	**89.7**	**10.3**	**2 271**
2014–15	Charter	98.2	1.8	226
	Domestic	95.5	4.5	551
	Total	**96.3**	**3.7**	**777**

1.2 Recreational fisheries

Albacore by virtue of its wide distribution in coastal waters over summer is seasonally locally important as a recreational species. It is taken by fishers targeting it predominantly for food, but it is also frequently taken as bycatch when targeting other gamefish. Albacore do not comprise part of the voluntary recreational gamefish tag and release programme. Albacore are taken almost exclusively using rod and reel (over 99% of the 2017–18 harvest), and from trailer boats (over 89% of the 2017–18 harvest). They are caught around the North Island and upper South Island, more frequently on the west coast, with harvest by area in 2017–18 being: FMA 1 (24.0%), FMA 2 (27.9%), FMA 5 (FMA 7 (0.6%), FMA 8 (11.9%) and FMA 9 (34.7%).

1.2.1 Management controls

There are no specific controls in place to manage recreational harvests of albacore.

1.2.2 Estimates of recreational harvest

No estimates of recreational harvest of albacore were generated from the telephone-diary surveys conducted in 1994, 1996 and 2000 because so few were reported. A National Panel Survey was conducted for the first time throughout the 2011–12 fishing year. The panel survey used face-to-face interviews of a random sample of 30 390 New Zealand households to recruit a panel of fishers and non-fishers for a full year (from Wynne-Jones et al 2014). The panel members were contacted regularly about their fishing activities and harvest information collected in standardised phone interviews. The national panel survey was repeated during the 2017–18 fishing year using very similar methods to produce directly comparable results (Wynne-Jones et al. 2019). Recreational catch estimates from the two national panel surveys are given in Table 4. Note that national panel survey estimates do not include recreational harvest taken under s111 general approvals.

Table 4: Recreational harvest estimates (in numbers of fish) for albacore (Wynne-Jones et al. 2014, 2019).

Stock	Year	Method	Number of fish	Total weight (t)	CV
ALB 1	2011–12	Panel survey	21 898	92.09	0.21
	2017–18	Panel survey	12 463	56.74	0.22

1.3 Customary non-commercial fisheries

It is uncertain whether albacore were caught by early Maori, although it is clear that they trolled lures (for kahawai) that are very similar to those still used by Tahitian fishermen for various small tunas. Given the number of other oceanic species known to Maori, and the early missionary reports of Maori regularly fishing several miles from shore, albacore were probably part of the catch of early Maori. An estimate of the current customary catch is not available.

1.4 Illegal catch

There is no known illegal catch of albacore in the EEZ or adjacent high seas.

1.5 Other sources of mortality

Discarding of albacore has not been reported in the albacore troll fishery (based on limited observer coverage in the 1980s). Low discard rates (average 2.9%) have been observed in the longline fishery over the period 2006–07 to 2009–10. Of those albacore discarded, the main reason recorded by observers was shark damage. Similarly, the loss of albacore at the side of the vessel was low (0.6%). Mortality in the longline fishery associated with discarding and loss while landing is estimated at 1.8% of the albacore catch by longline.

2. BIOLOGY

The troll fishery catches juvenile albacore typically 5 to 8 kg in size with the mean fork length for 1996–97 to 2006–07 being 63.5 cm (Figure 4).

Longline fleets typically catch much larger albacore over a broader size range (56–105 cm) with variation occurring as a function of latitude and season. The mean length of longline-caught albacore from 1987 to 2007 is 80.4 cm. The smallest longline-caught albacore are those caught in May to June immediately north of the Sub-tropical Convergence Zone (STCZ). Fish further north at this time and fish caught in the EEZ in autumn and winter are larger.

Sampling of troll caught albacore has been carried out annually (except 2008–09) since the 1996–97 fishing year. The sampling programme aims to sample in the ports of Auckland, Greymouth and New Plymouth (which was included for the first time in 2003). Initially the programme aimed to sample 1000 fish per month in each port. In 2010 the sample targets were changed and the programme now aims to sample approximately 5000 fish per year and the sample targets (Table 5) are distributed throughout the season to reflect the fishing effort distribution. In addition, in each port at least 100 fish per month are sub-sampled for weight. Length-weight relationships are presented in Table 6 and length-frequency distributions are presented in Figure 4.

Table 5: Catch sample targets for length measurements in the New Zealand troll sampling programme.

Month	Target number of fish
December	400
January	1 600
February	1 600
March	1 000
April	400
Total	5 000

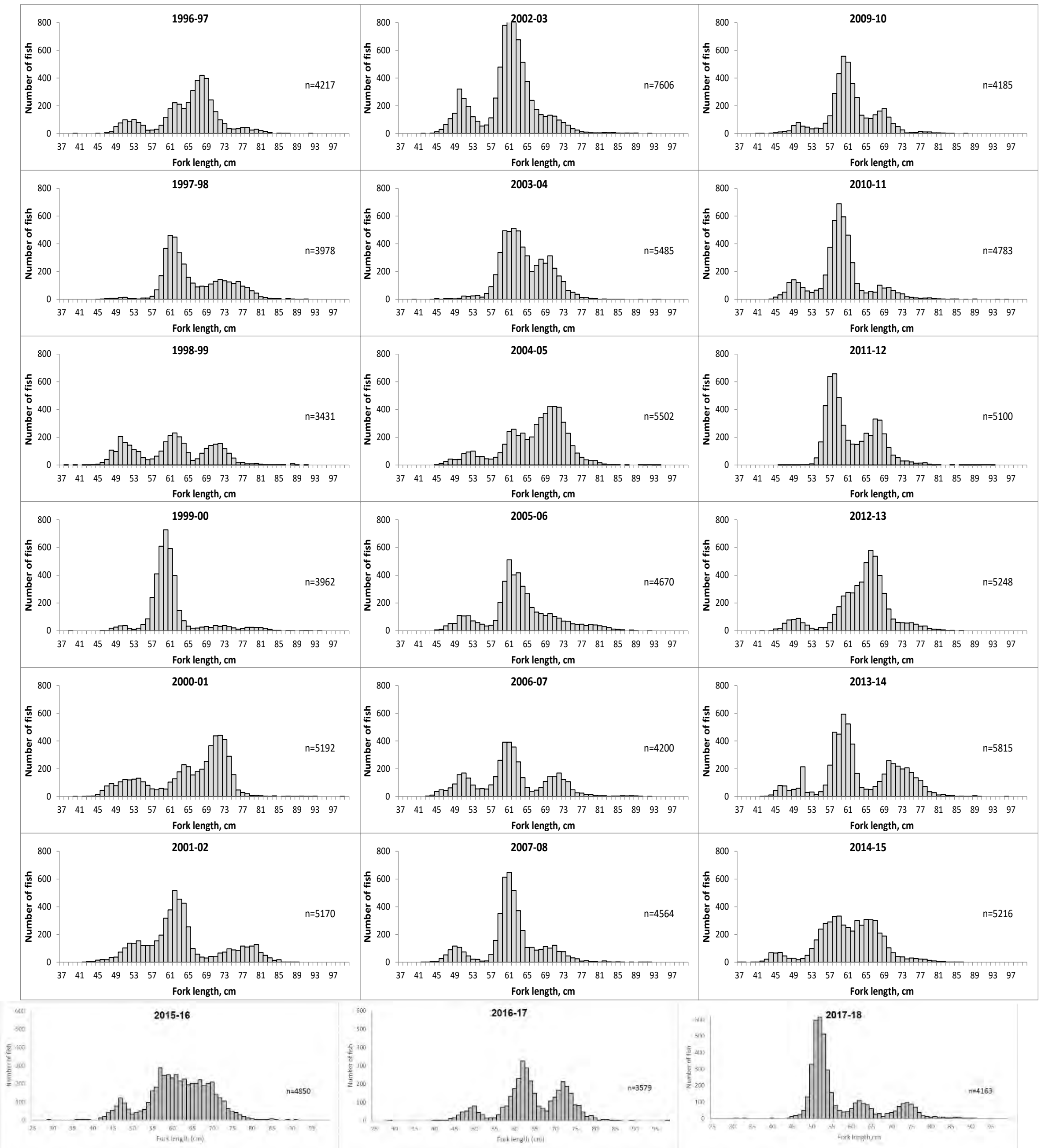


Figure 4: Size composition of albacore taken in the New Zealand domestic commercial troll fishery, 1996–97 to 2017–18.

Sex ratios appear to vary with fishery, at 1:1 (male:female) in the New Zealand troll and longline fishery, and 2:1 to 3:1 in the Tonga–New Caledonia longline fishery. Histological gonadosomatic index analysis has shown that female albacore from New Caledonian and Tongan waters spawn November–February.

Farley et al. (2012) completed a comprehensive analysis of South Pacific albacore biology. They found that otoliths were more reliable as ageing material then vertebrae. Their work using otoliths (validated by direct marking with oxytetracycline, and indirect methods) showed that the longevity of albacore was found to be at least 14 years, with significant variation in growth between sexes and across longitudes. They found that growth rates were similar between sexes up until age 4, after which the growth for males was on average greater than that for females, with males reaching an average maximum size more than 8 cm larger than females. Farley et al. (2012) contend that the different growth rates between sexes may be responsible for the observed dominance of males among fish in the larger size classes (greater than 95 to 100 cm fork length). This study shows that growth rates are also consistently greater at more easterly longitudes than at westerly longitudes for both females and males. While they are not able to identify the determinants of the longitudinal variation in growth of albacore, they suggest that variation in oceanography, particularly the depth of the thermocline, may affect regional productivity and therefore play a role in modifying growth of South Pacific albacore. Estimates of growth parameters from Farley et al. (2012) are presented in Table 7.

Table 6: The ln(length)/ln(weight) relationships of albacore [ln(greenweight) = b_0 + b_1 * ln(fork length)]. Weight is in kilograms and length in centimetres.

	n	b_0	SE b_0	b_1	SE b_1	R^2
Males	160	-10.56	0.18	2.94	0.04	0.97
Females	155	-10.10	0.26	2.83	0.06	0.93
Troll caught	320	-10.44	0.16	2.91	0.03	0.95
Longline caught	21 824	-10.29	0.03	2.90	0.01	0.91

Table 7: Parameter estimates (± standard error) from five candidate growth models fitted to length-at-age data for South Pacific albacore. Parameter estimates also given for the logistic model fitted separately to female and male length-at-age data. The small-sample bias-corrected form of Akaike's information criterion AICc are provided for each model fit, and Akaike differences ΔAICc, and Akaike weights *w*i are given for the fit of the five candidate models to all data. Note that the parameters *k* and *t* are defined differently in each model (see text for definitions), such that values are not comparable across models (Farley et al. 2012).

Sex	Model	L_∞	k	t	p	δ	γ	v	AICc	ΔAICc	w_i
All	VBGM	104.52	0.40	-0.49					11 831.67	23.89	0
		(0.44)	(0.01)	(0.05)							
	Gompertz	103.09	0.50	0.47					11 811.54	3.77	0.08
		(0.37)	(0.01)	(0.03)							
	Logistic	102.09	0.61	1.12					11 807.77	0.00	0.53
		(0.33)	(0.01)	(0.03)							
	Richards	102.30	0.58	0.98	1.32				11 809.40	1.63	0.24
		(0.49)	(0.04)	(0.24)	(0.68)						
	Schnute-	101.52	0.05			-0.97	3.54	2.07	11 810.25	2.48	0.15
	Richards	(0.60)	(0.08)			(0.08)	(2.65)	(0.76)			
Female	Logistic	96.97	0.69	0.99					5 746.90		
		(0.37)	(0.02)	(0.03)							
Male	Logistic	105.34	0.59	1.25					5 729.26		
		(0.44)	(0.02)	(0.04)							

3. STOCKS AND AREAS

Two albacore stocks (North and South Pacific) are recognised in the Pacific Ocean based on location and seasons of spawning, low longline catch rates in equatorial waters and tag recovery information. The South Pacific albacore stock is distributed from the coast of Australia and archipelagic waters of Papua New Guinea eastward to the coast of South America south of the equator to at least 49°S. However, there is some suggestion of gene flow between the North and South Pacific stocks based on an analysis of genetic population structure.

Most catches occur in longline fisheries in the EEZs of other South Pacific states and territories and in high seas areas throughout the geographical range of the stock.

4. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS

This section was updated for the November 2019 Fishery Assessment Plenary. This summary is from the perspective of the albacore troll and longline fishery; a more detailed summary from an issue-by-issue perspective is available in the Aquatic Environment and Biodiversity Annual Review where the consequences are also discussed (Ministry for Primary Industries 2019).

4.1 Role in the ecosystem

Albacore (*Thunnus alalunga*) are apex predators, found in the open waters of all tropical and temperate oceans, feeding opportunistically on a mixture of fish, crustaceans and squid, and juveniles also feed on a variety of zooplankton and micronecton species.

4.2 Incidental catch and non-target catch

4.2.1 Troll fishery

The majority of albacore caught in New Zealand waters is by troll fishing (91% of the albacore catch). The observer coverage of the troll fleet was ongoing between 2006–07 and 2011–12 and coverage averaged 0.7% of the effort during that time. Observer coverage was suspended after 2011–12 due to the difficulties experienced placing observers on the small vessels in this fishery.

From 2006 to 2012 the target albacore troll fishery catch averaged 93% albacore, with the remaining 7% made up mostly of teleosts. No incidental captures of protected species have been observed in this fishery.

4.2.2 Longline fishery

Recorded effort in target albacore longline fishery has been very low since 2004-05 and from 2016–17 onwards there has been no recorded effort. Observer coverage has been low to non-existent in this fishery since 2004–05. Since 2004-05 there have been no observed captures of marine mammals and seabirds in this fishery.

4.4 Benthic interactions

There are no known interactions with benthic habitats in this fishery.

5. STOCK ASSESSMENT

No assessment is possible for albacore within New Zealand fisheries waters as the proportion of the greater stock found within New Zealand fisheries waters is unknown and is likely to vary from year to year. With the establishment of WCPFC in 2004, stock assessments of the South Pacific Ocean (SPO) stock of albacore tuna are now undertaken by the Oceanic Fisheries Programme (OFP) of Secretariat of the Pacific Community (SPC) under contract to WCPFC.

Tremblay-Boyer et al. (2018a) described the 2018 stock assessment of albacore tuna (*Thunnus alalunga*) in the southern hemisphere component of the Western and Central Pacific Fisheries Commission (WCPFC) convention area. A further three years data were available since the last stock assessment was conducted in 2015, and the model time period extends to the end of 2016. Further developments to the stock assessment have been undertaken to address the recommendations of the 2015 stock assessment report (Harley et al. 2015), to address the recommendations of the 2018 pre-assessment workshop (PAW; Pilling & Brouwer 2018), and to explore uncertainties in the assessment model, particularly in response to the inclusion of additional years of data and to improve diagnostic weaknesses in previous assessments. This assessment is supported by the analysis of longline CPUE data, background analyses of other data inputs and definition of the regional and fisheries structures for the updated assessment (Tremblay-Boyer et al. 2018b).

Key changes made in the progression from the 2015 reference case to the 2018 diagnostic case model include:

- Updating all data up to the end of 2016.
- Utilising standardised CPUE indices calculated from the recently collated operational longline CPUE data set, including historical Japanese longline data within the CPUE which were not available in 2015, and treating targeting cluster as a covariate (rather than filtering the data).
- Moving to a simplified regional structure (2018 region structure).
- Moving from the traditional CPUE standardized index to one based upon a geostatistical model.
- Applying the CPUE standardized index to an 'index fishery' in each region.

In addition to the diagnostic case model, the results are also reported of one-off sensitivity models to explore the relative impacts of key data and model assumptions for the diagnostic case model on the stock assessment results and conclusions. A structural uncertainty analysis (model grid) for consideration in developing management advice, where all possible combinations of the most important axes of uncertainty from the one-off models is also included. It is recommended that management advice is formulated from the results of the structural uncertainty grid.

Across the range of models run in this assessment, the most important factors when evaluating stock status were the assumed level of natural mortality, and growth. For natural mortality, age invariant M values of 0.3 yr^{-1} (consistent with the 2015 assessment) and 0.4 yr^{-1} were assumed, with the latter resulting in more optimistic assessment outcomes. Age-dependent M settings were also evaluated as one-off sensitivities. Natural mortality remains a key uncertainty in this assessment, and it is appropriate that such uncertainty continue to be reflected in the overall stock assessment results. For growth, the conditional age-at-length data from recent work was incorporated into the diagnostic case model, while an alternative scenario fixed at the parameter values of the sex- combined 'Chen-Wells' growth model used within the 2017 North Pacific albacore reference case model run was also evaluated. Use of the latter resulted in more pessimistic assessment outcomes. There remains an unresolved inconsistency in the growth rates indicated by the VB curve fitted to the age-at-length data (approximately 20 cm per year for albacore 20–70 cm in length) and presumed annual modes with 10 cm spacing that consistently appear in the troll size composition data, and historically in the driftnet size composition data. Additional analysis of otoliths taken from 50–70 cm albacore in the troll fishery is required to identify the reason for this inconsistency. This is work that needs to be undertaken with high priority.

The general conclusions of this assessment are as follows:

- While biomass is estimated to have declined initially, estimates of spawning potential, and biomass vulnerable to the various longline fisheries, have been stable or possibly increasing slightly over the past 20 years. This has been influenced mainly by the estimated recruitment, which has generally been somewhat higher since 2000 than in the two decades previous.
- Most models also estimate an increase in spawning and longline vulnerable biomass since about 2011, driven by some high estimated recruitments, particularly around 2009.
- A steady increase in fishing mortality of adult age-classes is estimated to have occurred over most of the assessment period, accelerating since the 1990s but declining following the decline in longline catch seen since 2010. Juvenile fishing mortality increased until around 1990, and has remained stable at a low level since that time.
- Key stock assessment results across all models in the structural uncertainty grid show a wide range of estimates.

- All models indicate that South Pacific albacore is above the limit reference point (of 0.2 $SB_{F=0}$), with overall median depletion for 2016 ($SB_{latest}/SB_{F=0}$) estimated at 0.52 (80 percentile range 0.37–0.69).
- Recent average fishing mortality is estimated to be well below F_{MSY} (median F_{recent}/F_{MSY} = 0.2, 80 percentile range 0.08–0.41).
- A number of key research needs have been identified in undertaking this assessment that should be investigated either internally or through directed research. These include: the analysis of otoliths from individuals within the presumed annual modes seen in the troll data; studies on albacore size-related vulnerability to longline fishing; further development of the geostatistical analysis of operational-level CPUE data; further development of relevant MULTIFAN-CL functionality.

5.1 Stock status and trends

The median, 10 percentile and 90 percentile values of recent (2013–2016) spawning biomass ratio ($SB_{recent}/SB_{F=0}$) and recent fishing mortality in relation to F_{MSY} (F_{recent}/F_{MSY}) over the structural uncertainty grid were used to characterize uncertainty and describe the stock status.

A description of the structural sensitivity grid used to characterize uncertainty in the assessment is set out in Table 11. The regional structure used within the assessment is presented in Figure 7, and the time series of total annual catch by fishing gear for the diagnostic case model over the full assessment period is shown in Figure 8 for the total assessment region, and Figure 9 by model region. Estimated annual average recruitment, spawning potential, juvenile and adult fishing mortality and fishing depletion for the diagnostic case model are shown in Figures 10 – 13. Figure 14 displays Majuro plots summarising the results for each of the models in the structural uncertainty grid, while Figure 15 shows equivalent Kobe plots for SB_{recent} and SB_{latest} across the structural uncertainty grid. Figure 16 provides estimates of reduction in spawning potential due to fishing by region, and over all regions attributed to various fishery groups (gear-types) for the diagnostic case model. Table 12 provides a summary of reference points over the 72 models in the structural uncertainty grid. Figure 17 presents the history of the annual estimates of MSY for the diagnostic case model, compared with annual catch by the main gear types. Finally, Figure 18 presents the estimated time-series (or 'dynamic') Kobe plots for four example models from the assessment (one from each of the combinations of growth types, and natural mortality M set to 0.3 or 0.4).

SC14 noted that the median level of spawning biomass depletion from the uncertainty grid was $SB_{recent}/SB_{F=0}$ = 0.52 with a probable range of 0.37 to 0.63 (80% probability interval). There were no individual models where ($SB_{recent}/SB_{F=0}$) < 0.2 which indicated that the probability that recent spawning biomass was below the LRP was zero.SC14 noted that the grid median F_{recent}/F_{MSY} was 0.20, with a range of 0.08 to 0.41 (80% probability interval) and that no values of F_{recent}/F_{MSY} in the grid exceeded 1.

SC14 also noted that there was a 0% probability (0 out of 72 models) that the recent fishing mortality had exceeded F_{MSY}.

SC14 noted that the structural uncertainty grid for the south Pacific albacore had changed since the 2015 assessment, with the 2018 assessment examining additional axes of uncertainty including assumptions on growth and CPUE standardization approach. As a consequence, the uncertainty identified is higher than in previous assessments.

SC14 also noted that the assessment results show that while the stock depletion ($SB/SB_{F=0}$) has exhibited a long-term decline (Figure 13) the stock is not in an overfished state and overfishing is not taking place.

Table 11: Description of the structural sensitivity grid used to characterize uncertainty in the 2018 south Pacific albacore assessment. Levels used within the diagnostic case are starred.

Axis	Levels	Option
Steepness	3	0.65, 0.80*, 0.95
Natural mortality	2	0.3*, 0.4
Growth	2	Estimated* (K, L_∞) or fixed (Chen-Wells)
Size frequency weighting	3	Sample sizes divided by 20, 50* or 80
CPUE	2	Geostatistical*, Traditional

Table 12: Summary of reference points over all the 72 individual models in the structural uncertainty grid.

	Mean	Median	Min	10%	90%	Max
C_{latest}	61 719	61 635	60 669	60 833	62 704	63 180
MSY	100 074	98 080	65 040	70 856	130 220	162 000
$YF_{recentt}$	71 579	71 780	56 680	62 480	80 432	89 000
fmult	6.2	4.96	1.89	2.44	12.05	17.18
F_{MSY}	0.07	0.07	0.05	0.05	0.09	0.1
F_{recent}/F_{MSY}	0.23	0.2	0.06	0.08	0.41	0.53
SB_{MSY}	71 407	68 650	26 760	39 872	100 773	134 000
SB_0	443 794	439 800	308 800	353 870	510 530	696 200
SB_{MSY}/SB_0	0.16	0.17	0.07	0.1	0.21	0.23
$SB_{F=0}$	469 004	462 633	380 092	407 792	534 040	620 000
$SB_{MSY}/SB_{F=0}$	0.15	0.15	0.06	0.09	0.2	0.22
SB_{latest}/SB_0	0.55	0.56	0.33	0.42	0.69	0.74
$SB_{latest}/SB_{F=0}$	0.53	0.52	0.3	0.37	0.69	0.77
SB_{latest}/SB_{MSY}	4	3.42	1.45	1.96	7.07	10.74
$SB_{recent}/SB_{F=0}$	0.51	0.52	0.32	0.37	0.63	0.72
SB_{recent}/SB_{MSY}	3.88	3.3	1.58	1.96	6.56	9.67

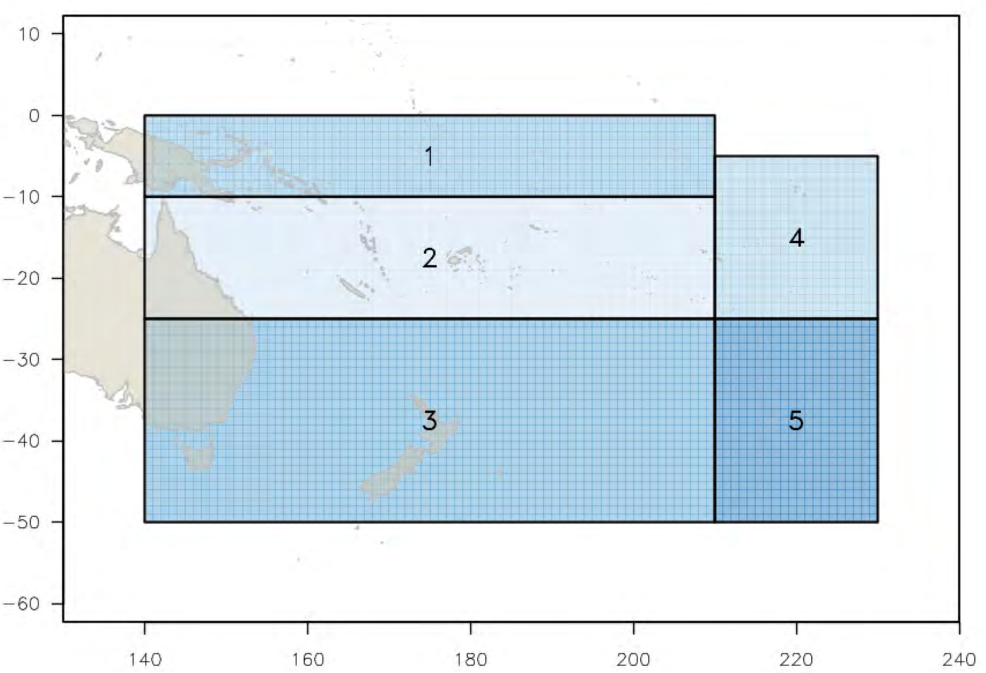


Figure 7: The geographical area covered by the stock assessment and the boundaries for the 5 regions under the updated 2018 regional structure.

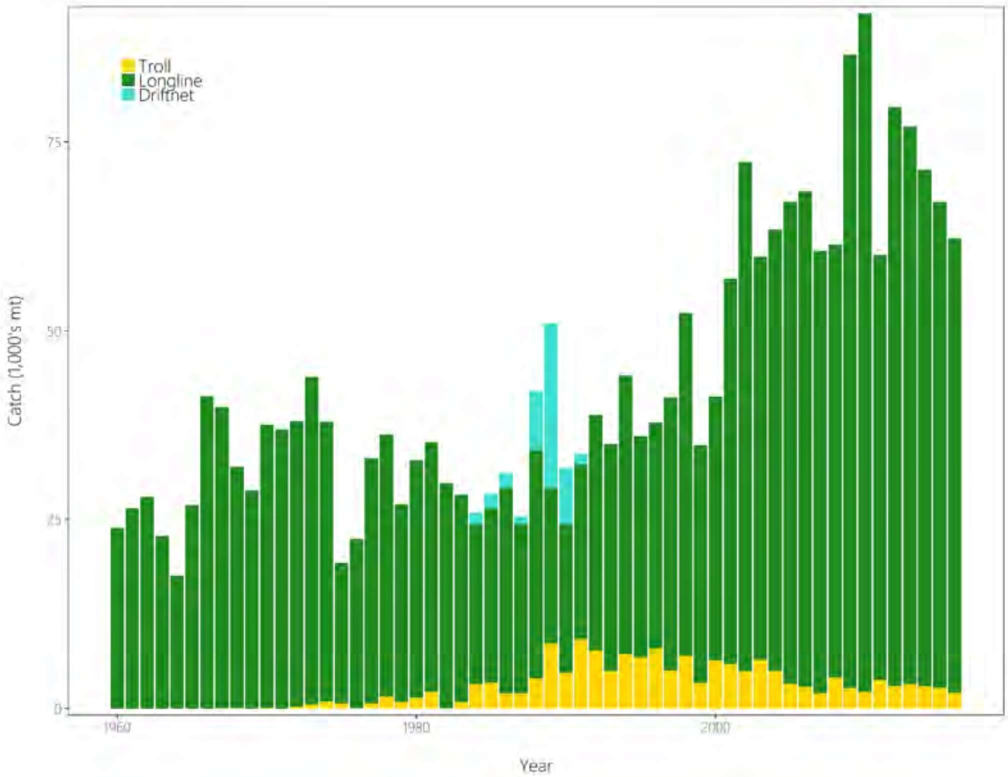


Figure 8: Time series of total annual catch (1000's mt) by fishing gear for the diagnostic case model over the full assessment period. The different colours refer to longline (green), troll (yellow) and driftnet (turquoise). Note that the catch by longline gear has been converted into catch-in-weight from catch-in-numbers.

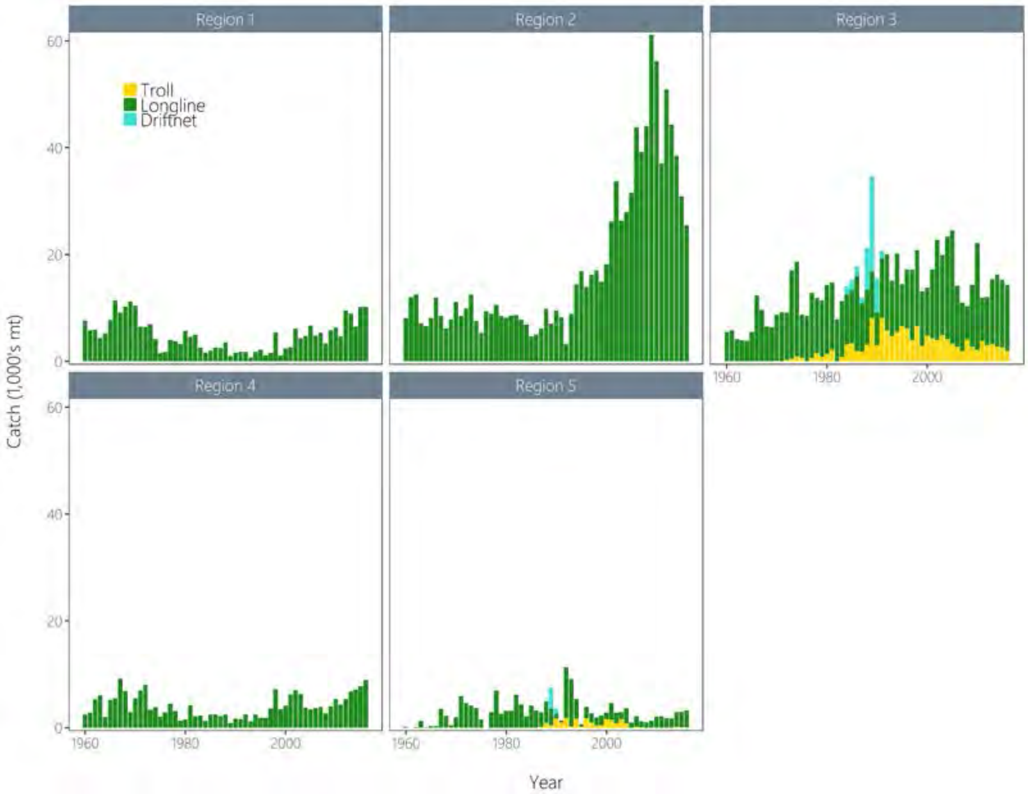


Figure 9: Time series of total annual catch (1000's mt) by fishing gear and assessment region from the diagnostic case model over the full assessment period. The different colours denote longline (green), driftnet (turquoise) and troll (yellow).

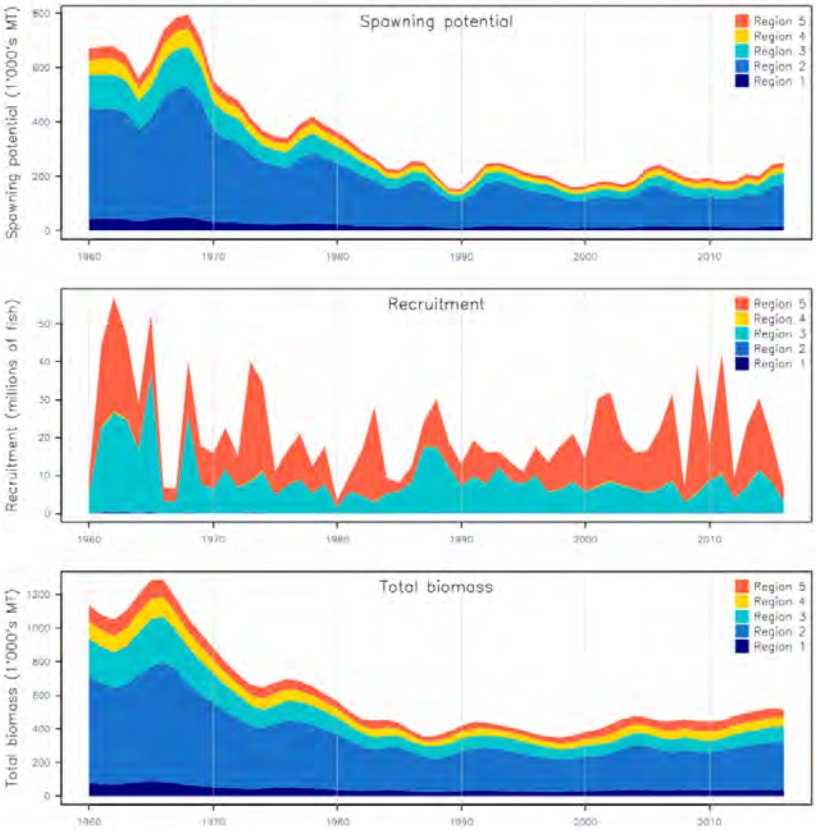


Figure 10: Estimated annual average recruitment, spawning potential and total biomass by model region for the diagnostic case model, showing the relative sizes among regions.

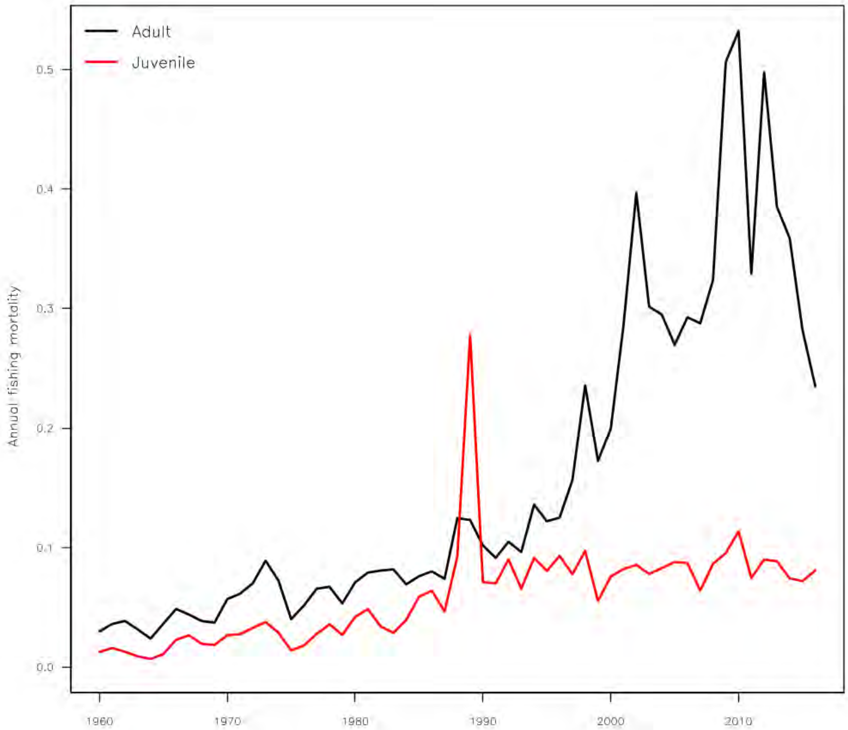


Figure 11: Estimated annual average juvenile and adult fishing mortality for the diagnostic case model.

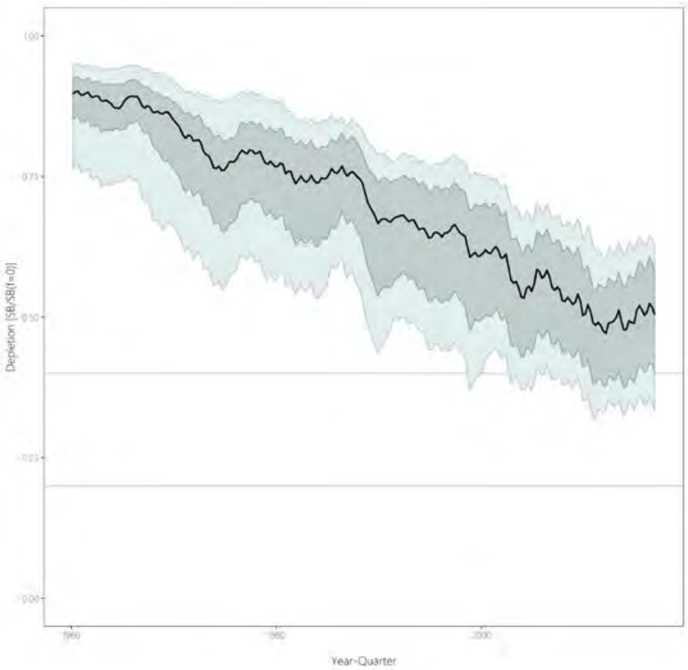


Figure 12: Distribution of time series depletion estimates across the structural uncertainty grid. Black line represents the grid median trajectory, dark grey region represents the 50%ile range, light grey the 90%ile range.

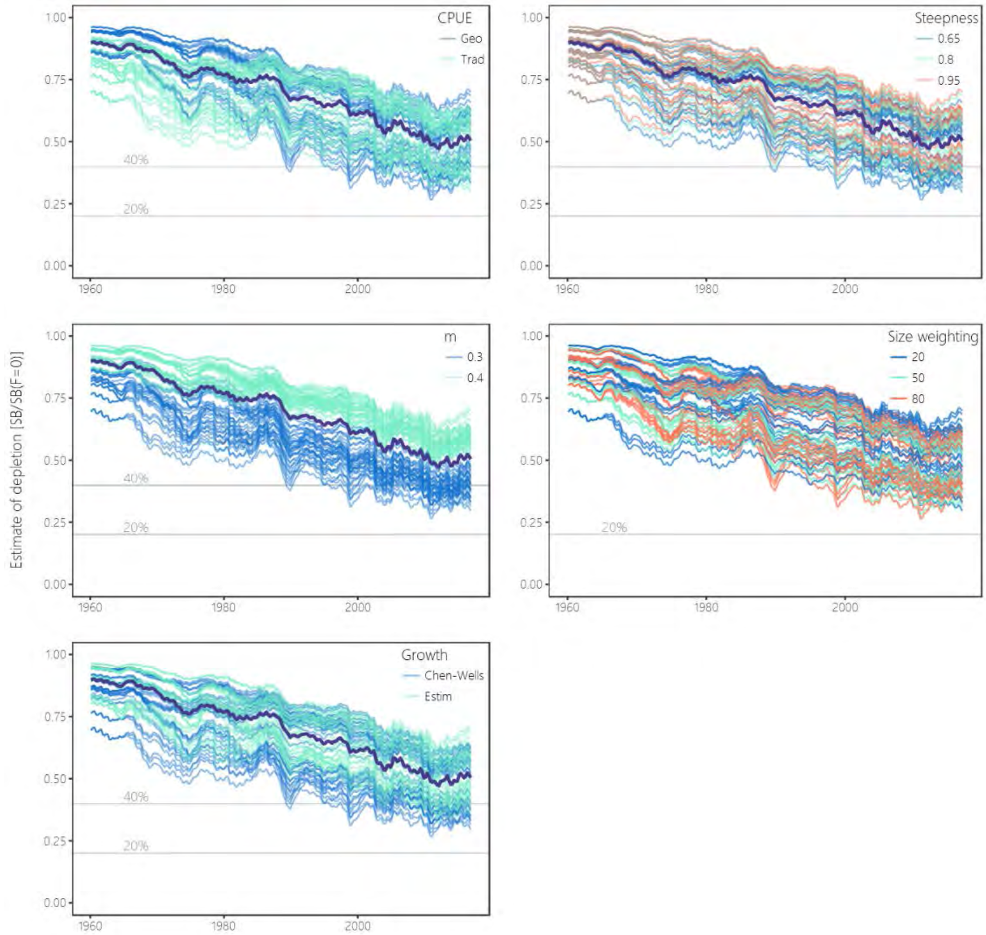


Figure 13: Plots showing the trajectories of fishing depletion (of spawning potential) for the model runs included in the structural uncertainty grid. The five panels show the models separated on the basis of the five axes used in the grid, with the colour denoting the level within the axes for each model.

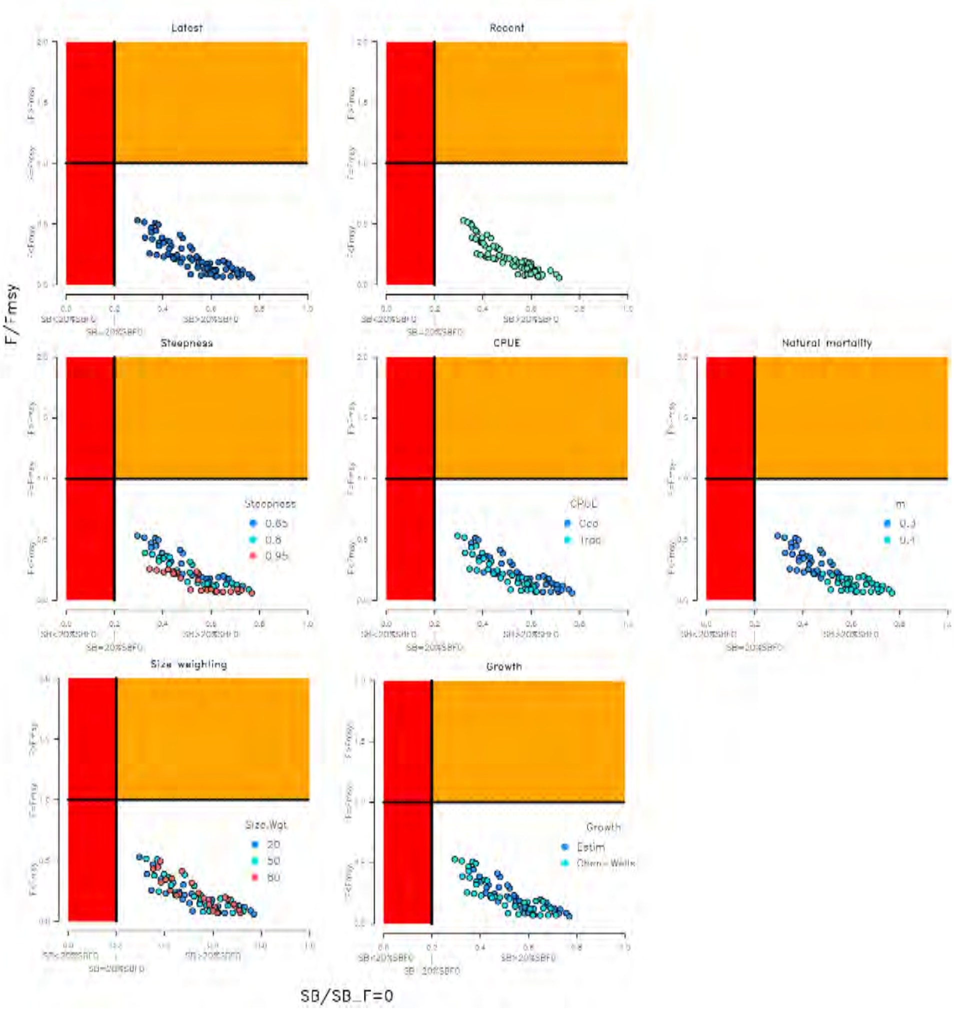


Figure 14: Majuro plots summarising the results for each of the models in the structural uncertainty grid under the $SB_{latest}/SB_{F=0}$ and the $SB_{recent}/SB_{F=0}$ reference points (top left) and each axis of uncertainty.

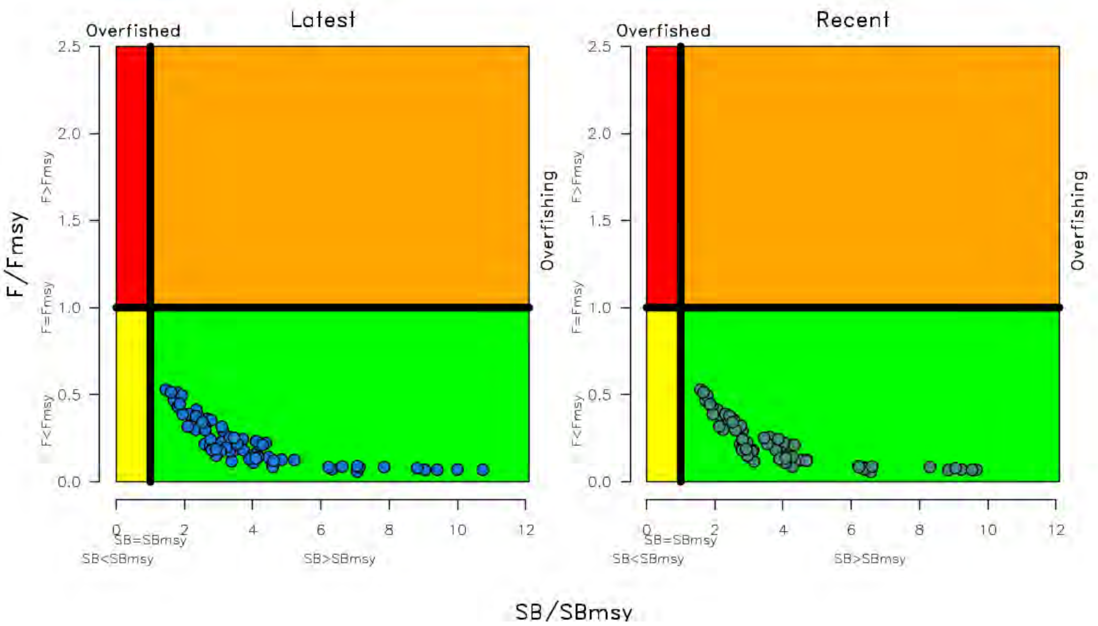


Figure 15: Kobe plots summarising the results for each of the models in the structural uncertainty grid under the $SB_{latest}/SB_{F=0}$ and the $SB_{recent}/SB_{F=0}$ reference points.

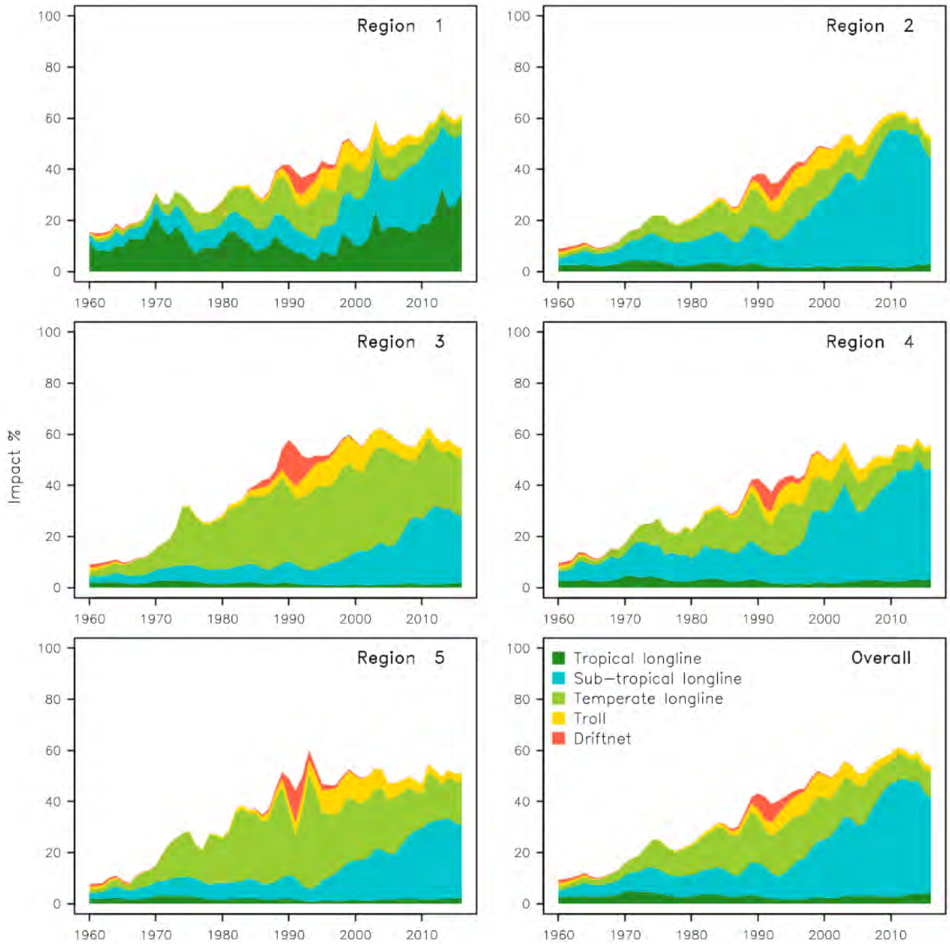


Figure 16: Estimates of reduction in spawning potential due to fishing (fishery impact = 1-$SB_{latest}/SB_{F=0}$) by region, and over all regions (lower right panel), attributed to various fishery groups for the diagnostic case model.

Figure 17: History of the annual estimates of MSY (red line) for the diagnostic case model compared with annual catch by the main gear types.

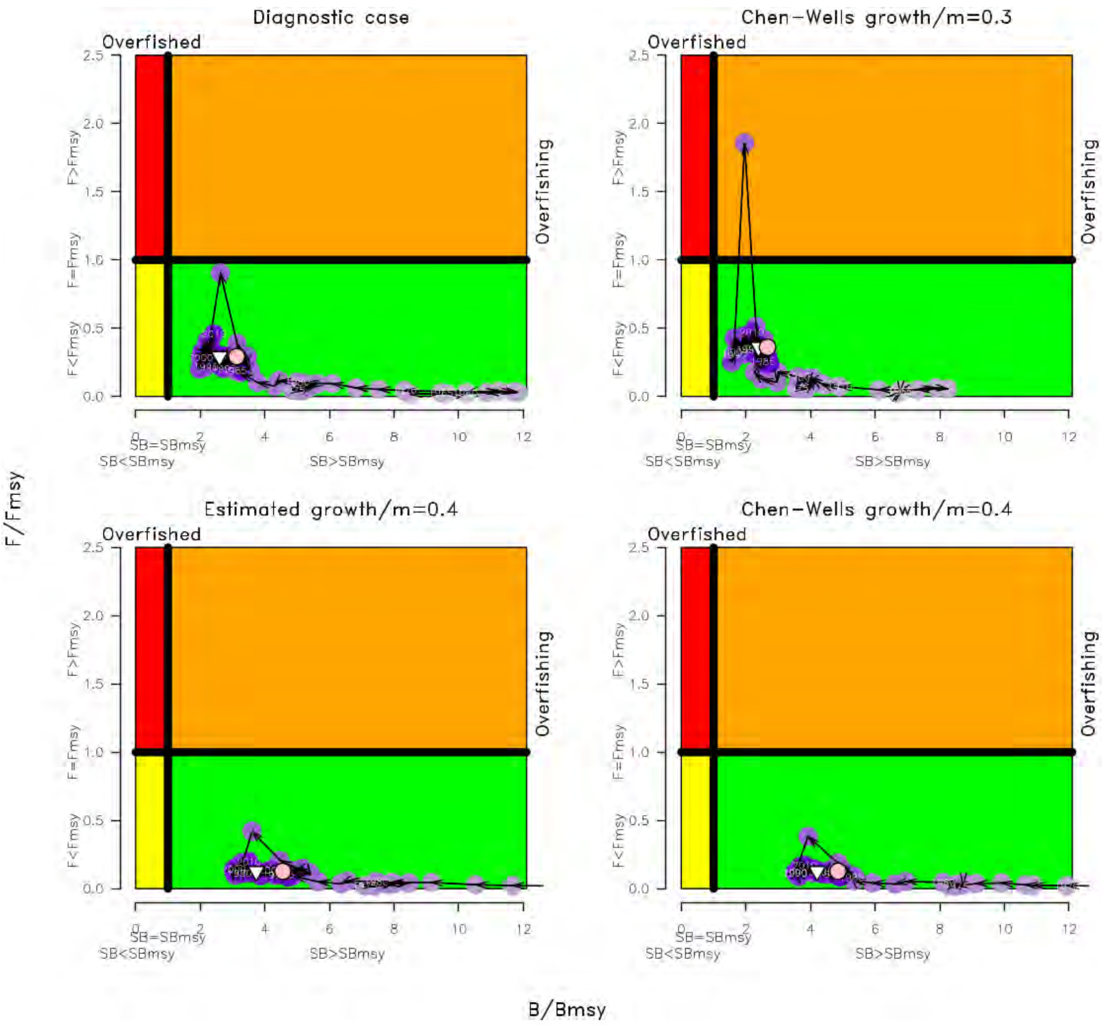


Figure 18: Estimated time-series (or 'dynamic') Kobe plots for four example models from the assessment (one from each of the combinations of growth types, and natural mortality *M* set to 0.3 or 0.4).

5.2 Management advice and implications

SC14 noted that the preliminary estimate of total catch of south Pacific albacore (within the WCPFC Convention Area south of the equator) for 2017 was 75 707 mt, which was a 33% increase from 2016 and a 13% increase over 2012–2016. (see SC14-SA-WP-02).

Preliminary catch for longliners in 2017 (72 785 mt) was 34% higher compared with 2016 and a 14% increase over 2012–2016. Preliminary other gear (primarily troll) catch in 2017 (2896t) was 17% higher compared with 2016 but a 1% decrease over 2012–2016. (see SC14-SA-WP-02).

Based on the uncertainty grid adopted by SC14, the WCPO albacore tuna spawning biomass is very likely to be above the biomass LRP and recent F is very likely below F_{MSY}, and therefore the stock is not experiencing overfishing (100% probability F < F_{MSY}) and is not in an overfished condition (100% probability SB_{recent} > LRP).

SC14 recalled its previous advice from SC11, SC12, and SC13 that longline fishing mortality and longline catch be reduced to avoid decline in the vulnerable biomass so that economically viable catch rates can be maintained, especially for longline catch of adult albacore. SC14 recommends that this advice be taken into consideration when the TRP for South Pacific albacore is discussed at WCPFC15.

5.3 Estimates of fishery parameters and abundance

There are no fishery-independent indices of abundance for the South Pacific stock. Relative abundance information is available from catch per unit effort data. Returns from tagging programmes provide information on rates of fishing mortality, however, the return rates are very low and lead to highly uncertain estimates of absolute abundance.

5.4 Biomass estimates

Estimates of absolute biomass are highly uncertain, however, relative abundance trends are thought to be more reliable. Spawning potential depletion levels ($SB_{latest}/SB_{F=0}$) of albacore were moderate at about 52%. However, the exploitable biomass is estimated to be depleted down to levels between 10% and 60%, depending on the fisheries region considered, having increased sharply in recent years particularly in the longline fisheries (Figure 16).

5.5 Yield estimates and projections

No estimates of MCY and CAY are available.

5.6 Other yield estimates and stock assessment results

No other yield estimates are available.

5.7 Other factors

Declines in CPUE have been observed in some Pacific Island fisheries. This is problematic for South Pacific states that rely on albacore for their longline fisheries. Given the recent expansion of the Pacific albacore fishery and recent declines in exploitable biomass available to longline fisheries, maintaining catch rates for Pacific Island states is important for the economic survival of their domestic longline operators.

6. STATUS OF THE STOCK

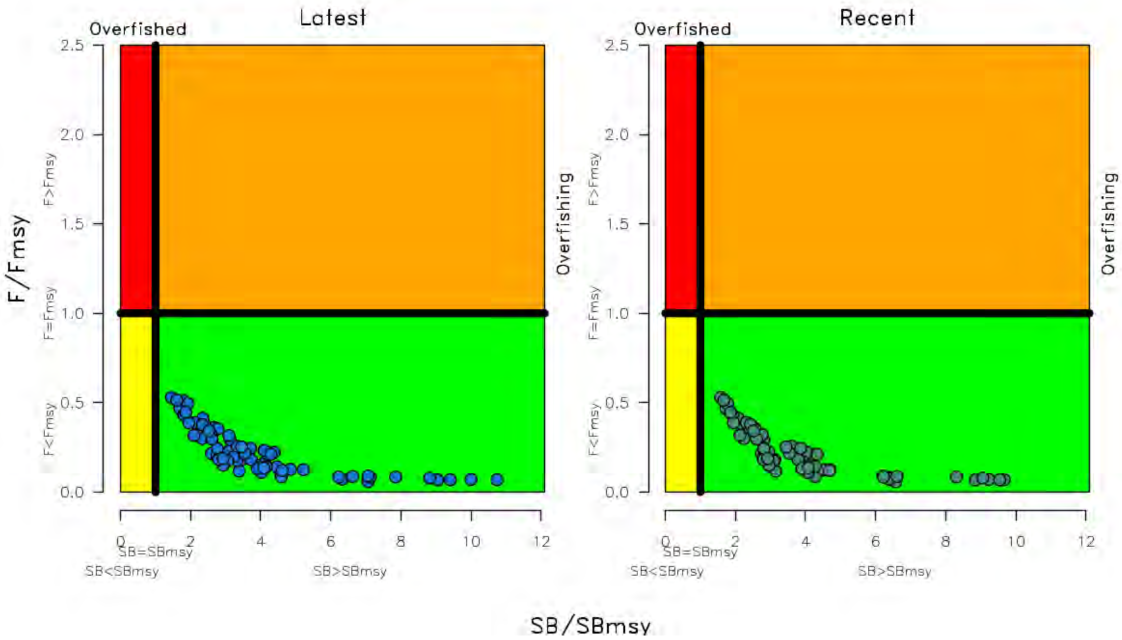
Stock status is summarised from Tremblay-Boyer et al. (2018a).

Stock structure assumptions

In the western and central Pacific Ocean, the South Pacific albacore stock is distributed from the coast of Australia and archipelagic waters of Papua New Guinea eastward to the coast of South America south of the equator to at least 49ºS. However, there is some suggestion of gene flow between the North and South Pacific stocks based on an analysis of genetic population structure. All biomass estimates in this table refer to spawning biomass (*SB*).

Stock Status	
Year of Most Recent Assessment	2018
Assessment Runs Presented	Base case model and selected sensitivity runs
Reference Points	Biomass-related target reference point (TRP) determined by WCPFC 15 as 56% SB_0 Soft Limit: Limit reference point of 20% SB_0 established by WCPFC equivalent to the HSS default of 20% SB_0 Hard Limit: Not established by WCPFC; but evaluated using HSS default of 10% SB_0 Overfishing threshold: F_{MSY}
Status in relation to Target	Recent levels of spawning biomass (52% SB_0) is About as Likely as Not (40–60%) to be at or above the agreed TRP of 56% SB_0Very Likely (> 90%) that $F < F_{MSY}$
Status in relation to Limits	Soft Limit: Unlikely (< 40%) to be below Hard Limit: Very Unlikely (< 10%) to be below
Status in relation to Overfishing	Overfishing is Very Unlikely (< 10%) to be occurring

Historical Stock Status Trajectory and Current Status



Kobe plots summarising the results for each of the models in the structural uncertainty grid under the $SB_{latest}/SB_{F=0}$ and $SB_{recent}/SB_{F=0}$ reference points.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Spawning biomass has been steadily declining, but is currently well above the MSY level.
Recent Trend in Fishing Intensity or Proxy	Fishing mortality has generally been increasing through time, but is currently well below the MSY level.
Other Abundance Indices	South Pacific albacore is the only WCPFC species that is assessed with standardised CPUE indices constructed with operational data. There was a rapid decline from the early 1960s until 1975 followed by a slower decline thereafter.
Trends in Other Relevant Indicator or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	There is no indication that current levels of catch are causing recruitment overfishing. However, current levels of fishing mortality may be affecting longline catch rates on adult albacore.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Very Unlikely (< 10%) Hard Limit: Exceptionally Unlikely (< 1%)
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Very Unlikely (< 10%)

Assessment Methodology and Evaluation		
Assessment Type	Level 1: Full Quantitative Stock Assessment	
Assessment Method	The assessment uses the stock assessment model and computer software known as MULTIFAN-CL	
Assessment Dates	Latest assessment: 2018	Next assessment: 2021
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	The model is age structured and the catch, effort, size composition and tagging data used in the model are classified both spatially and temporally.	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	- The structure of the assessment model was similar to the previous (2015) assessment, but there were some substantial revisions to key data sets, which are noted in the text.	
Major Sources of Uncertainty	- CPUE is used as an abundance index in the model. However, in the 1990s there was an increase in standardised CPUE in the west (Regions 1 and 3) that was not evident in the east (Regions 2 and 4). There was a decline in standardised CPUE for the Taiwan distant water fleet since 2000 that also occurred in most domestic Pacific Island fisheries. It is not certain whether depressed CPUE since 2002 results from a decline in population abundance or a change in the availability of albacore in the South Pacific that affected the Taiwan fleet and domestic Pacific Island fleets (Bigelow & Hoyle 2009). - There is also a conflict between the CPUE index and the longline length-frequency data.	

Qualifying Comments
Although the latest assessment made some good improvements there is still a need to resolve the conflict between the CPUE and the longline length-frequency data.

Environmental and Ecosystem Considerations	
Observer coverage	The observer coverage of the troll fleet averaged 0.7% of the effort between 2006–07 and 2011–12. Observer coverage was suspended after 2011–12 due to the difficulties experienced placing observers on the small vessels in this fishery. Recorded effort in target albacore longline fishery has been very low since 2004-05 and from 2016–17 onwards there has been no recorded effort. Observer coverage has been low to non-existent in this fishery since 2004–05.
Non-target fish and invertebrate catch	From 2006 to 2012 the troll catch averaged 93% albacore, with the remaining 7% made up mostly of bony fishes. No records of non-target catch are available for the albacore longline fishery.
Incidental catch of seabirds	No incidental captures of seabirds have been observed in the troll fishery or longline fishery since 2004-05.
Incidental catch of cetaceans	No incidental captures of cetaceans have been observed in the troll fishery or longline fishery since 2004-05.
Incidental catch of pinnipeds	No incidental captures of pinnipeds have been observed in the troll fishery or longline fishery since 2004-05.

Incidental catch of other protected species	No incidental captures of protected species have been observed in the troll fishery or longline fishery since 2004-05.
Benthic interactions	There are no known benthic interactions for this fishery

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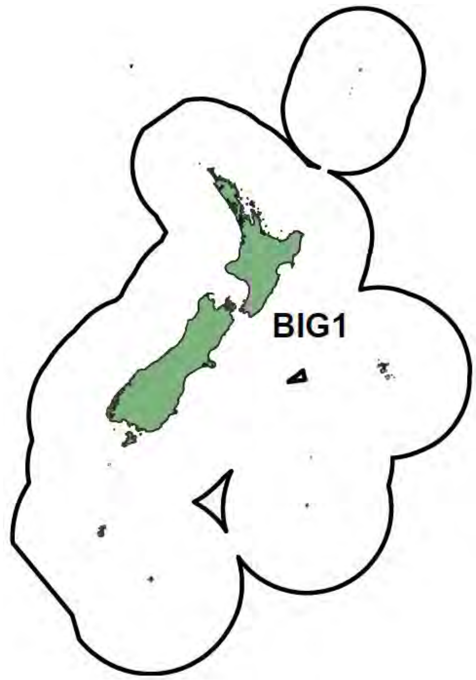
BIGEYE TUNA (BIG)

(Thunnus obesus)



1. FISHERY SUMMARY

Bigeye tuna were introduced into the QMS on 1 October 2004 under a single QMA, BIG 1, with allowances (t), TACC and TAC in Table 1.

Table 1: Recreational and customary non-commercial allowances, TACC and TAC (all in t) for BIG 1.

Fishstock	Recreational allowance	Customary non-commercial allowance	Other mortality	TACC	TAC
BIG 1	8	4	14	714	740

Bigeye were added to the Third Schedule of the 1996 Fisheries Act with a TAC set under s14 because bigeye is a highly migratory species, and it is not possible to estimate MSY for the part of the stock that is found within New Zealand fisheries waters.

Management of the bigeye stock throughout the western and central Pacific Ocean (WCPO) is the responsibility of the Western and Central Pacific Fisheries Commission (WCPFC). Under this regional convention New Zealand is responsible for ensuring that the management measures applied within New Zealand fisheries waters are compatible with those of the Commission.

At its second annual meeting (2005) the WCPFC passed a Conservation and Management Measure (CMM) (this is a binding measure that all parties must abide by) relating to conservation and management of tunas. Key aspects of this resolution were presented in the 2006 Plenary document. A number of subsequent CMMs that impact on the catches of bigeye have since been approved by the WCPFC.

At its annual meeting in 2014 the WCPFC approved CMM 2014-01. The aim of this CMM for bigeye is to reduce the fishing mortality rate for bigeye to a level no greater than F_{MSY}. This objective shall be achieved through a step-by-step approach through 2017 in accordance with the CMM. This measure is large and detailed with numerous exemptions and provisions. Reductions in fishing mortality are being attempted through seasonal Fish Aggregating Device (FAD) closures, high seas area closures (in high seas pockets) for the purse-seine fleets, purse-seine effort limits, longline effort reductions, bigeye longline catch limits by flag, as well as other methods. This measure was amended and updated in 2015 through CMM2015-01 and in 2017 through CMM2017-01.

In 2018 CMM 2018-01 (commonly referred to the "The tropical tuna bridging measure") was approved stating that pending agreement on a target reference point for bigeye, the spawning biomass depletion ratio (SB/SBF=0) is to be maintained at or above the average SB/SBF=0 for 2012–2015.

1.1 Commercial fisheries

Commercial catches by distant water Asian longliners of bigeye tuna in New Zealand fisheries waters, began in 1962 and continued under foreign license agreements until 1993. Bigeye were not a primary target species for these fleets and catches remained modest with the maximum catch in the 1980s reaching 680 t. Domestic tuna longline vessels began targeting bigeye tuna in 1990. There was an exponential increase in the number of hooks targeting bigeye, which reached a high of approximately 6.6 million hooks in 2000–01 and then declined thereafter.

Catches from within New Zealand fisheries waters are very small (0.2% average for 2001–09) compared to those from the greater stock in the WCPO (Tables 2 and 3). Figure 1 shows historical landings and TACC values for BIG 1 and BIG ET. Figure 1 also shows historical longline fishing effort. In contrast to New Zealand, where bigeye are taken almost exclusively by longline, 40% of the WCPO catches of bigeye are taken by purse seine and other surface gears (e.g., ring nets).

Table 2: Reported total New Zealand (within EEZ) landings (t)*, landings from the western and central Pacific Ocean (t) of bigeye tuna by calendar year from 1991 to present, and NZ ET catch estimates from 2001 to present.

Year	NZ landings (t)	Total landings (t)	NZ ET SPC estimate	Year	NZ landings (t)	Total landings (t)	NZ ET SPC estimate
1991	44	100 608		2005	176	141 342	353
1992	39	119 624		2006	178	151 646	997
1993	74	103 557		2007	213	134 258	651
1994	71	118 759		2008	133	144 101	713
1995	60	107 406		2009	254	149 545	204
1996	89	110 276		2010	132	126 458	134
1997	142	152 862		2011	174	146 254	125
1998	388	168 393		2012	154	158 573	95
1999	421	150 364		2013	110	145 883	81
2000	422	133 449		2014	122	154 601	185
2001	480	136 153	230	2015	81	134 682	20
2002	200	161 996	593	2016	177	146 465	27
2003	205	129 955	383	2017	97	120 308	60
2004	185	178 556	1 198	2018	136	145 402	17

Source: Licensed Fish Receiver Returns, Solander Fisheries Ltd, Anon (2006), Lawson (2008), WCPFC5-2008/IP11 (Rev. 2), Williams & Terawasi (2011) and WCPFC Yearbook 2012 Anon (2013).

* New Zealand purse-seine vessels operating in tropical regions also catch small levels of bigeye when fishing around Fish Aggregating Devices (FADs). These catches are not included here at this time as the only estimates of catch are based on analysis of observer data across all fleets rather than specific data for New Zealand vessels. Bigeye catches are combined with yellowfin catches on most catch effort forms.

Table 3: Reported catches and landings (t) of bigeye tuna by fleet and fishing year. NZ/MHR: New Zealand domestic and charter fleet, NZ ET: catches outside these areas from New Zealand flagged longline vessels, JPNFL: Japanese foreign licensed vessels, KORFL: foreign licensed vessels from the Republic of Korea, and LFRR: estimated landings from Licensed Fish Receiver Returns. [Continued next page]

	BIG 1 (all FMAs)					
Fishing year	**JPNFL**	**KORFL**	**NZ/MHR**	**Total**	**LFRR**	**NZ ET**
1979–80	205.8			205.8		
1980–81	395.9	65.3		461.2		
1981–82	655.3	16.8		672.1		
1982–83	437.1	11.1		448.2		
1983–84	567.0	21.8		588.8		
1984–85	506.3	51.6		557.9		
1985–86	621.6	10.2		631.8		
1986–87	536.1	17.6		553.7		
1987–88	226.9	22.2		249.1		
1988–89	165.6	5.5		171.1	4.0	
1989–90	302.7		12.7	315.4	30.7	0.4
1990–91	145.6		12.6	158.2	36.0	0.0
1991–92	78.0		40.9	118.9	50.0	0.8
1992–93	3.4		43.8	47.2	48.8	2.2
1993–94			67.9	67.9	89.3	6.1
1994–95			47.2	47.2	49.8	0.5
1995–96			66.9	66.9	79.3	0.7
1996–97			89.8	89.8	104.9	0.2
1997–98			271.9	271.9	339.7	2.6
1998–99			306.5	306.5	391.2	1.4
1999–00			411.7	411.7	466.0	7.6
2000–01			425.4	425.4	578.1	13.6
2001–02			248.9	248.9	276.3	2.0
2002–03			196.1	196.1	195.1	0.6
2003–04			216.3	216.3	217.5	0.8
2004–05*			162.9	162.9	163.6	0.7
2005–06*			177.5	177.5	177.1	0.14
2006–07*			196.7	196.7	201.4	0.05
2007–08*			140.5	140.5	143.8	0
2008–09*			237.2	237.2	240.2	0
2009–10*			161.2	161.2	169.7	9.9
2010–11*			181.1	181.1	201.0	20.3
2011–12*			174.0	174.0	276.5	125.0
2012–13*			154.0	154.0	148.0	95.0
2013–14*			116.0	116.0	116.0	235.0
2014–15*			83.2	83.2	83.2	0
2015–16*			172.8	172.8	172.8	0
2016–17			104.9	104.9	104.9	0
2017–18			136.7	136.7	136.7	0
2018–19			51.33	51.33	54.47	0

* MHR rather than LFRR data.

1.2 Recreational fisheries

Recreational fishers make occasional catches of bigeye tuna while trolling for other tunas and billfish, but the recreational fishery does not regularly target this species. There is no information on the size of the catch.

1.3 Customary non-commercial fisheries

An estimate of the current customary catch is not available, but it is considered to be low.

1.4 Illegal catch

There is no known illegal catch of bigeye tuna in the EEZ.

1.5 Other sources of mortality

The estimated overall incidental mortality rate from observed longline effort is 0.23% of the catch. Discard rates are 0.34% on average (from observer data), of which approximately 70% are discarded dead (usually because of shark damage). Fish are also lost at the surface in the longline fishery, 0.09% on average (from observer data), of which 100% are thought to escape alive.

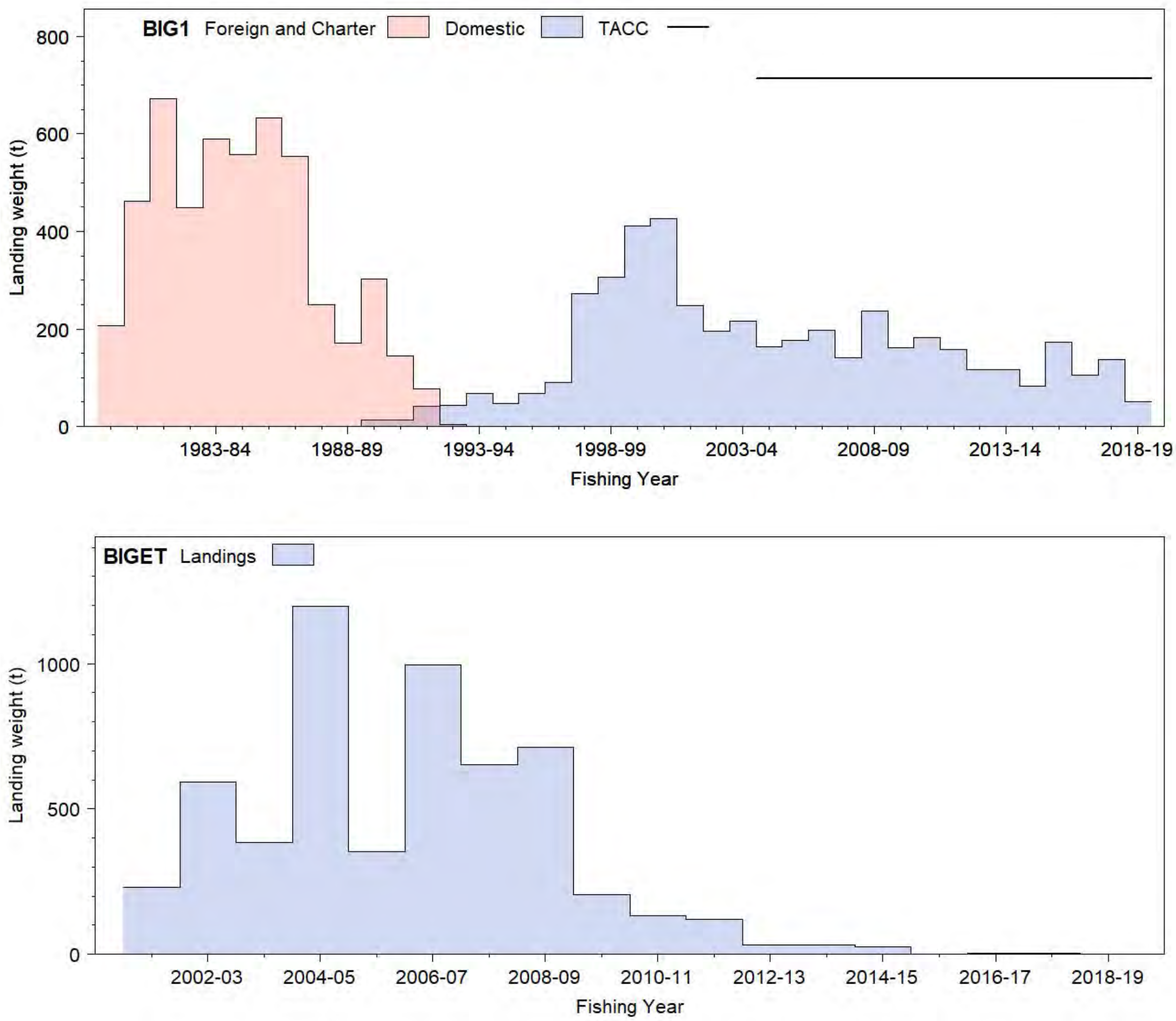


Figure 1: [Top] Bigeye catch by foreign licensed and New Zealand vessels from 1979–80 to 2018–19 within New Zealand waters (BIG 1) and [Bottom] Bigeye catch by foreign licensed and New Zealand vessels on the high seas from 2001–02 to 2018–19 for New Zealand vessels fishing on the high seas (BIG ET).

In 2012–13, the majority of bigeye tuna (88%) were caught in the bigeye tuna target surface-longline fishery (Figure 2). While bigeye are the target, blue sharks made up the bulk of the catch (34%) in 2017–18 (Figure 3). Longline fishing effort is distributed along the east coast of the North Island and the south-west coast of the South Island. The west coast South Island fishery predominantly targets southern bluefin tuna, whereas the east coast of the North Island targets a range of species including bigeye, swordfish and southern bluefin tuna.

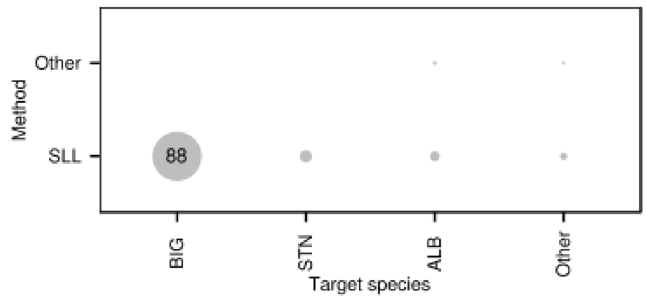


Figure 2: A summary of the proportion of landings of bigeye tuna taken by each target fishery and fishing method for 2012–13. The area of each circle is proportional to the percentage of landings taken using each combination of fishing method and target species. The number in the circle is the percentage. SLL = surface longline (Bentley et al. 2013).

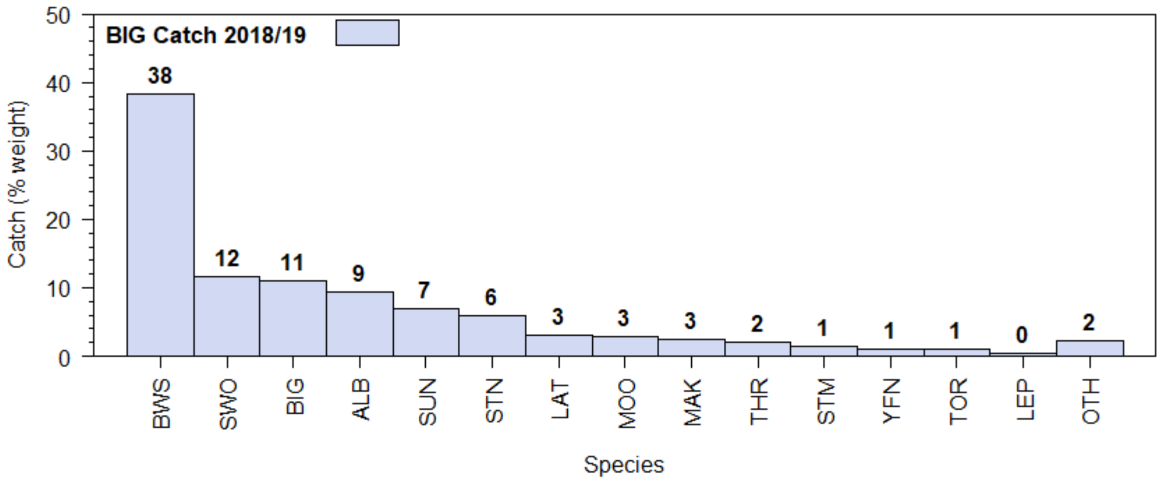


Figure 3: A summary of species composition of the bigeye target surface-longline estimated catch for 2018–19. The percentage by weight of each species is calculated for all surface-longline trips targeting bigeye tuna.

2. BIOLOGY

Bigeye tuna are epipelagic opportunistic predators of fish, crustaceans and cephalopods generally found within the upper few hundred metres of the ocean. Tagged bigeye tuna have been shown to be capable of movements of over 4000 nautical miles over periods of one to several years. Juveniles and small adults school near the surface in tropical waters while adults tend to live in deeper water. Individuals found in New Zealand waters are mostly adults. Adult bigeye tuna are distributed broadly across the Pacific Ocean, in both the Northern and Southern Hemispheres and reach a maximum size of 210 kg and maximum length of 250 cm. The maximum reported age is 14 years old and tag recapture data indicate that significant numbers of bigeye reach at least 8 years old. Spawning takes place in the equatorial waters of the Western Pacific Ocean (WPO) in spring and early summer.

Natural mortality and growth rates are both estimated within the stock assessment. Natural mortality is assumed to vary with age with values about 0.5 for bigeye larger than 40 cm. A range of von Bertalanffy growth parameters has been estimated for bigeye in the Pacific Ocean depending on area (Table 4).

Table 4: Biological growth parameters for bigeye tuna, by country.

Country	L_{∞} (cm)	K	t_0
Mexico	169.0	0.608	
French Polynesia	187.0	0.380	
Japan	195.0	0.106	-1.13
Hawaii	196.0	0.167	
Hawaii	222.0	0.114	
Hawaii	220.0	0.183	

SC14-SA-WP-03 provides an update on a regional study of bigeye tuna age and growth in the western and central Pacific Ocean (WCPO) presented at the Western Central Pacific Fisheries Commission (WCPFC) Scientific Committee meeting in 2017. The objectives of this extension project are to (i) prepare and read an additional 125 otoliths from fish >130 cm fork length (FL) using the annual increment method identified in Farley et al. (2017); and (ii) revise and update the age and growth estimates provided in Farley et al. (2017) based on the additional new data.

Annual age estimates were obtained for an additional 237 bigeye tuna in the WCPO to strengthen the growth analysis reported by Farley et al. (2017). Of these, 188 were from fish >130 cm FL and 49 from fish 90–129 cm FL. Daily age was also estimated for an additional 11 very small bigeye (31–39 cm FL). The new annual and daily age estimates were combined with those of Project 35 and historic SPC daily age estimates to obtain new von Bertalanffy growth parameters for bigeye tuna. Fish caught east of the assessment area and daily age estimates >1 year were excluded from the analysis. The resulting L_{∞} estimate was 156.9 cm FL, which is similar to that reported from Project 35 at SC13. The results of exploratory spatial analysis continue to indicate that there are differences in the growth rates of bigeye tuna across the Pacific.

The SPC Pre-assessment workshop in April 2018 recommended inter-laboratory comparison work be undertaken to standardise daily ageing methods between the WCPO and EPO. Since the age validation work completed in 2003 (Appendix A), an additional 30 SrCl2 marked otoliths have been returned which may be useful for further age validation work. The results of this comparison work were reported in SC15-SA-WP-02 *Workshop on yellowfin and bigeye age and growth,* with reference to SC15-SA-IP-19 *Report of the Workshop on Age and Growth of Bigeye and Yellowfin Tunas in the Pacific Ocean.* The paper described work undertaken by CSIRO, Fish Ageing Services (FAS) and the IATTC to assess and improve consistency in ageing methods using otoliths for bigeye and yellowfin. The objectives were to analyse otoliths from mark-recapture individuals for age validation purposes; compare daily and annual age estimates from paired otoliths from the same fish; analyse otoliths from 50 very small bigeye from assessment area 7 using daily ageing methods; and participate in an inter-lab workshop to jointly read and examine otoliths and share ageing methods to improve skill and resolve differences in the approaches used. However, differences in age estimates from counting daily (IATTC) and annual (FAS) increments in sister otoliths from the same individuals were not resolved in the workshop. They may only be resolved through large-scale direct age validation studies, such as mark-recapture experiments and/or the application of bomb radiocarbon validation methods.

3. STOCKS AND AREAS

Bigeye tuna are distributed throughout the tropical and sub-tropical waters of the Pacific Ocean. Analysis of mtDNA and DNA microsatellites in nearly 800 bigeye tuna failed to reveal significant evidence of widespread population subdivision in the Pacific Ocean (Grewe & Hampton 1998). While these results are not conclusive regarding the rate of mixing of bigeye tuna throughout the Pacific, they are broadly consistent with the results of SPC's and IATTC's tagging experiments on bigeye tuna. Before 2008, most bigeye tuna tagging in the Pacific occurred in the far eastern Pacific (east of about 120°W) and in the western Pacific (west of about 180°). While some of these tagged bigeye were recaptured at distances from release of up to 4000 nautical miles over periods of one to several years, the large majority of tag returns were recaptured much closer to their release points (Schaefer & Fuller 2002; Hampton & Williams 2005).

Since 2008, bigeye tuna tagging by the Pacific Tuna Tagging Programme has been focused in the equatorial central Pacific, between 180° and 140°W. Returns of both conventional and electronic tags from this programme have been suggestive of more extensive longitudinal, particularly west to east, displacements. It is hypothesised that while bigeye tuna in the far eastern and western Pacific may have relatively little exchange, those in the central part of the Pacific between about 180° and 120°W may mix more rapidly over distances of 1000–3000 nautical miles. In any event, it is clear that there is extensive movement of bigeye across the nominal WCPO/EPO boundary of 150°W. While stock assessments of bigeye tuna are routinely undertaken for the WCPO and EPO separately, these new data suggest that examination of bigeye tuna exploitation and stock status on a Pacific-wide scale, using an appropriately spatially structured model, should be a high priority.

4. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS

The figures and tables in this section were updated and additional text included for the November 2019 Fishery Assessment Plenary following review of the text by the Aquatic Environment Working Group in 2016. This summary is from the perspective of the bigeye tuna longline fishery; a more detailed summary from an issue-by-issue perspective is available in the Aquatic Environment and Biodiversity Annual Review where the consequences are also discussed (Ministry for Primary Industries 2019).

4.1 Role in the ecosystem

Bigeye tuna (*Thunnus obesus*) are epipelagic opportunistic predators of fish, crustaceans and cephalopods generally found within the upper few hundred metres of the ocean. Bigeye tuna are large pelagic predators, so they are likely to have a 'top down' effect on the fish, crustaceans and squid they feed on.

4.2 Incidental catch of seabirds, sea turtles and mammals

The protected species, capture estimates presented here include all animals recovered onto the deck (alive, injured or dead) of fishing vessels but do not include any cryptic mortality (e.g., seabirds caught on a hook but not brought onboard the vessel).

4.2.1 Incidental catch of seabirds

Between 2002–03 and 2017–18, there were 114 observed captures of birds in bigeye target longline fisheries (Table 5), for this fishery capture rates and estimated captures are presented in Table 6. Lower levels of observer coverage and higher commercial effort from 2002–03 to 2007–08 contributed to a highly variable observed capture rate during these years of the fishery (Figure 4). A subsequent decline in effort, where in 2017–18 effort was 11% of that recorded in 2002–03, and an increase in the proportion of effort observed has increased the precision of these capture estimates in recent years. Seabird captures were more frequent off the east coast of the North Island and Kermadec Island regions coinciding with the highest density of fishing effort (see Table 5 and Figure 5). Previously Bayesian models of varying complexity dependent on data quality were used (Richard & Abraham 2014); more recently a single model structure has been developed to provide a standard basis for estimating seabird captures across a range of fisheries

(Richard & Abraham 2015, Richard et al. 2017, Abraham & Richard 2019). Observed and estimated seabird captures in bigeye longline fisheries are provided in Table 6.

Through the 1990s the minimum seabird mitigation requirement for surface-longline vessels was the use of a bird scaring device (tori line) but common practice was that vessels set surface longlines primarily at night. In 2007 a notice was implemented under s11 of the Fisheries Act 1996 to formalise the requirement that surface-longline vessels only set during the hours of darkness and use a tori line when setting. This notice was amended in 2008 to add the option of line weighting and tori line use if setting during the day. In 2011 the notices were combined and repromulgated under a new regulation (Regulation 58A of the Fisheries (Commercial Fishing) Regulations 2001), which provides a more flexible regulatory environment under which to set seabird mitigation requirements. Late in 2019 work was commissioned to assess the operational functionality of an underwater bait setter during production fishing. The aim of this work was to assess the device without the use of other existing mitigation measures in the New Zealand Surface Longline fleet.

Current results for the risk posed by commercial fishing to seabirds have been assessed via a level 2 method, supported under the NPOA-Seabirds 2013 risk assessment framework (Ministry for Primary Industries 2013). The method used in the level 2 risk assessment arose initially from an expert workshop hosted by the Ministry of Fisheries in 2008. The overall framework is described in Sharp et al. (2011) and has been variously applied and improved in multiple iterations (Waugh et al. 2009, Richard et al. 2011, Richard & Abraham 2013, Richard et al. 2013, Richard & Abraham 2015, Richard et al. 2017, Richard et al. 2019). The method applies an ‘exposure-effects’ approach where exposure refers to the number of fatalities and is calculated from the overlap of seabirds with fishing effort compared with observed captures to estimate the species vulnerability (capture rates per encounter) to each fishery group. This is then compared to the population’s productivity, based on population estimates and biological characteristics to yield estimates of population-level risk. The NPO-Seabirds 2013 was reviewed in 2019, with the updated version expected in 2020.

The 2019 iteration of the level 2 risk assessment included the significant modifications made to the methodology during 2016: in order to include the full uncertainty around population size the total population size was included instead of N_{min} in the PST calculation; the allometric survival rate and age at first reproduction was used for the calculation of R_{max}; a revised correction factor was applied as the previous was found to be biologically implausible; a constraint was applied on the fatalities calculated based on observed survival rates; live release survival was included; change in vulnerability over time was allowed where there was enough data; and there was a switch to assuming that the number of incidents is related to vulnerability. There were also changes made to the fisheries groups, seabird demographic data were updated and the Stewart Island shag group was split into Otago and Foveaux shags. The 2019 Assessment of the risk of commercial fisheries to New Zealand seabirds, 2006–07 to 2016–17 addressed discrepancies identified in the allocation of observer effort and fishing effort. In addition to this two additional years of data were included for the 2015–16 and 2016–17 fishing years. A derived risk ratio, which is an estimate of aggregate potential fatalities across trawl and longline fisheries relative to the Population Sustainability Threshold, PST (an analogue of the Potential Biological Removals, PBR, approach) (Richard et al. 2017) is used to rank species. A risk ratio above 1 indicates that PBR exceeds PST and the population is at risk of not obtaining management objectives.

The 2019 iteration of the seabird risk assessment (Richard et al. 2019) assessed the bigeye target surface-longline fishery contribution to the total risk posed by New Zealand commercial fishing to seabirds (see Table 7). This fishery contributes 0.169 of risk to black petrel (13.7% of the total risk posed by New Zealand commercial fishing included in the risk assessment) and 0.021 of risk to Gibson’s albatross; both species were assessed to be at high risk from New Zealand commercial fishing. This fishery also contributes to the risk of medium risk species: 0.013 of risk to Antipodean albatross and 0.078 of risk to North Buller's albatross (Richard et al. 2017).

Table 5: Number of observed seabird captures in bigeye tuna longline fisheries, 2002–03 to 2017–18, by taxon and area. The risk category is an estimate of aggregate potential fatalities across trawl and longline fisheries relative to the Population Sustainability Threshold, PST (an analogue of the PBR approach) (Richard et al. 2017), data version 2019v1.

Taxon	Risk ratio	Northland and Hauraki	East Coast North Island	West Coast North Island	Bay of Plenty	Kermadec Islands	Total
Antipodean albatross	Medium	7	2	1	1		11
southern Buller's albatross	High	6	5	1			12
Gibson's albatross	High	9			1		10
Campbell black-browed albatross	Low	3	1				4
Salvin's albatross	High	1	2	1			4
Southern royal albatross	Negligible	2	1				3
Antipodean and Gibson's albatrosses	NA	2					2
New Zealand white-capped albatross	NA	2		1			3
Northern royal albatross	Low	1	1	1			2
Wandering albatross	NA	2					2
Albatrosses	NA				1		1
Black-browed albatrosses	NA				1		1
All albatrosses		**35**	**12**	**5**	**4**	**0**	**56**
Black petrel	Very high	25	1	5	1	1	33
Flesh-footed shearwater	High		9		5		14
White-chinned petrel	Negligible	2		1	3		6
Grey-faced petrel	Negligible	1		3			4
Gadfly petrels	NA	1					1
Total other seabirds		**29**	**10**	**9**	**9**	**1**	**58**

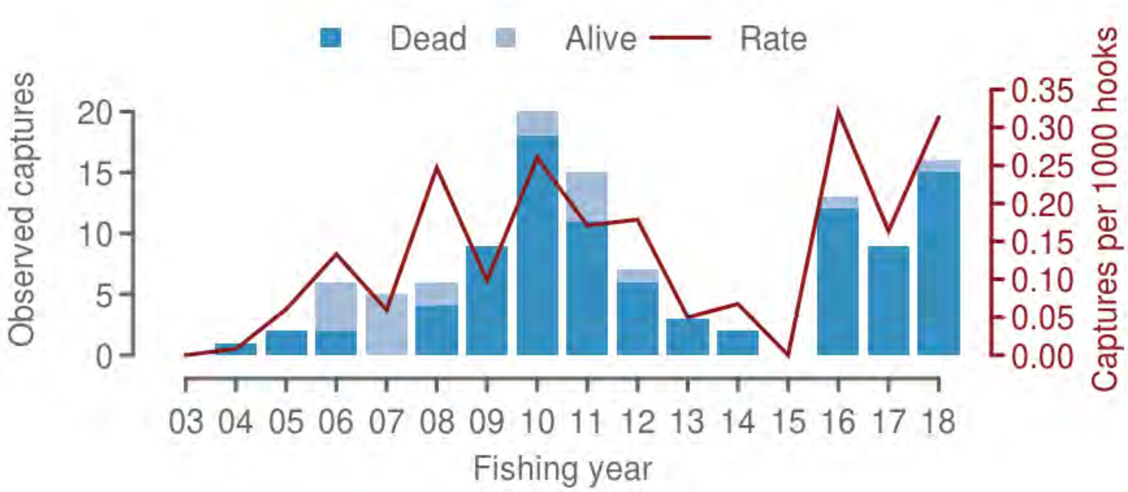


Figure 4: Observed captures of seabirds in bigeye tuna longline fisheries from 2002–03 to 2017–18.

Table 6: Effort, observed and estimated seabird captures by fishing year for the bigeye tuna fishery within the EEZ. For each fishing year, the table gives the total number of hooks; the number of observed hooks; observer coverage (the percentage of hooks that were observed); the number of observed captures (both dead and alive); the capture rate (captures per thousand hooks); and the mean number of estimated total captures (with 95% confidence interval). Estimates are based on methods described in Abraham & Berkenbusch 2019 and are available via https://data.dragonfly.co.nz/psc. Estimates from 2002–03 to 2017–18 are based on data version 2019v1.

Fishing year		Fishing effort		Observed captures		Estimated captures	
	All hooks	Observed hooks	% observed	Number	Rate	Mean	95% c.i.
2002–03	5 188 207	80 640	1.6	0	0.01	967	725–1287
2003–04	3 507 607	120 740	3.4	1	0.06	661	491–884
2004–05	1 648 181	33 116	2.0	2	0.13	313	225–429
2005–06	1 869 586	45 100	2.4	6	0.06	422	308–573
2006–07	1 532 071	84 150	5.5	5	0.25	327	234–450
2007–08	967 829	24 295	2.5	6	0.10	258	187–348
2008–09	1 565 517	91 295	5.8	9	0.26	365	267–498
2009–10	1 247 437	76 859	6.2	20	0.17	351	259–475
2010–11	1 646 956	87 730	5.3	15	0.18	407	301–552
2011–12	1 291 923	39 210	3.0	7	0.05	312	228–424
2012–13	994 535	60 280	6.1	3	0.07	260	188–363
2013–14	743 981	29 651	4.0	2	0.00	220	154–309
2014–15	387 005	24 470	6.3	0	0.32	114	78–164
2015–16	623 659	40 510	6.5	13	0.16	194	141–271
2016–17	497 967	55 041	11.1	9	0.31	147	104–204
2017–18	569 223	51 020	9.0	16	0.01	191	139–259

Table 7: Risk ratio of seabirds predicted by the level two risk assessment for the bigeye target surface longline fishery and all fisheries included in the level two risk assessment, 2006–07 to 2016–17, with a risk posed by the BIG target SLL fishery. The risk ratio is an estimate of aggregate potential fatalities across trawl and longline fisheries relative to the Population Sustainability Threshold, PST (an analogue of the PBR approach) (Richard et al. 2019). The current version of the risk assessment does not include a recovery factor. The New Zealand threat classifications are shown (Robertson et al. 2017).

			Risk ratio		
Species name	BIG target SLL	Total risk from NZ commercial fishing	% of total risk from NZ commercial fishing	Risk category	NZ Threat Classification
Black petrel	0.169	1.235	13.7	Very high	Threatened: Nationally Vulnerable
Northern Buller's albatross	0.078	0.263	29.6	Medium	At Risk: Naturally Uncommon
Gibson's albatross	0.021	0.307	6.8	High	Threatened: Nationally Critical
Westland petrel	0.018	0.538	3.3	High	At Risk: Naturally Uncommon
Antipodean albatross	0.013	0.168	7.7	Medium	Threatened: Nationally Critical
Flesh-footed shearwater	0.009	0.488	1.8	High	Threatened: Nationally Vulnerable
Campbell black-browed albatross	0.006	0.058	10.3	Low	Threatened: Nationally Vulnerable
New Zealand white-capped albatross	0.005	0.294	1.7	Medium	At Risk: Declining
Northern royal albatross	0.003	0.048	6.3	Low	At Risk: Naturally Uncommon
Southern royal albatross	0.003	0.025	12.1	Negligible	At Risk: Naturally Uncommon

4.2.2 Incidental catch of sea turtles

Between 2002–03 and 2017–18, there were 17 observed captures of turtles in bigeye tuna longline fisheries (Table 8, Table 9 and Figure 6). Observer recordings documented all sea turtles as captured and released alive. Sea turtle capture distributions are more common on the east coast of the North Island (Figure 7).

Table 8: Total observed captures of sea turtles in bigeye tuna longline fisheries between 2002–03 and 2017–18. Data grooming methods are described in Abraham & Berkenbusch (2019) and are available via https://data.dragonfly.co.nz/psc, data version 2019v01.

Species	East Coast North Island	Kermadec Islands	West Coast North Island	Northland and Hauraki	Total
Green turtle	1				1
Leatherback turtle	4	1	3	2	10
Loggerhead turtle	1				1
Unidentified turtle	3	0	2		5
Total	7	1	5	1	17

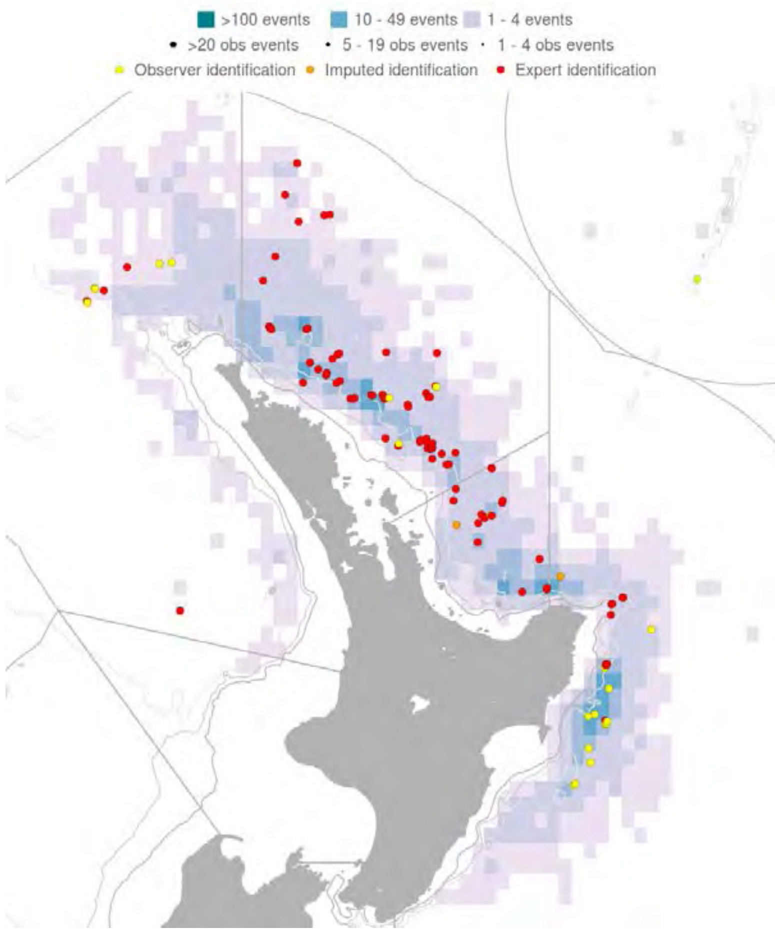


Figure 5: Distribution of fishing effort targeting bigeye tuna and observed seabird captures, 2002–03 to 2017–18. Fishing effort is mapped into 0.2-degree cells, with the colour of each cell being related to the amount of effort. Observed fishing events are indicated by black dots, and observed captures are indicated by red dots. Fishing is only shown if the effort could be assigned a latitude and longitude, and if there were three or more vessels fishing within a cell. Data grooming methods are described in Abraham & Berkenbusch (2019) and are available via https://data.dragonfly.co.nz/psc, data version 201891.

Figure 6: Observed captures of sea turtles in bigeye tuna longline fisheries from 2002–03 to 2017–18. Data grooming methods are described in Abraham & Berkenbusch (2019) and are available via https://data.dragonfly.co.nz/psc, data version 2019v1.

Table 9: Fishing effort and sea turtle captures in bigeye tuna longline fisheries by fishing year. For each fishing year, the table gives the total number of hooks; the number of observed hooks; observer coverage (the percentage of hooks that were observed); the number of observed captures (both dead and alive); and the capture rate (captures per thousand hooks). Data grooming methods are described in Abraham & Berkenbusch (2019) and are available via https://data.dragonfly.co.nz/psc, data version 2019v1.

	Fishing effort			Observed captures	
Fishing year	**All hooks**	**Observed hooks**	**% observed**	**Number**	**Rate**
2002–03	5 188 207	80 640	1.6	0	0.000
2003–04	3 507 607	120 740	3.4	1	0.008
2004–05	1 648 181	33 116	2.0	2	0.060
2005–06	1 869 586	45 100	2.4	1	0.022
2006–07	1 532 071	84 150	5.5	1	0.012
2007–08	967 829	24 295	2.5	0	0.000
2008–09	1 565 517	91 295	5.8	2	0.022
2009–10	1 247 437	76 859	6.2	0	0.000
2010–11	1 646 956	87 730	5.3	1	0.011
2011–12	1 291 923	39 210	3.0	0	0.000
2012–13	994 535	60 280	6.1	2	0.033
2013–14	743 981	29 651	4.0	0	0.000
2014–15	387 005	24 470	6.3	1	0.041
2015–16	623 659	40 510	6.5	3	0.074
2016–17	497 967	55 041	11.1	0	0.000
2017–18	569 223	51 020	9.0	3	0.059

4.2.3 Incidental catch of marine mammals

4.2.3.1 Cetaceans

Cetaceans are dispersed throughout New Zealand waters (Perrin et al. 2008). The spatial and temporal overlap of commercial fishing grounds and cetacean foraging areas has resulted in cetacean captures in fishing gear (Abraham & Thompson 2009, 2011). The analytical methods used to estimate capture numbers across the commercial fisheries have depended on the quantity and quality of the data, in terms of the numbers observed captured and the representativeness of the observer coverage. Ratio estimation is used to calculate total captures in longline fisheries by target fishery fleet and area (Baird 2008) and by all fishing methods (Abraham et al. 2010).

Between 2002–03 and 2017–18, there was one observed unidentified cetacean capture, two common dolphin, and one long finned pilot whale in bigeye longline fisheries (Tables 10 and 11). The capture of the unidentified cetacean took place on the west coast of the North Island and the common dolphins were caught in the Bay of Plenty and in Northland and Hauraki (Figures 8 and 9) (Abraham & Thompson 2011). The pilot whale long-finned recorded in 2018 was the first capture recorded for the East Coast North Island. All captures were recorded as being caught and released alive (see data version 2019v1 on https://data.dragonfly.co.nz/psc).

Table 10: Number of observed cetacean captures in bigeye tuna longline fisheries, 2002–03 to 2017–18, by species and area. Data preparation methods are described in Abraham & Berkenbusch (2019) and are available via https://data.dragonfly.co.nz/psc, data version 2019v1.

Species	East Coast North Island	West Coast North Island	Bay of Plenty	Northland and Hauraki	Total
Unidentified cetacean		1			1
Common dolphin			1	1	2
Pilot whale long-finned	1				1
Total	1	1	1	1	4

Table 11: Effort and cetacean captures by fishing year in bigeye tuna fisheries. For each fishing year, the table gives the total number of hooks; the number of observed hooks; observer coverage (the percentage of hooks that were observed); the number of observed captures (both dead and alive); and the capture rate (captures per thousand hooks). Data preparation methods are described in Abraham & Berkenbusch (2019) and are available via https://data.dragonfly.co.nz/psc, data version 2019v01.

Fishing year	Fishing effort			Observed captures	
	All hooks	Observed hooks	% observed	Number	Rate
2002–03	5 188 207	80 640	1.6	0	0.000
2003–04	3 507 607	120 740	3.4	1	0.008
2004–05	1 648 181	33 116	2.0	0	0.000
2005–06	1 869 586	45 100	2.4	0	0.000
2006–07	1 532 071	84 150	5.5	0	0.000
2007–08	967 829	24 295	2.5	0	0.000
2008–09	1 565 517	91 295	5.8	0	0.000
2009–10	1 247 437	76 859	6.2	0	0.000
2010–11	1 646 956	87 730	5.3	0	0.000
2011–12	1 291 923	39 210	3.0	0	0.000
2012–13	994 535	60 280	6.1	0	0.000
2013–14	743 981	29 651	4.0	0	0.000
2014–15	387 005	24 470	6.3	1	0.041
2015–16	623 659	40 510	6.5	0	0.000
2016–17	497 967	55 041	11.1	1	0.018
2017–18	569 223	51 020	9.0	1	0.020

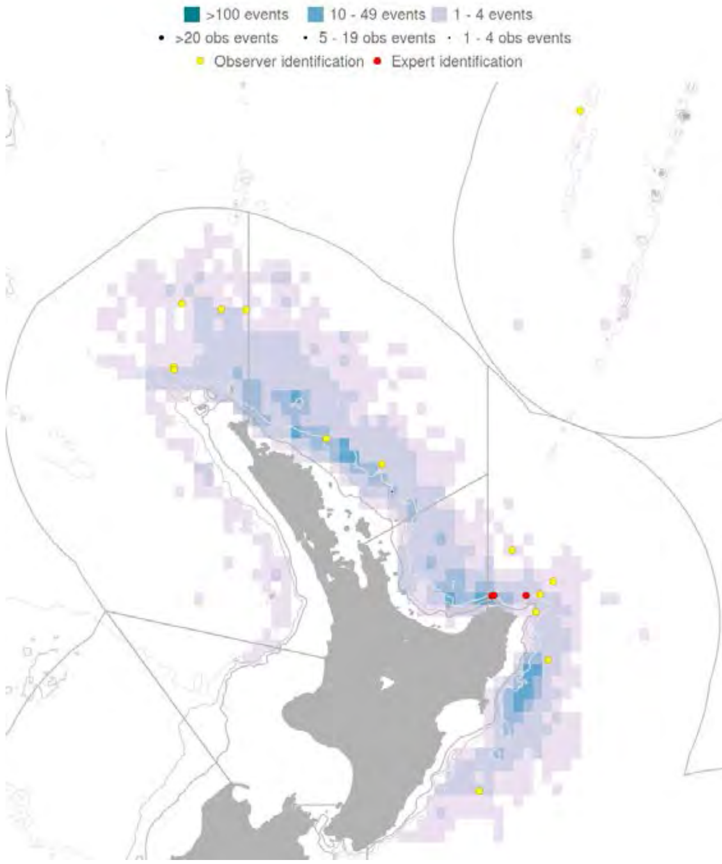


Figure 7: Distribution of fishing effort targeting bigeye tuna and observed sea turtle captures, 2002–03 to 2017–18. Fishing effort is mapped into 0.2-degree cells, with the colour of each cell being related to the amount of effort. Observed fishing events are indicated by black dots, and observed captures are indicated by red dots. Fishing is only shown if the effort could be assigned a latitude and longitude, and if there were three or more vessels fishing within a cell. Data grooming methods are described in Abraham & Berkenbusch (2019) and are available via https://data.dragonfly.co.nz/psc, data version 2019v01.

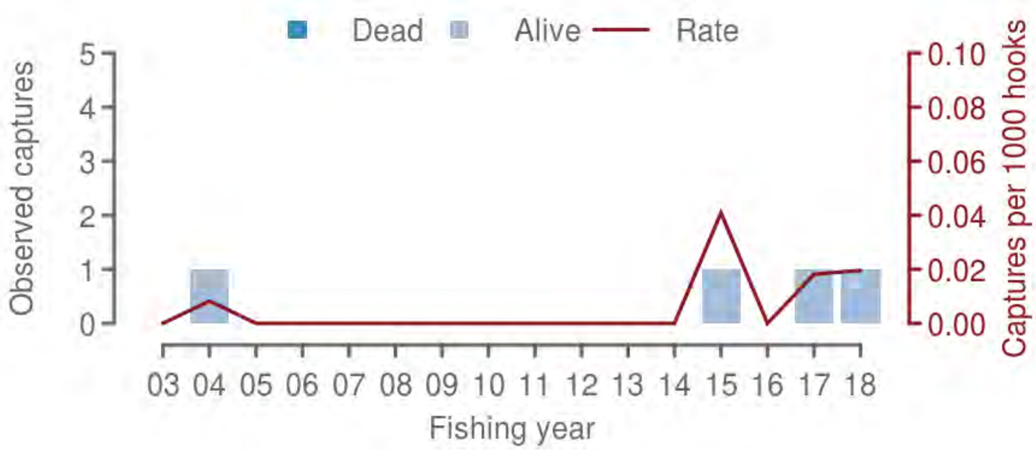


Figure 8: Observed captures of cetaceans in bigeye longline fisheries from 2002–03 to 2017–18. Data grooming methods are described in Abraham & Berkenbusch (2019) and are available via https://data.dragonfly.co.nz/psc, data version 2019v01

4.2.3.2 New Zealand fur seals

Currently, New Zealand fur seals are dispersed throughout New Zealand waters, especially in waters south of about 40ºS to Macquarie Island. The spatial and temporal overlap of commercial fishing grounds and New Zealand fur seal foraging areas has resulted in New Zealand fur seal captures in fishing gear (Mattlin 1987, Rowe 2009). Most fisheries with observed captures occur in waters over or close to the continental shelf, which slopes steeply to deeper waters relatively close to shore, and thus rookeries and haulouts, around much of the South Island and offshore islands. Captures on longlines occur when the fur seals attempt to feed on the bait and fish catch during hauling. Most New Zealand fur seals are released alive, typically with a hook and short snood or trace still attached.

The analytical methods used to estimate capture numbers across the commercial fisheries have depended on the quantity and quality of the data, in terms of the numbers observed captured and the representativeness of the observer coverage. New Zealand fur seal captures in surface-longline fisheries have been generally observed in waters south and west of Fiordland, but also in the Bay of Plenty/East Cape area. These capture rates include animals that are released alive (100% of observed surface-longline capture in 2008–09; Thompson & Abraham 2010). Between 2002–03 and 2017–18, there were two observed captures of New Zealand fur seals in bigeye longline fisheries (Tables 12 and 13, Figures 10 and 11).

Table 12: Number of observed New Zealand fur seal captures in bigeye tuna longline fisheries, 2002–03 to 2017–18 by species and area. Data grooming methods are described in Abraham & Berkenbusch (2019) and are available via https://data.dragonfly.co.nz/psc, data version 2019v01.

	West Coast North Island	Total
New Zealand fur seal	2	2

Table 13: Effort and captures of New Zealand fur seals by fishing year in bigeye tuna longline fisheries. For each fishing year, the table gives the total number of hooks; the number of observed hooks; observer coverage (the percentage of hooks that were observed); the number of observed captures (both dead and alive); and the capture rate (captures per thousand hooks). Estimates are based on methods described in Abraham & Berkenbusch (2019) and are available via https://data.dragonfly.co.nz/psc, data version 2019v01.

Fishing year			Fishing effort	Observed captures		Estimated captures	
	All hooks	Observed hooks	% observed	Number	Rate	Mean	95% c.i.
2002–03	5 188 207	80 640	1.6	0	0.000	27	2–74
2003–04	3 507 607	120 740	3.4	0	0.000	10	0–28
2004–05	1 648 181	33 116	2.0	0	0.000	4	0–14
2005–06	1 869 586	45 100	2.4	0	0.000	4	0–12
2006–07	1 532 071	84 150	5.5	0	0.000	2	0–7
2007–08	967 829	24 295	2.5	2	0.082	4	2–10
2008–09	1 565 517	91 295	5.8	0	0.000	4	0–12
2009–10	1 247 437	76 859	6.2	0	0.000	3	0–11
2010–11	1 646 956	87 730	5.3	0	0.000	4	0–14
2011–12	1 291 923	39 210	3.0	0	0.000	7	0–20
2012–13	994 535	60 280	6.1	0	0.000	4	0–12
2013–14	743 981	29 651	4.0	0	0.000	5	0–15
2014–15	387 005	24 470	6.3	0	0.000	2	0–6
2015–16	623 659	40 510	6.5	0	0.000	0	0–2
2016–17	497 967	55 041	11.1	0	0.000		
2017–18	569 223	51 020	9.0	0	0.000		

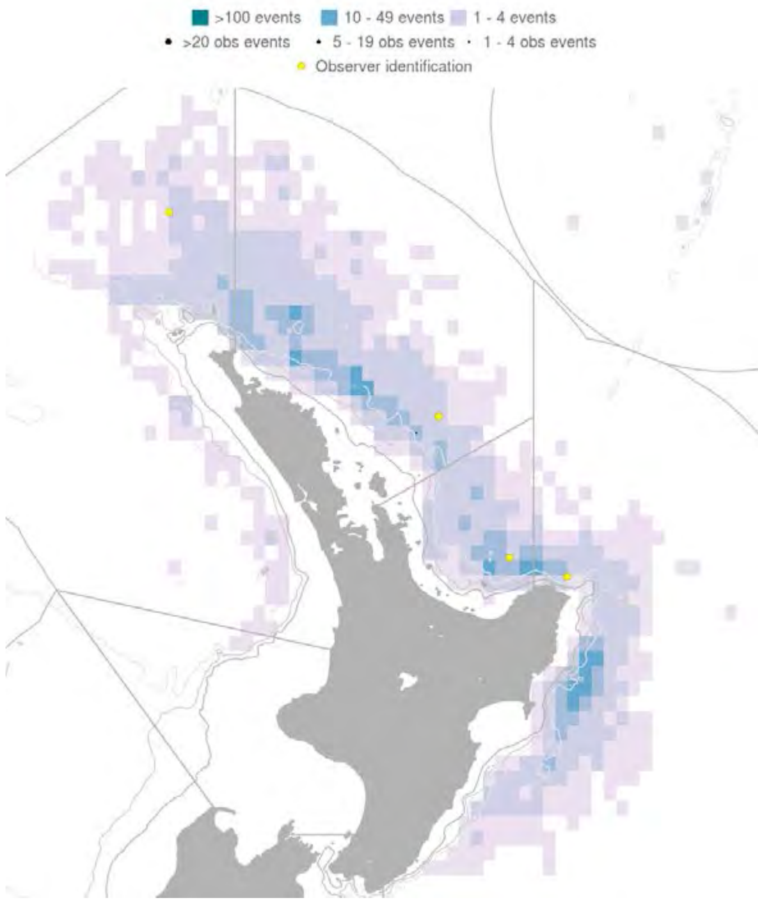


Figure 9: Distribution of fishing effort targeting bigeye tuna and observed cetacean captures, 2002–03 to 2017–18. Fishing effort is mapped into 0.2-degree cells, with the colour of each cell being related to the amount of effort. Observed fishing events are indicated by black dots, and observed captures are indicated by red dots. Fishing is only shown if the effort could be assigned a latitude and longitude, and if there were three or more vessels fishing within a cell. Data grooming methods are described in Abraham & Berkenbusch (2019) and are available via https://data.dragonfly.co.nz/psc, data version 2019v01.

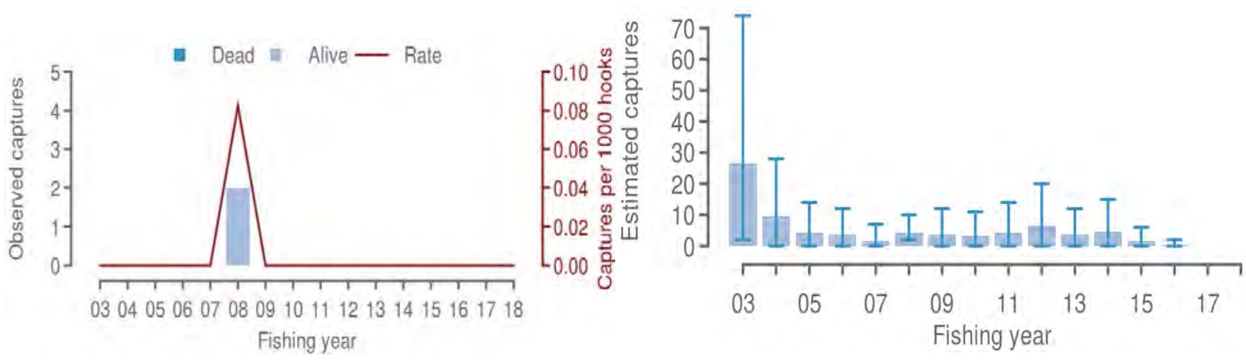


Figure 10: Observed (left) and estimated (right) captures of New Zealand fur seals in bigeye tuna longline fisheries from 2002–03 to 2017–18. Data grooming methods are described in Abraham & Berkenbusch (2019) and are available via https://data.dragonfly.co.nz/psc, data version 2019v01.

4.3 Incidental fish bycatch

Observer records indicate that a wide range of species are landed by the longline fleets in New Zealand fishery waters. Blue sharks are the most commonly landed species (by number), followed by lancetfish and porbeagle shark (Table 14).

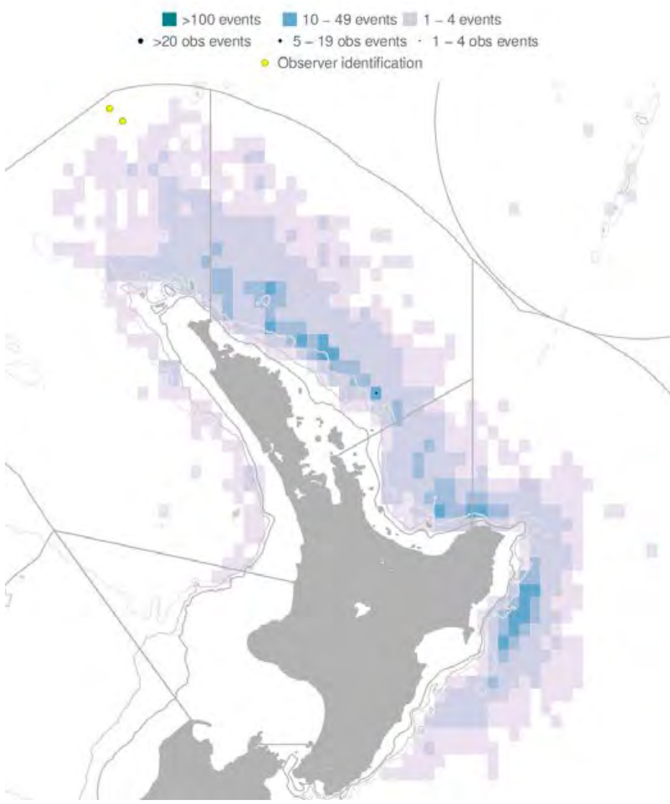


Figure 11: Distribution of fishing effort targeting bigeye tuna and observed New Zealand fur seal captures, 2002–03 to 201718. Fishing effort is mapped into 0.2-degree cells, with the colour of each cell being related to the amount of effort. Observed fishing events are indicated by black dots, and observed captures are indicated by red dots. Fishing is only shown if the effort could be assigned a latitude and longitude, and if there were three or more vessels fishing within a cell. Data grooming methods are described in Abraham & Berkenbusch (2019) and are available via https://data.dragonfly.co.nz/psc, data version 2019v01.

Table 14: Total estimated catch (numbers of fish) of common bycatch species in the New Zealand longline fishery as estimated from observer data from 2015 to 2018. Also provided is the percentage of these species retained (2018 data only) and the percentage of fish that were alive when discarded, N/A (none discarded). [Continued on next page]

Species	2015	2016	2017	2018	% retained (2018)	discards % alive (2018)
Blue shark	72 480	57 210	49 924	63 618	0.0	88.7
Lancetfish	12 962	17 442	13 274	13 163	0.0	33.5
Porbeagle shark	4 058	6 566	3 101	2 594	1.0	51.1
Rays bream	17 555	7 758	2 421	1 579	99.0	26.7
Moonfish	3 060	3 036	2 022	2 698	98.0	50.0
Pelagic stingray	979	1 414	1 798	2 949	0.0	100.0
Sunfish	770	4 849	1 648	3 648	0.0	99.8

Species	2015	2016	2017	2018	% retained (2018)	discards % alive (2018)
Mako shark	2 667	4 417	1 391	2 721	4.0	65.6
Rudderfish	373	237	680	253	45.0	89.4
Butterfly tuna	1 309	768	406	419	86.0	20.7
Escolar	653	669	300	594	67.0	67.9
Striped marlin	120	550	290	247	0.0	66.7
Thresher shark	177	601	260	253	0.0	76.0
Oilfish	584	281	227	602	42.0	85.4
Dealfish	842	63	72	25	0.0	31.8
School shark	88	24	59	187	84.0	100.0
Skipjack tuna	150	185	57	184	86.0	100.0
Deepwater dogfish	545	0	32	6	0.0	83.3
Big scale pomfret	59	16	17	34	100.0	n/a

4.4 Benthic interactions
There are no known interactions with benthic habitats.

4.5 Key environmental and ecosystem information gaps
Cryptic mortality is unknown at present but developing a better understanding of this in future may be useful for reducing uncertainty of the seabird risk assessment and could be a useful input into risk assessments for other species groups. The survival rates of released target and bycatch species is currently unknown.

Observer coverage in the New Zealand fleet is not spatially and temporally representative of the fishing effort.

5. STOCK ASSESSMENT

With the establishment of the WCPFC in 2004, stock assessments of the WCPO stock of bigeye tuna are undertaken by the Oceanic Fisheries Programme (OFP) of Secretariat of the Pacific Community under contract to WCPFC. As noted above, there is continuing work on a Pacific-wide bigeye assessment.

No assessment is possible for bigeye within the New Zealand EEZ as the proportion of the total stock found within New Zealand fisheries waters is unknown and is likely to vary from year to year.

The bigeye stock assessment in the western and central Pacific Ocean was fully assessed in 2017 in paper SC-13-SA-WP-05, and updated in 2018 in paper SC-14-SA-WP-03. A further three years of data were available since the last stock assessment was conducted in 2014, and the model time period extended to the end of 2015. New developments to the stock assessment included addressing the recommendations of the 2014 stock assessment report (Harley et al. 2014a), incorporation of new data such as a recent ageing of otoliths to estimate age-at-length for WCPO fish, investigation of an alternative regional structure, exploration of uncertainties in the assessment model, particularly in response to the inclusion of additional years of data, and improvement of diagnostic weaknesses of previous assessments.

Changes made in the progression from the 2014 reference case to 2017 diagnostic case models included:

- Updating all data up to the end of 2015.
- Utilising standardised CPUE indices calculated from the recently collated operational longline CPUE dataset.

- Investigating an alternative spatial structure with the boundaries between the tropical and northern temperate regions shifted from 20°N to 10°N.
- Investigating the use of a new growth curve based on the recently processed otoliths of Farley et al. (2017), which suggested a much lower asymptotic size for old fish.
- Implementation of new features developed in MFCL, including an annual stock recruitment relationship.

In addition to the diagnostic case model, the authors reported on the results of one-off sensitivity models that explored the relative impacts of key data and model assumptions for the diagnostic case model on the stock assessment results and conclusions. They also undertook a structural uncertainty analysis (model grid) for consideration in developing management advice where all possible combinations of the most important axes of uncertainty from the one-off models were included. In comparison to previous assessments, little emphasis was placed on the diagnostic case model. Instead it was recommended that management advice be formulated from the results of the structural uncertainty grid.

Across the range of models run in this assessment, the most important factors with respect to estimates of stock status were the choice of the new (lower asymptotic size) versus old (higher asymptotic size) growth curves. The former estimated considerably more optimistic results than the latter, and this was also the case when compared to the results of the 2014 assessment. The second key axis explored in the structural uncertainty grid was whether the 2014 or 2017 regional structures were assumed. Again, the latter estimated a significantly more optimistic stock status (though the effect of this assumption was less than for growth). The models assuming the 2017 regions essentially assigned more of the stock to the less exploited temperate regions from the highly exploited equatorial regions where fishing depletion was estimated to be higher.

The bigeye stock assessment in the western and central Pacific Ocean was updated in 2018 in paper SC-14-SA-WP-03. This paper describes the 2018 re-evaluation of bigeye tuna (*Thunnus obesus*) in the western and central Pacific Ocean, incorporating an updated growth curve resulting from analysis of an enhanced set of otolith data, as requested by SC13. The analysis conducted followed the same methodologies as the assessment conducted in 2017 (McKechnie et al. 2017a,b; Tremblay-Boyer et al. 2017). The updated results of the uncertainty analysis (model grid) are reported using the axes and weightings from SC13 for consideration in developing management advice. Following the precedent set by McKechnie et al. (2017a), it is recommended that management advice be formulated from the results of the structural uncertainty grid. In addition to updating the structural uncertainty grid, the uncertainty surrounding the spatial structure of the assessment is investigated by creating an additional model with the northern boundary of regions 3 and 4 at 15°N, as a one-off sensitivity from two models in the structural uncertainty grid.

Across the range of models in this re-evaluation, the most important factor with respect to the estimated stock status was once again the choice of growth curve ("Updated New" or "Old" growth). The "Updated New growth" model was considerably more optimistic than the "Old growth" model, but was very similar to the "new growth" model presented in 2017. The second key axis in the structural uncertainty grid was whether the northern boundary of regions 3 and 4 was assumed to be at 10° N or 20° N. The former models estimated more optimistic stock status than the latter, though the effect of this assumption was less than for growth. The 10° N model essentially estimates a larger stock size by assigning more stock to the less exploited temperate regions.

The general conclusions of the re-evaluation are as follows:

1. Models that assume the "Updated New growth" estimate depletion to be median($SB_{recent}/SB_{F=0}$)= 0.358 with an 80% probability interval of 0.295 to 0.412 and all models estimate stock above 20%$SB_{F=0}$.

2. All models that assume "Updated New growth" estimate a recent recruitment event that has increased spawning potential in the last several years, and it is expected that for the "Old growth" models these recruits will soon progress into the spawning potential and improve stock status, at least in the short-term.

3. Only the "Old growth" and 20° N boundary models estimate spawning potential to be below 20%$SB_{F=0}$ for all models in the set. These models estimate median($SB_{recent}/SB_{F=0}$) = 0.188 with an 80% probability interval of 0.123 to 0.275, which is consistent with the structural uncertainty grid of the 2017 assessment.

4. Using a weighting of 3:1 "Updated New:Old growth" as defined by SC13, the recent depletion estimates were median($SB_{recent}/SB_{F=0}$) = 0.334 with an 80% probability interval of 0.157 to 0.403. Of the 144 weighted runs, 21 (14.58%) estimated $SB_{recent}/SB_{F=0}$ below the LRP of 20% $SB_{F=0}$. Across the weighted grid, exploitation was estimated at median(F_{recent}/F_{MSY}) = 0.813 with an 80% probability interval of 0.682 to 1.245, where 32 of the 144 models estimated $F_{recent}/F_{MSY} > 1$ (22.22%).

5. Regarding the spatial structure of the model, in particular the northern boundary of regions 3 and 4, the Scientific Committee will have to weigh the spatial information from the various data sources. The spatial patterns in catch, CPUE and size structure across the key bigeye fisheries were investigated to inform discussions and highlight key data constraints. The results from a model that assumes a northern boundary at 15°N for regions 3 and 4 are compared to models from the structural uncertainty grid for comparable models that assumed a boundary at either 0°N or 20°N. The results from the 15°N model were most similar to the model that assumed a 10°N boundary. Given the similarity of these models, the increased complexity of including multiple spatial structures within a structural uncertainty grid, and concerns regarding data assumptions that may not be valid with 'intermediate' structures, it is recommended that the models with the 10°N boundaries be used to develop management advice.

5.1 Stock status and trends

The median values of relative recent (2012–2015) spawning biomass depletion ($SB_{recent}/SB_{F=0}$) and relative recent (2011–2014) fishing mortality (F_{recent}/F_{MSY}) over the uncertainty grid of 36 models (Table 15) were used to define stock status. The values of the upper 90th and lower 10th percentiles of the empirical distributions of relative spawning biomass and relative fishing mortality from the uncertainty grid were used to characterize the probable range of stock status.

A description of the updated structural sensitivity grid used to characterize uncertainty in the assessment is set out in Table 15. The time series of total annual catch by fishing gear over the full assessment period is shown in Figure 12. Estimated trends in spawning biomass depletion for the 36 models in the structural uncertainty grid is shown in Figure 13, and juvenile and adult fishing mortality rates from the diagnostic case model is shown in Figure 14. Figure 15 displays Majuro plots summarising the results for each of the models in the structural uncertainty grid. Figure 16 shows Kobe plots summarising the results for each of the models in the structural uncertainty grid. Table 16 provides a summary of reference points over the 36 models in the structural uncertainty grid.

SC14 agreed to use the "updated new growth" model to describe the stock status of bigeye tuna because SC14 considered it to be the best available scientific information. By removing results using the old growth model, the stock status becomes considerably more optimistic. However, SC14 also notes that questions remain regarding the "updated new growth" model.

Therefore, SC14 acknowledges that further study is warranted related to the new growth model, in particular as to the cause of the difference of growth between EPO and WCPO. An inter-laboratory ageing workshop is planned for late 2018 to review ageing approaches in the WCPO and EPO and to resolve differences, if they exist.

In addition, SC14 acknowledges that further study is warranted to refine the tagging dataset in the WCPO to assist validating age estimates of bigeye in the WCPO. SC14 further notes that adopting the new growth curve generates new broader questions related to the bigeye tuna stock assessment and agreed that several aspects need to be investigated further to inform future assessments.

Table 15: Description of the updated structural sensitivity grid used to characterise uncertainty in the assessment.

Axis	Levels	Option
Steepness	3	0.65, 0.80, 0.95
Growth	1	'Updated new growth'
Tagging over-dispersion	2	Default level (1), fixed (moderate) level
Size frequency weighting	3	Sample sizes divided by 10, 20, 50
Regional structure	2	10°N regions, 20°N regions

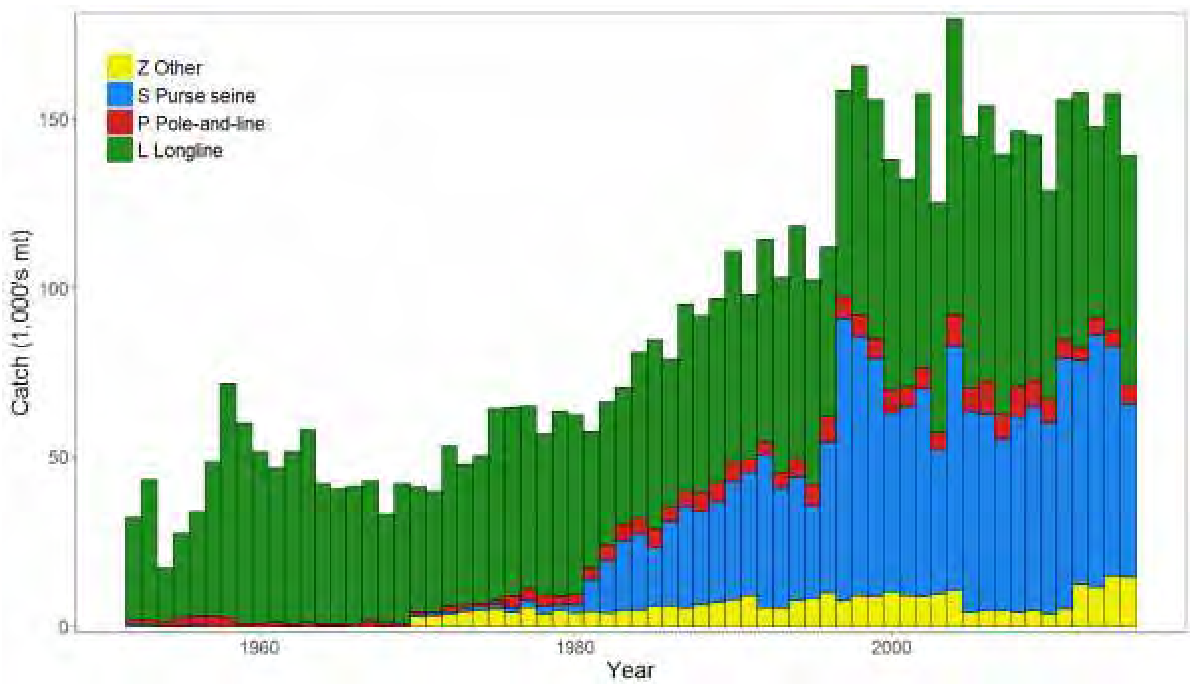


Figure 12: Time series of total annual catch (1000's mt) by fishing gear over the full assessment period.

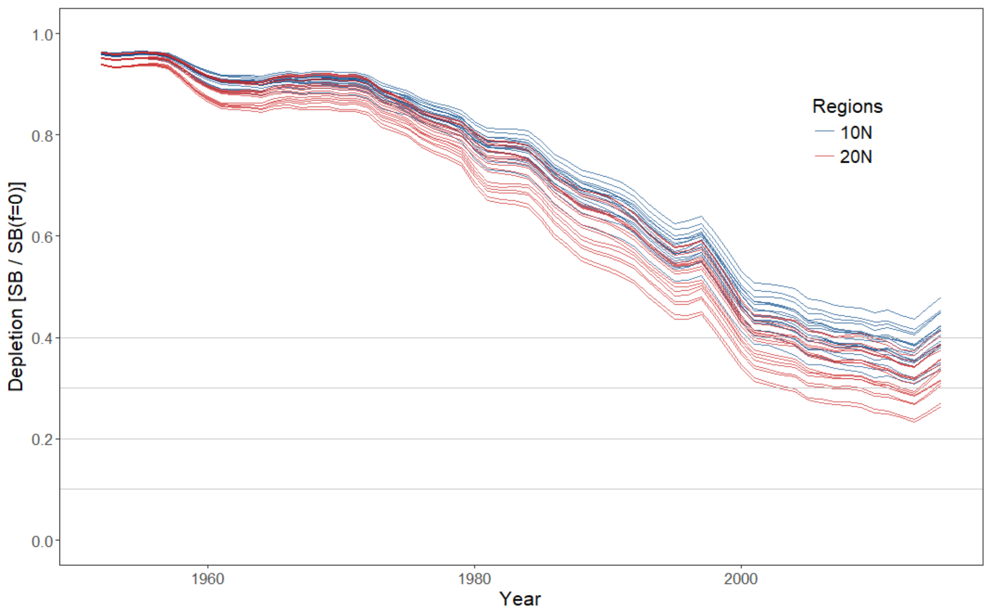


Figure 13. Plot showing the trajectories of spawning biomass depletion for the 36 model runs included in the structural uncertainty grid. The colours depict the models in the grid with the 10°N and 20°N spatial structures.

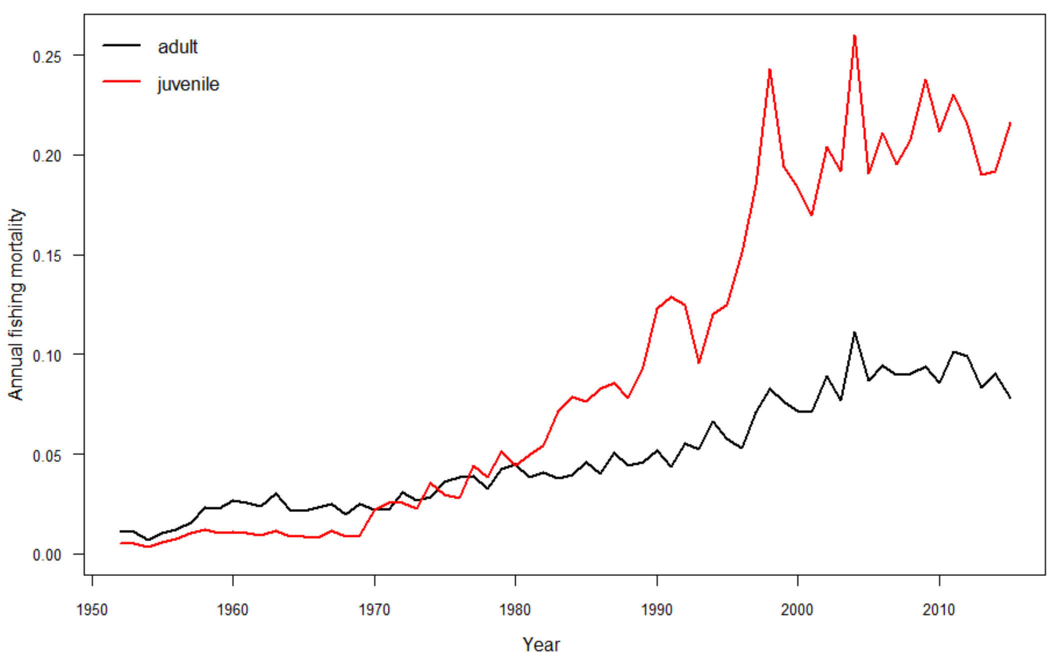
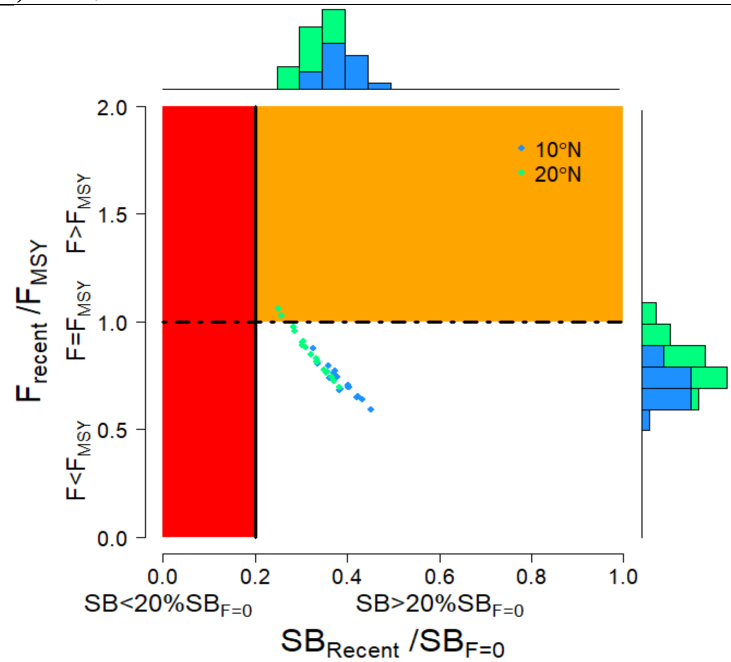


Figure 14: Estimated annual average juvenile and adult fishing mortality for the diagnostic case model.

SB$_{recent}$ (2012–2015) /*SB*$_{F=0}$



SB$_{latest}$ (2015) /*SB*$_{F=0}$

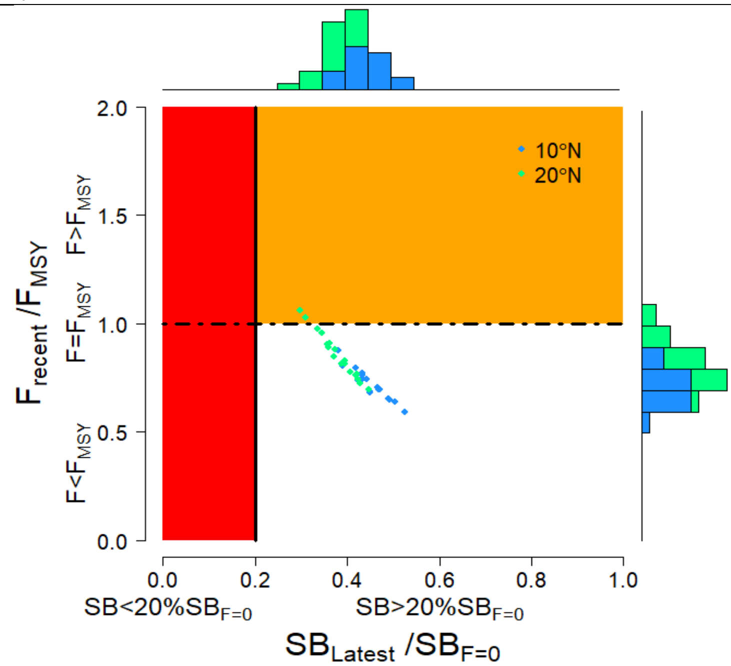
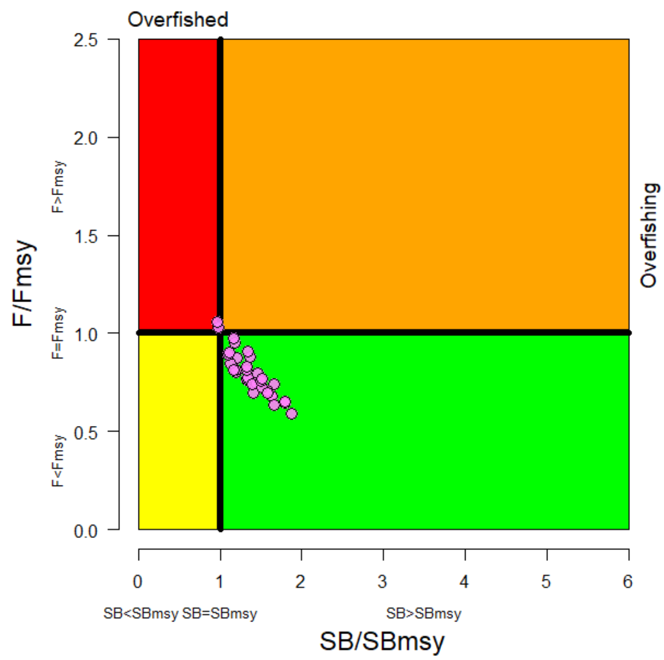


Figure 15: Majuro plot summarising the results for each of the models in the structural uncertainty grid. The plots represent estimates of stock status in terms of spawning biomass depletion and fishing mortality. The red zone represents spawning biomass levels lower than the agreed limit reference point, which is marked with the solid black line. The orange region is for fishing mortality greater than F_{MSY} (F_{MSY} is marked with the black dashed line). In the upper panel, the points represent $SB_{recent}/SB_{F=0}$, where SB_{recent} is the mean SB over 2012–2015. In the lower panel, the points represent $SBl_{atest}/SB_{F=0}$, where SB_{latest} is from 2015. In both panels the colours depict the models in the grid with the 10°N and 20°N regional structures.

SB_{recent} (2012–2015) / SB_{MSY}



SB_{latest} (2015) / SB_{MSY}

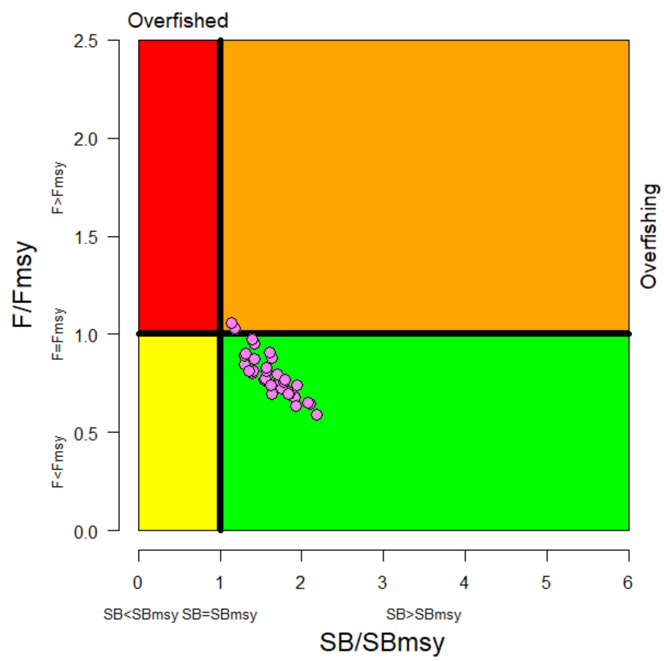


Figure 16: Kobe plot summarising the results for each of the models in the structural uncertainty grid. In the upper panel, the points represent SB_{recent}/SB_{MSY}, where SB_{recent} is the mean SB over 2012–2015. In the lower panel, the points represent SB_{latest}/SB_{MSY}, where SB_{latest} is from 2015.

Table 16: Summary of reference points over the 36 models in the structural uncertainty grid. Note that $SB_{recent}/SB_{F=0}$ is calculated where SB_{recent} is the mean SB over 2012–2015 at the request of the Scientific Committee.

	Mean	Median	Min	10%	90%	Max
C_{latest}	152 148	151 846	148 888	148 936	154 971	155 577
YF_{recent}	154 180	153 220	133 120	141 140	170 720	172 280
f_{mult}	1.291	1.301	0.946	1.075	1.499	1.690
F_{MSY}	0.050	0.049	0.044	0.045	0.054	0.056
MSY	158 551	159 020	133 520	143 040	173 880	180 120
F_{recent}/F_{MSY}	0.789	0.768	0.592	0.667	0.931	1.058
SB_0	1 674 833	1 675 500	1 261 000	1 415 500	1 941 000	2 085 000
$SB_{F=0}$	1 841 609	1 858 775	1 509 007	1 632 014	2 043 108	2 139 644
SB_{MSY}	471 956	476 050	340 700	386 600	577 400	614 200
SB_{MSY}/SB_0	0.281	0.280	0.260	0.262	0.300	0.302
$SB_{MSY}/SB_{F=0}$	0.255	0.255	0.226	0.235	0.280	0.287
SB_{latest}/SB_0	0.456	0.456	0.346	0.392	0.523	0.568
$SB_{latest}/SB_{F=0}$	0.414	0.420	0.298	0.351	0.480	0.526
SB_{latest}/SB_{MSY}	1.633	1.624	1.146	1.306	1.933	2.187
$SB_{recent}/SB_{F=0}$	0.353	0.358	0.251	0.295	0.412	0.452
SB_{recent}/SB_{MSY}	1.394	1.377	0.963	1.117	1.659	1.879

SC14 noted that there has been a long-term decrease in spawning biomass from the 1950s to the present for bigeye tuna and that this is consistent with previous assessments.

SC14 also noted that the central tendency of relative recent (2012–2015) spawning biomass depletion was median ($SB_{recent}/SB_{F=0}$) = 0.36 with a range of 0.30 to 0.41 (80% probability interval).

SC14 further noted that there was 0% probability (0 out of 36 models) that the recent spawning biomass had breached the adopted LRP.

SC14 noted that there has been a long-term increase in fishing mortality for both juvenile and adult bigeye tuna (Figure 14), consistent with previous assessments.

SC14 also noted that the central tendency of relative recent fishing mortality was median (F_{recent}/F_{MSY}) = 0.77 with an 80% probability interval of 0.67 to 0.93.

SC14 further noted that there was a roughly 6% probability (2 out of 36 models) that the recent fishing mortality was above F_{MSY}.

SC14 also noted that, regardless of the choice of uncertainty grid, the assessment results show that the stock has been continuously declining for about 60 years since the late 1950s, except for the recent small increase.

SC14 also noted the continued relatively higher levels of depletion in the equatorial and western Pacific (specifically Regions 3, 4, 7 and 8) and the associated higher levels of impact, especially on juvenile bigeye tuna, in these regions due to the associated purse-seine fisheries and the 'other' fisheries within the western Pacific (as shown in figures 46 and 47 of SC13-SA-WP-03).

Figure 17 presents the distributions of long term $SB/SB_{F=0}$ and Figure 18 those for F/F_{MSY} under each of the future fishing and recruitment combinations.

Potential outcomes under the 2013–15 average and CMM scenario conditions were strongly influenced by the assumed future recruitment levels.

Under the assumption that recent positive recruitments will continue into the future, spawning biomass relative to unfished levels is predicted to increase from recent levels under all examined future scenarios by 0–18% ($SB_{2045}/SB_{F=0}$ ranges from 0.36 to 0.42; Figure 17). While future uncertainty in stock status increases due to stochastic future recruitment levels, the risk of future spawning biomass falling below the LRP falls to between 0 and 5%, due to the improved overall stock size. Fishing mortality falls slightly under both the status quo and optimistic scenarios, assuming recent recruitment. However, fishing mortality increases under the pessimistic scenario, but remains below F_{MSY} (30% risk of $F > F_{MSY}$; Figure 18).

Under the assumption that less positive long-term recruitments are experienced in the future, spawning biomass relative to unfished levels will decline under all scenarios ($SB_{2045}/SB_{F=0}$ ranges from 0.25 to 0.30). The risk of spawning biomass falling below the LRP increases to between 17 and 32%. In all fishing scenarios, fishing mortality increases relative to recent levels (by 109–138%) and is well above F_{MSY}. Risk of fishing mortality exceeding F_{MSY} ranges from 93 to 98%.

It should be noted that even under assumption of long term recruitment levels, the risk of exceeding the LRP in the short term ranges between 2% and 7% (2020) and 12 and 26% (2025), with only the pessimistic scenario exceeding the 20% level of risk in 2025.

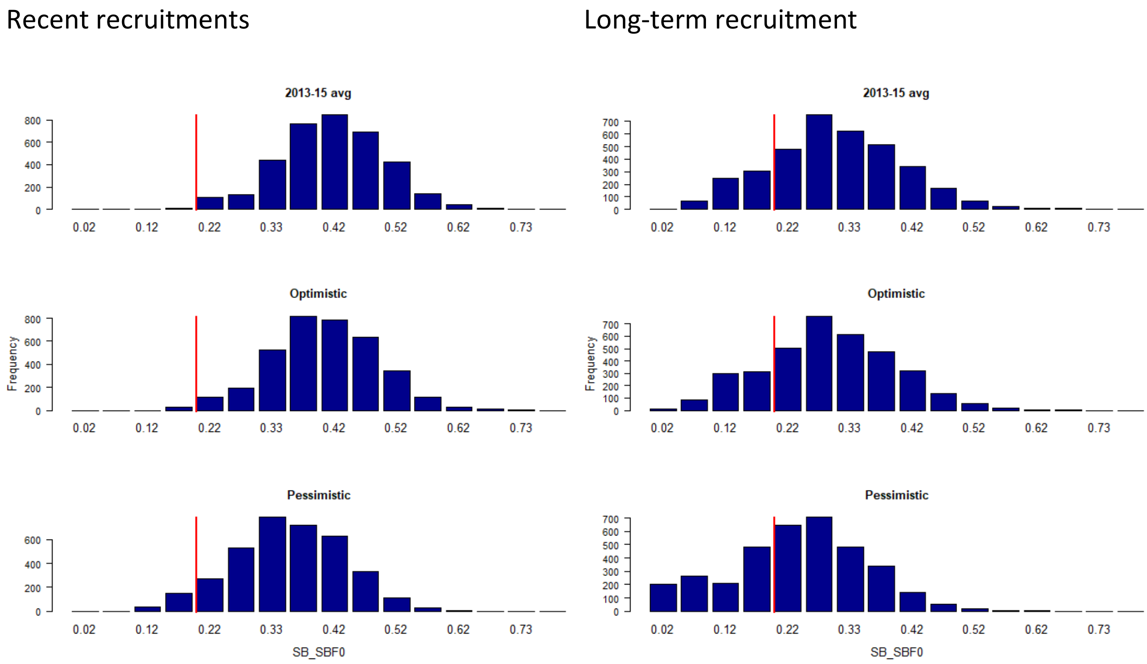


Figure 17: Distribution of $SB_{2045}/SB_{F=0}$ assuming recent and long term recruitment conditions (left and right columns, respectively), under the three future fishing scenarios: 2013-15 avg (2013–15 average conditions, top row); optimistic conditions (middle row); and pessimistic conditions (bottom row). Projection results from 'updated new growth' models (3600 projections) only where the red line indicates the LRP.

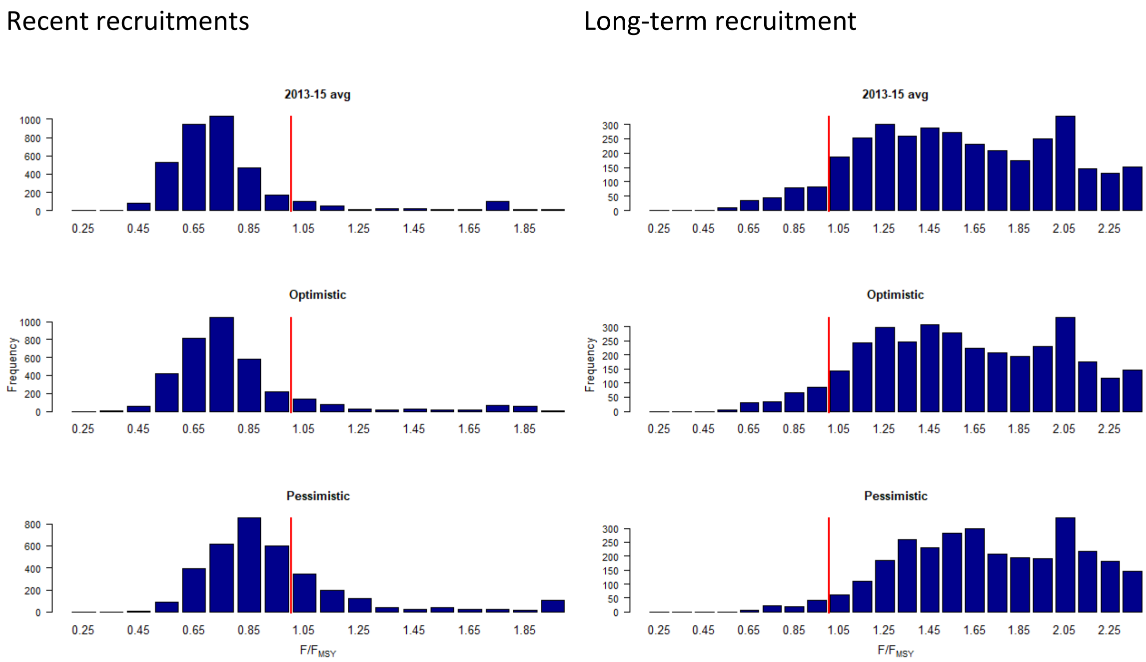


Figure 18: Distribution of F/F_{MSY} assuming recent and long term recruitment conditions (left and right columns, respectively), under the three future fishing scenarios: 2013-15 avg (2013–15 average conditions, top row); optimistic conditions (middle row); and pessimistic conditions (bottom row). Projection results from 'updated new growth' models (3600 projections) only.

SC14 noted that the preliminary estimate of total catch of WCPO bigeye tuna for 2017 was 126 929 mt, a 17% decrease from 2016 and a 19% decrease from the average 2012–2016. Longline catch in 2017 (58 164 mt) was an 8% decrease from 2016 and a 19% decrease from the 2012–2016 average. Purse seine catch in 2017 (56 194 mt) was a 12% decrease from 2016 and a 13% decrease from the 2012–2016 average. Pole and line catch (1411 mt) was a 65% decrease from 2016 and a 70% decrease from the average 2012–2016 catch. Catch by other gear (11 160 mt) was a 48% decrease from 2016 and a 28% decrease from the average catch in 2012–2016.

Based on the uncertainty grid adopted by SC14, the WCPO bigeye tuna spawning biomass is above the biomass LRP and recent F is very likely below F_{MSY}. The stock is not experiencing overfishing (94% probability $F<F_{MSY}$) and it is not in an overfished condition (0% probability $SB/SB_{F=0}$<LRP).

Although SC14 considers that the updated assessment is consistent with the previous assessment, SC14 also advises that the amount of uncertainty in the stock status results for the 2018 assessment update is lower than for the previous assessment due to the exclusion of old information on bigeye tuna growth.

SC14 noted that levels of fishing mortality and depletion differ among regions, and that fishery impact was higher in the tropical region (Regions 3, 4, 7 and 8 in the stock assessment model), with particularly high fishing mortality on juvenile bigeye tuna in these regions. SC14 therefore recommends that WCPFC15 could continue to consider measures to reduce fishing mortality from fisheries that take juveniles, with the goal to increase bigeye fishery yields and reduce any further impacts on the spawning biomass for this stock in the tropical regions.

SC14 noted that according to CMM 2017-01 bigeye tuna $SB/SB_{F=0}$ is to be maintained above the 2012–2015 level ($SB_{recent}/SB_{F=0}$ = 0.36) pending the agreement on a TRP. SC14 also noted that the projection results (Figure 19) based on scenarios estimating CMM 2017-01 indicated a high level of uncertainty on the levels of spawning stock biomass relative to the LRP and the objective of CMM 2017-01 in 2045. Under the scenario assuming long-term average recruitment continues into the future there was a

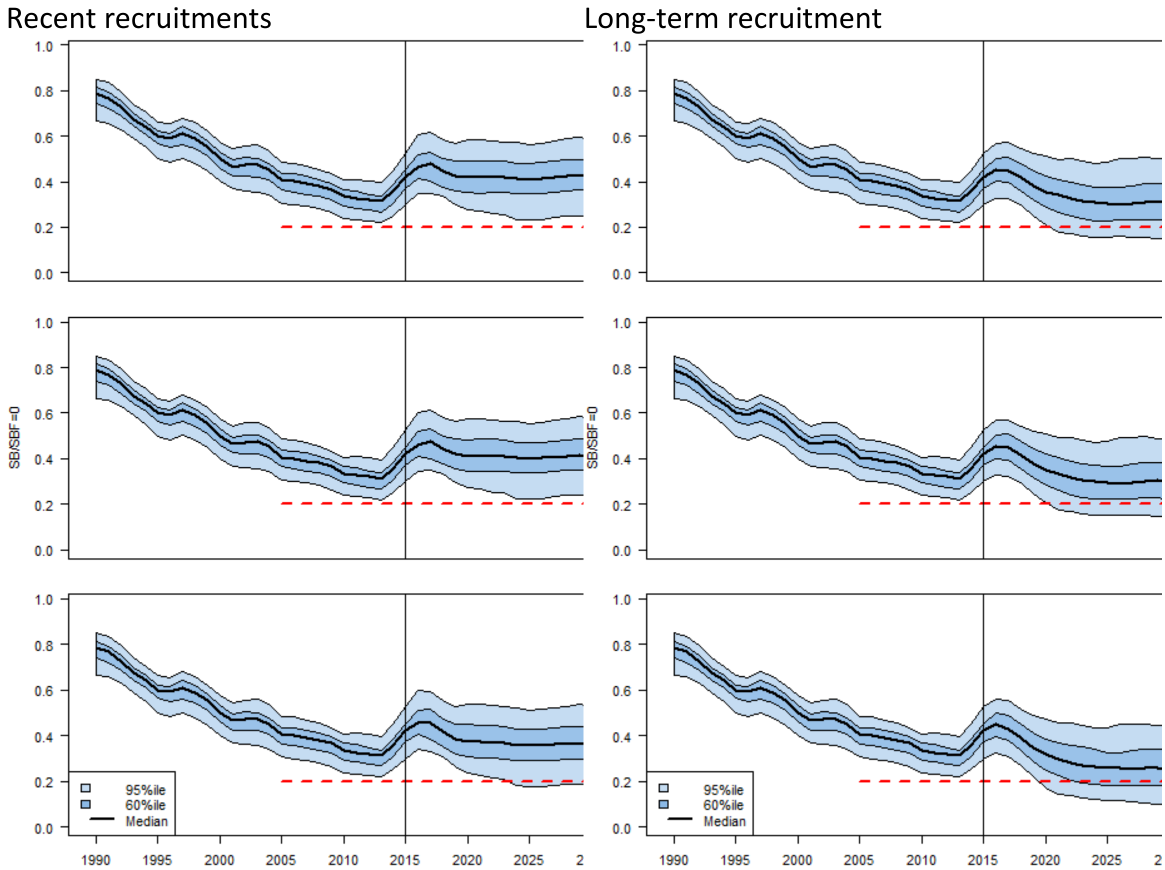


Figure 19: Time series of WCPO bigeye tuna spawning biomass (*SB/SB$_{F=0}$*) from the uncertainty grid of assessment model runs for the period 1990 to 2015 (the vertical line at 2015 represents the last year of the assessment), and stochastic projection results for the period 2016 to 2045 under the three future fishing scenarios ("2013-15 avg", "Optimistic" and "Pessimistic"; rows). During the projection period (2016–2045) levels of recruitment variability are assumed to match those over the "recent" time period (2005–2014; left panel) or the time period used to estimate the stock-recruitment relationship (1962–2014; right panel). The red dashed line represents the agreed limit reference point.

high risk (18–32%) of breaching the LRPs and a zero probability of achieving the objective of CMM 2017-01, while under the scenario which assumes higher more recent recruitments continues into the future there was a low risk (0–5%) of breaching the LRPs and a 100% probability of achieving the objective of CMM 2017-01.

However, SC14 also noted that the projections assume that longline catches would be maintained regardless of the decrease in biomass. This may result in unlikely high levels of effort. Therefore, the catch estimates under the long term recruitment scenario, especially in the longer term projections, are more uncertain.

5.2 Estimates of fishery parameters and abundance

There are no fishery independent indices of abundance for the bigeye stock. Relative abundance information is available from longline catch per unit effort data, though there is no agreement on the best method to standardise these data and several methods are compared. Returns from a large-scale tagging programme undertaken in the early 1990s, and an updated programme from 2007–09 undertaken by the SPC provide information on rates of fishing mortality, which in turn has improved estimates of abundance.

5.3 Biomass estimates
The stock assessment results and conclusions of the 2017 assessment show SB_{recent}/SB_{MSY} estimated at 1.38 over the period 2012–15. This estimate applies to the WCPO portion of the stock or an area that is approximately equivalent to the waters west of 150°W. Spawning biomass for the WCPO is estimated to have declined to about 36% of its initial level by 2012–15.

5.4 Yield estimates and projections
No estimates of MCY and CAY are available.

5.5 Other yield estimates and stock assessment results
SC10 achieved consensus to accept and endorse the reference case proposed in the assessment document, and that 0.2 $SB_{F=0}$ be used as the LRP for stock status purposes as agreed by WCPFC. There was further discussion about whether to use SB_{latest} or SB_{recent} as the terminal spawning biomass for management purposes. The SC agreed to use the most recent information on bigeye tuna spawning biomass, SB_{latest} corresponding to 2015, given recent trends of increasing catch, high fishing mortality and decreasing CPUE.

SC10 also endorsed the use of the candidate biomass-related target reference point (TRP) currently under consideration for skipjack tuna, i.e., 40–60% $SB_{F=0}$. At 0.42 $SB_{F=0}$, SB_{latest} is above the limit and near the target reference point.

5.7 Other factors

SC14 noted that the acceptance of the new growth model for BET raises a number of issues in relation to patterns of growth and stock structure of BET across the Pacific Ocean and recommended that the following research issues need to be addressed:

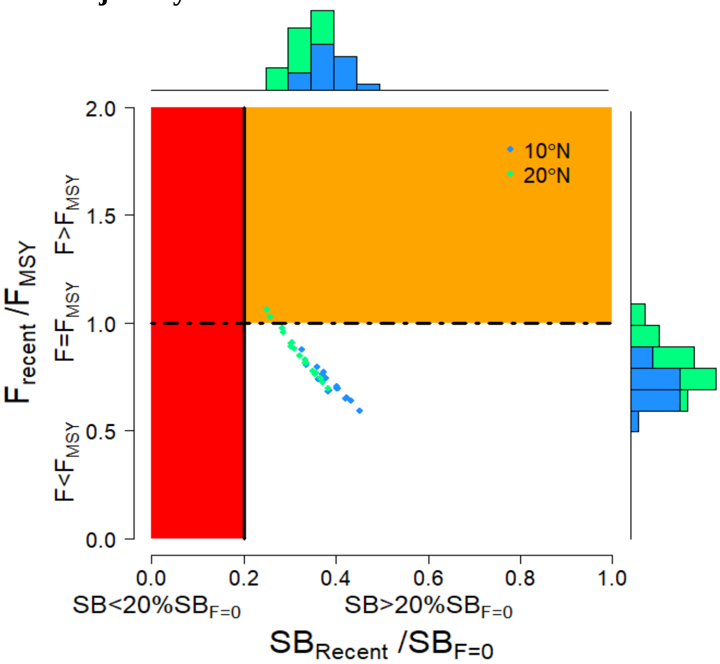
1) Two different growth models separated at 150˚W effectively means that Pacific BET should be assessed as a two-stock resource between the WCPO and EPO. However, catch information indicates that the fishing grounds near 150˚W are a core area of BET catch, thus influencing the assessments of both the WCPFC and IATTC. Also, tagging information suggests movement of BET between the WCPO and EPO. Therefore, the appropriateness off delineating the two stocks at 150˚W needs to be investigated.
2) The new growth analysis suggests area variant growth across the Pacific. While the level of variation is seen to be relatively small within the WCPO (and possibly within the margins of observation error), there is a suggestion of substantial change in growth around the boundary between the WCPO and the EPO (c.f. figure 14 in SC14-SA-WP-01). The reasons for this suggested change in growth remains unknown, but SC14 noted the utility of collecting more information from the regions either side of this boundary to inform a greater understanding of possible changes in growth around this area. While the incorporation of area-variant growth within the assessment model would also help explore this issue, SC14 noted the difficulty of this task.
3) SC11 concluded that the stock status of WCPO BET from the Pan-Pacific assessment and the WCPO-only assessment were similar when the growth models were similar in the EPO and WCPO. This conclusion needs to be revisited in light of the different growth between EPO and WCPO by adopting the new growth.

6. STATUS OF THE STOCKS

Stock structure assumptions
The stock is considered to cover the western and central Pacific Ocean. All estimates of biomass in this table refer to spawning biomass (SB).

Stock Status	
Year of Most Recent Assessment	2018
Assessment Runs Presented	Median of the structural uncertainty grid and 80% PI
Reference Points	Candidate biomass-related target reference point (TRP) currently under consideration for key tuna stocks is 40–60% SB_0 Limit reference point of 20% SB_0 established by WCPFC equivalent to the HSS default of 20% SB_0 Hard Limit: Not established by WCPFC; but evaluated using HSS default of 10% SB_0 Overfishing threshold: F_{MSY}
Status in relation to Target	Recent levels of spawning biomass (either the 2012–15 average or the 2015 estimate) About as Likely as Not (40–60%) to be at or above the lower bound of the target range Likely (> 60%) that $F < F_{MSY}$
Status in relation to Limits	Soft Limit: Unlikely (< 40%) to be below Hard Limit: Very Unlikely (< 10%) to be below
Status in relation to Overfishing	Overfishing is Unlikely (< 40%) to be occurring

Historical Stock Status Trajectory and Current Status



Temporal trend for the base case model in stock status relative to $SB_{F=0}$ (x-axis) and F_{MSY} (y-axis). The red zone represents spawning biomass levels lower than the agreed LRP, which is marked with the solid black line (0.2 $SB_{F=0}$). The orange region is for fishing mortality greater than F_{MSY} ($F=F_{MSY}$; marked with the black dashed line). The colours depict the models in the grid with the 10°N and 20°N regional structures.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass has decreased consistently since the 1950s. Spawning biomass for the WCPO is estimated to have declined to about half

	of the initial levels by about 1970, and has continued to decline (SB_{2015}/SB_0 = 0.46).
Recent Trend in Fishing Intensity or Proxy	Fishing mortality has generally increased and has recently escalated to levels near F_{MSY} ($F_{2012-15}/F_{MSY}$ = 0.78).
Other Abundance Indices	-
Trends in Other Relevant Indicator or Variables	Recruitment in all analyses was estimated to have been high during the last two decades. This result is similar to that of previous assessments.

Projections and Prognosis	
Stock Projections or Prognosis	Stochastic projection results were dependent upon the recruitment assumption. Under the long-term recruitment deviate assumption, the stock was Unlikely (< 40%) to be below the LRP level and About as Likely as Not (40–60%) to be below the SB_{MSY} level by 2035; under the recent recruitment assumption, the stock was Very Unlikely (< 10%) to be below both the LRP and SB_{MSY} levels by 2032.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Under the long-term recruitment deviate assumption, the stock was Unlikely (< 40%) to be below the LRP in 2032; under the recent recruitment assumption, the stock was Very Unlikely (< 10%) to be below the LRP in 2032.
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Under both recruitment assumptions, it was About as Likely as Not (40–60%) that fishing mortality would be above the F_{MSY} level in 2030.

Assessment Methodology and Evaluation		
Assessment Type	Level 1 – Full Quantitative Stock Assessment	
Assessment Method	MULTIFAN-CL	
Assessment Dates	Latest assessment: 2018	Next assessment: 2020
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch and effort data - Size data - Growth data; and - Tagging data	1 – All High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	Changes to the data from the 2014 assessment included: - Updating all data up to the end of 2015 - Utilising standardised CPUE indices calculated from the recently collated operational longline CPUE dataset Investigating an alternative spatial structure with the boundaries between the tropical and northern temperate regions shifted from 20°N to 10°N - Investigating the use of a new growth curve based on the recently processed otoliths of Farley et al. (2018), which suggested a much lower asymptotic size for old fish - Implementation of new features developed in MFCL, including an annual stock recruitment relationship	
Major Sources of Uncertainty	- High levels of uncertainty regarding the recruitment estimates and the resulting estimates of steepness - Estimates of growth rates - Determination of regional model structure	

Qualifying Comments
-

Environmental and Ecosystem Considerations	
Observer coverage	Highly variable year to year (from 1.6 to 11.1%), but higher from 2008 onwards
Non-target fish and invertebrate catch	Blue shark, lancetfish and porbeagle shark are the most commonly non-target fish species caught by the longline fleet (by number), but are rarely retained. Other species, like Rays bream and moonfish are caught more rarely, but are highly retained. Fish bycatch is managed through New Zealand domestic legislation and, to a limited extent, through WCPFC Conservation and Management Measure CMM2010-07. No invertebrates are caught in this fishery.
Incidental catch of seabirds	Observed capture rates of seabirds were highly variable prior to 2008 due to low levels of observer coverage. This fishery contributes to the risk posed to Black petrel, Northern Buller's albatross and Gibson's albatross, among other species. Seabird bycatch mitigation measures are required in the New Zealand and Australian EEZs and through the WCPFC Conservation and Management Measure CMM2007-04.
Incidental catch of cetaceans	Between 2002 and 2018, observers recorded one unidentified cetacean, two common dolphin, and one long finned pilot whale capture in bigeye longline fisheries. All of these cetaceans were released alive.
Incidental catch of pinnipeds	Between 2002 and 2018, there were two observed captures of New Zealand fur seals in bigeye longline fisheries. Both were released alive.
Incidental catch of other protected species	Between 2002 and 2018 incidental captures of 17 sea turtles were observed, these were leatherback turtles (10), unidentified turtles (5), Green (1) and Loggerhead (1) turtles. The WCPFC is attempting to reduce sea turtle interactions through Conservation and Management Measure CMM2008-03.
Benthic interactions	There are no known benthic interactions for this fishery.

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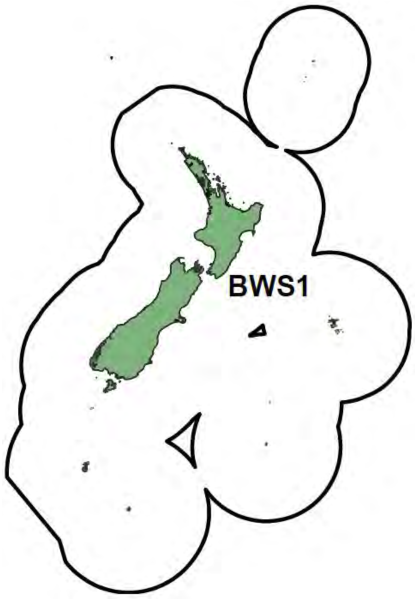
BLUE SHARK (BWS)

(*Prionace glauca*)



1. FISHERY SUMMARY

Blue shark was introduced into the QMS on 1 October 2004 under a single QMA, BWS 1, with allowances, TACC, and TAC in Table 1.

Table 1: Recreational and Customary non-commercial allowances, other mortalities, TACC and TAC (all in t) for blue shark.

Fishstock	Recreational allowance	Customary non-commercial allowance	Other mortality	TACC	TAC
BWS 1	20	10	190	1 860	2 080

Blue shark was added to the Third Schedule of the 1996 Fisheries Act with a TAC set under s14 because blue shark is a highly migratory species and it is not possible to estimate MSY for the part of the stock that is found within New Zealand fisheries waters.

Blue shark was also added to the Sixth Schedule of the 1996 Fisheries Act with the provision that:

'A commercial fisher may return any blue shark to the waters from which it was taken if –
(a) that blue shark is likely to survive on return; and
(b) the return takes place as soon as practicable after the blue shark is taken.'

The conditions of Schedule 6 releases have been amended for mako, porbeagle and blue shark. From 1 October 2014, fishers have been allowed to return these three species to the sea both alive and dead, although the status must be reported accurately. Those returned to the sea dead are counted against a fisher's ACE and the total allowable catch limit for that species.

Management of blue sharks throughout the western and central Pacific Ocean (WCPO) is the responsibility of the Western and Central Pacific Fisheries Commission (WCPFC). Under this regional convention New Zealand is responsible for ensuring that the management measures applied within New Zealand fisheries waters are compatible with those of the Commission.

1.1 Commercial fisheries

Most of the blue shark catch in the New Zealand EEZ is caught in the tuna surface-longline fishery. Relatively few blue sharks are caught by other methods. Data collected by Fisheries New Zealand Fishery Observer Services from the tuna longline fishery suggest that most of the blue shark catch has been processed (72% of the observed catch), although prior to 1 October 2014 usually only the fins were retained and the rest of the carcass was dumped (over 99% of the processed, observed catch). Greenweight (total weight) was obtained by applying species specific conversion factors to the weight of the fins landed. On 1 October 2014 a ban on shark finning was introduced; after this time any blue sharks for which the fins are retained are required to be landed with the fins attached (artificial attachment such as tying or securing the fins to the trunk is permitted). Figure 1 shows historical landings and fishing effort for BWS 1 and BWS ET.

Landings of blue sharks reported by fishers on CELRs, Catch CLRs, or TLCERs and by processors on LFRRs and MHRs are given in Table 2. Total weights reported by fishers were 551–1167 t per annum during 1997–98 to 2007–08. Processors (LFRRs) reported 525–1415 t per annum during 1997–98 to 2015–16. In addition to catches within New Zealand fisheries waters, small catches are taken by New Zealand vessels operating on the high seas (Figure 1).

Figure 1: [Top] Blue shark catch from 1989–90 to 2018–19 within New Zealand waters (BWS 1), and [bottom] 2002–03 to 2018–19 on the high seas (BWS ET).

In 2012–13, the majority of blue sharks (55%) were caught in the bigeye tuna fishery (Figure 2). Although there are no directed blue shark fisheries, blue sharks formed one of the three top catches by weight across all longline fisheries in 2017–18 (31%) (Figure 3). Longline fishing effort is distributed along the east coast of the North Island and the south-west coast of the South Island.

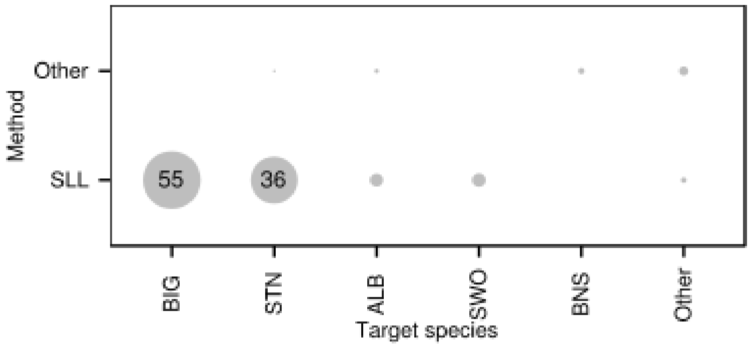


Figure 2: A summary of the proportion of landings of blue sharks taken by each target fishery and fishing method for 2012–13. The area of each circle is proportional to the percentage of landings taken using each combination of fishing method and target species. The number in the circle is the percentage. SLL = surface longline (Bentley et al. 2013).

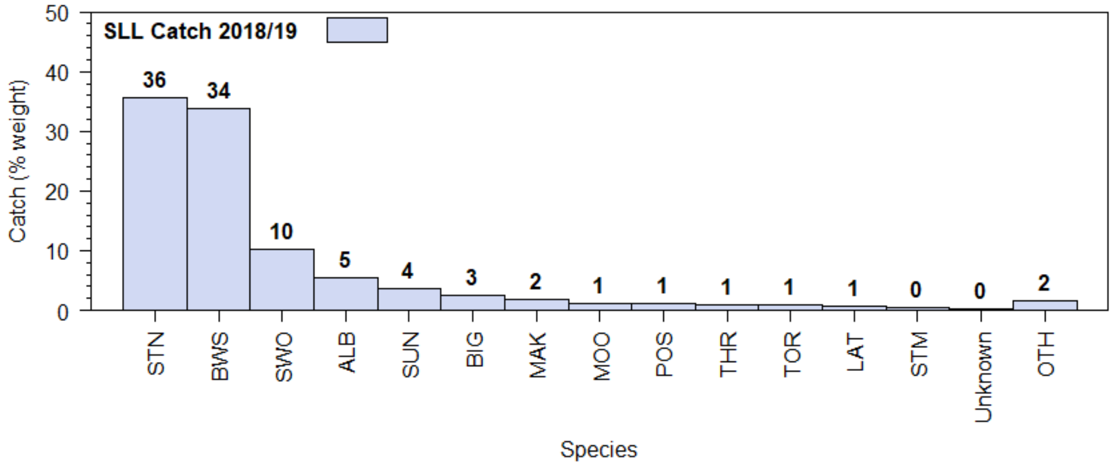


Figure 3: A summary of species composition of the surface-longline estimated catch for 2018–19. The percentage by weight of each species is calculated for all surface-longline trips.

Table 2: New Zealand estimated commercial landings of blue sharks (t) reported by fishers on CELRs, CLRs, or TLCERs and processors (LFRRs or MHRs) by fishing year. [Continued on next page]

Year	Total reported	LFRR/MHR
1989–90	12	5
1990–91	2	3
1991–92	18	13
1992–93	39	33
1993–94	371	118
1994–95	254	140
1995–96	152	166
1996–97	161	303
1997–98	551	537
1998–99	576	525
1999–00	641	1 031
2000–01	1 167	1 415
2001–02	1 076	1 105
2002–03*	968	914
2003–04*	649	649
2004–05*	734	734
2005–06*	656	656
2006–07*	790	794
2007–08*	681	687
2008–09*		804

Year	Total reported	LFRR/MHR
2009–10*		696
2010–11*		770
2011–12*		1 011
2012–13*		691
2013–14*		117
2014–15*		142
2015–16*		163
2016–17		116
2017–18		120
2018–19		86

[1] Note that there may be some misreporting of blue shark catches (Species code 'BWS') as bluenose (*Hyperoglyphe antarctica*; species code 'BNS') and vice versa. *MHR rather than LFRR data.

Table 3: Percentage of blue sharks (including discards) that were alive or dead when arriving at the longline vessel and observed during 2006–07 to 2014–15, by fishing year, fleet and region. Small sample sizes (number observed < 20) were omitted (Griggs & Baird 2013, Griggs et al. 2018).

Year	Fleet	Area	% alive	% dead	Number
2006–07	Australia	North	95.4	4.6	131
	Charter	North	89.8	10.2	2 155
		South	93.4	6.6	5 025
	Domestic	North	87.9	12.1	3 991
	Total		**90.8**	**9.2**	**11 302**
2007–08	Charter	South	89.2	10.8	2 560
	Domestic	North	88.6	11.4	5 599
	Total		**88.8**	**11.2**	**8 159**
2008–09	Charter	North	94.5	5.5	1 317
		South	95.1	4.9	4 313
	Domestic	North	92.0	8.0	3 935
		South	94.9	5.1	98
	Total		**93.7**	**6.3**	**9 663**
2009–10	Charter	South	95.6	4.4	2 004
	Domestic	North	85.7	14.3	2 853
		South	94.0	6.0	882
2010–11	Charter	North	100.0	0.0	25
		South	95.9	4.1	2 650
	Domestic	North	92.8	7.2	3 553
	Total		**94.1**	**5.9**	**6 228**
2011–12		South	93.0	7.0	5 394
	Domestic	North	93.5	6.5	5 672
		South	93.2	6.8	1 592
	Total		**93.2**	**6.8**	**12 668**
2012–13	Charter	North	96.1	3.9	256
		South	89.3	10.7	5 087
	Domestic	North	95.5	4.5	4 831
		South	95.6	4.4	180
	Total		**92.5**	**7.5**	**10 354**
2013–14	Charter	South	89.5	10.5	7 752
	Domestic	North	91.9	8.1	3 719
		South	93.8	6.2	2 146
	Total		**90.8**	**9.2**	**13 617**
2014–15	Charter	South	93.3	6.7	5 961
	Domestic	North	85.5	14.5	3 127
		South	92.2	7.8	922
	Total		**90.8**	**9.2**	**10 010**

Across all fleets in the longline fishery most of the blue sharks were alive when brought to the side of the vessel during 2006–07 to 2014–15 (Table 3). The percentage of blue shark catches retained has varied over time, becoming relatively low in 2014–15 (Table 4).

Table 4: Percentage of blue sharks that were retained, or discarded or lost, when observed on a longline vessel during 2006–07 to 2014–15, by fishing year and fleet. Small sample sizes (number observed < 20) omitted (Griggs & Baird 2013, Griggs et al. 2018).

Year	Fleet	% retained or finned	% discarded or lost	Number
2006–07	Australia	3.0	97.0	132
	Charter	85.1	14.9	8 272
	Domestic	33.2	66.8	3 994
	Total	67.5	32.5	12 398
2007–08	Charter	91.8	8.2	2 638
	Domestic	59.5	40.5	5 650
	Total	69.8	30.2	8 288
2008–09	Charter	87.5	12.5	5 723
	Domestic	54.0	46.0	4 049
	Total	73.6	26.4	9 772
2009–10	Charter	91.7	8.3	2 023
	Domestic	37.6	62.4	5 531
	Total	52.1	47.9	7 554
2010–11	Charter	89.0	11.0	2 675
	Domestic	43.0	57.0	3 736
	Total	62.2	37.8	6 411
2011–12	Charter	86.1	13.9	5 404
	Domestic	53.1	46.9	7 947
	Total	66.4	33.6	13 351
2012–13	Charter	76.8	23.2	5 344
	Domestic	12.7	87.3	5 233
	Total	45.1	54.9	10 577
2013–14	Charter	25.9	74.1	7 755
	Domestic	1.2	98.8	6 535
	Total	14.6	85.4	14 290
2014–15	Charter	0.4	99.6	6 218
	Domestic	0.1	99.9	4 163
	Total	0.3	99.7	10 381

Catches of blue sharks aboard tuna longline vessels have been concentrated off the west and south-west coasts of the South Island, and the north-east coast of the North Island (Figure 4). Most of the blue shark landings reported by fishers (TLCERs) are concentrated in FMAs 1, 2 and 7.

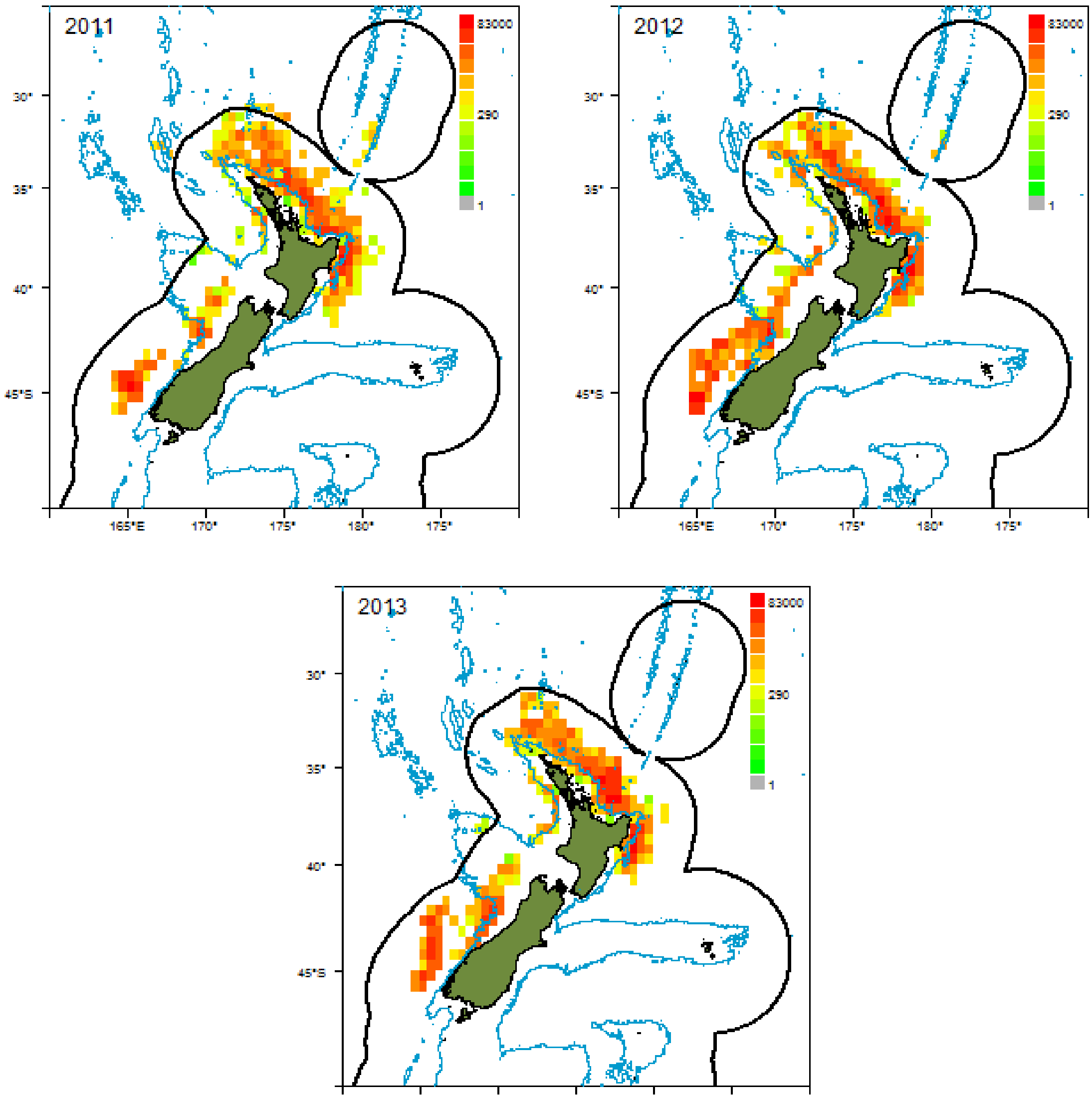


Figure 4: Blue shark catches (kg) by the surface-longline fishery in 0.5 degree rectangles by fishing year. Note the log scale used for the colour palette. Depth contour = 1000 m. Source: TLCER data (Francis et al. 2014).

1.2 Recreational fisheries

Blue sharks are caught in relatively large numbers by recreational fishers in the New Zealand EEZ. Although not as highly regarded as other large, pelagic sharks such as mako in northern New Zealand, blue sharks were the primary target gamefish in southern New Zealand in past years. Several hundred blue sharks were tagged and released each year by recreational fishers off Otago Heads in the late 1990s as part of the New Zealand Gamefish Tagging Programme. The total recreational catch is unknown but most are released. There were ten blue sharks weighed by New Zealand Sport Fishing Council clubs in 2017–18.

1.2.2 Estimates of recreational harvest

No estimates of recreational harvest of blue sharks were generated from the telephone-diary surveys conducted in 1994, 1996 and 2000 because so few were reported. A National Panel Survey was conducted for the first time throughout the 2011–12 fishing year. The panel survey used face-to-face interviews of a random sample of 30 390 New Zealand households to recruit a panel of fishers and non-fishers for a full year (from Wynne-Jones et al 2014). The panel members were contacted regularly about their fishing activities and harvest information collected in standardised phone interviews. The national panel survey was repeated during the 2017–18 fishing year using very similar methods to produce directly comparable results (Wynne-Jones et al 2019). Note that national panel survey estimates do not include recreational harvest taken under s111 general approvals. The National Panel Survey results do not include estimates for blue sharks as the surveys did not capture the fishers and fishing activity for the large gamefish species well.

1.3 Customary non-commercial fisheries

Prior to European settlement, Maori caught large numbers of cartilaginous fishes, including blue sharks. However, there are no estimates of current Maori customary catch.

1.4 Illegal catch

There is no known illegal catch of blue sharks.

1.5 Other sources of mortality

About 91% of all observed blue sharks caught in the tuna longline fishery are retrieved alive. Nearly 100% of all observed blue sharks are discarded. The proportion of sharks discarded dead is unknown. Mortality rates of blue sharks tagged and released by the New Zealand Gamefish Tagging Programme are also unknown.

2. BIOLOGY

Blue sharks (*Prionace glauca*) are large, highly migratory, pelagic carcharhinids found throughout the world’s oceans in all tropical and temperate waters from about 50° N to 50° S. They are slender in build, rarely exceeding 3 m in total length and 200 kg in weight. They feed opportunistically on a range of living and dead prey, including bony fishes, smaller sharks, squid and carrion (Horn et al. 2013).

In New Zealand waters, male blue sharks are sexually mature at about 190–195 cm fork length (FL) and females at about 170–190 cm FL. Gestation in female blue sharks lasts between 9–12 months and between 4–135 pups (averaging 26–56) are born alive, probably during the spring. Pups are probably born at about 50 cm FL. The few embryos from New Zealand fisheries waters examined to date consisted of mid-term pups 21–37 cm FL collected in July and a full-term pup 54 cm FL collected in February. Blue sharks 50–70 cm FL are caught year-round in New Zealand fisheries waters but only in small numbers, and mostly in FMAs 1 and 10.

Table 5: Estimates of biological parameters.

Fishstock	Estimate					Source
1. Natural mortality (M)						
BWS 1	0.19–0.21					Manning & Francis (2005)
2. Weight = a (length)[OBJ] (Weight in kg, length in cm fork length)						
	a	b				
BWS 1 males	1.578×10^{-6}	3.282				Ayers et al. (2004)
BWS 1 females	6.368×10^{-7}	3.485				
3. Von Bertalanffy model parameter estimates						
	k	t_0	L_∞			
BWS 1 males	0.0668	-1.7185	390.92			Manning & Francis (2005)
BWS 1 females	0.1106	-1.2427	282.76			
4. Schnute model (case 1) parameter estimates (are provided for comparison with the von Bertalanffy estimates above)						
	L_1	L_2	κ	γ	L_∞	
BWS 1 males	65.21	217.48	0.1650	0.1632	297.18	Manning & Francis (2005)
BWS 1 females	63.50	200.60	0.2297	0.0775	235.05	

Age and growth estimates are available for blue sharks in New Zealand waters (Manning and Francis 2005). These estimates were derived from counts of opaque growth zones in X-radiographs of sectioned vertebrae with the assumption that one opaque zone is formed per year. This assumption is untested. Female blue sharks appear to approach a lower mean asymptotic maximum length and grow at a faster rate than males. This is thought to result from the presence of relatively few large (over 250 cm FL), old female blue sharks in the length-at-age dataset analysed.

The Observer data suggest that large (over 250 cm FL) female blue sharks are missing from the catch, despite reliable personal observations to the contrary from commercial and recreational fishers. There is evidence of size and sex segregation in the distributions of blue sharks in the North Pacific, with large, pregnant females tending to be found nearer the equator than males or smaller females. It is possible that large female blue sharks occur in New Zealand but have not been adequately sampled by observers.

Growth rates estimated for New Zealand blue sharks are broadly comparable with those from overseas studies (Manning and Francis 2005). Males and females appear to grow at similar rates until about seven years of age, when their growth appears to diverge. Age-at-maturity is estimated at 8 years for males and 7–9 years for females. The maximum recorded ages of male and female blue sharks in New Zealand waters are 22 and 19 years, respectively. However, there is considerable uncertainty about the accuracy of blue shark age estimates, because a recent study recorded different vertebral readings between readers, and was unable to generate agreed ages (Francis and Ó Maolagáin 2016). Ageing validation is therefore required. Blue sharks appear to be fully recruited to the commercial longline fishery by the end of their second year. The commercial catch sampled by Observers consists of both immature and mature fish.

Estimates of biological parameters for blue sharks in New Zealand waters are given in Table 5.

3. STOCKS AND AREAS

The New Zealand Gamefish Tagging Programme has tagged and released 5048 blue sharks between 1979–80 and 2017–18 in the New Zealand EEZ. Most tagged sharks were captured and released off the east coast of the South Island. A total of 89 tagged sharks have been recaptured since the start of the tagging programme. The recapture data show dispersal of tagged sharks away from their release point, although the relationship between time at liberty and dispersal is unclear. While some tagged sharks have been recaptured with little apparent net movement away from their release point, others have been recaptured off Australia, New Caledonia, Vanuatu, Fiji, Tonga, Cook Islands and French Polynesia (Figure 5). The longest displacement distance for any fish recaptured in the New Zealand Gamefish Tagging Programme (4600 nautical miles) was from a blue shark recaptured off Chile. A Chilean-tagged blue shark was recaptured by a New Zealand fisher in 2017, indicating two-way movements across the South Pacific.

Although the data are relatively sparse, an overview of tagging data from Australia, New Zealand, the Central Pacific and California suggests that population exchange exists between not only the eastern and western South Pacific, but also between the South Pacific, south Indian, and even South Atlantic oceans. This suggests that blue sharks in the South Pacific constitute a single biological stock, although whether this is part of a single larger Southern Hemisphere stock is unclear. A recent genetic study using specimens from the Pacific and Atlantic oceans (including some from New Zealand) and multiple markers (mtDNA and nine microsatellites) found nearly complete genetic homogeneity across the entire studied range, indicating widespread mixing of blue sharks, and the need to use higher resolution genetic markers (e.g. whole genomes) in order to identify any meaningful stock boundaries (Bailleul et al. 2018).

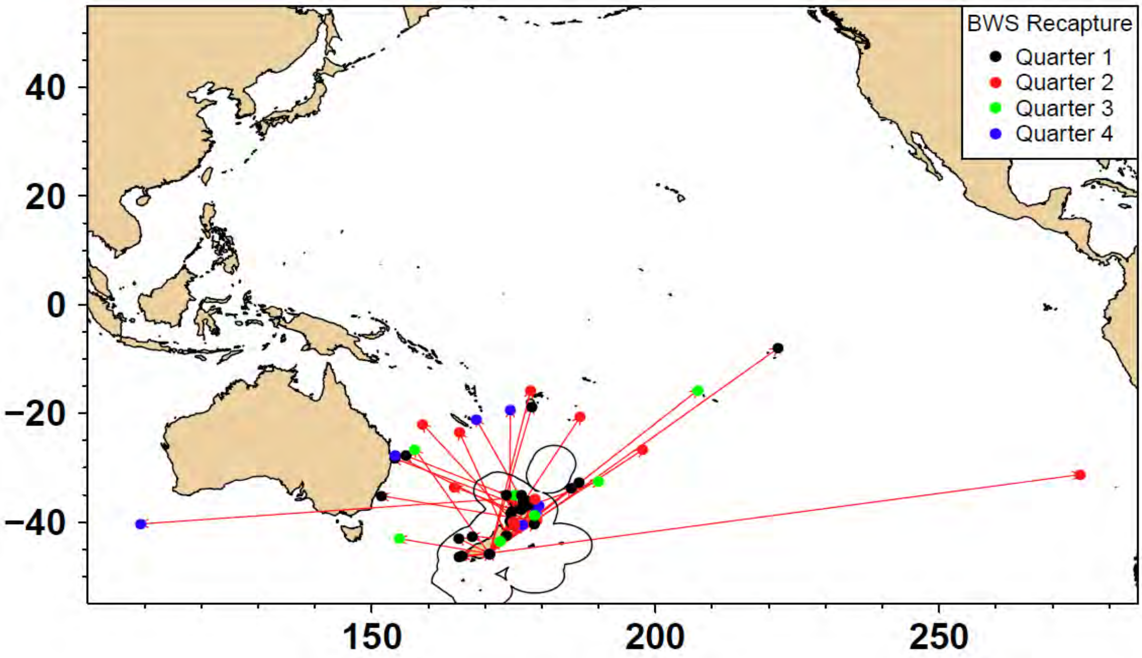


Figure 5: All release and recapture locations of blue sharks in the gamefish tagging programme, 1982–2016.

No other data are available on blue shark stock structure in the South Pacific.

4. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS

Most of the blue shark catch in the New Zealand EEZ is caught in the tuna and swordfish surface-longline fishery, please refer to those species for environmental and ecosystem considerations.

5. STOCK ASSESSMENT

With the establishment of the WCPFC in 2004, future stock assessments of the western and central Pacific Ocean stock of blue sharks will be reviewed by the WCPFC.

A new stock assessment for South Pacific blue shark was conducted in 2016. SC12 noted that the 2016 South Pacific blue shark assessment is preliminary and is considered to be a work in progress. As a result, it cannot be used to determine stock status and form the basis of management advice.

SC12 noted that there are a number of data uncertainties within the South Pacific blue shark assessment, especially with regard to historical and contemporary longline catch and CPUE estimates. The data-poor nature of the South Pacific blue shark assessment indicates that an improvement in the amount and quality of available biological and fishery information will be required in order to develop a useful integrated stock assessment model.

Quantitative stock assessments of blue sharks outside the New Zealand EEZ have been mostly limited to standardised CPUE analyses, although quantitative assessment models have been developed using conventional age-structured and MULTIFAN-CL methods. An indicator analysis of blue sharks in New Zealand waters was conducted in 2014.

Results of these indicator analyses (Figures 6 and 7) suggest that blue shark populations in the New Zealand EEZ have not been declining under recent fishing pressure, and may have been increasing since 2005 (Table 6, Francis et al. 2014). These changes are presumably in response to a decline in SLL fishing effort since 2003 (Figure 1), and a decline in annual landings since a peak in 2001 for blue sharks. Observer data from 1995 suggest that blue sharks may have undergone a down-then-up trajectory. The quality of observer data and model fits means these interpretations are uncertain. The stock status of blue sharks may be recovering. Conclusive determination of stock status will require a regional (i.e., South Pacific) stock assessment.

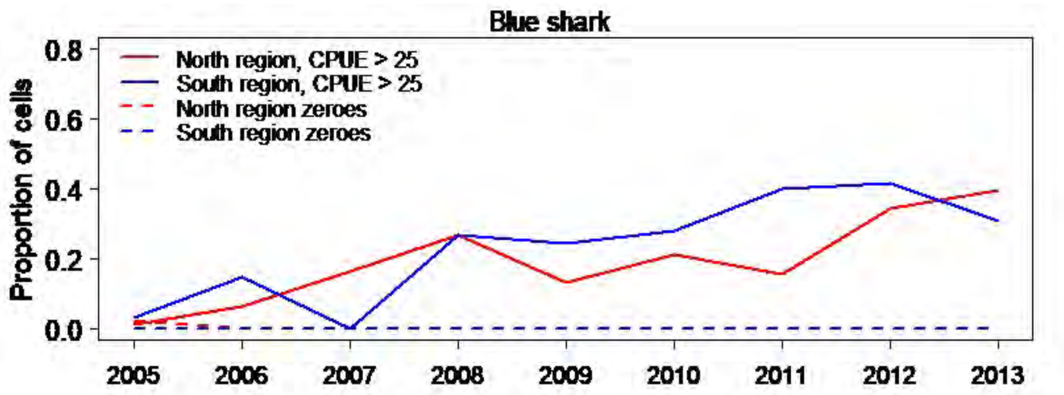


Figure 6: Blue shark distribution indicators. Proportions of 0.5 degree rectangles having CPUE greater than 25 per 1000 hooks, and proportions of rectangles having zero catches, for North and South regions by fishing year, based on estimated catches (processed and discarded combined) reported on TLCERs. North region comprises Fisheries Management Areas (FMAs) 1, 2, 8 and 9, and South region comprises FMAs 5 and 7.

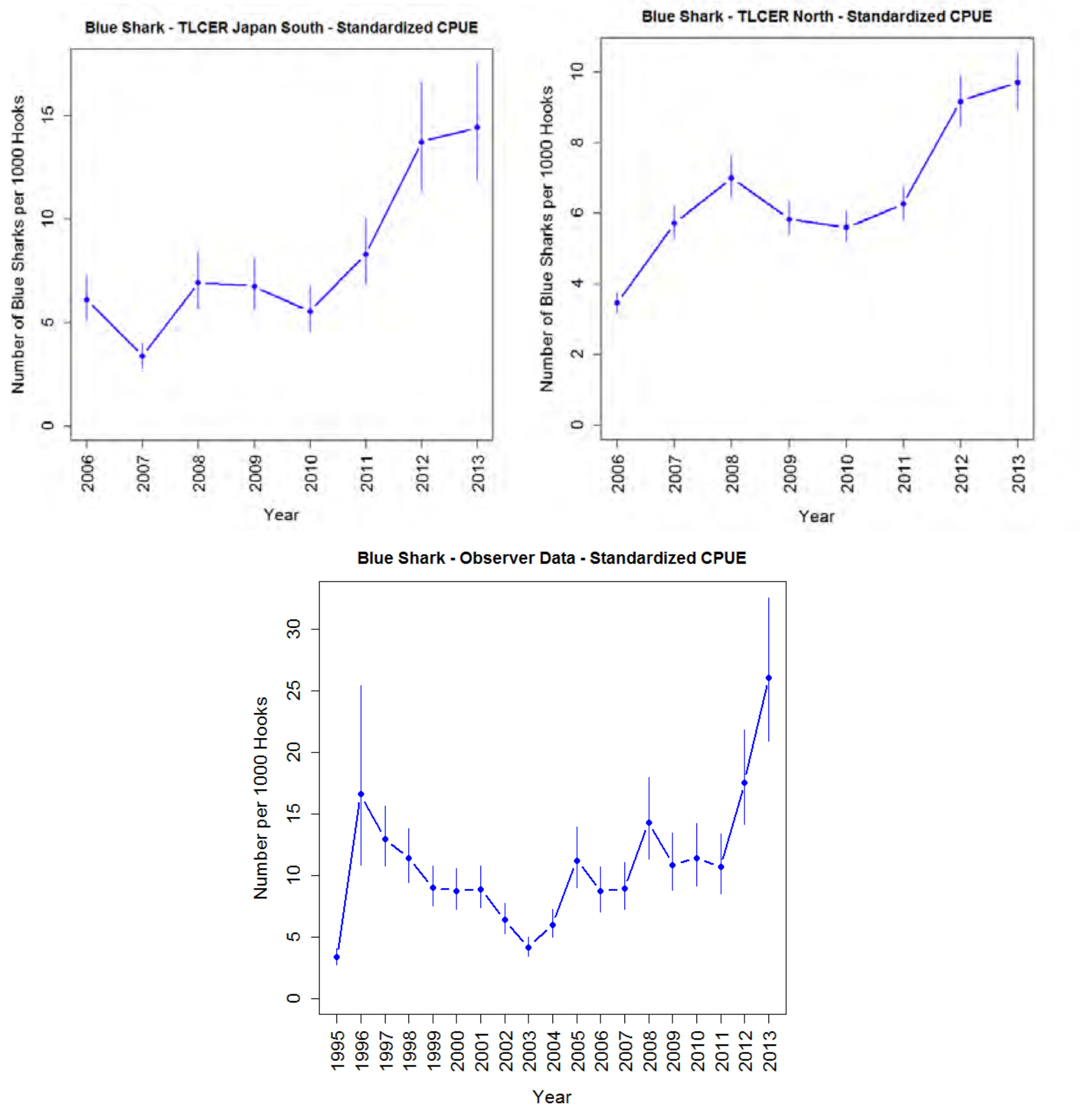


Figure 7: Standardised CPUE indices for commercial TLCER (Japan South and North) and observer datasets (all New Zealand).

Table 6: Summary of trends identified in abundance indicators since the 2005 fishing year based on both TLCER and observer data sets. The CPUE-Obs indicator was calculated for both North and South regions combined. North region comprises Fisheries Management Areas (FMAs) 1, 2, 8 and 9, and South region comprises FMAs 5 and 7. For the CPUE-TLCER indicator in South region, only the Japan dataset indicator is shown (the TLCER Domestic South dataset was small and probably unrepresentative). Green cells show indicators that suggest positive trends in stock size. Note that a downward trend in 'proportion-zeroes' is considered a positive stock trend. NA = indicator not applicable because of small sample size (Francis et al. 2014).

		North region			South region		
Indicator class	Indicator	Blue	Porbeagle	Mako	Blue	Porbeagle	Mako
Distribution	High-CPUE	Up	Up	Up	Up	Up	NA
Distribution	Proportion-zeroes	Nil	Down	Down	Nil	Nil	Down
Catch composition	GM index total catch - TLCER	Up (all species)			Up (all species)		
Catch composition	GM index total catch - Obs	Up (all species)			Nil (all species)		
Catch composition	GM index HMS shark catch - TLCER	Up (all species)			Up (all species)		
Catch composition	GM index HMS shark catch - Obs	Up (all species)			Nil (all species)		
Standardised CPUE	CPUE - TLCER	Up	Nil	Up	Up	Nil	Nil
Standardised CPUE	CPUE - Obs	Up	Nil	Nil	Up	Nil	Nil
Sex ratio	Proportion males	Nil	Nil	Nil	Nil	Nil	NA
Size composition	Median length - Males	Nil	Nil	Nil	Nil	Nil	NA
Size composition	Median length - Females	Nil	Nil	Nil	Nil	Nil	NA

Blue sharks are the most heavily fished of the three large pelagic shark species (blue, mako and porbeagle sharks) commonly caught in the tuna longline fishery. Compared to mako and porbeagle sharks, however, blue sharks are relatively fecund, fast growing, and widely distributed.

Observed length frequency distributions of blue sharks by area and sex are shown in Figure 8 for fish measured in 1993–2012. Length frequency distributions of blue sharks showed differences in size composition between North and South areas (Figure 8). There were more female blue sharks caught than males, with a higher proportion of females in the South than the North. Based on the length-frequency distributions and approximate mean lengths at maturity of 192.5 cm fork length for males and 180 cm for females (Francis & Duffy 2005), most blue sharks were immature (91.1% of males and 92.9% of females, overall). Greater proportions of mature male blue sharks were found in the North (12.1% mature in the North and 1.1% in the south), while more similar proportions of mature females were found in the North and South (4.5% and 8.4%, respectively).

A data-informed qualitative risk assessment was completed on all chondrichthyans (sharks, skates, rays and chimaeras) at the New Zealand scale in 2017 (Ford et al. 2018). Blue sharks had a risk score of 12 and were ranked lowest risk of the 11 QMS chondrichthyan species. Data were described as 'exist and sound' for the purposes of the assessment and consensus over this risk score was achieved by the expert panel.

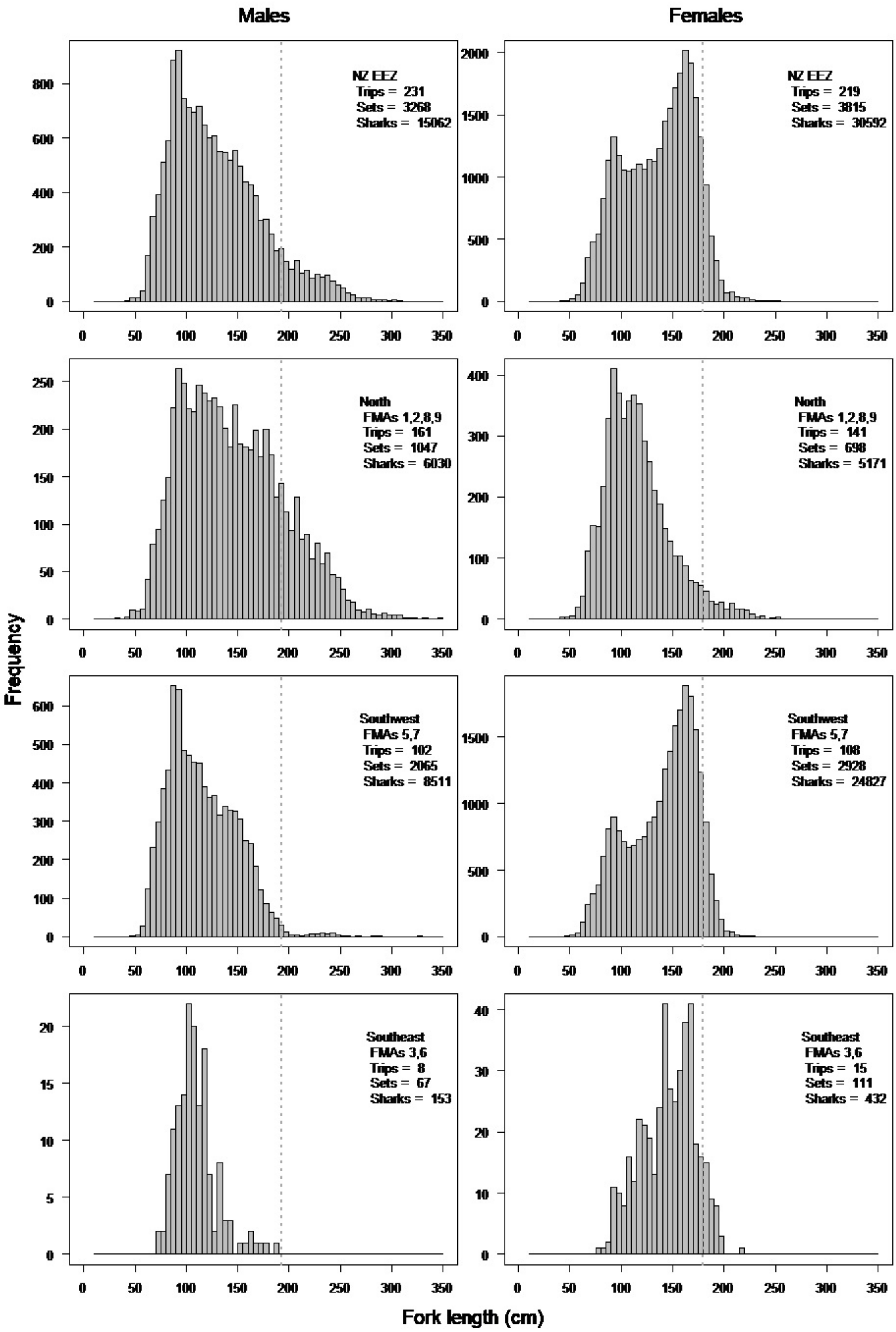


Figure 8: Length-frequency distributions of male and female blue sharks measured by observers aboard surface-longline vessels between 1993 and 2012 for the New Zealand EEZ, and North, Southwest and Southeast regions. The dashed vertical lines indicate the median length at maturity (Francis 2013).

6. STATUS OF THE STOCK

Stock structure assumptions

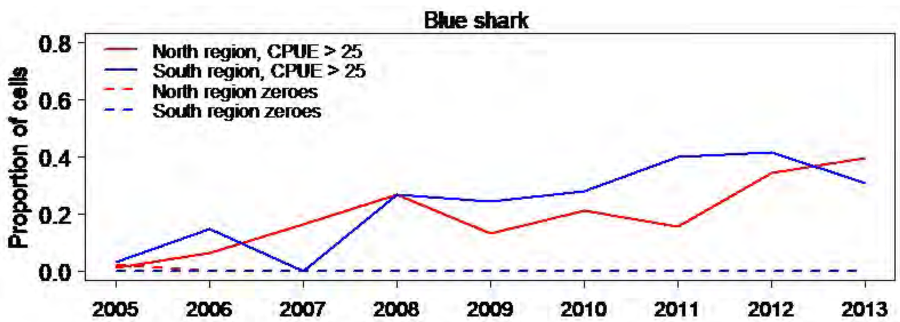
BWS 1 is assumed to be part of the wider south-western Pacific Ocean stock. However, there is no stock assessment for this wider stock. The results below are from indicator analyses of the New Zealand component of that stock only.

Stock Status	
Year of Most Recent Assessment	2014
Assessment Runs Presented	Indicator analyses only for NZ EEZ
Reference Points	Target: Not established Soft Limit: Not established but HSS default of 20% SB_0 assumed Hard Limit: Not established but HSS default of 10% SB_0 assumed Overfishing threshold: F_{MSY}
Status in relation to Target	Unknown
Status in relation to Limits	Unknown
Status in relation to Overfishing	Unknown

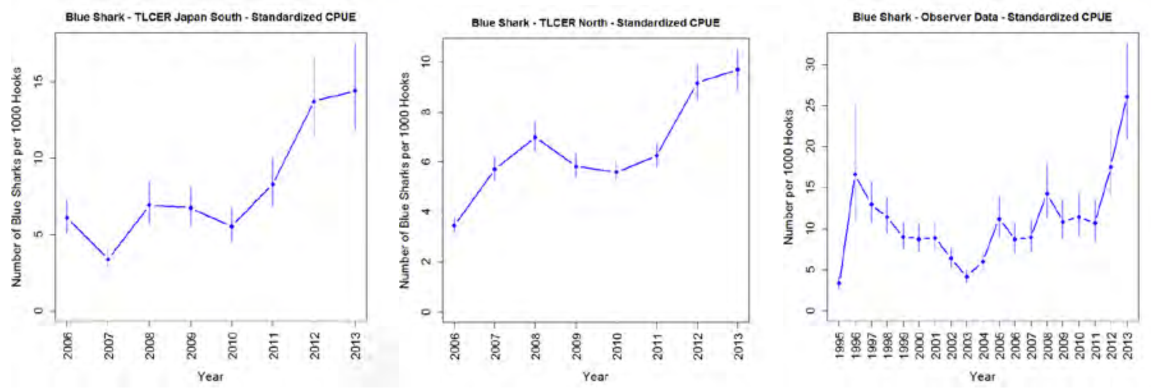
Historical Stock Status Trajectory and Current Status

Summary of trends identified in abundance indicators since the 2005 fishing year based on both TLCER and observer data sets. North region comprises Fisheries Management Areas (FMAs) 1, 2, 8 and 9, and South region comprises FMAs 5 and 7.

		North region			South region		
Indicator class	Indicator	Blue	Porbeagle	Mako	Blue	Porbeagle	Mako
Distribution	High-CPUE	Up	Up	Up	Up	Up	NA
Distribution	Proportion-zeroes	Nil	Down	Down	Nil	Nil	Down
Catch composition	GM index total catch - TLCER	Up (all species)			Up (all species)		
Catch composition	GM index total catch - Obs	Up (all species)			Nil (all species)		
Catch composition	GM index HMS shark catch - TLCER	Up (all species)			Up (all species)		
Catch composition	GM index HMS shark catch - Obs	Up (all species)			Nil (all species)		
Standardised CPUE	CPUE - TLCER	Up	Nil	Up	Up	Nil	Nil
Standardised CPUE	CPUE - Obs	Up	Nil	Nil	Up	Nil	Nil
Sex ratio	Proportion males	Nil	Nil	Nil	Nil	Nil	NA
Size composition	Median length - Males	Nil	Nil	Nil	Nil	Nil	NA
Size composition	Median length - Females	Nil	Nil	Nil	Nil	Nil	NA



Blue shark distribution indicators. Proportions of 0.5 degree rectangles having CPUE greater than 25 per 1000 hooks, and proportions of rectangles having zero catches, for North and South regions by fishing year, based on estimated catches (processed and discarded combined) reported on TLCERs. North region comprises Fisheries Management Areas (FMAs) 1, 2, 8 and 9, and South region comprises FMAs 5 and 7.



Standardised CPUE indices for comercial TLCER (Japan South and North) and observer datasets (all New Zealand).

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Appears to be increasing
Recent Trend in Fishing Intensity or Proxy	Appears to be decreasing
Other Abundance Indices	-
Trends in Other Relevant Indicator or Variables	Catches in New Zealand increased from the early 1990s to a peak in the early 2000s but declined slightly in the mid-2000s and have remained relatively stable since that time.

Projections and Prognosis		
Stock Projections or Prognosis	The stock is likely to increase if effort remains at current levels	
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unknown Hard Limit: Unknown	
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unknown	
Assessment Methodology and Evaluation		
Assessment Type	Level 2 – Partial Quantitative Stock Assessment: Standardised CPUE indices and other fishery indicators	
Assessment Method	Indicator analyses	
Assessment Dates	Latest assessment: 2014	Next assessment: Unknown
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	– Distribution – Species composition – Size and sex ratio – Catch per unit effort	1 – High quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	Historical catch recording may not be accurate.	

Qualifying Comments
-

Environmental and Ecosystem Considerations
Blue shark is a non-target catch in the tuna and swordfish surface-longline fishery in the New Zealand EEZ; please refer to those species for environmental and ecosystem considerations. Blue sharks are the most commonly landed non-target species (by number), followed by lancetfish and Ray's bream in this fishery.

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DREDGE OYSTER (OYU 5) – Foveaux Strait

(*Ostrea chilensis*)

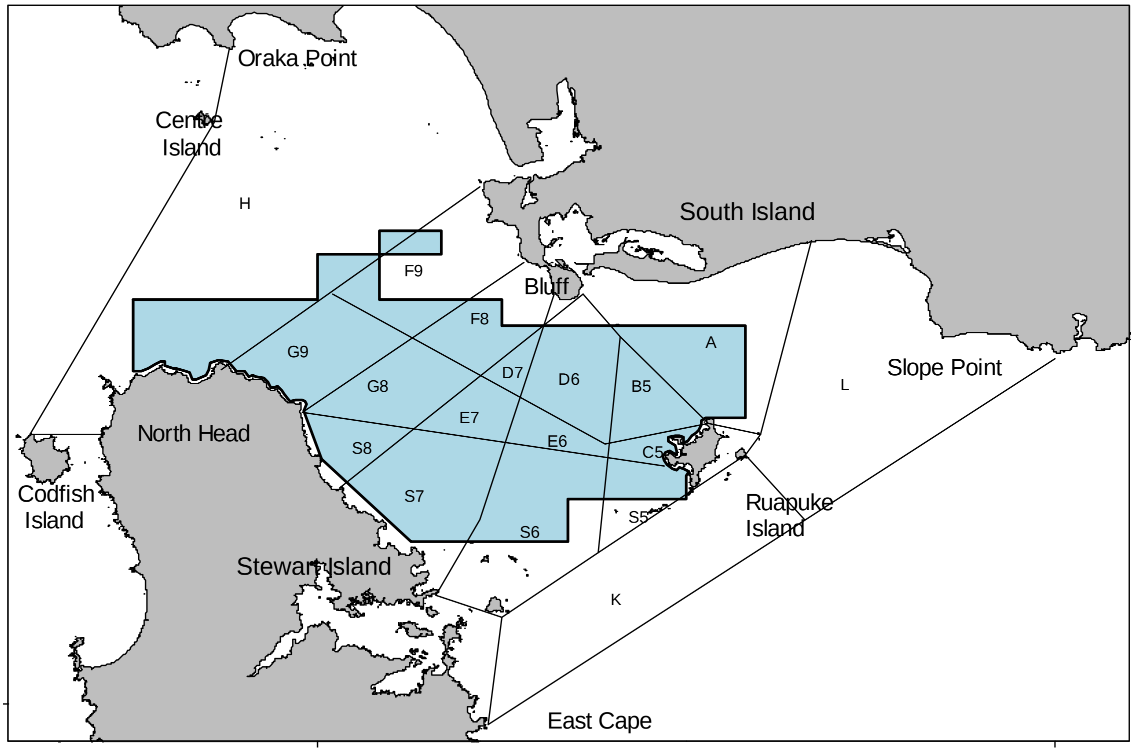

Figure 1: Foveaux Strait (OYU 5) stock boundary and oyster fishery statistical reporting areas, and the outer boundary of the 2007–2017 stock assessment survey area (blue shade) encompassing almost all the commercial fishery.

1. FISHERY SUMMARY

The Foveaux Strait oyster fishery OYU 5 was introduced into the Quota Management System in 1998, with a TAC of 20 300 000 oysters (Table 1).

Table 1: Total Allowable Catch (TAC) in numbers of oysters, allowances for customary and recreational fishing and Total Allowable Commercial Catch (TACC) for OYU 5 since the stock's introduction into the QMS in 1998. There is no allocation of other fishing mortality (–).

Year	TAC	Customary	Recreational	Other mortality	TACC
1998–present	20 300 000	144 000	430 000	–	14 950 000

1.1 Commercial fishery

The Foveaux Strait dredge oyster fishery has been fished for over 140 years. From the late 1880s to 1962 the fishery was managed by limiting the number of vessels licensed to fish. During this period vessel numbers varied between 5 and 12. The fishery was de-licensed in 1962 and boat numbers increased to 30 by 1969. Boundaries of statistical areas for recording catch and effort were established in 1960 and the outer boundary of the licensed oyster fishery was established in 1979. The western fishery boundary in Foveaux Strait is a line from Oraka Point to Centre Island to Black Rock Point (Codfish Island) to North Head (Stewart Island). The eastern boundary is from Slope Point, south to East Cape (Stewart Island). The OYU 5 stock boundaries and statistical reporting areas are shown in Figure 1.

Catch limits were introduced in 1963. In 1970, vessel numbers were limited to 23 by regulation. The catch limits were evenly divided between the 23 vessels. Before 1992, landings and catch limits in this fishery were recorded in sacks. Sacks contained an average of 774 oysters and weighed about 79 kg. Catch and effort has been traditionally recorded in sacks per hour dredged. Total landings of oysters between the 1880s and 1962 ranged between 15 and 77 million oysters. Reported landings for the period 1907–62 are shown in Table 2. Catch limits and total landings for 1963–92 are shown in Table 3.

Table 2: Reported landings of Foveaux Strait oysters 1907–62 (millions of oysters; sacks converted to numbers using a conversion rate of 774 oysters per sack). (Data summarised by Dunn (2005) from Marine Department Annual Reports.)

Year	Catch	Year	Catch	Year	Catch	Year	Catch	Year	Catch
1907	18.83	1919	16.56	1931	28.28	1943	56.59	1955	60.84
1908	17.34	1920	20.67	1932	29.01	1944	49.50	1956	58.63
1909	19.19	1921	19.01	1933	32.64	1945	58.85	1957	60.14
1910	18.20	1922	21.11	1934	40.44	1946	69.16	1958	64.44
1911	18.90	1923	22.28	1935	38.48	1947	63.09	1959	77.00
1912	19.00	1924	18.42	1936	49.08	1948	73.10	1960	96.85
1913	26.26	1925	20.01	1937	51.38	1949	75.34	1961	84.30
1914	19.15	1926	21.54	1938	52.05	1950	58.09	1962	53.42
1915	25.42	1927	16.26	1939	58.16	1951	70.15		
1916	22.61	1928	30.03	1940	51.08	1952	72.51		
1917	17.20	1929	30.44	1941	57.86	1953	55.44		
1918	19.36	1930	33.11	1942	56.87	1954	51.29		

Table 3: Reported landings and catch limits for the Foveaux Strait dredge oyster fishery from 1963–92 (millions of oysters; sacks converted to numbers using a conversion rate of 774 oysters per sack). Catch rate shown in sacks per hour. (Data summarised by Dunn (2005) from Marine Department Annual Reports.)

Year	Reported landings	Catch limit	Catch rate	Year	Reported landings	Catch limit	Catch rate
1963	58	132	6.0	1978	96[2]	89	17.1
1964	73	132	6.8	1979	88	89	16.6
1965	95	132	7.9	1980	88	89	15.2
1966	124	132	10.6	1981	89	89	13.4
1967	127	132	9.3	1982	88	89	13.2
1968	114	121	7.7	1983	89	89	12.3
1969	51	94	6.5	1984	89	89	13.8
1970	88	89	7.3	1985	82	89	12.1
1971	89	85	6.9	1986	60[3]	89	10.5
1972	77	85	6.7	1987	48[4]	50	10.9
1973	97[1]	85	10.0	1988	68	71	10.0
1974	92[1]	85	11.5	1989	66	89	10.7
1975	89	89	11.9	1990	36	36	6.4
1976	89	89	13.4	1991	42[5]	36	5.8
1977	92[2]	89	15.9	1992	5[6]	14	3.4

[1] Landings include catch given as incentive to explore 'un-fished' areas.
[2] Landings include catch given as an incentive to fish Area A.
[3] Season closed early after diagnosis of *B. exitiosa* infection confirmed.
[4] Catch limit reduced by the proportion of the fishery area with oysters infected by *B. exitiosa* and closed.
[5] Landings include catch given as an incentive to fish a 'firebreak' to stop the spread of *B. exitiosa*.
[6] Fishing only permitted in outer areas of fishery.

In 1986, the haplosporid disease *Bonamia exitiosa* (Bonamia) was identified as the cause of high mortality in the oyster population and the epizootic reduced oyster density, as well as the size and number of commercially fished areas over the next six years (see Cranfield et al. 2005, Doonan et al. 1994). Over that period, management of the fishery used changes to catch limits (Table 3) and spatial fishing strategies to minimise the effects of disease mortality and the spread of infection. In 1993 the oyster fishery was closed to allow the population to recover. The fishery was reopened in 1996 with a catch limit of 14.95 million oysters. This catch limit was converted to a catch quota of 1475 t using a conversion factor of 801 oysters per 79 kg sack, based on Bluff Oyster Enhancement Company data. From 1996, catches were recorded as numbers of oysters. Catch limits and total landings for 1996 to the present are shown in Table 4. Another *B. exitiosa* epizootic confirmed in March 2000 caused a decline in the oyster population and further reduced landings from 2003 (Table 4). Between 2003 and 2008, the Bluff Oyster Management Company (BOMC) shelved half of the TACC, harvesting about 7.5 million oysters annually. In 2011, the population size was continuing to increase and BOMC began to slowly reduce the level of shelving.

Table 4: Reported landings and catch limits for the Foveaux Strait dredge oyster fishery from 1996 to present. TACC was 14.95 million oysters over this period. Landings and catch limits reported in numbers (millions) of oysters. Reported catch rate based on number of sacks landed in CELR data, and revised catch rate based on numbers of oysters landed and converted to sacks (774 oysters per sack). Catch rate does not include oysters taken by crew as recreational catch. The numbers of oysters per sack can vary considerably (720–800 per sack, industry data) depending on the fishery areas from which they were caught, the sizes of oysters in these areas, and, and epifauna attached. Some oysters are landed in bins, and bins converted to sacks using a conversion factor of 0.5. Since 2009, fishers have been paid to high-grade the catch and they fish in areas where oyster meat quality is high, but catch rates are lower than for other areas with higher oyster densities, but with lower meat quality. CPUE from 2009 underestimates relative abundance.

Year	Reported landings	Catch limit including voluntary catch limits from 2003	Reported catch rate	Revised catch rate
1996	13.41	14.95	5.9	5.8
1997	14.82	14.95	7 0	7.0
1998	14.85	14.95	8.3	6.7
1999	14.94	14.95	7.5	6.8
2000	14.43	14.95	7.2	6.4
2001	15.11	14.95	7.0	6.8
2002	14.45	14.95	3.2	3.3
2003	7.46	7.475[1]	2.3	2.6
2004	7.48	7.475[1]	2.2	2.5
2005	7.57	7.475[1]	1.7	1.8
2006	7.44	7.475[1]	1.9	1.9
2007	7.37	7.475[1]	2.2	2.4
2008	7.49	7.475[1]	3.3[2]	3.3
2009	8.22	8.22[3]	3.9[2, 4]	3.0
2010	9.54	9.53	4.2[2, 4]	4.2
2011	10.6[5]	10.6[5]	4.2[2, 4]	4.1
2012	11.6	11.6	4.2[2, 4]	4.1
2013	13.2	13.2	5.5[2, 4]	5.5
2014	13.2	13.2	4.2[2, 4]	3.9[6]
2015	10.0	10.0	3.5[2, 4]	3.1[6]
2016	10.0	10.0	3.9[2, 4]	-
2017	10.0	10.0	3.0[2, 4]	2.9
2018	9.9	10.0	2.3	2.4

[1] 50% of the TACC was shelved for the season.
[2] Fishers given incentive to sort above MSL to increase market value, and changes in sorting potentially result in lower catch rates compared to previous years.
[3] BOMC unshelved 10% of their shelved quota.
[4] Catch reported in bins and sacks, bins converted to sacks by a conversion factor of 0.5.
[5] Landings data for 2011 includes 1.0 million oysters caught under a special permit for the Rugby World Cup.
[6] Fewer oysters per bin because of increases in high-grading of the catch.

The Bluff Oyster Enhancement Company Ltd (BOEC) was established in 1992 to facilitate an oyster enhancement programme in attempts to rebuild the OYU 5 stock back to its pre-1985 level. In 1997, BOEC was renamed the Bluff Oyster Management Company Limited (BOMC), which became a commercial stakeholder organisation (CSO) to represent the combined interests of owners of individual transferable quota (ITQ) shares in the Bluff Oyster fishery (OYU 5). In April 1997, individual quotas were granted, and quota holders were permitted to fish their entire quota on one vessel. The quota shares were evenly allocated based on the 23 vessel licences. Soon after, the numbers of vessels in the fleet declined from 23 to 11. At the same time, the Crown purchased 20% of the available quota from quota holders by tender from willing sellers and transferred it to the Waitangi Fisheries Commission.

The commercial fishing year for the oyster fishery is from 1 October to 30 September however, oysters have been traditionally harvested over a six-month season, 1 March to 31 August. Commercial and recreational fishery data is reported by calendar year and customary fishing by fishing year (1 October to 30 September) as customary permits are issued out of season. The landings of oysters from OYU 5 (millions of oysters) from 1995–96 to present are shown in Figure 2.

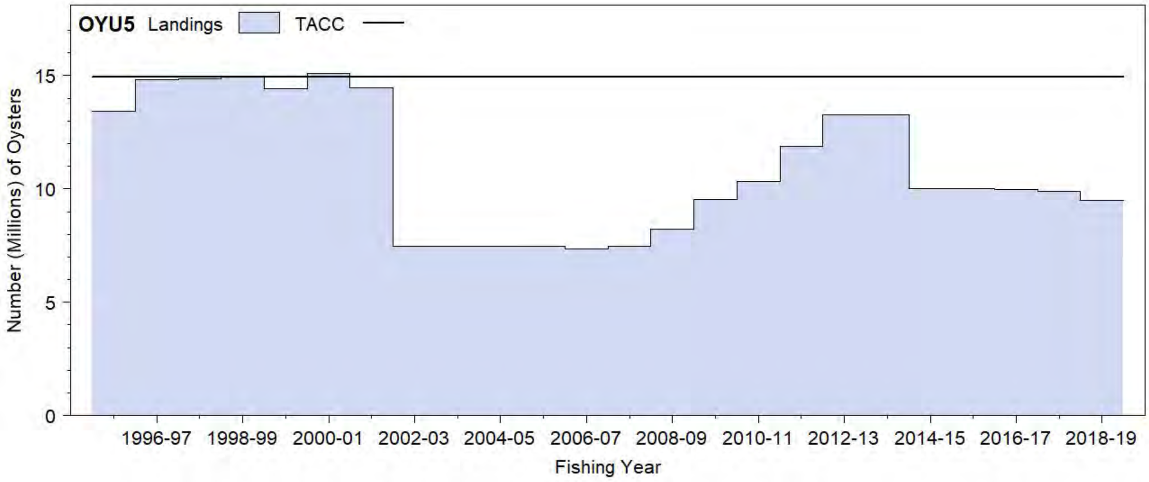

Figure 2: Landings and TACC for oysters from OYU 5 (millions of oysters) from 1995–96 to present.

1.2 Recreational fisheries

Recreational fishers may take 50 oysters per day during the open season (March–August). In 2002, Fisheries Officers estimated that between 70 and 100 recreational vessels were fishing from Bluff and smaller numbers from Riverton and Colac Bay. A charter boat fleet (approximately 17 vessels) based at Stewart Island, Bluff and Riverton also targets oysters during the oyster season.

The harvest estimates provided by telephone-diary surveys between 1992 and 2001 are no longer considered reliable for various reasons. A Recreational Technical Working Group concluded that these harvest estimates should be used only with the following qualifications: a) they may be very inaccurate; b) the 1996 and earlier surveys contain a methodological error; and c) the 2000 and 2001 estimates are implausibly high for many important fisheries. In response to these problems and the cost and scale challenges associated with onsite methods, a National Panel Survey was conducted for the first time throughout the 2011–12 fishing year (Table 5). The panel survey used face-to-face interviews of a random sample of 30 390 New Zealand households to recruit a panel of fishers and non-fishers for a full year. The panel members were contacted regularly about their fishing activities and harvest information collected in standardised phone interviews. The panel survey was repeated in 2017–18 using directly comparable methods (Wynne-Jones et al. 2019).

Table 5: Estimated numbers of oysters (all species combined) harvested by recreational fishers in OYU 5, excluding s111 approvals. Estimates from telephone-diary survey in 1991–92, 1996, 1999–00 and 2000–01, and from the National Panel Surveys in 2011–12 and 2017–18.

Survey	Numbers	CV	Reference
1991–92	16 000	0.60	Teirney et al. (1997)
1996	106 000	–	Bradford (1998)
1999–00	38 000	1.02	Boyd & Reilly (2002)
2000–01	129 000	1.15	Boyd et al. (2004)
2011–12	16 023	0.48	Wynne-Jones et al. (2014)
2017–18	50 569	0.39	Wynne-Jones et al. (2019)

Recreational catch taken on commercial vessels is shown in Table 6. The commercial oyster fleet are a major contributor to the level of recreational harvest. Commercial fishers are entitled to 50 oysters each day (subject to approval under s111 of the Fisheries Act 1996), with each commercial vessel's crew potentially taking up to 400 oysters as recreational catch each day. Recreational catches from commercial vessels have, in the past, been reported on catch and effort returns (CELRs); and since 2002, have been separately reported on returns and not included in commercial catch effort statistics.

Table 6: Reported annual recreational catch (numbers of oysters) taken from commercial vessels March to September 2002–19 (CELR data).

Year	Recreational catch from commercial vessels
2002	236 103
2003	282 345
2004	69 706
2005	111 748
2006	31 090
2007	90 544
2008	141 592
2009	182 331
2010	194 306
2011	179 587
2012	219 068
2013	257 140
2014	224 400
2015	186 018
2016	188 667
2017	216 447
2018	238 157
2019	956 640

1.3 Customary non-commercial fisheries

Reporting of Maori customary harvest is specified in the Fisheries (South Island Customary Fisheries) Regulations 1999. Ngai Tahu administers the reporting of customary catch of Foveaux Strait oysters to Fisheries New Zealand. Customary catch is reported in the quarter it is summarised, landing dates are not reported for catches under customary permits. A small amount of customary fishing is believed to take place between 31 August and 30 September, and no customary permits are supposed to be issued for the quarter 1 October to 31 December while oysters are spawning. Reported customary catch for 2000–01 to 2017–18 is given in Table 7.

Table 7: Fisheries New Zealand records of customary harvest of oysters (reported in numbers), 2000–01 to 2017–18. – no data. [Continued on next page]

Fishing year	Approved	Harvested
2000–01	75 792	72 996
2001–02	215 343	208 095
2002–03	1 800	1 560
2003–04	–	–
2004–05	–	–
2005–06	77 560	75 592
2006–07	65 400	65 400
2007–08	192 852	189 572
2008–09	354 982	347 390
2009–10	126 120	112 438
2010–11	336 264	326 526
2011–12	170 752	170 752

Fishing year	Approved	Harvested
2012–13	224 350	223 720
2013–14	163 454	162 988
2014–15	–	–
2015–16	231 198	221 952
2016–17	102 420	98 490
2017–18	56 890	56 890

1.4 Illegal catch

There are no estimates of illegal catch for OYU 5.

1.5 Other sources of mortality

1.5.1 Mortality caused by *Bonamia exitiosa*

Bonamia exitiosa is a haemocritic, haplosporid parasite (infects mainly haemocytes or blood cells) of flat oysters. It is known to infect *Ostrea chilensis* in New Zealand and Chile; *Ostrea angasi* in Australia; *Ostrea puelchana* in Argentina; *Ostrea* (*Ostreola*) *conchaphila* in California, USA; *Ostrea edulis* in Atlantic Spain and probably in the Gulf of Manfredonia (Italy); *Ostrea stentina* in Tunisia, and possibly northern New Zealand (this isolate is also similar to *Bonamia. roughleyi*); and *Crassostrea ariakensis* in North Carolina, USA (Mike Hine, pers. comm.). Further, an unknown species of Bonamia has been identified in two species of native oysters from Hawaii.

Mortality of oysters from *B. exitiosa* is a recurrent feature of the Foveaux Strait oyster population and the main driver of oyster abundance during epizootics. Large numbers of new clocks (shells of oysters that have died within six months) and oysters in poor condition (both indicative of *B. exitiosa* epizootics), were recorded as long ago as 1906. *B. exitiosa* has been identified in preserved oyster tissues sampled in 1964, at the end of an epizootic that caused a downturn in the fishery (Cranfield et al. 2005) and originally attributed to *Bucephalus longicornutus* (Hine & Jones 1994). A *B. exitiosa* epizootic occurred in the Foveaux Strait oyster fishery in 1986–92 and again in 2000–14. Prevalence of infection between 1996 and 2000 was not sampled, but is thought to be low (almost undetectable) from the low numbers of new clocks that were recorded in biennial oyster population surveys in that period.

The annual cycle of infection is described by Hine (1991). The parasite transmits directly, oyster to oyster, and disease spread is thought to be related to oyster density. Some oysters appear more tolerant of infection than others (Hine 1996). The relationship between the intensity and prevalence of infection in one year, the density of oysters, and the probability of oyster mortality the following year are poorly understood (Sullivan et al. 2005).

It is not known whether other diseases (including an apicomplexan, *Bucephalus* sp., coccidian, and microsporidian) contributed to or caused mortality in oysters during the 1986–92 and 2000–14 epizootics. No direct and immediate effect of oyster dredging on disease status can be determined.

Oyster mortality from Bonamia is considerably higher than the commercial catch. Based on the number of oysters sampled with fatal infections during stock assessment surveys, the projected mortality of recruit-sized oysters between the surveys and the oyster seasons have been estimated at 43, 46 and 81 million oysters for years 2007, 2009 and 2012 respectively. Smaller Bonamia surveys are undertaken in years between stock assessment surveys, and these surveys do not estimate mortality from the whole population. In 2014, a new series of Bonamia surveys began, sampling a core subset of strata that comprised 14 of the 26 stock assessment survey strata from 2012 that represented 75% of the recruit-sized oyster population and 46% of the stock assessment survey area.

Bonamia infection levels decreased markedly in 2016. Stations with no detectable infection were spread across the fishery. The highest and most extensive patterns of infection were in the eastern fishery area (strata C3 and B6), but these were relatively low. The prevalence of infection ranged from 0% to 28% in 2016; with no detectable infection at 13 of the 55 stations. The numbers of infected oysters declined from 49.8 million in 2015 to 25.3 million recruit-sized oysters in 2016. Summer mortality was 16.2 million oysters, 4.2% of the recruit-sized population. Summer mortality was much lower in 2016 than in 2015 (12.4–13.1%) (Michael et al. 2016).

Bonamia mortality declined over the stock area to about 5% of the recruit-sized population in 2016 and 2017. These low levels of mortality have not been recorded since 1998. Bonamia mortality was lower still in 2018 (2–3%). Non-fatal infections also declined in 2018 to about 0.1% of the recruit-sized population, suggesting low Bonamia mortality in 2019. The low oyster densities and low non-fatal infections suggest reduced transmission of Bonamia infection (Michael et al 2018).

Bonamia infection levels have been low since 2016. Estimates of the mean prevalence of *B. exitiosa* infection in recruit-sized oysters from the Bonamia survey area were 1.9% using heart imprints, and 7.4% using ddPCR in 2019, both estimates were similar to 2018. Bonamia mortality over the summer of 2018–19 in this area was low (2%), comprised of a pre-survey mortality of 0.7% and a post-survey mortality of 1.3%. Non-fatal infections (from heart imprints) represented 0.1% of the recruit-sized population in 2019. (Michael 2019b).

1.5.2 Incidental mortality caused by heavy dredges

Since 1965, heavy double-bit, double-ring-bag dredges have been used in the Foveaux Strait oyster fishery. These dredges weighed around 410 kg when first introduced. Each oyster skipper fine tunes their dredges and current dredge weights range from 460 kg to 530 kg. These dredges are heavier than the single-bit, single-ring-bag dredges employed between 1913 and 1964.

Incidental mortality of oysters from dredging with light (320 kg) and heavy (550 kg) dredges was compared experimentally in March 1997 (Cranfield et al. 1997). Oysters in the experiment had only a single encounter with the dredge. Numbers of dead oysters were counted seven days after dredging. The experiment found that mortality was inversely proportional to the size of oysters damaged and that lighter dredges damaged and killed fewer oysters. Recruit-sized oysters appeared to be quite robust (1–2% mortality) and few were damaged. Smaller oysters (10–57 mm in length) were less robust (6–8% mortality), but spat were very fragile and many were killed especially by the heavy commercial dredge (mortality of spat below 10 mm in height ranged from 19–36%). Incidental mortality from dredging may reduce subsequent recruitment in heavily fished areas but is unlikely to be important once oysters are recruited. The mortality demonstrated experimentally here has not been scaled to the size of the fishery and therefore its importance cannot be assessed.

2. BIOLOGY

Ostrea chilensis is a protandrous hermaphrodite that may breed all year round, but breeding peaks in the spring and summer months. Females produce few large (280–290 μm) yolky eggs, which after fertilisation continue to develop to pediveligers in the inhalant chamber for 18–32 days (depending on temperature). Most larvae are thought to settle immediately on release (at a size of 444–521 μm) and are thought to seldom disperse more than a few centimetres from the parent oyster. Some larvae are released early, at smaller sizes and spend some time in the plankton, and are capable of dispersing widely (Michael 2019a). Little is known about the timing and proportion of larvae released early in the plankton, and how this strategy may vary spatially and temporally, both within natal populations and the fishery. In Foveaux Strait, spat settlement is primarily during the summer months from December to February. Mean larval production of incubating oysters in Foveaux Strait was determined to be 5.09×10^4 larvae, and only 6–18% of the sexually mature oysters spawned as females each year.

Few data are available on recruitment. Stock recruitment relationships for the Foveaux Strait dredge oyster are unknown, but most oysters surviving post-settlement are typically found on live oysters and, to a lesser extent, on oyster shells and on the circular saw *Astraea heliotropium* (Keith Michael, NIWA, pers. comm.). Generally, recruitment of sessile organisms is highly variable and often environmentally and predation driven (Cranfield 1979). About 2% of oyster spat survive the first winter; most mortality appears to result from predation by polychaetes, crabs and small gastropods. Although settlement predominates on under surfaces of oysters and shell, most surviving spat are attached to the left (curved and generally uppermost) valve of living oysters. Mean density of six-month-old oyster spat settled on spat plates at six sites in western and eastern Foveaux Strait over the summer of 1999–2000 was 1700 m^2 (range 850–2900 m^2) (Cranfield et al., unpublished data).

Spat monitoring data and the numbers of 0+ oysters landed on the catch commercial sized oysters provide indices of early recruitment. These two indices are highly correlated over time, Pearson's correlation of 0.96 ($p < 0.001$) (Michael & Shima 2018).

Spawning stock size is not a reliable predictor of recruitment to the population or the fishery. Low recruitment can persist during periods of high spawning stock size and spawner densities (Michael & Shima 2018), and can be high at times of low spawning stock size and spawner densities (Michael et al. 2019). The Beverton-Holt stock-recruit relationship does not describe recruitment to OYU 5 well.

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Growth rates of oysters vary between years and between areas of Foveaux Strait. Spat generally grow 5 to 10 mm in height by the winter after settlement. Mean height after one year is 18–25 mm, 25–35 mm after two years, 30–51 mm after three years, 40–65 mm after four years, and 65–75 mm after the fifth year. Oysters recruit to the legal-sized population (a legal-sized oyster will not pass through a 58 mm diameter ring, i.e., it must be at least 58 mm in the smaller of the two dimensions of height or length) at ages of 4–8 years. There is evidence for strong seasonal variation in growth (Dunn et al. 1998b).

Dunn et al. (1998b) modelled the growth of a sample of oysters from four areas, grown in cages. Length-based growth parameters from this study are shown in Table 8.

Jeffs & Hickman (2000) estimated measures of maturity from the reanalysis of sectioned oyster gonads sampled at around monthly intervals from four sites in Foveaux Strait from April 1970 to April 1971. Analysis of these samples revealed that oysters were protandrous, maturing first as males at about 20 mm in shell height. Beyond 50 mm, most oysters developed ova while continuing to produce sperm, although oysters did not begin brooding larvae until 60 mm. Considerable quantities of ova were present in oysters throughout the year, but only a very small proportion of oysters spawned ova from July to December with a peak in October. Oysters commonly contained and released sperm throughout the year, although peak spawning was from November to March. The phagocytosis of reproductive material from the follicles of oysters was present in a small proportion of oysters throughout the year. However, it was much more common from January to March amongst both male and female reproductive material, including smaller (less than 50 mm), solely male oysters.

Table 8: Estimates of biological parameters.

Fishstock		**Estimate**	**Source**
1. Natural mortality (*M*)			
OYU 5		0.042	Dunn et al. (1998a)
		Assumed 0.1	Cranfield & Allen (1979)
		Assumed 0.1	Dunn (2007)
2. Length-based growth parameters from Dunn et al. 1998b			
Length-based growth as estimated from model 3, is presented below. Growth is given for change in diameter.			
$\Delta l = (L_{\infty_{area}} - l1)(1 - e^{-k_{area + year}(\Delta t + \phi)}) - \varepsilon$			
Estimated parameter values (and 95% confidence intervals)			
L_∞	Area A	92.2 mm (86.7–97.9)	
	Bird I.	76.2 mm (73.5–78.9)	
	Lee Bay	77.8 mm (73.4–81.4)	
	Saddle	81.0 mm (77.3–84.9)	
Estimated parameter values (and 95% confidence intervals)			
k	1979	(reference year)	
	1980	-0.29 (-0.33–-0.25)	
	1981	0.02 (-0.02–0.06)	
	Area A	0.48 (0.41–0.54)	
	Bird I.	0.85 (0.76–0.94)	
	Lee Bay	0.77 (0.68–0.86)	
	Saddle	0.51 (0.50–0.52)	
ϕ		-0.03	
3. Size at sexual maturity (Females)			
50 mm diameter (49 mm height)			Cranfield & Allen (1979)
50 mm in length			Jeffs & Hickman (2000)
4. Percentage of population breeding as females annually			
Foveaux Strait		6–18%	Cranfield & Allen (1979)
Foveaux Strait		~50%	Jeffs & Hickman (2000)

3. STOCKS AND AREAS

The Foveaux Strait oyster fishery has been managed as a single stock, and current stock assessments are undertaken in a fishery area defined by the 2007 survey area. Oyster growth is 'plastic' and influenced by habitat. Sub-populations within the fishery have different morphological characteristics, but are considered a single genetic stock. There has been considerable translocation of oysters from Foveaux Strait to Fiordland and the Catlins to establish natal populations or supplement existing populations, but no records of reverse translocations.

4. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS

This section was reviewed by the Aquatic Environment Working Group for inclusion in the Fishery Assessment Plenary November 2014. A broader summary of information on a range of issues related to the environmental effects of fishing and aspects of the marine environment and biodiversity of relevance to fish and fisheries is available in the Aquatic Environment and Biodiversity Annual Review (Ministry for Primary Industries 2019).

4.1 Role in the ecosystem

Dredge oysters (*Ostrea chilensis*) are benthic, epifaunal, sessile bivalve molluscs that have a relatively limited pelagic larval dispersal phase. They are patchily distributed around the New Zealand coast on a variety of substrates (biogenic reef, gravel, sand, mud) in intertidal to subtidal inshore waters, commonly in depths of up to 60 m or more. Commercially exploited beds of oysters occur in Foveaux Strait (OYU 5), Tasman Bay (OYS 7), and Cloudy and Clifford Bays (OYS 7C). Beds at the Chatham Islands (OYS 4) have potential for commercial exploitation. Oysters play important roles in the ecosystem that include influencing water quality by filtering phytoplankton and other suspended particles from the seawater, linking primary production with higher trophic levels, and acting as ecosystem engineers by stabilising sediments and providing structural habitat (biogenic reef) for other taxa (e.g., algae, ascidians, bryozoans, sponges, echinoderms, worms, molluscs, crustaceans, fish).

4.1.1 Trophic interactions

Oysters are active suspension feeders, consuming phytoplankton suspended in the water column. Their diet is the same as or similar to that of many other suspension feeding taxa, including other bivalves such as scallops, clams and mussels. Oysters are probably prey for a wide range of invertebrate and fish predators, but published records of known or suspected predators are limited. Reported invertebrate predators of *O. chilensis* include brittlestars (*Ophiopsammus maculata*) (Stead 1971b), starfish (*Coscinasterias calamaria* and *Astrostole scabra)* (Cranfield 1979) and flatworms (*Enterogonia orbicularis*) and flatworms (*Enterogonia orbicularis*) (Handley 2002), suspected invertebrate predators include octopus (*Pinnoctopus cordiformis*) and shell boring gastropods (*Poirieria zelandica, Xymene ambiguous and Xymenella pusillis*) (Brown 2012). Predators of oysters probably change with oyster size. Most mortality of oyster spat (small juveniles) during their first winter appears to result from predation by polychaetes, crabs and gastropods (Ministry for Primary Industries 2013b).

4.2 Non-target catch of fish and invertebrates

A range of non-target fish and invertebrate species are caught and discarded by dredge fisheries for *O. chilensis*. No data are available on the level or effect of this non-target catch and discarding by the fisheries. Invertebrate non-target catch data are available from dredge surveys of the oyster stocks, and the non-target catch of the fisheries is likely to be similar to that of the survey tows conducted in areas that support commercial fishing. Fish non-target catch data are generally not recorded on surveys, presumably because fish constitute a small fraction of the total non-target catch.

In OYU 5 (Foveaux Strait), Fleming (1952) sampled the macrofaunal non-target catch of oyster fishing a “near virgin” area of the fishery in 1950. More recently, presence-absence data on non-target catch of oyster dredging have been recorded during surveys and in fishers’ logbooks (Michael 2007). In a specific study of the benthic macrofauna non-target catch of the 2001 oyster dredge survey in Foveaux Strait, Rowden et al. (2007) identified at least 190 putative species representing 82 families and 12 phyla; ‘commercial’ survey strata were principally characterised by the families Balanidae (barnacles), Mytilidae (mussels), Ophiodermatidae (brittle stars), Ostreidae (oysters) and Pyuridae (tunicates). For the 2007 survey of OYU 5, Michael (2007) listed the percentage occurrence of sessile and motile species caught as non-target catch in the survey dredge tows. The five most commonly caught sessile species (excluding oysters) were hairy mussels *Modiolus areolatus* (80% occurrence), barnacles *Balanus* sp. (61%), kina *Evechinus chloroticus* (61%), nesting mussels *Modiolarca impacta* (53%), and ascidians *Pyura pulla* (51%). The five most commonly occurring motile non-target catch species were brittlestars *Ophiopsammus maculata* (90% occurrence), circular saw shells (gastropods) *Astraea heliotropium* (80%), hermit crabs *Pagurus novizelandiae* (80%), eight armed starfish *Coscinasterias muricata* (63%), and brown dipple starfish *Pentagonaster pulchellus* (54%). Common non-target catch species of oyster dredge surveys in Foveaux Strait were reported by Michael (2007) and are listed in Table 9.

Table 9: Invertebrate species commonly caught as non-target catch in dredge surveys of oysters (*O. chilensis*) in Foveaux Strait (Michael 2007).

Type	Species
Infaunal bivalves	*Glycymeris modesta* (small dog cockle), *Tawera spissa* (morning star shell), *Tucetona laticostata* (large dog cockle), *Pseudoxyperas elongata* ('tuatua'), *Venericardia purpurata* (purple cockle)
Epifaunal bivalves	*Modioilus areolatus* (hairy mussel), *Modiolarca impacta* (nesting mussel), *Aulacomya atra maoriana* (ribbed mussel), *Barbatia novaezelandiae* (ark shell), *Pecten novaezelandiae* (scallop), *Chlamys zelandiae* (lions paw scallop), *Neothyris lenticularis* (large lantern shell), *N. compressa* (compressed lantern shell)
Sponges	*Chondropsis topsentii* (cream sponge), *Crella incrustans* (red-orange sponge), *Dactylia palmata* (finger sponge)
Ascidians	*Pyura pachydermatina* (kaeo), *P. pulla*
Algae	Red algae spp.
Bryozoans	*Celleporaria agglutinans* (hard/plate coral), *Cinctipora elegans* (reef-building bryozoan), *Horera foliacea* (lace coral), *Hippomenella vellicata* (paper coral), *Tetrocycloecia neozelanica* (staghorn coral), *Orthoscuticella fusiformis* (soft orange bryozoan)
Barnacles and chitons	*Balanus decorus* (large pink barnacle), *Cryptochonchus porosus* (butterfly chiton), *Eudoxochiton nobilis* (noble chiton), *Rhyssoplax canaliculata* (pink chiton)
Starfish, brittlestars and holothurians	*Coscinasterias muricata* (eight armed starfish), *Pentagonaster pulchellus* (brown dipple starfish), *Ophiosammus maculata* (snaketail brittlestar), *Australostichopus mollis* (sea cucumber)
Crabs	*Pagurus novaezelandiae* (hermit crab), *Eurynolambrus australis* (triangle crab), *Metacarcinus novaezelandiae* (cancer crab), *Nectocarcinus* sp. (red crab)
Urchins	*Evechinus chloroticus* (kina), *Apatopygus recens* (heart urchin), *Goniocidaris umbraculum* (coarse-spined urchin), *Pseudechinus novaezelandiae* (green urchin), *P. huttoni* (white urchin), *P. albocinctus* (red urchin)
Gastropods	*Astraea heliotropium* (circular saw shell), *Alcithoe arabica* (volute), *Argobuccinum pustulosum tumidum, Turbo granosus, Cabestana spengleri, Charonia lampras*
Octopuses	*Pinnoctopus cordiformis* (common octopus), *Octopus huttoni* (small octopus)

4.2.1 Non-target catch in other oyster stocks

In OYS 7 (Tasman/Golden Bays), data on the non-target catch of the 1994–2014 dredge surveys have been collected but not analysed, except for preliminary estimation of the 1998–2013 non-target catch trajectories (Williams et al. 2014b). The surveys record the non-target catch of other target species of scallops (*Pecten novaezelandiae*) and green-lipped mussels (*Perna canaliculus*), and various other non-target catch in nine categories (Williams et al. 2014b). Observation of the 2014 survey sampling identified a problem with the way these categorical non-target catch data have been recorded, which limits their utility (Williams et al. 2014a).

In OYS 7C (Cloudy/Clifford Bays), a dredge survey of oysters in Cloudy and Clifford Bays was conducted in 2006, and the survey skipper recorded qualitative comments on the non-target catch of each tow, which included 'coral', 'sticks and seaweed', shells, volutes, 'red weed', horse mussels, shell with worm, small crabs, mussels and scallops (Brown & Horn 2006).

In OYS 4 (Chatham Islands), data on the non-target catch of a 2013 dredge survey of oysters off the north coast of Chatham Island were recorded (as estimated volumes of different non-target catch categories) but not analysed (Williams et al. 2013).

4.3 Incidental catch of seabirds, mammals and protected fish

There is no known incidental catch of seabirds, mammals or protected fish species from *O. chilensis* oyster fisheries.

4.4 Benthic interactions

There are a variety of benthic habitats in the different oyster fisheries areas, which generally occur either on coarse substrates usually found in areas of high natural disturbance (Foveaux Strait, Cloudy/Clifford Bays and the Chatham Islands) or on fine substrates typical of sheltered areas (Tasman Bay). Benthic habitats within the Foveaux Strait oyster fishery area were classified by Michael (2007) and comprise a variety of sand/gravel/shell flats and waves, rocky patch reef, and biogenic areas. Cranfield et al. (1999) referred to the latter as epifaunal reefs that he defined as 'tidally-oriented, linear aggregations of patch reefs formed by the bryozoan *Cinctipora elegans,* cemented by encrusting bryozoans, ascidians, sponges and polychaetes'. Cranfield et al.'s papers (Cranfield et al. 1999, 2001, 2003) suggested that epifaunal reefs are oyster habitat, but Michael's reports (Michael 2007, 2010) state that commercial fishing for oysters is mainly based on sand, gravel, and shell habitats with little epifauna. In Foveaux Strait, commercial oyster dredging occurs within an area of about 1000 km^2 (although only a portion of this is dredged each year), which is about one-third of the overall OYU 5 stock area (Michael 2010). Habitats within the Cloudy/Clifford Bays and the Chatham Islands fisheries areas have not been defined. The benthic habitat within the Tasman Bay oyster fishery area is predominately mud, although to some extent this may have been affected by land-based sedimentation into the bay and homogenisation of the substrate by dredging and trawling (Brown 2012).

It is well known that fishing with mobile bottom contact gears such as dredges has impacts on benthic populations, communities, and their habitats (e.g., Kaiser et al. 2006, Rice 2006). The effects are not uniform, but depend on at least: 'the specific features of the seafloor habitats, including the natural disturbance regime; the species present; the type of gear used, the methods and timing of deployment of the gear, and the frequency with which a site is impacted by specific gears; and the history of human activities, especially past fishing, in the area of concern' (Department of Fisheries and Oceans 2006). In New Zealand, the effects of oyster dredging on the benthos have been studied in Foveaux Strait (OYU 5) (Cranfield et al. 1999, 2001, 2003, Michael 2007) and Tasman/Golden Bays (OYS 7) (Tuck et al. 2011). The results of these studies are summarised in the Aquatic Environment & Biodiversity Annual Review (Ministry for Primary Industries 2019), and are consistent with the global literature: generally, with increasing fishing intensity there are decreases in the density and diversity of benthic communities and, especially, the density of emergent epifauna that provide structured habitat for other fauna.

The effects of dredging (Ministry for Primary Industries 2019) may be more severe in sheltered areas (e.g., Tasman Bay) than in exposed areas (e.g., Foveaux Strait, Cloudy/Clifford Bays, Chatham Islands). Dredging damages epifauna, and erect, structured habitats, such as biogenic/epifaunal reefs, are the most sensitive to dredging disturbance. Dredging destabilises sediment/shell substrates, suspends sediments and increases water turbidity; the sensitivity of habitats to suspended sediments and their deposition probably varies depending on the prevailing natural flow regime, being greater in muddy sheltered areas than in high-flow environments. Habitats disturbed by dredging tend to become simpler, more homogenous areas typically dominated by opportunistic species. Dredging generally results in reduced habitat structure and the loss of long-lived species.

For studies of the effects of oyster dredging in Foveaux Strait, interpretation of the authors differ (Ministry for Primary Industries 2019): 'Cranfield et al.'s papers (Cranfield et al. 1999, Cranfield et al. 2001, Cranfield et al. 2003) concluded that dredging biogenic reefs for their oysters damages their structure, removes epifauna, and exposes associated sediments to resuspension such that, by 1998, none of the original bryozoan reefs remained. Michael (2007) concluded that there are no experimental estimates of the effect of dredging in the strait or on the cumulative effects of fishing or regeneration, and that the previous conclusions cannot be supported. The authors agree that biogenic bycatch in the fishery has declined over time in regularly fished areas, that there may have been a reduction in biogenic reefs in the strait since the 1970s, and that simple biogenic reefs appear able to regenerate in areas that are no longer fished (dominated by byssally attached mussels or reef-building bryozoans). There is no consensus that reefs in Foveaux Strait were (or were not) extensive or dominated by the bryozoan *Cinctipora*.

Some areas of the Foveaux Strait (OYU 5) oyster fishery are also commercially fished (potted) for blue cod (*Parapercis colias*), and Cranfield et al. (2001) presented some evidence to suggest that dredged benthic habitats and blue cod densities regenerated in the absence of oyster dredging. Bottom trawling also occurs within the OYU 5 area, but there is little overlap with the main areas fished for oysters.

4.5 Other considerations

4.5.1 Spawning disruption

Fishing during spawning may disrupt spawning activity or success. Fishing-induced damage to oysters incurred during the period before spawning could interrupt gamete maturation. Oyster fishing also targets high-density beds of oysters, which are disproportionately more important for fertilisation success during spawning. In the Foveaux Strait fishery, the traditional harvesting period (1 March to 31 August) occurs after the main spring and summer peaks in oyster spawning activity (Jeffs & Hickman 2000).

4.5.2 Habitat of particular significance for fisheries management

None currently identified.

5. ANNUAL ABUNDANCE AND BONAMIA SURVEYS

Density and population size was reported by three size groups: recruit-sized, unable to pass through a 58 mm internal diameter ring; pre-recruits, able to pass through a 58 mm internal diameter ring, but unable to pass through a 50 mm ring; and small oysters, able to pass through a 50 mm internal diameter ring and down to 10 mm in length. All three size groups of oysters have increased between the 2017 and 2019 oyster surveys. A fourth “commercial’ size group was recorded in 2019, to better represent the size group targeted and retained by fishers (see Table 10).

Table 10: Percentage changes in the population size of recruit-sized, pre-recruit, and small oysters in the Bonamia survey area in 2012, 2016–2019. The mean oyster density per m^2 (Mean density) that determines catch rate (sacks per hour), coefficient of variation (CV) of the density estimate, mean population size in millions of oysters (Pop.n), bootstrapped upper and lower 95% confidence intervals (95%CI) in millions of oysters that reflect the variability in the catches and the percentage change in population size. Increases in population size are shaded green and decreases tan.

2012	**Mean density**	**CV**	**Pop.n**	**B.lower 95%CI**	**B.upper 95%CI**	
Recruit	1.40	0.09	688.1	449.2	1046.7	
Pre-recruit	0.60	0.10	297.4	192.6	454.4	
Small	0.92	0.16	451.3	261.5	731.7	
2016	**Mean density**	**CV**	**Pop.n**	**B.lower 95%CI**	**B.upper 95%CI**	**% change 2012-2016**
Recruit	0.78	0.09	385.2	246.9	593.8	-44.0
Pre-recruit	0.25	0.03	120.5	186.7	491.8	-59.5
Small	0.52	0.07	256.1	155.0	407.3	-43.3
2017	**Mean density**	**CV**	**Pop.n**	**B.lower 95%CI**	**B.upper 95%CI**	**% change 2016-2017**
Recruit	0.74	0.11	363.6	233.9	559.1	-5.6
Pre-recruit	0.25	0.12	123.1	77.5	191.7	2.2
Small	0.53	0.10	261.9	168.8	401.6	2.3
2018	**Mean density**	**CV**	**Pop.n**	**B.lower 95%CI**	**B.upper 95%CI**	**% change 2017-2018**
Recruit	1.00	0.11	494.1	315.0	764.9	35.9
Pre-recruit	0.36	0.11	178.4	113.5	276.5	44.9
Small	0.82	0.13	401.8	249.2	631.2	53.4
2019	**Mean density**	**CV**	**Pop.n**	**B.lower 95%CI**	**B.upper 95%CI**	**% change 2018-2019**
Recruit	1.10	0.13	542.5	337.0	851.0	9.8
Pre-recruit	0.44	0.15	216.5	129.6	346.1	21.4
Small	1.21	0.10	595.8	385.4	912.5	48.3

5.1 Recruit-sized oysters

In the stock assessment strata (Figure 3), recruit-sized oyster density declined between the 2012 and 2018 surveys with population size declining from 918.4 million oysters in 2012 to 527.4 million in 2017 and with an increase to 883.3 million oysters in 2018. Recruit-sized oyster density also declined in the core commercial strata (Bonamia survey area) with population size in these strata declining from 688.1 million oysters in 2012 to 363.6 million in 2017, and increased to 542.5 million oysters in 2019.

5.2 Pre-recruit-sized oysters

In the stock assessment strata (Figure 3), pre-recruit-sized oyster density declined between the 2012 and 2018 surveys with population size declining from 414.3 million oysters in 2012 to 168.2 million oysters in 2017 with a slight increase to 225.8 million oysters in 2018. Pre-recruit-sized oyster density also declined in the core commercial strata (Bonamia survey area). Population size in these strata declined from 297.4 million oysters in 2012 to 123.1 million oysters in 2017, and increased to 216.5 million oysters in 2019.

5.3 Small-sized oysters

In the stock assessment strata (Figure 3), small-sized oyster density declined between the 2012 and 2017 surveys with population size declining from 612.2 million oysters in 2012 to 364.3 million oysters in 2016 and to 361.6 million oysters in 2017. Small-sized oyster density also declined in the core commercial strata (Bonamia survey area) with population size in these strata declining from 451.4 million oysters in 2012 to 256.1 million oysters in 2016 and increased to 595.8 million oysters in 2019.

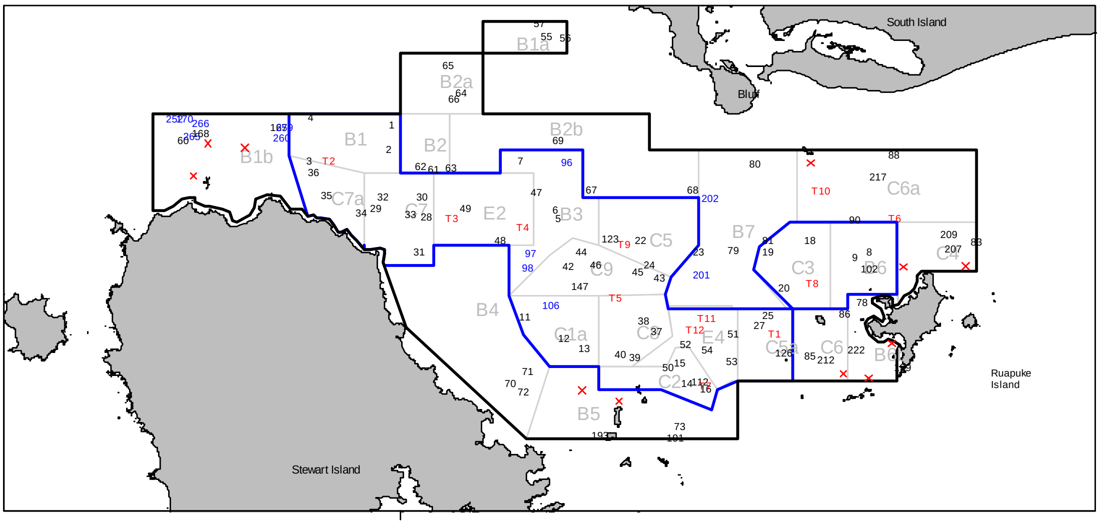


Figure 3: The 2007 stock assessment area with the survey boundary shown as a heavy, black outer line, the 2014 annual abundance and Bonamia survey area shown by heavy blue lines, and the 2017 survey strata shown as grey lines. Strata are labelled with grey text. Random first-phase stations sampled in 2017 are shown in black text, second-phase stations shown in blue text, and fixed stations shown in red text. First-phase stations not sampled in 2017 because of foul ground are shown as red crosses.

5.4 Distribution of oysters

The distribution of oyster densities of all sizes is widespread, covering most of the fishery area with the highest densities in core fishery strata. Densities of all three size groups of oysters were lower in 2018 than in 2012, but had increased between 2017 and 2018 (Figure 4). The numbers and sizes of localised areas of relatively high density of recruit-sized oysters decreased between 2012 and 2018, but increased between 2017 and 2018 (Figure 4). The decrease since 2012 is most likely the result of ongoing, low to moderate levels of *Bonamia exitiosa* mortality and reduced recruitment to the fishery. The distribution of recruit-sized oyster increased across the fishery in 2018 and 2019 (Figure 5).

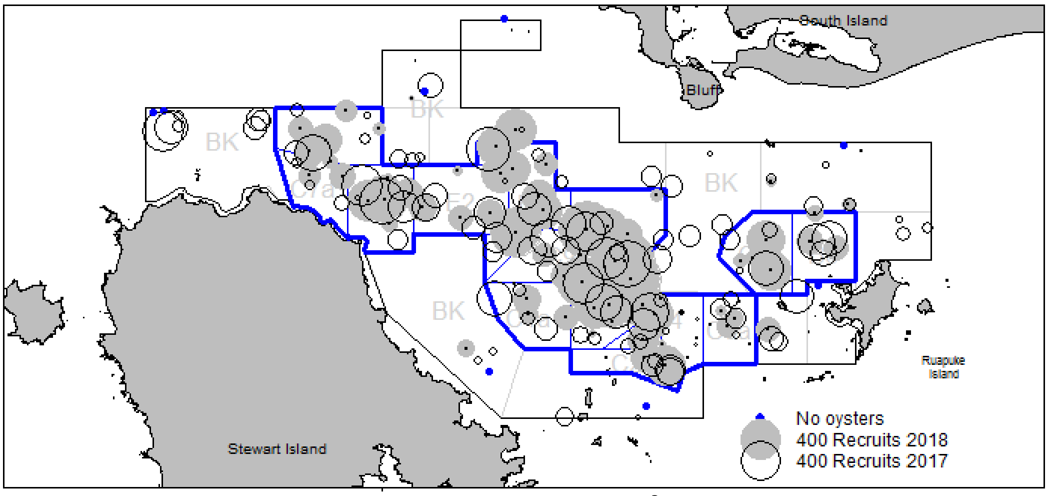


Figure 4: The densities (numbers of oysters per standard tow, 1221 m^2) of recruit-sized oysters sampled during the February surveys in 2018 (filled grey circles) and in 2017 (open black circles). Blue filled circles denote no oysters caught. The Bonamia survey area is shown by the blue lines.

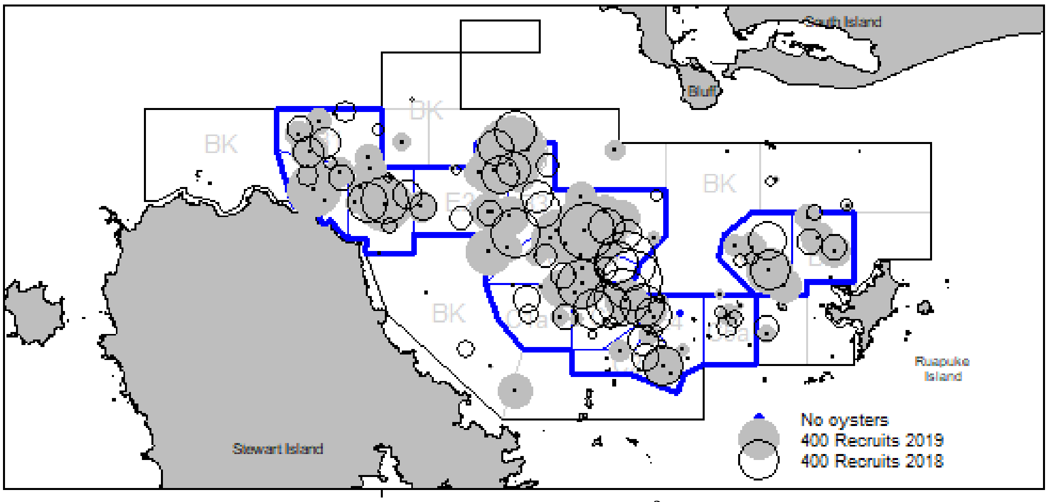


Figure 5: The densities (numbers of oysters per standard tow, 1221 m^2) of recruit-sized oysters sampled during the February surveys in 2019 (filled grey circles) and in 2018 (open black circles). Blue filled circles denote no oysters caught. The Bonamia survey area is shown by the blue lines.

6. STOCK ASSESSMENT

Surveys of the Foveaux Strait oyster population have been reported since 1906 (Dunn 2005) and see Sullivan et al. (2005) for details since 1960. Early surveys (1906, 1926–45) are summarised by Sorensen (1968). Stock assessments are conducted every five years with abundance, with Bonamia surveys being done in the years between stock assessments. The most recent stock assessment was conducted in 2017.

6.1 Estimates of fishery parameters and abundance

Estimates of fishery parameters used for stock assessment are given in Fu & Dunn (2009). CPUE data are used unstandardised. Fishery practices have changed from fishing for the highest catch rate to fishing for high meat quality at much lower catch rates to satisfy market requirements. These practices have resulted in more conservative estimates of CPUE and oyster density from catch and effort data. Inter-annual recruitment to the oyster population can vary markedly (unpub. data).

6.2 Biomass estimates

Before 2004 the Foveaux Strait oyster fishery was managed by current annual yield (CAY, Method 1, see the Introductory section of this Plenary) based on survey estimates of the population in designated commercial fishery areas. Since 2004, the TACC has been based on estimates of recruit-sized stock abundance from the Foveaux Strait oyster stock assessment model (Dunn 2005, 2007, Fu & Dunn 2009, Fu 2013) and projections of future recruit-sized stock abundance under different catch limits and levels of mortality from *B. exitiosa*.

In 2004, Dunn (2005) presented a Bayesian, length-based, single-sex stock assessment model for Foveaux Strait dredge oysters using the general-purpose stock assessment program CASAL (Bull et al. 2005). That model was updated in 2007 to account for new data available, and a more complex variant of that model was also investigated. For more detailed information on the model structure, data and parameter inputs, sensitivity runs, results and discussion refer to Fu & Dunn (2009) and Fu (2013). The assessment was updated to include data up to the 2016 fishing year and the abundance indices from the February 2017 stock assessment survey (Large et al. 2017).

The population model partitioned Foveaux Strait oysters into a single-sex population, with length (i.e., the anterior-posterior axis) classes from 2 mm to 100 mm, in groups of 2 mm, with the last group defined as oysters of at least 100 mm. The stock was assumed to reside in a single, homogeneous area. The partition accounted for numbers of oyster by length class within an annual cycle, where movement between length classes was determined by the growth parameters. Oysters entered the partition following recruitment and were removed by natural mortality (including disease mortality), and fishing mortality. The model's annual cycle was divided into two time steps (Table 11).

Table 11: Annual cycle of the population model, showing the processes taking place at each time step, their sequence within each time step, and the available observations. Fishing and natural mortality that occur together within a time step occur after all other processes, with 50% of the natural mortality for that time step occurring before and 50% after the fishing mortality.

Step	Period	Process	Proportion in time step
1	Oct–Feb	Maturation	1.0
		Growth	1.0
		Natural mortality	0.5
		Fishing (summer) mortality	1.0
		B. exitiosa mortality	1.0
2	Mar–Sep	Recruitment	1.0
		Natural mortality	0.5
		Fishing (winter) mortality	1.0

Oysters were assumed to recruit at age 1+, with a Beverton-Holt stock recruitment relationship (with steepness 0.9) and length at recruitment defined by a normal distribution with a mean of 15.5 mm and a CV of 0.4. Relative year class strengths were assumed to be known and equal to initial recruitment for the years up to 1984 – nine years before the first available length and abundance data on small oysters (less than 50 mm minimum diameter) and pre-recruits (oysters between 50 and 58 mm minimum diameter) were available; otherwise relative year class strengths were assumed to average 1.0. Growth rates and natural mortality (M) were assumed to be known. Disease mortality is assumed to be zero in the years where there were no reports of unusual mortality, and were otherwise estimated.

The models used seven selectivity ogives: the commercial fishing selectivity (assumed constant over all years and time steps of the fishery, aside from changes in the definition of legal size); a survey selectivity, which was then partitioned into three selectivities (one for each of the size-groups) – small (less than 50 mm minimum diameter), pre-recruit (at least 50 mm but less than 58 mm minimum diameter), and recruit (at least 58 mm minimum diameter); maturity ogive; and disease selectivity – assumed to follow a logistic curve equal to the maturity ogive. The selectivity ogives for fishing selectivity, maturity, and disease mortality were all assumed to be logistic. The survey selectivity ogives were assumed to be compound logistic with an additional parameter (amin) that describes the minimum possible value of the logistic curve. Selectivity functions were fitted to length data from the survey proportions-at-length (survey selectivities), and to the commercial catch proportions-at-length (fishing selectivity).

The maximum exploitation rate (i.e., the ratio of the maximum catch to vulnerable numbers of oysters in any year) was assumed to be relatively high, and was set at 0.5. No data are available on the maximum exploitation rate, but the choice of this value can have the effect of determining the minimum possible virgin stock size (B_0) allowed by the model.

The model was run for the years 1907–2017. Catch data were available for the years 1907–2016, with the catch for 2017 estimated to be 10 million oysters. Catches occurred in both time steps, with special permit and some customary catch assigned to the first time step (summer fishing mortality), and commercial, recreational, remaining customary and illegal catch assigned to the second time step (winter fishing mortality).

The priors assumed for most parameters are summarised in Table 12. In general, ogive priors were chosen to be non-informative and were uniform across wide bounds. The prior for disease mortality was defined so that estimates of disease mortality were encouraged to be low. An informed prior was used when estimating the survey catchability, where a reasonably strong lognormal prior was used, with a mean of 1.0 and a CV of 0.2.

Table 12: The priors assumed for key parameters. The parameters are mean and CV for lognormal (in natural space); and mean and s.d. for normal.

Parameter	Distribution	Parameters		Bounds	
CPUE q	Uniform-log	–	–	1×10^{-8}	0.1
1976 survey q	Lognormal	0.6	0.3	0.15	0.95
Mark-recapture survey q	Lognormal	0.6	0.3	0.10	0.90
YCS	Lognormal	1.0	1.0	0.01	100.0
Disease mortality	Normal	-0.2	0.2	0.00	0.80

6.2.1 Stock assessment results

Model estimates of numbers of oysters were made using the biological parameters and model input parameters described above. A full assessment in 2017 (Large et al. 2017) considered two model runs, the basic model and the revised model. The '2017 basic model' updated the basic model used in the 2012 assessment with catch, CPUE and commercial catch length-frequency data for the 2013, 2014, 2015 and 2016 fishing years; the inclusion of the February 2014, 2015, 2016 and 2017 biomass survey indices; and an assumed catch of 10 million oysters for the 2017 fishing year. The '2017 revised model' updated the 2012 revised model with similar input data. Table 13 describes the two model runs.

Table 13: Model run labels and descriptions.

Model run	Description
2017 basic model	Growth parameters assumed fixed; annual disease rates estimated as independent variables; the disease selectivity was the same as the maturity ogive; relative catchability q for the abundance surveys was fixed to be 1.
2017 revised model	Growth parameters estimated using tag-recapture data; annual disease rates assumed to be cubic-smooth; maturity and disease selectivity ogive decoupled; estimated relative catchability q for the abundance surveys

The revised model run suggested a similar stock status to the basic model, with the revised model estimating a similar growth rate to that fixed in the basic model. The relative estimates of B_0 from these model runs suggested much greater variability in the estimates of the initial population size, but estimates of the current status and recent change in the current status were very similar (see Table 14). Applying a smoothing penalty to the estimated annual disease mortality rates had little impact on the key estimated parameters of the model.

Stock assessments are planned for every five years (from 2012) and will update these two models with data on catch history (total landings), unstandardised CPUE, commercial catch sampling for size structure, and abundance indices from population surveys. The new time series of annual Bonamia surveys from 2014 (in years between stock assessments), will allow these models to be updated with total landings, catch rate and catch size structure, and comparable estimates of population size (abundance indices) from the whole survey area.

The 2017 basic model update suggested the virgin equilibrium spawning stock population size to be about 4191 (3053−5503) million oysters, and the current recruit-size stock abundance to be 703 (511−923) million oysters (Table 14). The 2017 revised model suggested a virgin equilibrium spawning stock population size of 3581 (3008−3593) million oysters, and a current recruit-size stock abundance of 564 (496−639) million oysters (Table 14).

Table 14: Bayesian median and 95% credible intervals of B_0 (millions), recruit-sized biomass and recruit-sized biomass as % B_0 for 2017 and 2012 from the 2017 and 2012 basic and revised models. The 2017 stock assessment updated the 2012 assessment with catch rate, total landings, and size structure from catch sampling, and new estimates of population size from the 2017 stock assessment survey.

Model	B_0	rB_{2017}	rB_{2017} (%B_0)	rB_{2012}	rB_{2012} (%B_0)
2012 Basic	3 510 (3 200–3 870)			1 070 (960–1 180)	30.6 (26.5–34.3)
2012 Revised	3 670 (3 350–4 050)			1 050 (950–1 160)	28.8 (25.4–33.0)
2017 Basic	4 191 (3 053–5 503)	703 (511–923)	16.8 (14.3–19.6)	1 485 (1 088–1 926)	35.4 (31.7–39.1)
2017 Revised	3 581 (3 008–3 593)	564 (496–639)	17.1 (14.5–20.0)	1 097 (991–1 196)	33.4 (29.5–37.2)

Projected stock estimates were made assuming that future recruitment will be lognormally distributed with a mean of 1.0 and standard deviation equal to the standard deviation of the log of recruitment between 1985 and 2014 (i.e., 0.34 with a 95% range of 0.29–0.39). Projections were made assuming no future disease mortality and with future disease mortality assumed to be $0.10y^{-1}$ and $0.20y^{-1}$. Four future annual commercial catches were considered of either 7.5, 15, 20 or 30 million oysters. Future customary, recreational and illegal catch were assumed equal to levels assumed for 2017. Projected output quantities are summarised in Tables 15–18. The plot of the median expected recruit-sized population is given in Figure 6.

Table 15: 2017 basic model median and 95% credible intervals of current spawning stock biomass 2017 (B_{2017}), and projected spawning stock abundance for 2018–20 (B_{2018}–B_{2020}) as a percentage of B_0, with an assumption of a future catch of 7.5, 15, 20 or 30 million oysters in 2018–22, and disease mortality of 0.0, 0.1, or 0.2 y^{-1}.

Disease mortality	Catch (millions)	B_{2017} (% B_0)	B_{2018} (% B_0)	B_{2019} (% B_0)	B_{2020} (% B_0)
0	7.5	23.6 (20.5–28.0)	24.5 (19.1–31.9)	28.7 (22.0–38.6)	33.1 (25.1–45.9)
	15	23.6 (20.5–28.0)	24.5 (19.1–31.9)	28.6 (21.8–38.5)	32.8 (24.9–45.7)
	20	23.6 (20.5–28.0)	24.5 (19.1–31.9)	28.5 (21.7–38.4)	32.6 (24.7–45.5)
	30	23.6 (20.5–28.0)	24.5 (19.1–31.9)	28.3 (21.6–38.2)	32.3 (24.3–45.2)
0.1	7.5	23.6 (20.5–28.0)	23.8 (18.5–31.0)	25.0 (18.9–33.9)	26.3 (19.7–37.2)
	15	23.6 (20.5–28.0)	23.8 (18.5–31.0)	24.9 (18.7–33.8)	26.0 (19.5–37.0)
	20	23.6 (20.5–28.0)	23.8 (18.5–31.0)	24.8 (18.7–33.7)	25.9 (19.3–36.8)
	30	23.6 (20.5–28.0)	23.8 (18.5–31)	24.6 (18.5–33.5)	25.6 (18.9–36.6)
0.2	7.5	23.6 (20.5–28.0)	23.1 (17.9–30.1)	21.9 (16.5–30.1)	21.3 (15.7–30.8)
	15	23.6 (20.5–28.0)	23.1 (17.9–30.1)	21.8 (16.4–30.0)	21.1 (15.5–30.5)
	20	23.6 (20.5–28.0)	23.1 (17.9–30.1)	21.7 (16.3–29.9)	21.0 (15.4–30.4)
	30	23.6 (20.5–28.0)	23.1 (17.9–30.1)	21.6 (16.1–29.8)	20.7 (15.1–30.1)

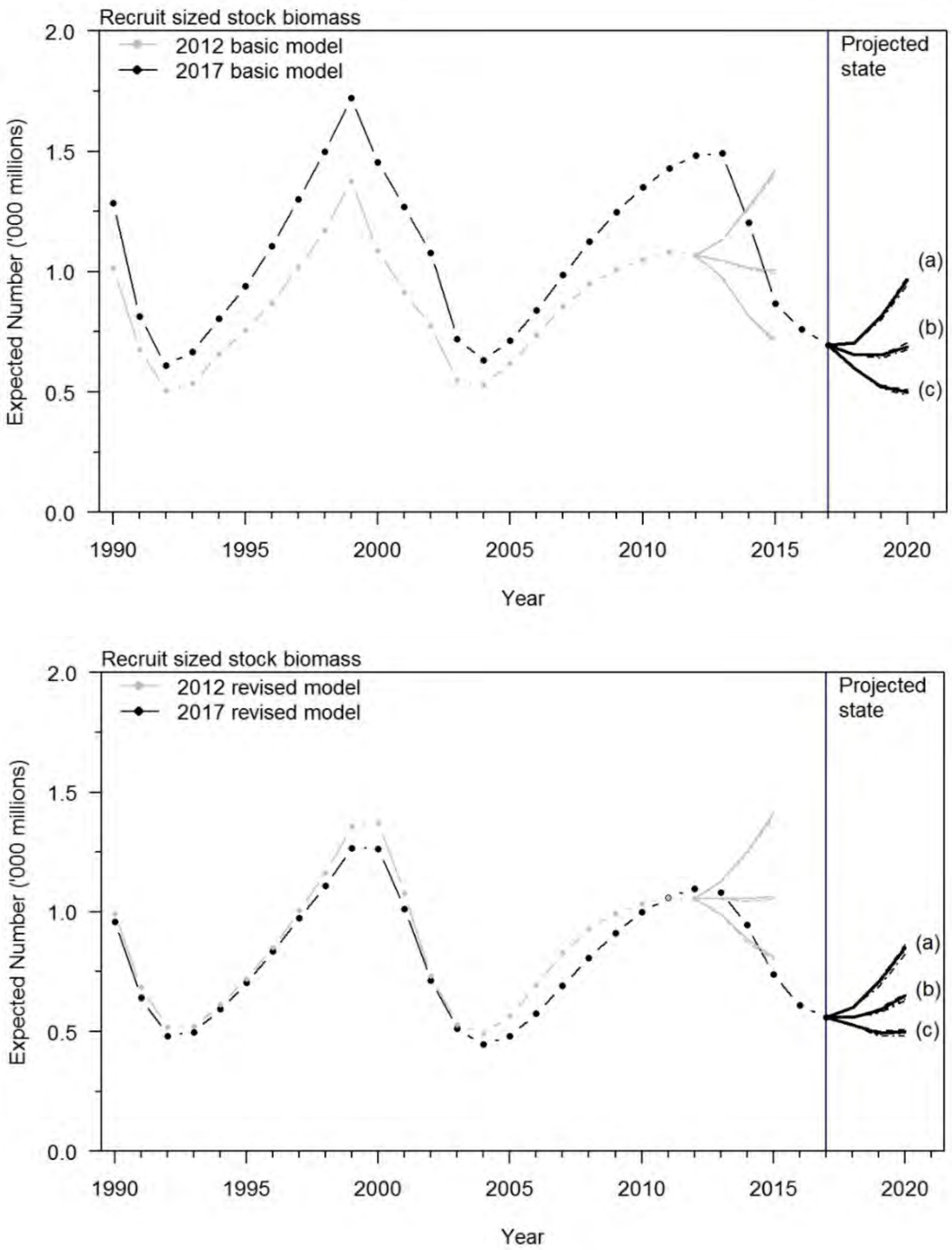


Figure 6: Model estimates of recent recruit-sized stock abundance and projected recruit-sized stock abundance for 2018–20 with catches of 7.5 (dashed line), 15 (solid line), 20 (dot line) and 30 million oysters (dot-dash line) under assumptions of (a) no disease mortality, (b) disease mortality of 0.10 y^{-1}, and (c) disease mortality of 0.20 y^{-1}, for the 2017 and 2012 basic model (top) and revised models for the same years respectively (bottom).

Under the assumptions of future disease mortality for the basic model, projections of commercial catch at either 7.5, 15, 20 or 30 million showed relatively little difference in expected population size. For example, the projected population size in 2020 with a commercial catch of 7.5 million was less than 1% higher than that with a commercial catch of 20 million oysters. Depending on the level of assumed disease mortality, projected status in 2020 ranged from about 26% B_0 (assuming no disease mortality) to approximately 13% B_0 (assuming disease mortality of $0.2y^{-1}$) for the 2017 basic model (Tables 15 and 16). For the 2017 revised model the projected status in 2020 ranged from about 26.1% B_0 in 2020 (assuming no disease mortality) to a level about 15.3% B_0 (assuming disease mortality of $0.2y^{-1}$) (Tables 17 and 18).

Table 16: 2017 basic model median and 95% credible intervals of expected recruit-size stock abundance for 2017–20 with an assumption of a future catch of 7.5, 15, 20 or 30 million oysters in 2017–20, and disease mortality rates of 0.0, 0.1, or 0.2 y^{-1}.

Disease mortality	Catch (millions)	rB_{2017} /r B_{2017}	rB_{2018} /r B_{2017}	rB_{2019} /r B_{2017}	rB_{2020} /r B_{2017}
0	7.5	1.00 (1.00–1.00)	1.01 (0.88–1.13)	1.18 (1.00–1.46)	1.41 (1.14–1.91)
	15	1.00 (1.00–1.00)	1.01 (0.88–1.13)	1.07 (0.99–1.45)	1.39 (1.13–1.89)
	20	1.00 (1.00–1.00)	1.01 (1.88–1.13)	1.16 (0.99–1.45)	1.38 (1.12–1.88)
	30	1.00 (1.00–1.00)	1.01 (1.88–1.13)	1.15 (0.97–1.44)	1.36 (1.10–1.86)
0.1	7.5	1.00 (1.00–1.00)	0.94 (0.82–1.04)	0.94 (0.80–1.18)	1.01 (0.80–1.38)
	15	1.00 (1.00–1.00)	0.94 (0.82–1.04)	0.94 (0.79–1.17)	0.99 (0.79–1.36)
	20	1.00 (1.00–1.00)	0.94 (0.82–1.04)	0.93 (0.79–1.17)	0.99 (0.78–1.36)
	30	1.00 (1.00–1.00)	0.94 (0.82–1.04)	0.92 (0.78–1.16)	0.97 (0.76–1.34)
0.2	7.5	1.00 (1.00–1.00)	0.86 (0.75–0.96)	0.76 (0.64–0.96)	0.73 (0.57–1.01)
	15	1.00 (1.00–1.00)	0.86 (0.75–0.96)	0.75 (0.63–0.95)	0.72 (0.55–1.00)
	20	1.00 (1.00–1.00)	0.86 (0.75–0.96)	0.75 (0.63–0.95)	0.71 (0.55–1.00)
	30	1.00 (1.00–1.00)	0.86 (0.75–0.96)	0.74 (0.62–0.94)	0.70 (0.53–0.99)

Table 17: 2017 revised model median and 95% credible intervals of current spawning stock biomass 2017 (B_{2017}), and projected spawning stock abundance for 2018–20 (B_{2018}–B_{2020}) as a percentage of B_0, with an assumption of a future catch of 7.5, 15, 20 or 30 million oysters in 2018–22, and disease mortality of 0.0, 0.1, or 0.2 y^{-1}.

Disease mortality	Catch (millions)	B_{2017} (% B_0)	B_{2018} (% B_0)	B_{2019} (% B_0)	B_{2020} (% B_0)
0	7.5	21.4 (18.3–25.7)	23.7 (18.7–30.2)	28.0 (22.1–36.5)	32.4 (25.6–42.8)
	15	21.4 (18.3–25.7)	23.7 (18.7–30.2)	27.8 (21.9–36.3)	32.1 (25.2–42.5)
	20	21.4 (18.3–25.7)	23.7 (18.7–30.2)	27.7 (21.8–36.2)	31.8 (25.0–42.2)
	30	21.4 (18.3–25.7)	23.7 (18.7–30.2)	27.7 (21.8–36.2)	31.8 (25.0–42.2)
0.1	7.5	21.4 (18.3–25.7)	23.1 (18.2–29.5)	23.1 (18.2–29.5)	23.1 (18.2–29.5)
	15	21.4 (18.3–25.7)	23.1 (18.2–29.5)	24.9 (19.5–32.8)	26.7 (20.8–35.8)
	20	21.4 (18.3–25.7)	23.1 (18.2–29.5)	24.7 (19.4–32.6)	26.5 (20.6–35.6)
	30	21.4 (18.3–25.7)	23.1 (18.2–29.5)	24.5 (19.2–32.4)	26.1 (20.2–35.2)
0.2	7.5	21.4 (18.3–25.7)	23.1 (18.2–29.5)	24.5 (19.2–32.4)	26.1 (20.2–35.2)
	15	21.4 (18.3–25.7)	22.5 (17.8–28.8)	22.3 (17.4–29.6)	22.4 (17.5–30.5)
	20	21.4 (18.3–25.7)	22.5 (17.8–28.8)	22.2 (17.3–29.5)	22.3 (17.3–30.4)
	30	21.4 (18.3–25.7)	22.5 (17.8–28.8)	22.0 (17.1–29.3)	21.9 (16.9–30.0)

Table 18: 2017 revised model median and 95% credible intervals of expected recruit-size stock abundance for 2017–20 with an assumption of a future catch of 7.5, 15, 20 or 30 million oysters in 2017–20, and disease mortality rates of 0.0, 0.1, or 0.2 y^{-1}.

Disease mortality	Catch (millions)	rB_{2017} /r B_{2017}	rB_{2018} /r B_{2017}	rB_{2019} /r B_{2017}	rB_{2020} /r B_{2017}
0	7.5	1.00 (1.00–1.00)	1.07 (0.95–1.16)	1.27 (1.10–1.53)	1.54 (1.27–2.02)
	15	1.00 (1.00–1.00)	1.07 (0.95–1.16)	1.26 (1.08–1.52)	1.52 (1.24–1.99)
	20	1.00 (1.00–1.00)	1.07 (0.95–1.16)	1.25 (1.07–1.51)	1.50 (1.23–1.97)
	30	1.00 (1.00–1.00)	1.07 (0.95–1.16)	1.23 (1.06–1.50)	1.47 (1.20–1.94)
0.1	7.5	1.00 (1.00–1.00)	1.00 (0.89–1.09)	1.06 (0.91–1.30)	1.18 (0.95–1.57)
	15	1.00 (1.00–1.00)	1.00 (0.89–1.09)	1.05 (0.90–1.28)	1.16 (0.93–1.55)
	20	1.00 (1.00–1.00)	1.00 (0.89–1.09)	1.04 (0.89–1.28)	1.14 (0.92–1.53)
	30	1.00 (1.00–1.00)	1.00 (0.89–1.09)	1.03 (0.88–1.26)	1.12 (0.90–1.51)
0.2	7.5	1.00 (1.00–1.00)	0.94 (0.83–1.02)	0.89 (0.76–1.10)	0.91 (0.72–1.22)
	15	1.00 (1.00–1.00)	0.94 (0.83–1.02)	0.88 (0.75–1.09)	0.89 (0.71–1.20)
	20	1.00 (1.00–1.00)	0.94 (0.83–1.02)	0.87 (0.75–1.08)	0.88 (0.70–1.19)
	30	1.00 (1.00–1.00)	0.94 (0.83–1.02)	0.86 (0.73–1.07)	0.86 (0.68–1.17)

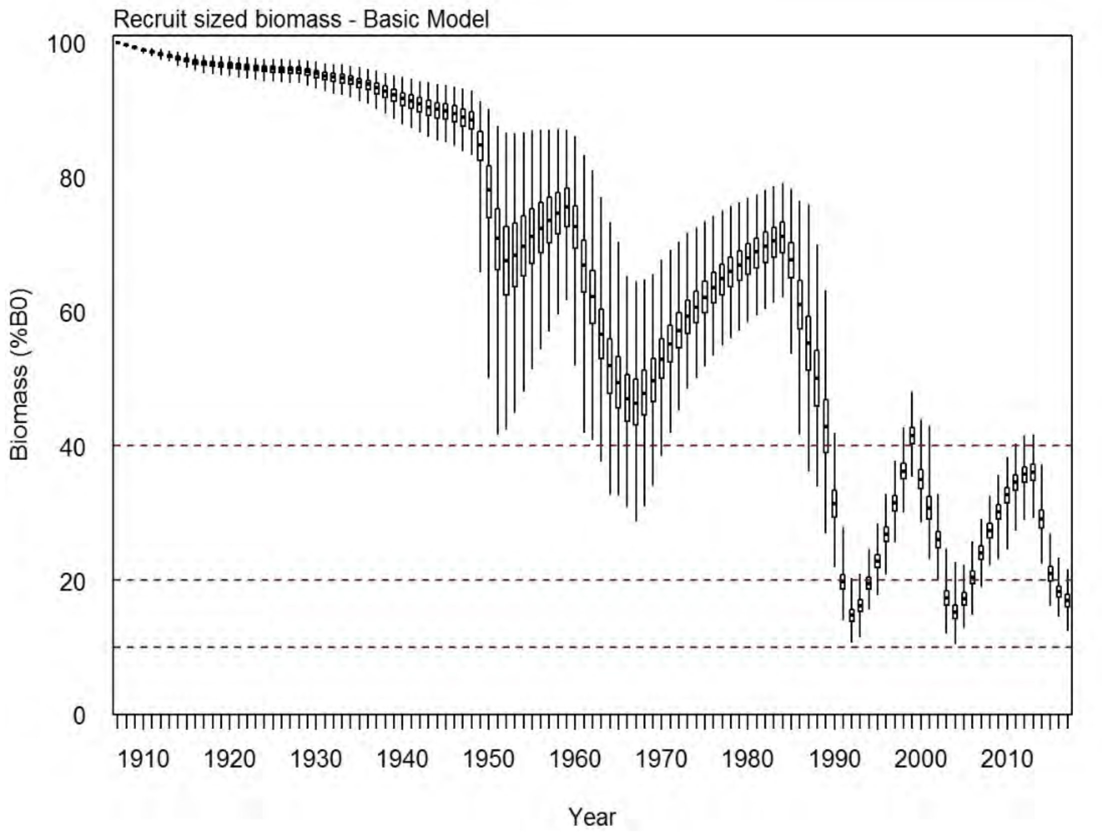
7. STATUS OF THE STOCKS

Stock structure assumptions

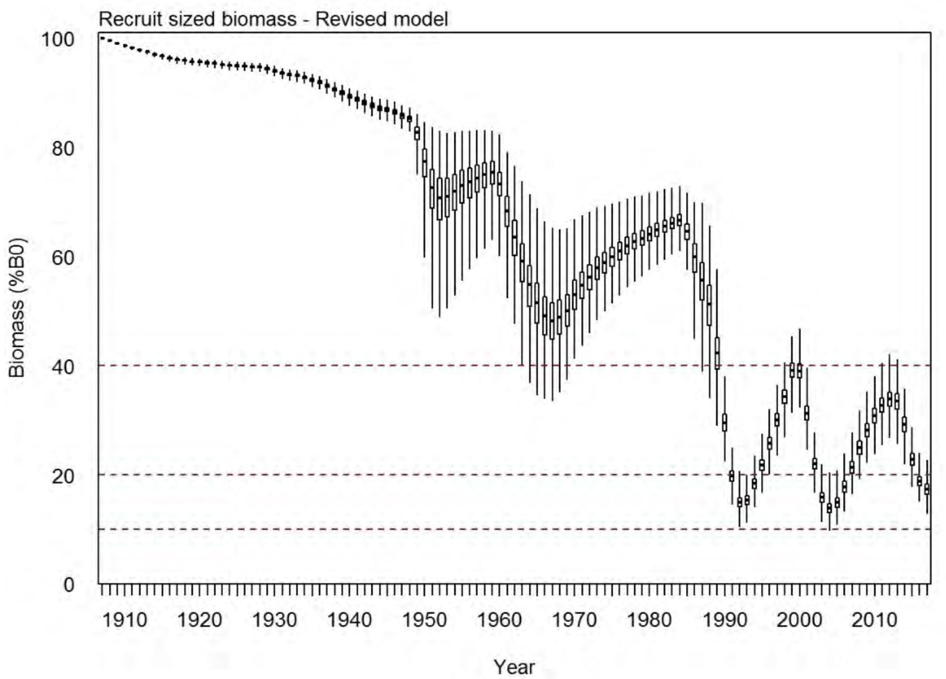
OYU 5 is assessed as a single stock defined by the survey boundaries.

Stock Status	
Year of Most Recent Assessment	2017
Assessment Runs Presented	Basic model (absolute biomass) and revised model (relative biomass)
Reference Points	Target(s): 40% B_0, with at least a 50% probability of achieving the target. Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: Not defined
Status in relation to Target	Unlikely (< 40%) to be at or above the target
Status in relation to Limits	Both models: Likely (> 60%) to be below the Soft Limit and Unlikely (< 10%) to be below the Hard Limit
Status in relation to Overfishing	At a TACC below 30 million oysters, fishing is expected to have no detectable effect. Future stock size is determined by levels of disease mortality and recruitment.

Historical Stock Status Trajectory and Current Status



2017 basic model estimated posterior distributions of Recruit-sized Biomass (rB_{year}) as a percentage of B_0. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median. Significant declines in population size are attributed to epizootics of *Bonamia exitiosa*.



2017 revised model estimated posterior distributions of Recruit-sized Biomass (rB_{year}) as a percentage of B_0. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median. Significant declines in population size are attributed to epizootics of *Bonamia exitiosa*.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	The 2017 abundance and *Bonamia* survey suggests a continued decrease in the recruit-sized population from 688.1 million oysters in 2012 to 385.2 million oysters in 2016 to 363.6 million oysters in 2017. The population sizes of all three size groups of oysters in the Bonamia survey area (46% of the stock assessment survey area, and represented 75% and 69% of the recruit-sized oyster population in 2012 and 2017 respectively) increased between 2017 and 2018. Recruit sized oysters were up 35% to 494.1 million oysters, pre-recruit oysters up 45 % to 178.4 million oysters, and small oysters up 53% to 401.8 million oysters in 2018 (Michael et al. 2018).In 2019, recruit sized oysters further increased 9.8% to 542.5 million, pre-recruit oysters increased 21.4% to 216.5 million, and small oysters increased 48.3% to 595.8 million.
Recent Trend in Fishing Mortality or Proxy	Landings have increased from 7.5 million oysters in 2012 to 13.2 million in 2013, but decreased to 10.0 million in 2015 because of the heightened disease mortality and low recruitment. Landings remained at 10.0 million in 2018.
Other Abundance Indices	Unstandardised catch and effort data are a good proxy for oyster density and are believed to reflect the status of commercial fishery areas. Commercial catch rates increased from 2005, from an annual rate of 1.8 sacks per hour in 2005 to 5.5 sacks per hour in 2013. Since 2013 the rate has decreased to 2.4 sacks per hour in 2018. High grading since 2009 has probably resulted in more conservative estimates of catch and effort.

Trends in Other Relevant Indicators or Variables	From 2005 to 2013, mortality from Bonamia was relatively low (about 10% of recruited oysters), recruitment to the fishery exceeded *B. exitiosa* mortality, and the population size of recruited oysters increased. In 2014, Bonamia infection was still widespread, but patchily distributed in the fishery area. Summer mortality in 2017 was estimated to be about 5%.

Projections and Prognosis	
Stock Projections or Prognosis	Projections from the basic and revised 2017 stock assessment models suggested that recruit-sized stock abundance in 2020, with 0% *B. exitiosa* mortality and a catch level of 15 million oysters, would increase to about 26.9% B_0 or 21.6% B_0 respectively. With a mortality of 20% *B. exitiosa* mortality and a catch level of 15 million oysters, recruit-sized stock abundance would decrease to about 13.8% B_0 or 15.0% B_0 respectively.
Probability of Current Catch or TACC causing biomass to remain below or to decline below Limits	While uncertainty exists in levels of future recruitment and continued *B. exitiosa* related mortality, projections from the Foveaux Strait oyster stock assessment model indicate that current catch limits are unlikely to have any significant negative effect on future stock levels.
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Very Unlikely (< 10%)

Assessment Methodology and Evaluation		
Assessment Type	1 – Full Quantitative Stock assessment	
Assessment Method	Bayesian length based stock assessment model	
Assessment Dates	Latest assessment: 2017	Next full assessment: 2022
Overall Assessment Quality (rank)	1 – High Quality	
Main data inputs (rank)	- catch history (total landings) - unstandardised CPUE - commercial catch length frequency sampling - abundance indices from population surveys	1 – High Quality (all)
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	- Total landings, catch rates and catch size structure updated - New estimates of population size from the 2017 survey included	
Major Sources of Uncertainty	Stock size is highly dependent on the levels of mortality from Bonamia and continued recruitment around the long-term average. Interannual and spatial variability in oyster growth rates may affect transitions of pre-recruit oysters to the recruited oyster population.	

Qualifying Comments
In the absence of disease mortality, and with long-term average recruitment, the fishery has previously shown an ability to rebuild quickly at catches similar to recent levels. Recruitment to the oyster population had been low between 2009 and 2015. The 2016 survey showed that Bonamia infection and summer mortality were relatively low, and there was an upward trend in the

population sizes of all three size groups of oysters. The declining trend in the fishery from 2012 to 2015 has slowed in 2016 and 2017. Because of the relatively low numbers of pre-recruit and small sized oysters, any rebuilding of the recruit-sized population is likely to be slow. At relatively low levels of catch (less than 30 million oysters per year), the future trend in the abundance of oysters in the Foveaux Strait fishery is driven by disease mortality from Bonamia and the levels of recruitment. Disease mortality was low in 2019 and is expected to remain low in 2020. Population sizes of the three size groups of oysters continued to increase between 2018 and 2019. Spat monitoring, catch sampling and the survey data show increased recruitment to the oyster population, and increases in pre-recruit and small oysters will support future increases in recruit-sized oysters. In the medium-term, all the key indicators for the future rebuilding of the OYU 5 fishery are strongly positive.

Environmental and Ecosystem Considerations	
Observer coverage	No observer coverage
Non-target fish and invertebrate catch	In 2007, the OYU 5 Bonamia surveys recorded that the five most commonly caught sessile species (excluding oysters) were hairy mussels *Modiolus areolatus* (80% occurrence), barnacles *Balanus* sp. (61%), kina *Evechinus chloroticus* (61%), nesting mussels *Modiolarca impacta* (53%), and ascidians *Pyura pulla* (51%). The five most commonly occurring motile non-target catch species were brittlestars *Ophiopsammus maculata* (90% occurrence), circular saw shells (gastropods) *Astraea heliotropium* (80%), hermit crabs *Pagurus novizelandiae* (80%), eight armed starfish *Coscinasterias muricata* (63%), and brown dipple starfish *Pentagonaster pulchellus* (54%).
Incidental catch of seabirds	There is no known incidental catch of seabirds from *O. chilensis* oyster fisheries.
Incidental catch of mammals	There is no known incidental catch of mammals from *O. chilensis* oyster fisheries.
Incidental catch of other protected species	There is no known incidental catch of protected fish species from *O. chilensis* oyster fisheries.
Benthic interactions	Dredging damages biogenic/epifaunal reefs, destabilises sediment/shell substrates, suspends sediments and increases water turbidity. Dredging generally results in reduced habitat structure and the loss of long-lived species. Habitats disturbed by dredging tend to become simpler, more homogenous areas typically dominated by opportunistic species Some high-flow and exposed environments are less sensitive to damages from dredging. The magnitude of dredging effects on the benthic environment of the Foveaux strait has been controversial.

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DREDGE OYSTERS (OYS 7) – Nelson/Marlborough

(*Ostrea chilensis*)

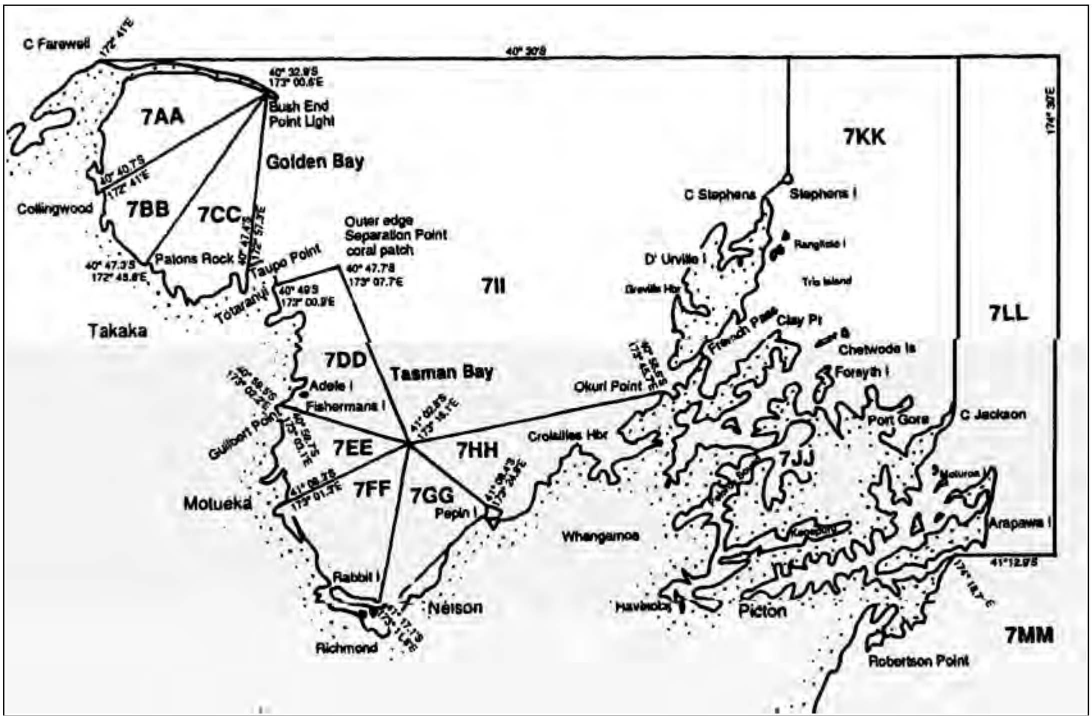


Figure 1: Nelson/Marlborough dredge oyster (OYS 7) stock boundaries and statistical areas.

1. FISHERY SUMMARY

OYS 7 comprises the Nelson/Marlborough area from Cape Farewell in the north, throughout Golden Bay, Tasman Bay and the Marlborough Sounds, to West Head, Tory Channel in the south (see Figure 1). OYS 7 is considered a separate fishery from OYS 7C (West Head, Tory Channel to Clarence Point) on the basis of differences in habitat and environmental parameters. OYS 7 was introduced into the QMS on 1 October 1996 with a TACC of 505 t. There is no TAC for this fishery (Table 1).

Table 1: Total Allowable Commercial Catch (TACC, t) declared for OYS 7 since introduction into the QMS in 1996. There is no Total Allowable Catch, allowances for customary fishing, recreational fishing or for other fishing mortality set (–).

Year	TAC	Customary	Recreational	Other mortality	TACC
1996–present	–	–	–	–	505

1.1 Commercial fishery

Dredge oysters in the Nelson/Marlborough area were first exploited in 1845. From 1963 to 1981 oysters were landed mainly as bycatch, first by the green-lipped mussel (*Perna canaliculus*) dredge fishery and subsequently by the scallop (*Pecten novaezelandiae*) dredge fishery (Drummond 1994a). In 1981 the Challenger scallop fishery was closed and commercial dredge operators started targeting oysters.

Shellfish dredging in Tasman Bay, Golden Bay and the Marlborough Sounds became a multi-species fishery with oysters, scallops and green-lipped mussels caught together. Until 1999, oyster and scallop seasons did not overlap and this prevented both species being landed together. Since then a relaxation of seasonal restrictions has meant there is now potential for the seasons to overlap.

In 1983, fishery regulations and effort restrictions were updated (Drummond 1994a). Fishery regulations included a minimum size (legal sized oysters could not pass through a 58 mm internal diameter ring), an open season (1 March to 31 August), area closures and a prohibition on dredging at night. A 500 t (greenweight) catch restriction was implemented for Tasman Bay in 1986 and extended to include Golden Bay in 1987 (Drummond 1987). The 500 t catch restriction was revoked in 1996 and a TACC of 505 t was set when oysters were brought into the Quota Management System. The commercial oyster season was extended to 12 months and since 1 October 1999 catch has been reported by fishing year, which runs from 1 October to 30 September. Fishers had been required to land all legal sized oysters, but approval was given to return oysters to the sea as long as they are likely to survive.

From 1980, catches of oysters, from Tasman Bay, Golden Bay and the Marlborough Sounds were recorded on weekly dredge forms for each Shellfish Management Area (Table 2). In 1992, the Nelson/Marlborough dredge oyster statistical areas were established (see Figure 1) by adopting the same reporting areas used by the scallop fishery. Prior to 1999, when the oyster season ran from 1 March to 31 August, catch data was presented by calendar year (Table 3). Thereafter reported landings are given by fishing year, 1 October to 30 September. Data from 1989 to 1999 show oysters landed out of season and these data have been included in the summaries shown in Tables 2–4. Most of the catch in OYS 7 comes from Tasman Bay, with small landings from Golden Bay (Table 4).

In recent years, the industry has voluntarily restricted catch levels according to the biomass and distribution of the population estimated in the annual biomass survey, and the economics of catch per unit effort during the season. Landings are reported in greenweight and have been negligible since 2008–09 (see Figure 2).

Table 2: Reported and adjusted catch (t, greenweight) in the Challenger fishery, 1963–88 (from Annala et al. 2001). Sourced from MAF Marine Dept. Report on Fisheries between 1963 and 1980, the FSU database between 1981 and 1986, and Quota Management System (QMS) in 1987 and 1988. Catches are adjusted to account for non-reporting of factory reject oysters (16.2% by number) and use of an incorrect conversion factor.

Year	Reported catch	Adjusted catch	Year	Reported catch	Adjusted catch	Year	Reported catch	Adjusted catch
1963	3	3	1972	65	82	1981	389	492
1964	6	8	1973	190	240	1982	432	546
1965	0	0	1974	78	99	1983	593	750
1966	24	33	1975	136	172	1984	259	328
1967	44	57	1976	392	496	1985	405	512
1968	69	87	1977	212	268	1986	527	667
1969	22	28	1978	40	51	1987	380	–
1970	74	94	1979	83	105	1988	256	–
1971	34	43	1980	160	202			

Table 3: Reported landings (t, greenweight) in the Challenger fishery for the 1989–99 oyster seasons (1 March–31 August). Data extracted from Fisheries New Zealand database, originally reported on Quota Monitoring Returns (QMR).

Year	QMR	Year	QMR
1989	538	1995	694
1990	206	1996	572
1991	187	1997	447
1992	290	1998	436
1993	476	1999	335
1994	584		

Table 4: Reported landings (t, greenweight) in the Challenger fishery after October 1999 when the fishing season was extended to a full year (1 October–30 September). Data extracted from Fisheries New Zealand database, originally reported on Quota Monitoring Returns (QMR) for 1999–00 and 2000–01 and on Monthly Harvest Returns (MHR) thereafter.

Fishing year	QMR	MHR
1999–00	132	–
2000–01	25	–
2001–02	–	1.4
2002–03	–	183.0
2003–04	–	97.5
2004–05	–	146.8
2005–06	–	170.9
2006–07	–	132.1
2007–08	–	21.0
2008–09	–	< 0.1
2009–10	–	0.0
2010–11	–	5.9
2011–12	–	0.0
2012–13	–	0.0
2013–14	–	1.37
2014–15	–	0.094
2015–16	–	0.3
2016–17	–	0.1
2017–18	–	0
2018–19	-	0

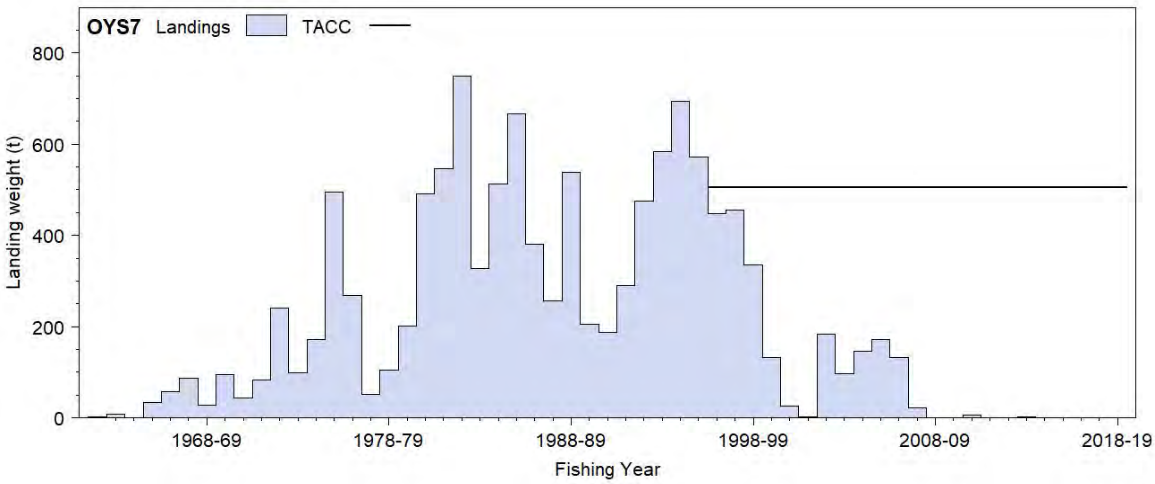


Figure 2: Landings of oysters from OYS 7 (t, green weight). Oyster season 1 March to 31 August for years 1963 to 1999. No seasonal restrictions from the 1999−2000 fishing year (October stock) shown as year 2000 onwards. Adjusted catch 1963−86; reported catch 1987−88; Quota Monitoring Returns (QMR) 1989–2001; and Monthly Harvest Returns (MHR) 2002 to present. TACC from 1996.

1.2 Recreational fishery

The recreational daily bag limit for oysters in the Challenger fishery area is 50 per person. Oysters that cannot pass through a 58 mm internal diameter solid ring are deemed legal size. The recreational season for dredge oysters in the Challenger area is all year round. Oysters must be landed in their shells. Recreational fishers take oysters in Tasman and Golden Bays by diving and dredging. Estimates of recreational harvest of all species combined, including harvest reported using generic descriptions such as "oysters" from various surveys are given in Table 5. Harvest aggregated across species of oysters is given here because some surveys did not differentiate between species and others included a large proportion of total harvest recorded against generic codes.

Table 5: Estimated numbers of oysters (all species combined) harvested by recreational fishers in OYS 7, excluding s111 approvals. Estimates from telephone-diary survey in 1991–92, 1996, 1999–00 and 2000–01, from an access point interview survey in 2003–04 (CV is approximate), and from the National Panel Surveys in 2011–12 and 2017–18.

Survey	Numbers	CV	Reference
1991–92	38 000	0.33	Teirney et al (1997)
1996	182 000	–	Bradford (1998)
1999–00	114 000	0.52	Boyd & Reilly (2002)
2000–01	80 000	0.46	Boyd et al. (2004)
2003–04	5 800	0.22	Cole et al. (2006)
2011–12	13 523	0.76	Wynne-Jones et al. (2014)
2017–18	3 477	1.00	Wynne-Jones et al. (2019)

1.3 Customary fisheries
There are no data available on the customary catch.

1.4 Illegal catch
There is no quantitative information on the level of illegal catch.

1.5 Other sources of mortality
The Nelson/Marlborough area occasionally experiences blooms of diatoms, which result in an anaerobic slime that smothers benthic fauna (Bradford 1998, Mackenzie et al. 1983, Tunbridge 1962). The level of dredge oyster mortality from this source is unknown.

Bonamia exitiosa (Bonamia) is a haemocritic, haplosporid parasite (infects mainly haemocytes or blood cells) of flat oysters and is known to infect *Ostrea chilensis* in New Zealand and Chile and various other species of *Ostrea* in other countries. Bonamia has caused catastrophic mortality in the Foveaux Strait oyster fishery and is endemic in oysters in the OYS 7 area (Hine, pers. comm.). *Apicomplexan* has also been identified in poor-condition oysters dredged from Tasman Bay. *Apicomplexan* is a group of obligate pathogens that are thought to predispose oysters to infection by Bonamia. The level of mortality caused by disease agents in OYS 7 is unknown.

Drummond & Bull (1993) reported some incidental mortality from dredging. No other data are available on incidental mortality of oysters in OYS 7 caused by fishing. A study on incidental mortality of oysters was completed by Cranfield et al. (1997), however, this work was specific to the Foveaux Strait oyster fishery so may or may not have relevance to OYS 7.

2. BIOLOGY

The biology of *O. chilensis* was summarised by Handley & Michael (2001), and further biological data were presented in Brown et al. (2008). Most of the parameters required for management purposes are based on the Foveaux Strait fishery described by Cranfield & Allen (1979).

Oysters in OYS 7 (Tasman Bay) tend to be uniformly distributed at a lower density on muddy habitat. Environmental factors such as hydrodynamics, seasonal water temperature and riverine inputs differ substantially among the OYS 7, OYS 7C and OYU 5 areas and these factors will influence the biological characteristics of these oyster populations.

Oyster stocks in the OYS 7 area are generally low and seasonally variable, suggesting high variability in recruitment (Osborne 1999). Challenger oysters are reported to spawn at temperatures above 12°C (Brown et al. 2008). Compared to the Foveaux Strait fishery, in Tasman and Golden Bay significantly smaller and less developed larvae have been collected in the plankton, implying that Challenger oysters appear to release their larvae into the plankton for longer periods (Cranfield & Michael 1989). Cranfield & Michael (1989) estimated that the larvae could disperse 20 km in 5–12 days, but a more recent study concluded that although a small proportion may travel several kilometres, the majority of the larvae disperse no further than a few hundred metres from the parent population (Brown et al. 2008). Tunbridge (1962), Stead (1976) and Drummond (1994a) all pointed out that the productivity of the fishery is likely to be limited by a paucity of settlement substrate in the soft sediment habitat of Tasman and Golden Bay. Brown et al. (2008) demonstrated increased oyster productivity where shell material was placed on the seabed as a settlement substrate for oyster larvae, and oyster productivity was higher in areas enhanced with brood stock.

The variability in shell shapes and high variability in growth rate between individuals, between areas within the OYS 7 fishery, and between years, require careful consideration in describing growth. Assuming that the minimum legal size of oysters could range in diameter (1/2 length + height) from 58 mm to 65 mm, data from Drummond (1994b) indicated that Tasman Bay oysters could grow to legal size in two to three years. Modelling of limited data from Tasman Bay in Brown et al. (2008) indicated that 77% of three-year-old oysters and 82% of 4-year-old oysters would attain lengths greater than the minimum legal size of 58 mm length at the start of the fishing season. Osborne (1999) used results from a MAF Fisheries study conducted between 1990 and 1994 to construct a von Bertalanffy equation describing oyster growth in the OYS 7 fishery. Estimated biological parameters including instantaneous natural mortality (*M*) from Drummond (1993, 1994b) and growth parameters for von Bertalanffy equations from Osborne (1999) and from Brown et al. (2008) are given in Table 6. Mortality estimates by Drummond (1994b) and growth parameters in Osborne (1999) were derived from a tagging study conducted in Tasman Bay between 1990 and 1992 (Drummond 1994a). Von Bertalanffy growth parameters in Brown et al. (2008) were estimated based on a limited data set from enhanced habitat experiments, and describe growth of young oysters. Estimates of *M* based on experimental data from Foveaux Strait and Tasman Bay ranged from 0.042 (Dunn et al. 1998) to 0.92 (Drummond et al. 1994a). However, after some discussion the Shellfish Working Group (SFWG) concluded that those figures were not realistic, and that *M* was likely to lie between 0.1 and 0.3.

Table 6: Estimated biological parameters for oysters in OYS 7. Mortality (M) estimates from Drummond (1993, 1994b). Parameters derived for von Bertalanffy equations describing growth of oysters (diameter in millimetres) in Tasman Bay from Osborne (1999) and Brown et al. (2008).

Parameter	Estimate	Uncertainty		Source
	mean	s.d.	95% c.i.	
M	0.92	-	0.48	Drummond (1994)
M	0.2	-	-	Drummond (1993)
k	0.99	0.16	-	Brown et al. (2008)
k	0.597	-	-	Osborne (1999)
L_{inf}	67.52	3.91	-	Brown et al. (2008)
L_{inf}	85.43	-	-	Osborne (1999)
t_0	0.11	0.02	-	Brown et al. (2008)

3. STOCKS AND AREAS

Patches of commercial densities of oysters within the OYS 7 fishery are largely restricted to Tasman Bay. The oyster population in OYS 7 is likely to be biologically isolated from populations in Foveaux Strait (OYU 5) and the Chatham Islands (OYS 4) on the basis of geographical distance. The populations in OYS 7 and OYS 7C could also be biologically distinct due to their geographical separation, potentially causing limited dispersal of larvae between the two areas.

4. STOCK ASSESSMENT

Scallop and oyster surveys that estimated oyster densities since 1959 are shown in Table 7. Surveys between 1959 and 1995 used different dredges, survey designs and methods and are not comparable. Surveys since 1996 have estimated oyster biomass concurrently with scallops from one- or two-phase, stratified random designs, but strata have not been optimised for oysters. Although surveys of oyster biomass are comparable from 1996, the high CV limit the usefulness of these survey data to establish meaningful trends in the fishery.

Table 7: Surveys of oysters in Tasman Bay (TB), Golden Bays (GB) and the Marlborough Sounds (MS) from 1959 to present. Surveys either targeted oysters (Target species) to estimate oyster density and distribution or sampled oysters concurrently in surveys targeting scallops (Scallops), but without optimising survey designs for oysters.

Survey	Location	Target species	Survey design	Reference
1959–60	TB	Scallops	Targeted	Choat (1960)
1961	TB, GB	Oysters	Grid and targeted	Tunbridge (1962)
1969–75	TB, GB	Oysters	Targeted	Stead (1976)
1984–86	TB, GB	Oysters	Grid	Drummond (unpub. report)
1996	TB, GB, MS	Scallops	Two-phase stratified random	Cranfield et al. (1996)
1997	TB, GB, MS	Scallops	Two-phase stratified random	Cranfield et al. (1997)
1998	TB, GB, MS	Scallops	Two-phase stratified random	Osborne (1998)
1999	TB, GB, MS	Scallops	Two-phase stratified random	Breen & Kendrick (1999)
2000	TB, GB, MS	Scallops	Two-phase stratified random	Breen (2000)
2001	TB, GB, MS	Scallops	Two-phase stratified random	Horn (2001)
2002	TB, GB, MS	Scallops	Two-phase stratified random	Horn (2002)
2003	TB, GB, MS	Scallops	Two-phase stratified random	Horn (2003)
2004	TB, GB, MS	Scallops	Two-phase stratified random	Horn (2004)
2005	TB, GB, MS	Scallops	Two-phase stratified random	Horn (2005)
2006	TB, GB, MS	Scallops	Two-phase stratified random	Horn (2006)
2007	TB, GB, MS	Scallops	Two-phase stratified random	Brown (2007)
2008	TB, GB	Scallops	Two-phase stratified random	Brown et al. (2008)
2009	TB, GB, MS	Scallops	Single-phase stratified random	Williams et al. (2009)
2010	TB	Oysters	Grid and targeted	Michael (2010)
2010	TB, GB, MS	Scallops	Single-phase stratified random	Williams et al. (2010)
2011	TB, GB, MS	Scallops	Single-phase stratified random	Williams & Michael (2011)
2012	TB, GB, MS	Oysters	Single-phase stratified random	Williams & Bian (2012)
2013	MS	Scallops	Single-phase stratified random	Williams et al. (2013a)
2014	TB, GB, MS	Scallops	Single-phase stratified random	Williams et al. (2014a)
2015	TB, GB, MS	Scallops	Single-phase stratified random	Williams et al. (2015a)
2015	TB, GB, MS	Scallops	Single-phase stratified random	Williams et al. (2015b)
2017	TB, GB, MS	Scallops	Single-phase stratified random	Williams et al. (2017)
2018	MS	Scallops	Single-phase stratified random	Williams et al. (2018)
2019	MS	Scallops	Single-phase stratified random	Williams et al. (2019)

4.1 Estimates of fishery parameters and abundance

Growth and mortality are poorly estimated for oysters from OYS 7. Growth estimates from Drummond's (1994b) mark recapture data and estimates from Osborne (1999) give von Bertalanffy parameter estimates of 79.6 and 85.4 for L_∞, and 2.03 and 0.60 for k respectively. Drummond (1994b) estimated M=0.92 (considered unlikely by the Shellfish Working Group) and M=0.17. The Shellfish Working Group considers M is most likely to lie between 0.1 and 0.3.

Estimates of the numbers of recruits (oysters unable to pass through a 58 mm ring) and pre-recruits (less than 58 mm) from Tasman Bay and Golden Bay since 1998 are shown in Table 8.

4.2 Biomass estimates

Estimates of the recruited biomass (≥ 58 mm) of oysters in both Tasman Bay and Golden Bay (made from surveys of oysters and scallops combined) show a general decline from 1998 to 2012 (Table 9).

Table 8: Relative estimates (millions) uncorrected for dredge efficiency of recruited and pre-recruit oysters in Tasman and Golden Bays from surveys (1998 to present).

	Tasman Bay				Golden Bay			
Year	**Recruits**	**CV**	**Pre-recruits**	**CV**	**Recruits**	**CV**	**Pre-recruits**	**CV**
1998	28.7	7.3	30.4	10.1	1.4	13.3	0.4	18.7
1999	24.7	8.6	39.6	13.6	1.9	23.7	1.2	24.8
2000	21.8	8.9	33.5	9.9	1	14.3	0.5	17.6
2001	17.8	9	23.1	9.1	0.4	20.1	0.4	28.1
2002	15.9	10.6	24.5	11.2	0.4	21.4	0.3	27.1
2003	12.4	9.7	34.3	13.4	0.4	27.1	0.4	27.6
2004	10.9	6.7	16.1	8.1	0.4	25.4	0.2	18.8
2005	11.3	10.2	25.2	17.7	0.3	38.8	0.3	41.6
2006	10.7	8.6	18.5	14.8	0.1	29.1	0.04	46.6
2007	14.8	14.3	6.5	19.4	0.1	32	0.04	32.3
2008	9.6	20.5	8.9	25.2	0.04	47.1	0.01	39.5
2009	14.7	20	18.8	36	–•	–•	–•	–•
2010	14	26	9	54	–•	–•	–•	–•
2011	8	48	19	61	–•	–•	–•	–•
2012	6.8	22	21	21	–•	–•	–•	–•
2013	–•	–•	–•	–•	–•	–•	–•	–•
2014	–•	–•	–•	–•	–•	–•	–•	–•
2015	–•	–•	–•	–•	–•	–•	–•	–•
2016	–•	–•	–•	–•	–•	–•	–•	–•
2017	–•	–•	–•	–•	–•	–•	–•	–•
2018	–•	–•	–•	–•	–•	–•	–•	–•

• Golden Bay has not been surveyed since 2009 because this area has not been targeted for commercial fishing.
• Tasman Bay has not been surveyed since 2012.

Table 9: Estimates of relative biomass (t) of recruited oysters from Tasman and Golden Bays (1998 to present).

	Tasman Bay		Golden Bay					
Year	**Biomass (t)**	**CV**	**Biomass (t)**	**CV**	**Total biomass (t)**	**References**	**Total catch (t)**	**Exploitation rate (catch/biomass)**
1998	2 214	7.3	113	11.5	2 327	Osborne (1999)	436	0.19
1999	2 012	8.1	151	22.1	2 163	Breen & Kendrick (1999)	335	0.15
2000	1 810	8.8	86	15.4	1 895	Breen (2000)	132	0.07
2001	1 353	9.7	25	20.3	1 378	Horn (2001)	25	0.02
2002	1 134	10	28	21.9	1 162	Horn (2002)	1	0.00
2003	1 019	10	23	26.6	1 042	Horn (2003)	183	0.18
2004	894	6.9	28	22.4	921	Horn (2004)	98	0.11
2005	932	11.3	24	30.8	956	Horn (2005)	147	0.15
2006	817	26.1	10	8.0	827	Horn (2006)	171	0.21
2007	1 275	13.5	10	31.4	1 285	Brown (2007)	132	0.10
2008	744	20.8	3	52.0	747	Tuck & Brown (2008)	21	0.03
2009	1 208	19	–•	–•	1 208	Williams et al. (2009)	0	0.00
2010	1 259	27	–•	–•	1 259	Williams et al. (2010)	0	0.00
2011	622	42	–•	–•	622	Williams & Michael (2011)	6	0.01
2012	567	23	–•	–•	567	Williams & Bian (2012)	0	0.00
2013	–•	–•	–•	–•	–•			
2014	–•	–•	–•	–•	–•			
2015	–•	–•	–•	–•	–•			
2016	–•	–•	–•	–•	–•			
2017	–•	–•	–•	–•	–•			
2018	–•	–•	–•	–•	–•			

• Golden Bay has not been surveyed since 2009 because this area has low densities of oysters and is not targeted for commercial fishing.
• Tasman Bay has not been surveyed since 2012.

4.3 Yield estimates and projections

Drummond (1994b) estimated a MCY of 300 tonnes using Method 4 in the Guide to Biological Reference Points (see Introduction to this Plenary), but Osborne concluded that catch levels in OYS 7 appear to be driven by the economics of the catch rates (Osborne 1999). Equation 2 of the Guide to Biological Reference Points was used to estimate MCY (Table 10):

$$MCY = 0.5F_{0.1}B_{AV}$$

Where B_{AV} = 1191 tonnes (from relative biomass estimates from CSEC surveys 1998 to 2012). The natural mortality (*M*) values used in the yield calculations were restricted to the range 0.1 to 0.3. This was reduced from the previous range of 0.042 to 0.9 because the extreme values were considered, by the SFWG, to be very unlikely. These estimates are not corrected for dredge efficiency (assumed to be 100%) and are likely to be conservative.

Table 10: Estimates of $F_{0.1}$ and MCY for *M* 0.1–0.3. MCY 1 was estimated using $F_{0.1}$1 from Osborne (1999), MCY 2 from $F_{0.1}$2 estimated from von Bertalanffy growth parameters estimated by Osborne (1999), growth data from Drummond (1994b) and Foveaux Strait oyster size weight data, and MCY 3 from $F_{0.1}$3 estimated von Bertalanffy growth parameters from GROTAG using the same growth and size weight data.

M	$F_{0.1}$ 1	MCY 1	$F_{0.1}$ 2	MCY 2	$F_{0.1}$ 3	MCY 3
0.1	0.29	173	0.17	101	0.22	131
0.2	–		–		0.38	226
0.3	0.45	268	0.38	226	0.55	327

CAY was estimated for OYS 7 using Method 1 of the Guide to Biological Reference Points assuming dredge oysters are landed over the year, and using $F_{0.1}$ estimated by three different methods, a range of assumed *M* (0.1 to 0.3), and the 2012 estimate of recruited biomass (567 t; Table 11).

$$CAY = \frac{F_{ref}}{F_{ref} + M}\left(1 - e^{-(F_{ref}+M)}\right)B_{beg}$$

Table 11: Estimates of CAY for OYS 7 using different estimates of $F_{0.1}$ over a range of assumed values for *M* (0.1–0.3), and an estimate of recruited biomass in 2012 (567 t). CAY 1 was estimated using $F_{0.1}$1 from Osborne (1999), CAY 2 from $F_{0.1}$2 estimated from von Bertalanffy growth parameters estimated by Osborne (1999) using growth data (Drummond 1994b) and Foveaux Strait oyster size weight data, CAY 3 from $F_{0.1}$3 estimated von Bertalanffy growth parameters from GROTAG using the same growth and size weight data.

M	$F_{0.1}$ 1	CAY 1	$F_{0.1}$ 2	CAY 2	$F_{0.1}$ 3	CAY 3
0.1	0.29	136	0.17	84	0.22	107
0.2	–		–		0.38	163
0.3	0.45	180	0.38	156	0.55	210

The risk to the stock associated with harvesting at the estimated CAYs cannot be determined.

4.4 Other yield estimates and stock assessment results

There are no other yield estimates and stock assessments.

4.5 Other factors

The challenger dredge oyster fishery is thought to be recruitment-limited. Drummond (1994a), Stead (1976) and Tunbridge (1962) attributed the lack of dense aggregations of oysters in the Challenger fishery (compared to Foveaux Strait) to a scarcity of suitable settlement surfaces. Challenger Oyster Enhancement Company (COEC) initiated habitat enhancement trials in 2008, aimed at boosting productivity of the fishery (Brown et al. 2008), but these areas have been bottom trawled and there has been no monitoring to determine the effectiveness of the enhancement.

5. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS

This section was reviewed by the Aquatic Environment Working Group for inclusion in the Fishery Assessment Plenary November 2014. A broader summary of information on a range of issues related to the environmental effects of fishing and aspects of the marine environment and biodiversity of relevance to fish and fisheries is available in the Aquatic Environment and Biodiversity Annual Review (Ministry for Primary Industries 2019).

5.1 Role in the ecosystem

Dredge oysters (*Ostrea chilensis*) are benthic, epifaunal, sessile bivalve molluscs that have a relatively limited pelagic larval dispersal phase. They are patchily distributed around the New Zealand coast on a variety of substrates (biogenic reef, gravel, sand, mud) in intertidal to subtidal inshore waters, commonly in depths of up to 60 m or more. Commercially exploited beds of oysters occur in Foveaux Strait (OYU 5), Tasman Bay (OYS 7), and Cloudy and Clifford Bays (OYS 7C). Beds at the Chatham Islands (OYS 4) have potential for commercial exploitation. Oysters play important roles in the ecosystem that include influencing water quality by filtering phytoplankton and other suspended particles from the seawater, linking primary production with higher trophic levels, and acting as ecosystem engineers by stabilising sediments and providing structural habitat (biogenic reef) for other taxa (e.g., algae, ascidians, bryozoans, sponges, echinoderms, worms, molluscs, crustaceans, fish).

5.1.1 Trophic interactions

Oysters are active suspension feeders, consuming phytoplankton suspended in the water column. Their diet is the same as or similar to that of many other suspension feeding taxa, including other bivalves such as scallops, clams and mussels. Oysters are probably prey for a wide range of invertebrate and fish predators, but published records of known or suspected predators are limited. Reported invertebrate predators of *O. chilensis* include brittlestars (*Ophiopsammus maculata*) (Stead 1971), starfish (*Coscinasterias calamaria* and *Astrostole scabra*) (Cranfield 1979) and flatworms (*Enterogonia orbicularis*) (Handley 2002); suspected invertebrate predators include octopus (*Pinnoctopus cordiformis*) and shell boring gastropods (*Poirieria zelandica*, *Xymeme ambiguous* and *Xymenella pusillis*) (Brown 2012). Predators of oysters probably change with oyster size. Most mortality of oyster spat (small juveniles) during their first winter appears to result from predation by polychaetes, crabs and gastropods (Ministry for Primary Industries 2013).

5.2 Non-target catch of fish and invertebrates

A range of non-target fish and invertebrate species are caught and discarded by dredge fisheries for *O. chilensis*. No data are available on the level or effect of this non-target catch and discarding by the fisheries. Invertebrate non-target catch data are available from dredge surveys of the oyster stocks, and the non-target catch of the fisheries is likely to be similar to that of the survey tows conducted in areas that support commercial fishing. Fish non-target catch data are generally not recorded on surveys, presumably because fish constitute a small fraction of the total non-target catch.

In OYS 7 (Tasman/Golden Bays), data on the non-target catch of the 1994–2014 dredge surveys have been collected but not analysed, except for preliminary estimation of the 1998–2013 non-target catch trajectories (Williams et al. 2014b). The surveys record the non-target catch of other target species of scallops (*Pecten novaezelandiae*) and green-lipped mussels (*Perna canaliculus*), and various other non-target catch in nine categories (Williams et al. 2014b). Observation of the 2014 survey sampling identified a problem with the way these categorical non-target catch data have been recorded, which limits their utility (Williams et al. 2014a).

5.2.1 Non-target catch in other oyster stocks

In OYU 5 (Foveaux Strait), Fleming (1952) sampled the macrofaunal non-target catch of oyster fishing in a ‘near virgin’ area of the fishery in 1950. More recently, presence-absence data on the non-target catch of oyster dredging have been recorded during surveys and in fishers’ logbooks (Michael 2007). In a specific study of the benthic macrofauna non-target catch of the 2001 oyster dredge survey in Foveaux Strait, Rowden et al. (2007) identified at least 190 putative species representing 82 families and 12 phyla; ‘commercial’ survey strata were principally characterised by the families Balanidae (barnacles), Mytilidae (mussels), Ophiodermatidae (brittle stars), Ostreidae (oysters) and Pyuridae (tunicates). For the 2007 survey of OYU 5, Michael (2007) listed the percentage occurrence of sessile and motile species caught as non-target catch in the survey dredge tows. The five most commonly caught sessile species (excluding oysters) were hairy mussels *Modiolus areolatus* (80% occurrence), barnacles *Balanus* sp. (61%), kina *Evechinus chloroticus* (61%), nesting mussels *Modiolarca impacta* (53%), and ascidians *Pyura pulla* (51%). The five most commonly occurring motile non-target catch species were brittlestars *Ophiopsammus maculata* (90% occurrence), circular saw shells (gastropods) *Astraea heliotropium* (80%), hermit crabs *Pagurus novizelandiae* (80%), eight armed starfish *Coscinasterias muricata* (63%), and brown dipple starfish *Pentagonaster pulchellus* (54%). Common non-target catch species of oyster dredge surveys in Foveaux Strait were reported by Michael (2007) and are listed below in Table 12.

Table 12: Invertebrate species commonly caught as non-target catch in dredge surveys of oysters (*O. chilensis*) in Foveaux Strait. Sourced from Michael (2007).

Type	Species
Infaunal bivalves	*Glycymeris modesta* (small dog cockle), *Tawera spissa* (morning star shell), *Tucetona laticostata* (large dog cockle), *Pseudoxyperas elongata* (‘tuatua’), *Venericardia purpurata* (purple cockle)
Epifaunal bivalves	*Modioilus areolatus* (hairy mussel), *Modiolarca impacta* (nesting mussel), *Aulacomya atra maoriana* (ribbed mussel), *Barbatia novaezelandiae* (ark shell), *Pecten novaezelandiae* (scallop), *Chlamys zelandiae* (lions paw scallop), *Neothyris lenticularis* (large lantern shell), *N. compressa* (compressed lantern shell)
Sponges	*Chondropsis* topsentii (cream sponge), *Crella incrustans* (red-orange sponge), *Dactylia palmata* (finger sponge)
Ascidians	*Pyura pachydermatina* (kaeo), *P. pulla*
Algae	Red algae spp.
Bryozoans	*Celleporaria agglutinans* (hard/plate coral), *Cinctipora elegans* (reef-building bryozoan), *Horera foliacea* (lace coral), *Hippomenella vellicata* (paper coral), *Tetrocycloecia neozelanica* (staghorn coral), *Orthoscuticella fusiformis* (soft orange bryozoan)
Barnacles and chitons	*Balanus decorus* (large pink barnacle), *Cryptochonchus porosus* (butterfly chiton), *Eudoxochiton nobilis* (noble chiton), *Rhyssoplax canaliculata* (pink chiton)
Starfish, brittlestars and holothurians	*Coscinasterias muricata* (eight armed starfish), *Pentagonaster pulchellus* (brown dipple starfish), *Ophiosammus maculata* (snaketail brittlestar), *Australostichopus mollis* (sea cucumber)
Crabs	*Pagurus novaezelandiae* (hermit crab), *Eurynolambrus australis* (triangle crab), *Metacarcinus novaezelandiae* (cancer crab), *Nectocarcinus* sp. (red crab)
Urchins	*Evechinus chloroticus* (kina), *Apatopygus recens* (heart urchin), *Goniocidaris umbraculum* (coarse-spined urchin), *Pseudechinus novaezelandiae* (green urchin), *P. huttoni* (white urchin), *P. albocinctus* (red urchin)
Gastropods	*Astraea heliotropium* (circular saw shell), *Alcithoe arabica* (volute), *Argobuccinum pustulosum tumidum, Turbo granosus, Cabestana spengleri, Charonia lampras*
Octopuses	*Pinnoctopus cordiformis* (common octopus), *Octopus huttoni* (small octopus)

In OYS 7C (Cloudy/Clifford Bays), a dredge survey of oysters in Cloudy and Clifford Bays was conducted in 2006, and the survey skipper recorded qualitative comments on the non-target catch of each tow, which included ‘coral’, ‘sticks and seaweed’, shells, volutes, ‘red weed’, horse mussels, shell with worm, small crabs, mussels and scallops (Brown & Horn 2006).

In OYS 4 (Chatham Islands), data on the non-target catch of a 2013 dredge survey of oysters off the north coast of Chatham Island were recorded (as estimated volumes of different non-target catch categories) but not analysed (Williams et al. 2013b).

5.3 Incidental catch of seabirds, mammals and protected fish

There is no known incidental catch of seabirds, mammals or protected fish species from *O. chilensis* oyster fisheries.

5.4 Benthic interactions

There are a variety of benthic habitats in the different oyster fisheries areas, which generally occur either on coarse substrates usually found in areas of high natural disturbance (Foveaux Strait, Cloudy/Clifford Bays and the Chatham Islands) or on fine substrates typical of sheltered areas (Tasman Bay). Benthic habitats within the Foveaux Strait oyster fishery area were classified by Michael (2007) and comprise a variety of sand/gravel/shell flats and waves, rocky patch reef, and biogenic areas. Cranfield et al. (1999) referred to the latter as epifaunal reefs that he defined as 'tidally oriented, linear aggregations of patch reefs formed by the bryozoan *Cinctipora elegans*, cemented by encrusting bryozoans, ascidians, sponges and polychaetes'. Cranfield et al.'s papers (Cranfield et al. 1999, Cranfield et al. 2001, Cranfield et al. 2003) suggested that epifaunal reefs are oyster habitat, but Michael's reports (Michael 2007, 2010) state that commercial fishing for oysters is mainly based on sand, gravel and shell habitats with little epifauna. In Foveaux Strait, commercial oyster dredging occurs within an area of about 1000 km^2 (although only a portion of this is dredged each year), which is about one-third of the overall OYU 5 stock area (Michael 2010). Habitats within the Cloudy/Clifford Bays and the Chatham Islands fisheries areas have not been defined. The benthic habitat within the Tasman Bay oyster fishery area is predominately mud, although to some extent this may have been affected by land-based sedimentation into the bay and homogenisation of the substrate by dredging and trawling (Brown 2012).

It is well known that fishing with mobile bottom contact gears such as dredges has impacts on benthic populations, communities and their habitats (e.g., Kaiser et al. 2006, Rice 2006). The effects are not uniform, but depend on at least: 'the specific features of the seafloor habitats, including the natural disturbance regime; the species present; the type of gear used, the methods and timing of deployment of the gear, and the frequency with which a site is impacted by specific gears; and the history of human activities, especially past fishing, in the area of concern' (Department of Fisheries and Oceans 2006). In New Zealand, the effects of oyster dredging on the benthos have been studied in Foveaux Strait (OYU 5) (Cranfield et al. 1999, Cranfield et al. 2001, Cranfield et al. 2003, Michael 2007) and Tasman/Golden Bays (OYS 7) (Tuck et al. 2011). The results of these studies are summarised in the Aquatic Environment and Biodiversity Annual Review (Ministry for Primary Industries 2019), and are consistent with the global literature: generally, with increasing fishing intensity there are decreases in the density and diversity of benthic communities and, especially, the density of emergent epifauna that provide structured habitat for other fauna.

The effects of dredging (Ministry for Primary Industries 2019) may be more severe in sheltered areas (e.g., Tasman Bay) than in exposed areas (e.g., Foveaux Strait, Cloudy/Clifford Bays, Chatham Islands). Dredging damages epifauna, and erect, structured habitats, such as biogenic/epifaunal reefs, are the most sensitive to dredging disturbance. Dredging destabilises sediment/shell substrates, suspends sediments and increases water turbidity; the sensitivity of habitats to suspended sediments and their deposition probably varies depending on the prevailing natural flow regime, being greater in muddy sheltered areas than in high flow environments. Habitats disturbed by dredging tend to become simpler, more homogenous areas typically dominated by opportunistic species. Dredging generally results in reduced habitat structure and the loss of long-lived species.

For studies of the effects of oyster dredging in Foveaux Strait, interpretation of the authors differ (Ministry for Primary Industries 2019): 'Cranfield et al.'s papers (Cranfield et al. 1999, Cranfield et al. 2001, Cranfield et al. 2003) concluded that dredging biogenic reefs for their oysters damages their structure, removes epifauna, and exposes associated sediments to resuspension such that, by 1998, none of the original bryozoan reefs remained. Michael (2007) concluded that there are no experimental estimates of the effect of dredging in the strait or on the cumulative effects of fishing or regeneration, that environmental drivers should be included in any assessment, and that the previous conclusions cannot be supported. The authors agree that biogenic bycatch in the fishery has declined over time in regularly fished areas, that there may have been a reduction in biogenic reefs in the strait since the 1970s, and that simple biogenic reefs appear able to regenerate in areas that are no longer fished (dominated by byssally attached mussels or reef-building bryozoans). There is no consensus that reefs in Foveaux Strait were (or were not) extensive or dominated by the bryozoan *Cinctipora*.'

Some areas of the Foveaux Strait (OYU 5) oyster fishery are also commercially fished (potted) for blue cod (*Parapercis colias*), and Cranfield et al. (2001) presented some evidence to suggest that dredged benthic habitats and blue cod densities regenerated in the absence of oyster dredging. Bottom trawling also occurs within the OYU 5 area, but there is little overlap with the main areas fished for oysters. In OYS 7, other benthic fisheries (e.g., bottom trawl, scallop, green-lipped mussel) occur and probably also interact with oysters and their habitats.

5.5 Other considerations

5.5.1 Spawning disruption

Fishing during spawning may disrupt spawning activity or success. In the Foveaux Strait fishery, the traditional harvesting period (1 March to 31 August) occurs after the main spring and summer peaks in oyster spawning activity (Jeffs & Hickman 2000). Fishing-induced damage to oysters incurred during the period before spawning could interrupt gamete maturation. Oyster fishing also targets high-density beds of oysters, which are disproportionately more important for fertilisation success during spawning.

5.5.2 Habitat of particular significance for fisheries management

None currently identified.

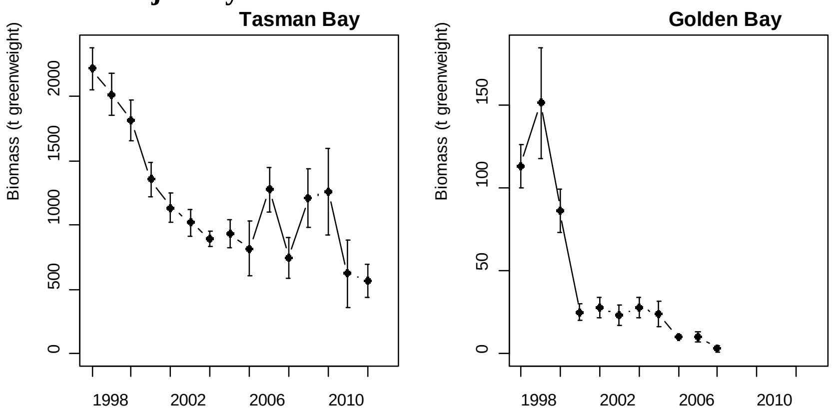
6. STATUS OF THE STOCKS

Stock structure assumptions

Current management assumes that the Challenger (OYS 7) oyster fishery is separate from the other oyster fisheries (i.e., Foveaux Strait (OYU 5), Tory Channel, Cloudy and Clifford Bays (OYS 7C), and the Chatham Islands (OYS 4)). The stock structure of OYS 7 is assumed to be a single biological stock, although the extent to which the populations in Tasman Bay, Golden Bay and the Marlborough Sounds are separate reproductively or functionally is not known. Localised patches of oysters in commercial densities within the OYS 7 fishery are largely restricted to Tasman Bay, which is likely to be a single stock.

Stock Status	
Year of Most Recent Assessment	2012
Reference Points	Target: default = 40% B_0, with at least a 50% probability of achieving the target Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: F_{MSY}
Status in relation to Target	Unlikely (< 40%) to be at or above the target
Status in relation to Limits	Likely (> 60%) to be below Soft Limit Unknown relative to Hard Limit
Status in relation to Overfishing	Unknown

Historical Stock Status Trajectory and Current Status



Estimated (mean and CV of) recruited oyster biomass (t greenweight) in Tasman Bay and Golden Bay since 1998. Biomass estimates uncorrected for dredge efficiency; oysters were not surveyed in Golden Bay in 2009–12.

Fishery and Stock Trends	
Trend in Biomass or Proxy	The current biomass of the OYS 7 stock is probably at its lowest level since the CSEC survey time series started in 1998. The estimated biomass of recruited oysters in Tasman Bay decreased from over 2000 t in 1998 to less than 1000 t in 2004, apparently fluctuated around that level until 2011, and was an estimated 567 t in 2012. Recruited oyster biomass in Golden Bay has shown a similar downturn, albeit with a much more rapid decline between 1999 and 2001, followed by a period of relative stability at a low level up to 2005, and a gradual decline to a negligible level in 2008. No surveys have been undertaken since 2012.
Recent trend in Fishing Intensity or Proxy	The exploitation rate on recruited oysters in OYS 7 was about 0.14 for the periods 1998–2000 and 2003–07, but was negligible in the periods 2001–02 and 2008–14.
Other Abundance Indices	The abundance of pre-recruit oysters has declined at a similar rate to the recruited abundance.
Trends in Other Relevant Indicator or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	No projections have been conducted.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: The TACC is higher than the maximum estimates of CAY and MCY and catches at this level are Very Likely (> 90%) to cause the biomass to remain below the Soft Limit in the near term. Hard Limit: Catches at the level of the TACC are also Likely (> 60%) to cause the stock to drop below the Hard Limit in the near term.
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unknown

Assessment Methodology and Evaluation		
Assessment Type	Level 2 – Partial Quantitative Stock Assessment - annual random stratified dredge surveys	
Assessment Method	Yields are estimated as a proportion of the survey biomass for a range of assumed values of natural mortality and with assumed dredge efficiency of 100%.	
Assessment Dates	Latest assessment: 2012	Next assessment: Unknown
Overall Assessment Quality Rank	1 – High Quality	
Main data inputs (rank)	Biomass survey: 2012	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	The natural mortality (*M*) values used in the yield calculations were restricted to the range 0.1 to 0.3. This was reduced from the previous range of 0.042 to 0.9 because the extreme values were considered very unlikely.	
Major Sources of Uncertainty	Natural mortality (*M*) and dredge efficiency are poorly known but are integral parameters of the method used to estimate yield.	

Qualifying Comments
The OYS 7 dredge oyster fishery has a lack of dense aggregations of oysters (compared to Foveaux Strait); this is attributed to a scarcity of suitable settlement surface. Recruited biomass is being used as proxy for spawning biomass. Other benthic fisheries (e.g. bottom trawl, scallop, green-lipped mussel) occur in OYS 7 and probably interact with oysters and their habitat. The cause of the declines in these shellfish is unknown, but is probably associated with factors other than simply the magnitude of direct removals by fishing. It may be a combination of natural (e.g. oceanographic) and anthropogenic (e.g. indirect effects of fishing, land-based) factors.

Environmental and Ecosystem Considerations	
Observer coverage	No observer coverage.
Non-target fish and invertebrate catch	In OYS 7, data on the non-target catch of the 1994–2014 dredge surveys have been collected but not analysed, except for preliminary estimation of the 1998–2013 non-target catch. The surveys record the non-target catch of other target species of scallops (*Pecten novaezelandiae*) and green-lipped mussels (*Perna canaliculus*), and various other non-target catch in nine categories.
Incidental catch of seabirds	There is no known incidental catch of seabirds from *O. chilensis* oyster fisheries.
Incidental catch of mammals	There is no known incidental catch of mammals from *O. chilensis* oyster fisheries.
Incidental catch of other protected species	There is no known incidental catch of protected fish species from *O. chilensis* oyster fisheries.
Benthic interactions	Dredging damages biogenic/epifaunal reefs, destabilises sediment/shell substrates, suspends sediments and increases water turbidity. Dredging generally results in reduced habitat structure and the loss of long-lived species. Habitats disturbed by dredging tend to become simpler, more homogenous areas typically dominated by opportunistic species. High-flow and exposed environments are less sensitive to damage from dredging. The magnitude of dredging effects on the benthic environment of the Foveaux strait has been controversial.

7. FOR FURTHER INFORMATION

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DREDGE OYSTERS (OYS 7C) – Challenger Marlborough

(Ostrea chilensis)

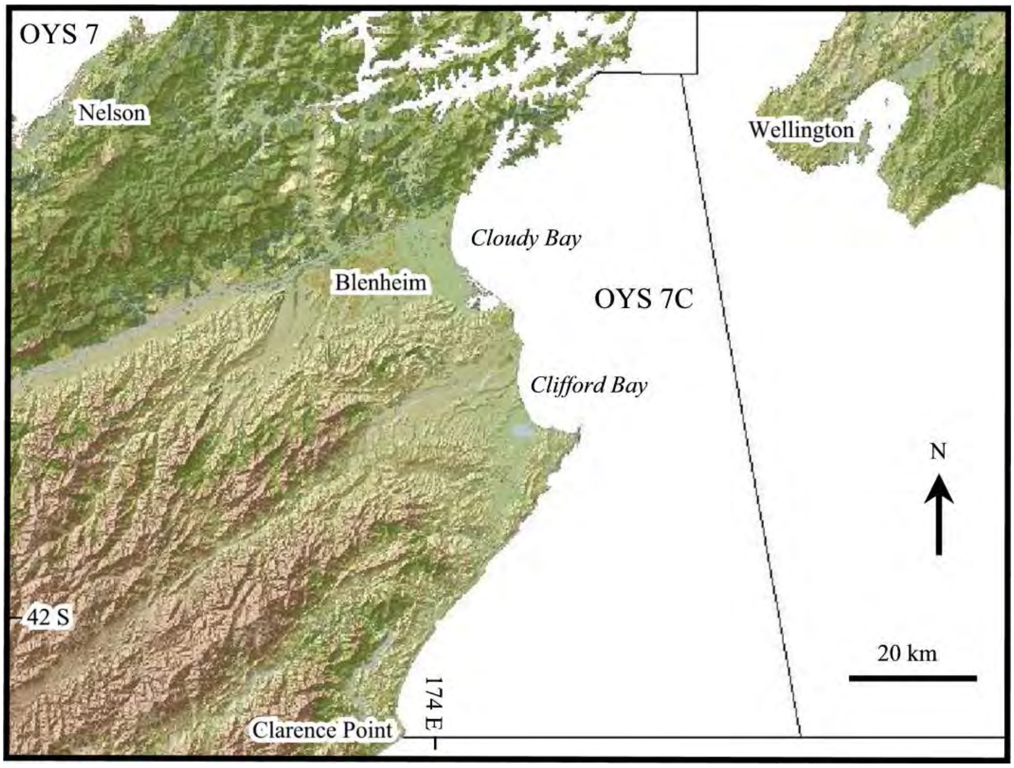


Figure 1: OYS 7C dredge oyster stock boundary.

1. FISHERY SUMMARY

OYS 7C encompasses an area from West Head, Tory Channel in the north to Clarence Point in the south including Cloudy Bay and Clifford Bay in the southern part of Cook Strait (see Figure 1). OYS 7C is considered a separate fishery from OYS 7 (Golden Bay, Tasman Bay and Marlborough Sounds) on the basis of differences in habitat and environmental parameters.

OYS 7C was introduced into the QMS on 1 October 2005 with a TAC of 5 t and a TACC of 2 t. Following a survey in April 2007, the TAC was increased to 50 t with a TACC of 43 t on 1 October 2007. In 2009, with information from CPUE and catch data, the TAC was reviewed again and resulted in a TAC increase to 72 t in October 2009 (Table 1). At the time of the review the Shellfish Working Group suggested that raising the TACC by a further 15–20 t was unlikely to be detrimental to the fishery in the short term, however without improved estimates of mortality, growth and dredge efficiency, it was difficult to predict the effects that an increased TACC would have on the status of the fishery in the medium to long term, and that a research strategy for improved assessment was required.

Table 1: Total Allowable Commercial Catch (TACC, t) declared for OYS 7C since introduction into the QMS in 2005.

Fishing year	TAC	TACC	Customary	Recreational	Other
2005–07	5	2	1	1	1
2007–09	50	43	1	1	5
2009–present	72	63	1	1	7

1.1 Commercial fishery

Commercial landings for OYS 7C are reported in greenweight. The fishing year runs from 1 October to 30 September and fishers can harvest year round (there is no oyster season defined by regulations).

There is historical evidence of limited exploitation of oyster beds within Port Underwood as early as the 1800s (K. Wright, pers. comm., in Drummond 1994a). Limited fishing under a special permit took place south of Tory Channel on the east coast of the South Island in 1990 and 1991.

Since 2005, landed catch has been reported via Monthly Harvest Returns (Table 2), although landings were negligible until 2007–08 when the recent commercial operation was initiated. During 2007–08 fishing took place over 30 fishing days from December to February and in 2008–09 fishing took place from January to April. Landings were at about the level of the TACC up to and including 2010–11. They were lower between 2012–13 and 2015–16 due to oyster grading and marketing requirements (less than 6 tonnes each year) and there has not been any report of commercial catch since 2016–17 (Figure 2, Table 2).

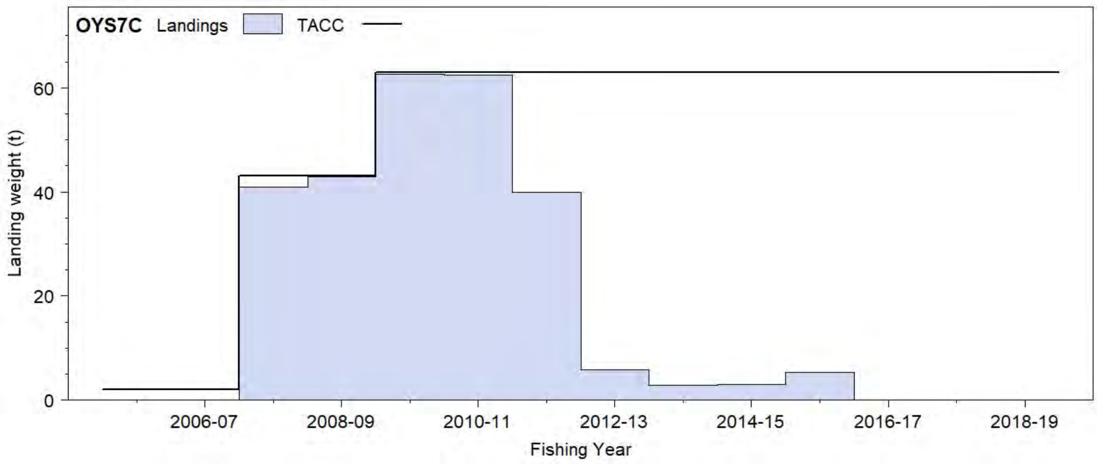


Figure 2: Reported landings (t) and TACC for OYS 7C from 2005–06 to present.

Table 2: Reported landings (t) in the OYS 7C fishery since October 2005 (QMS). Reported catch is landed greenweight summarised from Monthly Harvest Returns.

Fishing year	TACC	Reported landings (MHR)
2005–06	2	0.1
2006–07	2	0
2007–08	43	40.9
2008–09	43	38.2
2009–10	63	62.7
2010–11	63	62.5
2011–12	63	39.9
2012–13	63	5.9
2013–14	63	2.8
2014–15	63	3.1
2015–16	63	5.3
2016–17	63	0.0
2017–18	63	0.0
2018–19	63	0.0

1.2 Recreational fishery

The recreational catch allowance for OYS 7C is 1 t. The recreational daily bag limit for oysters in the Challenger fishery area is 50 per person. Oysters that cannot pass through a 58 mm internal diameter solid ring are deemed legal size. Recreational fishing for dredge oysters in the Challenger area is permitted year-round. Oysters must be landed in their shells. National Panel Surveys of recreational harvest were conducted throughout the 2011–12 and 2017–18 fishing years (Wynne-Jones et al. 2014, 2019). An estimated 17 000 oysters was harvested from OYS 7 in 2011–12 (CV = 1.06) but no panellists reported harvesting oysters from OYS 7 in 2017–18.

1.3 Customary fisheries

The customary catch allowance for OYS 7C is 1 t. There are no data available on the customary catch.

1.4 Illegal catch

There is no quantitative information on the level of illegal catch.

1.5 Other sources of mortality

Bonamia exitiosa (Bonamia) is a haemocritic, haplosporid parasite (infects mainly haemocytes or blood cells) of flat oysters and is known to infect *Ostrea chilensis* in New Zealand and Chile and various other species of *Ostrea* in other countries. Bonamia has caused catastrophic mortality in the Foveaux Strait oyster fishery and is endemic in oysters in the OYS 7 area (Hine, pers. comm.). The level of mortality caused by disease is unknown.

An allowance of 7 t for Other Mortality (including incidental fishing mortality, heightened natural mortality such as disease mortality, and illegal harvest) is included in the TAC.

2. BIOLOGY

There are no biological studies of *O. chilensis* specific to the OYS 7C area. In the absence of area-specific estimates, parameters required for management purposes are based on the Foveaux Strait fishery described by Cranfield & Allen (1979) or the OYS 7 (Tasman Bay) fishery. The biology of oysters in the neighbouring area of OYS 7 (Tasman and Golden Bays) was summarised by Handley & Michael (2001), and further biological data was presented in Brown et al. (2008). All this work is summarised below.

Oysters in OYS 7C (Cloudy Bay/Clifford Bay) and OYU 5 (Foveaux) both comprise rather discrete patches of oysters on a predominantly sandy substrate whereas OYS 7 (Tasman Bay) oysters tend to be more uniformly distributed at a lower density on muddy habitat. Environmental factors such as hydrodynamics, seasonal water temperature and riverine inputs differ substantially among the OYS 7, OYS 7C and OYU 5 areas and are likely to influence the biological characteristics of those oyster populations. Oysters in OYS 7C are generally more abundant and occur at higher densities than in OYS 7 (Brown & Horn 2007).

The variability in shell shapes and high variability in growth rate between individuals, between areas within the OYS 7 fishery, and between years, require careful consideration in describing growth. Assuming the minimum legal size could range in diameter (1/2 length + height) from 58 mm to 65 mm, data from Drummond (1994b) indicated that Tasman Bay oysters could grow to legal size in two to three years. Modelling of limited data from Tasman Bay in Brown et al. (2008) indicated that 77% of three-year-old oysters and 82% of 4-year-old oysters would attain lengths greater than the minimum legal size of 58 mm length at the start of the fishing season. Osborne (1999) used results from a MAF Fisheries study conducted between 1990 and 1994 to construct a von Bertalanffy equation describing oyster growth in the OYS 7 fishery. Estimated biological parameters including instantaneous natural mortality (*M*) from Drummond (1993, 1994b) and growth parameters for von Bertalanffy equations from Osborne (1999) and from Brown et al. (2008) are given in Table 3. Mortality estimates by Drummond (1994b) and growth parameters in Osborne (1999) were derived from a tagging study conducted in Tasman Bay between 1990 and 1992 (Drummond 1993). Von Bertalanffy growth parameters in Brown et al. (2008) were estimated based on a limited data set from enhanced habitat experiments, and describe growth of young oysters. Estimates of *M* based on experimental data from Foveaux Strait and Tasman Bay ranged from 0.042 (Dunn et al. 1998) to 0.92 (Drummond et al. 1994a). However, after some discussion the Shellfish Working Group concluded that those figures were not realistic, and that *M* was more likely to lie between 0.1 and 0.3.

Table 3: Estimated biological parameters for oysters in OYS 7 and OYU 5. In the absence of data specific to OYS 7C these estimates are used for management purposes in OYS 7C.

1. Natural Mortality (*M*)

Area	Estimate	Source
Tasman Bay	0.920	Drummond (1994b)
Tasman Bay	0.200	Drummond (1993)
Foveaux Strait	0.042	Dunn et al. (1998)
Foveaux Strait	0.100	Allen (1979)

2. von Bertalanffy growth (change in diameter mm) parameter estimates from OYS 7 t_0 not provided by Osborne (1999)

K	L_{inf}	t_0	Source
0.597	85.43	-	Osborne (1999)
0.99 +/- 0.16 (s.d.)	67.52	0.11	Brown et al. (2008)

3. STOCKS AND AREAS

Fishing within OYS 7C has been limited to two discrete areas; one in parts of Clifford and Cloudy Bays and the other immediately south of Tory Channel, and commercial oyster fishing has not extended south of Cape Campbell. The oyster population in OYS 7C is likely to be biologically isolated from populations in Foveaux Strait (OYU 5) and the Chatham Islands (OYS 4) on the basis of geographical distance. The populations in OYS 7C and OYS 7 could also be biologically distinct due to their geographical separation, which quite likely leads to limited dispersal of larvae between the two areas.

4. STOCK ASSESSMENT

4.1 Estimates of fishery parameters and abundance

A survey of OYS 7C was carried out in 2007 (Brown & Horn 2007) and estimates of the number of recruits (oysters unable to pass through a 58 mm ring) and pre-recruits (less than 58 mm) from Clifford and Cloudy Bays are given in Table 4. Dredge efficiency was assumed to be 100% for the purposes of the survey.

Table 4: Estimate of number of recruit and pre-recruit oysters from Brown & Horn (2007).

Year	Area (Ha)	Recruit no.		Pre-recruit no.	
		Estimate	CV %	Estimate	CV %
2007	43 709	19.5 million	19	14 million	19

4.2 Biomass estimates

Estimates of recruited biomass, from the 2007 survey are given in Table 5.

Table 5: Estimate of relative recruited (≥ 58 mm) oyster biomass (t greenweight) in OYS 7C (Brown & Horn 2007).

Year	Area (Ha)	Biomass (t)	CV
2007	43 709	1 778	0.19

4.3 Yield estimates and projections

For new fisheries where there are insufficient data to conduct a yield per recruit analysis, yield can be estimated using the formula from Mace (1988) recommended by the Ministry of Fisheries Science Group (Ministry of Fisheries Science Group 2008) for calculation of Maximum Constant Yield (MCY).

$$MCY = 0.25MB_0$$

Where B_0 is an estimate of virgin recruited biomass (here assumed to be equal to the recruited biomass estimate from the 2007 survey (1778 t, Brown & Horn 2007) divided by dredge efficiency) and M is an estimate of natural mortality. A range of MCY estimates are given in Table 6 using values for dredge efficiency of 100% and 64% (Bull 1989), and values for M ranging from 0.1 to 0.3 taken from studies conducted in the Foveaux and Nelson/Marlborough oyster fisheries.

Table 6: Estimates of MCY for *M* of 0.1–0.3. MCY 1 was estimated using a dredge efficiency of 64% from Bull (1989) and MCY 2 was estimated assuming a dredge efficiency of 100%.

M	MCY 1	MCY 2
0.1	69	44
0.2	139	89
0.3	208	133

There are no CAY estimates for OYS 7C.

4.4 Other yield estimates

There are no other yield estimates for OYS 7C.

4.5 Other factors

Dredging for oysters will have an impact on the soft sediment habitats within Cloudy and Clifford Bays, and will affect both the dredge oyster beds and other species found in association with these beds. In addition, various areas within the fishery (mainly around coastal rocky reefs) are understood to support a range of sensitive invertebrate species including soft corals, large erect and divaricating bryozoans, starfish, horse mussels and crabs. The impacts of dredging are likely to be more severe on these habitats than on soft sediments, and will increase with increasing fishing effort, but there is insufficient information to quantify the degree of impact under any given TAC. There may be some overlap with other fisheries that contact the bottom in this area, but this has not been quantified.

Industry has proposed to voluntarily restrict fishing to two discrete areas to mitigate the effects of fishing. These areas are where oyster densities are highest. Bycatch of benthic invertebrates was collected during the biomass survey and could be analysed to help to determine the distribution of sensitive habitats.

5. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS

This section was reviewed by the Aquatic Environment Working Group for inclusion in the Fishery Assessment Plenary November 2014. A broader summary of information on a range of issues related to the environmental effects of fishing and aspects of the marine environment and biodiversity of relevance to fish and fisheries is available in the Aquatic Environment and Biodiversity Annual Review (Ministry for Primary Industries 2019).

5.1 Role in the ecosystem

Dredge oysters (*Ostrea chilensis*) are benthic, epifaunal, sessile bivalve molluscs that have a relatively limited pelagic larval dispersal phase. They are patchily distributed around the New Zealand coast on a variety of substrates (biogenic reef, gravel, sand, mud) in intertidal to subtidal inshore waters, commonly in depths of up to 60 m or more. Commercially exploited beds of oysters occur in Foveaux Strait (OYU 5), Tasman Bay (OYS 7), and Cloudy and Clifford Bays (OYS 7C). Beds at the Chatham Islands (OYS 4) have potential for commercial exploitation. Oysters play important roles in the ecosystem that include influencing water quality by filtering phytoplankton and other suspended particles from the seawater, linking primary production with higher trophic levels, and acting as ecosystem engineers by stabilising sediments and providing structural habitat (biogenic reef) for other taxa (e.g., algae, ascidians, bryozoans, sponges, echinoderms, worms, molluscs, crustaceans, fish).

5.1.1 Trophic interactions

Oysters are active suspension feeders, consuming phytoplankton suspended in the water column. Their diet is the same as or similar to that of many other suspension feeding taxa, including other bivalves such as scallops, clams and mussels. Oysters are probably prey for a wide range of invertebrate and fish predators, but published records of known or suspected predators are limited. Reported invertebrate predators of *O. chilensis* include brittlestars (*Ophiopsammus maculata*) (Stead 1971), starfish (*Coscinasterias calamaria* and *Astrostole scabra*) (Cranfield 1979) and flatworms (*Enterogonia orbicularis*) (Handley 2002); suspected invertebrate predators include octopus (*Pinnoctopus cordiformis*) and shell boring gastropods (*Poirieria zelandica*, *Xymeme ambiguous* and *Xymenella pusillis*) (Brown 2012). Predators of oysters probably change with oyster size. Most mortality of oyster spat (small juveniles) during their first winter appears to result from predation by polychaetes, crabs and gastropods (Ministry for Primary Industries 2013b).

5.2 Non-target catch of fish and invertebrates

A range of non-target fish and invertebrate species are caught and discarded by dredge fisheries for *O. chilensis* but no data are available on the level or effect of this non-target catch and discarding. Invertebrate non-target catch data are available from dredge surveys of the oyster stocks, and the non-target catch of the fisheries is likely to be similar to that of the survey tows conducted in areas that support commercial fishing. Fish non-target catch data are generally not recorded on surveys, presumably because fish constitute a small fraction of the total non-target catch.

A dredge survey of oysters in Cloudy and Clifford Bays in OYS 7C was conducted in 2006, and the survey skipper recorded qualitative comments on the non-target catch of each tow, which included ‘coral’, ‘sticks and seaweed’, shells, volutes, ‘red weed’, horse mussels, shell with worm, small crabs, mussels and scallops (Brown & Horn 2006).

5.2.1 Non-target catch in other oyster stocks

The macrofaunal non-target catch of oyster fishing in a ‘near virgin’ area of the fishery was sampled in OYU 5 (Foveaux Strait) in 1950 (Fleming 1952). More recently, presence-absence data on the non-target catch of oyster dredging have been recorded during surveys and in fishers’ logbooks (Michael 2007). In a specific study of the benthic macrofauna non-target catch of the 2001 oyster dredge survey in Foveaux Strait, Rowden et al. (2007) identified at least 190 putative species representing 82 families and 12 phyla; ‘commercial’ survey strata were principally characterised by the families Balanidae (barnacles), Mytilidae (mussels), Ophiodermatidae (brittle stars), Ostreidae (oysters) and Pyuridae (tunicates). For the 2007 survey of OYU 5, Michael (2007) listed the percentage occurrence of sessile and motile species caught as non-target catch in the survey dredge tows. The five most commonly caught sessile species (excluding oysters) were hairy mussels *Modiolus areolatus* (80% occurrence), barnacles *Balanus* sp. (61%), kina *Evechinus chloroticus* (61%), nesting mussels *Modiolarca impacta* (53%), and ascidians *Pyura pulla* (51%). The five most commonly occurring motile non-target catch species were brittlestars *Ophiopsammus maculata* (90% occurrence), circular saw shells (gastropods) *Astraea heliotropium* (80%), hermit crabs *Pagurus novizelandiae* (80%), eight armed starfish *Coscinasterias muricata* (63%), and brown dipple starfish *Pentagonaster pulchellus* (54%). Common non-target catch species of oyster dredge surveys in Foveaux Strait were reported by Michael (2007) and are listed in Table 7.

Table 7: Invertebrate species commonly caught as non-target catch in dredge surveys of oysters (*O. chilensis*) in Foveaux Strait (Michael 2007).

Type	Species
Infaunal bivalves	*Glycymeris modesta* (small dog cockle), *Tawera spissa* (morning star shell), *Tucetona laticostata* (large dog cockle), *Pseudoxyperas elongata* ('tuatua'), *Venericardia purpurata* (purple cockle)
Epifaunal bivalves	*Modioilus areolatus* (hairy mussel), *Modiolarca impacta* (nesting mussel), *Aulacomya atra maoriana* (ribbed mussel), *Barbatia novaezelandiae* (ark shell), *Pecten novaezelandiae* (scallop), *Chlamys zelandiae* (lions paw scallop), *Neothyris lenticularis* (large lantern shell), *N. compressa* (compressed lantern shell)
Sponges	*Chondropsis* topsentii (cream sponge), *Crella incrustans* (red-orange sponge), *Dactylia palmata* (finger sponge)
Ascidians	*Pyura pachydermatina* (kaeo), *P. pulla*
Bryozoans	*Celleporaria agglutinans* (hard/plate coral), *Cinctipora elegans* (reef-building bryozoan), *Horera foliacea* (lace coral), *Hippomenella vellicata* (paper coral), *Tetrocycloecia neozelanica* (staghorn coral), *Orthoscuticella fusiformis* (soft orange bryozoan)
Barnacles and chitons	*Balanus decorus* (large pink barnacle), *Cryptochonchus porosus* (butterfly chiton), *Eudoxochiton nobilis* (noble chiton), *Rhyssoplax canaliculata* (pink chiton)
Starfish, brittlestars and holothurians	*Coscinasterias muricata* (eight armed starfish), *Pentagonaster pulchellus* (brown dipple starfish), *Ophiosammus maculata* (snaketail brittlestar), *Australostichopus mollis* (sea cucumber)
Crabs	*Pagurus novaezelandiae* (hermit crab), *Eurynolambrus australis* (triangle crab), *Metacarcinus novaezelandiae* (cancer crab), *Nectocarcinus* sp. (red crab)
Urchins	*Evechinus chloroticus* (kina), *Apatopygus recens* (heart urchin), *Goniocidaris umbraculum* (coarse-spined urchin), *Pseudechinus novaezelandiae* (green urchin), *P. huttoni* (white urchin), *P. albocinctus* (red urchin)
Gastropods	*Astraea heliotropium* (circular saw shell), *Alcithoe arabica* (volute), *Argobuccinum pustulosum tumidum, Turbo granosus, Cabestana spengleri, Charonia lampras*
Octopuses	*Pinnoctopus cordiformis* (common octopus), *Octopus huttoni* (small octopus)

In OYS 7 (Tasman/Golden Bays), data on the non-target catch of the 1994–2014 dredge surveys have been collected but not analysed, except for preliminary estimation of the 1998–2013 non-target catch trajectories (Williams et al. 2014b). The surveys record the non-target catch of other target species of scallops (*Pecten novaezelandiae*) and green-lipped mussels (*Perna canaliculus*), and various other non-target catch in nine categories (Williams et al. 2014b). Observation of the 2014 survey sampling identified a problem with the way these categorical non-target catch data have been recorded, which limits their utility (Williams et al. 2014a).

In OYS 4 (Chatham Islands), data on the non-target catch of a 2013 dredge survey of oysters off the north coast of Chatham Island were recorded (as estimated volumes of different non-target catch categories) but not analysed (Williams et al. 2013).

5.3 Incidental catch of seabirds, mammals and protected fish

There is no known incidental catch of seabirds, mammals or protected fish species from *O. chilensis* oyster fisheries.

5.4 Benthic interactions

There are a variety of benthic habitats in the different oyster fisheries areas, which generally occur either on coarse substrates usually found in areas of high natural disturbance (Foveaux Strait, Cloudy/Clifford Bays and the Chatham Islands) or on fine substrates typical of sheltered areas (Tasman Bay). Benthic habitats within the Foveaux Strait oyster fishery area were classified by Michael (2007) and comprise a variety of sand/gravel/shell flats and waves, rocky patch reef, and biogenic areas. Cranfield et al. (1999) referred to the latter as epifaunal reefs that he defined as 'tidally oriented, linear aggregations of patch reefs formed by the bryozoan *Cinctipora elegans*, cemented by encrusting bryozoans, ascidians, sponges and polychaetes'. Cranfield et al.'s papers (Cranfield et al.

1999, Cranfield et al. 2001, Cranfield et al. 2003) suggested that epifaunal reefs are oyster habitat, but Michael's reports (Michael 2007, 2010) state that commercial fishing for oysters is mainly based on sand, gravel, and shell habitats with little epifauna. In Foveaux Strait, commercial oyster dredging occurs within an area of about 1000 km^2 (although only a portion of this is dredged each year), which is about one-third of the overall OYU 5 stock area (Michael 2010). Habitats within the Cloudy/Clifford Bays and the Chatham Islands fisheries areas have not been defined. The benthic habitat within the Tasman Bay oyster fishery area is predominately mud, although to some extent this may have been affected by land-based sedimentation into the bay and homogenisation of the substrate by dredging and trawling (Brown 2012).

It is well known that fishing with mobile bottom contact gears such as dredges has impacts on benthic populations, communities and their habitats (e.g., Kaiser et al. 2006, Rice 2006). The effects are not uniform, but depend on at least: 'the specific features of the seafloor habitats, including the natural disturbance regime; the species present; the type of gear used, the methods and timing of deployment of the gear, and the frequency with which a site is impacted by specific gears; and the history of human activities, especially past fishing, in the area of concern' (Department of Fisheries and Oceans 2006). In New Zealand, the effects of oyster dredging on the benthos have been studied in Foveaux Strait (OYU 5) (Cranfield et al. 1999, Cranfield et al. 2001, Cranfield et al. 2003, Michael 2007) and Tasman/Golden Bays (OYS 7) (Tuck et al. 2011). The results of these studies are summarised in the Aquatic Environment and Biodiversity Annual Review (Ministry for Primary Industries 2019), and are consistent with the global literature: generally, with increasing fishing intensity there are decreases in the density and diversity of benthic communities and, especially, the density of emergent epifauna that provide structured habitat for other fauna.

The effects of dredging (Ministry for Primary Industries 2019) may be more severe in sheltered areas (e.g., Tasman Bay) than in exposed areas (e.g., Foveaux Strait, Cloudy/Clifford Bays, Chatham Islands). Dredging damages epifauna, and erect, structured habitats, such as biogenic/epifaunal reefs, are the most sensitive to dredging disturbance. Dredging destabilises sediment/shell substrates, suspends sediments and increases water turbidity; the sensitivity of habitats to suspended sediments and their deposition probably varies depending on the prevailing natural flow regime, being greater in muddy sheltered areas than in high flow environments. Habitats disturbed by dredging tend to become simpler, more homogenous areas typically dominated by opportunistic species. Dredging generally results in reduced habitat structure and the loss of long-lived species.

For studies of the effects of oyster dredging in Foveaux Strait, interpretation of the authors differ (Ministry for Primary Industries 2019): 'Cranfield et al.'s papers (Cranfield et al. 1999, Cranfield et al. 2001, Cranfield et al. 2003) concluded that dredging biogenic reefs for their oysters damages their structure, removes epifauna, and exposes associated sediments to resuspension such that, by 1998, none of the original bryozoan reefs remained. Michael (2007) concluded that there are no experimental estimates of the effect of dredging in the strait or on the cumulative effects of fishing or regeneration, that environmental drivers should be included in any assessment, and that the previous conclusions cannot be supported. The authors agree that biogenic bycatch in the fishery has declined over time in regularly fished areas, that there may have been a reduction in biogenic reefs in the strait since the 1970s, and that simple biogenic reefs appear able to regenerate in areas that are no longer fished (dominated by byssally attached mussels or reef-building bryozoans). There is no consensus that reefs in Foveaux Strait were (or were not) extensive or dominated by the bryozoan *Cinctipora*.

Some areas of the Foveaux Strait (OYU 5) oyster fishery are also commercially fished (potted) for blue cod (*Parapercis colias*), and Cranfield et al. (2001) presented some evidence to suggest that dredged benthic habitats and blue cod densities regenerated in the absence of oyster dredging. Bottom trawling also occurs within the OYU 5 area, but there is little overlap with the main areas fished for oysters. In OYS 7, other benthic fisheries (e.g., bottom trawl, scallop, green-lipped mussel) occur and probably also interact with oysters and their habitats.

5.5 Spawning disruption

Fishing during spawning may disrupt spawning activity or success. In the Foveaux Strait fishery, the traditional harvesting period (1 March to 31 August) occurs after the main spring and summer peaks in oyster spawning activity (Jeffs & Hickman 2000). Fishing-induced damage to oysters incurred during the period before spawning could interrupt gamete maturation. Oyster fishing also targets high-density beds of oysters, which are disproportionately more important for fertilisation success during spawning.

5.6 Habitat of particular significance for fisheries management

None currently identified.

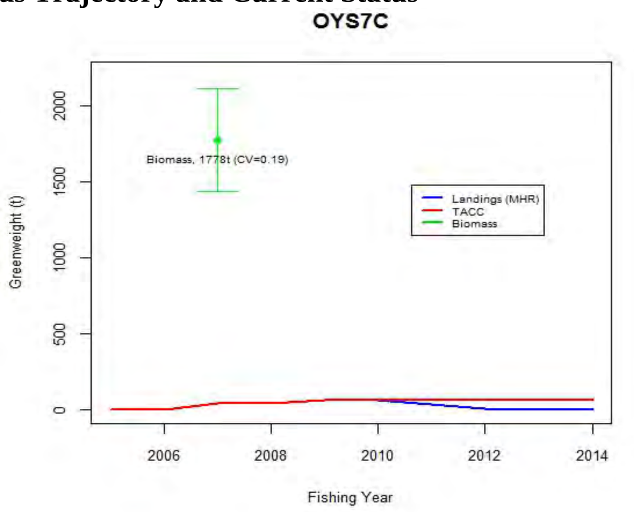
6. STOCK STATUS

Stock structure assumptions

Current management assumes that the OYS 7C oyster fishery is separate from the other oyster fisheries (i.e., Challenger (OYS 7), Foveaux Strait (OYU 5), and the Chatham Islands (OYS 4)). The stock structure of OYS 7C is assumed to be a single biological stock. Survey data show that oysters are patchily distributed in the commercial fishery area of OYS 7C and it has been suggested that the oyster populations may be mainly self-recruiting.

Stock Status	
Year of Most Recent Assessment	2007
Reference Points	Target: Default = 40% B_0, with at least a 50% probability of achieving the target Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: F_{MSY}
Status in relation to Target	Very Likely (> 90%) to be at or above the target
Status in relation to Limits	Based on annual commercial oyster removals of less than 4% of the estimated 2007 stock size, the status is likely to be close to virgin size and is Very Unlikely (< 10%) to be below the soft and hard limits.
Status in relation to Overfishing	Overfishing is Very Unlikely (< 10%) to be occurring.

Historical Stock Status Trajectory and Current Status



Estimated relative biomass (t greenweight) of recruited oysters (≥ 58 mm) (green point and error bars denoting CV), TACC (solid red line), and reported landings (blue line, t greenweight) since 1998. The biomass estimate is from a 2007 survey and is uncorrected for dredge efficiency. Landings data from MHRs. Fishing year beginning 2005–06 to 2014–15.

Fishery and Stock Trends	
Recent trend in Biomass or Proxy	Only one biomass survey has been conducted, in 2007, from which the recruited biomass was estimated to be 1778 t (assuming 100% dredge efficiency).
Recent trend in Fishing Intensity or Proxy	The OYS 7C commercial fishery got underway in 2007–08; in that fishing year the exploitation rate was an estimated at 0.02 (assuming 100% dredge efficiency).
Other Abundance Indices	-
Trends in Other Relevant Indicator or Variables	Landings were at about the level of the TACC up to and including 2010–11, but were lower in recent years due to oyster grading and marketing requirements.

Projections and Prognosis	
Stock Projections or Prognosis	Quantitative stock projections are unavailable
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unknown Hard Limit: Unknown
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Very Unlikely (< 10%)

Assessment Methodology and Evaluation		
Assessment Type	Level 2: Partial Quantitative Stock Assessment	
Assessment Method	Yields are estimated as a proportion of the survey biomass for a range of assumed values of natural mortality and dredge efficiency.	
Assessment Dates	Latest assessment: 2009	Next assessment: Unknown
Overall Assessment Quality Rank	1 – High Quality	
Main data inputs (rank)	Biomass survey: 2007	1 – High Quality
Period of Assessment	Latest assessment: 2009	Next assessment: Unknown
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	There has been only a single biomass survey of this fishstock and repeat surveys should be scheduled at regular intervals. Natural mortality (*M*) and dredge efficiency are poorly known but are integral parameters of the method used to estimate yield. There is also major uncertainty about the response of localised populations to fishing.	

Qualifying Comments
Some of the surveyed area was not actively fished up to 2009. There are areas of potential oyster habitat that are not fished due to sanitation concerns and substrate that is marginal for fishing. In 2009, the Shellfish FAWG was asked to evaluate the implications of raising the TACC (of 50 t) by 15–20 t. In 2009 it was considered Very Unlikely (< 10%) that an increase in the TACC of this amount would cause the biomass to decline below the Soft Limit in the next 3 to 5 years. On 1 October 2009 the TACC was changed to 63 t.

Environmental and Ecosystem Considerations	
Observer coverage	No observer coverage
Non-target fish and invertebrate	In OYS 7C, a dredge survey of oysters in Cloudy and

catch	Clifford Bays was conducted in 2006, and the survey skipper recorded qualitative comments on the non-target catch of each tow, which included 'coral', 'sticks and seaweed', shells, volutes, 'red weed', horse mussels, shell with worm, small crabs, mussels and scallops.
Incidental catch of seabirds	There is no known incidental catch of seabirds from *O. chilensis* oyster fisheries.
Incidental catch of mammals	There is no known incidental catch of mammals from *O. chilensis* oyster fisheries.
Incidental catch of other protected species	There is no known incidental catch of protected fish species from *O. chilensis* oyster fisheries.
Benthic interactions	Dredging damages biogenic/epifaunal reefs, destabilises sediment/shell substrates, suspends sediments and increases water turbidity. Dredging generally results in reduced habitat structure and the loss of long-lived species. Habitats disturbed by dredging tend to become simpler, more homogenous areas typically dominated by opportunistic species High-flow and exposed environments are less sensitive to damages from dredging. The magnitude of dredging effects on the benthic environment of the Foveaux strait has been controversial.

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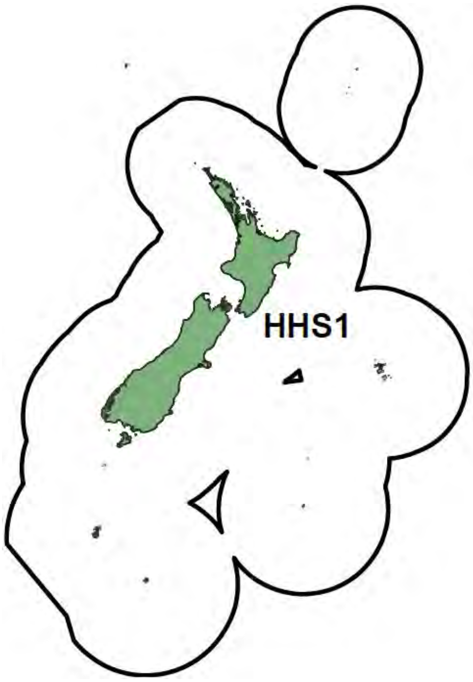
SMOOTH HAMMERHEAD SHARK (HHS)

(*Sphyrna zygaena*)



1. FISHERY SUMMARY

Smooth hammerhead sharks (*Sphyrna zygaena*) are not currently managed under the QMS. No assigned fishing allowances exist. However, as hammerhead shark has been listed as an Appendix II species under CITES it is appropriate to include it in this document.

The Western and Central Pacific Fisheries Commission (WCPFC) has listed hammerhead sharks (as a group) as a key shark species, and the management of smooth hammerhead sharks throughout the western and central Pacific Ocean (WCPO) is the responsibility of the WCPFC. As such, New Zealand (which is a signatory to the WCPFC) is responsible for ensuring that the management measures applied within New Zealand fisheries waters are compatible with or better than those of the Commission, and that our data collection requirements will allow New Zealand to report catches of hammerhead sharks as required.

1.1 Commercial fisheries

There are no target fisheries for hammerhead sharks in New Zealand. However, they are caught as bycatch in several commercial fisheries within New Zealand fishery waters.

The majority of small hammerhead sharks are caught in inshore setnet and bottom longline fisheries. The distribution of hammerhead shark catches around New Zealand is shown in Figures 1–3. A small number of large hammerheads are caught as bycatch in the surface-longline fisheries targeting highly migratory species. Surface-longline fishing effort is mainly distributed along the east coast of the North Island and the south-west coast South Island. The west coast South Island fishery predominantly targets southern bluefin tuna and rarely catches hammerhead sharks, whereas the fishery on the east coast of the North Island targets a range of species including bigeye tuna, swordfish and southern bluefin tuna. It is unknown what proportion of hammerhead sharks are released alive from the surface-longline fishery.

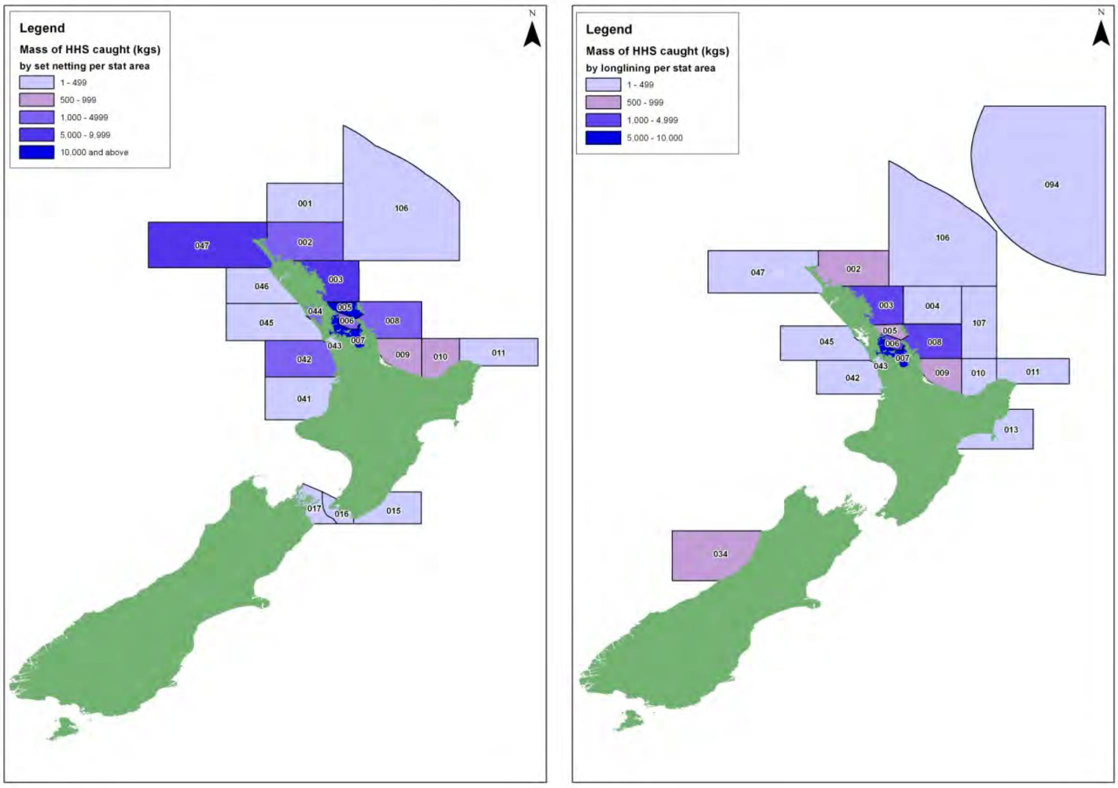


Figure 1: Mass of hammerhead sharks per statistical area caught by set-net [left] and longline [right] fisheries. These maps have been produced using data extracted from the catch effort database. HHS data from 1 Dec 1989–30 June 2013 have been mapped. Only captures where the primary method was set net or longline are included. Data were plotted using the fishing event start position. If no statistical area was supplied, then it was derived using the latitude and longitude. Only records that reported the weight of HHS have been mapped (if no weight was reported, then this is not included on the map).

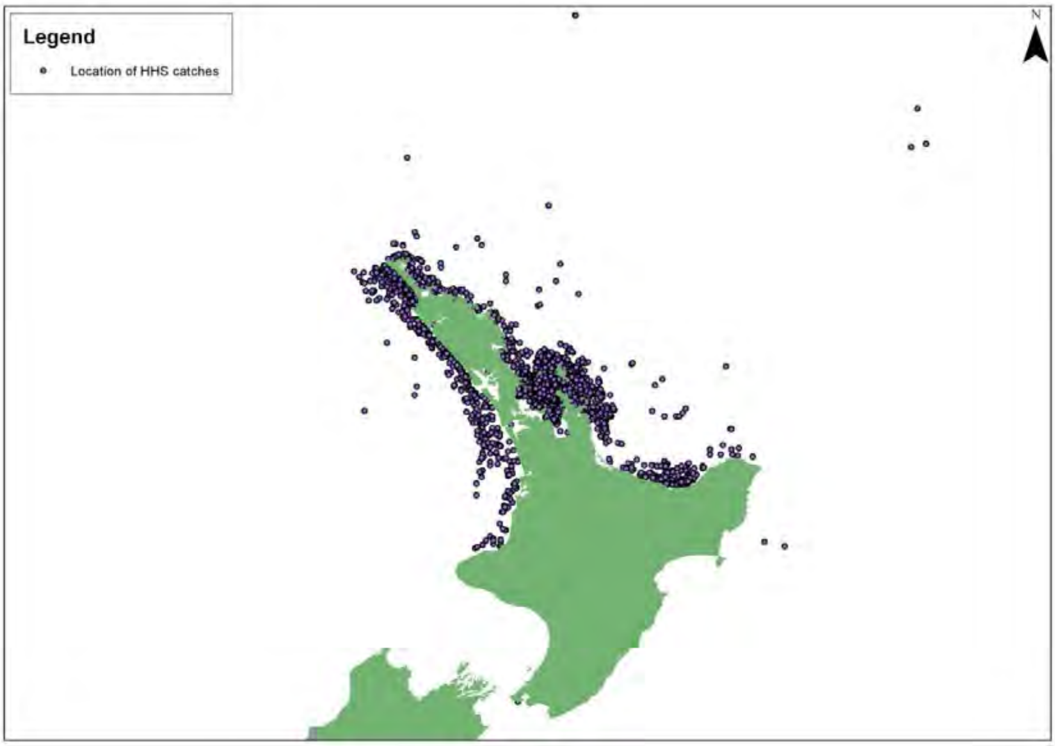


Figure 2: Location of hammerhead shark catches throughout the New Zealand Exclusive Economic Zone. This map has been produced using data extracted from the catch effort database. HHS data from 1 Dec 1989–30 June 2013 have been mapped. Data were mapped using the fishing event start position. Only records that reported by latitude and longitude have been included.

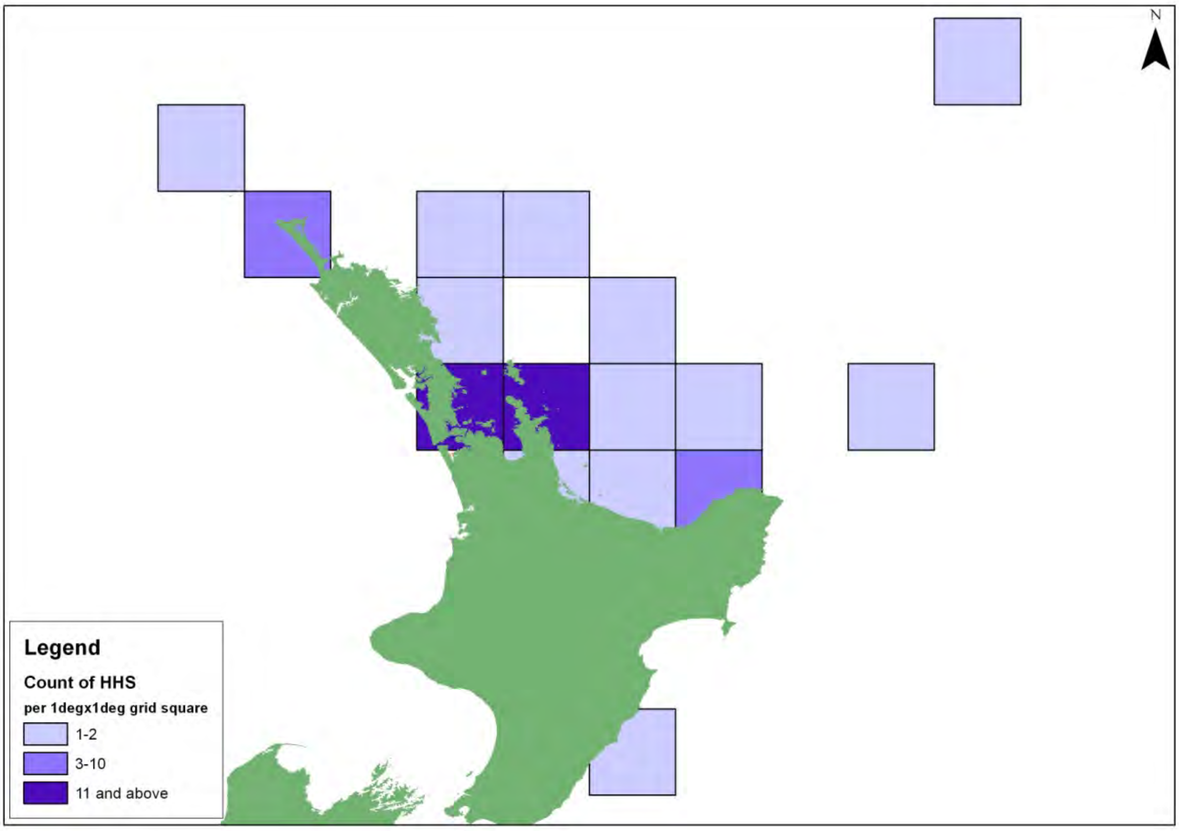


Figure 3: Number of hammerhead sharks observed caught per 1° x 1° grid square. This map has been produced using data extracted from the COD (observer) database. HHS data for all years (up to 30 June 2013) have been included. The data have been plotted using the start position of the fishing event. Only records that reported the number of HHS caught have been included.

1.2 Recreational fisheries

Hammerhead sharks are rarely targeted by recreational fishers. There may be considerable cryptic bycatch of juveniles in recreational set nets.

Recreational catch estimates are available from two national panel surveys. They are caught around the upper North Island, with harvest by area in 2017–18 being: FMA 1 (83.5%) and FMA 9 (16.5%).

1.2.2 Estimates of recreational harvest

Recreational catch estimates are available from national panel surveys conducted in the 2011–12 fishing year (Wynne-Jones et al. 2014) and the 2017–18 fishing year (Wynne-Jones et al. 2019). The panel surveys used face-to-face interviews of a random sample of New Zealand households to recruit a panel of fishers and non-fishers for a full year. The panel members were contacted regularly about their fishing activities and catch information collected in standardised phone interviews. Note that the national panel survey estimates include harvest taken on recreational charter vessels, but for hammerhead sharks is unlikely to estimate this proportion of the catch well. The national panel survey estimate does not include recreational harvest taken under s111 general approvals. The national panel survey was repeated during the 2017–18 fishing year using very similar methods to produce directly comparable results (Wynne-Jones et al. 2019).

The harvest estimate from the 2011–12 survey was 1429 fish. The harvest estimate from the 2017–18 survey was 1158 fish (CV 0.46).

1.3 Customary non-commercial fisheries

There is no customary non-commercial fishery for hammerhead shark.

1.4 Illegal catch

There is no known illegal catch of hammerhead shark.

1.5 Other sources of mortality

The proportion of sharks discarded dead is unknown. Mortality rates of hammerhead sharks tagged and released by the New Zealand Gamefish Tagging Programme are also unknown.

2. BIOLOGY

Only one species of hammerhead shark (*S. zygaena*) has been recorded in New Zealand waters. Several tropical and subtropical species occur in Australia and the South Pacific Ocean and these may occasionally visit New Zealand.

Juvenile *S. zygaena* are common in shallow coastal waters of the northern North Island, but are rare further south. Coastal waters appear to serve as a nursery for this species, with highest concentrations occurring in the Firth of Thames, Hauraki Gulf, eastern Bay of Plenty and 90-Mile Beach. Other areas are probably also important (e.g., Kaipara and Manukau Harbours) but data to confirm this are sparse.

Length-frequency data from research trawl surveys showed that newborn young first occur in coastal waters during summer at a total length of around 60 cm. These young grow to about 70 cm by the following spring. Larger sharks up to 150 cm probably represent the 1+ and 2+ age classes (Francis 2016). Aerial survey observations indicate that juveniles of 150–200 cm total length are abundant off the west coast of the North Island.

The habitat of adult hammerheads is unknown. However, a shark tagged in the outer Hauraki Gulf in 2011 was recaptured in Tonga, about 2225 km away. At recapture, it measured 229 cm fork length (c. 285 cm TL) and weighed 85 kg, and was probably mature (Francis 2016). Elsewhere in the world, large *S. zygaena* have been recorded travelling 1,000 km or more so they are probably much more mobile than juveniles.

Although few data are available on the smooth hammerhead's life-history characteristics, it is a large hammerhead shark and presumably at least as biologically vulnerable as the scalloped hammerhead shark (*Sphyrna lewini*) (Casper et al. 2005). Preliminary, unvalidated studies of age and growth in the Atlantic Ocean suggest that *S. zygaena* can live for 20–25 years (Coelho et al. 2011, Rosa et al. 2015).

3. STOCKS AND AREAS

Genetic studies show that there is significant population structuring of this species among ocean basins, and in some cases within ocean basins (e.g., between the south-west and south-east Pacific Ocean); however there is no genetic structuring between New Zealand and Australia, suggesting the existence of gene flow across the Tasman Sea (Hernandez 2013).

4. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS

Smooth hammerhead sharks are primarily taken as non-target catch in set-net and bottom-longline fisheries, please refer to those fisheries for environmental and ecosystem considerations.

4.1 Role in the ecosystem

The smooth hammerhead shark (*Sphyrna zygaena*) is found worldwide in temperate and tropical seas (Casper et al. 2005). It is coastal-pelagic and semi-oceanic and occurs on the continental shelf, to 200 m depth (Ebert 2003). The smooth hammerhead is an active-swimming predator, predominantly feeding on squid and teleosts (Casper et al. 2005). Based on specimens caught by recreational anglers off New South Wales, Australia, Stevens (1984) reported that 76% of specimens with food in their stomachs contained squid and 54% teleosts.

5. STOCK ASSESSMENT

There is insufficient information with which to conduct a stock assessment of hammerhead sharks.

5.1 Estimates of fishery parameters and abundance

No estimates of fisheries parameters or abundance are available for this species.

5.2 Biomass estimates

No estimates of biomass are available for this species.

5.3 Yield estimates and projections

Yield estimate and projections have not been estimated for *S. zygaena.*

6. STATUS OF THE STOCKS

Hammerhead sharks in New Zealand are likely to be part of a wider south-western Pacific Ocean stock. The text below relates only to the New Zealand component of that stock.

Stock Status	
Year of Most Recent Assessment	No assessment
Assessment Runs Presented	-
Reference Points	Target: Not established Soft Limit: Not established by WCPFC; but HSS default of 20% SB_0 assumed Hard Limit: Not established by WCPFC; but HSS default of 10% SB_0 assumed Overfishing threshold: Not established
Status in relation to Target	Unknown
Status in relation to Limits	Unknown
Status in relation to Overfishing	Unknown

Historical Stock Status Trajectory and Current Status
-

Fishery and Stock Trends	
Recent trend in Biomass or Proxy	Unknown
Recent trend in Fishing Intensity or Proxy	Unknown
Other Abundance Indices	Unknown
Trends in Other Relevant Indicators or Variables	Unknown

Projections and Prognosis	
Stock Projections or Prognosis	Unknown
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unknown Hard Limit: Unknown
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unknown

Assessment Methodology and Evaluation		
Assessment Type	-	
Assessment Method	-	
Assessment Dates	Latest assessment: N/A	Next assessment: None planned
Overall assessment quality rank	-	
Main data inputs (rank)	-	-
Data not used (rank)	-	-
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	-	

Qualifying Comments
This fishery is largely a bycatch fishery.

Environmental and Ecosystem Considerations
Smooth hammerhead sharks are primarily taken as non-target catch in set-net and bottom-longline fisheries, please refer to those fisheries for environmental and ecosystem considerations.

7. RESEARCH NEEDS

The key research needs are to determine the link between the New Zealand stock and the wider Pacific stock, and to assess the trends in the stock status for this species.

8. FOR FURTHER INFORMATION

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Wynne-Jones, J; Gray, A; Heinemann, A; Hill, L; Walton, L. (2019) National Panel Survey of Marine Recreational Fishers 2017–18. *New Zealand Fisheries Assessment Report 2019/24*. 104 p.

MAKO SHARK (MAK)

(*Isurus oxyrinchus)*

1. FISHERY SUMMARY

Mako sharks were introduced into the QMS on 1 October 2004 under a single QMA, MAK 1, with a TAC of 542 t, a TACC of 406 t and a recreational allowance of 50 t. The TAC was reviewed in 2012 with the reduced allocation and allowances applied from 1 October 2012 in Table 1. The decrease was in response to sustainability concerns that mako sharks are considered to be at risk of overfishing internationally because of their low productivity.

Table 1: Recreational and customary non-commercial allowances, TACC and TAC (t) for mako sharks.

Fishstock	Recreational allowance	Customary non-commercial allowance	Other mortality	TACC	TAC
MAK 1	30	10	36	200	276

Mako sharks were added to the Third Schedule of the 1996 Fisheries Act with a TAC set under s14 because mako sharks are a highly migratory species and it is not possible to estimate MSY for the part of the stock that is found within New Zealand fisheries waters.

The conditions of Schedule 6 releases have been amended for mako, porbeagle and blue sharks. From 1 October 2014, fishers have been allowed to return these three species to the sea both alive and dead, although the status must be reported accurately. Those returned to the sea dead are counted against a fisher's ACE and the total allowable catch limit for that species. On 1 October 2014 a ban on shark finning was introduced; after this time any mako sharks for which the fins are retained are required to be landed with the fins attached (artificial attachment such as tying or securing the fins to the trunk is permitted).

Management of the mako shark throughout the western and central Pacific Ocean (WCPO) is the responsibility of the Western and Central Pacific Fisheries Commission (WCPFC). Under this regional convention New Zealand is responsible for ensuring that the management measures applied within New Zealand fisheries waters are compatible with those of the Commission.

1.1 Commercial fisheries

Most of the commercial catch of mako sharks is taken by tuna longliners and bottom longliners and they are also incidental bycatch of bottom and midwater trawlers. The TACC was reduced from 400 t to 200 t for the 2012–13 fishing year.

Landings of mako sharks reported on CELR (landed), CLR, LFRR and MHR forms are shown in Table 2 and Figure 1. There was a steady increase in the weight of mako sharks landed in the late 1990s, reaching a peak in 2000–01, resulting from a large increase in domestic fishing effort in the tuna longline fishery, and probably also improved reporting. Landings then declined to about one-quarter of the peak landings between 2003–04 and 2018–19.

In addition to catch taken within New Zealand fisheries waters, a small amount (less than 1 t in recent years) is taken by New Zealand longline vessels fishing on the high seas.

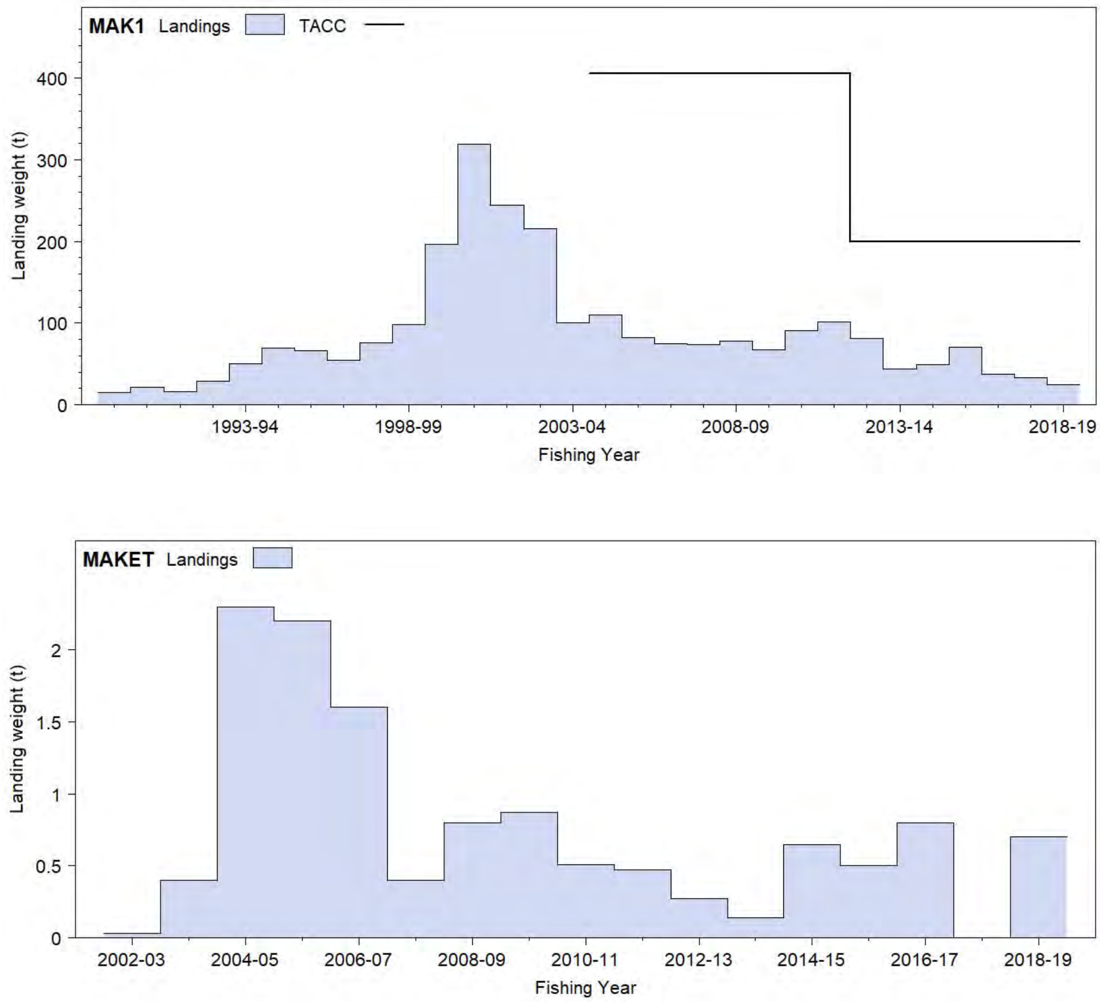


Figure 1: [Top] Mako shark catch from 1989–90 to 2018–19 within New Zealand waters (MAK 1) and [bottom] 2002–03 to 2018–19 on the high seas (MAK ET).

Table 2: New Zealand commercial landings (t) of mako sharks reported by fishers (CELRs and CLRs) and processors (LFRRs) by fishing year.

Year	Total reported	LFRR/MHR
1989–90	11	15
1990–91	15	21
1991–92	17	16
1992–93	24	29
1993–94	44	50
1994–95	63	69
1995–96	67	66
1996–97	51	55
1997–98	86	76
1998–99	93	98
1999–00	148	196
2000–01	295	319
2001–02	242	245
2002–03*	233	216
2003–04*	100	100
2004–05*	107	112
2005–06*	83	84
2006–07*	76	75
2007–08*	72	74
2008–09*	82	78
2009–10*		67
2010–11*		91
2011–12*		102
2012–13*		81
2013–14*		44
2014–15*		50
2015–16*		71
2016–17*		38
2017–18*		33
2018–19*		25

* MHR rather than LFRR data.

Catches of mako sharks aboard tuna longliners have been concentrated off the west and south-west coast of the South Island, and the north-east coast of the North Island (Figure 2). Most of the mako landings were taken in FMAs 1 and 2.

In 2012–13, the majority of mako sharks (55%) were caught in the bigeye tuna target surface-longline fishery (Figure 3). In 2017–18, across all longline fisheries mako were in the top ten species by weight (3% of reported catches) (Figure 4). Longline fishing effort is distributed along the east coast of the North Island and the south-west coast of the South Island. The west coast South Island fishery predominantly targets southern bluefin tuna, whereas the fishery off the east coast of the North Island targets a range of species including bigeye, swordfish and southern bluefin tuna.

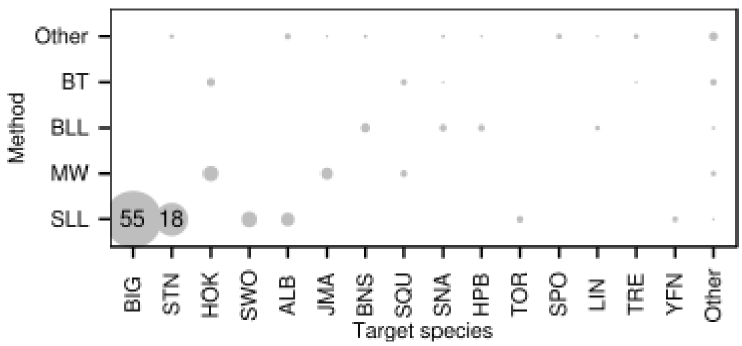


Figure 3: A summary of the proportion of landings of mako sharks taken by each target fishery and fishing method for the 2012–13 fishing year. The area of each circle is proportional to the percentage of landings taken using each combination of fishing method and target species. The number in the circle is the percentage. SLL = surface longline, MW = midwater trawl, BLL = bottom longline, BT = bottom trawl (Bentley et al. 2013).

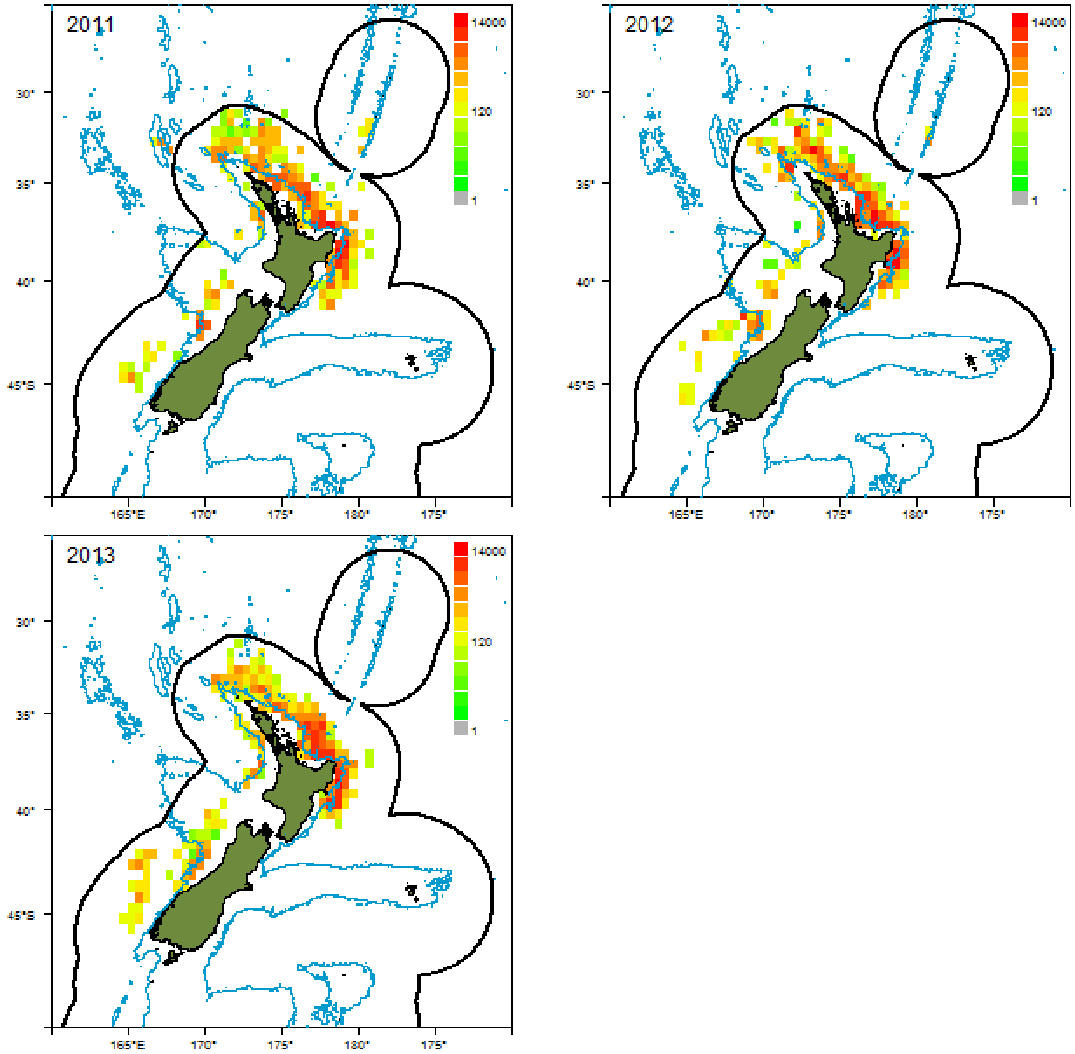


Figure 2: Mako shark catches (kg) by the surface-longline fishery in 0.5 degree rectangles by fishing year. Note the log scale used for the colour palette. Depth contour = 1000 m.

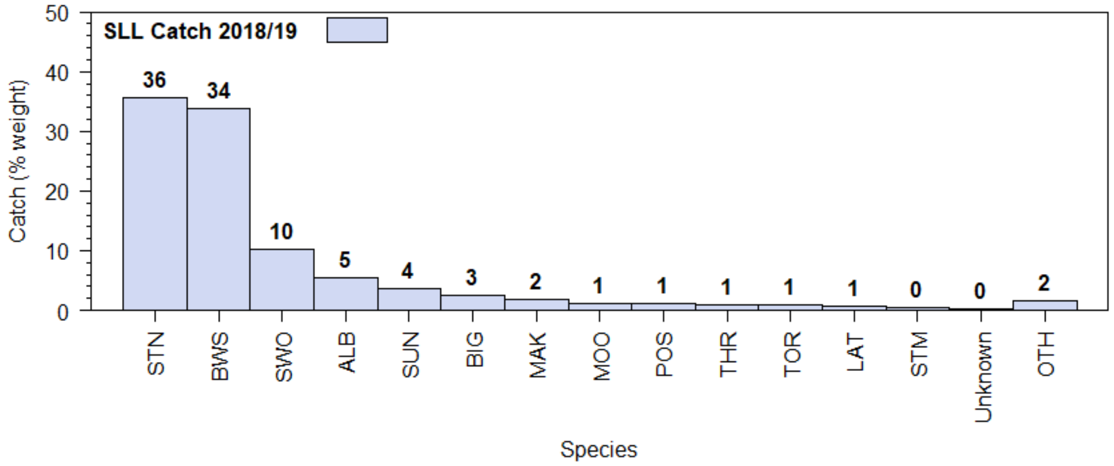


Figure 4: A summary of species composition of the surface-longline estimated catch for the 2018–19 fishing year. The percentage by weight of each species is calculated for all surface-longline trips.

Across all fleets in the longline fishery in 2014–15, 77.5% of the mako sharks were alive when brought to the side of the vessel (Table 3). The percentage of mako shark catches retained has varied over time, becoming relatively low in 2014–15 (Table 4).

Table 3: Percentage of mako sharks (including discards) that were alive or dead when arriving at the longline vessel and observed during 2006–07 to 2014–15, by fishing year, fleet and region. Small sample sizes (number observed < 20) were omitted (Griggs & Baird 2013, Griggs et al. 2018). [Continued next page]

Year	Fleet	Area	% alive	% dead	Number
2006–07	Australia	North	82.1	17.9	28
	Charter	North	83.0	17.0	276
		South	93.1	6.9	29
	Domestic	North	67.6	32.4	262
	Total		**76.6**	**23.4**	**595**
2007–08	Domestic	North	63.8	36.2	304
	Total		**64.7**	**35.3**	**320**
2008–09	Charter	North	88.6	11.4	44
		South	100.0	0.0	31
	Domestic	North	69.6	30.4	289
	Total		**74.4**	**25.6**	**367**
2009–10	Domestic	North	76.1	23.9	330
	Total		**75.9**	**24.1**	**348**
2010–11	Domestic	North	73.0	27.0	515
	Total		**73.8**	**26.2**	**530**
2011–12		South	86.4	13.6	22
	Domestic	North	67.6	32.4	296
	Total		**68.9**	**31.1**	**328**
2012–13	Charter	North	80.8	19.2	26
		South	79.6	20.4	49
	Domestic	North	79.0	21.0	119
	Total		**78.7**	**21.3**	**197**
2013–14	Domestic	North	68.6	31.4	188
		South	64.1	35.9	39
	Total		**68.7**	**31.3**	**246**
2014–15	Charter	South	88.9	11.1	27
	Domestic	North	76.7	23.3	163
		South	69.6	30.4	23
	Total	**Total**	**77.5**	**22.5**	**213**

Table 4: Percentage of mako sharks that were retained, or discarded or lost, when observed on a longline vessel during 2006–07 to 2014–15, by fishing year and fleet. Small sample sizes (number observed < 20) omitted (Griggs & Baird 2013, Griggs et al. 2018).

Year	Fleet	% retained or finned	% discarded or lost	Number
2006–07	Australia	17.9	82.1	28
	Charter	93.8	6.2	323
	Domestic	37.0	63.0	262
	Total	**66.1**	**33.9**	**613**
2007–08	Domestic	66.6	33.4	305
	Total	**68.2**	**31.8**	**321**
2008–09	Charter	100.0	0.0	85
	Domestic	58.7	41.3	293
	Total	**68.0**	**32.0**	**378**
2009–10	Domestic	19.1	80.9	350
	Total	21.6	78.4	361
2010–11	Domestic	27.9	72.1	580
	Total	**30.1**	**69.9**	**598**
2011–12	Charter	96.0	4.0	25
	Domestic	47.1	52.9	314
	Total	**50.7**	**49.3**	**339**
2012–13	Charter	80.0	20.0	75
	Domestic	13.2	86.8	129
	Total	**37.7**	**62.3**	**204**
2013–14	Charter	95.2	4.8	21
	Domestic	24.0	76.0	258
	Total	**29.4**	**70.6**	**279**
2014–15	Charter	59.3	40.7	27
	Domestic	6.8	93.2	190
	Total	**13.4**	**86.6**	**217**

1.2 Recreational fisheries

Historically there was a recreational target fishery for mako sharks and they were highly prized as a sport fish. Most mako sharks are now taken as a bycatch while targeting other species. Reported catch has declined since the mid-1990s. Fishing clubs affiliated to the New Zealand Sports Fishing Council have reported landing 8 mako sharks in 2017–18. In addition recreational fishers tag and release 200 to 500 mako sharks per season. Using New Zealand Sports Fishing Council records only, it is estimated that 97% of mako sharks caught by recreational fishers associated with sport fishing clubs were tagged and released in 2017–18.

Recreational catch estimates are available from two national panel surveys. They are caught around the upper North Island, with harvest by area in 2017–18 being: FMA 1 (4.2%), FMA 2 (73.0%), and FMA 9 (22.8%).

1.2.2 Estimates of recreational harvest

Recreational catch estimates are available from national panel surveys conducted in the 2011–12 fishing year (Wynne-Jones et al. 2014) and the 2017–18 fishing year (Wynne-Jones et al. 2019). The panel survey used face-to-face interviews of a random sample of New Zealand households to recruit a panel of fishers and non-fishers for a full year. The panel members were contacted regularly about their fishing activities and catch information collected in standardised phone interviews. Note that the national panel survey estimates include harvest taken on recreational charter vessels, but for mako sharks is unlikely to estimate this proportion of the catch well. The national panel survey estimate does not include recreational harvest taken under s111 general approvals. The national panel survey was repeated during the 2017–18 fishing year using very similar methods to produce directly comparable results (Wynne-Jones et al. 2019).

The harvest estimate from the 2011–12 survey was 529 fish. The harvest estimate from the 2017–18 survey was 1048 fish (CV 0.46). This estimate was derived from landings of five mako by three panellists.

1.3 Customary non-commercial fisheries

There are no estimates of Maori customary catch of mako sharks. Traditionally, mako were highly regarded by Maori for their teeth, which were used for jewellery. Target fishing trips were made, with sharks being caught by flax rope nooses to avoid damaging the precious teeth.

1.4 Illegal catch

There is no known illegal catch of mako sharks.

1.5 Other sources of mortality

Many of the mako sharks caught by tuna longliners (about 75%) are alive when the vessel retrieves the line. It is not known how many of the sharks that are returned to the sea alive under the provisions of Schedule 6 of the Fisheries Act survive. A research study to estimate survival rates of returned mako sharks using popup tags has recently been conducted by NIWA for WCPFC. Estimates of post release mortality for mako after 60 days were estimated to be 20%. Recommendations that came out of the subsequent workshop included data collections to further enable evaluation of shark mitigation effectiveness, including; handling practices and release methods, condition at haulback and condition at release, shark length, length of trailing gear, gangion materials, hooking location, hook type. Dead discards are now allowed under Schedule 6 of the Fisheries Act, and these may be under-reported.

2. BIOLOGY

Mako sharks occur worldwide in tropical and warm temperate waters, mainly between latitudes 50ºN and 50ºS. In the South Pacific, mako are rarely caught south of 40ºS in winter–spring (August–November) but in summer–autumn (December–April) they penetrate at least as far as 55ºS. Mako sharks occur throughout the New Zealand EEZ (to at least 49ºS), but are most abundant in the north, especially during the colder months.

Mako sharks produce live young around 57–69 cm (average 61 cm) fork length (FL). In New Zealand, male mako sharks mature at about 180–185 cm FL and female mako mature at about 275–285 cm FL (Francis & Duffy 2005). The length of the gestation period is uncertain, but is thought to be 18 months with a resting period between pregnancies leading to a two- or three-year pupping cycle. Only one pregnant female has been recorded from New Zealand, but newborn young are relatively common. Litter size is 4–18 embryos. If the reproductive cycle lasts three years, and mean litter size is 12, mean annual fecundity would be 4 pups per year.

Estimates of mako shark age and growth in New Zealand were derived by counting vertebral growth bands, and assuming that one band pair (one opaque and one translucent band) is formed each year. This assumption has been validated for North Atlantic mako sharks but there is evidence that fast-growing juveniles in California waters deposit two band pairs per year, and length-frequency modes suggest the same is true for New Zealand juveniles (Francis 2016). Males and females grow at similar rates until age 16 years, after which the relative growth of males probably declines. In New Zealand, males mature at about 9–10 years and females at 20–21 years. The maximum ages recorded are 29 and 28 years for males and females respectively.

The longest reliably measured mako appears to be a 351 cm FL female from the Indian Ocean, but it is likely that they reach or exceed 366 cm FL. In New Zealand, mako recruit to commercial fisheries during their first year at about 70 cm FL, and much of the commercial catch is immature and less than 6 years old. Sharks less than 150 cm FL are rarely caught south of Cook Strait, where most of the catch by tuna longliners consists of sub-adult and adult males.

Mako sharks are active pelagic predators of other sharks and bony fishes, and to a lesser extent squid. As top predators, mako sharks probably associate with their main prey, but little is known of their relationships with other species.

Estimates of biological parameters are given in Table 5.

Table 5: Estimates of biological parameters.

Fishstock	Estimate				Source
1. Natural mortality (M)					
MAK 1	0.10–0.15				Bishop et al. (2006)
2. Weight = a(length)^b (Weight in kg, length in cm fork length)					
Both sexes combined	a		b		
MAK 1	2.388×10^{-5}		2.847		Ayers et al. (2004)
3. Schnute growth parameters	L_1	L_{10}	κ	γ	
MAK 1 males	100.0	192.1	-	3.40	Bishop et al. (2006)
MAK 1 females	99.9	202.9	-0.07	3.67	Bishop et al. (2006)
MAK 1 males less than 16 years	100.4	184.9	-0.13	5.16	Francis (2016)
MAK 1 females less than 16 years	97.6	180.1	-0.20	5.17	Francis (2016)

3. STOCKS AND AREAS

Up to June 2018, 1 139 mako sharks had been tagged and released in New Zealand waters and 377 recaptured. Most of the tagged fish in recent years were small to medium sharks with estimated total weights at 90 kg or less, with a mode at 40 to 50 kg, and they were mainly tagged off east Northland and the west coast of the North Island. Most recaptures have been within 500 km of the release site, with sharks remaining around east Northland or travelling to the Bay of Plenty and the west coast of North Island. However, long distance movements out of the New Zealand EEZ are frequent, with mako sharks travelling to eastern Australia or the western Tasman Sea (1500–2000 km), the tropical islands north of New Zealand (New Caledonia, Fiji, Tonga, Solomon Islands: 1500–2400 km) and to the Marquesas Islands in French Polynesia (4600 km). Electronic tagging of juvenile mako sharks, and adult males, showed relatively high site fidelity, with all 14 sharks remaining in the NZ EEZ for many months. Most of the sharks showed an offshore movement in winter, with some travelling up the Kermadec Ridge, or to Fiji, New Caledonia and the Coral Sea. Several of the sharks subsequently returned to New Zealand. This indicates that juvenile mako sharks may undergo seasonal migrations but that they spend much of their life in New Zealand coastal waters. Little is known about the movements of adults, but they appear to travel further afield than juveniles.

Several DNA analyses of mako sharks worldwide have shown that there are distinct stocks in the North Atlantic, South Atlantic, North Pacific, Southwest Pacific and Southeast Pacific (Clarke et al. 2015, Corrigan et al. 2018). This is consistent with tagging data that have shown no movements of New Zealand sharks beyond the Southwest Pacific.

4. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS

There is no directed fishery for mako, they are exposed to incidental capture, so there is no information on bycatch of other species in target mako shark fisheries.

4.2 Non-target fish catch

Mako shark is a non-target catch in the tuna and swordfish surface-longline fishery in the New Zealand EEZ.

Observer records indicate that a wide range of species are landed by the surface longline fleets in New Zealand fishery waters. Blue sharks are the most commonly landed species (by number), followed by lancetfish and Ray’s bream.

4.3 Benthic interactions

There are no known interactions with benthic habitats for this fishery.

4.4 Key environmental and ecosystem information gaps

Cryptic mortality is unknown at present.

Observer coverage in the New Zealand fleet has historically not been spatially or temporally representative of the fishing effort. However in 2013 the observer effort was restructured to rectify this by planning observer deployment to correspond with recent spatial and temporal trends in fishing effort.

5. STOCK ASSESSMENT

With the establishment of the WCPFC in 2004, future stock assessments of the western and central Pacific Ocean stock of mako sharks will be reviewed by the WCPFC. There is currently a shark research plan that has been developed within the context of the WCPFC, but mako sharks will not be a focus of that plan in the near future.

There have been no stock assessments of mako sharks in New Zealand, or elsewhere in the world. No estimates of yield are possible with the currently available data. Indicator analyses (Figures 5 and 6) suggest that mako shark populations in the New Zealand EEZ have not been declining under recent fishing pressure, and may have been increasing since 2005 (Table 6, Francis et al. 2014). These changes are presumably in response to a decline in SLL fishing effort since 2002 Figure 1), and declines in annual landings since a peak in 2000–01 for mako sharks. Observer data from 1995 suggest that mako sharks may have undergone a down-then-up trajectory. The quality of observer data and model fits means that these interpretations are uncertain. The stock status of mako sharks may be recovering. Conclusive determinations of stock status will require regional (i.e., South Pacific) stock assessments.

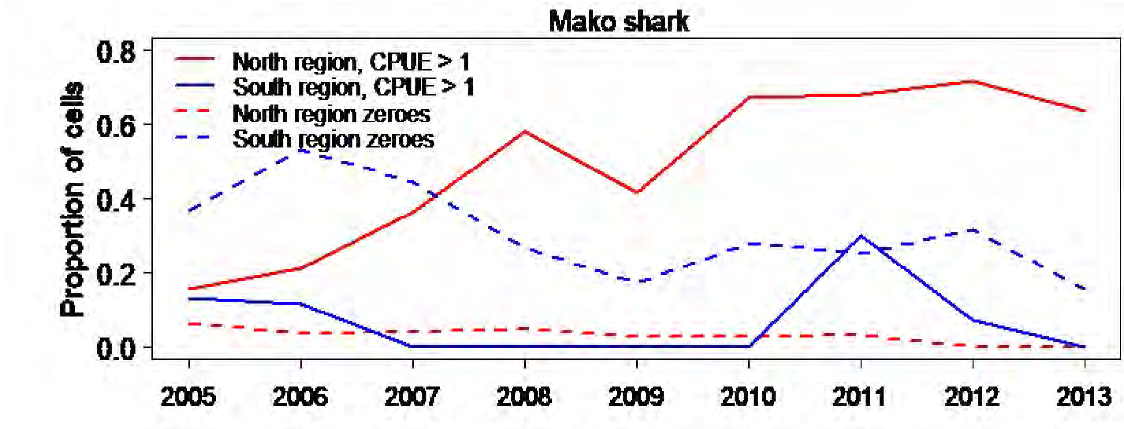


Figure 5: Mako shark distribution indicators. Proportions of 0.5 degree rectangles having CPUE greater than 1 per 1000 hooks, and proportions of rectangles having zero catches, for North and South regions by fishing year, based on estimated catches (processed and discarded combined) reported on TLCERs (Francis et al. 2014). North region comprises Fisheries Management Areas (FMAs) 1, 2, 8 and 9, and South region comprises FMAs 5 and 7.

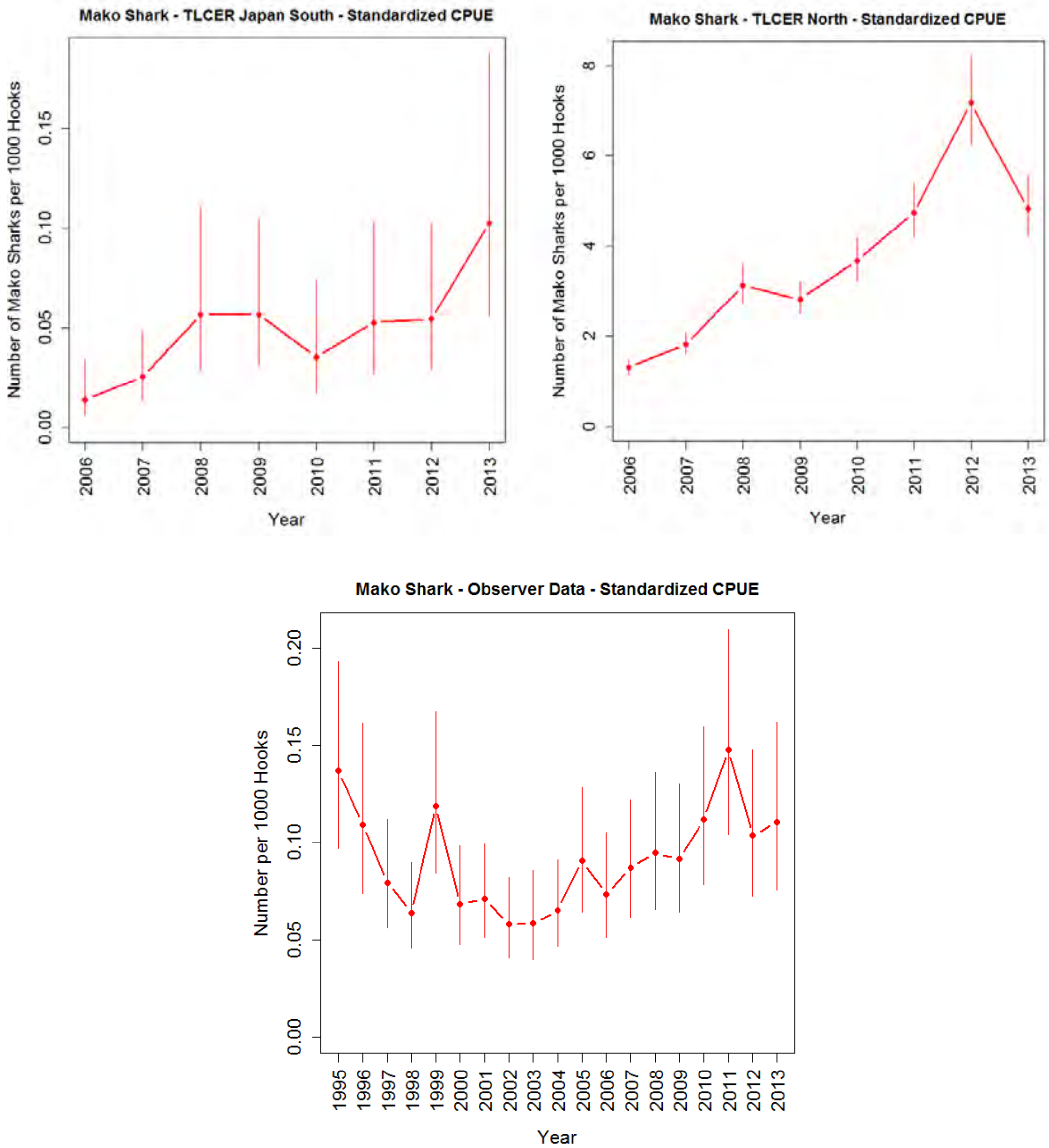


Figure 6: Standardised CPUE indices for commercial TLCER (Japan South and North), and observer datasets (all New Zealand).

Table 6: Summary of trends identified in abundance indicators since the 2005 fishing year based on both TLCER and observer data sets. The CPUE-Obs indicator was calculated for both North and South regions combined. North region comprises Fisheries Management Areas (FMAs) 1, 2, 8 and 9, and South region comprises FMAs 5 and 7. For the CPUE-TLCER indicator in South region, only the Japan dataset indicator is shown (the TLCER Domestic South dataset was small and probably unrepresentative). Green cells show indicators that suggest positive trends in stock size. Note that a downward trend in 'proportion-zeroes' is considered a positive stock trend. NA = indicator not applicable because of small sample size (Francis et al. 2014).

		North region			South region		
Indicator class	Indicator	Blue	Porbeagle	Mako	Blue	Porbeagle	Mako
Distribution	High-CPUE	Up	Up	Up	Up	Up	NA
Distribution	Proportion-zeroes	Nil	Down	Down	Nil	Nil	Down
Catch composition	GM index total catch - TLCER	Up (all species)			Up (all species)		
Catch composition	GM index total catch - Obs	Up (all species)			Nil (all species)		
Catch composition	GM index HMS shark catch - TLCER	Up (all species)			Up (all species)		
Catch composition	GM index HMS shark catch - Obs	Up (all species)			Nil (all species)		
Standardised CPUE	CPUE - TLCER	Up	Nil	Up	Up	Nil	Nil
Standardised CPUE	CPUE - Obs	Up	Nil	Nil	Up	Nil	Nil
Sex ratio	Proportion males	Nil	Nil	Nil	Nil	Nil	NA
Size composition	Median length - Males	Nil	Nil	Nil	Nil	Nil	NA
Size composition	Median length - Females	Nil	Nil	Nil	Nil	Nil	NA

Compared with a wide range of shark species, the productivity of mako sharks is very low. Females have a high age-at-maturity, moderately high longevity (and therefore low natural mortality rate) and low annual fecundity. The low fecundity is cause for serious concern, as the ability of the population to replace sharks removed by fishing is very limited.

Observer records show that few mako sharks were observed in the South region and there were no discernible differences between males and females (Figure 7). There were more males than females, especially in the South region (FMAs 5 and 7). With mean length of maturity of 182.5 cm FL for males and 280 cm FL for females (Francis & Duffy 2005), most mako sharks were immature (85.1% of males and 100.0% of females, overall) (Griggs & Baird 2013).

A data-informed qualitative risk assessment was completed on all chondrichthyans (sharks, skates, rays and chimaeras) at the New Zealand scale in 2017 (Ford et al. 2018). Mako sharks had a risk score of 15 and were ranked second equal lowest risk of the eleven QMS chondrichthyan species. Data were described as 'exist and sound' for the purposes of the assessment and the risk score was achieved by consensus of the expert panel, but with low confidence. This low confidence was due to the fact that no data were available on adult stock size.

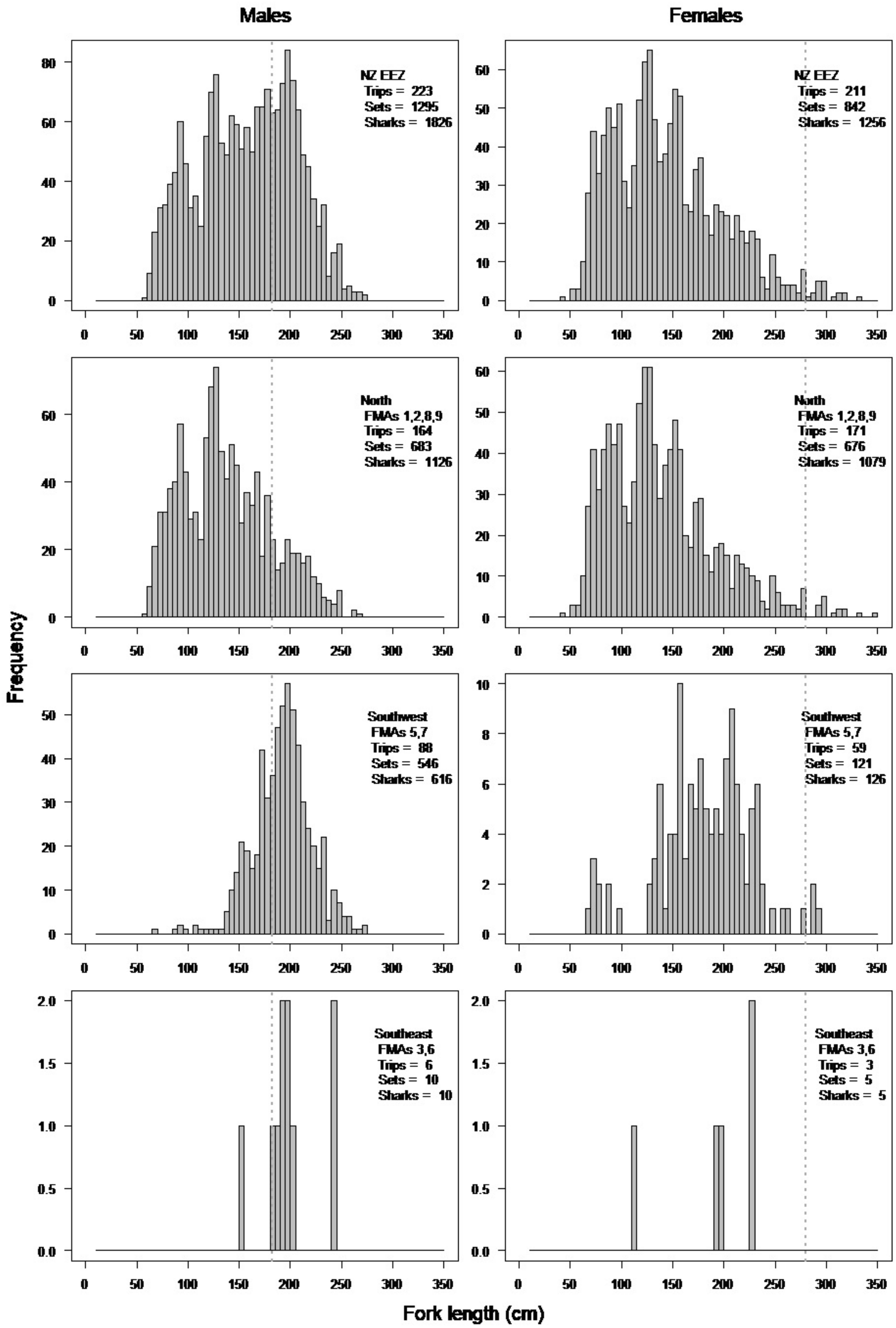


Figure 7: Length-frequency distributions of male and female mako sharks measured by observers aboard surface-longline vessels between 1993 and 2012 for the New Zealand EEZ, and North, Southwest and Southeast regions. The dashed vertical lines indicate the median length at maturity (Francis 2013).

6. STATUS OF THE STOCK

Stock structure assumptions

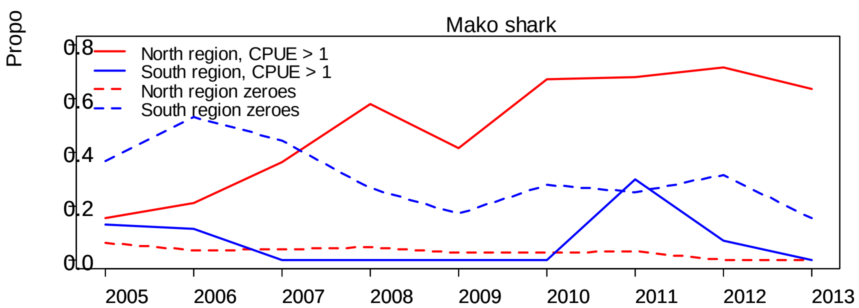
MAK 1 is assumed to be part of the wider south-western Pacific Ocean stock. However, there is no stock assessment for this wider stock. The results below are from indicator analyses of the New Zealand component of that stock only.

Stock Status	
Year of Most Recent Assessment	2014
Assessment Runs Presented	Indicator analyses for NZ EEZ only
Reference Points	Target: Not established Soft Limit: Not established but HSS default of 20% SB_0 assumed Hard Limit: Not established but HSS default of 10% SB_0 assumed Overfishing threshold: F_{MSY}
Status in relation to Target	Unknown
Status in relation to Limits	Unknown
Status in relation to Overfishing	Unknown

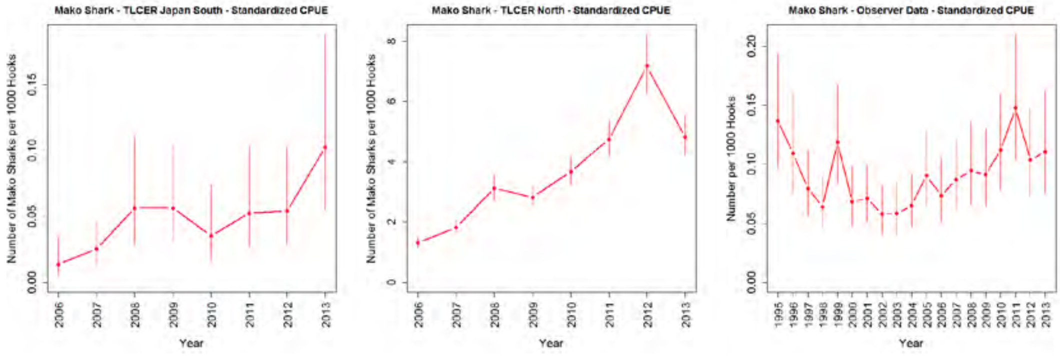
Historical Stock Status Trajectory and Current Status

Summary of trends identified in abundance indicators since the 2005 fishing year based on both TLCER and observer data sets. North region comprises Fisheries Management Areas (FMAs) 1, 2, 8 and 9, and South region comprises FMAs 5 and 7.

		North region			South region		
Indicator class	Indicator	Blue	Porbeagle	Mako	Blue	Porbeagle	Mako
Distribution	High-CPUE	Up	Up	Up	Up	Up	NA
Distribution	Proportion-zeroes	Nil	Down	Down	Nil	Nil	Down
Catch composition	GM index total catch - TLCER	Up (all species)			Up (all species)		
Catch composition	GM index total catch - Obs	Up (all species)			Nil (all species)		
Catch composition	GM index HMS shark catch - TLCER	Up (all species)			Up (all species)		
Catch composition	GM index HMS shark catch - Obs	Up (all species)			Nil (all species)		
Standardised CPUE	CPUE - TLCER	Up	Nil	Up	Up	Nil	Nil
Standardised CPUE	CPUE - Obs	Up	Nil	Nil	Up	Nil	Nil
Sex ratio	Proportion males	Nil	Nil	Nil	Nil	Nil	NA
Size composition	Median length - Males	Nil	Nil	Nil	Nil	Nil	NA
Size composition	Median length - Females	Nil	Nil	Nil	Nil	Nil	NA



Mako shark distribution indicators. Proportions of 0.5 degree rectangles having CPUE greater than 1 per 1000 hooks, and proportions of rectangles having zero catches, for North and South regions by fishing year, based on estimated catches (processed and discarded combined) reported on TLCERs (Francis et al. 2014). North region comprises Fisheries Management Areas (FMAs) 1, 2, 8 and 9, and South region comprises FMAs 5 and 7.



Standardised CPUE indices for commercial TLCER (Japan South and North) and observer datasets (all New Zealand).

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Appears to be increasing
Recent Trend in Fishing Intensity or Proxy	Appears to be decreasing
Other Abundance Indices	-
Trends in Other Relevant Indicator or Variables	Catches in New Zealand increased from the early 1980s to a peak in the early 2000s but have declined from highs of 319 t to 44–103 t between 2005–06 and 2014–15.

Projections and Prognosis	
Stock Projections or Prognosis	The stock is likely to increase if effort remains at current levels.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unknown Hard Limit: Unknown
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unknown

Assessment Methodology and Evaluation		
Assessment Type	Level 2 – Partial Quantitative Stock Assessment: Standardised CPUE indices and other fishery indicators	
Assessment Method	Indicator analyses	
Assessment Dates	Latest assessment: 2014	Next assessment: Unknown
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Distribution - Species composition - Size and sex ratio - Catch per unit effort	1 – High quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	Catch recording before 2005 may not be accurate.	

Qualifying Comments
-

Environmental and Ecosystem Considerations
Mako shark is a non-target catch in the tuna and swordfish surface-longline fishery in the New Zealand EEZ, please refer to those species for environmental and ecosystem considerations. Blue sharks are the most commonly landed non-target species (by number), followed by lancetfish and Ray's bream in this fishery.

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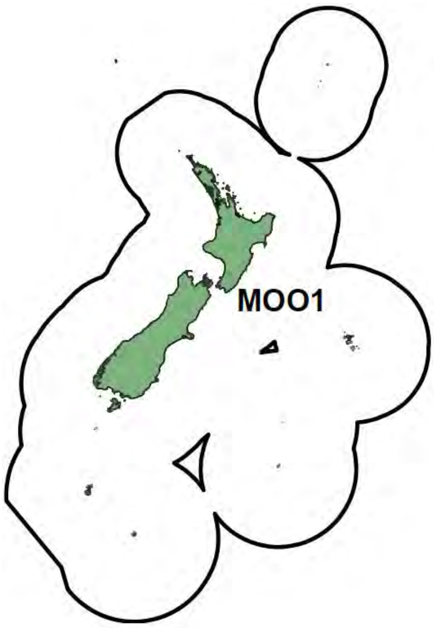
MOONFISH (MOO)

(Lampris guttatus)



1. FISHERY SUMMARY

Moonfish were introduced into the QMS on 1 October 2004 under a single QMA, MOO 1, with the TAC equal to the TACC (Table 1).

Table 1: Recreational and customary non-commercial allowances, TACCs and TACs (all in t) of moonfish.

Fishstock	Recreational allowance	Customary non-commercial allowance	Other mortality	TACC	TAC
MOO 1	0	0	0	527	527

Moonfish were added to the Third Schedule of the 1996 Fisheries Act with a TAC set under s14.

1.1 Commercial fisheries

Most moonfish (70%) are caught as bycatch in surface-longline fisheries (in the top seven most common bycatch species in the surface-longline fishery; see Table 5). The main fisheries catching moonfish by surface longlining are targeting bigeye tuna (*Thunnus obesus*) and, to a lesser extent, southern bluefin tuna (*T. maccoyii*), albacore (*T. alalunga*) and yellowfin tuna (*T. albacares*). Midwater trawling accounts for 18% of the catch, bottom trawling 8% and bottom longlining 1%. The main target fisheries using midwater trawling are for southern blue whiting (*Micromesistius australis*) and hoki (*Macruronus novaezelandiae*), and bottom trawling for hoki and gemfish (*Rexea solandri*).

When caught on tuna longlines most moonfish are alive (79.8%). Most moonfish catch is kept and landed, as there is a market demand. It is likely that landing data for moonfish reasonably represents actual catches, although it may include small amounts (less than 1%) of the less common *Lampris* spp. and the more southerly occurring species (*Lampris immaculatus*) because of misidentification. Most of the catch taken by the tuna longline fishery was aged 2 to 14 years, and most (71%) of the commercial catch appears to be of adult fish. Figure 1 shows the historic landings and longline fishing effort for moonfish inside and outside the New Zealand EEZ.

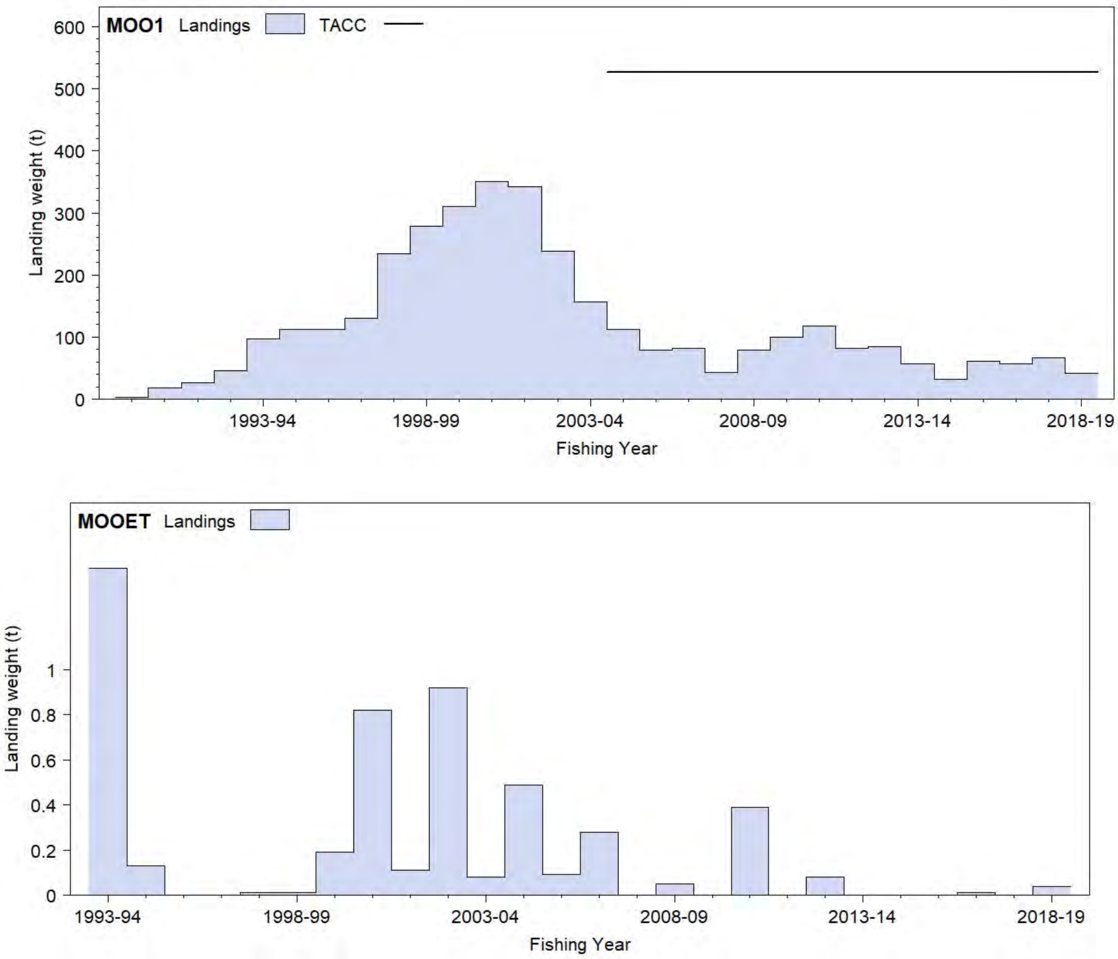


Figure 1: [Top] Moonfish catch from 1989–90 to 2018–19 within New Zealand waters (MOO 1) and [Bottom] 1993–94 to 2018–19 on the high seas (MOO ET).

Reported landings in New Zealand increased each year from 3 t in 1989–90 to a maximum of 351 t in 2000–01, but have declined since then as a result of decreasing effort in the surface-longline fishery (Table 2). From 2005–06 to 2013–14 landings have averaged around 75 t. New Zealand landings of moonfish appear to represent about 70% of the reported catch of moonfish in the wider South Pacific area based on Food and Agriculture Organisation of the United Nations statistics. However, this may reflect general non-reporting of bycatch.

Table 2: Reported landings (t) of moonfish (CELR, CLR and LFRR data from 1989–90 to 2000–01, MHR data from 2001–02 onwards).

Fishing year	MOO 1 (all FMAs)	Fishing year	MOO 1 (all FMAs)
1989–90	3	2004–05	112
1990–91	18	2005–06	80
1991–92	26	2006–07	82
1992–93	46	2007–08	43
1993–94	97	2008–09	80
1994–95	112	2009–10	100
1995–96	112	2010–11	118
1996–97	130	2011–12	84
1997–98	234	2012–13	85
1998–99	278	2013–14	56
1999–00	311	2014–15	32
2000–01	351	2015–16	61
2001–02	342	2016–17	57
2002–03	239	2017–18	67
2003–04	156	2018–19	41

In 2012–13, the majority of moonfish were caught in the bigeye tuna (76%) and southern bluefin tuna (13%) surface-longline fisheries (Figure 2). In 2017–18, across all longline fisheries blue sharks and southern Bluefin tuna made up the bulk of the catch (31% each) (Figure 3). Longline fishing effort is distributed along the east coast of the North Island and the south-west coast of the South Island. The west coast South Island fishery predominantly targets southern bluefin tuna, whereas the east coast of the North Island targets a range of species including bigeye, swordfish and southern bluefin tuna.

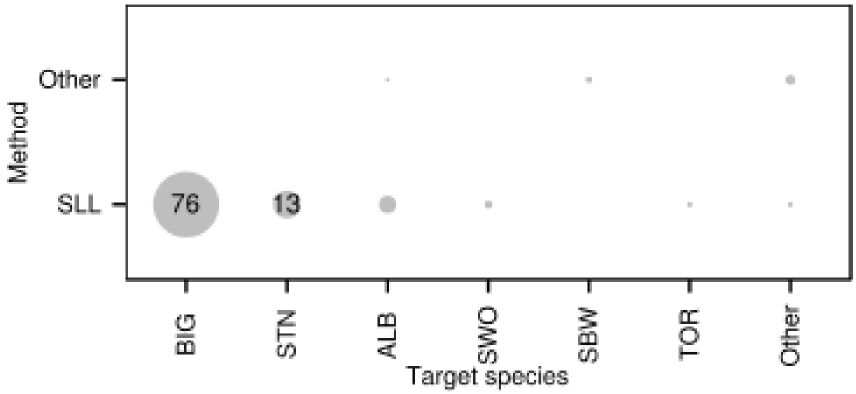


Figure 2: A summary of the proportion of landings of moonfish taken by each target fishery and fishing method for 2012–13. The area of each circle is proportional to the percentage of landings taken using each combination of fishing method and target species. The number in the circle is the percentage. SLL = surface longline (Bentley et al. 2013).

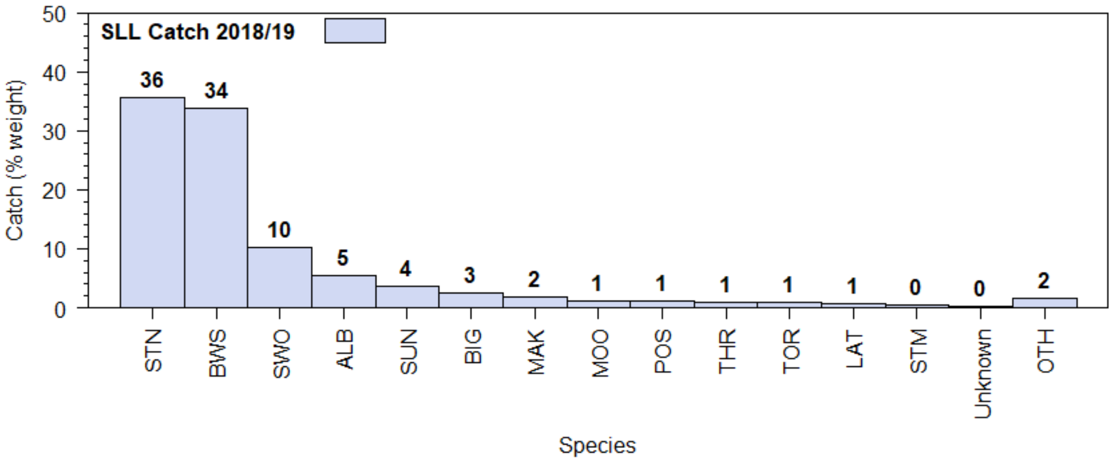


Figure 3: A summary of species composition of the surface-longline estimated catch for 2018–19. The percentage by weight of each species is calculated for all surface-longline trips.

By far the majority of moonfish have been alive when brought to the side of the vessel (Table 3). From 2006–07 to 2014–15, most of the moonfish catch has been retained (Table 4).

Table 3: Percentage of moonfish (including discards) that were alive or dead when arriving at the longline vessel and observed during 2006–07 to 2014–15, by fishing year, fleet and region. Small sample sizes (number observed < 20) were omitted (Griggs & Baird 2013, Griggs et al. 2018).

Year	Fleet	Area	% alive	% dead	Number
2006–07	Australia	North	80.0	20.0	20
	Charter	North	85.2	14.8	472
		South	84.2	15.8	114
	Domestic	North	65.6	34.4	180
	Total		**80.4**	**19.6**	**786**
2007–08	Charter	South	100.0	0.0	41
	Domestic	North	78.4	21.6	97
	Total		**84.8**	**15.2**	**138**
2008–09	Charter	North	100.0	0.0	60
		South	100.0	0.0	30
	Domestic	North	72.6	27.4	201
	Total		**81.1**	**18.9**	**291**
2009–10	Charter	South	98.6	1.4	69
	Domestic	North	71.5	28.5	333
	Total		**76.0**	**24.0**	**408**
2010–11	Charter	South	90.5	9.5	21
	Domestic	North	76.5	23.5	341
	Total		**77.3**	**22.7**	**362**
2011–12	Charter	South	91.7	8.3	24
	Domestic	North	63.0	37.0	127
	Total		**67.7**	**32.3**	**155**
2012–13	Charter	North	85.7	14.3	42
		South	90.5	9.5	42
	Domestic	North	67.8	32.2	87
	Total		**77.8**	**22.2**	**171**
2013–14	Charter	South	93.8	6.3	96
	Domestic	North	67.4	32.6	132
	Total		**76.2**	**23.8**	**244**
2014–15	Charter	South	95.8	4.2	48
	Domestic	North	60.5	39.5	38
	Total		**76.8**	**23.2**	**95**

Table 4: Percentage of moonfish that were retained, or discarded or lost, when observed on a longline vessel during 2006–07 to 2014–15, by fishing year and fleet. Small sample sizes (number observed < 20) omitted (Griggs & Baird 2013, Griggs et al. 2018). [Continued on next page]

Year	Fleet	% retained	% discarded or lost	Number
2006–07	Australia	100.0	0.0	20
	Charter	91.6	8.4	616
	Domestic	97.2	2.8	180
	Total	**93.0**	**7.0**	**816**
2007–08	Charter	100.0	0.0	41
	Domestic	100.0	0.0	96
	Total	**100.0**	**0.0**	**137**
2008–09	Charter	100.0	0.0	107
	Domestic	98.5	1.5	201
	Total	**99.0**	**1.0**	**308**

Year	Fleet	% retained	% discarded or lost	Number
2009–10	Charter	100.0	0.0	76
	Domestic	96.5	3.5	345
	Total	**97.1**	**2.9**	**421**
2010–11	Charter	100.0	0.0	22
	Domestic	97.1	2.9	343
	Total	**97.3**	**2.7**	**365**
2011–12	Charter	100.0	0.0	26
	Domestic	96.3	3.7	134
	Total	**96.9**	**3.1**	**160**
2012–13	Charter	97.6	2.4	84
	Domestic	97.7	2.3	87
	Total	**97.7**	**2.3**	**171**
2013–14	Charter	96.5	3.5	114
	Domestic	90.8	9.2	153
	Total	**93.3**	**6.7**	**267**
2014–15	Charter	94.0	6.0	50
	Domestic	87.2	12.8	47
	Total	**90.7**	**9.3**	**97**

1.2 Recreational fisheries
There is no information on recreational catch levels of moonfish. Moonfish has not been recorded from any of the recreational surveys.

1.3 Customary non-commercial fisheries
There is no information on customary catch, although customary fishers consider moonfish good eating and may have used moonfish in the past.

1.4 Illegal catch
There is no known illegal catch of moonfish.

1.5 Other sources of mortality
There is no information on other sources of mortality although moonfish are occasional prey of blue and mako sharks in New Zealand waters, suggesting that there may be some unobserved shark depredation of longline-caught moonfish.

2. BIOLOGY

Until recently, little was known about the biology of moonfish in New Zealand waters. Studies have examined growth rates, natural mortality, and maturity for moonfish.

Age and growth of moonfish (*Lampris guttatus*) in New Zealand waters was assessed using counts of growth bands on cross sections of the second dorsal fin ray. MPI observers working on tuna longline vessels collected fin samples. Observers also collected maturity data, and length-frequency data were obtained from the longline observer database.

Thin sections were cut from fin rays 3.5–4 times the condyle width above the fin base. Sections were read blind (without knowing the fish length) by two readers. Readability scores were poor and the four readers who examined the fin rays came to two different interpretations.

Length-at-age data did not show any marked differences between males and females. Von Bertalanffy growth curves were fitted to the age estimates of both readers individually, and also to the mean ages of the two readers. The mean age provides the best available age estimate for moonfish samples.

However, because of differences between readers, and the unvalidated nature of the estimates, the growth curves must be interpreted with caution, especially for younger fish.

The growth curves suggest rapid early growth. The maximum age estimated in this study was 13 or 14 years depending on the reader, but this is probably an underestimate of true longevity. Using a maximum age of 14 years, Hoenig's method provides an *M* estimate of 0.30. If moonfish live to 20 years, this would reduce to 0.21. The Chapman-Robson estimate of *Z* is 0.13–0.14 for ages at recruitment of 2–4 years. However, the sample was not randomly selected and so this is probably unreliable. The best estimate of *M* may be around 0.20–0.25.

Length and age-at-maturity could not be accurately determined due to insufficient data, but it appears that fish longer than about 80 cm fork length are mature. The corresponding age-at-maturity would be 4.3 years. Sexual maturity may therefore be attained at about 4–5 years. A few spawning females were collected in the Kermadec region, and at East Cape, suggesting that moonfish spawn in northern New Zealand. Identification of the location and timing of spawning are important areas of further research and are a prerequisite for obtaining good estimates of length and age at maturity.
Moonfish in New Zealand waters may be a species complex of *L. guttatus* and a new species, large-eye moonfish. This needs clarification in New Zealand.

3. STOCKS AND AREAS

There is no information on the stock structure of moonfish.

4. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS

This summary is from the perspective of moonfish but there is no directed fishery for them.

4.1 Role in the ecosystem

Moonfish (*Lampris guttatus*) are a midwater pelagic fish, found between 50 and 400 m depth. They often exhibit vertical behaviour like many other large pelagic visual predators, including swordfish and bigeye tuna, with deeper day and shallower night depth distributions (Polovina et al. 2008). While no published data exists on the diet of *L. guttatus* in the South Pacific, a study on the diet of southern moonfish (*Lampris immaculatus*) along the Patagonian Shelf showed that they had a narrow range of prey items with the most common being the deepwater onychoteuthid squid (*Moroteuthis ingens*) (Jackson et al. 2000; Polovina et al. 2008). Large pelagic sharks such as great white and mako are thought to prey on moonfish.

4.2 Non-target fish catch

Moonfish is a non-target catch in the tuna and swordfish surface-longline fishery in the New Zealand EEZ. Observer records indicate that a wide range of species are landed by the longline fleets in New Zealand waters. Blue sharks are the most commonly landed species (by number), followed by lancetfish and Ray's bream (Table 5).

Table 5: Total estimated catch (numbers of fish) of common bycatch species in the New Zealand longline fishery as estimated from observer data from 2015 to 2018. Also provided is the percentage of these species retained (2018 data only) and the percentage of fish that were alive when discarded, N/A (none discarded). [Continued on next page]

Species	2015	2016	2017	2018	% retained (2018)	discards % alive (2018)
Blue shark	72 480	57 210	49 924	63 618	0.0	88.7
Lancetfish	12 962	17 442	13 274	13 163	0.0	33.5
Porbeagle shark	4 058	6 566	3 101	2 594	1.0	51.1
Rays bream	17 555	7 758	2 421	1 579	99.0	26.7
Moonfish	3 060	3 036	2 022	2 698	98.0	50.0

Species	2015	2016	2017	2018	% retained (2018)	discards % alive (2018)
Pelagic stingray	979	1 414	1 798	2 949	0.0	100.0
Sunfish	770	4 849	1 648	3 648	0.0	99.8
Mako shark	2 667	4 417	1 391	2 721	4.0	65.6
Rudderfish	373	237	680	253	45.0	89.4
Butterfly tuna	1 309	768	406	419	86.0	20.7
Escolar	653	669	300	594	67.0	67.9
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Thresher shark	177	601	260	253	0.0	76.0
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School shark	88	24	59	187	84.0	100.0
Skipjack tuna	150	185	57	184	86.0	100.0
Deepwater dogfish	545	0	32	6	0.0	83.3
Big scale pomfret	59	16	17	34	100.0	n/a

4.3 Benthic interactions
There are no known benthic interactions for this fishery.

5. STOCK ASSESSMENT

There is insufficient information to conduct a stock assessment of moonfish.

5.1 Estimates of fishery parameters and abundance
There are no estimates of relevant fisheries parameters or abundance indices for moonfish.

5.2 Biomass estimates
There are no biomass estimates for moonfish.

5.3 Other yield estimates and stock assessment results
There are no other yield estimates or stock assessment results.

5.4 Other factors
While there is little information on stock status, available data suggests that moonfish are moderately productive and that most (71%) of New Zealand’s catches are of mature fish. Provided that juvenile moonfish are not experiencing high fishing mortality elsewhere in their range, it is unlikely that the stock is currently depleted.

6. STATUS OF THE STOCK

Stock structure assumptions
MOO 1 is assumed to be part of the wider south-western Pacific Ocean stock but the text below relates only to the New Zealand component of that stock.

Stock Status	
Year of Most Recent Assessment	No assessment
Assessment Runs Presented	-
Reference Points	Target: Not established Soft Limit: Not established by WCPFC; but HSS default of 20% SB_0 assumed Hard Limit: Not established by WCPFC; but HSS default of 10% SB_0 assumed Overfishing threshold: Unknown

Status in relation to Target	Unknown
Status in relation to Limits	Unknown
Status in relation to Overfishing	Unknown

Fishery and Stock Trends	
Recent trend in Biomass or Proxy	Unknown
Recent trend in Fishing Intensity or Proxy	Unknown
Other Abundance Indices	Unknown
Trends in Other Relevant Indicators or Variables	Catches in New Zealand increased from the late 1980s to 2000 but declined from 351 t in 2000–01 to 43 t in 2007–08, and have remained low since. This decline in catch coincides with a decline in longline fishing effort.

Projections and Prognosis	
Stock Projections or Prognosis	Unknown
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unknown Hard Limit: Unknown
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unknown

Assessment Methodology and Evaluation		
Assessment Type	Level 4: Low information evaluation – There are only data on catch and TACC, with no other fishery indicators.	
Assessment Method	2 – Medium or Mixed Quality: information has been subjected to peer review and has been found to have some shortcomings.	
Assessment Dates	Latest assessment: None	Next assessment:
Overall assessment quality rank	N/A	
Main data inputs (rank)	- Commercial reported catch and effort	1 – High Quality for the charter fleet but low for all the other fleets
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	-	

Qualifying Comments
This fishery is largely a bycatch fishery. There are some issues associated with species identification with a new species recently described as the large-eye moonfish.
Environmental and Ecosystem Considerations
Moonfish is a non-target catch in the tuna and swordfish surface-longline fishery in the New Zealand EEZ, please refer to those species for environmental and ecosystem considerations. Blue sharks are the most commonly landed non-target species (by number), followed by lancetfish and Ray’s bream in this fishery.

7. FOR FURTHER INFORMATION

Anon (2003) Information summaries and indicative areas for species proposed to be introduced to the QMS in October 2004. NIWA Report on MFish Project MOF2002/03F. (Unpublished report held by Fisheries New Zealand, Wellington.)

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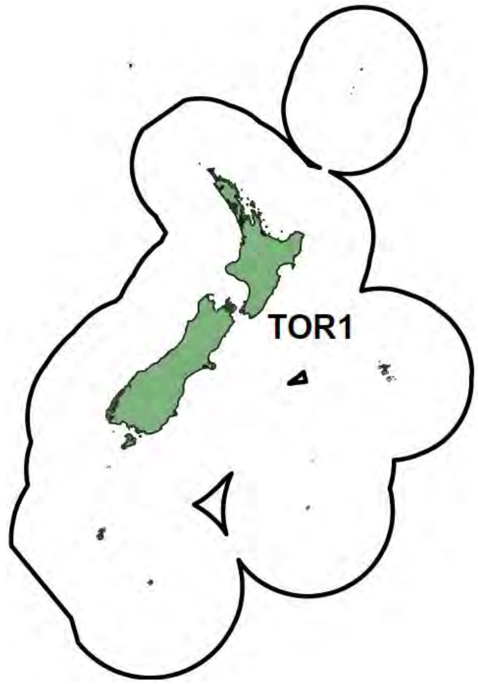
PACIFIC BLUEFIN TUNA (TOR)

(Thunnus orientalis)



1. FISHERY SUMMARY

Pacific bluefin tuna was introduced into the QMS on 1 October 2004 under a single QMA, TOR 1, with allowances, TACC, and TAC in Table 1.

Table 1: Recreational and customary non-commercial allowances, TACCs and TACs (all in t) for Pacific bluefin tuna.

Fishstock	Recreational allowance	Customary non-commercial allowance	Other mortality	TACC	TAC
TOR 1	25	0.50	3.5	116	145

Pacific bluefin tuna were added to the Third Schedule of the 1996 Fisheries Act with a TAC set under s14 because Pacific bluefin tuna is a highly migratory species and it is not possible to estimate MSY for the part of the stock that is found within New Zealand fisheries waters.

Pacific bluefin tuna is believed to be a single Pacific-wide stock and is covered by two regional fisheries management organisations, the Western and Central Pacific Fisheries Commission (WCPFC), and the Inter-American Tropical Tuna Commission (IATTC). They cooperate in the management of the Pacific bluefin tuna stock throughout the Pacific Ocean. Under the WCPFC Convention, New Zealand is responsible for ensuring that the management measures applied within New Zealand fisheries waters are compatible with those of the Commission's.

1.1 Commercial fisheries

Pacific bluefin tuna was not widely recognised as a distinct species until the late 1990s. It was previously regarded as a sub-species of *Thunnus thynnus* (northern bluefin tuna, NTU). Prior to June 2001, catches of this species were either recorded as NTU or misidentified as southern bluefin tuna. Fishers have since become increasingly able to accurately identify TOR and, from June 2001, catch reports have rapidly increased. Catches of TOR may still be underreported to some degree as there is still some reporting against the NTU code. Recent genetic work suggests that true NTU (*Thunnus thynnus*) are not taken in the New Zealand fishery (see Biology section below for further details). Figure 1 shows the historical landings and domestic longline fishing effort for TOR 1.

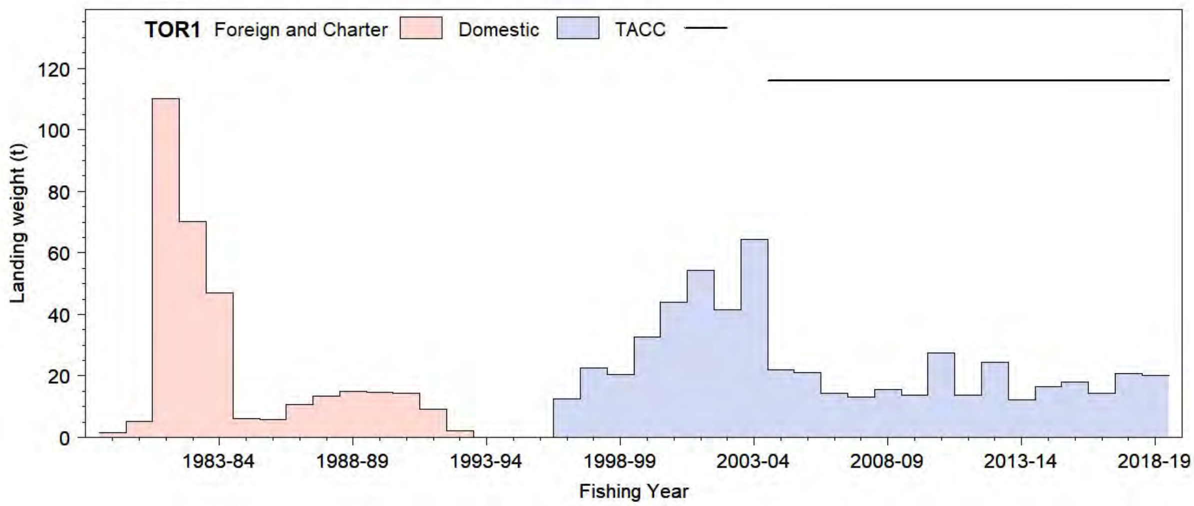


Figure 1: Commercial catch of Pacific bluefin tuna by foreign licensed and New Zealand vessels from 1979–80 to 2018–19 within New Zealand waters (TOR 1).

Table 2: Reported total New Zealand landings (t) of Pacific bluefin tuna (includes landings attributed to NTU), 1991 to 2015 and total Pacific Ocean catches.

Year	NZ landings (t)	Total stock (t)	Year	NZ landings (t)	Total stock (t)	Year	NZ landings (t)	Total stock (t)
1991	1.5	15 781	2000	20.9	33 900	2009	16.0	19 928
1992	0.3	13 995	2001	49.8	18 712	2010	13.6	18 057
1993	5.6	10 811	2002	55.4	18 959	2011	27.4	17 651
1994	1.9	16 961	2003	40.8	18 419	2012	13.3	15 636
1995	1.8	29 225	2004	67.3	25 357	2013	23.9	12 124
1996	4.2	23 519	2005	20.1	28 988	2014	12.1	17 065
1997	14.3	24 632	2006	21.1	26 074	2015	16.5	11 020
1998	20.4	15 763	2007	14	21 189			
1999	21.2	29 153	2008	14.0	24 794			

Source: NZ landings, for 1991–2002 Licensed Fish Receiver Returns data and Solander Fisheries Ltd. 2003–present MHR data. Total Pacific landings for ISC members from http://isc.ac.affrc.go.jp/index.html. This covers most catches from this stock, but does not include South Pacific catches by coastal states in the South Pacific.

Pacific bluefin has been fished in the New Zealand EEZ since at least 1960, with some catch likely but undocumented prior to that time. New Zealand catches are small compared to total stock removals (Table 2).

Catches from within New Zealand fisheries waters are very small compared to those from the greater stock in the Pacific Ocean (0.14% average of the Pacific-wide catch for 1999–2009). In contrast to New Zealand, where Pacific bluefin tuna are taken almost exclusively by longline, the majority of catches are taken in purse-seine fisheries in the western and central Pacific Ocean (Japan and Korea) and Eastern Pacific Ocean (Mexico). Much of the fish taken by the Mexican fleet are grown in sea pens.

Prior to the introduction into the QMS, the highest catches were made in FMA 1 and FMA 2. While it is possible to catch Pacific bluefin as far south as 48ºS, few catches are made in the colder southern FMAs. Although recent catches have occurred in FMA 7, fish have been in poor condition with little commercial value. Catches are almost exclusively by tuna longlines, typically as a bycatch of sets targeting bigeye tuna. Catches by fishing year and fleet are provided in Table 3.

Table 3: Reported catches or landings (t) of Pacific bluefin tuna by fleet and fishing year. NZ/MHR: New Zealand domestic and charter fleet, MHR data from 2001–02 to present; NZ ET: catches from New Zealand flagged longline vessels outside these areas; JPNFL: Japanese foreign licensed vessels; KORFL: foreign licensed vessels from the Republic of Korea; and LFRR: estimated landings from Licensed Fish Receiver Returns.

	TOR 1 (all FMAs)				
Fishing year	**JPNFL**	**NZ/MHR**	**Total**	**LFRR**	**NZ ET**
1979–80	1.5		1.5		
1980–81	5.3		5.3		
1981–82	110.1		110.1		
1982–83	70.1		70.1		
1983–84	47		47		
1984–85	6		6		
1985–86	5.7		5.7		
1986–87	10.6		10.6	0.0	
1987–88	13.5		13.5	0.0	
1988–89	15.1		15.1	0.0	
1989–90	14.7		14.7	0.0	
1990–91	14.5		14.5	1.5	
1991–92	9.1		9.1	0.3	
1992–93	2.1		2.1	5.6	
1993–94	0.1		0.1	1.9	
1994–95			0	1.8	
1995–96			0	4.0	
1996–97		12.5	12.5	13.0	
1997–98		22.5	22.5	20.9	0.4
1998–99		20.6	20.6	17.9	0.1
1999–00		32.6	32.6	23.1	0.1
2000–01		43.9	43.9	51.8	1.0
2001–02		54.4	54.4	53.3	0.0
2002–03		41.6	41.6	39.8	0.0
2003–04		64.3	64.3	58.1	0.0
2004–05		22.9	22.9	22.9	0.0
2005–06		21.1	21.1	20.3	0.0
2006–07		14.3	14.3	14.5	0.0
2007–08		13.1	13.1	11.9	0.0
2008–09		15.7	15.7	15.5	0.0
2009–10		13.6	13.6	12.4	0.0
2010–11		27.4	27.4	26.7	0.0
2011–12		13.7	13.7	13.4	0.0
2012–13		23.9	23.9	23.9	0.0
2013–14		12.1	12.1	12.1	0.0
2014–15		16.5	16.5	16.5	0.0
2015–16		18.0	18.0	17.6	0.0
2016–17		14.4	14.4	14.4	0.0
2017–18		20.7	20.7	20.7	0.0
2018–19		20.1	20.1	21.4	0.0

In 2012–13, the majority of Pacific bluefin tuna were caught in the bigeye tuna surface-longline fishery (57%), with about 22% of the catch coming from the southern bluefin tuna surface-longline fishery (Figure 2). There is no targeted commercial fishery for Pacific bluefin tuna in New Zealand. In New Zealand longline fisheries, Pacific bluefin tuna make up less than 1% of the commercial catch (Figure 3). Longline fishing effort is distributed along the east coast of the North Island and the south-west coast of the South Island. The west coast South Island fishery predominantly targets southern bluefin tuna, whereas the east coast of the North Island targets a range of species including bigeye, swordfish and southern bluefin tuna.

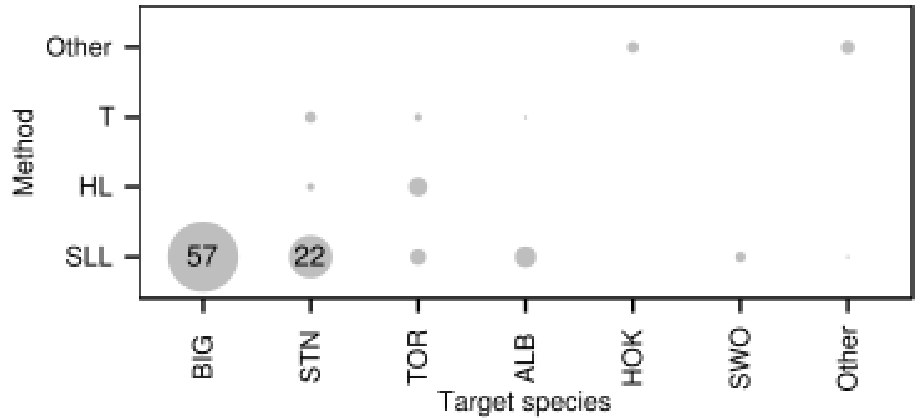


Figure 2: A summary of the proportion of landings of Pacific bluefin tuna taken by each target fishery and fishing method. The area of each circle is proportional to the percentage of landings taken using each combination of fishing method and target species. The number in the bobble is the percentage. SLL = surface longline, HL = hand line and T = trawl (Bentley et al. 2013).

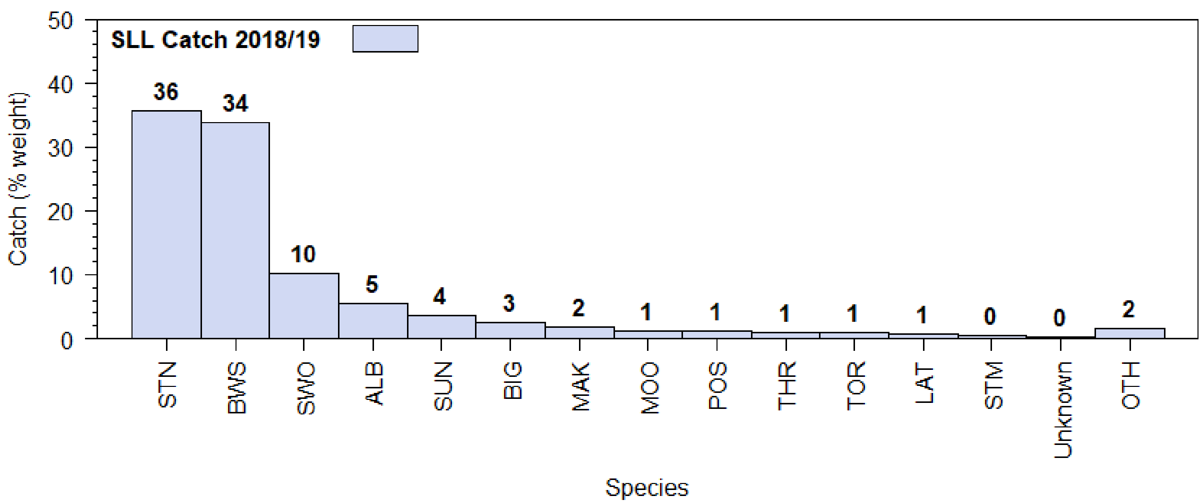


Figure 3: A summary of species composition of all surface-longline estimated catch. The percentage by weight of each species is calculated for all surface-longline trips.

1.2 Recreational fisheries

Recreational fishers make occasional catches of Pacific bluefin tuna. In 2004 a target recreational fishery developed off the west coast of the South Island targeting large Pacific bluefin tuna that feed on spawning aggregations of hoki (*Macruronus novaezealandiae*). Fish taken in this fishery have been submitted for various world records for this species. Some information on charter vessel catch was collected through voluntary reporting and in 2011 recreational charter boats were required to register and report catch and effort in this fishery. A small number of private boats are also active in the fishery. The recreational allowance for Pacific bluefin was increased from 1 t to 25 t per year from 1 October 2011 to recognise the growth in this fishery. There has been a decline in catch rates and recreational fishing effort since 2015.

1.2.2 Estimates of recreational harvest

No estimates of recreational harvest of Pacific Bluefin tuna were generated from the telephone-diary surveys conducted in 1994, 1996 and 2000 because so few were reported. A National Panel Survey was conducted for the first time throughout the 2011–12 fishing year. The panel survey used face-to-face interviews of a random sample of 30 390 New Zealand households to recruit a panel of fishers and non-fishers for a full year (from Wynne-Jones et al. 2014). The panel members were contacted regularly about their fishing activities and harvest information collected in standardised phone interviews. The national panel survey was repeated during the 2017–18 fishing year using very similar methods to produce directly comparable results (Wynne-Jones et al. 2019). Note that national panel survey estimates do not include recreational harvest taken under s111 general approvals. The National Panel Survey results do not include estimates for Pacific bluefin tuna as the surveys did not capture the fishers and fishing activity for the large gamefish species well.

1.3 Customary non-commercial fisheries

There is no quantitative information available to allow the estimation of the harvest of Pacific bluefin tuna by customary fishers; however, the Maori customary catch of Pacific bluefin is probably negligible because of its seasonal and offshore distribution.

1.4 Illegal catch

There is no known illegal catch of Pacific bluefin tuna in New Zealand fisheries waters.

1.5 Other sources of mortality

There is likely to be a low level of shark damage and discard mortality of Pacific bluefin caught on tuna longlines that may be on the order of 1–2% assuming that all tuna species are subject to equivalent levels of incidental mortality. There have been reports that some fish hooked in the target recreational fishery have been lost due to entanglement of the fishing line with trawl warps. The survival of these lost fish is not known. An allowance of 3.5 t has been made for other sources of mortality.

2. BIOLOGY

Pacific bluefin tuna are epipelagic opportunistic predators of fish, crustaceans and cephalopods found within the upper few hundred metres of the water column. Individuals found in New Zealand fisheries waters are mostly adults. Adult Pacific bluefin occur broadly across the Pacific Ocean, especially the waters of the North Pacific Ocean.

There has been some uncertainty among fishers regarding bluefin tuna taken in New Zealand waters. Some fishers believe that three species of bluefin tuna are taken in New Zealand waters with some small catches of true 'Northern' Atlantic tuna (*Thunnus thynnus*, NTU) in addition to Pacific and southern bluefin tuna. This belief is based on several factors including differences in morphology and the prices obtained for certain fish on the Japanese market.

To address this issue, muscle tissue samples were taken from 20 fish for which there was uncertainty as to whether the fish was a Pacific bluefin tuna (*Thunnus orientalis*) or an Atlantic bluefin tuna. A further sample from a fish thought to be a southern bluefin tuna was also included. The tissue samples were sequenced for the COI region of DNA, and the sequences compared with COI sequences for the three species of tuna held in GenBank. All of the DNA sequences, except one, matched with sequences for Pacific bluefin tuna. The final sample was confirmed as a southern bluefin tuna. Therefore, based on DNA analysis, there is presently no evidence that Atlantic bluefin tuna are taken in New Zealand waters. Further tissue samples from fish thought by fishers to be NTU will be collected by scientific observers.

Adult Pacific bluefin reach a maximum size of 550 kg and length of 300 cm. Maturity is reached at 3 to 5 years of age and individuals live to 15+ years old. Spawning takes place between Japan and the Philippines in April, May and June, spreading to the waters off southern Honshu in July and to the Sea of Japan in August. Pacific bluefin of 270 to 300 kg produce about 10 million eggs but there is no information on the frequency of spawning. Juveniles make extensive migrations north and eastwards across the Pacific Ocean as 1–2-year-old fish. Pacific bluefin caught in the southern hemisphere, including those caught in New Zealand waters, are primarily adults.

Natural mortality is assumed to vary from about 0.1 to 0.4 and to be age specific in assessments undertaken by the IATTC. A range of von Bertalanffy growth parameters have been estimated for Pacific bluefin based on length-frequency analysis, tagging and reading of hard parts (Table 4).

Table 4: von Bertalanffy growth parameters for Pacific bluefin tuna.

Method	*L* infinity	*k*	t_0
Length frequencies	300.0		
Scales	320.5	0.1035	- 0.7034
Scales	295.4		
Tagging	219.0	0.211	

The length:weight relationship of Pacific bluefin based on observer data from New Zealand caught fish yields the following:

whole weight = $8.058\ e^{0.015\ \text{length}}$ $R^2 = 0.895$, n = 49 (weight is in kg and length is in cm).

Although the sample size of genetically confirmed Pacific bluefin that have been sexed by observers is small (50 fish), the sex ratio in New Zealand waters is not significantly different from 1:1.

3. STOCKS AND AREAS

Pacific bluefin tuna constitutes a single Pacific-wide stock that is primarily distributed in the northern hemisphere.

Between 2006 and 2008 42 Pacific bluefin were tagged from recreational charter vessels in New Zealand waters using Pop-off Satellite Archival Tags (PSATs), and all tags that have 'reported' indicate that these fish survived catch and release and spent several months within the New Zealand or Australian EEZs and adjacent waters over spring and summer. In addition 138 Pacific bluefin have been released with conventional tags. There have been four recaptures all from the West Coast recreational fishery. One fish was recaptured after two years, 22 nautical miles from the release point and another after four years at liberty just 60 miles from where it was released. Both of these fish had carried PSAT tags.

4. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS

This summary is from the perspective of Pacific bluefin tuna but there is no directed fishery for this species. The incidental catch sections below reflect the New Zealand longline fishery as a whole and are not specific to this species; a more detailed summary from an issue-by-issue perspective is available in the Aquatic Environment and Biodiversity Annual Review where the consequences are also discussed (Ministry for Primary Industries 2016).

4.1 Role in the ecosystem

Pacific bluefin tuna (*Thunnus orientalis*) is one of the largest teleost fish species (Kitagawa et al. 2004), comprising a single population that spawns only to the south of Japan and in the Sea of Japan (Sund et al. 1981). Pacific bluefin tuna are large pelagic predators, so they are likely to have a 'top down' effect on the fish, crustaceans and squid they feed on.

4.2 Non-target fish catch

Observer records indicate that a wide range of species are landed by the longline fleets in New Zealand fishery waters. Blue sharks are the most commonly caught species (by number), followed by lancetfish and Porbeagle shark (Table 5).

Table 5: Total estimated catch (numbers of fish) of common bycatch species in the New Zealand longline fishery as estimated from observer data from 2015 to 2018. Also provided is the percentage of these species retained (2018 data only) and the percentage of fish that were alive when discarded, N/A (none discarded).

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Deepwater dogfish	545	0	32	6	0.0	83.3
Big scale pomfret	59	16	17	34	100.0	n/a

4.3 Benthic interactions

There are no known interactions with benthic habitats for this fishery.

5. STOCK ASSESSMENT

No assessment is possible for Pacific bluefin tuna within the New Zealand fishery waters as the proportion of the greater stock found within these waters is unknown and is likely to vary from year to year. Pacific bluefin tuna is assessed as one stock in the entire Pacific Ocean.

5.1 Stock status and trends

SC14 noted that ISC provided the following conclusions on the stock status of Pacific bluefin tuna from the 2018 assessment.

Table 6: Total biomass, spawning stock biomass and recruitment of Pacific bluefin tuna (*Thunnus orientalis*) estimated by the base-case model, where coefficient of variation (CV) measures relative variability defined as the ratio of the standard deviation to the mean.

Fishing year	Total biomass (t)	Spawning stock biomass (t)	CV for SSB	Recruitment (x1000 fish)	CV for R
1952	150825	114227	0.51	13352	
1953	146228	107201	0.49	21843	0.17
1954	147385	96239	0.49	34556	0.15
1955	152230	83288	0.50	14106	0.19
1956	169501	76742	0.49	34261	0.11
1957	188830	82975	0.46	12574	0.15
1958	208078	108677	0.41	3436	0.30
1959	214898	147004	0.39	7963	0.22
1960	218055	155183	0.39	7745	0.21
1961	211262	168125	0.39	23323	0.10
1962	197361	151993	0.42	10794	0.18
1963	181329	129755	0.45	27615	0.10
1964	169581	114448	0.45	5827	0.32
1965	159109	100628	0.46	11584	0.35
1966	144866	95839	0.44	8645	0.44
1967	121987	89204	0.44	10803	0.38
1968	107216	83374	0.45	13656	0.24
1969	93223	69074	0.47	6413	0.30
1970	81816	57958	0.48	7120	0.40
1971	71900	49980	0.48	12596	0.34
1972	67819	43035	0.46	22742	0.17
1973	65474	37205	0.44	11058	0.27
1974	65059	29896	0.44	13570	0.17
1975	63515	27733	0.38	11011	0.18
1976	66532	30485	0.30	9171	0.32
1977	64320	36220	0.25	25078	0.17
1978	69199	33382	0.25	15057	0.26
1979	69609	28007	0.29	11509	0.20
1980	71313	30757	0.25	7584	0.27
1981	72109	28867	0.21	11703	0.13
1982	53715	25408	0.21	6965	0.21
1983	31185	15086	0.29	10078	0.15
1984	33147	12813	0.31	9231	0.20
1985	36319	12846	0.28	9601	0.19
1986	35877	15358	0.23	7857	0.19
1987	31609	14632	0.25	6224	0.22
1988	33868	15709	0.25	8796	0.14
1989	38189	15519	0.25	4682	0.28
1990	46388	19468	0.23	18462	0.09
1991	61501	25373	0.21	11803	0.11
1992	70077	32022	0.20	4426	0.17
1993	79910	43691	0.18	4365	0.18
1994	90135	51924	0.19	28350	0.04
1995	103322	67152	0.18	17414	0.09
1996	98854	66841	0.18	17564	0.06
1997	99196	61069	0.19	10919	0.10
1998	95373	60293	0.19	15014	0.08
1999	91963	56113	0.20	23450	0.05
2000	87384	53835	0.21	14335	0.06
2001	76182	50222	0.21	15786	0.05
2002	77727	47992	0.20	13509	0.06
2003	74204	47569	0.19	7769	0.09
2004	68407	40707	0.20	26116	0.04
2005	63042	33820	0.21	14659	0.06
2006	50197	27669	0.23	11645	0.06
2007	43558	22044	0.24	21744	0.04
2008	41169	16754	0.27	20371	0.04
2009	35677	13011	0.27	8810	0.07
2010	33831	12188	0.25	15948	0.05
2011	34983	13261	0.23	13043	0.06
2012	37451	15892	0.20	6284	0.09
2013	39113	18107	0.20	11874	0.06
2014	38918	19031	0.19	3561	0.14
2015	38322	19695	0.20	7765	0.13
2016	41191	21331	0.22	15988	0.21
Average (1952-2016)	89579	53722	0.31	13402	0.17
Median (1952-2014)	71900	43035	0.25	11703	0.16

The base-case model results show that: (1) *SSB* fluctuated throughout the assessment period, (2) *SSB* steadily declined from 1996 to 2010; and (3) the slow increase of the stock continues since 2011 including the most recent two years (2015–2016). Based on the model diagnostics, the estimated biomass trend for the last 30 years is considered robust although *SSB* prior to the 1980s is uncertain due to data limitations. Using the base-case model, the 2016 *SSB* (terminal year) was estimated to be around 21 000 t in the 2018 assessment, which is an increase from 19 000 t in 2014 (Table 6 and Figure 4).

Historical recruitment estimates have fluctuated since 1952 without an apparent trend. The low recruitment levels estimated in 2010–2014 were a concern in the 2016 assessment. The 2015 recruitment estimate is lower than the historical average while the 2016 recruitment estimate (15.988 million fish) is higher than the historical average (13.402 million fish) (Figure 4, Table 6). The uncertainty of the 2016 recruitment estimate is higher than in previous years because it occurs in the terminal year of the assessment and is mainly informed by one observation from the troll age-0 CPUE index. The troll CPUE series has been shown to be a good predictor of recruitment, with no apparent retrospective error in the recruitment estimates of the terminal year given the current model construction. As the 2016 recruits grow and are observed by other fleets, the magnitude of this year class will be more precisely estimated in the next stock assessment. The above average recruitment estimated in 2016 had a positive impact on the projection results.

Estimated age-specific fishing mortalities (*F*) on the stock during the periods 2012–2014 and 2015–2016 compared with 2002–2004 estimates (the base period for the WCPFC Conservation and Management Measure) are presented in Figure 5. A substantial decrease in estimated *F* is observed in ages 0–2 in 2015–2016 from the previous years. Note that stricter management measures in the WCPFC and IATTC have been in place since 2015.

The WCPFC adopted an initial rebuilding biomass target (the median *SSB* estimated for the period 1952 through to 2014) and a second rebuilding biomass target (20% $SSB_{F=0}$ under average recruitment), without specifying a fishing mortality reference level.[1] The 2018 assessment estimated the initial rebuilding biomass target to be 6.7% $SSB_{F=0}$ and the corresponding fishing mortality expressed as SPR of $F_{6.7\%SPR}$ (Table 7). SPR is the ratio of the cumulative spawning biomass that an average recruit is expected to produce over its lifetime when the stock is fished at the current intensity to the cumulative spawning biomass that could be produced by an average recruit over its lifetime if the stock was unfished. Because the projections include catch limits, fishing mortality is expected to decline, i.e., $F_{x\%SPR}$ will increase, as biomass increases. The Kobe plot shows that the point estimate of SSB_{2016} was 3.3% $SSB_{F=0}$ and the 2016 fishing mortality corresponds to $F_{6.7\%SPR}$ (Figure 6).

Table 8 provides an evaluation of stock status against some common reference points. It shows that the PBF stock is overfished relative to biomass-based limit reference points adopted for other species in WCPFC (20% $SSB_{F=0}$) and is subject to overfishing relative to most of the common fishing intensity-based reference points.

Figure 7 depicts the historical impacts of the fleets on the PBF stock, showing the estimated biomass when fishing mortality from respective fleets is zero. Historically, the WPO coastal fisheries group has had the greatest impact on the PBF stock, but since about the early 1990s the WPO purse seine fleets, in particular those targeting small fish (ages 0–1), have had a greater impact, and the effect of these fleets in 2016 was greater than any of the other fishery groups. The impact of the EPO fishery was large before the mid-1980s, decreasing significantly thereafter. The WPO longline fleet has had a limited effect on the stock throughout the analysis period, because the impact of a fishery on a stock depends on both the number and size of the

[1] The IATTC has adopted the first rebuilding target, the second target is to be discussed at a future IATTC meeting.

fish caught by each fleet; i.e., catching a high number of smaller juvenile fish can have a greater impact on future spawning stock biomass than catching the same weight of larger mature fish.

SC14 noted the following stock status from ISC:

Based on these findings, the following information on the status of the Pacific bluefin tuna stock is provided:

1. No biomass-based limit or target reference points have been adopted to evaluate the overfished status for PBF. However, the PBF stock is overfished relative to the potential biomass-based reference points evaluated (SSB_{MED} and 20% $SSB_{F=0}$, Table 8 and Figure 6).
2. No fishing intensity-based limit or target reference points have been adopted to evaluate overfishing for PBF. However, the PBF stock is subject to overfishing relative to most of the potential fishing intensity-based reference points evaluated (Table 8 and Figure 6).

SC14 noted that the total PBF catch in 2017 was 14 707 mt, 11% increase from 2016 and 9% increase from the average 2012–2016. PBF is caught by various fishing gears including purse seine, longline, set net, troll, pole-and-line, handline and recreational fisheries. The detailed catch information by fishery is available in the ISC 2018 stock assessment (SC14-SA-WP-06).

SC14 noted the current very low level of spawning biomass (3.3% SSB_0), the current level of overfishing, and that the projections are strongly influenced by the inclusion of a relatively high but uncertain recruitment in 2016. The majority of CCMs recommended a precautionary approach to the management of Pacific Bluefin tuna, especially in relation to the timing of increasing catch levels, until the rebuilding of the stock to higher biomass levels is achieved.

SC14 noted the following conservation advice from ISC:

- After the steady decline in *SSB* from 1995 to the historical low level in 2010, the PBF stock appears to have started recovering slowly. The 2016 stock biomass is below the two biomass rebuilding targets adopted by the WCPFC while the 2015–16 fishing intensity (spawning potential ratio) is at a level corresponding to the initial rebuilding target.
- The 2018 base case assessment results are consistent with the 2016 model results. However, the 2018 projection results are more optimistic than the 2016 projections, mainly due to the inclusion of the relatively good recruitment in 2016, which is above the historical average level (119%) and twice as high as the median of the low recruitment scenario (which occurred 1980–1989).
- Based on these results, the following conservation information is provided:

    - The projection based on the base-case model mimicking the current management measures by the WCPFC (CMM 2017-08) and IATTC (C-16-08) under the low recruitment scenario resulted in an estimated 98% probability of achieving the initial biomass rebuilding target (6.7% $SSB_{F=0}$) by 2024. This estimated probability is above the threshold (75% or above in 2024) prescribed by the WCPFC Harvest Strategy (Harvest Strategy 2017-02) (scenario 0 of Table 10; see also Figure 8 and Figure 9). The low recruitment scenario is more precautionary than the recent 10 years recruitment scenario.

    - The Harvest Strategy specifies that recruitment switches from the low recruitment scenario to the average recruitment scenario beginning in the year after achieving the initial rebuilding target. The estimated probability of achieving the second biomass rebuilding target (20% $SSB_{F=0}$) 10 years after the achievement of the initial rebuilding target or by 2034, whichever is earlier, is 96% (scenario 1 of Table 9, Table 10, and Table 11; Figure 8 and Figure 9). This estimate is above the threshold (60% or above in 2034) prescribed by the WCPFC Harvest

Strategy. However, it should be recognized that these projection results are strongly influenced by the inclusion of the relatively high, but uncertain recruitment estimate for 2016.

- The Harvest Strategy adopted by WCPFC (Harvest Strategy 2017-02) guided projections conducted by ISC to provide catch reduction options if the projection results indicate that the initial rebuilding target will not be achieved or to provide relevant information for potential increase in catch if the probability of achieving the initial rebuilding target exceeds 75%. The projection results showed that the probability of achieving the initial rebuilding target was above the level (75% or above in 2024) prescribed in the WCPFC Harvest Strategy (Table 11). Accordingly, the ISC examined some optional scenarios with higher catch limits, which can be found in Appendix 1 of the PBF 2018 stock assessment report (SC14-SA-WP-06).

Table 7: Spawning stock biomass and fishing intensity of Pacific bluefin tuna (*Thunnus orientalis*) in 1995 (recent high biomass), 2002–2004 (WCPFC reference year biomass), 2011 (biomass 5 years ago), and 2016 (latest) compared to those of the adopted WCPFC biomass rebuilding targets. SPR is used as a measure of fishing intensity; the lower the number the higher the fishing intensity that year.

	Initial rebuilding target	**Second rebuilding target**	**1995 (recent high)**	**2002-2004 (reference year)**	**2011 (5 years ago)**	**2016 (latest)**
Biomass (%$SSB_{F=0}$)	*SSB* median1952-2014 = 6.7%	20%	10.4%	7.1%	2.1%	3.3%
SPR	6.7%	20%	5.1%	3.4%	4.9%	6.7%

Table 8. Ratios of the estimated fishing mortalities and intensities (Fs and 1-SPRs for 2002–04, 2012–14, 2015–16) relative to potential fishing intensity-based reference points, and terminal year *SSB* (t) for each reference period, and depletion ratios for the terminal year of the reference period for Pacific bluefin tuna (*Thunnus orientalis*).

	F_{max}	F0.1	Fmed	Floss	(1-SPR)/(1-SPRxx%)				Estimated SSB for terminal year of each reference period	Depletion ratio for terminal year of each reference period
					SPR10%	SPR20%	SPR30%	SPR40%		
2002-2004	1.77	2.47	1.04	0.78	1.07	1.21	1.38	1.61	40,707	6.3%
2012-2014	1.47	2.04	0.86	0.65	1.05	1.19	1.36	1.58	19,031	3.0%
2015-2016	1.32	1.85	0.78	0.58	1.02	1.15	1.32	1.54	21,311	3.3%

Table 9: Future projection scenarios for Pacific bluefin tuna (*Thunnus orientalis*).

Scenario #	**WPO**						**EPO*3**			**Catch limit Increase**			
	Fishing mortality*1	**Catch limit**					**Catch limit**						
		Japan*2		**Korea**		**Taiwan**	**Commercial**		**Sports**	**WPO**		**EPO**	
		Small	**Large**	**Small**	**Large**	**Large**	**Small**	**Large**		**Small**	**Large**	**Small**	**Large**
0*4	F	4,007	4,882	718		1,700	3,300		-	0%		0%	
1	F	4,007	4,882	718		1,700	3,300		-	0%		0%	

Table 10: Future projection scenarios for Pacific bluefin tuna (*Thunnus orientalis*) and their probability of achieving various target levels by various time schedules based on the base-case model.

Scenario #	Catch limit Increase				Initial rebuilding target			Second rebuilding target		Median SSB (mt) at 2034
	WPO		EPO		The year expected to achieve the target with >60% probability	Probability of achiving the target at 2024	Probability of SSB is below the target at 2024 under the low recruitment	The year expected to achieve the target with >60% probability	Probability of achiving the target at 2034	
	Small	Large	Small	Large						
0[*1]	0%		0%		2020	98%	2%	N/A	3%	74,789
1	0%		0%		2020	99%	2%	2028	96%	263,465

***1 In scenario 0, the future recruitments were assumed to be at the low recruitment (1980–1989) level forever. In other scenarios, recruitment was switched from low recruitment to average recruitment from the next year of achieving the initial rebuilding target.**

Table 11: Expected yield for Pacific bluefin tuna (*Thunnus orientalis*) under various harvesting scenarios based on the base-case model.

Scenario #	Catch limit Increase				Expected annual yield in 2019, by area and size category (mt)				Expected annual yield in 2024, by area and size category (mt)				Expected annual yield in 2034, by area and size category (mt)			
	WPO		EPO		WPO		EPO		WPO		EPO		WPO		EPO	
	Small	Large	Small	Large	Small	Large	Small	Large	Small	Large	Small	Large	Small	Large	Small	Large
0	0%	0%	0%		4,477	4,384	3,530		4,704	6,133	3,457		4,704	6,211	3,451	
1	0%	0%	0%		4,477	4,384	3,530		4,745	6,202	3,665		4,747	6,640	3,703	

***1 F indicates the geometric mean values of quarterly age-specific fishing mortality during 20022004.**
***2 The Japanese unilateral measure (transferring 250 mt of catch upper limit from that for small PBF to that for large PBF during 2017–2020) would be reflected.**
***3 Fishing mortality for the EPO commercial fishery was assumed to be high enough to fulfil its catch upper limit (F multiplied by two). The fishing mortality for the EPO recreational fishery was assumed to be the F2009-11 average level.**
***4 In scenario 0, the future recruitments were assumed to be at the low recruitment (1980–1989) level forever. In other scenarios, recruitment was switched from low recruitment to average recruitment from the next year of achieving the initial rebuilding target.**

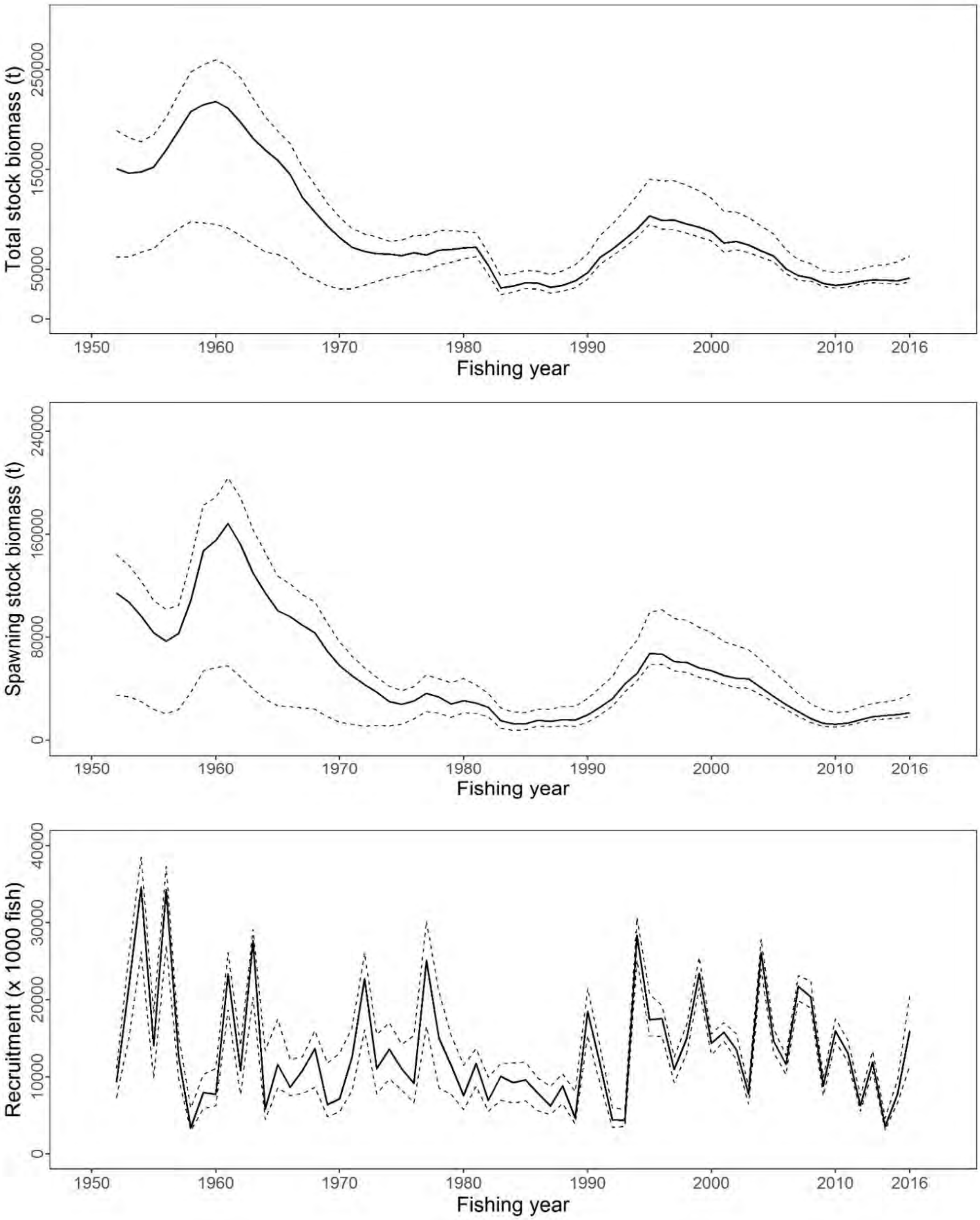

Figure 4: Total stock biomass (top), spawning stock biomass (middle) and recruitment (bottom) of Pacific bluefin tuna (*Thunnus orientalis*) from the base-case model. The solid lines indicate point estimates and the dashed lines indicate the 90% confidence intervals.

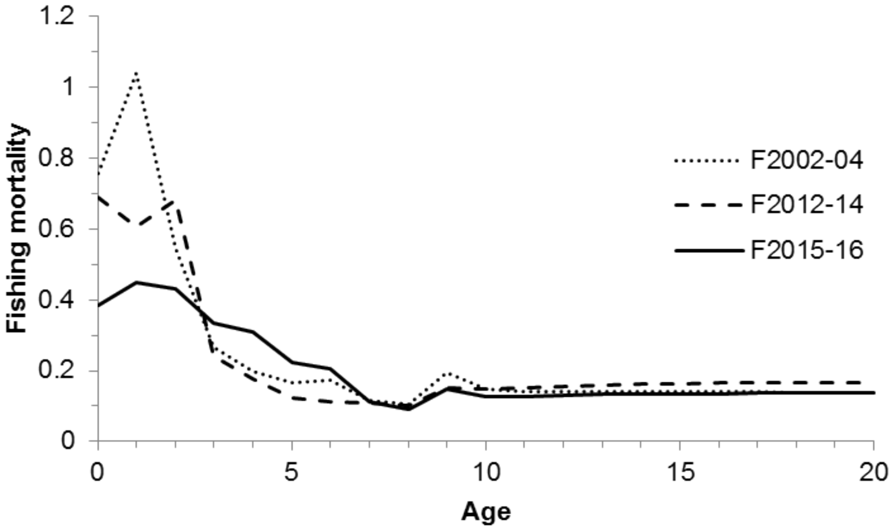

Figure 5: Geometric means of annual age-specific fishing mortalities of Pacific bluefin tuna (*Thunnus orientalis*) in 2002–2004 (dotted line), 2012–2014 (dashed line), and 2015–2016 (solid line).

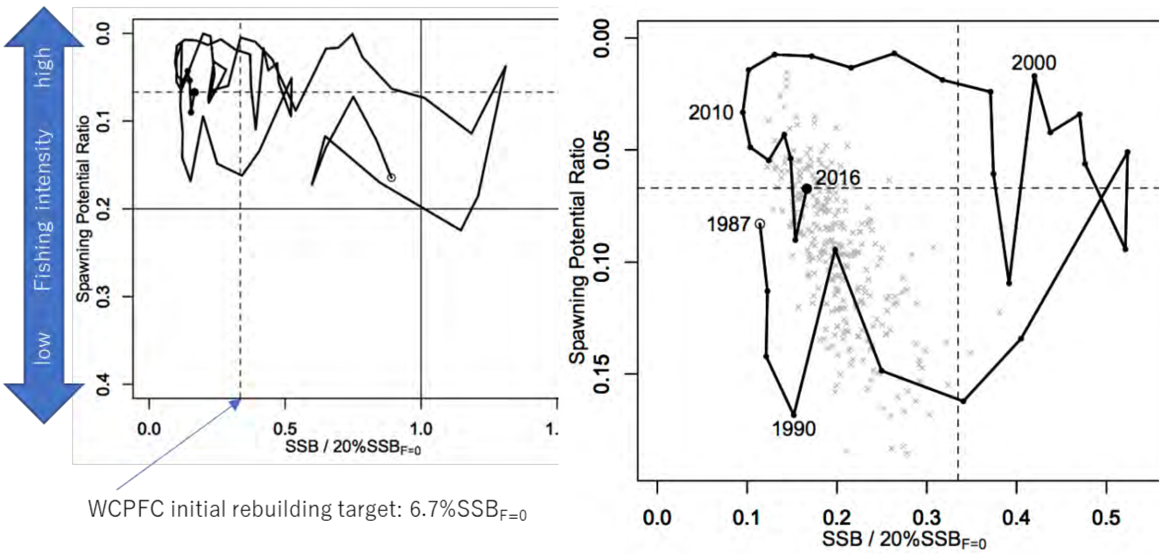

Figure 6: Kobe plots for Pacific bluefin tuna (*Thunnus orientalis*). X axis shows the annual *SSB* relative to 20% $SSB_{F=0}$ and the Y axis shows the spawning potential ratio as a measure of fishing intensity. Solid vertical and horizontal lines in the left figure show 20% $SSB_{F=0}$ (which corresponds to the second biomass rebuilding target) and the corresponding fishing intensity, respectively. Dashed vertical and horizontal lines in both figures show the initial biomass rebuilding target (SSB_{MED} = 6.7% $SSB_{F=0}$) and the corresponding fishing intensity, respectively. SSB_{MED} is calculated as the median of estimated *SSB* over 1952–2014. The left figure shows the historical trajectory, where the open circle indicates the first year of the assessment (1952) while solid circles indicate the last five years of the assessment (2012–2016). The right figure shows the trajectory of the last 30 years, where grey dots indicate the uncertainty of the terminal year.

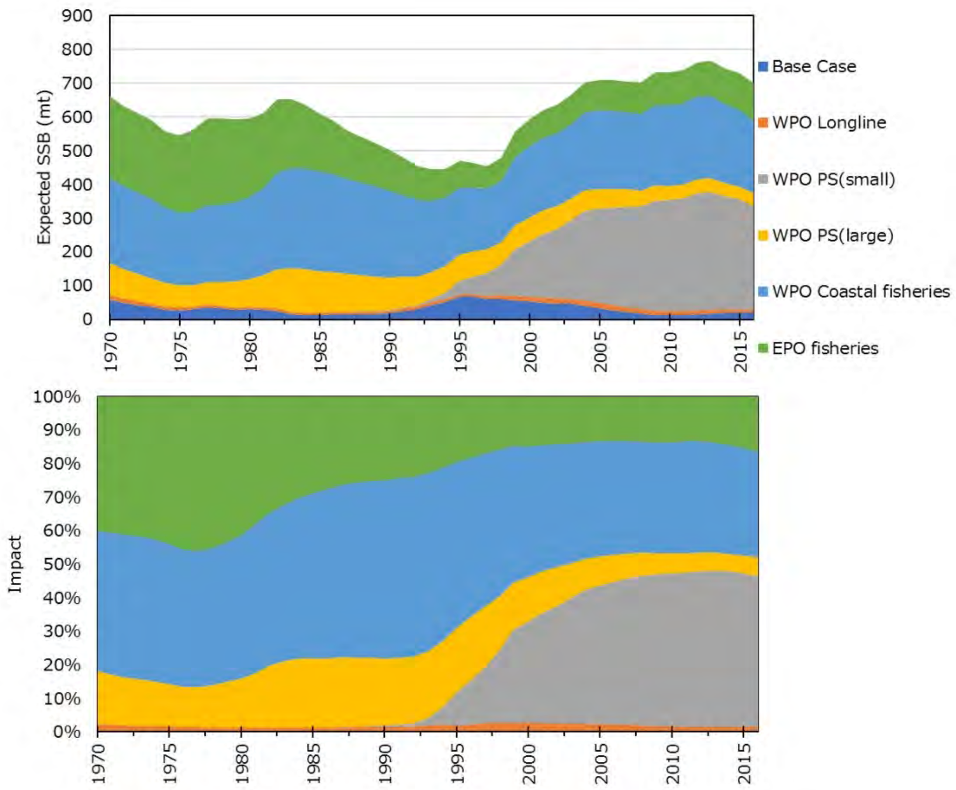

Figure 7: Trajectory of the spawning stock biomass of a simulated population of Pacific bluefin tuna (*Thunnus orientalis*) when zero fishing mortality is assumed, estimated by the base-case model. (top: absolute impact, bottom: relative impact). Fleet definition; WPO longline: F1, F12, F17. WPO purse seine for small fish: F2, F3, F18. WPO purse seine: F4, F5. WPO coastal fisheries: F6-11, F16, F19. EPO fisheries: F13, F14, F15.

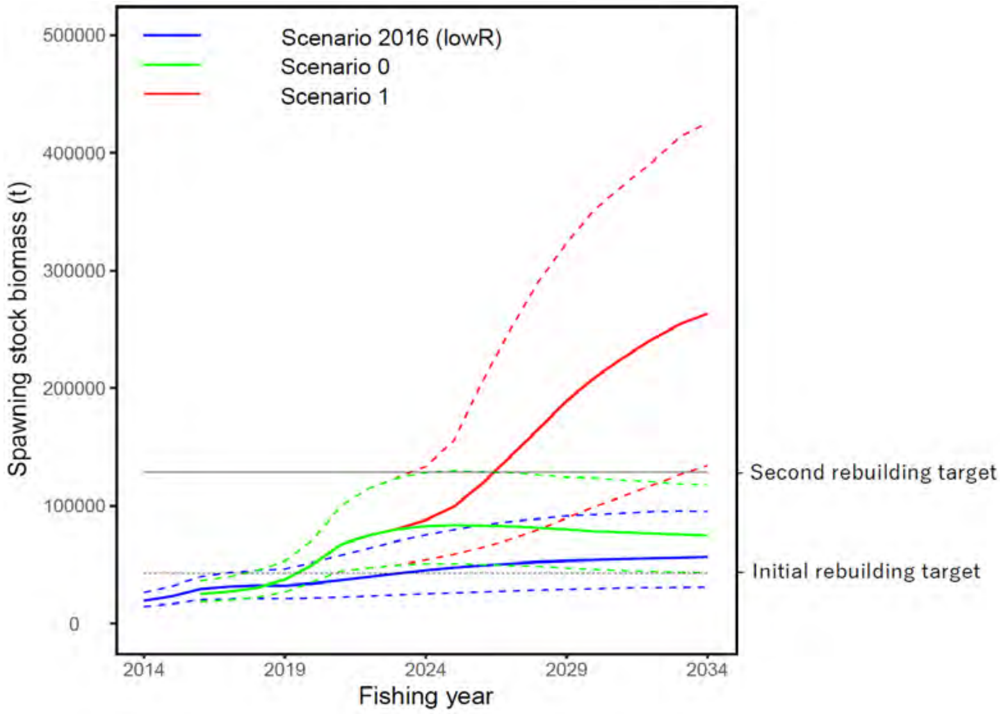

Figure 8: Comparison of future *SSB* of Pacific bluefin tuna (*Thunnus orientalis*) under the current management measures assuming low recruitment using the 2016 assessment (scenario 2016 lowR), assuming low recruitment using the 2018 assessment (scenario 0), and assuming a shift of the recruitment scenario from low to average after achieving the initial rebuilding target using the 2018 assessment (scenario 1).

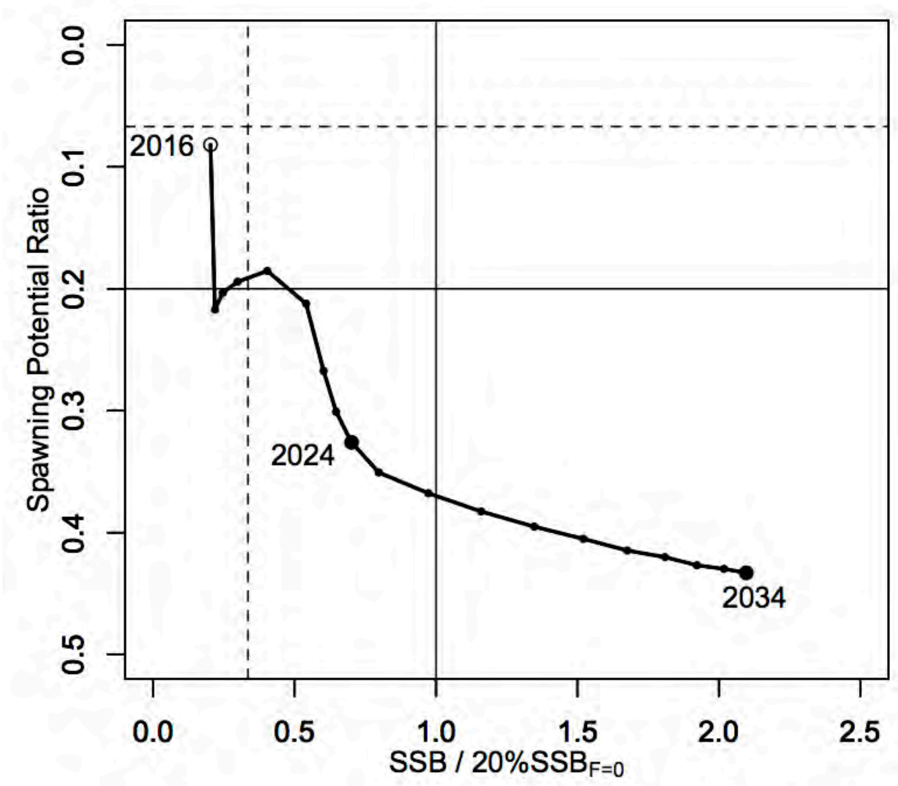

Figure 9: A projection result (scenario 1 from Table 10) for Pacific bluefin tuna (*Thunnus orientalis*) in a form of Kobe plot. The X axis shows the *SSB* value relative to 20% $SSB_{F=0}$ (second rebuilding target) and the Y axis shows the spawning potential ratio as a measure of fishing intensity. Vertical and horizontal solid lines indicate the second rebuilding target (20% $SSB_{F=0}$) and the corresponding fishing intensity, respectively, while vertical and horizontal dashed lines indicate the initial rebuilding target (SSB_{MED} = 6.7% $SSB_{F=0}$) and the corresponding fishing intensity, respectively.

5.2 Estimates of fishery parameters and abundance

There are no fishery-independent indices of abundance for the Pacific bluefin tuna stock. Relative abundance information is available from standardised indices of longline catch per unit effort data.

5.3 Biomass estimates

These estimates apply to the entire distribution of the stock in the Pacific Ocean. The ratio of *SSB* in 2016 relative to the theoretical unfished *SSB* ($SSB_{2014}/SSB_{F=0}$, the depletion ratio) is 3.3%.

The base-case model results show that: (1) *SSB* fluctuated throughout the assessment period, (2) *SSB* steadily declined from 1996 to 2010; and (3) the slow increase of the stock continues since 2011 including the most recent two years (2015–2016).

5.4 Yield estimates and projections

No estimates of MCY and CAY are available.

6. STATUS OF THE STOCKS

Stock structure assumptions
Western and central Pacific Ocean. All biomass in these tables refer to spawning biomass (*SB*).

Stock Status	
Year of Most Recent Assessment	2018
Assessment Runs Presented	Base-case model
Reference Points	Target: Not established; default = B_{MSY} Soft Limit: Not established by WCPFC or IATTC; but evaluated using HSS default of 20% SB_0 Hard Limit: Not established by WCPFC or IATTC; but evaluated using HSS default of 10% SB_0 Overfishing threshold: F_{MSY}
Status in relation to Target	Very Unlikely (< 10%) to be at or above B_{MSY} Very Unlikely (< 10%) that $F < F_{MSY}$
Status in relation to Limits	Very Likely (> 90%) to be below the Soft Limit Very Likely (> 90%) to be below the Hard Limit
Status in relation to Overfishing	Overfishing is Very Likely (> 90%) to be occurring

Historical Stock Status Trajectory and Current Status
-

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass is close to the lowest level ever experienced.
Recent Trend in Fishing Intensity or Proxy	A substantial decrease in estimated *F* is observed in ages 0–2 in 2015–2016 from the previous years.
Other Abundance Indices	-
Trends in Other Relevant Indicator or Variables	Historical recruitment estimates have fluctuated since 1952 without an apparent trend. The low recruitment levels estimated in 2010–2014 were a concern in the 2016 assessment. The 2015 recruitment estimate is lower than the historical average while the 2016 recruitment estimate is higher than the historical average

Projections and Prognosis	
Stock Projections or Prognosis	Results of stock projections suggest that even under the low recruitment scenario, SB will increase.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Very Likely (> 90%) Hard Limit: Very Likely (> 90%)
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Very Likely (> 90%)

Assessment Methodology and Evaluation		
Assessment Type	Level 1: Full Quantitative Stock assessment	
Assessment Method	Stock Synthesis	
Assessment Dates	Latest assessment: 2018	Next assessment: Unknown
Overall assessment quality rank	1 – High Quality	

Main data inputs (rank)	- catch - size composition - catch-per-unit of effort (CPUE) from 1952 to 2011	1 – High Quality 1 – High Quality 2 – Medium or Mixed Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- Steepness (fixed at 0.999) - The assumed natural mortality rate	

Qualifying Comments
-

Environmental and Ecosystem Considerations
Pacific bluefin tuna is a non-target catch in the tuna and swordfish surface-longline fishery in the New Zealand EEZ, please refer to those species chapters for environmental and ecosystem considerations. Blue sharks are the most commonly landed non-target species (by number) in the new Zealand longline fishery, followed by lancetfish and Ray's bream.

7. FOR FURTHER INFORMATION

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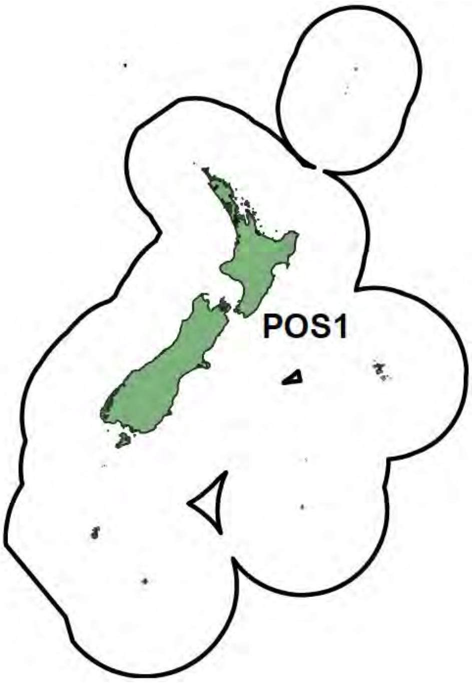
PORBEAGLE SHARK (POS)

(*Lamna nasus)*



1. FISHERY SUMMARY

Porbeagle sharks were introduced into the QMS on 1 October 2004 under a single QMA, POS 1, with a TAC of 249 t, a TACC of 215 t and a recreational allowance of 10 t. The TAC was reviewed in 2012 with the reduced allocation and allowances applied from 1 October 2012 in Table 1. The decrease was in response to sustainability concerns surrounding porbeagle sharks, which are slow growing and have low fecundity, making them particularly vulnerable to overexploitation.

Table 1: Recreational and customary non-commercial allowances, TACCs and TACs (all in t) for porbeagle sharks.

Fishstock	Recreational allowance	Customary non-commercial allowance	Other mortality	TACC	TAC
POS 1	6	2	11	110	129

Porbeagle sharks were added to the Third Schedule of the 1996 Fisheries Act with a TAC set under s14 because porbeagle sharks are a highly migratory species and it is not possible to estimate MSY for the part of the stock that is found within New Zealand fisheries waters.

Porbeagle sharks were also added to the Sixth Schedule of the 1996 Fisheries Act with the provision that:

> 'A commercial fisher may return any porbeagle shark to the waters from which it was taken from if –
> (a) that porbeagle shark is likely to survive on return; and
> (b) the return takes place as soon as practicable after the porbeagle shark is taken.'

The conditions of Schedule 6 releases have been amended for mako, porbeagle and blue sharks. From 1 October 2014, fishers have been allowed to return these three species to the sea both alive and dead, although the status must be reported accurately. Those returned to the sea dead are counted against a fisher's ACE and the total allowable catch limit for that species.
Management of the porbeagle shark throughout the western and central Pacific Ocean (WCPO) is the responsibility of the Western and Central Pacific Fisheries Commission (WCPFC). Under this regional

convention New Zealand is responsible for ensuring that the management measures applied within New Zealand fisheries waters are compatible with those of the Commission.

1.1 Commercial fisheries

About three-quarters of the commercial catch of porbeagle sharks is taken by tuna longliners, and most of the rest by midwater trawlers. About 60% of porbeagle sharks caught by tuna longliners are processed, and the rest are discarded. A high proportion of the catch was finned, but an increasing proportion of released sharks was reported as green, and small amounts were processed for their flesh. Figure 1 shows historical landings and longline fishing effort for POS 1.

Catches of porbeagle sharks by tuna longliners are concentrated off the west and south-west coast of the South Island, and the north-east coast of North Island (Figure 2). The target species for this fishery are mainly southern bluefin, bigeye and albacore tuna. Most of the porbeagle landings reported on TLCER forms were taken in FMAs 1, 2 and 7, with significant amounts also coming from trawl fisheries in FMAs 3, 5 and 6. Landings of porbeagle sharks reported by fishers on CELR (landed), CLR or TLCERs and by processors on LFRR and MHR forms are shown in Table 2. The decrease in reported landings in 2014–15 was due to the change to regulations for Schedule 6 releases. Historical landings have recently been re-calculated to correct for changes in and use of inappropriate conversion factors, and to allow for mortality of released sharks (Francis 2017).

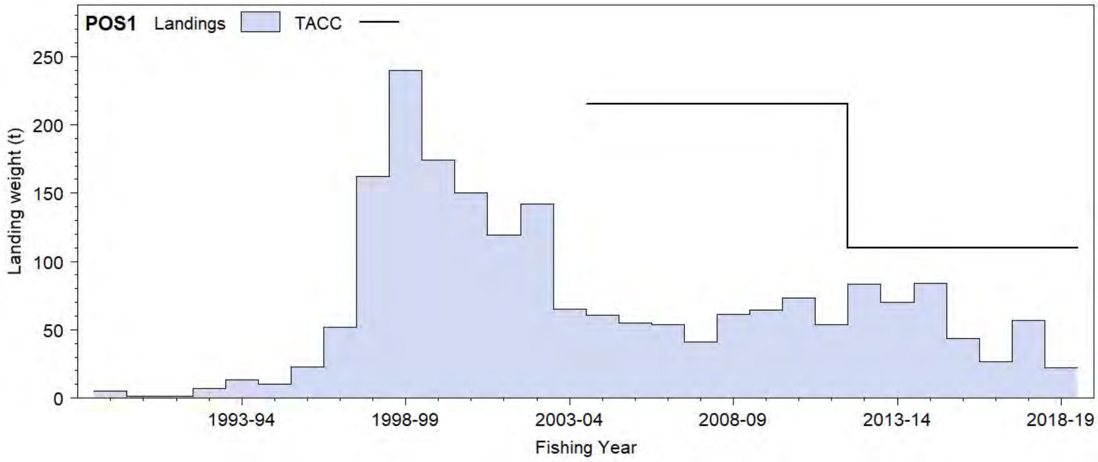


Figure 1: Catch of porbeagle sharks from 1989–90 to 2018–19 within New Zealand waters (POS 1).

Table 2: New Zealand commercial landings (t) of porbeagle sharks reported by fishers on CELRs, CLRs or TLCERs) and processors (LFRRs or MHRs) by fishing year (– no data available). [Continued on next page]

Year	Total Reported	LFRR/MHR
1989–90	–	5
1990–91	1	1
1991–92	1	1
1992–93	7	7
1993–94	10	13
1994–95	16	10
1995–96	26	23
1996–97	39	52
1997–98	205	162
1998–99	301	240
1999–00	215	174
2000–01	188	150
2001–02	161	119
2002–03*	152	142
2003–04*	84	65
2004–05*	62	60
2005–06*	54	55
2006–07*	53	54
2007–08*	43	41
2008–09*	64	61

Year	Total Reported	LFRR/MHR
2009–10*	–	65
2010–11*	–	73
2011–12*	–	54
2012–13*	–	81
2013–14*	–	70
2014–15*	–	84
2015–16	–	43
2016–17	–	27
2017–18	–	57
2018–19	-	22

* MHR rather than LFRR data.

In 2012–13, the majority of porbeagle sharks were caught in the southern bluefin tuna target surface-longline fishery (34%), followed by bigeye tuna (16%) and a small proportion (12%) are landed in the hoki target midwater trawl fishery (Figure 3). Across all surface-longline fisheries porbeagle made up 2% of the catch in 2017–18 (Figure 4). Longline fishing effort is distributed along the east coast of the North Island and the south-west coast of the South Island. The west coast South Island fishery predominantly targets southern bluefin tuna, whereas the east coast of the North Island targets a range of species including bigeye, swordfish and southern bluefin tuna.

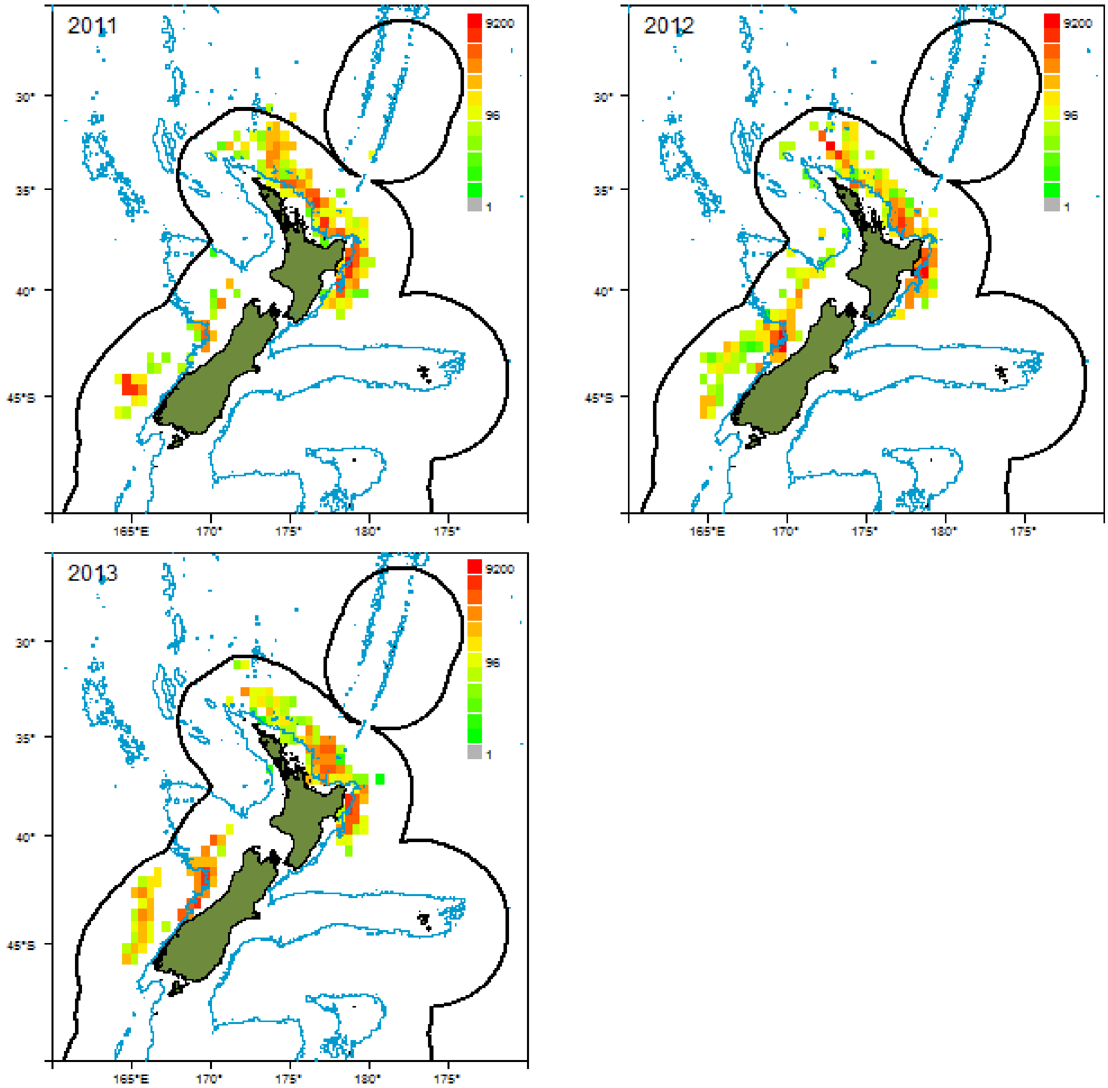


Figure 2: Porbeagle shark catches (kg) by the surface-longline fishery in 0.5 degree rectangles by fishing year. Note the log scale used for the colour palette. Depth contour = 1000 m.

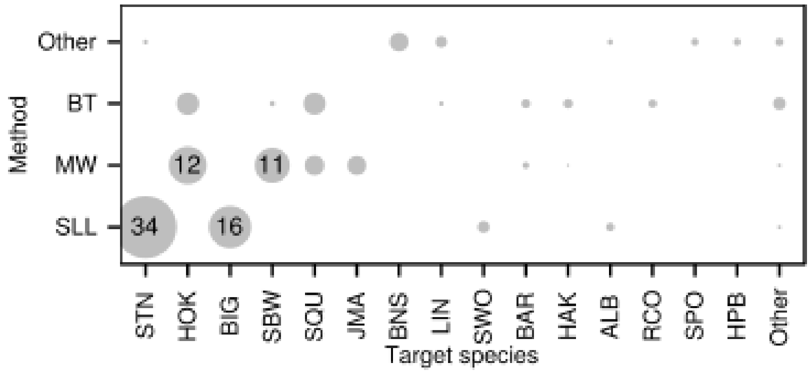


Figure 3: A summary of the proportion of landings of porbeagle shark taken by each target fishery and fishing method for 2012–13. The area of each circle is proportional to the percentage of landings taken using each combination of fishing method and target species. The number in the circle is the percentage (Bentley et al. 2013).

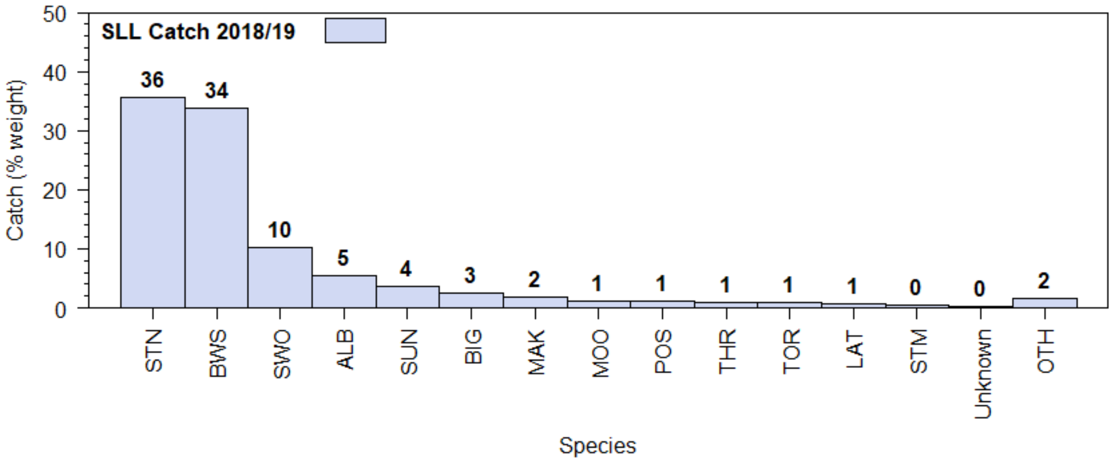


Figure 4: A summary of species composition of the surface-longline estimated catch in 2017–18. The percentage by weight of each species is calculated for all trips classified under the activity.

Across all fleets in the longline fishery during most of the years 2006–07 to 2014–15, 50–70% of the porbeagle sharks were alive when brought to the side of the vessel (Table 3). The percentage of porbeagle shark catches retained has varied over time, becoming relatively low in 2014–15 (Table 4). Since the regulation change on 1 October 2014 both the charter and domestic fleets have discarded most of their porbeagle catch.

Table 3: Percentage of porbeagle sharks (including discards) that were alive or dead when arriving at the longline vessel and observed during 2006–07 to 2014–15, by fishing year, fleet and region. Small sample sizes (number observed < 20) were omitted (Griggs & Baird 2013, Griggs et al. 2018). [Continued on next page]

Year	Fleet	Area	% alive	% dead	Number
2006–07	Charter	North	60.5	39.5	223
		South	87.3	12.7	370
	Domestic	North	44.8	55.2	134
	Total		**71.3**	**28.7**	**727**
2007–08	Charter	South	77.6	22.4	49
	Domestic	North	59.6	40.4	488
	Total		**61.3**	**38.7**	**537**
2008–09	Charter	North	91.0	9.0	78
		South	85.4	14.6	158
	Domestic	North	57.9	42.1	254
	Total		**71.5**	**28.5**	**494**

Year	Fleet	Area	% alive	% dead	Number
2009–10	Charter	South	82.4	17.6	68
	Domestic	North	40.4	59.6	322
		South	30.0	70.0	20
	Total		**46.8**	**53.2**	**410**
2010–11		South	75.6	24.4	82
	Domestic	North	62.0	38.0	686
	Total		**63.2**	**36.8**	**771**
2011–12	Charter	South	75.0	25.0	84
	Domestic	North	64.1	35.9	415
		South	37.1	62.9	124
	Total		**60.2**	**39.8**	**623**
2012–13	Charter	South	82.0	18.0	111
	Domestic	North	72.3	27.7	155
		South	33.3	66.7	27
	Total		**70.6**	**29.4**	**303**
2013–14	Charter	South	73.8	26.2	313
	Domestic	North	66.5	33.5	206
		South	28.3	71.7	198
	Total		**59.1**	**40.9**	**717**
2014–15	Charter	South	84.9	15.1	245
	Domestic	North	48.6	51.4	175
		South	32.0	68.0	50
	Total		**65.7**	**34.3**	**470**

1.2 Recreational fisheries

An estimate of the recreational harvest is not available. The recreational catch of porbeagle sharks is probably negligible, because they usually occur over the outer continental shelf or beyond. They are occasionally caught by gamefishers but most are tagged and released. In 2001, 40 porbeagle sharks were tagged by recreational fishers but numbers have dwindled from this peak to one or two per year.

1.3 Customary non-commercial fisheries

An estimate of the current customary catch is not available. The Maori customary catch of porbeagle sharks is probably negligible, because they usually occur over the outer continental shelf or beyond.

1.4 Illegal catch

There is no known illegal catch of porbeagle sharks.

1.5 Other sources of mortality

Many of the porbeagle sharks caught by tuna longliners are alive when the vessel retrieves the line, but it is not known how many of the released, discarded sharks survive.

Table 4: Percentage of porbeagle sharks that were retained, or discarded or lost, when observed on a longline vessel during 2006–07 to 2014–15, by fishing year and fleet. Small sample sizes (number observed < 20) omitted (Griggs & Baird, Griggs et al. 2018). [Continued on next page]

Year	Fleet	% retained or finned	% discarded or lost	Number
2006–07	Charter	86.6	13.4	628
	Domestic	38.1	61.9	134
	Total	**78.1**	**21.9**	**762**

Year	Fleet	% retained or finned	% discarded or lost	Number
2007–08	Charter	89.8	10.2	49
	Domestic	35.7	64.3	488
	Total	**40.6**	**59.4**	**537**
2008–09	Charter	91.1	8.9	257
	Domestic	46.9	53.1	258
	Total	**68.9**	**31.1**	**515**
2009–10	Charter	79.2	20.8	72
	Domestic	46.0	54.0	348
	Total	**51.7**	**48.3**	**420**
2010–11	Charter	73.3	26.7	86
	Domestic	30.8	69.2	714
	Total	**35.4**	**64.6**	**800**
2011–12	Charter	64.3	35.7	84
	Domestic	32.8	67.2	609
	Total	**36.7**	**63.3**	**693**
2012–13	Charter	60.3	39.7	121
	Domestic	15.4	84.6	188
	Total	**33.0**	**67.0**	**309**
2013–14	Charter	24.8	75.2	318
	Domestic	31.1	68.9	454
	Total	**28.5**	**71.5**	**772**
2014–15	Charter	0.0	100.0	248
	Domestic	11.2	88.8	232
	Total	**5.4**	**94.6**	**480**

2. BIOLOGY

Porbeagles live mainly in the latitudinal bands 30–50ºS and 30–70ºN. They occur in the North Atlantic Ocean, and in a circumglobal band in the Southern Hemisphere. Porbeagles are absent from the North Pacific Ocean, where the closely related salmon shark, *Lamna ditropis*, fills their niche. In the South Pacific Ocean, porbeagles are caught north of 30ºS in winter–spring only; in summer they are not found north of about 35ºS. They appear to penetrate further south during summer and autumn, and are found near many of the sub-Antarctic islands in the Indian and south-west Pacific Oceans. Porbeagle sharks are not found in the tropics.

Porbeagles are live-bearers (aplacental viviparous), and the length at birth is 58–67 cm fork length (FL) in the south-west Pacific. Females mature at around 170–180 cm FL and males at about 140–150 cm FL. The gestation period is about 8–9 months. In the north-west Atlantic, all females sampled in winter were pregnant, suggesting that there is no extended resting period between pregnancies, and that the female reproductive cycle lasts for one year. Litter size is usually four embryos, with a mean litter size in the south-west Pacific of 3.75. If the reproductive cycle lasts one year, annual fecundity would be about 3.75 pups per female.

Studies of the age and growth of New Zealand porbeagles produced growth curves and estimates of the natural mortality rate (Table 5). However, attempts to validate ages using bomb radiocarbon analysis were unsuccessful, but suggested that the ages of porbeagles older than about 20 years were progressively underestimated; for the oldest sharks the age underestimation may have been as much as 50% (Francis et al. 2007). Consequently, the growth parameters provided in Table 5 are probably only accurate for ages up to about 20 years. Males mature at 6–8 years, and females mature at 13–16 years. Longevity is unknown but may be about 65 years.

In New Zealand, porbeagle sharks recruit to tuna longline fisheries during their first year at about 70 cm FL, and the catch is dominated by juveniles, with about half of the males and two-thirds of the females being under 100 cm fork length. Most sharks caught by tuna longliners are 70–170 cm FL. The size and sex distribution of both sexes are similar up to about 150 cm, but larger individuals are predominantly male; few mature females are caught. Regional differences in length composition suggest segregation by size. The size and sex composition of sharks caught by trawlers are unknown.

Porbeagles are active pelagic predators of fish and cephalopods. Pelagic fish dominate the diet but squid are also commonly eaten, especially by the small sharks (Horn et al. 2013).

Table 5: Estimates of biological parameters.

	Fishstock	Estimate	Source
Natural mortality (m)	POS 1	0.05-0.10	Francis (unpublished data)
Weight	POS 1, both sexes.	a = 2.143×10^{-5}; b = 2.924	Ayers et al. (2004)
Von Bertalanffy model parameter estimates	POS 1, males	$k = 0.133$, $t_0 = -4.22$, $L_\infty = 185.8$	Francis (2015)
	POS 1, females	$k = 0.086$, $t_0 = -6.10$, $L_\infty = 210.9$	Francis (2015)

3. STOCKS AND AREAS

In the north-west Atlantic, most tagged sharks moved short to moderate distances (up to 1500 km) along continental shelves, although one moved about 1800 km off the shelf into the mid-Atlantic Ocean. Sharks tagged off southern England were mainly recaptured between Denmark and France, with one shark moving 2370 km to northern Norway. Only one tagged shark has crossed the Atlantic: it travelled 4260 km from south-west Eire to 52°W off eastern Canada. Thus porbeagles from the north-west and north-east Atlantic appear to form two distinct stocks. Based on the disjunct (antitropical) geographical distribution, differences in biological parameters, and genetic analyses, North Atlantic porbeagles are reproductively isolated from Southern Hemisphere porbeagles.

The stock structure of porbeagle sharks in the Southern Hemisphere is unknown. However, given the scale of movements of tagged sharks (Francis et al. 2015), it seems likely that sharks in the south-west Pacific comprise a single stock. There is no evidence to indicate whether this stock extends to the eastern South Pacific or Indian Ocean.

4. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS

This summary is from the perspective of the porbeagle shark but there is no directed fishery for the species so there is no information on the bycatch of other species in porbeagle fisheries.

4.1 Role in the ecosystem

4.1.1 Diet

Porbeagle sharks (*Lamna nasus*) are active pelagic predators of fish and cephalopods. Porbeagle sharks less than 75 cm feed mostly on squid but their diet changes to fish as they grow, with fish comprising more than 60% of the diet for porbeagle sharks 75 cm and over (Figure 5) (Griggs et al. 2007, Horn et al. 2013).

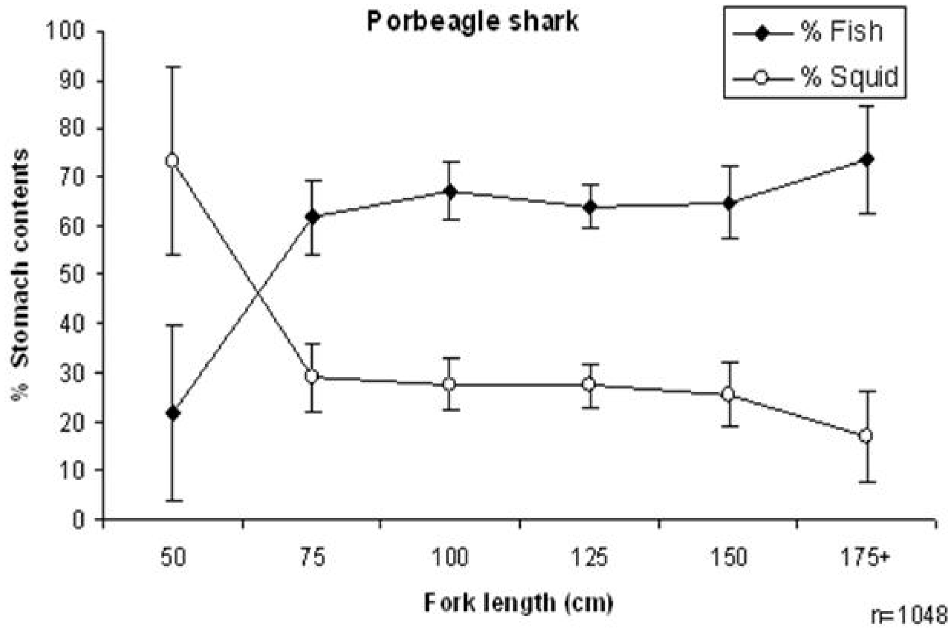


Figure 5: Changes in percentage of fish and squid in stomachs of porbeagle sharks as a function of fork length.

4.2 Non-target fish catch

Porbeagle shark is a non-target catch in the tuna and swordfish surface-longline fishery in the New Zealand EEZ.

Observer records indicate that a wide range of species are landed by the surface longline fleets in New Zealand fishery waters. Blue sharks are the most commonly landed species (by number), followed by lancetfish and Ray's bream (Table 6).

4.3 Benthic interactions

There are no known interactions with benthic habitats for this fishery.

Table 6: Total estimated catch (numbers of fish) of common bycatch species in the New Zealand longline fishery as estimated from observer data from 2015 to 2018. Also provided is the percentage of these species retained (2018 data only) and the percentage of fish that were alive when discarded, N/A (none discarded).

Species	2015	2016	2017	2018	% retained (2018)	discards % alive (2018)
Blue shark	72 480	57 210	49 924	63 618	0.0	88.7
Lancetfish	12 962	17 442	13 274	13 163	0.0	33.5
Porbeagle shark	4 058	6 566	3 101	2 594	1.0	51.1
Rays bream	17 555	7 758	2 421	1 579	99.0	26.7
Moonfish	3 060	3 036	2 022	2 698	98.0	50.0
Pelagic stingray	979	1 414	1 798	2 949	0.0	100.0
Sunfish	770	4 849	1 648	3 648	0.0	99.8
Mako shark	2 667	4 417	1 391	2 721	4.0	65.6
Rudderfish	373	237	680	253	45.0	89.4
Butterfly tuna	1 309	768	406	419	86.0	20.7
Escolar	653	669	300	594	67.0	67.9
Striped marlin	120	550	290	247	0.0	66.7
Thresher shark	177	601	260	253	0.0	76.0
Oilfish	584	281	227	602	42.0	85.4
Dealfish	842	63	72	25	0.0	31.8
School shark	88	24	59	187	84.0	100.0
Skipjack tuna	150	185	57	184	86.0	100.0
Deepwater dogfish	545	0	32	6	0.0	83.3
Big scale pomfret	59	16	17	34	100.0	n/a

5. STOCK ASSESSMENT

With the establishment of the WCPFC in 2004, future stock assessments of porbeagle sharks in the western and central Pacific Ocean stock will be reviewed by the WCPFC. There is currently a shark research plan that has been developed within the context of the Western and Central Pacific Fisheries Commission. The stock status of porbeagle sharks from the entire Southern Hemisphere range of the species was assessed in 2017 (Hoyle et al. 2017).

There have been no stock assessments of porbeagle sharks in New Zealand. No estimates of yield are possible with the currently available data.

Indicator analyses suggest that porbeagle shark populations in the New Zealand EEZ have not been declining under recent fishing pressure, and may have been increasing since 2005 (Francis & Large 2017; Figures 6 and 7, Table 7). These changes are presumably in response to a decline in SLL fishing effort since 2001–02 (Figure 1), and declines in annual landings since peaks in 1999 for porbeagle sharks (Table 2). There is some inconsistency among trends identified for porbeagle shark by the distribution and CPUE indicators, and by the standardised CPUE indices for the North and South fisheries. Some year-to-year CPUE variations were too large to represent changes in population biomass, and may instead reflect changes in availability to the fishery. Furthermore, some CPUE models fitted the data poorly and may be unreliable. Nevertheless, when taken as a group, the indicators suggest that the porbeagle population around New Zealand has been stable or increasing during the last decade.

In 2017, NIWA carried out a stock status risk assessment of the Southern Hemisphere porbeagle 'stock' (analysed as five separate sub-stocks) for WCPFC and the Common Oceans (ABNJ) Tuna Project. SC13 reviewed the report and it was subsequently revised (Hoyle et al. 2017).

The risk assessment of Southern Hemisphere porbeagle sharks assessed status by comparing estimates of fishing mortality against three maximum impact sustainable threshold reference points equivalent to r, $0.75r$ and $0.5r$, where r refers to the estimated intrinsic rate of increase of the species.

5.1 Stock status and trends

SC13 noted that although the stock status of the species is currently unknown the results of the assessment show that fishing mortality on the Southern Hemisphere stock is very low, and that it decreases eastward from the waters off South Africa to the waters off New Zealand. In the assessment area (eastern Atlantic to western Pacific Ocean) in the last decade (2005 to 2014), median F values ranged from 0.0008 to 0.0015 (mean 0.0010). This fishing mortality was less than 9% of the MIST based on r in all years assessed (1992–2014) and fell to half that level in more recent years, with at most a 3% probability of exceeding the MIST based on r in 2010–14. For the same scenarios, fishing mortality is less than 12% of the MIST based on $0.75r$ and less than 18% of the MIST based on $0.5r$.

These scenarios are based on 100% capture mortality, and assuming that some porbeagles survive their encounter with the fishery would reduce the estimated risk levels even further.

5.2 Management advice and implications

SC13 advised WCPFC14 that although the stock status of the species is currently unknown there is a very low risk that the Southern Hemisphere porbeagle shark is subject to overfishing anywhere within its range.

SC13 recommended that WCPFC14 request the Common Oceans (ABNJ) Tuna Project to explore options for data improvements through liaison with other regional fishery bodies managing fisheries catching Southern Hemisphere porbeagle sharks.

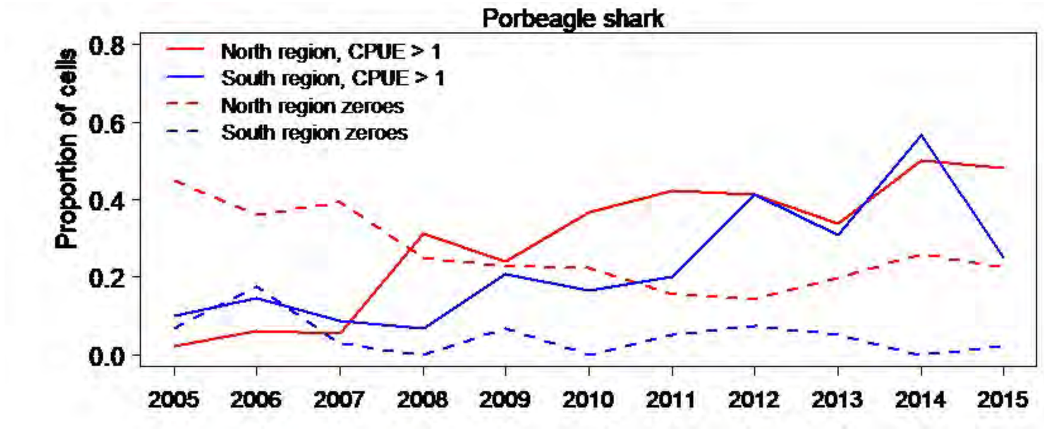


Figure 6: Porbeagle shark distribution indicators. Proportions of 0.5 degree rectangles having CPUE greater than 1 per 1000 hooks, and proportions of rectangles having zero catches, for North and South regions by fishing year, based on estimated catches (processed and discarded combined) reported on TLCERs. North region comprises Fisheries Management Areas (FMAs) 1, 2, 8 and 9, and South region comprises FMAs 5 and 7.

Relative to a wide range of shark species, the productivity of porbeagle sharks is very low. Females have a high age-at-maturity, high longevity (and therefore low natural mortality rate) and low annual fecundity. The low fecundity is cause for strong concern, as the ability of the stock to replace sharks removed by fishing is very limited.

Observed length-frequency distributions of porbeagle sharks by area and sex are shown in Figure 8 for fish measured between 1993 and 2012. Few mature females are caught by the surface-longline fishery, and they are mainly taken around the South Island. Mature males are frequently caught throughout New Zealand. A strong mode of 0+ juveniles occurs at 70–85 cm in northern and south-western New Zealand, but not off the east coast of the South Island where water temperatures are significantly colder.

A data-informed qualitative risk assessment was completed on all chondrichthyans (sharks, skates, rays and chimaeras) at the New Zealand scale in 2017 (Ford et al. 2018). Porbeagle sharks had a risk score of 15 and were ranked second equal lowest risk of the eleven QMS chondrichthyan species. Data were described as ‘exist and sound’ for the purposes of the assessment and the risk score was achieved by consensus of the expert panel, but with low confidence. This low confidence was due to the fact that no data were available on adult stock size.

Table 7: Summary of trends identified in abundance indicators up to the 2013 fishing year based on both TLCER and observer data sets. The CPUE-Obs indicator was calculated for both North and South regions combined. North region comprises Fisheries Management Areas (FMAs) 1, 2, 8 and 9, and South region comprises FMAs 5 and 7. For the CPUE-TLCER indicator in South region, only the Japan dataset indicator is shown (the TLCER Domestic South dataset was small and probably unrepresentative). Green cells show indicators that suggest positive trends in stock size. Note that a downward trend in ‘proportion-zeroes’ is considered a positive stock trend. NA = indicator not applicable because of small sample size.

		North region			South region		
Indicator class	Indicator	Blue	Porbeagle	Mako	Blue	Porbeagle	Mako
Distribution	High-CPUE	Up	Up	Up	Up	Up	NA
Distribution	Proportion-zeroes	Nil	Down	Down	Nil	Nil	Down
Catch composition	GM index total catch - TLCER		Up (all species)			Up (all species)	
Catch composition	GM index total catch - Obs		Up (all species)			Nil (all species)	
Catch composition	GM index HMS shark catch - TLCER		Up (all species)			Up (all species)	
Catch composition	GM index HMS shark catch - Obs		Up (all species)			Nil (all species)	
Standardised CPUE	CPUE - TLCER	Up	Nil	Up	Up	Nil	Nil
Standardised CPUE	CPUE - Obs	Up	Nil	Nil	Up	Nil	Nil
Sex ratio	Proportion males	Nil	Nil	Nil	Nil	Nil	NA
Size composition	Median length - Males	Nil	Nil	Nil	Nil	Nil	NA
Size composition	Median length - Females	Nil	Nil	Nil	Nil	Nil	NA

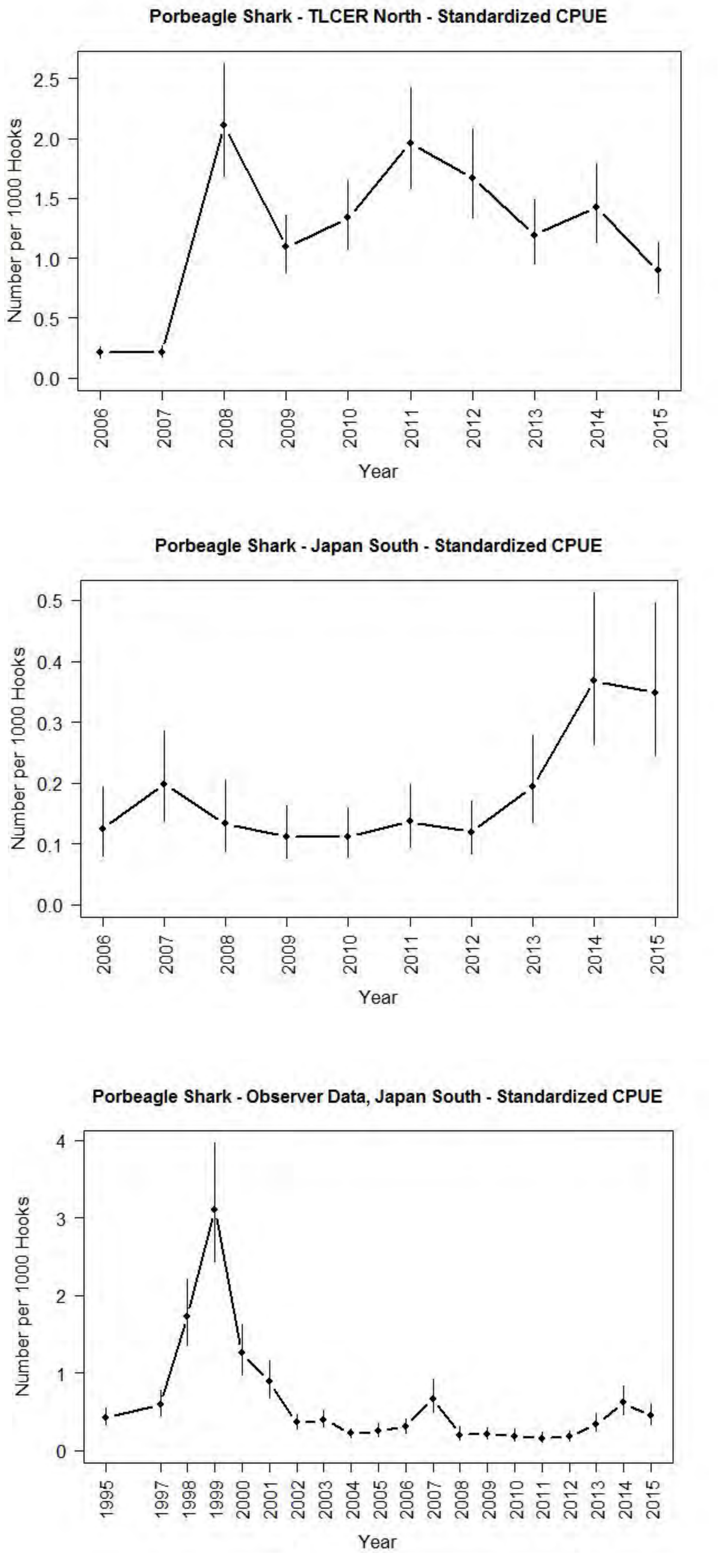


Figure 7: Standardised CPUE indices for commercial TLCER (Japan South and North) and observer data (Japan South).

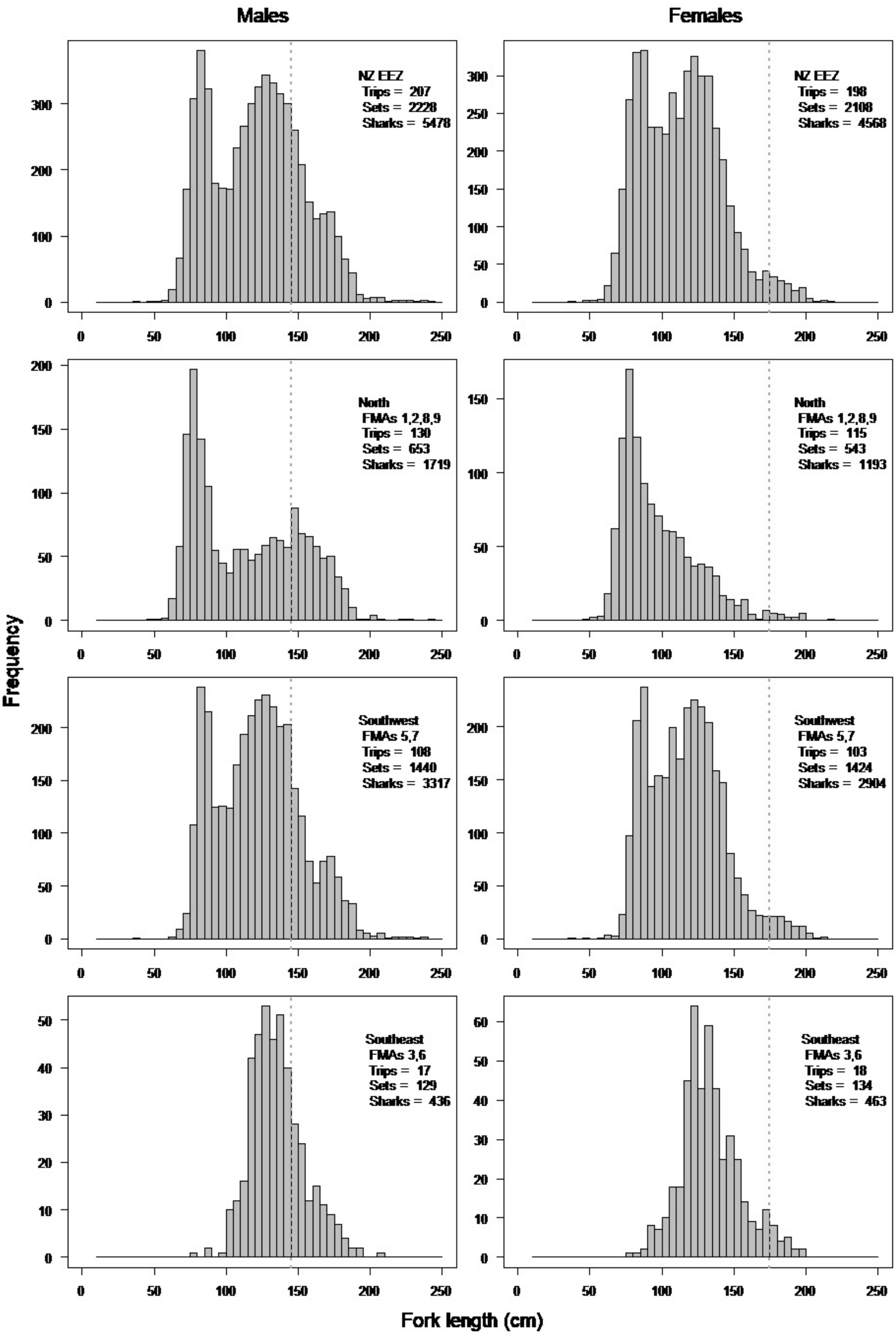


Figure 8: Length-frequency distributions of male and female porbeagle sharks measured by observers aboard surface-longline vessels between 1993 and 2012 for the New Zealand EEZ, and North, Southwest and Southeast regions. The dashed vertical lines indicate the median length at maturity (Francis 2013).

6. STATUS OF THE STOCK

Stock structure assumptions

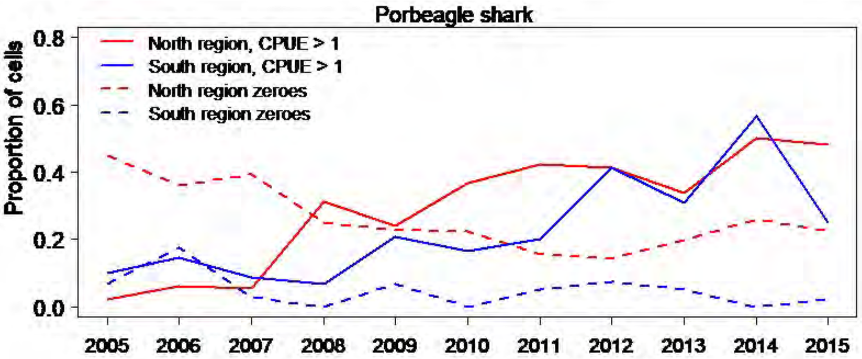
POS 1 is assumed to be part of the wider south-western Pacific Ocean stock. The results below are from indicator analyses (up to 2013) of the New Zealand component of that stock only, and a stock status risk assessment of the entire Southern Hemisphere porbeagle 'stock'.

Stock Status	
Year of Most Recent Assessment	2014 – Indicator analyses for NZ EEZ 2017 –Risk assessment of Southern Hemisphere porbeagle shark
Assessment Runs Presented	Indicator analyses only for NZ EEZ
Reference Points	Target: Not established Soft Limit: Not established but HSS default of 20% SB_0 assumed Hard Limit: Not established but HSS default of 10% SB_0 assumed Overfishing threshold: F_{MSY}
Status in relation to Target	Unknown
Status in relation to Limits	Unknown
Status in relation to Overfishing	Exceptionally Unlikely (<1%)

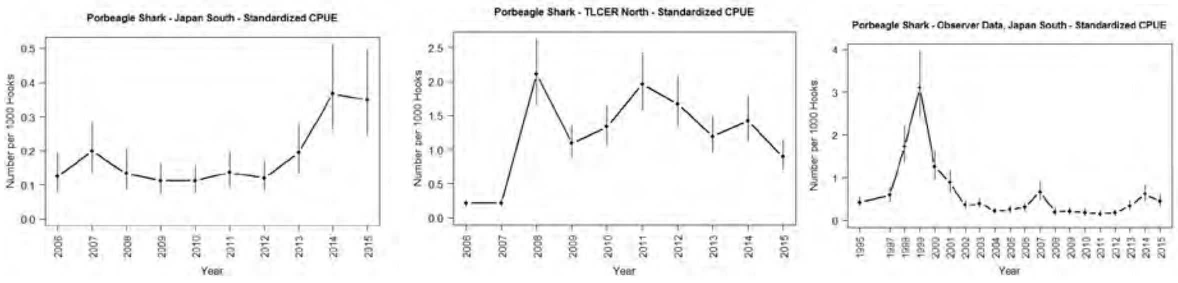
Historical Stock Status Trajectory and Current Status

Summary of trends identified in abundance indicators up to the 2013 fishing year based on both TLCER and observer data sets. North region comprises Fisheries Management Areas (FMAs) 1, 2, 8 and 9, and South region comprises FMAs 5 and 7.

		North region			South region		
Indicator class	Indicator	Blue	Porbeagle	Mako	Blue	Porbeagle	Mako
Distribution	High-CPUE	Up	Up	Up	Up	Up	NA
Distribution	Proportion-zeroes	Nil	Down	Down	Nil	Nil	Down
Catch composition	GM index total catch - TLCER	Up (all species)			Up (all species)		
Catch composition	GM index total catch - Obs	Up (all species)			Nil (all species)		
Catch composition	GM index HMS shark catch - TLCER	Up (all species)			Up (all species)		
Catch composition	GM index HMS shark catch - Obs	Up (all species)			Nil (all species)		
Standardised CPUE	CPUE - TLCER	Up	Nil	Up	Up	Nil	Nil
Standardised CPUE	CPUE - Obs	Up	Nil	Nil	Up	Nil	Nil
Sex ratio	Proportion males	Nil	Nil	Nil	Nil	Nil	NA
Size composition	Median length - Males	Nil	Nil	Nil	Nil	Nil	NA
Size composition	Median length - Females	Nil	Nil	Nil	Nil	Nil	NA



Porbeagle shark distribution indicators. Proportions of 0.5 degree rectangles having CPUE greater than 1 per 1000 hooks, and proportions of rectangles having zero catches, for North and South regions by fishing year, based on estimated catches (processed and discarded combined) reported on TLCERs. North region comprises Fisheries Management Areas (FMAs) 1, 2, 8 and 9, and South region comprises FMAs 5 and 7.



Standardised CPUE indices for commercial TLCER (Japan South and North) and observer datasets (all New Zealand).

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Appears to be increasing
Recent Trend in Fishing Intensity or Proxy	Appears to be decreasing
Other Abundance Indices	-
Trends in Other Relevant Indicator or Variables	Catches in New Zealand increased from the late 1980s to a peak in 1998/99 of 240 t, then declined to 41 t in 2007–08, and have remained less than 100 t since.

Projections and Prognosis	
Stock Projections or Prognosis	The stock is likely to increase if effort remains at current levels.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unknown Hard Limit: Unknown
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Exceptionally Unlikely (< 1%)

Assessment Methodology and Evaluation		
Assessment Type	Level 2 – Partial Quantitative Stock Assessment: Standardised CPUE indices and other fishery indicators Southern Hemisphere sustainability risk assessment	
Assessment Method	Indicator analyses and Southern Hemisphere sustainability risk assessment	
Assessment Dates	Latest assessment: 2014 and 2017	Next assessment: Unknown
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Distribution - Species composition - Size and sex ratio - Catch per unit effort	1 – All High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- Historical catch recording before 2005 may not be accurate.	

Qualifying Comments
Relative to a wide range of shark species, the productivity of porbeagle sharks is very low. Females have a high age-at-maturity, high longevity (and therefore low natural mortality rate) and

low annual fecundity. The low fecundity and high longevity are cause for strong concern, as the ability of the stock to replace sharks removed by fishing is very limited.

Environmental and Ecosystem Considerations

Porbeagle shark is a non-target catch in the tuna and swordfish surface-longline fishery in the New Zealand EEZ, please refer to those species for environmental and ecosystem considerations.

7. FOR FURTHER INFORMATION

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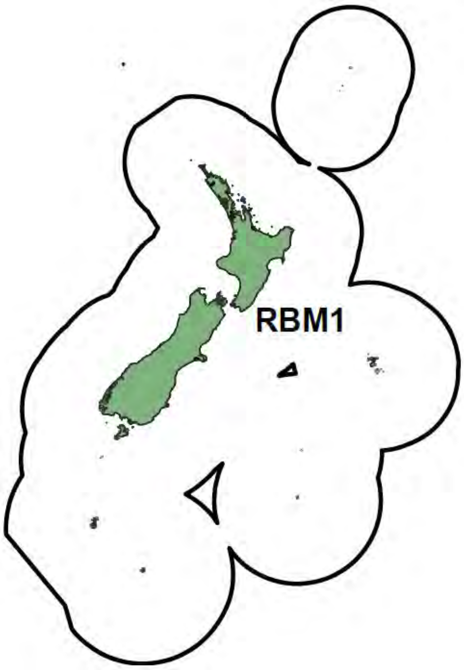
RAY'S BREAM (RBM)

(Brama brama)



1. FISHERY SUMMARY

Ray's bream (*Brama brama*) was introduced into the QMS on 1 October 2004 under a single QMA, RBM 1, with allowances, TACC and TAC in Table 1.

Table 1: Recreational and customary non-commercial allowances, TACC and TAC (all in tonnes) for Ray's bream.

Fishstock	Recreational allowance	Customary non-commercial allowance	Other mortality	TACC	TAC
RBM 1	10	5	50	980	1 045

At least two closely related species (*Brama brama* and *Brama australis*) are thought to be caught in New Zealand fisheries. Southern Ray's bream (*Brama australis*), which is difficult to distinguish using external features from *B. brama*, has been reported in both catch statistics and research surveys but the actual proportions of the two species in the catch is unknown. A third closely related species, bronze bream (*Xenobrama microlepis*), is more easily distinguished from the other two, but is also likely to have been recorded as Ray's bream in catch statistics.

1.1 Commercial fisheries

Ray's bream is a highly migratory species and has a wide distribution, being found throughout the subtropical to sub-Antarctic waters across the whole South Pacific between New Zealand and Chile. The catch of Ray's bream, while fluctuating, appeared to have been declining within New Zealand fisheries waters, from a high of 1001 t in 2000–01 to 143 t in 2011–12, followed by a larger catch of 627 t in 2012–13 (Tables 2 and 3). Licensed Fish Receiver Returns indicate that between 119 and 815 t were processed for the same period.

Based on records since 2003–04, most (46%) Ray's bream is caught by midwater trawl. Bottom trawling accounts for 27% of the total, surface longlining 18%, trolling 5% and bottom longlining 3%. Ray's bream is caught by midwater trawlers in all FMAs around the South Island, with the largest number in midwater trawls being taken from Stewart-Snares shelf (FMA 5) and the Chatham Rise (FMA 3). The major catches by bottom trawling have occurred on the Chatham Rise (FMA 3). Ray's bream is taken on surface tuna longlines on the east coast of the North Island, especially in the Bay of Plenty/East Cape (FMA 1). Most of the South Island longline catch comes from the west coast in FMAs 5 and 7. It is also taken by tuna trolling, especially on the west coast of the South Island (FMA 7). While observer coverage of the troll fleet is limited (0.5% of fishing days), observer records for the troll vessels have identified 100% of the Ray’s bream in the troll catch as *B. brama.* Figure 1 shows historical landings and longline fishing effort for the two Ray’s bream fisheries.

The majority of Ray’s bream are caught in the New Zealand squid, hoki and Jack mackerel midwater trawl fisheries with 11% of the Ray’s bream landings coming from the Southern bluefin target surface-longline fishery and small numbers coming from a range of other fisheries in 2012–13 (Figure 2). Ray’s bream make up less than 1% of the surface-longline catch by weight (Figure 3). Most of the New Zealand Ray’s bream catch is landed on the west coast of the South Island and sub-Antarctic islands (Figure 4).

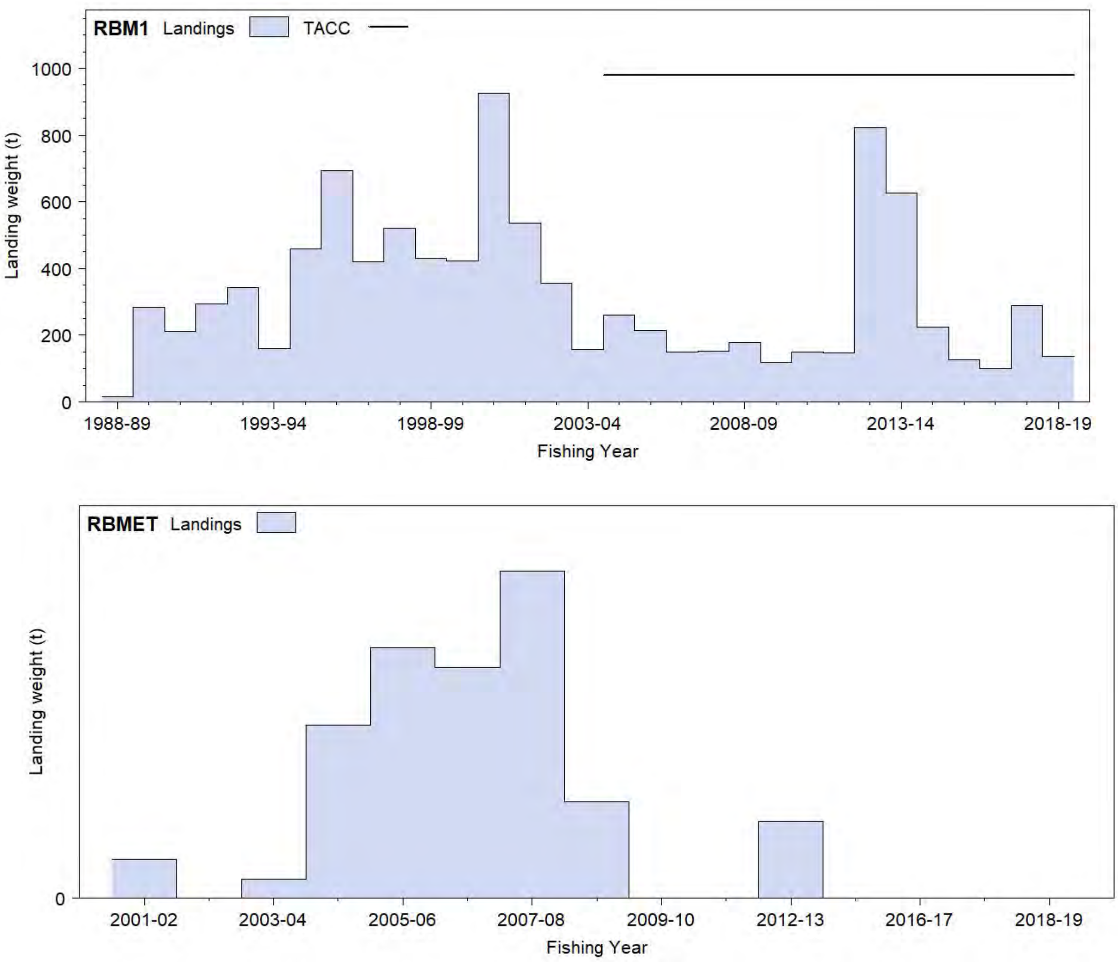


Figure 1: [Top] Ray’s bream catch from 1988–89 to 2018–19 within New Zealand waters (RBM 1) and [Bottom] 2001–02 to 2018–19 on the high seas (RBM ET).

Table 2: Reported commercial landings and discards (t) of Ray's bream from CELRs and CLRs, and LFRRs (processor records) by fishing year.

	Reported by fishers			
	CELR and CLR		Total	Processed
Year	Landed	Discarded	reported	LFRR
1988–89	9	0	9	16
1989–90	328	< 1	328	284
1990–91	239	< 1	239	211
1991–92	297	< 1	297	295
1992–93	340	1	341	342
1993–94	151	3	154	160
1994–95	462	8	470	460
1995–96	717	3	720	693
1996–97	356	7	362	421
1997–98	546	8	554	520
1998–99	425	10	435	431
1999–00	444	23	467	423
2000–01	941	60	1 001	926

Table 3: LFRR and MHR data on Ray's bream catches by fishing year.

Year	LFRR data	MHR data
2001–02	541	536
2002–03	347	357
2003–04	154	157
2004–05	257	259
2005–06	212	215
2006–07	149	149
2007–08	149	152
2008–09	176	179
2009–10	119	119
2010–11	137	150
2011–12	143	147
2012–13	815	823
2013–14	622	627
2014–15	218	224
2015–16	121	125
2016–17	96	101
2017–18	284	290
2018–19	133	137

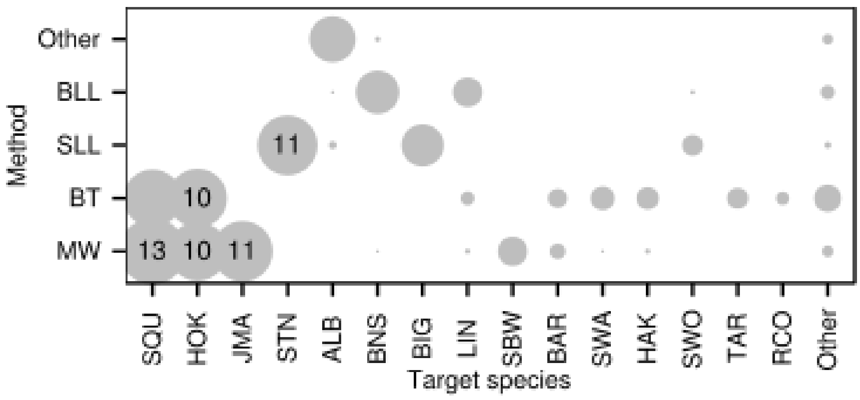


Figure 2: A summary of the proportion of landings of Ray's bream taken by each target fishery and fishing method. The area of each circle is proportional to the percentage of landings taken using each combination of fishing method and target species. The number in the circle is the percentage. SLL = surface longline, MW = midwater trawl, BLL = bottom longline, BT = bottom trawl (Bentley et al. 2013).

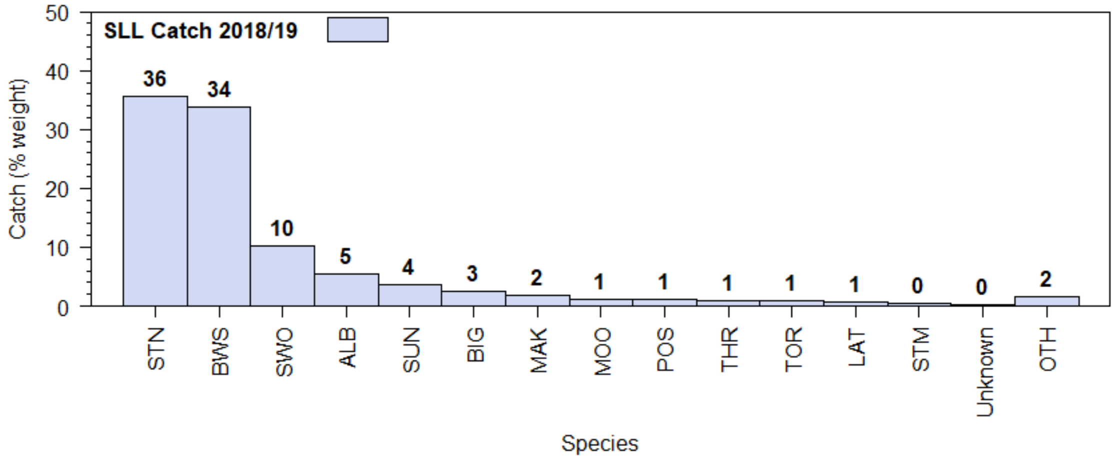


Figure 3: A summary of species composition of the surface-longline estimated catch. The percentage by weight of each species is calculated for all surface-longline trips.

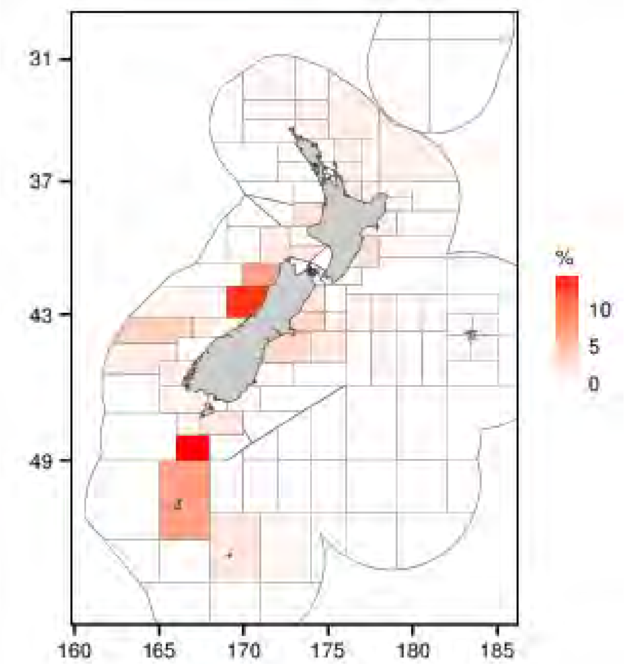


Figure 4: Distribution of catch of Ray's bream by statistical area for all years and all fishing gears (Bentley et al. 2013).

Across all fleets of the longline fishery from 2006–07 to 2014–15, a substantial majority of the Ray's bream were alive when brought to the side of the vessel (Table 4). Except in 2014–15, the domestic fleets retained more than 65% of their Ray's bream catch, while the foreign charter fleet retained more than 85% of their Ray's bream catch (Table 5).

Table 4: Percentage of Ray's bream (including discards) that were alive or dead when arriving at the longline vessel and observed during 2006–07 to 2014–15, by fishing year, fleet and region. Small sample sizes (number observed < 20) were omitted (Griggs & Baird 2013, Griggs et al. 2018). [Continued on next page]

Year	Fleet	Area	% alive	% dead	Number
2006–07	Charter	North	87.0	13.0	215
		South	96.0	4.0	10 350
	Domestic	North	65.8	34.2	442

Year	Fleet	Area	% alive	% dead	Number
	Total		**94.6**	**5.4**	**11 019**
Year	**Fleet**	**Area**	**% alive**	**% dead**	**Number**
2007–08	Charter	South	95.7	4.3	3 680
	Domestic	North	70.2	29.8	151
	Total		**94.6**	**5.4**	**3 831**
2008–09	Charter	North	90.1	9.9	313
		South	97.9	2.1	4 277
	Domestic	North	78.8	21.2	551
		South	94.1	5.9	34
	Total		**95.4**	**4.6**	**5 175**
2009–10	Charter	South	96.3	3.7	3 259
	Domestic	North	85.6	14.4	264
		South	92.0	8.0	88
	Total		**95.5**	**4.5**	**3 611**
2010–11	Charter	South	97.4	2.6	5 689
	Domestic	North	83.2	16.8	967
	Total		**95.3**	**4.7**	**6 662**
2011–12	Charter	South	92.2	7.8	2 965
	Domestic	North	97.1	2.9	693
		South	83.9	16.1	255
	Total		**92.5**	**7.5**	**3 915**
2012–13	Charter	South	96.0	4.0	4 377
	Domestic	North	87.8	12.2	180
	Total		**95.6**	**4.4**	**4 578**
2013–14	Charter	South	92.8	7.2	2 295
	Domestic	North	76.5	23.5	34
		South	69.0	31.0	129
	Total		**91.3**	**8.7**	**2 458**
2014–15	Charter	South	92.8	7.2	4 746
	Domestic	North	45.0	55.0	20
		South	75.2	24.8	226
	Total		**91.8**	**8.2**	**4 992**

1.2 Recreational fisheries

Recreational fishers take Ray's bream infrequently, generally as bycatch when targeting bluenose, hāpuku and bass over deep reefs. The recreational harvest is assumed to be low, and is likely to be insignificant in the context of the total landings.

Table 5: Percentage of Ray's bream that were retained, or discarded or lost, when observed on a longline vessel during 2006–07 to 2014–15, by fishing year and fleet. Small sample sizes (number observed < 20) omitted (Griggs & Baird 2013, Griggs et al. 2018). [Continued on next page]

Year	Fleet	% retained	% discarded or lost	Number
2006–07	Charter	96.8	3.2	11 744
	Domestic	95.7	4.3	442
	Total	**96.8**	**3.2**	**12 198**
2007–08	Charter	96.8	3.2	3 714
	Domestic	98.7	1.3	152
	Total	**96.9**	**3.1**	**3 866**

Year	Fleet	% retained	% discarded or lost	Number
2008–09	Charter	98.7	1.3	4 646
	Domestic	98.3	1.7	585
	Total	**98.7**	**1.3**	**5 231**
2009–10	Charter	98.8	1.2	3 291
	Domestic	95.3	4.7	361
	Total	**98.4**	**1.6**	**3 652**
2010–11	Charter	98.7	1.3	5 705
	Domestic	96.7	3.3	996
	Total	**98.4**	**1.6**	**6 701**
2011–12	Charter	97.1	2.9	2 973
	Domestic	93.8	6.2	1 006
	Total	**96.3**	**3.7**	**3 979**
2012–13	Charter	97.2	2.8	4 389
	Domestic	93.2	6.8	205
	Total	**97.0**	**3.0**	**4 594**
2013–14	Charter	95.5	4.5	2 300
	Domestic	97.6	2.4	164
	Total	**95.6**	**4.4**	**2 464**
2014–15	Charter	93.5	6.5	4 774
	Domestic	94.0	6.0	299
	Total	**93.5**	**6.5**	**5 073**

1.3 Customary non-commercial fisheries
There is no quantitative information available to allow the estimation of the harvest of Ray's bream by customary fishers, however, the harvest is assumed to be insignificant in the context of the commercial landings.

1.4 Illegal catch
There is no known illegal catch of Ray's bream.

1.5 Other sources of mortality
Ray's bream is a desirable species, and only a small percentage (about 1–5% annually) has been reported or observed as having been discarded. Most of the trawl catch of Ray's bream that is reported on CELR and CLR forms is retained. Most of the discarding appears to occur in the tuna fisheries, but these fisheries only take a small proportion of the total catch of Ray's bream. There may be some unobserved shark and cetacean depredation of longline caught Ray's bream.

2. BIOLOGY

Until recently, little was known about the biology of Ray's bream in New Zealand waters. A 2004 study examined growth rates, natural mortality and maturity for Ray's bream. Unfortunately, the actual species examined in this study could not be determined. It is possible that more than one species was involved, and the species (one or more) may not have been representative of the New Zealand catch recorded as Ray's bream. Until further samples are collected, the identification cannot be confirmed, but it is likely that the study was based wholly or partly on Southern Ray's bream (*Brama australis*).

It is expected that the main biological characteristics of Ray's bream will be similar to Southern Ray's bream, so the general findings of the recent study are reported here (Table 6). The small otoliths proved to be extremely difficult to age; notwithstanding this, Southern Ray's bream appear to have rapid initial growth, reaching 40–50 cm in 3–5 years, with little increase in length after this time. The maximum age observed was 25 years.

Table 6: Estimates of biological parameters.

Parameter		Estimate		Source
1. Weight = a·(length)^b (Weight in t, length in cm)				
	Both sexes	a = 5.31 x10^{-9}	b = 3.320	Livingston et al. 2004

3. STOCKS AND AREAS

Ray's bream probably come from a wide-ranging single stock found throughout the South Pacific Ocean and southern Tasman Sea. The catch of Ray's bream elsewhere in the South Pacific needs to be considered when assessing the status of Ray's bream within New Zealand's fisheries waters.

4. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS

This summary is from the perspective of Ray's bream but there is no directed fishery for them.

4.1 Role in the ecosystem

Ray's bream (*Brama brama*) is found in midwater depths down to 1000 m. Ray's bream undertakes daily vertical migrations (Lobo & Erzini 2001) and is thought to feed opportunistically on small fish and cephalopods. It is known to be predated on by deepwater sharks such as the deepwater dogfish species *Centrophorus squamosus* and *Centroscymnus owstonii,* and the school shark *Galeorhinus galeus* (Dunn et al. 2010).

4.2 Non-target fish catch

Ray's bream is a non-target catch in midwater trawl, bottom trawl, surface longlining, trolling and bottom longlining fisheries in the New Zealand EEZ. Ray's bream is one of the most commonly landed non-target species (by number), in the longline fishery (Table 7).

4.3 Benthic interactions

Please refer to other fisheries for benthic interactions.

5. STOCK ASSESSMENT

No assessments are available for Ray's bream; therefore estimates of biomass and yield are not available.

Table 7: Total estimated catch (numbers of fish) of common bycatch species in the New Zealand longline fishery as estimated from observer data from 2015 to 2018. Also provided is the percentage of these species retained (2018 data only) and the percentage of fish that were alive when discarded, N/A (none discarded). [Continued on next page]

Species	2015	2016	2017	2018	% retained (2018)	discards % alive (2018)
Blue shark	72 480	57 210	49 924	63 618	0.0	88.7
Lancetfish	12 962	17 442	13 274	13 163	0.0	33.5
Porbeagle shark	4 058	6 566	3 101	2 594	1.0	51.1
Rays bream	17 555	7 758	2 421	1 579	99.0	26.7
Moonfish	3 060	3 036	2 022	2 698	98.0	50.0
Pelagic stingray	979	1 414	1 798	2 949	0.0	100.0
Sunfish	770	4 849	1 648	3 648	0.0	99.8
Mako shark	2 667	4 417	1 391	2 721	4.0	65.6
Rudderfish	373	237	680	253	45.0	89.4
Butterfly tuna	1 309	768	406	419	86.0	20.7

Species	2015	2016	2017	2018	% retained (2018)	discards % alive (2018)
Escolar	653	669	300	594	67.0	67.9
Striped marlin	120	550	290	247	0.0	66.7
Thresher shark	177	601	260	253	0.0	76.0
Oilfish	584	281	227	602	42.0	85.4
Dealfish	842	63	72	25	0.0	31.8
School shark	88	24	59	187	84.0	100.0
Skipjack tuna	150	185	57	184	86.0	100.0
Deepwater dogfish	545	0	32	6	0.0	83.3
Big scale pomfret	59	16	17	34	100.0	n/a

5.1 Estimates of fishery parameters and abundance

A time series of relative abundance estimates is available from the Chatham Rise trawl survey, but these estimates may not be a reliable index of relative abundance because Ray's bream are thought to reside in the midwater and their vulnerability to the trawl survey gear is unknown, and could be extremely low. Similarly, a time series of unstandardised CPUE from the tuna longline fishery is highly variable and may not reflect relative abundance.

5.2 Biomass estimates

No biomass estimates are available for Ray's bream.

5.3 Other yield estimates and stock assessment results

There are no other yield estimates or stock assessment results available for Ray's bream.

5.4 Other factors

At least three closely related species are thought to be caught in New Zealand fisheries. Two species from the genus *Brama*, Ray's bream (*Brama brama*) and Southern Ray's bream (*Brama australis*), are difficult to distinguish from external features and have been reported together in both catch statistics and research survey data in unknown ratios. A third closely related species, bronze bream (*Xenobrama microlepis*), is more easily distinguished from the other two, but is also likely to have been recorded as Ray's bream in catch statistics.

As none of the reported catch is from target fishing, the quota allocated under the QMS system will cover bycatch of midwater trawl fisheries for squid, hoki and Jack mackerels, and target tuna longline fisheries.

It is not known if observers distinguished Ray's bream from Southern Ray's bream (*Brama australis*) in the past and it is possible that there are two species with different distributions. However observer training and fish identification guides now used by the observers should allow for correct identification and as a result the incidents of misidentification in recent years is likely to be low.

6. STATUS OF THE STOCKS

Stock structure assumptions
RBM 1 is assumed to be part of the wider south-western Pacific Ocean stock but the assessment below relates only to the New Zealand component of that stock.

Stock Status	
Year of Most Recent Assessment	No assessment
Assessment Runs Presented	-
Reference Points	Target: Not established Soft Limit: Not established but HSS default of 20% SB_0 assumed Hard Limit: Not established but HSS default of 10% SB_0 assumed Overfishing threshold: Not established
Status in relation to Target	Unknown
Status in relation to Limits	Unknown
Status in relation to Overfishing	Unknown

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Unknown
Recent Trend in Fishing Intensity or Proxy	Unknown
Other Abundance Indices	Catches in New Zealand increased from the late 1980s to 2000 but have declined from highs of 1001 t in the early 2000s to 290 t in 2017–18.

Projections and Prognosis	
Stock Projections or Prognosis	Unknown
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unknown Hard Limit: Unknown
Probability of Current Catch or TACC causing Overfishing to remain or to commence	Unknown

Assessment Methodology and Evaluation		
Assessment Type	Level 4: Low information evaluation – There are only data on catch and TACC, with no other fishery indicators.	
Assessment Method	-	
Assessment Dates	Latest assessment: None	Next assessment: Unknown
Overall assessment quality rank	N/A	
Main data inputs (rank)	-	
Data not used (rank)	-	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	-	

Qualifying Comments
There is no target fishery for Ray's bream but it is a non-target catch in midwater trawl, bottom trawl, surface longlining, trolling and bottom longlining.

Environmental and Ecosystem Considerations
Ray's bream is a non-target catch in midwater trawl, bottom trawl, surface longlining, trolling and bottom longlining fisheries in the New Zealand EEZ, please refer to those fisheries for environmental and ecosystem considerations. Ray's bream is one of the most commonly landed non-target species (by number), in the longline fishery.

7. FOR FURTHER INFORMATION

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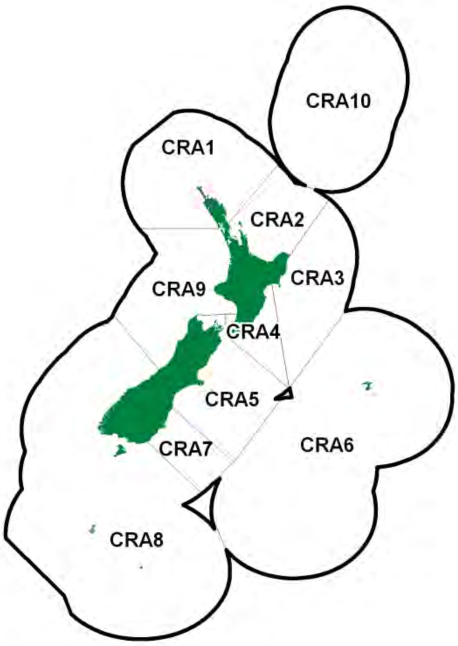
ROCK LOBSTER (CRA and PHC)

(*Jasus edwardsii*, *Sagmariasus verreauxi*)
Crayfish, Kōura papatea, Pawharu



1. INTRODUCTION

Fisheries New Zealand is in the process of splitting the rock lobster chapter into several smaller units, which will ultimately include an introductory chapter and separate stock assessment chapters for each of the main CRA stocks. At present, separate chapters have been developed for an overall Introduction (this chapter), and the CRA 1, CRA 2, CRA 3 and CRA 6 stock assessments. The remaining stock assessments are still grouped together in a different chapter. Those rock lobster Management Procedures that have not yet been phased out are detailed in the current chapter.

2. FISHERY SUMMARY

Two species of rock lobsters are taken in New Zealand coastal waters. The red rock lobster (*Jasus edwardsii*) supports nearly all the landings and is caught all around the North and South Islands, Stewart Island, and the Chatham Islands. The packhorse rock lobster (*Sagmariasus verreauxi*) is taken mainly in the north of the North Island, including the Bay of Plenty. Packhorse lobsters (PHC) grow to a much larger size than red rock lobsters (CRA) and have different shell colouration and shape.

The rock lobster fisheries were brought into the Quota Management System (QMS) on 1 April 1990, when Total Allowable Commercial Catches (TACCs) were set for each Quota Management Area (QMA) shown above. Before this, rock lobster fishing was managed by input controls, including limited entry, minimum legal size (MLS) regulations, a prohibition on the taking of berried females and soft-shelled lobsters, and some local area closures. Most of these input controls have been retained, but the limited entry provisions were removed and allocation of individual transferable quota (ITQ) was made to the previous licence holders based on catch history.

Historically, three rock lobster stocks were recognised for stock assessment purposes:

- NSI – the North and South Island (including Stewart Island) red rock lobster stock

- CHI – the Chatham Islands red rock lobster stock
- PHC – the New Zealand packhorse rock lobster stock

In 1994, the Rock Lobster Fishery Assessment Working Group (RLFAWG) agreed to divide the historical NSI stock into three substocks based on groupings of the existing QMAs (without assigning CRA 9):

- NSN – the northern stocks CRA 1 and 2
- NSC – the central stocks CRA 3, 4 and 5
- NSS – the southern stocks CRA 7 and 8

Since 2001, assessments have been carried out at the QMA level. Exploratory assessments at the statistical area level began in 2016 and have continued to the present. The fishing year runs from 1 April to 31 March.

In 2018, the management of six of the nine rock lobster QMAs was controlled by the operation of management procedures (MPs), which were based on a 'harvest control rule' that converted standardised CPUE into a TACC for the following year. These rules were evaluated through computer simulation and found to meet the requirements of the Fisheries Act. The six QMAs that used MPs were CRA 1, CRA 3, CRA 4, CRA 5, CRA 7 and CRA 8. CRA 2, CRA 6, and CRA 9 are not managed by MP (see Section 4 for a detailed discussion of each rule). The 2019 operation of these six MPs has been placed in jeopardy due to extensive (and on-going) changes to the collection of catch and effort data in the rock lobster potting fishery during the switch from paper forms to electronic reporting. The RLFAWG is concerned that the new data collection system will not be comparable to the previous system and thus will invalidate the simulations which established the original rules. Previous New Zealand experience with changes to the collection of catch/effort data has demonstrated that it is not possible to assume that data will be comparable between the two systems. Given that the changeover from the old paper forms to electronic reporting is still in progress, the rock lobster stock assessment team is evaluating the available data for each QMA to determine if the relevant MP can be safely operated. In 2019, the MPs for CRA 1 and CRA 3 were abandoned.

The 2017 CRA 2 stock assessment concluded that the stock was below the soft limit and therefore required implementing a rebuilding plan (Webber et al. 2018). This rebuilding plan consisted of a simple fixed catch rather than an MP. CRA 6 had its first length-based stock assessment in 2018, but no MP was developed for this QMA. An MP for CRA 9 was developed in 2014 but abandoned in 2016, after two years of operation, because analysis indicated that the CRA 9 CPUE analysis was not sufficiently reliable to support an MP. The TACC for CRA 10 is nominal because it is not fished commercially. The TACC for PHC 1 increased from 30 t in 1990 to its current value of 40.3 t at the beginning of the 1992–93 fishing year, following quota appeals.

TACs (Total Allowable Catch: includes TACC plus all non-commercial allowances) were set for the first time in 1997–98 for three CRA QMAs. Setting a TAC is a requirement under the Fisheries Act 1996 and TACs have been set since 1997–98 whenever adjustments have been made to the TACCs or non-commercial allowances. Figure 1 shows historical commercial landings and TACC values for all CRA stocks.

The MLS in the commercial fishery for red rock lobster is based on tail width (TW), except in the Otago (CRA 7) fishery, where the MLS for commercial fishing is a tail length (TL) of 127 mm for both sexes. The female MLS in all other rock lobster QMAs except Southern (CRA 8) has been 60 mm TW since mid-1992. For CRA 8 the female MLS has been 57 mm TW since 1990. The male MLS has been 54 mm TW for all QMAs since 1988, except in Otago (see above) and Gisborne (CRA 3), where since 1993 it has been 52 mm TW for the June–August period. A closed season applies in CRA 6 from 01 March to 30 April in each year.

Box 1. Summary of management actions by QMA since 1990 for rock lobster:

QMA	Type of management	Frequency of review	Year first MP implemented	Year of TACC/TAC changes since 1990
CRA 1 (Northland)	MP	5 years	2015	1991, 1992, 1993, 1996, 1999, 2015
CRA 2 (Bay of Plenty)	TAC/TACC	Unknown	2014	1991, 1992, 1993, 1997, 2014, 2018
CRA 3 (Gisborne)	MP	5 years	2005	1991, 1992, 1993, 1996, 1997, 1998, 2005, 2009, 2012, 2013, 2014, 2017, 2019
CRA 4 (Wairarapa)[1]	MP	5 years	2007	1991, 1992, 1993, 1999, 2009, 2010, 2011 , 2013, 2014, 2016, 2017, 2018
CRA 5 (Marlborough/Kaikoura)[2,3]	MP	5 years	2009	1991, 1992, 1993, 1996, 1999, 2016
CRA 6 (Chatham Islands)	TAC/TACC	Unknown	Not applicable	1991, 1993, 1997, 1998
CRA 7 (Otago)[3]	MP	5 years	1996	1991, 1992, 1993, 1996, 1999, 2001, 2004, 2006, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2017, 2018
CRA 8 (Stewart Island/Fiordland)[3]	MP	5 years	1996	1991, 1992, 1993, 1999, 2001, 2004, 2006, 2008, 2009, 2011, 2018, 2019
CRA 9 (Westland, Taranaki)	Not assessed	Suspended (2016)	2014	1991, 1992, 1993, 2014
CRA 10 (Kermadec Island)	Not assessed	Unspecified	Not applicable	–
PHC 1 (all NZ)	Not assessed	Unspecified	Not applicable	1991, 1992

[1]Voluntary TACC reductions based on an MP were made by the CRA 4 industry in 2007 and 2008. The MP was implemented by Ministry of Fisheries in 2009 and a revised MP was adopted in 2017.
[2]The CRA 5 MP was implemented by MPI in 2012 but industry had operated a voluntary rule since 2009.
[3]New MPs were implemented for CRA 5 and CRA 8 in 2016, with the CRA 8 MP using CPUE based on the retained lobsters only. For CRA 7, following a new stock assessment and re-evaluation of the MP in 2015, the old MP was retained. For CRA 5 in 2016, there was only an increase in recreational allowance from 40 t to 87 t.

Beginning with the 1993–94 fishing year, the CRA 3 fishery was closed, by regulation, to all users from September to the end of November. The commercial fishery was additionally shut for all of December up to 15 January. The month of May was also closed to commercial fishing. These regulatory closures ended after 2001–02, except for the May closure, which was retained until the end of the 2013–14 fishing year. After the regulatory closures disappeared in 2001–02, the fishing industry instituted a voluntary closure from 15 December to 15 January, beginning with the 2002–03 fishing year. From the 2008–09 fishing year, the voluntary closure was extended to start in September, but only in Statistical Areas 909 and 910. Industry in Area 911 (Mahia) opted at that time to remain open in the spring–summer (SS) season, but chose to impose a 54 mm MLS on all male lobster taken. For recreational fishers, the red rock lobster MLS has been 54 mm TW for males since 1990 and 60 mm TW for females since 1992 in all areas. The commercial and recreational MLS for packhorse rock lobster is 216 mm TL for both sexes.

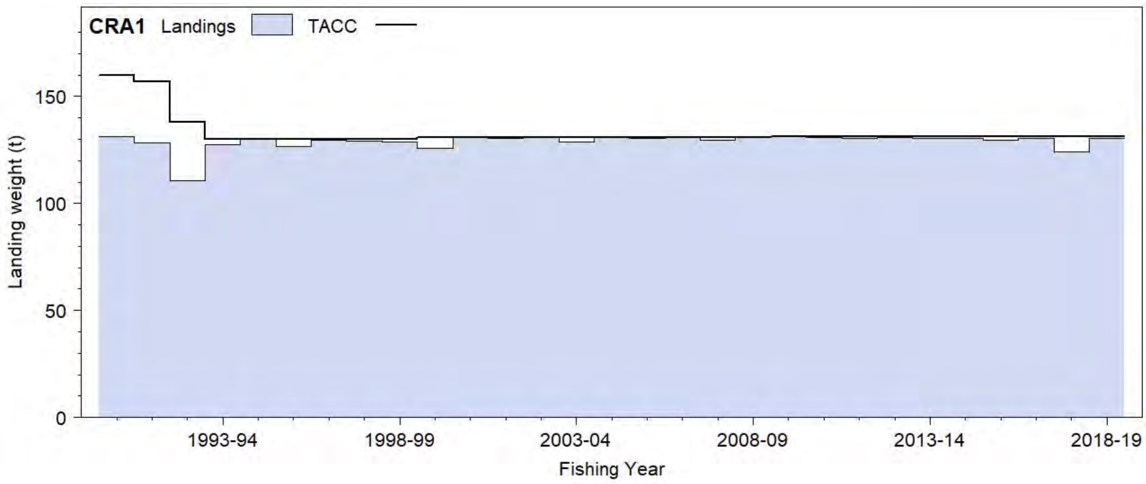
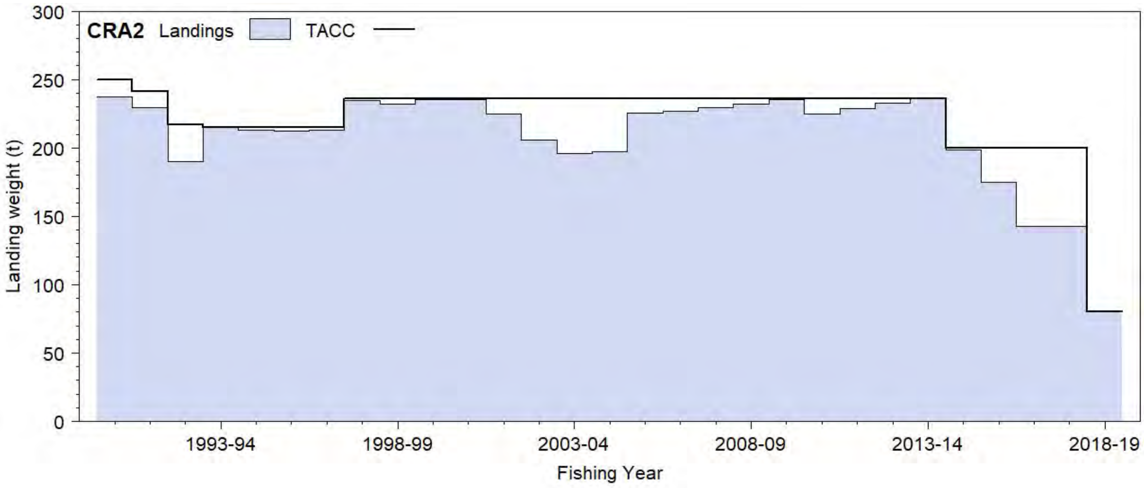
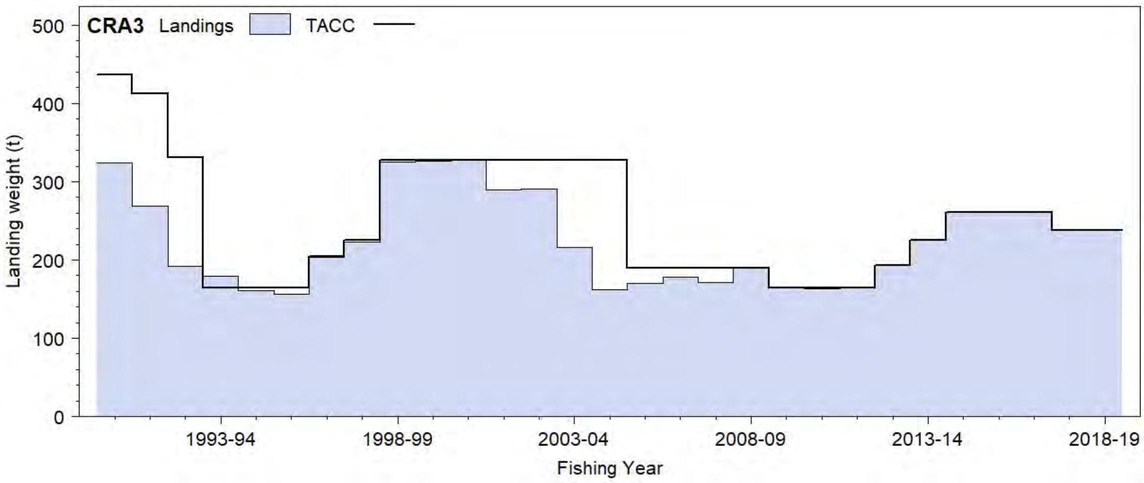


Figure 1: Historical landings and TACC for the nine main CRA stocks and PHC 1. [Continued on next page]





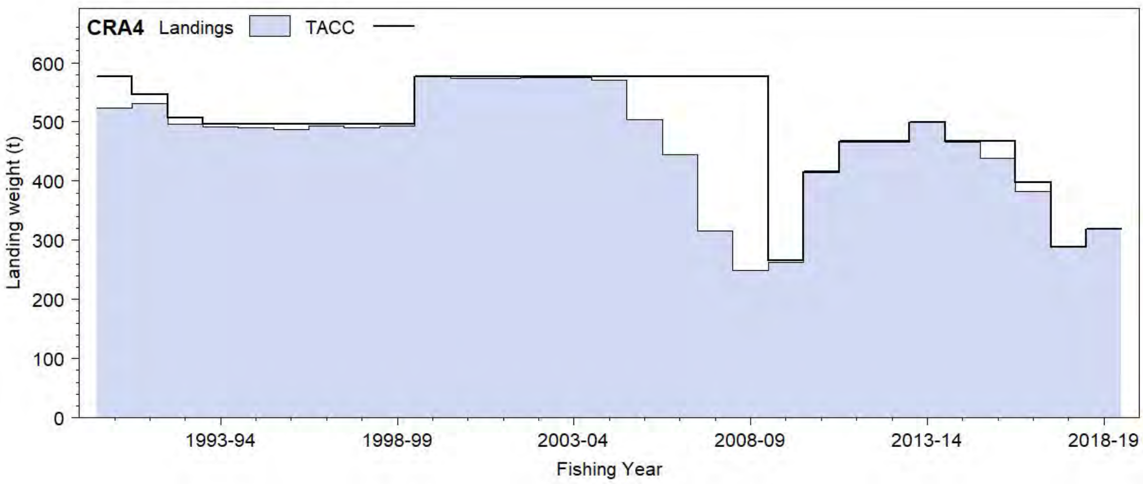
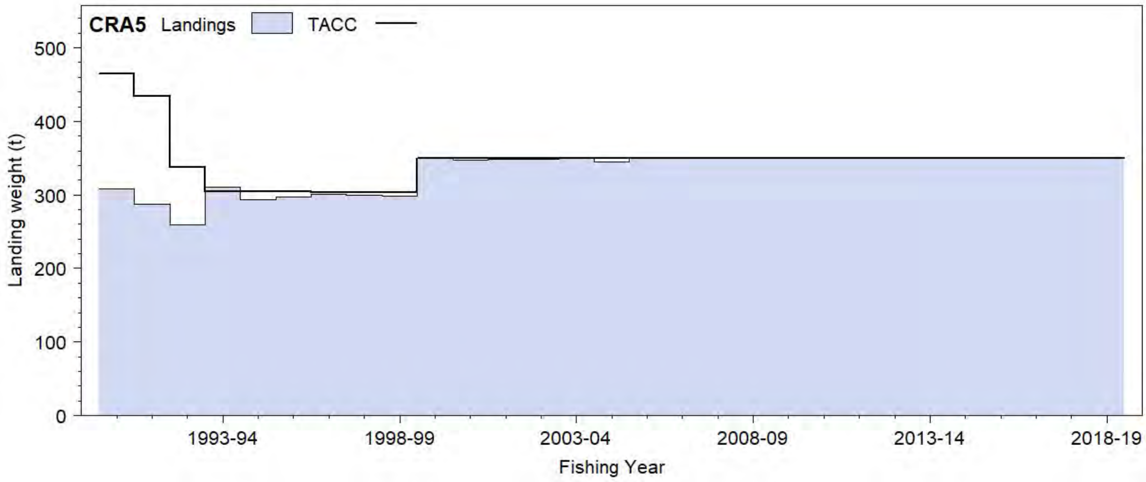
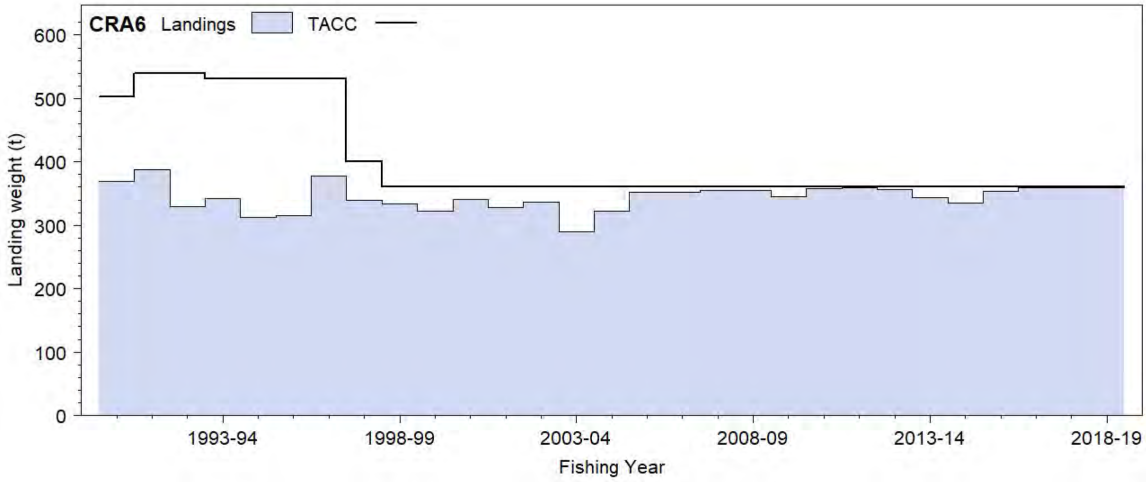


Figure 1: Historical landings and TACC for the nine main CRA stocks and PHC 1. [Continued on next page]





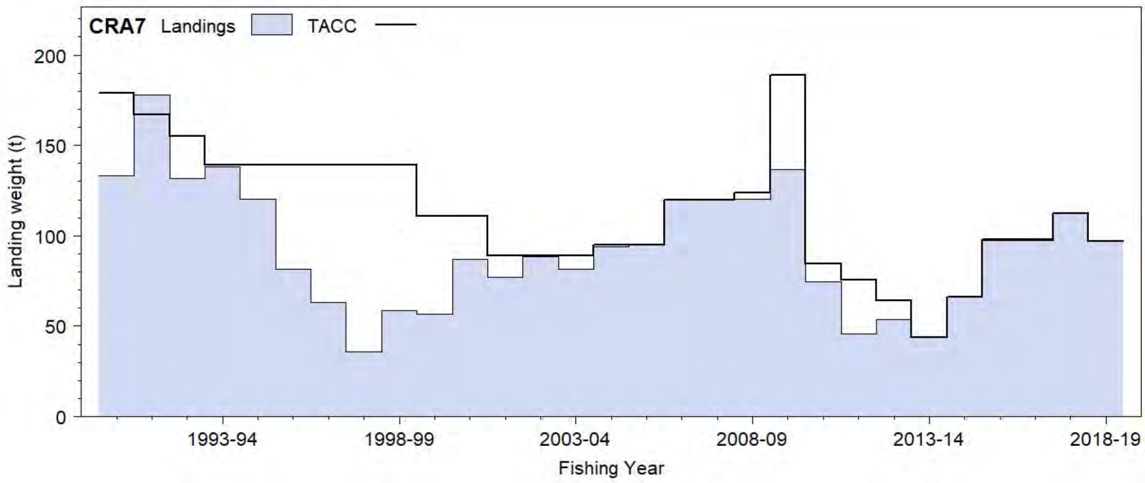


Figure 1: Historical landings and TACC for the nine main CRA stocks and PHC 1. **[Continued on next page]**

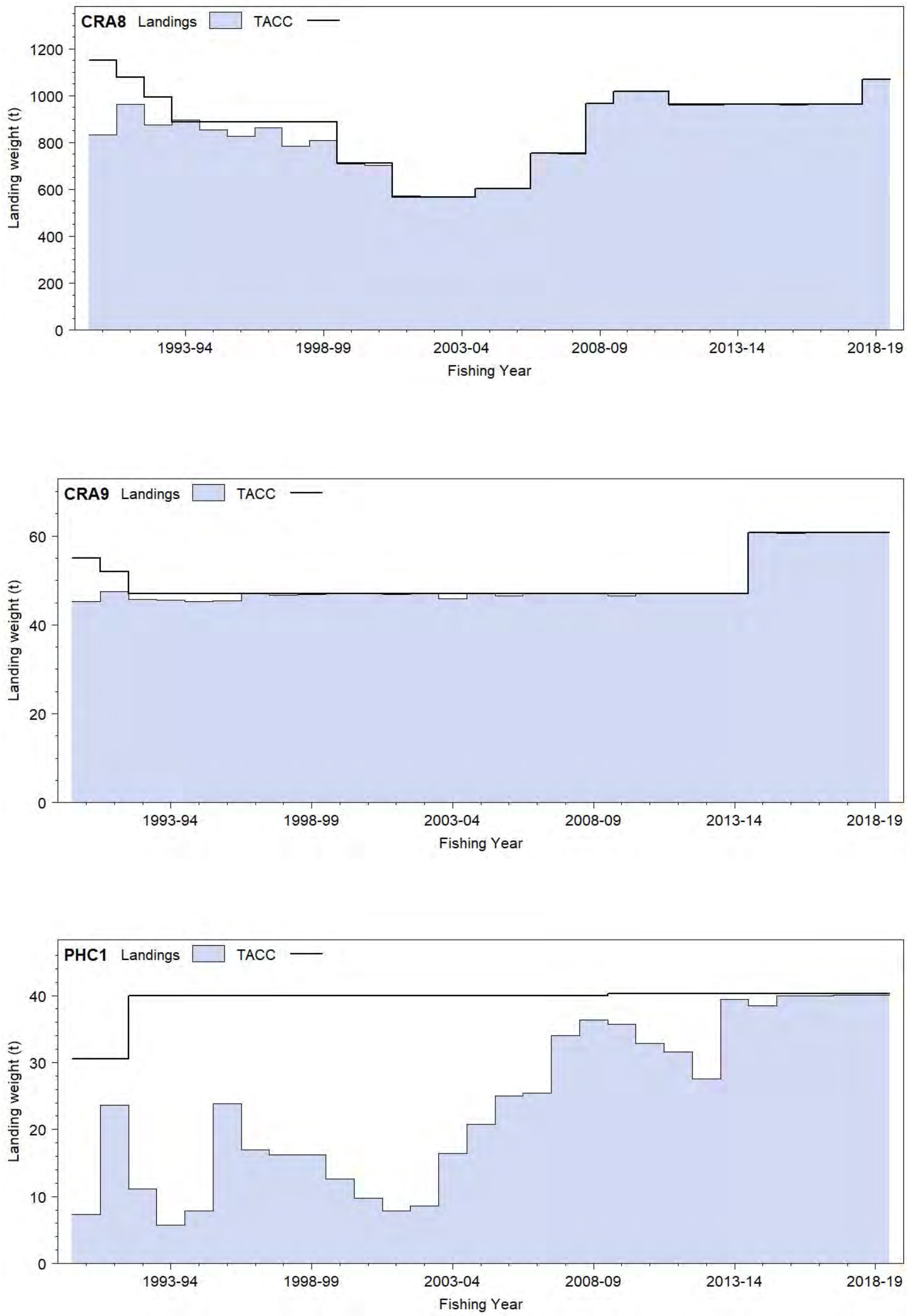


Figure 1: Historical landings and TACC for the nine main CRA stocks and PHC 1.

2.1 Commercial fisheries

Table 1 provides a summary by fishing year of the reported commercial catches, TACCs, and TACs by Fishstock (CRA). The Quota Management Reports (QMRs) and their replacement Monthly Harvest Reports (MHRs; since 1 October 2001) provide the most accurate information on landings. Other sources of annual catch estimates include the Licensed Fish Receiver Returns (LFRRs) and the Catch, Effort, and Landing Returns (CELRs).

Table 1: Reported commercial catch (t) from QMRs or MHRs (after 1 October 2001), commercial TACC (t) and total TAC (t) (where this quantity has been set) for *Jasus edwardsii* by rock lobster QMA for each fishing year since the species was included in the QMS on 1 April 1990. –, TAC not set for QMA or catch not available (current fishing year). [Continued on next page]

	CRA 1			CRA 2			CRA 3			CRA 4		
Fishing year	**Catch**	**TACC**	**TAC**	**Catch**	**TACC**	**TAC**	**Catch**	**TACC**	**TAC**	**Catch**	**TACC**	**TAC**
1990–91	131.1	160.1	–	237.6	249.5	–	324.1	437.1	–	523.2	576.3	–
1991–92	128.3	157.0	–	229.7	241.3	–	268.8	411.9	–	530.5	545.7	–
1992–93	110.5	138.0	–	190.3	216.6	–	191.5	330.9	–	495.7	506.7	–
1993–94	127.4	130.5	–	214.9	214.6	–	179.5	163.9	–	492.0	495.7	–
1994–95	130.0	130.5	–	212.8	214.6	–	160.7	163.9	–	490.4	495.7	–
1995–96	126.7	130.5	–	212.5	214.6	–	156.9	163.9	–	487.2	495.7	–
1996–97	129.4	130.5	–	213.2	214.6	–	203.5	204.9	–	493.6	495.7	–
1997–98	129.3	130.5	–	234.4	236.1	452.6	223.4	224.9	379.4	490.4	495.7	–
1998–99	128.7	130.5	–	232.3	236.1	452.6	325.7	327.0	453.0	493.3	495.7	–
1999–00	125.7	131.1	–	235.1	236.1	452.6	326.1	327.0	453.0	576.5	577.0	771.0
2000–01	130.9	131.1	–	235.4	236.1	452.6	328.1	327.0	453.0	573.8	577.0	771.0
2001–02	130.6	131.1	–	225.0	236.1	452.6	289.9	327.0	453.0	574.1	577.0	771.0
2002–03	130.8	131.1	–	205.7	236.1	452.6	291.3	327.0	453.0	575.7	577.0	771.0
2003–04	128.7	131.1	–	196.0	236.1	452.6	215.9	327.0	453.0	575.7	577.0	771.0
2004–05	130.8	131.1	–	197.3	236.1	452.6	162.0	327.0	453.0	569.9	577.0	771.0
2005–06	130.5	131.1	–	225.2	236.1	452.6	170.1	190.0	319.0	504.1	577.0	771.0
2006–07	130.8	131.1	–	226.5	236.1	452.6	178.7	190.0	319.0	444.6	577.0	771.0
2007–08	129.8	131.1	–	229.7	236.1	452.6	172.4	190.0	319.0	315.2	577.0	771.0
2008–09	131.0	131.1	–	232.3	236.1	452.6	189.8	190.0	319.0	249.4	577.0	771.0
2009–10	130.9	131.1	–	235.2	236.1	452.6	164.0	164.0	293.0	262.2	266.0	461.0
2010–11	130.8	131.1	–	224.8	236.1	452.6	163.7	164.0	293.0	414.8	415.6	610.6
2011–12	130.4	131.1	–	229.0	236.1	452.6	163.9	164.0	293.0	466.2	466.9	661.9
2012–13	130.9	131.1	–	234.3	236.1	452.6	193.3	193.3	322.3	466.3	466.9	661.9
2013–14	130.3	131.1	–	235.7	236.1	452.6	225.5	225.5	354.5	499.4	499.7	694.7
2014–15	130.2	131.1	–	198.6	200.0	416.5	260.4	261.0	390.0	465.5	467.0	662.0
2015–16	129.4	131.1	273.1	174.7	200.0	416.5	260.8	261.0	390.0	438.1	467.0	662.0
2016–17	130.6	131.1	273.1	142.5	200.0	416.5	260.9	261.0	390.0	382.9	397.0	592.0
2017–18	124.3	131.1	273.1	142.8	200.0	416.5	237.7	237.9	366.9	289.0	289.0	484.0
2018–19	130.6	131.1	273.1	78.1	80.0	173.0	240.0	237.9	366.9	318.4	318.8	513.8
2019–20	–	131.1	273.1	–	80.0	173.0	–	222.9	351.9	–	318.8	513.8

	CRA 5			CRA 6			CRA 7			CRA 8		
Fishing year	**Catch**	**TACC**	**TAC**	**Catch**	**TACC**	**TAC**	**Catch**	**TACC**	**TAC**	**Catch**	**TACC**	**TAC**
1990–91	308.6	465.2	–	369.7	503.0	–	133.4	179.4	–	834.5	1 152.4	–
1991–92	287.4	433.7	–	388.3	539.6	–	177.7	166.8	–	962.7	1 077.0	–
1992–93	258.8	337.7	–	329.4	539.6	–	131.6	154.5	–	876.5	993.7	–
1993–94	311.0	303.7	–	341.8	530.6	–	138.1	138.9	–	896.1	888.1	–
1994–95	293.9	303.7	–	312.5	530.6	–	120.3	138.9	–	855.6	888.1	–
1995–96	297.6	303.7	–	315.3	530.6	–	81.3	138.9	–	825.6	888.1	–
1996–97	300.3	303.2	–	378.3	530.6	–	62.9	138.7	–	862.4	888.1	–
1997–98	299.6	303.2	–	338.7	400.0	480.0	36.0	138.7	–	785.6	888.1	–
1998–99	298.2	303.2	–	334.2	360.0	370.0	58.6	138.7	–	808.1	888.1	–
1999–00	349.5	350.0	467.0	322.4	360.0	370.0	56.5	111.0	131.0	709.8	711.0	798.0
2000–01	347.4	350.0	467.0	342.7	360.0	370.0	87.2	111.0	131.0	703.4	711.0	798.0
2001–02	349.1	350.0	467.0	328.7	360.0	370.0	76.9	89.0	109.0	572.1	568.0	655.0
2002–03	348.7	350.0	467.0	336.3	360.0	370.0	88.6	89.0	109.0	567.1	568.0	655.0
2003–04	349.9	350.0	467.0	290.4	360.0	370.0	81.4	89.0	109.0	567.6	568.0	655.0
2004–05	345.1	350.0	467.0	323.0	360.0	370.0	94.2	94.9	114.9	603.0	603.4	690.4
2005–06	349.5	350.0	467.0	351.7	360.0	370.0	95.0	94.9	114.9	603.2	603.4	690.4

	CRA 1			CRA 2			CRA 3			CRA 4		
Fishing year	Catch	TACC	TAC	Catch	TACC	TAC	Catch	TACC	TAC	Catch	TACC	TAC
2006–07	349.8	350.0	467.0	352.1	360.0	370.0	120.2	120.2	140.2	754.9	755.2	842.2
2007–08	349.8	350.0	467.0	356.0	360.0	370.0	120.1	120.2	140.2	752.4	755.2	842.2
2008–09	349.7	350.0	467.0	355.3	360.0	370.0	120.3	123.9	143.9	966.0	966.0	1 053.0
2009–10	349.9	350.0	467.0	345.2	360.0	370.0	136.5	189.0	209.0	1 018.3	1 019.0	1 110.0
2010–11	350.0	350.0	467.0	357.4	360.0	370.0	74.8	84.5	104.5	1 018.3	1 019.0	1 110.0
2011–12	350.0	350.0	467.0	359.7	360.0	370.0	45.7	75.7	95.7	961.2	962.0	1 053.0
2012–13	350.0	350.0	467.0	355.9	360.0	370.0	53.8	63.9	83.9	960.8	962.0	1 053.0
2013–14	350.0	350.0	467.0	343.6	360.0	370.0	44.0	44.0	64.0	964.6	962.0	1 053.0
2014–15	349.2	350.0	467.0	334.5	360.0	370.0	66.0	66.0	86.0	962.0	962.0	1 053.0
2015–16	350.1	350.0	467.0	353.3	360.0	370.0	97.6	97.7	117.7	961.8	962.0	1 053.0
2016–17	350.0	350.0	514.0	359.5	360.0	370.0	97.6	97.7	117.7	961.9	962.0	1 053.0
2017–18	350.0	350.0	514.0	359.1	360.0	370.0	112.7	112.5	132.5	961.9	962.0	1 053.0
2018–19	349.9	350.0	514.0	359.9	360.0	370.0	97.0	97.0	117.0	1 070.6	1 070.7	1 161.7
2019–20	–	350.0	514.0	–	360.0	370.0	–	97.0	117.0	–	1 129.6	1 220.6

	CRA 9			Total		
Fishing year	Catch	TACC	TAC	Catch[1]	TACC[1]	TAC[1]
1990–91	45.3	54.7	–	2 907.4	3 777.8	–
1991–92	47.5	51.5	–	3 020.9	3 624.5	–
1992–93	45.7	47.1	–	2 629.9	3 264.9	–
1993–94	45.5	47.0	–	2 746.2	2 913.0	–
1994–95	45.2	47.0	–	2 621.5	2 913.0	–
1995–96	45.4	47.0	–	2 548.6	2 913.0	–
1996–97	46.9	47.0	–	2 690.5	2 953.3	–
1997–98	46.7	47.0	–	2 584.2	2 864.1	1 312.0
1998–99	46.9	47.0	–	2 726.0	2 926.2	1 275.6
1999–00	47.0	47.0	–	2 748.5	2 850.2	3 442.6
2000–01	47.0	47.0	–	2 795.9	2 850.2	3 442.6
2001–02	46.8	47.0	–	2 593.0	2 685.2	3 277.6
2002–03	47.0	47.0	–	2 591.1	2 685.2	3 277.6
2003–04	45.9	47.0	–	2 451.5	2 685.2	3 277.6
2004–05	47.0	47.0	–	2 472.3	2 726.4	3 318.8
2005–06	46.6	47.0	–	2 475.8	2 589.4	3 184.8
2006–07	47.0	47.0	–	2 604.6	2 766.6	3 362.0
2007–08	47.0	47.0	–	2 472.5	2 766.6	3 362.0
2008–09	47.0	47.0	–	2 640.7	2 981.0	3 576.5
2009–10	46.6	47.0	–	2 688.8	2 762.2	3 362.6
2010–11	47.0	47.0	–	2 781.7	2 807.3	3 407.7
2011–12	47.0	47.0	–	2 753.0	2 792.8	3 393.2
2012–13	47.0	47.0	–	2 792.2	2 810.3	3 410.7
2013–14	47.1	47.0	–	2 840.1	2 855.4	3 455.8
2014–15	60.8	60.8	115.8	2 827.2	2 857.8	3 560.3
2015–16	60.6	60.8	115.8	2 826.5	2 889.5	3 865.0
2016–17	60.8	60.8	115.8	2 746.7	2 819.5	3 842.0
2017–18	60.7	60.8	115.8	2 638.1	2 703.2	3 725.7
2018–19	60.8	60.8	115.8	2 726.9	2 706.2	3 605.2
2019–20	–	60.8	115.8	–	2 750.2	3 649.2

[1]ACE was shelved voluntarily by the CRA 4 Industry: to 340 t in 2007–08 and 250 t in 2008–09

Table 2: Reported standardised CPUE (kg/potlift) (Starr 2019) for *Jasus edwardsii* by QMA from 1979–80 to 2018–19. Sources of data: from 1979–80 to 1988–89 from the QMS-held FSU data; from 1989–90 to 2018–19 from the CELR data held by Fisheries New Zealand, using the 'F2' algorithm corrected for 'LFX' destination code landings (see text for definition). The CRA 1, CRA 2, CRA 3 and CRA 6 series beginning from 1989–90 have been estimated using a vessel explanatory variable constrained to vessels with at least five years in the fishery. The analyses for all other QMAs and the FSU period 1979–88 to 1988–89 for CRA 1, CRA 2, CRA 3 and CRA 6 do not use a vessel explanatory variable. '–': no data. [Continued on next page]

Fishing year	CRA 1	CRA 2	CRA 3	CRA 4	CRA 5	CRA 6	CRA 7	CRA 8	CRA 9
1979–80	0.825	0.522	0.769	0.826	0.598	2.182	0.958	1.947	1.257
1980–81	0.992	0.628	0.853	0.801	0.727	2.013	0.843	1.695	1.364

Fishing year	CRA 1	CRA 2	CRA 3	CRA 4	CRA 5	CRA 6	CRA 7	CRA 8	CRA 9
1981–82	0.929	0.523	0.842	0.859	0.650	2.292	0.717	1.632	1.036
1982–83	1.004	0.436	0.910	0.924	0.717	1.659	0.462	1.395	0.867
1983–84	0.955	0.357	0.832	0.839	0.642	1.630	0.400	1.051	0.893
1984–85	0.887	0.345	0.673	0.761	0.650	1.300	0.536	1.017	0.851
1985–86	0.829	0.400	0.643	0.727	0.533	1.370	0.714	1.204	0.754
1986–87	0.810	0.361	0.558	0.773	0.469	1.500	0.816	1.069	0.874
1987–88	0.755	0.315	0.397	0.675	0.392	1.320	0.689	1.124	0.888
1988–89	0.664	0.343	0.408	0.569	0.342	1.269	0.404	0.843	0.883
1989–90	0.922	0.677	0.522	0.560	0.348	1.304	0.331	0.829	–
1990–91	0.894	0.564	0.442	0.516	0.352	1.388	0.420	0.802	0.828
1991–92	0.884	0.508	0.321	0.519	0.295	1.315	0.972	0.787	0.868
1992–93	0.797	0.453	0.250	0.498	0.285	1.207	0.391	0.667	0.942
1993–94	0.837	0.516	0.492	0.545	0.328	1.095	0.617	0.890	1.180
1994–95	0.992	0.625	0.923	0.695	0.355	1.049	0.453	0.793	0.946
1995–96	1.312	0.847	1.524	0.918	0.398	1.078	0.289	0.855	1.363
1996–97	1.219	1.030	1.818	1.234	0.519	1.097	0.245	0.800	1.156
1997–98	1.252	1.145	2.271	1.439	0.725	1.095	0.176	0.684	1.075
1998–99	1.243	1.173	1.885	1.637	0.855	1.268	0.255	0.688	1.422
1999–00	1.028	0.891	1.792	1.476	0.933	1.252	0.224	0.745	0.965
2000–01	1.228	0.748	1.307	1.383	1.198	1.186	0.340	0.905	1.202
2001–02	1.236	0.526	0.987	1.182	1.396	1.151	0.497	0.983	1.145
2002–03	1.157	0.395	0.645	1.216	1.570	1.260	0.600	1.147	1.491
2003–04	1.163	0.396	0.513	1.250	1.761	1.198	0.593	1.712	1.734
2004–05	1.172	0.468	0.423	0.953	1.351	1.340	0.878	1.880	2.152
2005–06	1.038	0.437	0.543	0.817	1.364	1.418	1.276	2.296	2.101
2006–07	1.038	0.519	0.538	0.673	1.401	1.634	1.750	2.784	2.185
2007–08	1.362	0.493	0.571	0.587	1.443	1.418	1.548	3.047	1.771
2008–09	1.255	0.465	0.624	0.742	1.661	1.538	1.781	4.094	1.323
2009–10	1.376	0.424	0.821	1.036	2.105	1.352	1.081	3.923	1.584
2010–11	1.144	0.377	1.114	1.035	2.046	1.438	0.801	3.220	2.315
2011–12	1.047	0.347	1.642	1.255	1.904	1.436	0.685	3.169	1.988
2012–13	1.284	0.367	2.314	1.406	1.776	1.450	0.678	3.304	2.955
2013–14	1.251	0.336	2.141	1.199	1.644	1.416	2.054	3.405	2.209
2014–15	1.182	0.299	1.967	1.048	1.797	1.343	2.088	3.236	2.319
2015–16	1.139	0.247	1.699	0.752	1.570	1.341	2.052	3.477	1.972
2016–17	1.166	0.258	1.695	0.653	1.739	1.706	2.774	3.811	1.953
2017–18	1.296	0.246	1.482	0.828	1.933	1.767	2.097	5.028	2.156
2018–19	1.394	0.380	1.298	0.904	1.720	2.027	2.958	5.163	1.961

2.1.1 Problems with rock lobster commercial catch and effort data

There are two types of data on the Catch Effort Landing Return (CELR) form: the top part of each form contains the fishing effort and an estimated catch associated with that effort. The bottom part of the form contains the landed catch and other destination codes, which may span several records of effort. Estimated catches from the top part of the CELR form often show large differences from the catch totals on the bottom part of the form, particularly in CRA 5 and CRA 8 (Vignaux & Kendrick 1998, Bentley et al. 2005b). Substantial discrepancies were identified in 1997 between the estimated and weighed catches in CRA 5 (Vignaux & Kendrick 1998) and were attributed to fishers including all rock lobster catch in the estimated total, including those returned to the sea by regulation. This led to an overestimate of CPUE, but this problem appeared to be confined to CRA 5, and was remedied by providing additional instruction to fishers on how to properly complete the forms.

After 1998, all CELR catch data used in stock assessments have been modified to reflect the landed catch (bottom of form) rather than the estimated catch (top of form). This resulted in changes to the CPUE values compared to those reported before 1998.

In 2003, it was concluded that the method used to correct estimated to landed catch (‘Method C1’, Bentley et al. 2005b) was biased because it dropped trips with no reported landings, leading to estimates of CPUE that were too high. In some areas, this bias was getting worse because of an increasing trend of passing catches through holding pots to maximise the value of the catch. The catch/effort data system operated by Fisheries New Zealand does not maintain the link between catch derived from the effort expended on a trip with the landings recorded from the trip. Therefore, catches from previous trips, held in holding pots, can be combined with landings from the active trip.

Beginning in 2003, the catch and effort data used in these analyses were calculated using a revised procedure described as ‘Method B4’ in Bentley et al. (2005b). This procedure sums all landings and effort for a vessel within a calendar month and allocates the landings to statistical areas based on the reported area distribution of the estimated catches. The method assumes that landings from holding pots tend to balance out at the level of a month. In the instances where there are vessel/month combinations with no landings, the method drops all data for the vessel in the month with zero landings and in the following month, with the intent of excluding uncertain data in preference to incorrectly reallocating landings.

In 2012, the RLFAWG agreed to change from method ‘B4’ to method ‘F2’, a new procedure designed to correct estimated catch data to reflect landings. The new procedure is thought to better represent the estimation/landing process and should be more robust to data errors and other uncertainties. The ‘F2’ method uses annual estimates, by vessel, of the ratio of landed catch divided by estimated catch to correct every estimated catch record in a QMA for the vessel for that year. Vessel-year combinations are removed entirely from the analysis when the ratio is less than 0.8 (overestimates of landed catch) or greater than 1.2 (underestimates of landed catch). Testing of the ‘F2’ method was undertaken to establish that CPUE series based on the new procedure did not differ substantially from previous series. In general, the differences tended to be minor for most QMAs, with the exception of CRA 1 and CRA 9, where there were greater differences (Starr 2014). Additional work completed in June 2013 determined that the problems with the CRA 9 standardised CPUE analysis could be resolved if vessels that had landed less than 1 t in a year were excluded from the analysis (Breen 2014). Consequently, the standardised CPUE analyses reported in Table 2 use the F2 algorithm, scaled to the combined ‘L’, ‘F’ and ‘X’ landings (see following paragraph). This now includes CRA 5, which previously used the ‘B4’ algorithm because of the poor reporting practices used in the 1990s (Vignaux & Kendrick 1998). CRA 5 was switched to the ‘F2’ algorithm as part of a 2015 stock assessment, to align it with the other QMAs and because the two algorithms estimate nearly identical CPUE indices before 2005.

The data used to calculate the standardised (Table 2) and geometric (Table 4) CPUE estimates have been subjected to error screening (Bentley et al. 2005b) and the estimated catches have been scaled using the F2 algorithm to the combined landings made to Licensed Fish Receivers (destination code ‘L’), Section 111 landings for personal use (destination code ‘F’), and legal discards (destination code ‘X’). The RLFAWG accepted the use of these additional destination codes because of the increasing practice of discarding legal lobsters with the overall increase in abundance. The estimates of CPUE would be biased if discarded legal fish were not included in the analysis. The reporting of releases using destination code ‘X’ became mandatory on 1 April 2009, so this correction was not available before that date.

Methods for calculating the standardised CPUE estimates up to the 2017 CRA 2 stock assessment are documented in Starr (2019). The 2018 CRA 6 stock assessment (Starr et al. 2019) and the 2019 CRA 1 and CRA 3 stock assessments (Starr et al. in prep) used a Bayesian GLM procedure to derive a CPUE series that better represents analysis uncertainty but returns a similar overall series trend. Note that the standardised indices presented in Table 2 were calculated using maximum likelihood (Starr 2019) rather than the Bayesian procedure applied in the stock assessments.

The 2017 CRA 2 stock assessment determined that a better fit to the CPUE and length-frequency data could be obtained if an additional parameter (‘*qdrift*’) describing a multiplicative increasing CPUE ‘efficiency’ was added to the model. However, the benefit from this additional parameter disappeared when the standardisation model added a vessel explanatory variable. This variable allowed the model to standardise for efficiency changes in the fleet configuration because vessels with lower CPUE coefficients appeared to leave the fishery from the late 1990s, resulting in higher unstandardised CPUE.

Since 2017, a vessel explanatory factor has been added to the CPUE analyses used in the stock assessments and the stock assessment team has determined that adding a vessel explanatory factor will be the default approach, along with applying a ‘*qdrift*’ parameter.

The CRA 1, CRA 2, CRA 3 and CRA 6 CPUE values in Table 2, beginning in 1989–90, have been standardised for a vessel effect, using vessels that had been in the fishery for at least five years. A vessel explanatory factor had not been previously used in the standardisation procedure because vessel coefficients were not consistently coded between the CELR and FSU datasets and a single '*q*' parameter was used to link the two series. The inconsistencies in vessel coefficients stopped being an issue because the 2017 CRA 2 and subsequent stock assessments have all estimated separate catchability parameters (*q*) for the FSU and CELR data, allowing for a CELR dataset standardisation model that included a vessel effect.

2.1.2 Description of fisheries

***Jasus edwardsii*, CRA 1 and CRA 2**
CRA 1 extends from Kaipara Harbour on the west coast to Te Arai Point, south of Whangarei (Figure 2). This QMA includes the Three Kings Islands, designated with a separate statistical area (901). Commercial fishing occurs on both sides of the North Island peninsula, as well as at the Three Kings.

A TAC was set for CRA 1 for the first time in 2015, even though the CRA 1 stakeholders elected to maintain the TACC at its original level (Table 1). Commercial landings have remained at or near the 131 t TACC since the early 1990s (Table 1). In the 2017–18 fishing year, there were 12 vessels operating in CRA 1, a total that has remained nearly unchanged since the mid-2000s (Starr 2019).

CRA 2 extends from Te Arai Point, south of Whangarei, to East Cape at the easternmost end of the Bay of Plenty. This QMA includes the Hauraki Gulf, both sides of the Coromandel peninsula, and the Bay of Plenty. Commercial fishing is mainly confined to the Bay of Plenty, extending from the eastern side of the Coromandel peninsula to East Cape. Lobster potting also occurs around Little and Great Barrier Islands. There were 29 vessels operating in CRA 2 in 2017–18, the same as in 2016–17 and a drop from 33 vessels in 2015–16 (Starr 2019). Previous to these fishing years, between 31 and 39 vessels fished in CRA 2 from the late 1990s (Starr 2018). This fishery supports processing and export operations primarily in Tauranga, Whitianga, and Auckland. The TAC was reduced on 1 April 2018 from 416.5 t to 173.1 t in response to poor abundance and estimated low recruitments. The new TAC comprises an 80 t TACC, 34 t for recreational catch, 16.5 t for customary harvest, and 42.5t for illegal removals. The CRA 2 industry voluntarily shelved 25 t of the 200 t TACC in 2015–16 even though the operation of the Rule 4 MP did not require a TACC reduction. The amount of shelving was increased to 49 t in 2016–17 and 2017–18.

CPUE levels in CRA 1 and CRA 2 differ: CRA 1 has always had higher catch rates than CRA 2, even in the 1980s when catch rates were generally lower. CPUE in CRA 1 has ranged between 1.0 and nearly 1.4 kg/potlift since the mid-1990s. CPUE in the three years between 2014–15 to 2016–17 was below 1.2 kg/potlift but has since risen to 1.4 kg/potlift in 2018–19, the highest CPUE in the last 30 years (Table 2). CRA 2 CPUE had been below 0.6 kg/potlift from 2001–02, dropping to below 0.4 kg/potlift in 2010–11 and below 0.3 kg/potlift in 2014–15, where it remained until 2018–19, when it rose by 50% to nearly 0.4 kg/potlift (Table 2). CRA 2 has the lowest average CPUE (calculated from 1989–90 in terms of kg/potlift) among the nine CRA QMAs.

***Jasus edwardsii*, CRA 3, CRA 4 and CRA 5**
CRA 3 extends from East Cape, around the Mahia peninsula, to the Wairoa River (Figure 2). Commercial fishing occurs throughout this QMA. TACs and TACCs have been set for this QMA seven times since 2000–01, with the most recent change for the upcoming 2019–20 fishing year (Table 1). Twenty-five vessels caught at least 1 t of rock lobster in 2017–18 and the number of commercial vessels operating in CRA 3 has been below 30 since 2005–06 (Starr 2019). The CRA 3 TACC was lowered to

238 t from 261 t for the 2017–18 fishing year and again to 223 t for the 2019–20 fishing year through the operation of the CRA 3 MP (Table 1).

The CRA 4 fishery extends from the Wairoa River in northern Hawke's Bay, southwards through Hawke's Bay, the Wairarapa and the Wellington coasts, then passing north to the Manawatu River on the Kapiti coast. For 2016–17 the TACC was set at 397 t, lower than that specified by the management procedure. Allowances of 35 t were made for customary fishing; 85 t for recreational and 75 t for illegal removals. Although the CRA 4 TACC was dropped from 397 t to 289 t for the 2017–18 fishing year through the operation of a new CRA 4 MP resulting from the 2016 stock assessment, the operation of the same MP in 2017 resulted in an increase in the TACC to 319 t for the 2018–19 fishing year. The MP-recommended increase from 319 t to 380 t for 2019–20 was rejected by the Minister.

The CRA 5 fishery extends from the western side of the Marlborough Sounds across to Cape Jackson and then southwards to the Banks Peninsula. There are three distinct regions of commercial fishing – Picton/Port Underwood, Ward-Kaikoura-Motunau, and Banks Peninsula, although a small number of commercial vessels work the area from Nelson through to D'Urville Island. The bulk of the commercial catch is taken from the area bounded by Tory Channel in the north and Motunau in the south. The CRA 5 fishery was impacted by the November 2016 earthquake which restricted fisher access to the productive Cape Campbell region and is thought to have reduced catch rates in the Kaikoura region.

The CRA 5 TAC was set at 514 t, with a TACC of 350 t and allowances of 40 t for customary catch, 87 t for recreational and 37 t for other mortalities since 2016–17 (Table 1). The CRA 5 TACC has been unchanged at 350 t since 1999–2000 (Table 1).

CPUE trends have differed among these three QMAs, with CRA 3 CPUE peaking in 1997–98, CRA 4 in 1998–99, and CRA 5 in 2009–10 (Table 2). However, these QMAs all show approximately the same pattern: low CPUEs in the 1980s (below 1 kg/potlift) followed by a strong rise in CPUE beginning in the early 1990s (first in CRA 3, followed closely by CRA 4, and finally by CRA 5 in the late 1990s). CRA 3 and CRA 4 dropped from their respective peaks in the late 1990s to lows in the mid-2000s followed by a rising trend to 2012–13 in both QMAs. CPUE in CRA 3 and CRA 4 dropped in each year after the 2012–13 peak up to 2016–17. CRA 4 made a recovery in 2017–18 and again in 2018–19 while CRA 3 continued to decline, with CRA 3 having dropped 44% from the 2012–13 peak by 2018–19 and CRA 4 having dropped by 36% from the same peak by 2018–19. CRA 5, unlike CRA 3 and CRA 4, while having dropped from the last peak in 2009–10, has shown a relatively flat trend since 2011–12, varying between 1.6–1.9 kg/potlift.

Jasus edwardsii, CRA 6

The region designated as CRA 6 is geographically large, being all waters within a 200 nautical mile radius of the Chatham Islands and Bounty Islands, but the area being fished is restricted to a relatively narrow coastal margin adjacent to the Chatham Islands coastline. The TAC (at 370 t) and the TACC (at 360 t) have remained unchanged since 1998–99 (Table 1). Mean annual CPUE in the Chatham Island fishery was higher than in the other New Zealand QMAs in the 1980s (Table 2). However, CPUE declined after the mid-1980s to levels more similar to those observed in other QMAs (Table 2). CPUE has fluctuated around 1.2 and 1.6 kg/potlift since 2001–02, with the 2018–19 CPUE, at 2.0 kg/potlift, being the highest value since 1989–90.

Jasus edwardsii, CRA 7 and CRA 8

The CRA 7 fishery extends from the Waitaki River south along the Otago coastline to Long Point. The TACC has been set by the operation of a management procedure that was first implemented in 2013. The 2019–20 CRA 7 TAC is 117 t, with allowances of 10 t for customary catch, 5 t for recreational catch, 5 t for illegal removals, and a TACC of 97 t. The TACC was raised for the 2015–16 and 2017–18 fishing years and then dropped for the 2018–19 fishing year through the operation of the CRA 7 MP. The CRA 7 commercial fishery operates with an MLS of 127 mm tail length for both males and females (equivalent to 47 mm TW for males and 48 mm TW for females). The fishery is open to recreational fishing with MLS 54 mm TW for males and 60 mm TW for females.

The CRA 8 fishery is the largest South Island fishery geographically, extending from Long Point south to Stewart Island and the Snares, the islands and coastline of Foveaux Strait, and then northwards along the Fiordland coastline to Bruce Bay. From 1996 to the present, the TAC has been controlled by management procedures and the TACC has been fully caught from 1998 onwards. The TAC was raised, through the operation of the MP in 2018–19, to 1162 t with a TACC of 1071 t and allowances of 30 t for customary, 33 t for recreational, and 28 t for other mortalities. The TACC was raised again in 2019–20 by the MP to 1130 t, increasing the TAC to 1221 t and leaving the remaining allowances unchanged.

Catch rates were generally lower in CRA 7 compared with those in CRA 8, with CPUE in CRA 7 being stable but low (often below 0.5 kg/potlift) until the early 2000s, while CRA 8 showed a similar pattern, but at a higher level (Table 2). Both QMAs then showed spectacular increases in CPUE, peaking in 2006–07 near 1.8 kg/potlift in CRA 7 and rising to more than 4 kg/potlift in CRA 8 in 2008–09. CRA 7 dropped to levels below 1 kg/potlift between 2010–11 and 2012–13, but has since risen to nearly 3.0 kg/potlift in 2018–19, which is the highest level observed in CRA 7 since the beginning of the series. CRA 8 dropped proportionately less than CRA 7 to just above 3.1 kg/potlift in 2011–12, but has since risen to over 5.0 kg/potlift in 2017–18 and 2018–19. These are the highest observed CPUE in any of the rock lobster QMAs over the 40 years on record (Table 2).

Jasus edwardsii, CRA 9

The CRA 9 fishery is geographically large but has the smallest TACC of any region (with the exception of CRA 10, which is not commercially fished). The fishery extends from north of Bruce Bay to the Kaipara Harbour but commercial lobster fishing is constrained to the north-west coast of the South Island and the area between Patea and Kawhia, on the Taranaki coastline.

Mean annual CPUE was at or less than 1 kg/potlift from 1981–82 to 1994–95, followed by a strong increase that peaked between 2004–05 and 2006–07, again in 2010–11 and at the highest level in the series (just below 3.0 kg/potlift) in 2012–13. CPUE has exceeded 1.9 kg/potlift in 12 of the 15 years since 2004–05 when it first exceeded 2.0 kg/potlift. In recent years the low numbers of vessels fishing, poor reporting, and the large size of the area have led to rejection of CRA 9 CPUE as an index of abundance in CRA 9.

Sagmariasus verreauxi, PHC stock

The packhorse rock lobster QMA includes all of New Zealand. QMS reported landings of the PHC stock more than halved between 1998–99 and 2001–02 and were below 30 t/year up to 2007–08 (Table 3). Landings have since exceeded 30 t/year, except for 2012–13, when 27.5 t were reported. Subsequent landings have been close to the TACC.

Table 3: Reported landings and TACC for *Sagmariasus verreauxi* (PHC) from 1990–91 to 2018–19. Data from QMR or MHR (after 1 Oct 2001).

Fishing year	Landings (t)	TACC (t)	Fishing year	Landings (t)	TACC (t)
1990–91	7.4	30.5[1]	2005–06	25.0	40.3
1991–92	23.6	30.5	2006–07	25.4	40.3
1992–93	11.1	40.3	2007–08	34.0	40.3
1993–94	5.7	40.3	2008–09	36.4	40.3
1994–95	7.9	40.3	2009–10	35.7	40.3
1995–96	23.8	40.3	2010–11	32.8	40.3
1996–97	16.9	40.3	2011–12	31.6	40.3
1997–98	16.2	40.3	2012–13	27.5	40.3
1998–99	16.2	40.3	2013–14	39.4	40.3
1999–00	12.6	40.3	2014–15	38.5	40.3
2000–01	9.8	40.3	2015–16	39.9	40.3
2001–02	3.4	40.3	2016–17	40.0	40.3
2002–03	8.6	40.3	2017–18	40.1	40.3
2003–04	16.4	40.3	2018–19	40.1	40.3
2004–05	20.8	40.3			

1 Entered QMS at 27 t in 1990–91, but raised immediately to 30.5 t in first year of operation due to quota appeals.

Jasus edwardsii CPUE by statistical area

Table 4 shows geometric mean statistical area CPUEs for the most recent six years, for all rock lobster statistical areas reported on CELR forms (Figure 2). The values of CPUE and the trends in the fisheries vary within and between CRA areas.

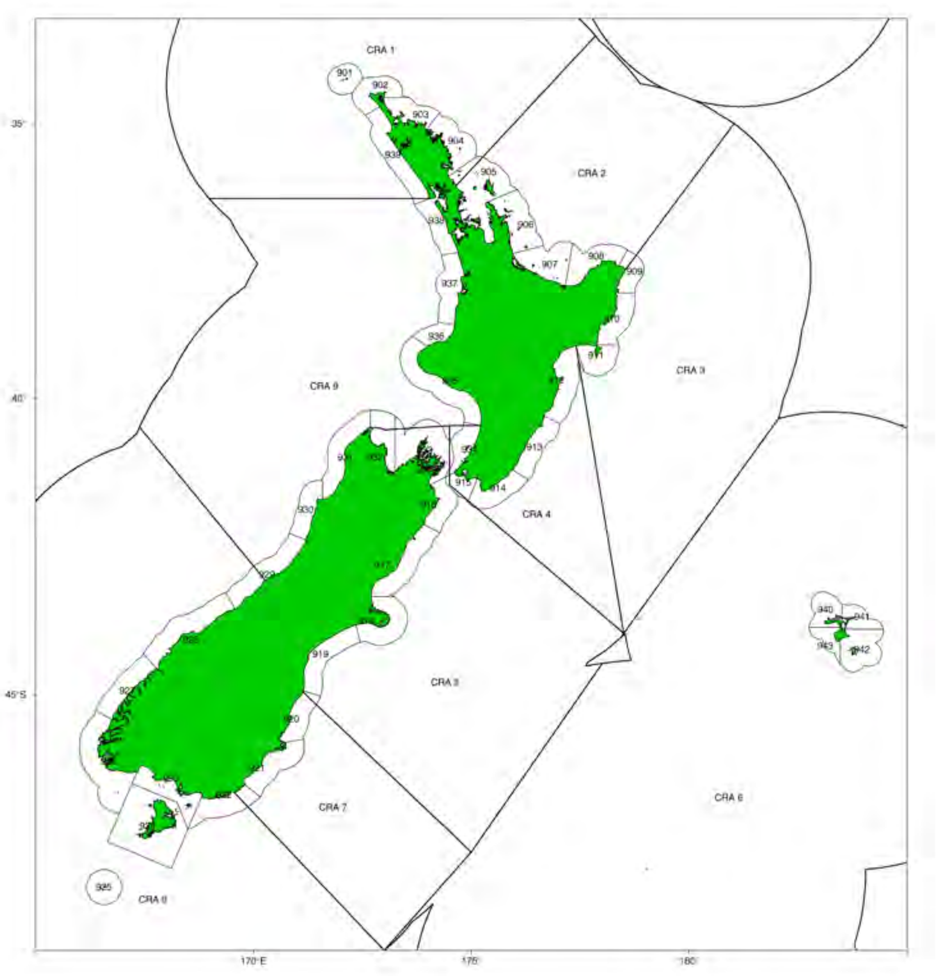


Figure 2: Rock lobster statistical areas as reported on CELR forms.

Table 4: Geometric mean CPUE (kg/potlift) for each statistical area for the six most recent fishing years. Data are from the Fisheries New Zealand CELR database and estimated catches have been corrected by the amount of fish landed from the bottom part of the form using the 'F2' algorithm scaled to the 'LFX' destination code (see Section 1.1.1 for explanation). –, value not available because fewer than three vessels were fishing or there was no fishing. [Continued on next page]

CRA	Stat Area	13/14	14/15	15/16	16/17	17/18	18/19	CRA	Stat Area	13/14	14/15	15/16	16/17	17/18	18/19
1	901	1.892	1.982	2.110	2.146	2.040	2.347	6	940	1.415	1.528	1.399	1.784	1.713	1.836
1	902	1.464	–	–	–	–	1.924	6	941	1.427	1.138	1.207	1.804	1.613	1.609
1	903	1.167	1.285	1.160	–	–	1.072	6	942	1.288	1.206	1.227	1.616	1.724	2.103
1	904	0.669	0.456	–	0.395	0.465	–	6	943	1.457	1.169	1.379	1.457	1.733	1.860
1	939	2.248	1.727	–	–	–	–	7	920	1.590	1.421	1.509	1.689	1.539	2.074
2	905	0.340	0.376	0.273	0.272	0.219	0.327	7	921	2.160	2.206	2.344	2.576	1.838	3.195
2	906	0.302	0.267	0.236	0.264	0.248	0.406	8	922	–	–	–	–	–	–
2	907	0.441	0.391	0.288	0.327	0.381	0.655	8	923	2.508	3.344	2.790	–	–	–
2	908	0.352	0.294	0.265	0.297	0.289	0.505	8	924	2.594	2.592	3.414	4.009	3.138	3.784
3	909	2.083	1.631	1.466	1.593	1.389	1.374	8	925	–	–	3.354	–	–	5.481
3	910	1.638	1.376	1.102	1.101	1.015	0.687	8	926	2.760	2.719	3.018	3.424	4.354	4.503

CRA	Stat Area	13/14	14/15	15/16	16/17	17/18	18/19	CRA	Stat Area	13/14	14/15	15/16	16/17	17/18	18/19
3	911	1.900	1.859	1.760	1.729	1.822	2.430	8	927	2.509	2.185	3.021	2.728	4.916	4.370
4	912	0.582	0.526	0.552	0.590	0.702	0.936	8	928	2.813	2.814	2.276	2.334	3.503	3.786
4	913	1.175	0.835	0.762	0.656	0.831	0.902	9	929	–	–	–	–	–	–
4	914	1.162	0.930	0.562	0.493	0.671	0.616	9	930	–	–	–	–	–	–
4	915	1.093	1.327	0.828	0.597	0.720	0.800	9	931	–	–	–	–	–	–
4	934	–	–	–	–	–	–	9	935	–	–	–	–	–	1.780
5	916	1.054	1.611	0.805	0.831	1.731	1.279	9	936	–	–	–	–	–	–
5	917	2.020	2.062	1.982	2.406	2.157	1.925	9	937	–	–	–	–	–	–
5	918	–	–	4.475	–	–	3.862	9	938	–	–	–	–	–	–
5	919	–	–	–	–	–	–								
5	932	–	–	–	–	–	–								
5	933	0.586	0.560	0.481	0.434	0.403	0.449								

2.2 Recreational fisheries

Recreational fisheries harvest can be estimated using either: ‘onsite’ or access point methods where participants are surveyed on the water or at boat ramps; or ‘offsite’ methods where post-event interviews and/or diaries are used to collect data. The first estimates in New Zealand were made using offsite telephone-diary surveys (Table 5). These surveys provided estimates of the numbers of lobsters harvested, which were converted to harvest by weight using mean rock lobster weights from boat ramps interviews or from commercial sampling data.

Table 5: Available estimates of recreational rock lobster harvest (in numbers and in t by QMA, where available) from regional telephone and diary surveys in 1992, 1993, 1994, 1996, 2000 and 2001 (Bradford 1997, 1998, Teirney et al. 1997, Boyd & Reilly 2004). 2011–12 data from National Panel Survey (Wynne-Jones et al. 2014, Heinemann et al. 2015), Kaikoura/Motunau 2012–13: Kendrick & Handley (2014); Northland 2013–14: Holdsworth 2014; western Bay of Plenty 2010 & 2011: Holdsworth (2016); 2017–18 data from a second National Panel survey (Wynne-Jones et al. 2019) –, not available.] [Continued on next page]

QMA/FMA	Number	CV (%)	Nominal point estimate (t)
Recreational Harvest South Region 1 Sept 1991 to 30 Nov 1992			
CRA 5	65 000	31	40
CRA 7	8 000	29	7
CRA 8	29 000	28	21
Recreational Harvest Central Region 1992–93			
CRA 1	1 000	–	–
CRA 2	4 000	–	–
CRA 3	8 000	–	–
CRA 4	65 000	21	40
CRA 5	11 000	32	10
CRA 8	1 000	–	
Northern Region Survey 1993–94			
CRA 1	56 000	29	38
CRA 2	133 000	29	82
CRA 9	6 000	–	–
1996 Survey			
CRA 1	74 000	18	51
CRA 2	223 000	10	138
CRA 3	27 000	–	–
CRA 4	118 000	14	73
CRA 5	41 000	16	35
CRA 7	3 000	–	–
CRA 8	22 000	20	16
CRA 9	26 000	–	–
2000 Survey			
CRA 1	107 000	59	102.3
CRA 2	324 000	26	235.9
CRA 3	270 000	40	212.4
CRA 4	371 000	24	310.9
CRA 5	151 000	34	122.3

QMA/FMA	Number	CV (%)	Nominal point estimate (t)
CRA 7	1 000	63	1.3
CRA 8	13 000	33	23.3
CRA 9	65 000	64	52.8
2001 Roll Over Survey			
CRA 1	161 000	68	153.5
CRA 2	331 000	27	241.4
CRA 3	215 000	48	168.7
CRA 4	289 000	22	350.5
CRA 5	226 000	22	182.4
CRA 7	10 000	67	9.4
CRA 8	29 000	43	50.9
CRA 9	34 000	68	27.7
National panel survey: Oct 2011–Sep 2012			
CRA 1	29 720	30	23.98
CRA 2	58 413	24	40.86
CRA 3	13 912	33	8.07
CRA 4	53 813	17	44.17
CRA 5	47 493	23	43.47
CRA 7	357	103	0.23
CRA 8	5 149	60	6.93
CRA 9	15 530	30	17.96
Kaikoura & Motunau 2012–13:			
CRA 5	96 800	10	54.56
Northland: 1 Apr 2013–31 Mar 2014			
CRA 1	50 400	17	37.3
Western Bay of Plenty: CRA 2			
Nov 2010–Sep 2011	55 260	47	40.9
Oct 2011–Sep 2012	31 602	47	22.1
National panel survey: Oct 2017–Sep 2018			
CRA 1	19 350	47	15.91
CRA 2	19 123	36	14.21
CRA 3	22 515	26	12.21
CRA 4	52 145	23	41.38
CRA 5	51 464	21	40.96
CRA 7	82	100	0.09
CRA 8	24 732	36	16.17
CRA 9	20 034	34	17.07

The harvest estimates provided by the telephone-diary surveys are not considered reliable by the Marine Amateur Fishing Working Group (MAFWG) because the method was prone to 'soft refusal' bias during recruitment and overstated catches during reporting (Wright et al. 2004). The recreational harvest estimates provided by the 2000 and 2001 telephone-diary surveys were thought by the MAFWG to be implausibly high for many species.

Onsite methods for estimating recreational harvest were developed to provide direct estimates of recreational harvest in fisheries suitable for this form of survey (e.g., Hartill et al. 2007). Onsite methods tend to be costly and difficult to mount, especially for 'diffuse' or specialised fisheries like rock lobster. Hartill (2008), in his review of options for monitoring rock lobster recreational catch, concluded that the best method to monitor these fisheries was an access point boat ramp survey, combined with a telephone-diary or aerial overflight survey for scaling the estimates.

Problems with the earlier surveys led to the development of a rigorously designed National Panel Survey (NPS) for the 2011–12 1 October–30 September fishing year (Wynne-Jones et al. 2014,). The NPS used face-to-face interviews of a random sample of 30 390 households to recruit a panel of 7013 fishers and non-fishers for a full year. The panel members were contacted regularly about their fishing activities and catch information was collected in standardised computer-assisted telephone interviews. The NPS was repeated for the 2017–18 1 October–30 September fishing year (Wynne-Jones et al. 2019), implementing the design of the previous NPS and covering 34 431 dwellings with a panel of 6 975 fishers.

Onsite surveys focused on rock lobster were completed for the western Bay of Plenty (CRA 2) in 2010 and 2011 (Holdsworth 2016), for CRA 5 (Kaikoura–Motunau only) from January–April 2013 (2012–13, Kendrick & Handley 2014), and for CRA 1 in 2013–14, extending from Rangiputa to Mangawhai Heads and covering most of Statistical Areas 903 and 904 (Table 5: Holdsworth 2014). This latter area is estimated to represent 70% of the total CRA 1 recreational catch, based on the 2011–12 NPS.

Table 6: Historical recreational and customary catch estimates used in recent CRA assessments. All ramped catches started from 20% of the 1979 estimate of recreational catch.

QMA	First year	Last year	'Base' recreational catch (t)	Notes: Recreational Catch[8]	Customary catch (t)	Notes: Customary catch
CRA 1[1]	1945	2018	1994=40.152 1996=53.058 2011=24.089 2013=37.3 2017=15.91	A scaling parameter between the 5 survey estimates and the CRA 1 SS commercial CPUE was estimated assuming a lognormal likelihood. CVs: 1994&1996=0.5365, 2011=0.3; 2013=0.17; 2017=0.47	10	Constant from 1945
CRA 2[2]	1979	2016	1994=95.42 1996=149.9 2010=40.90 2011=40.86 2011=22.10	A scaling parameter between the 5 survey estimates and the CRA 2 SS commercial CPUE was estimated assuming a lognormal likelihood. A CV of 0.24 was assigned to the 2011 NPS estimate and the other 4 estimates used a CV=1.5 x 0.24 = 0.36	5	Constant from 1979
CRA 3[3]	1945	2018	1992=4.272 1996=14.418 2011=8.069 2017=12.21	A scaling parameter between the 5 survey estimates and the CRA 1 SS commercial CPUE was estimated assuming a lognormal likelihood. CVs: 1994&1996=0.4229, 2011=0.33; 2017=0.26	20	Constant from 1945
CRA 4[4]	1945	2015	45.833 (=mean of 1994/1996/2011 estimates)	Ramped from 1945; after 1979, the CRA 4 SS CPUE in each year was scaled by the ratio of the mean 'base recreational catches' relative to the mean of the standardised SS CPUE in 1994/1996/2011.	20	Constant from 1945
CRA 5[5]	1945	2014	1994=37.72 1996=23.08 2011=80	Fitted exponential function (Eq. 1) to the 1994, 1996 and assumed (80 t) 2011 recreational survey estimates to the unstandardised Area 917 CPUE estimates.	10	Constant from 1945
CRA 6[6]	1965	2017	5 t/year	by WG agreement: guided by Davey et al. (2011) survey (see Section 1.2.3)	4	Constant from 1965 (by WG agreement)
CRA 7[5]	1963	2014	5 t/year	Constant values were used from 1979 to 2014 and ramped values beginning at 1 t (=20% of constant value) in 1945 and ending at 5 t in 1979 were used from 1945 to 1979.	1	Constant from 1963
CRA 8[5]	1963	2014	20 t/year	Constant values were used from 1979 to 2014 and ramped values beginning at 1 t (=20% of constant value) in 1945 and ending at 5 t in 1979 were used from 1945 to 1979.	6 (15)	Constant at 6 t from 1963–2012 and then increased proportionately to 15 t in 2014
CRA 9[7]	1945	2012	2011=17.96	Ramped from 1945; after 1979, the CRA 9 SS CPUE in each year was scaled by the ratio of the 'base recreational catch' relative to the 2011 standardised SS CPUE.	1	Constant from 1963

[1] see CRA 1 chapter
[2] Starr et al. (2018)
[3] see CRA 3 chapter
[4] Starr et al. (2017)
[5] Starr et al. (2016)
[6] Starr et al. (2019)
[7] Breen (2014)
[8] The maximum of catches declared under the 1996 Fisheries Act Section 111 (**Table 7**) has been added to the recreational trajectory for every QMA in this table.

Table 6 presents the recreational catch estimates used in all recent rock lobster stock assessments. The RLFAWG has little confidence in the early estimates of recreational catch, but believes that the NPS and recent onsite surveys have provided more reliable estimates of recreational catch in those QMAs with a relatively large number of participants. Decisions about the validity of these estimates and their use in stock assessments are detailed in the individual CRA working group reports.

2.3 Section 111 commercial landings

Commercial fishermen are allowed to take home lobsters for personal use under Section 111 of the Fisheries Act. These lobsters must be declared on landing forms using the destination code ‘F’. The maximum in recent fishing years for these landings by QMA has ranged from about 1.68 t (CRA 7) to nearly 19 t (CRA 8) (Table 7).

Table 7: Section 111 commercial landings (in t, summed from landing destination code ‘F’) by fishing year and QMA. –, no data.

Fishing year	CRA 1	CRA 2	CRA 3	CRA 4	CRA 5	CRA 6	CRA 7	CRA 8	CRA 9
2001	0.11	0.23	0.14	0.65	0.46	0.00	0.08	0.25	0.01
2002	0.49	0.61	0.50	2.66	1.96	0.00	0.15	1.95	0.91
2003	2.22	1.02	0.37	3.40	2.91	0.06	0.09	1.68	0.97
2004	3.55	0.73	0.31	3.71	3.19	0.09	0.10	3.51	1.64
2005	3.08	0.78	0.99	3.68	4.39	0.00	0.15	4.57	2.13
2006	5.02	1.28	0.98	3.11	5.10	0.02	0.29	5.81	1.22
2007	3.83	1.03	1.17	2.71	5.41	0.41	0.93	7.79	1.46
2008	3.63	1.18	1.37	2.19	6.11	0.54	1.50	9.57	1.60
2009	4.01	1.37	2.25	3.22	6.24	0.30	1.69	10.72	2.26
2010	3.67	1.19	2.18	4.70	6.58	0.28	0.43	13.54	1.85
2011	4.16	1.17	2.21	4.73	4.83	0.47	0.08	14.91	1.90
2012	4.21	1.19	2.58	5.84	7.22	1.03	0.10	15.82	1.85
2013	3.94	1.66	2.94	4.81	6.63	1.01	0.14	13.23	1.70
2014	3.58	2.04	3.03	5.18	6.12	0.63	0.13	13.93	3.76
2015	3.34	1.38	2.83	5.11	6.10	0.62	0.33	13.74	2.96
2016	3.01	1.17	3.05	4.20	5.70	0.85	0.44	12.83	1.88
2017	2.85	1.28	2.37	3.05	6.19	0.81	0.53	12.40	2.38
2018	2.05	1.19	2.90	4.43	5.19	1.68	0.49	18.78	2.50
Maximum	5.02	2.04	3.05	5.84	7.22	1.68	1.69	18.78	3.76

2.4 Customary non-commercial fisheries

Customary catches used in each stock assessment are summarised in the final two columns of Table 6 and in the respective CRA 1, CRA 2, CRA 3, CRA 6 and other CRA chapters.

2.5 Illegal catch

Illegal catches used in each recent stock assessment are presented in the respective CRA 1, CRA 2, CRA 3, and CRA 6 chapters. MPI Compliance estimates of illegal catch are provided for some years in Table 8. These MPI Compliance estimates of illegal catch were historically provided in two categories (“reported” or “R” and “not reported” or “NR”), with the R category being catches that were eventually landed legally and thus needed to be subtracted from the legal landings to avoid double counting. The NR category consists of unreported catches that were never part of the legal landings. The stock assessment model assumes that both illegal catch categories are taken from the population without reference to the MLS or to the prohibition to taking gravid females.

Table 8: Available estimates of illegal catches (tonnes) by CRA QMA from 1990, as provided by Fisheries New Zealand (formerly MFish) Compliance over a number of years. R (reported): illegal catch that will eventually be processed though the legal catch/effort system; NR (not reported): illegal catch outside of the catch/effort system. Cells without data or missing rows have been deliberately left blank or filled with dashes. Years without any Compliance estimates in any QMA have been suppressed in this table. [Continued on next page]

Fishing	CRA 1		CRA 2		CRA 3		CRA 4		CRA 5		CRA 6		CRA 7		CRA 8		CRA 9	
Year	R	NR	R	NR	R	NR	R	NR	R	NR	R	NR	R	NR	R	NR	R	NR
1990	–	38	–	70	–	288.3	–	160.1	–	178	–	85	34	9.6	25	5	–	12.8
1992	–	11	–	37	–	250	–	30	–	180	–	70	34	5	60	5	–	31
1994	–	15	–	70	5	37	–	70	–	70	–	70	–	25	–	65	–	18
1995	–	15	–	60	0	63	–	64	–	70	–	70	–	15	–	45	–	12
1996	0	72	5	83	20	71	0	75	0	37	70	–	15	5	30	28	0	12

Fishing	CRA 1		CRA 2		CRA 3		CRA 4		CRA 5		CRA 6		CRA 7		CRA 8		CRA 9	
Year	R	NR	R	NR	R	NR	R	NR	R	NR	R	NR	R	NR	R	NR	R	NR
1997	–	–	–	–	4	60	–	–	–	–	–	–	–	–	–	–	–	–
1998	–	–	–	–	4	86.5	–	–	–	–	–	–	–	–	–	–	–	–
1999	–	–	–	–	0	136	–	–	–	–	–	–	–	23.5	–	54.5	–	–
2000	–	–	–	–	3	75	–	64	–	40	–	–	–	–	–	–	–	–
2001	–	72	–	88[1]	0	75	–	–	–	–	–	10	–	–	–	–	–	1
2002	–	–	–	–	0	75	9	51	5	47	–	–	–	1	–	18	–	–
2003	–	–	–	–	0	89.5	–	–	–	–	–	–	–	–	–	–	–	–
2004	–	–	–	–	–	–	10	30	–	–	–	–	–	–	–	–	–	–
2011	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	3	–	–
2014	–	–	–	–	–	–	–	–	–	30	–	–	–	–	–	–	–	–
2015	–	–	–	–	–	–	–	40	–	–	–	–	–	–	–	–	–	–
2016	–	–	–	40[2]	–	–	–	–	–	–	–	–	–	–	–	–	–	–
2018	–	40[2]	–	–	–	50	–	–	–	–	–	–	–	–	–	–	–	–

[1] this value discarded by RLFAWG agreement
[2] this value is not an estimate: it is assumed by agreement by the RLFAWG

Illegal catch estimates before 1990 were derived from unpublished estimates of discrepancies between reported catch totals and total exported weight that were developed for the period 1974 to 1980 (Table 9; McKoy, pers. comm.). For years before 1972–73 and from 1981–82 to 1989–90, illegal catch was estimated by multiplying the average 1974–1980 discrepancy ratio by QMA with the reported catch in each QMA (Table 9).

Table 9: Export discrepancy estimates by year for all of New Zealand (McKoy, pers. comm.). The QMA export discrepancy catch is calculated using the fraction for the reported QMA commercial catch $C_{q,y}$ relative to the total New Zealand commercial catch C_y, starting with the total New Zealand export discrepancy for that year I_y: $I_{q,y} = I_y\left(C_{q,y}/C_y\right)$. This calculation is not performed for CRA 9 as there were no estimates of commercial catch available from 1974 to 1978. The average ratio of the export discrepancy catch for each QMA $\overline{P}_q$ relative to the reported QMA commercial catches is used in each CRA QMA to estimate illegal catches before 1990: $I_{q,y} = \overline{P}_q C_{q,y}$ if $y<1974 \| (y>1980 \& y<1990)$.

Year	Estimates of total export discrepancies (t) I_y	QMA	$\overline{P}_q = \sum_{y=1974}^{1980} I_{q,y} \Big/ \sum_{y=1974}^{1980} C_{q,y}$
1974	463	CRA 1	0.192
1975	816	CRA 2	0.171
1976	721	CRA 3	0.164
1977	913	CRA 4	0.183
1978	1146	CRA 5	0.187
1979	383	CRA 6	0.181
1980	520	CRA 7	0.183
		CRA 8	0.187
		CRA 9	–

2.6 Other sources of mortality

Other sources of mortality include handling mortality caused by the return of under-sized, high-grading, and berried female lobsters to the water and predation by octopus and other predators within pots. Octopus predation can be quantified from observer catch sampling data but estimates are not used. Stock assessments beginning in 2017 have assumed that handling mortality was 10% of returned lobsters until 1990 and then 5%, based on a literature review and the reasoning that greater care would be taken for the product with the development of the live export market.

2.7 Time series of mortalities

Plots of all rock lobster catches by QMA from 1945 are presented in Figure 3. The sources for all commercial catches, including catches before 1979, are documented in Bentley et al. (2005b). Historical estimates of recreational, customary, and illegal catches have been generated for every stock assessment and these have been extended using the same rules for those assessments that are not current. Finally, the TAC is plotted each QMA.

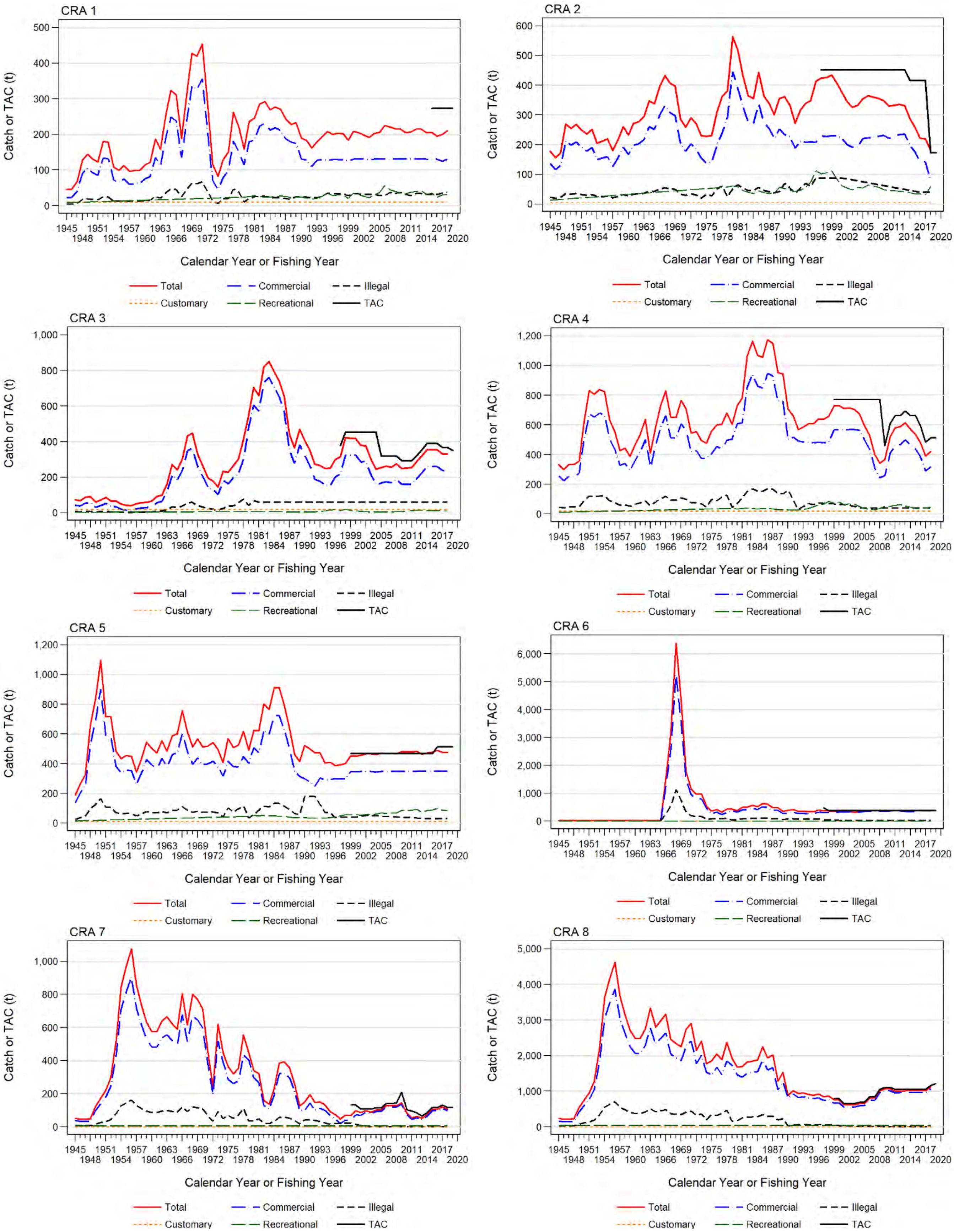


Figure 3: Catch trajectories (t) from 1945 to 2018 and TACs from the year of establishment to 2019 for CRA 1 to CRA 9.
[Continued on next page]

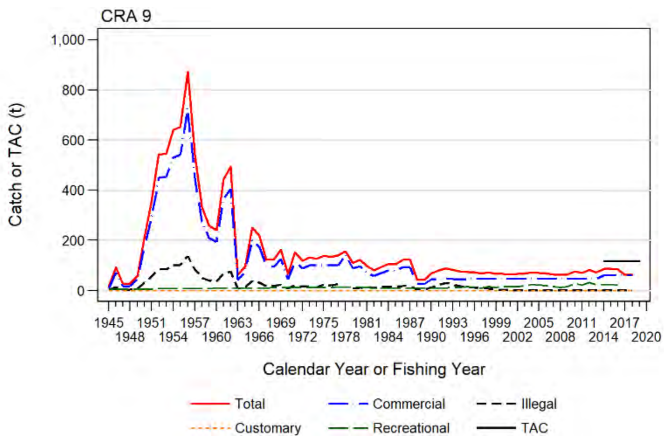


Figure 3: Catch trajectories (t) from 1945 to 2018 and TACs from the year of establishment to 2019 for CRA 1 to CRA 9, showing current best estimates for commercial, recreational, customary and illegal categories. Also shown is the sum of these four catch categories. Note that calendar year catches are plotted from 1945 to 1977. Statutory fishing year (1 April to 31 March) catches are plotted from 1979 on. Catches for 1978 are for 15 months, including January to March 1979.

3. BIOLOGY

Although lobsters cannot be aged in numbers sufficient for use in fishery assessments, they are thought to be relatively long-lived. *J. edwardsii* and *S. verreauxi* occur both in New Zealand and southern Australia. The following summary applies only to *J. edwardsii* in New Zealand.

Sexual maturity in females is reached from 34–77 mm TW (about 60–120 mm carapace length), depending on locality within New Zealand. For instance, in CRA 3, 50% maturity appears to be about 40 mm TW while most females in the south and south-east of the South Island do not breed before reaching MLS.

Mating takes place after moulting in autumn, and the eggs hatch in spring into naupliosoma larvae. Most of the phyllosoma larval development takes place in oceanic waters tens to hundreds of kilometres offshore over at least 12 months. Near the edge of the continental shelf the final-stage phyllosoma metamorphoses into the settling stage, the puerulus. Puerulus settlement takes place mainly at depths less than 20 m, but not uniformly over time or between regions. Settlement indices measured on collectors can fluctuate widely from year to year. Values used for some biological parameters in stock assessments are shown in Table 10.

Table 10: Values used for some biological parameters.

1. Natural mortality (*M*) [1]

Area	Both sexes
CRA 1, 2 ,3, 4, 5, 7, 8	0.12

[1] This value has been used as the mean of an informative prior; *M* was estimated as a parameter of the model and is usually substantially updated.

2. Fecundity = a TW^b (TW in mm) (Breen & Kendrick 1998)[2]

Area	*a*	*b*
NSN	0.21	2.95
CRA 4 & CRA 5	0.86	2.91
NSS	0.06	3.18

[2] Fecundity has not been used by post-1999 assessment models.

3. Weight = a TW^b (weight in kg, TW in mm) (Breen & Kendrick 1998, Fisheries New Zealand unpublished data)

	Females		Males	
Area	***a***	***b***	***a***	***b***
CRA 1, 2, 3, 4, 5	1.30 E-05	2.5452	4.16 E-06	2.9354
NSS	1.04 E-05	2.6323	3.39 E-06	2.9665
CRA 6[1]	1.05 E-05	2.6205	6.63 E-07	3.3629

[1] Breen & Kendrick (unpublished and recalculated for the CRA 6 stock assessment)

Long-distance migrations of rock lobsters have been observed in some areas. During spring and early summer, variable proportions of usually small males and immature females move various distances against the current from the east and south coasts of the South Island towards Fiordland and south Westland.

3.1 Growth modelling

The primary sources of information for growth are tag-recapture data, and, to a lesser extent, catch sampling data. Lobsters have been caught, measured, tagged and released, then recaptured and remeasured at some later time (and in some instances re-released and re-recaptured later). Since 1998, statistical length-based models have been used to estimate the expected increment-at-size, which is represented stochastically by growth transition matrices for each sex. Growth increments-at-size are assumed to be normally distributed with means and variances determined from the growth model. The transition matrices contain the probabilities that a lobster will move into specific size bins given its initial size.

The growth model contains parameters for expected increment at 30 mm and 80 mm TW, a shape parameter (1 = linear), the CV of the increment for each sex, and the observation error.

Since 2006, the growth model applied to the tag-recapture data has been a continuous model – giving a predicted growth increment for any time at liberty – whereas the older versions assumed specific moulting periods between which growth did not occur. For assessment models used from 2006 to 2014, records from lobsters at liberty for fewer than 30 days were excluded. In that period, the robust normal distribution precluded the need for extensive grooming of outliers. In 2015, the grooming was relaxed so that only records from lobsters at liberty for less than 1 day were excluded. Lobsters at liberty for short time periods provide the growth models with information on observation error. Growth parameters are estimated simultaneously with other parameters of the assessment model in an integrated way, so that growth estimates might be affected by the size frequency and CPUE data as well as the tag-recapture data.

In 2019, juvenile growth at 30 mm TW was estimated to be about 8 mm/year (Roberts & Webber, unpublished analysis). This estimate was based on cohort progression in successive juvenile dive surveys made at the Gisborne wharf before 1980. The 8 mm per year growth at 30 mm TW was considerably less than the equivalent growth increment estimated by previous stock assessment models, an unsurprising result considering that there are no tagging data less than 40 mm TW. In order to constrain the growth model used in the stock assessment, the fixed value used for the *Galpha* parameter was dropped from 50 mm TW to 30 mm TW (the size at which lobsters enter the model) and the *Galpha* prior was narrowed. Model runs were made for the CRA 3 stock assessment which excluded tags that had been at liberty for less than one year because the resulting growth estimates at 30 mm TW were more consistent with the juvenile growth estimate based on dive surveys.

3.2 Settlement indices

Annual levels of puerulus settlement have been collected from 1979 at sites in Gisborne, Napier, Castlepoint, Kaikoura, Moeraki, Chalky Inlet, Halfmoon Bay, and Jackson Bay (Table 11). Each site has at least one group of three collectors that are checked monthly when possible, and the monthly catches of the puerulus from each collector are used as the basis for producing a standardised index of settlement (Forman et al. 2018). Standardised settlement indices are available for each key site (Table 12).

Table 11: Location of collector groups used for the standardisation of puerulus settlement indices, the years of operation, and the number of collectors monitored within each group at the last sampling.

QMA	Key site	Collector groups	Years of operation	Number of collectors
CRA 3	Gisborne	Whangara (GIS002)	1991–present	5
		Tatapouri (GIS003)	1994–2006	5
		Kaiti (GIS004)	1994–present	5
CRA 4	Napier	Port of Napier (NAP001)	1979–present	5
		Westshore (NAP002)	1991–1999	3
		Cape Kidnappers (NAP003)	1994–present	5
		Breakwater (NAP004)	1991–2002	3
CRA 4	Castlepoint	Castlepoint (CPT001)	1983–present	9
		Orui (CPT002)	1991–present	5
		Mataikona(CPT003)	1991–2006	5
CRA 5	Kaikoura	South peninsula (KAI001)	1981–present	5
		South peninsula (KAI002)	1988–2003	3
		North peninsula (KAI003)	1980–present	5
		North peninsula (KAI004)	1992–2003	3
		South Kaikoura (KAI005)	2008–present	3
		Hamuri Bluff (KAI006)	2008–present	3
		Gooch Bay (KAI008)	1980–1983	3
		Middle South Coast (KAI009)	1981–1988	3
CRA 7	Moeraki	Wharf (MOE002)	1990–2006	3
		Pier (MOE007)	1998–2017[1]	6
		Wharf (MOE008)	2017–present	6
CRA 8	Halfmoon Bay	Wharf (HMB001)	1980–present	8
		Thompsons (HMB002)	1988–2002	3
		Old Mill (HMB003)	1990–2002	3
		The Neck (HMB004)	1992–2002	3
		Mamaku Point (HMB005)	1992–2002	3
CRA 8	Chalky Inlet	Chalky Inlet (CHI001)	1986–2004	5
		Chalky Inlet (CHI001)	2010–2012	4
CRA 8	Jackson Bay	Wharf (JAC001)	1999–present	5
		Jackson Head (JAC002)	1999–2006	3

[1] Site MOE007 abandoned from 2018 for safety reasons. New site (MOE008) not included in standardisation procedure.

Table 12: Standardised puerulus settlement indices by fishing year 1 April–31 March (source: A. McKenzie, NIWA). –: no usable sampling was done; 0.00: no observed settlement. [Continued on next page]

Fishing year	Gisborne CRA 3	Napier CRA 4	Castlepoint CRA 4	Kaikoura CRA 5	Moeraki CRA 7	Halfmoon Bay CRA 8	Chalky Inlet CRA 8	Jackson Bay CRA 8
1979	–	0.80	–	–	–	–	–	–
1980	–	1.28	–	–	–	–	–	–
1981	–	2.11	–	0.56	–	7.98	–	–
1982	–	1.18	2.37	0.75	–	0.38	–	–
1983	–	1.36	1.15	0.16	–	3.87	–	–
1984	–	0.42	0.71	0.38	–	0.30	–	–
1985	–	0.22	0.57	0.24	–	0.00	0.36	–
1986	–	–	0.81	0.09	–	0.11	0.21	–
1987	3.56	–	1.61	1.07	–	1.55	1.42	–
1988	3.02	1.40	0.93	0.40	–	0.22	1.31	–
1989	1.07	1.22	1.14	0.82	–	0.59	1.64	–
1990	0.48	1.07	1.08	1.61	–	0.42	1.84	–
1991	1.15	2.53	2.10	6.81	0.00	0.92	1.03	–
1992	3.08	2.16	2.12	5.40	0.09	0.53	0.52	–
1993	1.92	2.27	1.06	2.08	0.00	0.00	0.14	–
1994	3.29	1.57	0.87	1.09	0.00	1.17	1.64	–
1995	1.17	1.08	0.91	0.61	0.07	0.39	0.40	–
1996	1.79	1.58	1.27	0.65	0.61	0.33	1.76	–
1997	1.08	1.10	1.68	2.02	0.26	0.55	1.41	–
1998	1.95	1.00	1.07	2.00	0.35	0.29	0.50	–
1999	0.30	0.44	0.34	1.31	0.06	0.23	1.70	0.23

Fishing year	Gisborne CRA 3	Napier CRA 4	Castlepoint CRA 4	Kaikoura CRA 5	Moeraki CRA 7	Halfmoon Bay CRA 8	Chalky Inlet CRA 8	Jackson Bay CRA 8
2000	0.98	0.75	0.52	1.32	2.67	1.19	1.26	0.51
2001	1.22	1.26	0.71	0.54	1.11	1.72	0.60	0.20
2002	1.03	1.48	0.77	3.31	0.58	1.44	1.42	1.21
2003	2.97	1.34	0.92	3.39	4.82	3.90	1.56	0.46
2004	0.78	1.08	0.49	1.04	0.24	0.15	0.30	0.36
2005	2.70	1.31	1.27	2.29	0.05	0.00	–	1.03
2006	0.30	0.66	0.48	1.12	0.04	0.13	–	0.23
2007	0.40	0.95	1.03	1.67	0.04	0.47	–	0.20
2008	0.69	0.66	1.03	1.61	0.07	0.09	–	0.07
2009	1.85	0.90	1.06	0.51	0.44	1.00	–	0.13
2010	0.66	0.96	1.17	1.26	0.97	1.64	7.03	1.70
2011	0.20	0.50	0.88	0.55	0.69	0.14	1.44	1.92
2012	0.72	0.71	0.59	1.11	0.80	0.18	4.37	6.48
2013	1.00	0.98	1.70	0.74	1.17	0.74	–	11.40
2014	0.42	1.04	0.69	1.32	0.34	0.85	–	18.78
2015	1.62	1.08	1.65	0.83	7.73	0.55	–	4.37
2016	1.25	0.70	1.85	2.76	2.81	1.36	–	11.38
2017	0.18	1.03	1.04	0.90	–	1.99	–	0.99
2018	0.35	0.39	1.07	0.38	–	0.62	–	2.28

4. STOCKS AND AREAS

There is no evidence for genetic subdivision of lobster stocks within New Zealand based on biochemical genetic and mitochondrial DNA studies. The observed long-distance migrations in some areas and the long larval life probably result in genetic homogeneity among areas. Gene flow at some level probably occurs to New Zealand from populations in Australia (Chiswell et al. 2003).

Subdivision of stocks on other than genetic grounds has been considered (Booth & Breen 1992, Bentley & Starr 2001). There are geographic discontinuities in the prevalence of antennal banding, size at onset of maturity in females, migratory behaviour, fishery catch and effort patterns, phyllosoma abundance patterns, and puerulus settlement levels. These observations led to division of the historical NSI stock into three substocks (NSN, NSC and NSS) for assessments in the 1990s. Cluster analysis based on similarities in CPUE trends between rock lobster statistical areas provided support for these stock definitions (Bentley & Starr 2001).

Since 2001, these historical stock definitions have not been used, and rock lobsters in each of the CRA QMA areas have been assumed to constitute separate Fishstocks for the purposes of stock assessment and management.

Sagmariasus verreauxi forms one stock centred in northern New Zealand and may be genetically subdivided from populations of the same species in Australia.

5. DECISION RULES AND MANAGEMENT PROCEDURES

This section describes the current (as of November 2019) operational management procedures (MPs) used to manage rock lobster QMAs for the 2020–21 fishing year.

MPs are functions, often referred to as harvest control rules (HCRs), that specify one or more inputs and return an output value. New Zealand rock lobster MPs use standardized catch per unit effort (CPUE) as the input and a catch limit as the output. Other controls, such as minimum or maximum change thresholds, may also be used to modify the output.

Some work has investigated the use of MPs with additional inputs (e.g. settlement indices, Bentley et al. 2005a) but so far other inputs have not been used formally for management in New Zealand. Before

2007, the input CPUE was from the preceding fishing year. This approach resulted in a one-year lag between observed CPUE and the resulting catch limit (i.e. the fishing year ends on the 31 March and any new catch limit from the MP is applied to the year beginning in April the following year). To shorten the lag to six months, "offset- year" CPUE was developed. Much exploratory work has been done on CPUE and its standardisation (e.g. Starr 2012).

The first New Zealand MP and its successors were used to rebuild the depleted CRA 8 stock in New Zealand and to concurrently manage the volatile CRA 7 stock (Starr et al. 1997; Bentley et al. 2003; Breen et al. 2008; Haist et al. 2013). There are now four rock lobster QMAs with MPs (CRA 4, CRA 5, CRA 7, and CRA 8). CRA 1, CRA 2, CRA 3, CRA 6, and CRA 9 are managed without MPs.

In the CRA 4 fishery, industry adopted a MP to reduce their catches voluntarily (quota "shelving", Breen 2009) prior to formal requirement by Fisheries New Zealand for catch reductions. A voluntary MP for CRA 5 was designed to maintain high abundance (Breen et al. 2009a).

The CRA 2 stock assessment in 2017 suggested that the stock was below the soft limit and therefore required a rebuilding plan (Webber et al. 2018). The chosen rebuilding plan used a fixed catch rather than a MP. A stock assessment for CRA 6 was done in 2018 (Rudd et al. 2019) but a MP was not developed for managing this QMA because planned changes to the collection of catch and effort data made it unlikely that offset year CPUE would be available after November 2019 in its present form. A MP for CRA 9 was abandoned in 2016, after two years of operation, because analysis indicated that the CRA 9 CPUE was not sufficiently robust to support a stock assessment and a TACC-altering MP. New stock assessments done in 2019 for CRA 1 and CRA 3, coupled with substantive changes in the manner in which catch and effort data are collected, resulted in a decision to manage these QMAs using fixed catch levels expected to be held over the next five years.

5.1 Management Procedure for CRA 4

A summary of MPs in CRA 4 is provided in Table 13. The CRA 4 MP is based on work done in 2016 (Breen et al. 2017), using an operating model based on the CRA 4 stock assessment model. Rules evaluated were generalised plateau step rules. From the options recommended (National Rock Lobster Management Group 2017), the Minister adopted the rule specified in Table 14.

The Final Advice Paper (National Rock Lobster Management Group 2017) for the 2017–18 fishing year described the rule as follows:

- *The output variable is TACC (tonnes);*
- *Offset-year standardised CPUE is used as an input to the rule to determine the TACC for the fishing year that begins in the following April;*
- *CPUE is calculated using the 2012 F2_LFX procedure*
- *The management procedure is to be evaluated every year (no "latent year"), based on offset-year CPUE; and*
- *The minimum change threshold for the TACC is 5%. There is no maximum change threshold for the TACC.*

The proposed new CRA 4 management procedures are both generalised plateau step rules… For Rule 6: at a CPUE value of zero the TACC is zero; the TACC then increases linearly to 0.9 kg/potlift; between CPUEs of 0.9 and 1.3 kg/potlift the TACC is 380 tonnes; as CPUE increases above 1.3 kg/potlift, the TACC increases in steps with a width of 0.1 kg/potlift and a height of 5.3% of the preceding TACC.

Table 13: Summary of CRA 4 MPs.

First year with MP	2007
First year of current MP	2017
Review scheduled	2021
Input	F2-LFX offset year CPUE
Output	TACC
Type of rule	generalised plateau step rule
Minimum change	5%
Maximum change	none
Latent year	none
2019–20 customary allowance	35
2019–20 recreational allowance	85
2019–20 other mortality allowance	75
2019–20 total non-commercial allowance	195
2019–20 TACC	318.8
2019–20 TAC	513.8

Table 14: Parameters for the CRA 4 generalised plateau step rule.

Parameter	Function	Value
par1	rule type	4
par2	CPUE at TACC = 0	0
par3	CPUE at plateau left	0.9
par4	CPUE at plateau right	1.3
par5	plateau height	380
par6	step width	0.1
par7	step height	0.053
par8	minimum change	0.05
par9	maximum change	0
par10	latent year switch	0

The first MP for CRA 4 was voluntary (Breen et al. 2009b), based on the work of Breen & Kim (2006), and was used to guide ACE (Annual Catch Entitlement, related to quota) shelving for 2007 and 2008. The Minister adopted the current MP in March 2017 for the 2017–18 fishing year.

- In November 2016, standardised offset-year CPUE was 0.6851 kg/potlift (Table 15 and Figure 4), giving a TACC of 289.264 tonnes (Table 15 and Figure 5). This result was accepted by the Minister.
- In November 2017, standardised offset-year CPUE increased to 0.7550 kg/potlift, giving a TACC of 318.778 tonnes. This result was accepted by the Minister after rounding to 1 decimal place.
- In November 2018, standardised offset-year CPUE increased to 0.9012 kg/potlift, giving a TACC on the plateau of 380.0 tonnes. This TACC change was +19.2%, well above the minimum change threshold of 5%, so the MP result was an increase in the TACC. However, this result was not accepted by the Minister who decided to retain the previous year's TACC of 318.8 tonnes.
- In November 2019, standardised offset-year CPUE increased to 0.8961 kg/potlift, giving a TACC just below the plateau of 378.4 tonnes. This TACC change was +18.7%, well above the minimum change threshold of 5%, so the MP result was an increase in the TACC.

Table 15: History of the current CRA 4 management procedure and its operation in 2019. "Rule result TACC" is the result of the management procedure. "Applied TACC" and "Applied TAC" are the catch limits decided by the Minister

Offset year	Offset year CPUE (kg/potlift)	Applied to fishing year	Rule result TACC (tonnes)	Applied TACC (tonnes)	Applied TAC (tonnes)
2016	0.6851	2017–18	289.264	289.0	484.0
2017	0.7550	2018–19	318.778	318.8	513.8
2018	0.9012	2019–20	380.000	318.8	513.8
2019	0.8961	2020–21	378.353	-	-

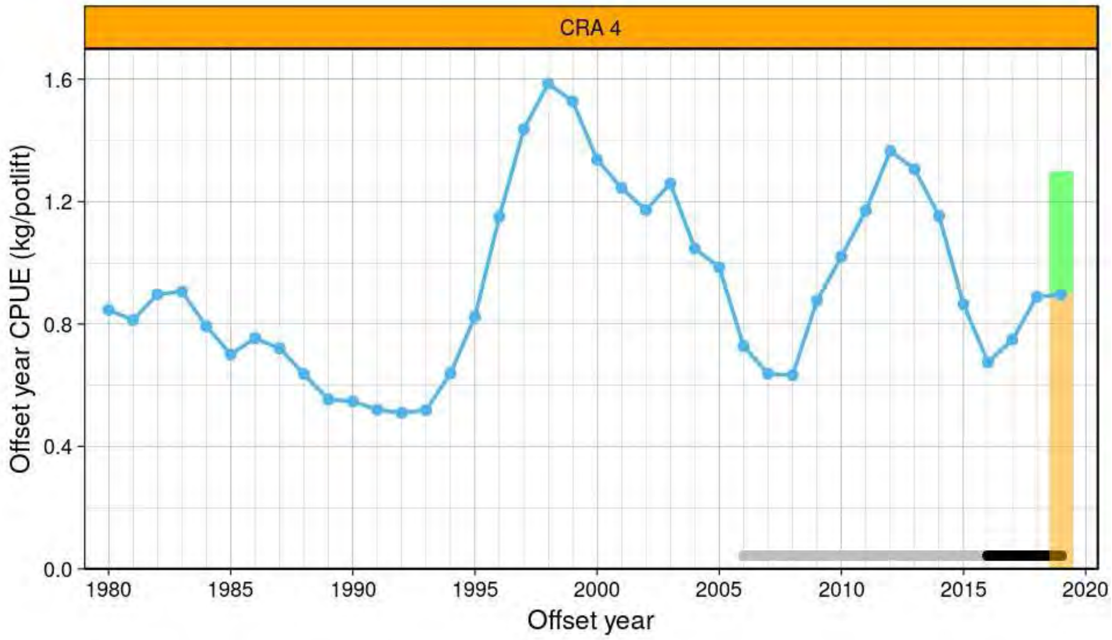


Figure 4: Offset-year CPUE (F2-LFX) (kg/potlift) for CRA 4. The coloured bar represents the plateau (green), the slope (orange), and the CPUE at which the TACC = 0 (red). The horizontal black line indicates the years that the current MP has operated, the grey indicates the years that other MPs operated.

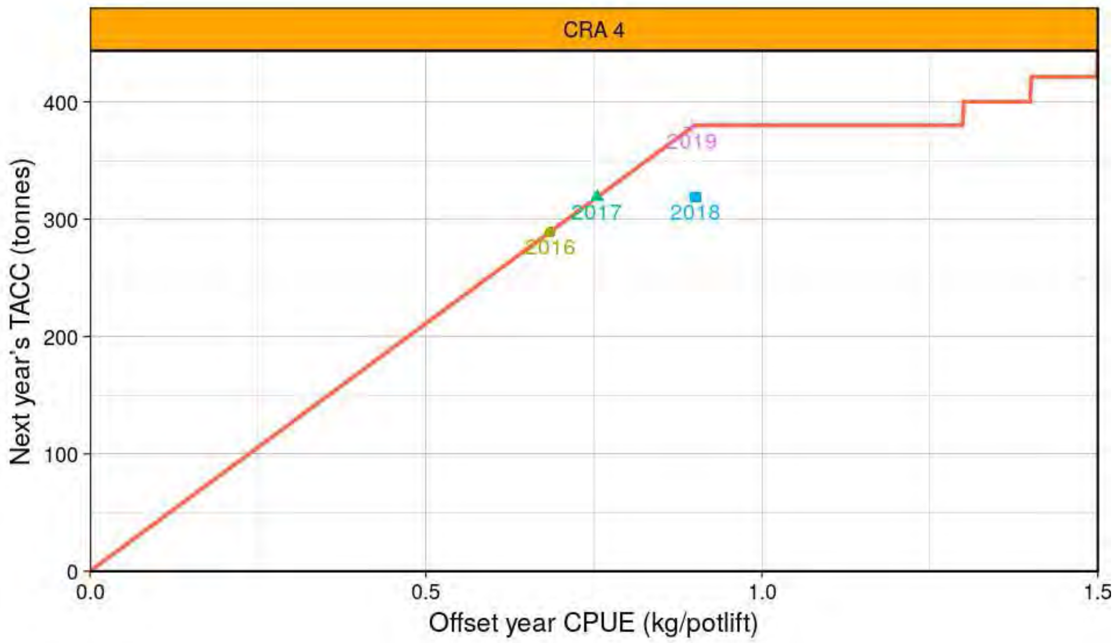


Figure 5: History of the current CRA 4 management procedure. The coloured symbols show the 2016 to 2019 offset-year CPUE and the resulting TACCs.

5.2 Management Procedure for CRA 5

A summary of MPs in CRA 5 is provided in Table 16. The CRA 5 MP is based on MPEs done in 2015 (Starr & Webber 2016), using an operating model based on the CRA 5 stock assessment model. Rules evaluated were generalised plateau step rules. From the options recommended, the (National Rock Lobster Management Group 2016) chose, and the Minister accepted, the rule specified in Table 17. The Minister increased the recreational allowance from 40 to 87 tonnes.

Table 16: Summary of CRA 5 MPs.

First year with MP	2009
First year of current MP	2016
Review scheduled	2020
Input	F2-LFX offset year CPUE
Output	TACC
Type of rule	generalised plateau step rule
Minimum change	5%
Maximum change	None
Latent year	None
2019–20 customary allowance	40
2019–20 recreational allowance	87
2019–20 other mortality allowance	37
2019–20 total non-commercial allowance	164
2019–20 TACC	350
2019–20 TAC	514

Table 17: Parameters for the CRA 5 generalised plateau step rule.

Parameter	**Function**	**Value**
par1	rule type	4
par2	CPUE at TACC = 0	0.3
par3	CPUE at plateau left	1.2
par4	CPUE at plateau right	2.2
par5	plateau height	350
par6	step width	0.2
par7	step height	0.055
par8	minimum change	0.05
par9	maximum change	0
par10	latent year switch	0

The Final Advice Paper (National Rock Lobster Management Group 2016) for the 2016–17 fishing year described the new harvest control rule as follows:

- *The output variable is TACC (tonnes);*
- *Offset-year standardised CPUE is used as an input to the rule to determine the TACC for the fishing year that begins in the following April;*
- *CPUE is calculated using the 2012 F2_LFX procedure which uses:*
- *landings to a licensed fisher receiver, along with recreational landings from a commercial vessel and the amount of rock lobsters returned to the water in accordance with Schedule 6 of the Act (i.e. high-graded rock lobsters),*
- *estimates, by vessel, of the ratio of annual landed catch divided by annual estimated catch to correct every landing record in a quota management area for the vessel;*
- *The management procedure is to be operated every year (no "latent year"), based on offset-year CPUE;*
- *The minimum change threshold for the TACC is 5%. There is no maximum change threshold for the TACC.*

The proposed new CRA 5 management procedure is based on a generalised plateau step rule... Between CPUEs of zero and 0.3 kg/potlift the TACC is zero, the TACC then increases linearly with CPUE to 350 *tonnes at a CPUE of 1.2 kg/potlift. The TACC remains at 350 tonnes until CPUE reaches 2.2 kg/potlift and then increases by 5.5% in CPUE steps of 0.2 kg/potlift.*

The current rule was adopted by the Minister for the 2016–17 fishing year. The Minister retained the customary allowance of 40 tonnes and the illegal allowance of 37 tonnes, but increased the recreational allowance from 40 to 87 tonnes (Table 16).

- In November 2015, standardised F2-LFX offset-year CPUE was 1.7890 (Table 18 and Figure 6), which specified a TACC of 350 tonnes, on the plateau (Table 18 and Figure 7). This result was accepted by the Minister.
- In November 2016, standardised F2-LFX offset-year CPUE was 1.5902, which specified a TACC of 350 tonnes, which remained on the plateau. This result was accepted by the Minister.
- In November 2017, standardised F2-LFX offset-year CPUE was 2.0482, which specified a TACC of 350 tonnes, which remained on the plateau. This result was accepted by the Minister.
- In November 2018, standardised F2-LFX offset-year CPUE was 1.7977, which specified a TACC of 350 tonnes, which remained on the plateau. This result was accepted by the Minister.
- In November 2019, standardised F2-LFX offset-year CPUE was 1.7500, which specified a TACC of 350 tonnes, which remained on the plateau.

Table 18: History of the current CRA 5 management procedure and its operation in 2019. "Rule result TACC" is the result of the management procedure. "Applied TACC" and "Applied TAC" are the catch limits decided by the Minister.

Offset year	Offset year CPUE (kg/potlift)	Applied to fishing year	Rule result TACC (tonnes)	Applied TACC (tonnes)	Applied TAC (tonnes)
2015	1.7890	2016–17	350	350	514
2016	1.5902	2017–18	350	350	514
2017	2.0482	2018–19	350	350	514
2018	1.7977	2019–20	350	350	514
2019	1.7500	2020–21	350	-	-

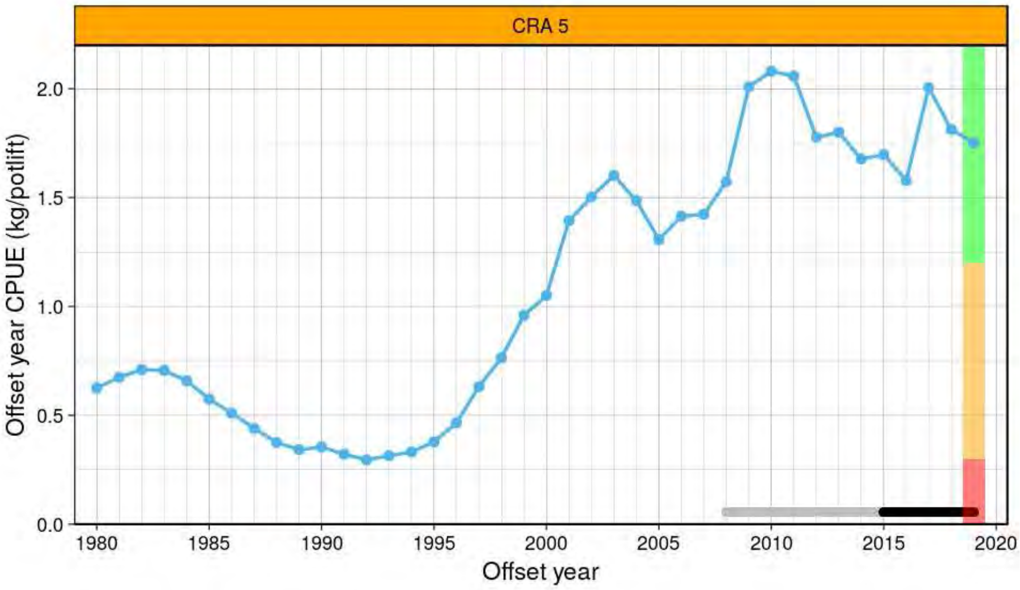


Figure 6: Offset-year CPUE (F2-LFX) (kg/potlift) for CRA 5. The coloured bar represents the plateau (green), the slope (orange), and the CPUE at which the TACC = 0 (red). The horizontal black line indicates the years that the current MP has operated, the grey indicates the years that other MPs operated.

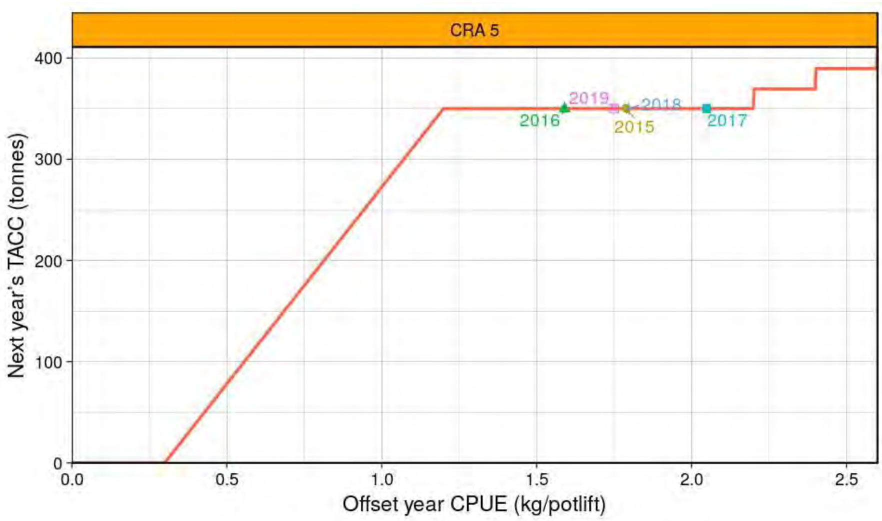


Figure 7: History of the current CRA 5 management procedure. The coloured symbols show the 2015 to 2019 offset-year CPUE and the resulting TACCs.

5.3 Management Procedure for CRA 7

A summary of MPs in CRA 7 is provided in Table 19. The CRA 7 MP is based on MPEs done in 2012, which used an operating model based on the 2012 joint stock assessment for CRA 7 and CRA 8 (Haist et al. 2013). This MP was re-evaluated in 2015 after a new stock assessment (Haist et al. 2016) and was retained. Rules evaluated in 2012 and again in 2015 were generalised slope rules. From the options originally recommended (National Rock Lobster Management Group 2013) the Minister adopted the rule specified in Table 20. This rule replaced an earlier rule and is the latest in a series (Starr et al. 1997; Bentley et al. 2003; Breen et al. 2008).

Table 19: Summary of CRA 7 MPs.

First year with MP	1996
First year of current MP	2013
Review scheduled	2020
Input	F2-LFX offset year CPUE
Output	TACC
Type of rule	generalised plateau slope rule
Minimum change	10%
Maximum change	50%
Latent year	None
2019–20 customary allowance	10
2019–20 recreational allowance	5
2019–20 other mortality allowance	5
2019–20 total non-commercial allowance	20
2019–20 TACC	97
2019–20 TAC	117

Table 20: Parameters for the CRA 7 generalised plateau step rule.

Parameter	**Function**	**Value**
par1	rule type	3
par2	CPUE at TACC = 0	0.17
par3	CPUE at plateau left	1
par4	CPUE at plateau right	1.75
par5	plateau height	80
par6	slope	3
par7	n.a.	0
par8	minimum change	0.1
par9	maximum change	0.5
par10	latent year switch	0

The Final Advice Paper (National Rock Lobster Management Group 2013) for the 2013–14 fishing year described the rule as follows:
Some important elements of the new Rule 39 CRA 7 Management Procedure are:

- *the output variable is TACC (tonnes) (non-commercial catch assumptions are made from the operating model).*
- *offset-year standardised CPUE is used as an input to the rule to determine the TACC for the fishing year that begins in the following April.*
- *CPUE is calculated using the new "F2-LFX" procedure which uses:*
    - *Ministry for Primary Industries landings to a licensed fisher receiver, along with recreational landings from a commercial vessel and the amount of rock lobsters returned to the water in accordance with Schedule 6 of the Act (i.e. high-graded rock lobsters),*
    - *estimates, by vessel, of the ratio of annual landed catch divided by annual estimated catch to correct every landing record in a quota management area for the vessel.*
- *the management procedure is to be evaluated every year (no "latent year"), based on offset-year CPUE.*
- *the new CRA 7 Management Procedure is based on a generalised plateau rule. Below a CPUE of 0.17 kg/potlift, the TACC is zero; between a CPUE of [0.17] and 1.0 kg/potlift, the TACC increases linearly with CPUE to a plateau of 80 tonnes, which extends to a CPUE of 1.75 kg/potlift. As CPUE increases above 1.75 kg/potlift, TACC increases linearly. The minimum change threshold for the TACC is 10% and the maximum change threshold is 50%.*

The Minister adopted this rule in 2013 for the 2013–14 fishing year.

- In November 2012 The standardised offset-year CPUE was 0.625 kg/potlift (Table 21and Figure 8), giving a TACC of 44.96 tonnes (Table 21 and Figure 9). The Minister accepted this result and retained the previous non-commercial allowances of customary 10 tonnes, recreational 5 tonnes, and other mortality 5 tonnes, to set a TAC of 64 tonnes (Table 19).
- In November 2013 the offset-year CPUE had more than doubled to 1.356 kg/potlift, which suggested a TACC of 80 tonnes. The increase was greater than the maximum allowed increase of 50%, so the TACC was increased by 50% to 66 tonnes. The Minister accepted this result and used the same allowances to set a TAC of 86 tonnes.
- In November 2014 the offset-year CPUE had increased to 2.304 kg/potlift, giving a TACC of 97.72 tonnes. The Minister accepted this result and retained the same allowances as before, giving a TAC of 117.72 tonnes.
- In November 2015, standardised F2-LFX offset-year CPUE had decreased slightly to 2.212 kg/potlift and the preliminary rule result was a TACC of 94.797 tonnes. Because this would be a change of only 2.9%, less than minimum change threshold of 10%, the MP result was no change to the TACC.
- In November 2016, standardised F2-LFX offset-year CPUE had increased to 2.766 kg/potlift and the preliminary rule result was a TACC of 112.512 tonnes. The increase of 25% was greater than the 10% minimum change threshold, so the MP result was an increase in the 2017–18 TACC to 112.512 tonnes. The Minister accepted this result.
- In November 2017, standardised F2-LFX offset-year CPUE decreased to 2.328 kg/potlift and the preliminary rule result was a TACC of 98.499 tonnes, a 12.5% decrease from the TACC of 112.52 tonnes. Because this is greater than the minimum change threshold of 10%, the result was a 12.5% decrease in the 2018–19 TACC to 98.499 tonnes. The Minister accepted this result and set the TACC at 97 tonnes.
- In November 2018, standardised F2-LFX offset-year CPUE decreased to 2.292 kg/potlift and the preliminary rule result was a TACC of 97.343 tonnes. This change in TACC is less than 1% and less than the minimum change threshold of 10%, resulting in no change to the TACC. The Minister accepted this result.
- In November 2019, standardised F2-LFX offset-year CPUE increased to 3.217 kg/potlift and the preliminary rule result was a TACC of 126.947 tonnes. This change in TACC is 30.9% which is greater than the minimum change threshold of 10%.

Table 21: History of the current CRA 7 management procedure and its operation in 2019. "Rule result TACC" is the result of the management procedure. "Applied TACC" and "Applied TAC" are the catch limits decided by the Minister.

Offset year	Offset year CPUE (kg/potlift)	Applied to fishing year	Rule result TACC (tonnes)	Applied TACC (tonnes)	Applied TAC (tonnes)
2012	0.625	2013–14	43.960	44.00	64.00
2013	1.356	2014–15	66.000	66.00	86.00
2014	2.304	2015–16	97.720	97.72	117.72
2015	2.212	2016–17	97.720	97.72	117.72
2016	2.766	2017–18	112.512	112.52	132.52
2017	2.328	2018–19	98.499	97.00	117.00
2018	2.292	2019–20	97.343	97.00	117.00
2019	3.217	2020–21	126.947	-	-

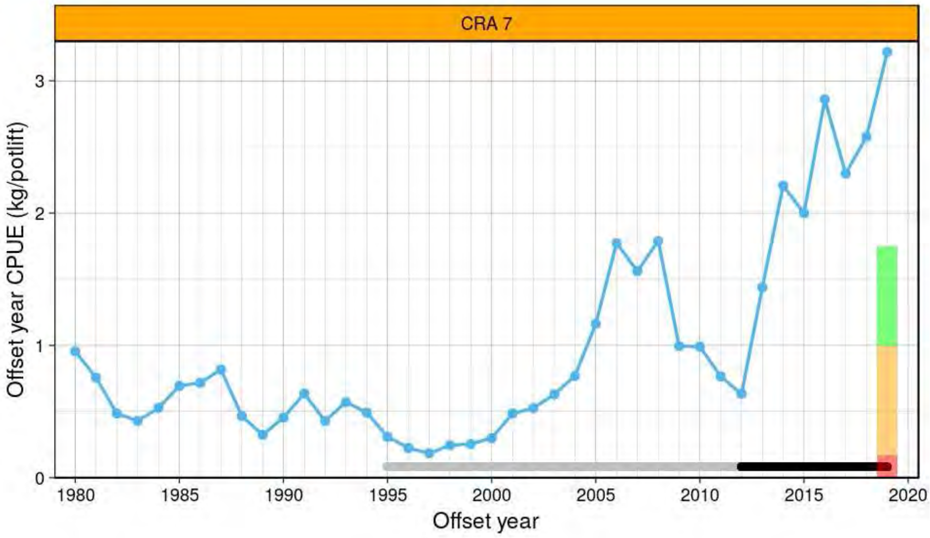


Figure 8: Offset-year CPUE (F2-LFX) (kg/potlift) for CRA 7. The coloured bar represents the plateau (green), the slope (orange), and the CPUE at which the TACC = 0 (red). The horizontal black line indicates the years that the current MP has operated, the grey indicates the years that other MPs operated.

Figure 9: History of the current CRA 7 management procedure. The coloured symbols show the 2012 to 2019 offset-year CPUE and the resulting TACCs.

5.4 Management Procedure for CRA 8

A summary of MPs in CRA 8 is provided in Table 22. The CRA 8 MP is based on MPEs done in 2015, using an operating model based on the combined CRA 7 and CRA 8 stock assessment (Haist et al. 2016). The input CPUE is based only on the sizes of fish that are landed, not on all sizes including the larger ones that are not economic. This was called "$CPUE" or "money-fish CPUE" in the MPEs and is calculated using the F2-LF algorithm (see Starr 2019). The more usual F2-LFX procedure includes destination X (i.e. legal lobsters returned to the sea). From the options recommended, the National Rock Lobster Management Group (2016) chose, and the Minister adopted, the rule specified in Table 23. This rule replaced a similar rule and is the fifth in a series that began in 1996 (Starr et al. 1997; Bentley et al. 2003; Breen et al. 2008; Haist et al. 2013). Except for an extended plateau and the altered input, the adopted rule is very similar to the previous CRA 8 MP when the allowances are the same (the previous rule generated a TAC, this rule generates a TACC)

Table 22: Summary of CRA 8 MPs.

First year with MP	1996
First year of current MP	2016
Review scheduled	2020
Input	F2-LF offset year CPUE
Output	TACC
Type of rule	generalised plateau step rule
Minimum change	5%
Maximum change	None
Latent year	None
2019–20 customary allowance	30
2019–20 recreational allowance	33
2019–20 other mortality allowance	28
2019–20 total non-commercial allowance	91
2019–20 TACC	1129.6
2019–20 TAC	1220.6

Table 23: Parameters for the CRA 8 generalised plateau step rule.

Parameter	Function	Value
par1	rule type	4
par2	CPUE at TACC = 0	0.5
par3	CPUE at plateau left	1.9
par4	CPUE at plateau right	3.2
par5	plateau height	962
par6	step width	0.5
par7	step height	0.055
par8	minimum change	0.05
par9	maximum change	0
par10	latent year switch	0

The Final Advice Paper (National Rock Lobster Management Group 2016) for the 2016–17 fishing year described the rule as follows:

Some important elements of the proposed new CRA 8 management procedure are:

- *The output variable is TACC (tonnes);*
- *Offset-year standardised CPUE is used as an input to the rule to determine the TACC for the fishing year that begins in the following April;*
- *CPUE is calculated using the new "F2_LF" procedure, which gives the "money-fish" CPUE, or $CPUE. This procedure uses:*

- o *landings to a licensed fisher receiver, along with recreational landings from a commercial vessel (it does not include the amount of rock lobsters returned to the water in accordance with Schedule 6 of the Act (i.e. high-graded rock lobsters) as does the F2_LFX procedure),*
- o *estimates, by vessel, of the ratio of annual landed catch divided by annual estimated catch to correct every landing record in a quota management area for the vessel;*

- *The management procedure is to be evaluated every year (no "latent year"), based on offset-year CPUE;*
- *The minimum change threshold for the TACC is 5%. There is no maximum change threshold for the TACC.*

The proposed new CRA 8 management procedure is based on a generalised plateau step rule … Between CPUEs of zero and 0.5 kg/potlift the TACC is zero, the TACC then increases linearly with CPUE to 962 tonnes at a CPUE of 1.9 kg/potlift. The TACC remains at 962 tonnes until CPUE reaches 3.2 kg/potlift and then increases by 5.5% in CPUE steps of 0.5 kg/potlift.

History of the CRA 8 MP is shown in Table 24.

- In November 2015, standardised offset-year F2-LF CPUE was 3.0620 kg/potlift (Table 24 and Figure 10), which gave a TACC on the plateau (Table 24 and Figure 11).
- In November 2016, standardised offset-year F2-LF CPUE was 3.0254 kg/potlift, which gave a suggested TACC on the plateau of 962.0 tonnes.
- In November 2017, standardised offset-year F2-LF CPUE was 3.7113 kg/potlift, which gave a suggested TACC above the plateau of 1070.7 tonnes. This TACC change was+11.3%, well above the minimum change threshold of 5%, so the MP result was an increase in the TACC. The Minister accepted this result and increased the TACC.
- In November 2018, standardised offset-year F2-LF CPUE was 4.2481 kg/potlift, which gave a suggested TACC above the plateau of 1129.6 tonnes. This TACC change was +5.5%, above the minimum change threshold of 5%, so the MP result was an increase in the TACC. The Minister accepted this result and increased the TACC.
- In November 2019, standardised offset-year F2-LF CPUE was 4.8743 kg/potlift, which gave a suggested TACC above the plateau of 1191.7 tonnes. This TACC change was +5.5%, above the minimum change threshold of 5%, so the MP result was an increase in the TACC.

Table 24: History of the current CRA 8 management procedure and its operation in 2019. "Rule result TACC" is the result of the management procedure. "Applied TACC" and "Applied TAC" are the catch limits decided by the Minister.

Offset year	Offset year CPUE (kg/potlift)	Applied to fishing year	Rule result TACC (tonnes)	Applied TACC (tonnes)	Applied TAC (tonnes)
2015	3.0620	2016–17	962.0	962.0	1 053.0
2016	3.0254	2017–18	962.0	962.0	1 053.0
2017	3.7113	2018–19	1 070.7	1 070.7	1 161.7
2018	4.2481	2019–20	1 129.6	1 129.6	1 220.6
2019	4.8743	2020–21	1 191.7	-	-

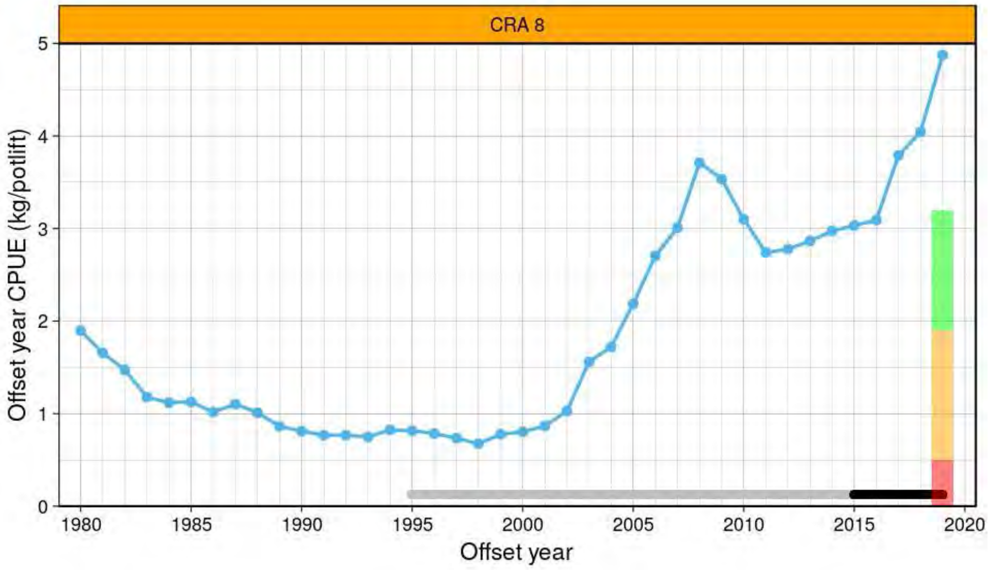


Figure 10: Offset-year CPUE (F2-LF) (kg/potlift) for CRA 8. The coloured bar represents the plateau (green), the slope (orange), and the CPUE at which the TACC = 0 (red). The horizontal black line indicates the years that the current MP has operated, the grey indicates the years that other MPs operated.

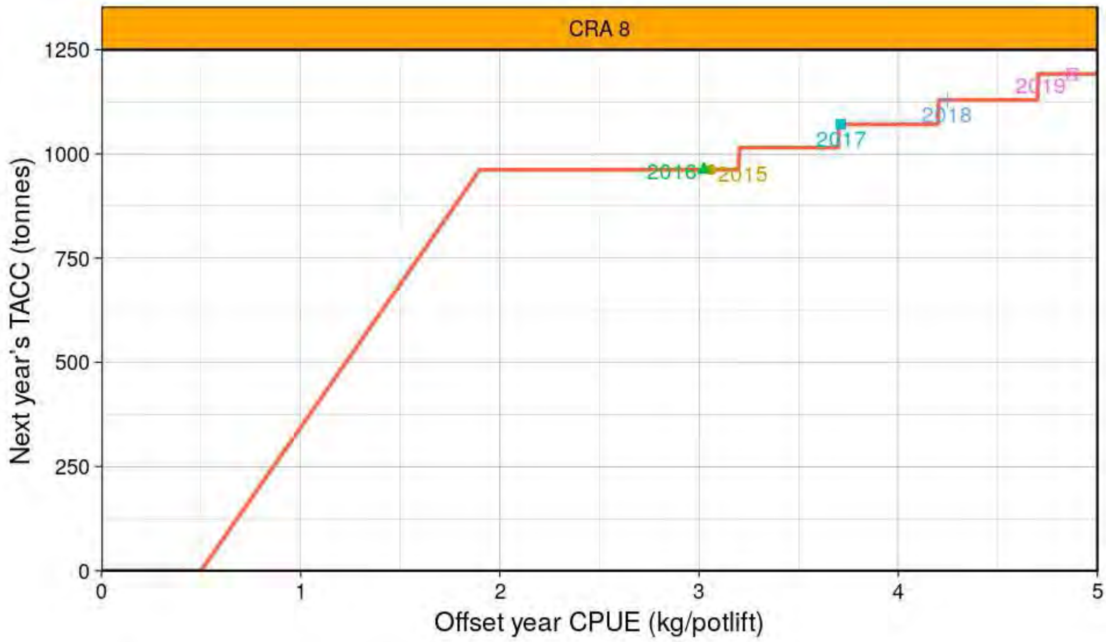


Figure 11: History of the current CRA 8 management procedure. The coloured symbols show the 2015 to 2019 offset-year CPUE and the resulting TACCs.

6. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS

This section was last updated in 2019. This summary is from the perspective of the rock lobster fisheries; a more detailed summary from an issue-by issue perspective is available in the Ministry's Aquatic Environment and Biodiversity Annual Review 2018 (Ministry for Primary Industries 2019).

The environmental effects of rock lobster fishing have been covered more extensively by Breen (2005) and only those issues deemed most important, or of particular relevance to fisheries management, are covered here.

6.1 Ecosystem role

Rock lobsters are predominantly nocturnal (Williams & Dean 1989). Their diet is reported to be comprised primarily of molluscs and other invertebrates (Booth 1986, Andrew & Francis 2003). Survey and experimental work has shown that predation by rock lobsters in marine reserves is capable of influencing the demography of surf clams of the genus *Dosinia* (Langlois et al. 2005, Langlois et al. 2006).

Predation by rock lobsters has been suggested as contributing to trophic cascades in a number of studies in New Zealand (e.g., Babcock et al. 1999, Edgar & Barrett 1999). Schiel (2013), in reviewing the Leigh Marine Reserve story, questions whether results from north-eastern New Zealand are generally applicable to the rest of New Zealand. Schiel (1990) argued that sea urchins did not seem to demonstrate widescale dominance outside north-eastern New Zealand, although at that time there were limited surveys elsewhere, and suggested that sea urchin outbreaks were rare in southern waters despite heavy lobster fishing at that time. Schiel & Hickford (2001) found that barrens were more characteristic of kelp communities north of Cook Strait. In the south they were not common. A literature review (Breen unpublished) suggests that the evidence for lobster-driven trophic cascades in New Zealand is very thin.

Published scientific observations support predation upon rock lobsters by octopus (Brock et al. 2003), rig (King & Clarke 1984), blue cod, groper, southern dogfish (Pike 1969) and seals (Yaldwyn 1958, cited in Kensler 1967).

6.2 Non-target catch of fish and invertebrates

The levels of incidental catch landed from rock lobster potting were analysed for the period 1989–2003 (table 26 in Bentley et al. 2005b). Non-rock lobster catch landed ranged from 2 to 11% of the estimated rock lobster catch weight per QMA over this period. These percentages are based on estimated catches only and it is likely that not all bycatch is reported (only the top five species are requested) and that the quality of the weight estimates will vary between species There were 129 species recorded landed from lobster pots over this period. The most frequently reported incidental species caught (comprising on average greater than 99% of the bycatch per QMA) were, in decreasing order of catch across all stocks: octopus, conger eel, blue cod, trumpeter, sea perch, red cod, butterfish and leatherjackets.

6.3 Incidental catch of seabirds and marine mammals

Recovery of shags from lobster pots has been documented in New Zealand. One black shag (*Phalacrocorax carbo*) of 41 recovered dead from a Wairarapa banding study was found drowned in a crayfish pot hauled up from 12 m depth (Sim & Powlesland 1995). A survey of rock lobster fishers on the Chatham Islands (Bell 2012) reported no shag bycatch in the past five years (2007–08 to 2011–12 fishing season), only 2 shag captures between five and ten years ago (2001–02 to 2006–07 fishing season), and 18 shags caught more than 10 years ago (prior to 2000–01 season). The fishers suggested the lack of reported shag captures in the past five years was attributable to changes in pot design and baiting methodologies.

From January 2000 until November 2018, 31 entanglements (29 marine mammal individuals, two individuals were entangled twice) were attributed to commercial or recreational rock lobster pot lines from around New Zealand, mainly around Kaikoura (DOC Marine Mammal Database). One orca (found in the Hauraki Gulf) and one Hector's dolphin (off Kaikoura) were found entangled and dead. In general mortalities are likely to be caused by prolonged entanglement, and therefore might not be observed within the same area. CRA 5 commercial fishermen work to a voluntary code of practice to avoid entanglements, but recreational fishers do not. The commercial fishermen in CRA 5 also cooperate with the Department of Conservation to assist releases when entanglements occur.

6.4 Benthic impacts

Potting is the main method of targeting rock lobster and is usually assumed to have very little direct impact on non-target species. No information exists regarding the benthic impacts of potting in New Zealand.

A study on the impacts of lobster pots was completed in a report on the South Australian rock lobster fisheries (Casement & Svane 1999). This fishery is likely to be the most comparable to New Zealand as the same species of rock lobster is harvested and many of the same species are present, although the details of pots and how they are fished may differ. The report concluded that the mass of algae removed in pots probably has no ecological significance.

Two other studies provide results from other parts of the world, but the comparability of these studies to New Zealand is questionable given differences in species and fishing techniques. The Western Australia Fishery Department calculated the proportion of corals (the most sensitive fauna) likely to be impacted by potting, and concluded it was low, i.e., between 0.1 and 0.3% per annum (Department of Fisheries Western Australia 2007). This kind of calculation for the New Zealand fishery would require better habitat maps than currently exist for most parts of the coast (Breen 2005) as well as finer-scale catch information than the Ministry currently possesses. Direct effects of potting on the benthos have been studied in Great Britain (Eno et al. 2001) and four weeks of intensive potting resulted in no significant effects on any of the rocky-reef fauna quantified. Observations in this paper indicated that sea pens were bent (but not damaged) and one species of coral was damaged by pots.

The only regulatory limitation on where lobster pots can be used is inside marine reserve boundaries; however, in Fiordland, four areas within marine reserves have been designated for commercial pot storage due to the shortage of suitable space (Fiordland Marine Guardians 2008). Likewise, in the Taputeranga marine reserve (Wellington) an area is designated for vessel mooring and the storage of ‘holding pots’ by commercial fishermen.

6.5 Other considerations

An area near North Cape is currently closed to packhorse lobster fishing to mitigate sub-legal handling disturbance in this area. This closure was generated due to the smaller sizes of animals there and results from a tagging study that showed movement away from this area into nearby fished areas (Booth 1979).

6.6 Key information gaps

Breen (2005) identified that the most likely areas to cause concern for rock lobster fishing in a detailed risk assessment were: ghost fishing, everyday bycatch and its effect on bycatch species, effects on habitats and protected species, and indirect effects on marine communities caused by the removal of large predators. At this time no prioritisation has been applied to this list.

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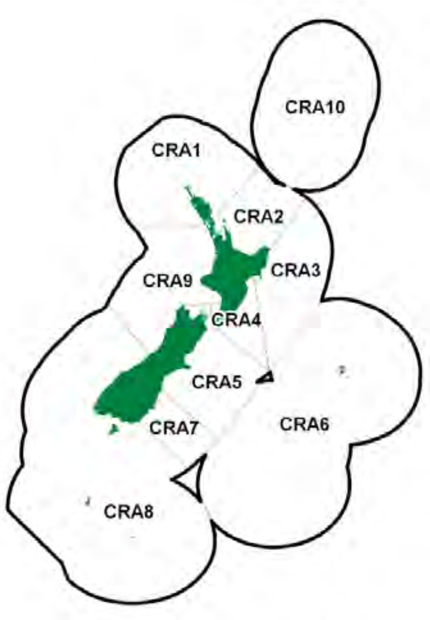
ROCK LOBSTER (CRA 1)

(*Jasus edwardsii*) Crayfish, Kōura papatea, Pawharu



1. FISHERY SUMMARY

1.1 Commercial fisheries

Table 1 provides a summary by fishing year of the reported commercial catches, TACCs, and TACs for CRA 1. Landings and TACC are plotted in Figure 1.

Table 1: Reported commercial catch (t) from QMRs or MHRs (after 1 October 2001), commercial TACC (t) and total TAC (t) (where this quantity has been set) for rock lobster, *Jasus edwardsii,* in QMA 1 for each fishing year since the species was included in the QMS on 1 April 1990. –, TAC not set for QMA or catch not available (current fishing year).

			CRA 1
Fishing year	Catch	TACC	TAC
1990–91	131.1	160.1	–
1991–92	128.3	157.0	–
1992–93	110.5	138.0	–
1993–94	127.4	130.5	–
1994–95	130.0	130.5	–
1995–96	126.7	130.5	–
1996–97	129.4	130.5	–
1997–98	129.3	130.5	–
1998–99	128.7	130.5	–
1999–00	125.7	131.1	–
2000–01	130.9	131.1	–
2001–02	130.6	131.1	–
2002–03	130.8	131.1	–
2003–04	128.7	131.1	–
2004–05	130.8	131.1	–
2005–06	130.5	131.1	–
2006–07	130.8	131.1	–
2007–08	129.8	131.1	–
2008–09	131.0	131.1	–
2009–10	130.9	131.1	–
2010–11	130.8	131.1	–
2011–12	130.4	131.1	–
2012–13	130.9	131.1	–
2013–14	130.3	131.1	–
2014–15	130.2	131.1	–
2015–16	129.4	131.1	273.1
2016–17	130.6	131.1	273.1
2017–18	124.3	131.1	273.1
2018–19	130.6	131.1	273.1
2019–20	–	131.1	273.1

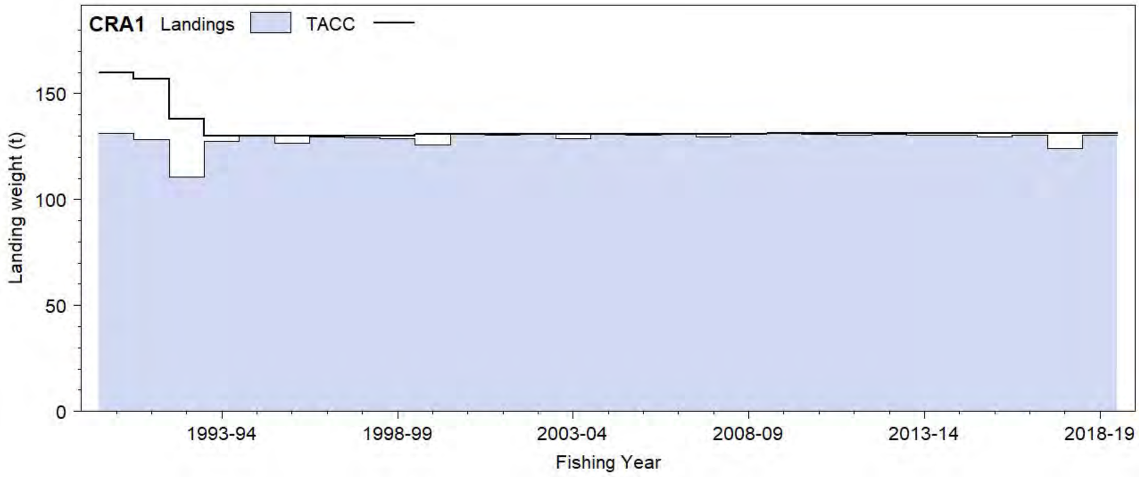


Figure 1: Historical commercial landings and TACC for CRA 1.

1.2 Recreational fisheries

For general information on recreational catch refer to the Introduction – Rock Lobster chapter.

Seven annual recreational survey catch estimates are available for CRA 1 (Table 2). Estimates from the two Kingett Mitchell national telephone diary surveys in 1999–00 and 2000–01 (Boyd et al. 2004; Boyd & Reilly 2004) were not accepted by the RLFAWG for the 2014 CRA 1 stock assessment (Starr et al. 2015a) because these survey estimates were considered implausibly high for CRA 1. The earlier regional 1994 and national 1996 telephone diary surveys, conducted by researchers at the University of Otago, were considered biased in a review of the available recreational surveys (unpublished minutes: Recreational Technical Working Group [Auckland NIWA, 10–11 June 2004]) because the interview questions possibly underestimated fisher participation rates by allowing for an easy exit from the interview ("soft refusal" bias). These two early surveys continue to be used by the RLFAWG in spite of this advice because the estimates are plausible and no other recreational information is available for these years. Both the Kingett Mitchell and the Otago surveys were potentially biased high because recreational logbook participants were not closely supervised and may not have accurately recorded their fishing activity. The much higher harvest estimates in the Kingett Mitchell surveys were a result of higher claimed participation in saltwater fishing over the previous 12 months in the initial screening survey.

Table 2: Information used to estimate recreational catch for CRA 1.

Survey	**Numbers**	**Mean weight (kg)**	**Catch Weight (t)**	**Assumed CV**
1994 (Otago: Bradford 1997)	56 000	0.717[1]	40.15	1.5*(0.3+0.47)/2
1996 (Otago: Bradford 1998)	74 000	0.717[1]	53.06	1.5*(0.3+0.47)/2
2000 (Boyd & Reilly 2004)	107 000[2]	–	102.3	not used
2001 (Boyd et al. 2004)	161 000[2]	–	153.5	not used
2011 (NPS: Wynne-Jones et al. 2014)	29 739[3]	0.81	23.98	0.30
2013 (Holdsworth 2014)	50 430	0.78	37.30	0.17
2017 (NPS: Wynne-Jones 2019)	19 350[4]	0.82	15.91	0.47
Section 111 reported landings				
Maximum reported landings (t) (in 2006–07)			5.015	

[1] SS mean weight (kg) calculated from commercial sampling data from 1994 to 1996 assuming recreational minimum legal sizes (Starr et al. 2003)
[2] as reported by Boyd & Reilly (2004) and Boyd et al. (2004)
[3] estimate provided in Wynne-Jones et al. (2014)
[4] estimate provided in Wynne-Jones et al. (2019)

Two large-scale population-based diary/interview surveys (National Panel Survey or NPS) have been conducted from 1 October 2011–30 September 2012 (Wynne-Jones et al. 2014) and from 1 October 2017–30 September 2018 (Wynne-Jones et al. 2019), with the intention of estimating FMA-and QMA-specific annual catches for all major finfish and non-finfish species (Heinemann et al. 2015). This survey was based on a design that resembled the New Zealand national census, making use of the census population strata ("mesh blocks" of dwellings as the basis for identifying recreational fishers). A door-to-door survey of households in randomly selected strata was used to select participants who would report their catch for an entire year. A structured and carefully-designed Computer Assisted Telephone Interview (CATI) method was used to record harvest in detail from those who had fished. The survey results were thought to be plausible for CRA 1, with 32 (2011) and 34 (2017) fishers providing 90 and 65 trips where rock lobster were caught for respective survey years (see table 60 in Wynne-Jones et al. 2014 and table 51 in Wynne-Jones 2019). These estimates have relatively high CVs (0.30 in 2011 and 0.47 in 2017; Table 3). The 2011 survey provided estimates of the distribution of fishing platforms used to take lobsters in CRA 1, with large and small motor boats accounting for about three quarters of the catch and only 15% coming from land (Table 3). The primary capture method used to take rock lobster in CRA 1 was diving (87%) followed by potting (11%) (Table 3). NPS survey results from logbook participants were in terms of number of fish. Mean recreational catch weight for the most important finfish and non-finfish species QMAs was estimated in a parallel project (Hartill & Davey 2015).

Table 3: Fishing platform and capture method categories for CRA 1 during 2011–12 estimated by the national NPS recreational survey (Wynne-Jones et al. 2014). The final line shows the 2011–12 CRA 1 total estimates. CV=standard error of the estimate, which does not include error associated with the estimate of mean weight.

Category	Numbers	CV	Catch (t)[1]	CV	% of Total Catch Weight
Platform (Appendix Table 27.3 in Wynne-Jones et al. 2014)					
Trailer motor boat	22 690	0.36	18.29	0.36	76
Larger motor boat or launch	1 289	0.42	1.04	0.42	4
Trailer yacht	0		0		0
Larger yacht or keeler	1 126	0.87	0.91	0.87	4
Kayak canoe or rowboat	209	0.80	0.17	0.80	1
Off land including beach rocks or jetty	4 425	0.60	3.57	0.60	15
Something else	0		0		0
Capture method (Appendix Table 27.4 in Wynne-Jones et al. 2014)					
Rod or line (not long line)	0		0		0
Long-line including set line kontiki or kite	0		0		0
Net (not including landing net used if caught on line)	0		0		0
Pot (e.g. for crayfish)	5 478	0.90	4.42	0.90	18
Dredge grapple or rake	0		0		0
Hand gather or floundering from shore	763	1.03	0.62	1.03	3
Hand gather by diving	23 498	0.35	18.95	0.35	79
Spearfishing	0		0		0
Some other method	0		0		0
Total	29 739	0.30	23.98	0.30	100

[1] uses mean weight estimate of 801 grams (Hartill & Davey 2015)

The Blue Water Marine Research (BWMR) catch estimate (Table 2) was based on data collected by a stratified (summer/winter; weekday/weekend) on-site survey conducted across 75 access points between Rangiputa and Mangawhai Heads in East Northland and 10 949 interviews over the period 1 April 2013 to 31 March 2014 (Holdsworth 2014). A catch estimate for all of CRA 1 was generated using scaling factors derived from the 2011 NPS survey: the survey area was estimated to have covered 69% of the total CRA 1 recreational fishery. Mean weights were derived from length frequencies collected by the survey during the sampling period.

A recreational catch vector was developed by assuming that recreational catch has been proportional to the CRA 1 SS abundance, as reflected in the unstandardised (geometric mean) SS CPUE from Areas 903 and 904. These areas were used because the majority of the recreational fishery takes place in these statistical areas, located on the east coast of the North Island (about 70% of the total QMA– Holdsworth 2014). These areas have lower commercial CPUE than the remaining three CRA 1 statistical areas and do not show the large increase in CPUE which started in the early 2000s that was seen in the other statistical areas. The unstandardised SS CPUE vector was calculated for combined Areas 903 and 904 using data prepared with the F2-LFX algorithm (see Starr 2019). By agreement in the RLFAWG, the recreational catch vector was based on five of the seven survey estimates (in tonnes – see Table 2) from the 1994 and 1996 (Otago University surveys), the 2011 and 2017 NPS surveys and the 2013 BWMR survey. The two NPS surveys and the BWMR survey were assumed to be less biased, so the estimated survey CVs were used. The CVs for the two Otago University surveys were assumed to be 50% higher than that of the mean of the two NPS surveys. A scalar quantity *q* (Eq. 1) was estimated by obtaining the best fit to these survey estimates when minimising a log-normal distribution using the CVs indicated in Table 2.

Eq. 1

$$W_t = w_t \; N_t$$
$$\hat{W}_t = \hat{q} \; CPUE_t$$
$$\mathrm{LL} = \sum_{t=1}^{5} \left(\frac{\left(\mathrm{LN}(W_t) - \mathrm{LN}(\hat{W}_t)\right)^2}{2\sigma_t^2} \right)$$

where:

t subscripts five recreational survey estimates in Table 1:

1=1994 Otago; 2=1996 Otago; 3=2011 NPS; 4=2013 Holdsworth; 5=2017 NPS.

$w_t =$ mean spring/summer weight >= MLS for sampled lobster in year/survey t for CRA 1

$N_t =$ mean number lobsters in year/survey t for CRA 1

$CPUE_t =$ Area 903/904 mean spring/summer unstandardised CPUE in year t

$\hat{W}_t =$ CRA 1 estimated recreational catch (tonnes) for year t

The estimated recreational catch trajectory (Eq. 2) based on the *q* estimated in Eq. 1 matches the 2013 BWMR observation (Holdsworth 2014) while overshooting the 2011 and 2017 NPS surveys and underestimating the two Otago University observations (Figure 2). The *q* parameter was estimated to be 37 tonnes/CPUE-unit and the recreational catch vector accounted for about 1000 tonnes of historical catch from 1979 to 2018.

Eq. 2

$$\hat{W}_y = \hat{q} \; CPUE_y \text{ if } y >= 1979$$
$$\hat{W}_{1945} = 0.2 * \hat{W}_{1979}$$
$$\hat{W}_y = \hat{W}_{y-1} + \frac{(\hat{W}_{1979} - \hat{W}_{1945})}{(1979 - 1945)} \text{ if } y > 1945 \;\&\; y < 1979$$

For assessments since 2006, the RLFAWG has included recreational landings made by commercial vessels under Section 111 of the Fisheries Act. Greenweight landings with destination code “F” were extracted from the CRACE database (Bentley et al. 2005), which showed a maximum annual value of 5015 kg for CRA 1, occurring in 2006–07. The RLFAWG has agreed to add the maximum catch estimate to the estimated recreational catch in each year since 1979 (Figure 2), increasing the total 1979 to 2018 recreational catch in the model to 1195 t.

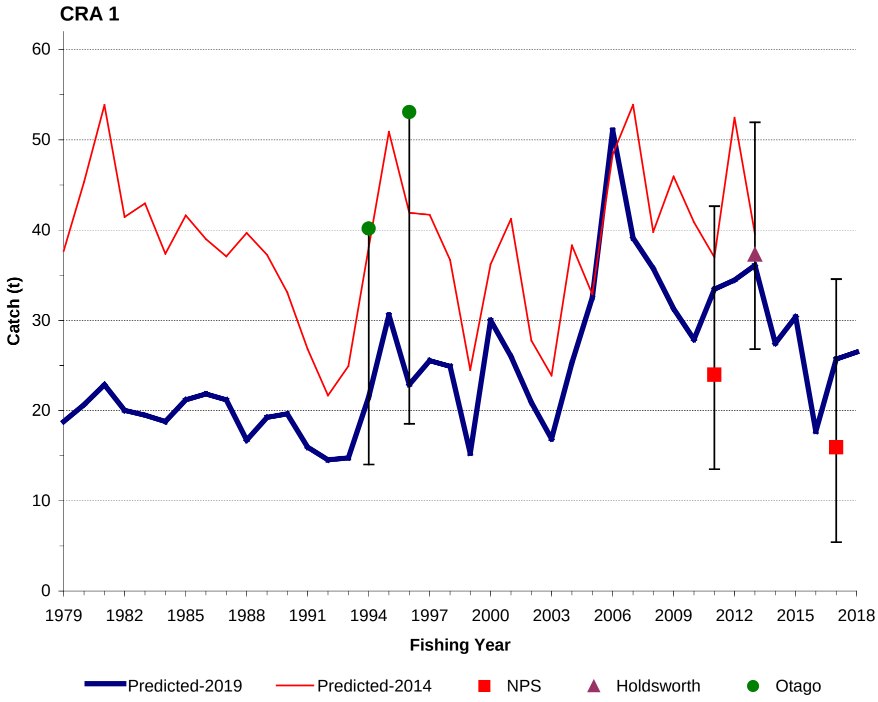


Figure 2: CRA 1 recreational catch trajectory (tonnes) (Eq. 2) based on the unstandardised (geometric mean) SS seasonal CPUE series for Statistical Areas 903 and 904 fitted to five recreational catch surveys (Eq. 1 and Table 2). Error bars are ±2 s.e., assuming a lognormal distribution, with the upper error bars for the two Otago estimates suppressed. Also shown is the equivalent recreational catch series used in the 2014 CRA 1 stock assessment.

1.3 Customary non-commercial fisheries

For general information on customary non-commercial catch refer to the Introduction – Rock Lobster chapter.

Fisheries New Zealand were asked to provide estimates of current and historical customary catches, and an appreciation of their uncertainty. Fisheries New Zealand advised that a constant customary catch of 10 t should be assumed. This was split between seasons with 90% assumed taken in the SS.

1.4 Illegal catch

For general information on illegal catch refer to the Introduction – Rock Lobster chapter.

The RLFAWG rejected using the MPI Compliance estimates of illegal catch (see table 8 in the Introduction – Rock Lobster chapter) to generate a time series of illegal catches for CRA 1. This decision was made because members felt that many of the estimates, particularly in the early 1990s, represented a substantial proportion of the legal catch and were not credible. Instead, the RLFAWG agreed to use a fixed percentage of the total commercial catch from 1981 to 2018, with both 10% and 20% selected by the WG. The RLFAWG also agreed to scale the resulting 38 year catch total proportionately to the annual standardised CPUE index over the same period. This series was started in 1981 because the McKoy "export discrepancy" procedure ended in 1980 (see following paragraph).

The following procedure was used to estimate illegal catch before 1981:

- Starting with the estimates of export discrepancies for all of New Zealand for 1974–80 (McKoy, unpublished data), the CRA 1 illegal catches for each of these seven years were estimated from the ratio of the reported commercial catch in CRA 1 relative to the total New Zealand reported commercial catch for the same years.
- The average ratio of the export discrepancy catch to the reported commercial catch was calculated for the period 1974–80 (see table 9 in the Introduction – Rock Lobster chapter). This

ratio was used to generate an illegal catch estimate for all years before 1981 with no data (1945 through 1973) by multiplying the reported catch by the average ratio. This approach was agreed by the RLFAWG on 15 Aug 2002.

The two annual illegal catch trajectories used in the 2019 CRA 1 stock assessment are plotted in Figure 33. When these annual catch estimates were used in the stock assessment model as seasonal catches, we assumed that they were distributed between seasons in the same proportion as the commercial catch for each year.

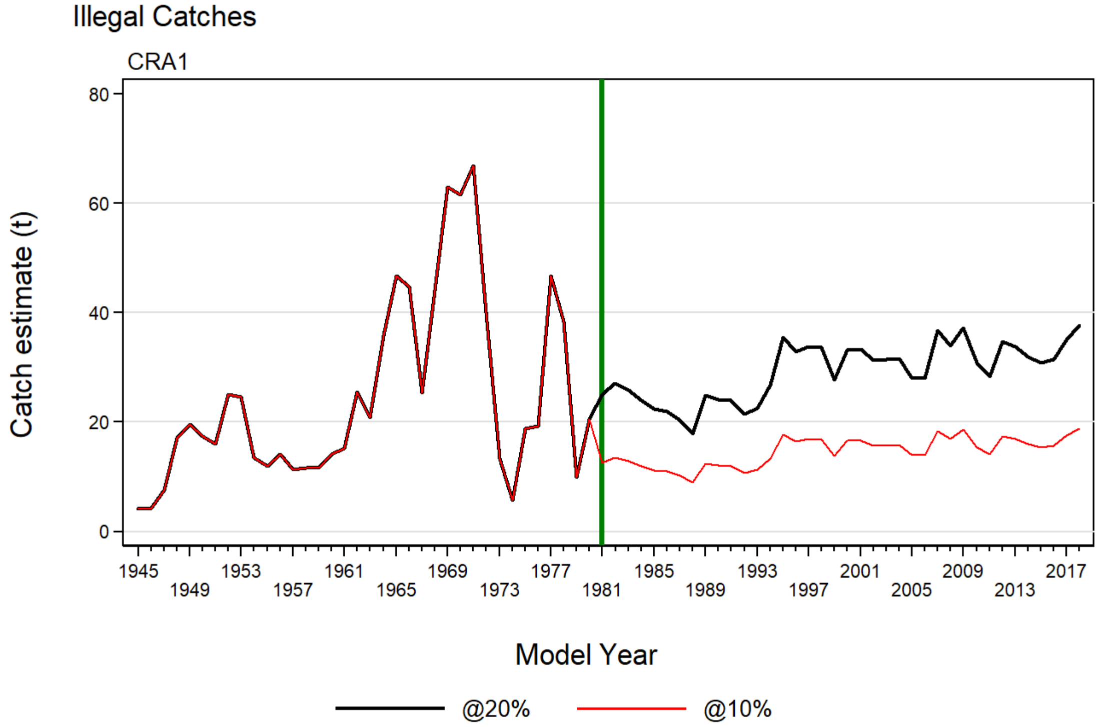


Figure 3: CRA 1 illegal catch trajectories for the 2019 stock assessment. The 10% and 20% labels refer to the percentage of the summed commercial catch from 1981 to 2018 that comprise the illegal catch over the same period. The vertical green line indicates 1981.

2. BIOLOGY

Refer to Section 2 in the Introductory Rock Lobster chapter for a general presentation of rock lobster biological considerations, including growth, natural mortality and puerulus settlement.

3. STOCKS AND AREAS

For information on stocks and areas refer to the Introduction – Rock Lobster chapter.

4. DECISION RULES AND MANAGEMENT PROCEDURES

For information on decision rules and management procedures refer to the Introduction – Rock Lobster chapter.

5. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS

For information on environmental and ecosystem considerations refer to the Introduction – Rock Lobster chapter.

6. STOCK ASSESSMENT

A new stock assessment was conducted in 2019 for CRA 1 and is summarised below. CRA 1 was last assessed in 2014 (Webber & Starr 2015). A management procedure was also developed and evaluated from that assessment.

In 2019 a stock assessment was attempted with separate sub-areas in the model, but it was unsuccessful due to the lack of data in some statistical areas.

Length-frequency sampling and tagging

The CRA 1 fishing industry participated in the voluntary logbook programme in 1994, and while the fishers did not use this design in most subsequent years, they have made a strong commitment to the voluntary logbook programme from 2014 to the present. Some observer (catch sampling) length-frequency data were collected in 1976, and the programme was resumed from 1997 to the present. Both sets of data were used in the 2019 stock assessment. Tagging effort in CRA 1 has largely focused on area 939, as well as 901 to a lesser degree. Due to the limited number of tags available in CRA 1, particularly in the East Northland area (Areas 903 and 904), the tagging data set was supplemented with CRA 2 tags from areas 905 and 906, which have had considerable tagging effort.

Model structure, including changes from 2014 CRA 1 stock assessment

The 2019 CRA 1 stock assessment made the following modelling changes from the 2014 stock assessment:

- the lobster stock dynamics (LSD) model was used;
- the model was fit to three CPUE series: CR from 1963 to 1973, FSU from 1979 to 1988, and CELR from 1989 to 2016, with the CELR series standardised by including a vessel explanatory variable based on vessels with at least five years in the fishery;
- the model was only fit to the first tag-recapture event, discarding all subsequent recovery events;
- size distribution sample weights by year, season and sampling source (logbook and catch sampling) are now scaled by the number of size measurements in each of the three sex categories (male, immature female, mature female);
- maximum size bin increased from 90 mm to 100 mm; 108 length bins, 36 for each sex category (males, immature and mature females), each 2 mm TW wide, beginning at left-hand edge 30 mm TW to the 100 mm TW plus group;
- handling mortality changed from 10% to 5% from 1990 onwards;
- only one selectivity epoch assumed due to the limited length frequency data prior to 1994.

The following assumptions are consistent with those made for the 2014 CRA 1 stock assessment:

- the reconstruction starts in 1945 from a size distribution in equilibrium with R_0;
- a single-stock model combining all information from Statistical Areas 901, 902, 903, 904, 905, and 939;
- a seasonal time step with autumn–winter (AW, April through to September) and spring–summer (SS) from 1979 through 2018;
- MLS and escape gap regulations are changed over the model reconstruction period. These changes were modelled by incorporating a time series of MLS regulations by sex;
- it was determined from the logbook data that the discard of large lobsters is not common in CRA 1, making it unnecessary to model this process at this time.

Data used and their sources are listed in Table 44 and Figure 4.

The assessment assumed that recreational catch was proportional to SS CPUE from 1979 through to 2018. Estimates from four large-scale ‘off-site’ CRA 1 recreational surveys in 1994, 1996, 2011 and 2017 along with one ‘on-site’ East Northland recreational survey in 2013 were fitted to the SS CPUE indices, assuming a lognormal distribution, to estimate a scaling factor that was used to scale the SS CPUE observations to the total annual CRA 1 recreational catch from 1979–2018 (see Section 1.2).

Table 4: Data types and sources available for the 2019 stock assessment of CRA 1. Fishing years are named from the first nine months, i.e., 1998–99 is called 1998. N/A – not applicable or not used; New Zealand RLIC – New Zealand Rock Lobster Industry Council Ltd.; FSU – Fisheries Statistics Unit; CELR – catch and effort landing returns.

		CRA 1	
Data type	**Data source**	**Begin year**	**End year**
CPUE	FSU and CELR	1979	2018
Observer proportions-at-size	Fisheries New Zealand and New Zealand RLIC	1976	2018
Logbook proportions-at-size	New Zealand RLIC	1994	2018
Tag recovery data	New Zealand RLIC and Fisheries New Zealand	1975	2018
Historical MLS regulations	Annala (1983), Fisheries New Zealand	1945	2018
Escape gap regulation changes	Annala (1983), Fisheries New Zealand	1945	2018
Puerulus settlement	Fisheries New Zealand	N/A	N/A
Retention	New Zealand RLIC	N/A	N/A

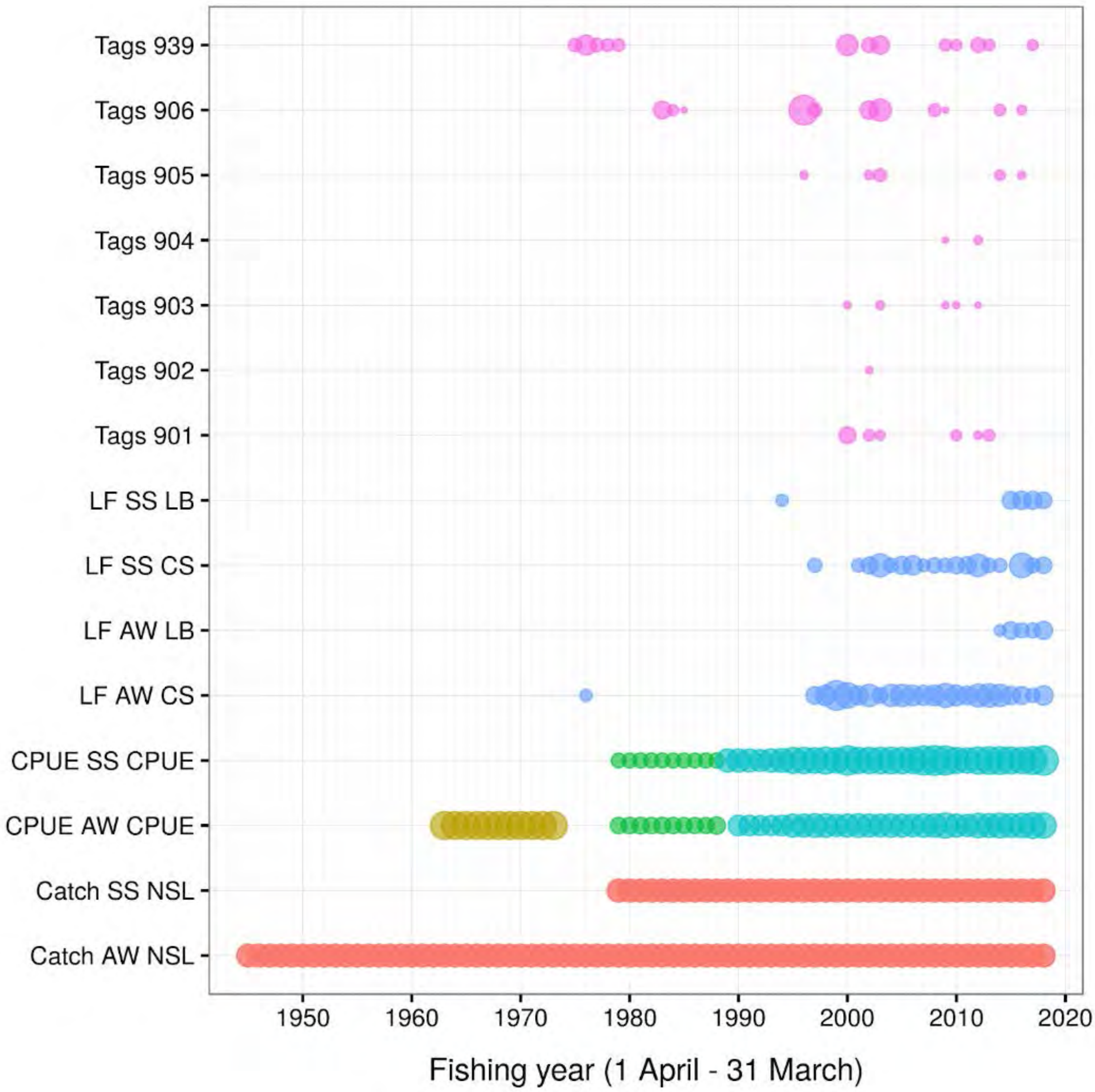


Figure 4: Extent of data for each fishing year used in the CRA 1 stock assessment. The size of the bubbles respectively represent the relative number of recaptured tags, the effective sample size for length frequency distributions, the standard deviation for CPUE, and a fixed size for catch. The different bubble colours represent different data sets (e.g. for CPUE, the CR, FSU and CELR series).

The numbers of male, immature female and mature female lobsters in each size class were updated in each season as a result of:

a) **Recruitment:** New recruits to the model were added equally for each sex for each season as a normal distribution with a mean size (32 mm) and standard deviation (2 mm), truncated at the smallest size class (30 mm). Recruitment in a specific year was determined by the mean recruitment parameter and the estimated annual deviations from mean recruitment. The vector of recruitment deviations in log space was assumed to be normally distributed with a mean of zero. Recruitment deviations were estimated for 1979 through to 2016. The 2017 and 2018 recruitment deviations were fixed to be the same as the 2016 recruitment deviation.

b) **Mortality:** Natural, fishing and handling mortalities were applied to each sex category in each size class. Natural mortality was assumed to be constant and independent of sex and length. Fishing mortality was determined from observed catch and model biomass, modified by legal sizes, sex-specific vulnerabilities, and selectivity. Handling mortality was assumed to be 10% for lobsters returned to the water before CRA entered the QMS in 1990 and was 5% for discarded lobsters thereafter. Two fisheries were modelled: one that operated only on fish above the MLS, excluding berried females (SL fishery – including legal commercial and recreational) and one that did not respect size limits and restrictions on berried females (NSL fishery – the illegal fishery plus the Maori customary fishery). Selectivity and vulnerability functions were otherwise the same for the SL and NSL fisheries. Vulnerability by sex category and season was estimated relative to males in AW, which were assumed to have the highest vulnerability. Instantaneous fishing mortality rates for each fishery were calculated using Newton-Raphson iteration (three iterations) from catch, model biomass and natural mortality.

c) **Fishery selectivity:** A three-parameter fishery selectivity function was assumed, with parameters describing the shapes of the ascending and descending limbs and the size at which vulnerability is at a maximum. Selectivity was estimated for a single epoch due to there being limited length-frequency data available prior to 1994. As in previous rock lobster stock assessments, the descending limb of the selectivity curve was fixed at a high value to prevent underestimating vulnerability of large lobsters.

d) **Growth and maturation:** For each size class and sex category, a growth transition matrix specified the probability of an individual remaining in the same size class or moving into all other size classes. Maturation of females was estimated as a two-parameter logistic curve.

Model fitting

The best fit to the data was obtained by maximising the total likelihood function using Stan, an 'open-source' modelling language optimised for performing Bayesian analyses. The model was fitted to both standardised CPUE series assuming a lognormal distribution, to proportions-at-length with a multinomial distribution, to sex ratios using a multinomial distribution, and to tag-recapture data with a robust normal distribution. For the CPUE likelihoods, CVs for each index value were initially set at the standard error from the GLM analysis along with an additional 25% of process error.

Proportions-at-length, assumed to be representative of the commercial catch, were available (see Table 44 and Figure 4) from observer catch sampling and voluntary logbooks: data were summarised for each data source by area/month strata and weighted by the commercial catch taken in each stratum, the number of lobsters measured by sex category, and the number of days sampled. Data from observers and logbooks were fitted separately, with proportions normalised and fitted within each sex class, and with the model estimating proportions-at-sex separately using a multinomial distribution. These data were weighted within the model using the iterative method of Francis (2011).

In all model runs, it was assumed that CPUE was directly proportional to vulnerable biomass, that growth was not density-dependent, and that there is no stock-recruit relationship. Parameters estimated, along with the priors, are provided in Table 55. Fixed parameters and their values are given in Table 66.

Table 5: Specifications for estimated parameters in the CRA 1 models including the upper and lower bounds, prior type, prior mean and standard deviation (SD), and the initial values.

Season	Sex	par	Lower bound	Upper bound	Prior type	Prior mean	Prior std/CV
		R_0	exp(1)	exp(25)	uniform		
		M	0.01	0.35	lognormal	0.12	0.4
		*Rdev*s	-2.3	2.3	uniform		
		qCR	exp(-25)	exp(0)	uniform		
		qFSU	exp(-25)	exp(0)	uniform		
		qCELR	exp(-25)	exp(0)	uniform		
		Mat50	10	80	normal	50	50
		Mat95	1	60	normal	10	10
	male	*Galpha*	1	20	normal	5	10
	male	*Gdiff*	0.001	0.99	beta	1	1
	male	*Gshape*	0.1	15	normal	4.81	5
	male	*GCV*	0.01	2	normal	0.59	5
	female	*Galpha*	1	20	normal	5	10
	female	*Gdiff*	0.001	0.99	beta	1	1
	female	*Gshape*	0.1	15	normal	4.51	5
	female	*GCV*	0.01	2	normal	0.82	5
		Gobs	0.0001	10	normal	1.48	1
	male	*SelLH*	1	50	normal	20	100
	female	*SelLH*	1	50	normal	20	100
	male	*SelM*	30	90	normal	50	50
	female	*SelM*	30	90	normal	50	50
SS	male	*vuln1*	0.01	1	beta	1	1
AW	immafem	*vuln2*	0.01	1	beta	1	1
SS	imma & matfem	*vuln3*	0.01	1	beta	1	1
AW	matfem	*vuln4*	0.01	1	beta	1	1
		qdrift	-0.08	0.08	normal	0	1
		U_0	0.00	0.99	beta	1	1
		Gdd	0.00	1.00	beta	1	1

Table 6: Fixed quantities used in the CRA 1 models.

Quantity	Value	Quantity	Value
data set weights		**fixed parameters**	
Tags	1	*sigmaR*	0.4
CELR CPUE	2.8	male length-weight *a*	4.16e-6
FSU CPUE	0.85	male length-weight *b*	2.935
CR CPUE	0.93	female length-weight *a*	1.3e-5
sex ratio	38	female length-weight *b*	2.545
LFs	7.62	**recruitment**	
catch and handling		last year of estimated *Rdevs*	2016
handling mortality, 1945–1989	0.10 t	years for estimating *Rdev*'s for projections	2007-2016
handling mortality, 1990–2018	0.05 t	years for estimating autocorrelation	1945-2016
projected SL commercial catch	130.56 t	recruitment size mean	32 mm
projected SL recreational catch	31.48 t	recruitment size SD	2 mm
Projected NSL illegal catch	37.68 t	recruitment autocorrelation	0.20
Projected NSL customary catch	10.0 t	**other**	
growth		Newton-Raphson iterations	3
length at Galpha	30	Tail compression: male bins	4 to 36
length at Gbeta	80	Tail compression: female immature bins	4 to 22
length at Gmin	0.5	Tail compression: female mature bins	4 to 36

Bayesian inference

Bayesian inference was used to estimate parameter uncertainty. This procedure was conducted in the following steps:

1. Model parameters were estimated by the LSD model using maximum likelihood and the prior probability distributions. These estimates are called the MAP (maximum a posteriori) estimates.
2. Samples from the joint posterior distribution of parameters were generated with Markov chain Monte Carlo (MCMC) simulations using the Hamiltonian Monte Carlo (HMC) algorithm.
3. Four chains, each with a burn-in period of 500 samples and length of 500 samples, were made, retaining every second sample, for a total of 1000 samples in the posterior distribution.

Performance indicators and results

Vulnerable biomass in the assessment model was determined by the MLS, selectivity, relative sex and seasonal vulnerability, and berried state for mature females. All mature females were assumed to be berried during the AW season, thus not vulnerable to the SL fishery, and not berried and vulnerable in the SS season.

Agreed indicators are summarised in Table 77. The interim target VB_{REF} was calculated as the vulnerable biomass (offset year) corresponding to CPUE of 1.4 kg/potlift, the midpoint of the plateau for the decision rule developed in 2014, assuming the catchability coefficient q at the median of the posterior distribution from the 2014 stock assessment. We used the q from 2014 because this was the value used to develop the rule and the 2019 and 2014 q estimates are not comparable because they represent fits to different CPUE time series. VB_{REF} is only intended to be used as an interim target until a CPUE-based rule can be operated again, possibly after the electronic reporting has been in place for at least five years (Figure 55).

Base case results (Figure 5, Figure 6 and Table 8) suggested that the AW biomass decreased to a low point in 1974, increased to a peak in the early-1980s, and decreased to the lowest point in the time series in 1992. From 1993 to present, the base case results suggest vulnerable AW biomass has remained relatively constant at a level just above the lowest point from 1993. Median estimated biomass at the beginning of 2019 was about 76% of VB_{REF} (90% credibility interval: 62–95%) (Table 8).

Note that B_{MSY} has been removed from this table as the RLFAWG and Plenary determined that more work needed to be conducted to evaluate how this quantity is determined for rock lobsters.

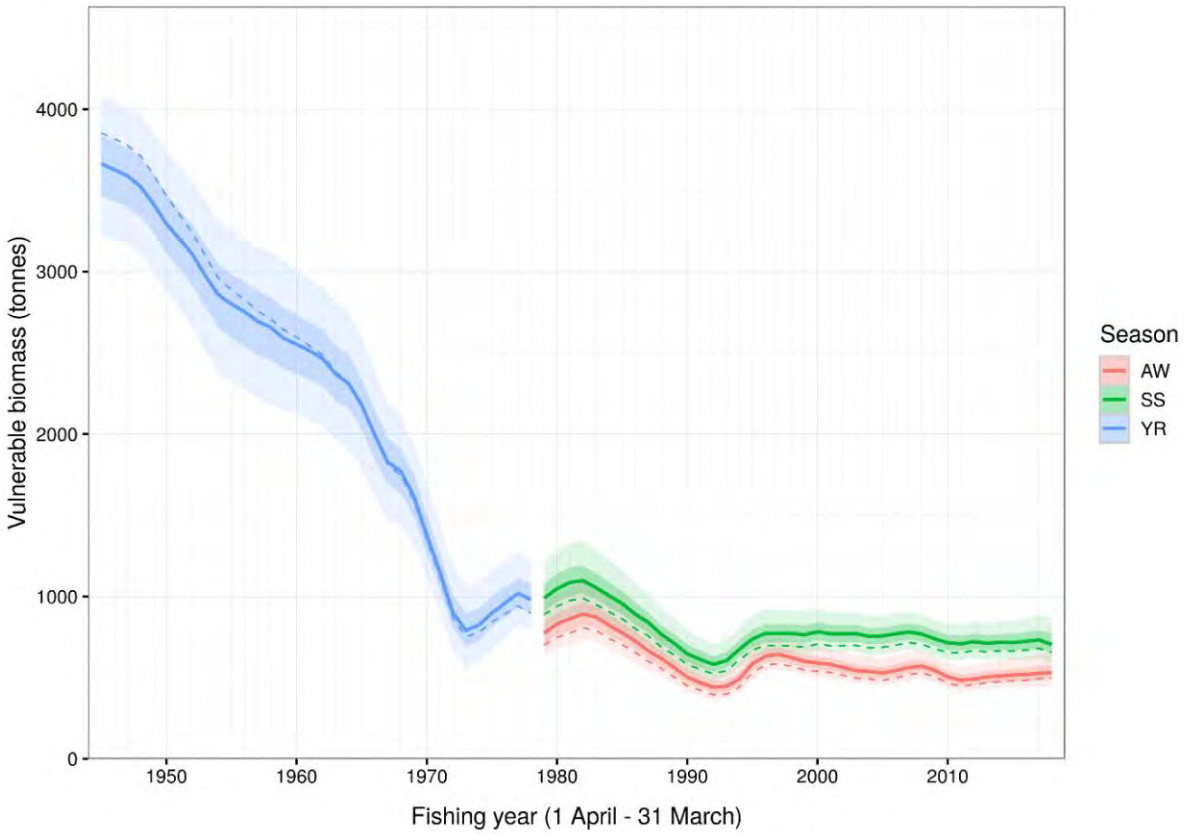


Figure 5: Posterior distribution of the CRA 1 base case vulnerable reference biomass by season, with dashed lines indicating the equivalent MAP estimates. Variable shading intensity indicates the 50% and 90% credible intervals.

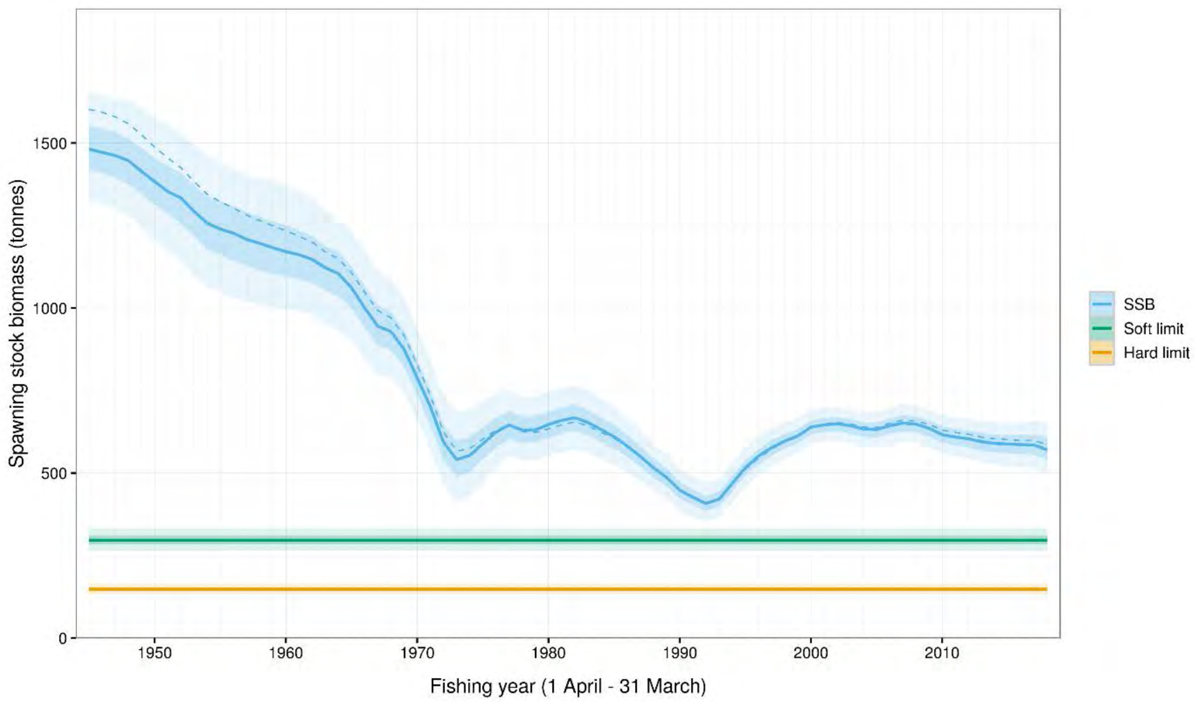


Figure 6: Posterior distribution of the CRA 1 base case spawning biomass, with dashed lines indicating the equivalent MAP estimates. Variable shading intensity indicates the 50% and 90% credible intervals.

Table 7: Reference points, performance indicators, and stock status probabilities for the CRA 1 stock assessment. [Continued on next page]

Type	Description
Reference Points	
B_0	beginning of season AW vulnerable reference biomass before fishing (1945)
SSB_0	female AW spawning stock biomass before fishing began (1945)
B_{0now}	equilibrium vulnerable reference biomass using mean 2007–2016 recruitment
SSB_{0now}	equilibrium female spawning biomass using mean 2007–2016 recruitment
B_{0TOT}	equilibrium total biomass
B_{MIN}	the lowest beginning AW vulnerable reference biomass in the series
B_{2019}	beginning of season AW vulnerable reference biomass for 2019
B_{2023}	beginning of season AW vulnerable reference biomass for 2023
VB_{2019}	Average of vulnerable biomass for season SS in 2018 and AW in 2019
VB_{2023}	Average of vulnerable biomass for season SS in 2022 and AW in 2023
SSB_{2019}	female spawning stock biomass at beginning of 2019 AW season
SSB_{2023}	female spawning stock biomass at beginning of 2023 AW season
$B_{2019TOT}$	beginning of season AW total biomass for 2019
$CPUE_{2019}$	AW CPUE at beginning of 2019 (in kg/potlift)
$CPUE_{2023}$	AW CPUE at beginning of 2023 (in kg/potlift)
H_{2018}	total handling mortality for 2018 (tonnes)
H_{2022}	total handling mortality for 2022 (tonnes)
VB_{REF}	Interim target vulnerable biomass associated with the CPUE midpoint on the plateau of the control rule (using the *q* estimated in the 2014 assessment)
Performance indicators	
B_{2019} / B_0	ratio of B_{2019} to B_0
B_{2023} / B_0	ratio of B_{2023} to B_0
B_{2023} / B_{2019}	ratio of B_{2023} to B_{2019}
SSB_{2019}/SSB_0	ratio of SSB_{2019} to SSB_0
SSB_{2023}/SSB_0	ratio of SSB_{2023} to SSB_0
SSB_{2023}/SSB_{2019}	ratio of SSB_{2023} to SSB_{2019}
$B_{2019TOT} / B_{0TOT}$	ratio of $B_{2019TOT}$ to B_{0TOT}

Type	Description
$B_{2023TOT}$ / B_{0TOT}	ratio of $B_{2023TOT}$ to B_{0TOT}
$B_{2023TOT}$ / $B_{2019TOT}$	ratio of $B_{2023TOT}$ to $B_{2019TOT}$
VB_{2019} / VB_{REF}	ratio of VB_{2019} to VB_{REF}
VB_{2023} / VB_{REF}	ratio of VB_{2023} to VB_{REF}
Probabilities	
P(B_{2019}>B_{MIN})	probability B_{2019} is greater than B_{MIN}
P(SSB_{2019}<20%SSB_0)	probability SSB_{2019} is less than 20%SSB_0
P(SSB_{2019}<10%SSB_0)	probability SSB_{2019} is less than 10%SSB_0
P(B_{2023}>B_{2019})	probability B_{2023} is greater than B_{2019}
P(SSB_{2023}>SSB_{2019})	probability SSB$_{2023}$ is greater than SSB$_{2019}$
P($B_{2023TOT}$>$B_{2019TOT}$)	probability $Btot_{2023}$ is greater than $Btot_{2019}$
P(VB_{2019}>VB_{REF})	Probability VB_{2019} is greater than VB_{REF}
P(VB_{2023}>VB_{REF})	Probability VB_{2023} is greater than VB_{REF}

Table 8: CRA 1 base case sensitivity runs and combined model MCMC outputs, reporting the 5th, 50th (median), and 95th quantiles of the posterior distributions. Growth increment values in mm TW, biomass values in tonnes and R_0 in numbers. Handling mortality (H) in tonnes and CPUE in kg/potlift. '–': not applicable. [Continued on next page]

	base			no_qdrift			start_1979		
	5%	**50%**	**95%**	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**
Likelihoods									
Total	11320	11330	11340	11270	11280	11300	10940	10950	10960
Prior	-4.358	3.489	12.990	-4.161	3.534	12.710	12.410	17.450	23.560
Tag	5413	5416	5421	5414	5417	5422	4809	4812	4817
Sex ratio	1925	1929	1934	1876	1880	1885	2006	2010	2015
LFs	4140	4146	4152	4143	4148	4154	4253	4259	4265
CPUE[CR]	-8.60	-7.58	-5.39	-8.487	-7.161	-4.544	-	-	-
CPUE[FSU]	-43.25	-41.40	-38.08	-43.24	-40.97	-37.47	-39.080	-36.690	-33.110
CPUE[CELR]	-119.40	-115.00	-109.30	-121.30	-116.80	-111.20	-119.50	-114.70	-109.00
Standard deviation normalised residuals (SDNR)									
Tag	1.475	1.563	1.711	1.477	1.564	1.719	1.428	1.497	1.591
Sex ratio	0.998	1.042	1.102	0.992	1.040	1.098	0.975	1.018	1.076
LFs	0.330	0.360	0.425	0.337	0.367	0.423	0.336	0.368	0.447
CPUE[CR]	0.894	0.978	1.132	0.894	1.008	1.188	-	-	-
CPUE[FSU]	1.008	1.099	1.232	1.013	1.113	1.256	0.982	1.090	1.235
CPUE[CELR]	1.028	1.103	1.189	1.036	1.106	1.191	1.025	1.105	1.191
Mean absolute residual (MAR)									
Tag	0.683	0.699	0.714	0.681	0.697	0.716	0.682	0.699	0.717
Sex ratio	0.630	0.708	0.779	0.627	0.714	0.798	0.637	0.703	0.767
LFs	0.100	0.106	0.112	0.101	0.106	0.112	0.100	0.106	0.112
CPUE[CR]	0.486	0.634	0.921	0.468	0.634	0.959	-	-	-
CPUE[FSU]	0.472	0.651	0.858	0.464	0.657	0.891	0.451	0.622	0.829
CPUE[CELR]	0.688	0.834	0.982	0.669	0.816	0.948	0.691	0.823	0.961
Parameters									
R_0	198600	230100	272400	202100	237000	284600	190500	218900	253800
M	0.093	0.108	0.125	0.094	0.111	0.131	0.074	0.090	0.109
q-drift	0.006	0.016	0.026	-	-	-	0.004	0.014	0.023
qCPUE	0.001	0.002	0.002	0.002	0.002	0.002	0.001	0.002	0.002
qFSU	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.001
qCR	0.029	0.038	0.049	0.031	0.040	0.053	-	-	-
mat50	46.820	50.170	52.310	47.010	50.230	52.390	46.170	49.720	51.910
mat95	8.175	12.700	20.530	8.338	12.490	20.490	6.403	10.790	18.120
Galpha male	14.790	16.310	17.700	14.840	16.290	17.860	16.220	17.920	19.400
Gbeta male	2.412	2.625	2.835	2.443	2.645	2.880	2.268	2.467	2.703
Gshape male	2.546	3.019	3.493	2.569	3.028	3.561	3.007	3.570	4.111
GCV male	0.388	0.405	0.422	0.389	0.405	0.424	0.387	0.406	0.425
Galpha female	17.100	18.530	19.690	17.750	19.060	19.850	17.180	18.580	19.680
Gbeta female	1.152	1.232	1.321	1.160	1.253	1.355	1.094	1.165	1.247
Gshape female	5.017	5.526	5.999	5.249	5.757	6.110	5.046	5.524	5.987
GCV female	0.734	0.773	0.811	0.734	0.773	0.811	0.756	0.796	0.838
StdObs	0.363	0.532	0.672	0.347	0.526	0.664	0.526	0.663	0.797
vuln1	0.724	0.757	0.789	0.714	0.743	0.776	0.690	0.728	0.767
vuln2	0.413	0.603	0.868	0.393	0.578	0.834	0.412	0.593	0.849
vuln3	0.525	0.641	0.814	0.517	0.629	0.816	0.481	0.596	0.728
vuln4	0.382	0.472	0.603	0.391	0.488	0.628	0.352	0.434	0.532

	base			no_qdrift			start_1979		
	5%	**50%**	**95%**	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**
SelL male	8.466	10.110	12.160	8.437	9.975	11.900	8.696	10.350	12.290
SelM male	59.450	62.160	65.200	59.360	61.940	64.920	59.170	62.030	64.800
SelL female	12.640	15.850	20.380	12.590	15.880	20.320	12.060	14.660	18.250
SelM female	64.100	69.780	78.390	63.540	69.180	77.530	62.570	67.210	73.190
U_0	-	-	-	-	-	-	0.092	0.133	0.182
Derived parameters: vulnerable reference biomass									
B_0	2810	3216	3642	2720	3169	3724	3168	4000	5009
B_{0now}	2664	3145	3694	2791	3322	3961	3100	3789	4757
B_{MIN}	356	430	513	304	362	430	331	403	498
B_{2019}	398	498	646	539	654	795	401	504	652
B_{2023}	237	433	714	415	643	885	267	459	745
B_{2019} / B_0	0.117	0.155	0.210	0.155	0.208	0.273	0.090	0.125	0.184
B_{2023} / B_0	0.071	0.135	0.231	0.128	0.202	0.297	0.064	0.115	0.201
B_{2023} / B_{2019}	0.524	0.849	1.248	0.692	0.965	1.275	0.602	0.888	1.262
Derived parameters: spawning biomass (females only)									
SSB_0	1327	1481	1653	1304	1482	1674	1422	1750	2146
SSB_{0now}	1232	1412	1621	1320	1515	1745	1398	1665	2037
SSB_{2019}	469	548	643	569	647	738	510	588	685
SSB_{2023}	400	545	724	533	684	847	452	595	773
SSB_{2019}/SSB_0	0.312	0.370	0.443	0.373	0.437	0.513	0.273	0.336	0.416
SSB_{2023}/SSB_0	0.267	0.369	0.498	0.354	0.456	0.579	0.249	0.338	0.456
SSB_{2023}/SSB_{2018}	0.787	0.969	1.175	0.867	1.025	1.190	0.818	0.988	1.195
Derived parameters: total biomass									
B_{0tot}	4362	4916	5502	4248	4864	5603	4819	5969	7398
B^{tot}_{2019}	1048	1255	1532	1311	1533	1792	1093	1282	1550
B^{tot}_{2023}	847	1200	1663	1121	1534	1997	897	1242	1728
B^{tot}_{2019}/B_0	0.206	0.256	0.326	0.253	0.316	0.394	0.164	0.213	0.290
B^{tot}_{2023}/B_0	0.168	0.242	0.351	0.226	0.314	0.423	0.144	0.208	0.309
B^{tot}_{2023}/B_{2019}	0.759	0.942	1.195	0.831	0.995	1.193	0..778	0.966	1.201
Derived parameters: vulnerable biomass									
VB_{REF}	-	801	-	-	801	-	-	801	-
VB_{2019}	499	607	763	634	765	922	489	607	759
VB_{2023}	353	540	811	524	746	998	374	577	822
VB_{2019} / VB_{REF}	0.623	0.757	0.952	0.790	0.954	1.150	0.610	0.758	0.946
VB_{2023} / VB_{REF}	0.411	0.674	1.012	0.654	0.930	1.245	0.466	0.695	1.026
Other derived parameters									
$CPUE_{2018}$	1.073	1.166	1.264	1.109	1.190	1.278	1.089	1.180	1.276
$CPUE_{2023}$	0.640	1.025	1.533	0.776	1.131	1.494	0.700	1.077	1.617
H_{2018}	2.124	2.367	2.645	2.003	2.206	2.445	2.122	2.386	2.652
H_{2023}	2.319	3.244	4.528	2.016	2.854	3.772	2.269	3.198	4.434
B_{male} / B_{female}	0.855	0.989	1.127	0.919	1.059	1.200	0.791	0.921	1.069
Probabilities									
$P(B_{2019}>B_{MIN})$		0.813			1.000			0.910	
$P(SSB_{2019}<20\%SSB_0)$		0.000			0.000			0.000	
$P(SSB_{2019}<10\%SSB_0)$		0.000			0.000			0.000	
$P(B_{2023}>B_{2019})$		0.254			0.408			0.298	
$P(SSB_{2023}>SSB_{2019})$		0.401			0.604			0.464	
$P(B^{tot}_{2023}> B^{tot}_{2019})$		0.329			0.477			0.389	
$P(VB_{2019}>VB_{REF})$		0.020			0.336			0.022	
$P(VB_{2023}>VB_{REF})$		0.053			0.364			0.064	

Two MCMC sensitivity runs were made:

i. without estimating the *q*-drift parameter; and

ii. starting the model in 1979.

Results from the base case and the two sensitivity trials are compared in Table 8.

Indicators based on B_0

Current vulnerable reference biomass is predicted to be at 16% of B_0 (B_{2019}/B_0 = 0.16 [90% credible interval (CI) = 0.12-0.21)] and is projected to decrease to 14% of B_0 by 2023 at current catch (B_{2023}/B_0 = 0.14 [90% CI = 0.07-0.23], Table 8).

The *no_qdrift* model estimated the relative vulnerable reference biomass to be 1.34 times higher than the relative vulnerable reference biomass for the base case (B_{2019}/B_0 = 0.21 [90% CI = 0.16-0.27]; Table 8).

The *start_1979* model estimated slightly higher unfished vulnerable reference biomass than the base case, resulting in a 2019 relative vulnerable reference biomass 81% of the base case (B_{2019}/B_0 = 0.13 [90% CI = 0.09-0.18]; Table 8).

B_{2019} was higher than B_{MIN} for all models, with a probability of 0.813 for the base case, 0.910 for the *start_1979* sensitivity, and 1.000 for the *no_qdrift* sensitivity (Table 8).

Indicators based on SSB_0

Current spawning stock biomass is predicted to be at 37% of SSB_0 (SSB_{2019}/SSB_0 = 0.37 [90% CI = 0.31-0.44] and projected to remain constant when projected at current catch (SSB_{2023}/SSB_0 0.37 [90% CI = 0.27-0.50]. There is zero probability of being below the soft limit (20% SSB_0). At current catch, there is probability of 0.40 that spawning biomass in 2023 will be higher than in 2019 (Table 8).

Relative spawning biomass in 2019 under the *no_qdrift* scenario was estimated to be 1.18 times higher than the base case (SSB_{2019}/SSB_0 = 0.44 [90% CI = 0.37-0.51]) (Table 8).

The *start_1979* model estimated spawning biomass to generally be higher than the base case, but because unfished spawning biomass was also estimated higher than the base case, the relative spawning biomass was estimated equal to or lower than the base case throughout the time series, resulting in a 2019 relative spawning biomass at 91% of the base case (SSB_{2019}/SSB_0 = 0.34 [90% CI = 0.27-0.42]; Table 8).

Indicators based on interim target VB_{REF}

The base model estimated that the offset-year vulnerable biomass at the start of 2019 was 67% of the VB_{REF} ([90% CI = 0.44-1.01]; Table 8). The *no_qdrift* model estimated that the offset-year vulnerable biomass at the start of 2019 was 93% of VB_{REF} ([90% CI = 0.65-1.25]) while the *start_1979* model estimate was 70% of VB_{REF} ([90% CI = 0.47-1.03]; Table 8).

Under current levels of catch, the probability that vulnerable biomass in 2023 would be above the VB_{REF} was 0.05 for the base case, 0.36 for the *no_qdrift* scenario, and 0.06 for the *start_1979* scenario (Table 8).

7. FUTURE RESEARCH CONSIDERATIONS

Future research considerations are similar for CRA 1 and CRA 3 and are therefore duplicated in each chapter. They include:

- Further develop a new method to derive target reference points for rock lobsters where, in the absence of a Management Procedure, catch may need to be held constant between full stock assessments.
- Re-evaluate the method used to determine Effective Sample Sizes for length composition data.
- Explore the potential to develop alternative growth models with fewer parameters, especially for cases when there are a limited number of datasets.
- Consider further analysing the potential for a bias in the estimation of growth that could result from the timing of tagging with respect to the timing of moulting.
- Review the validity of the prior for M.

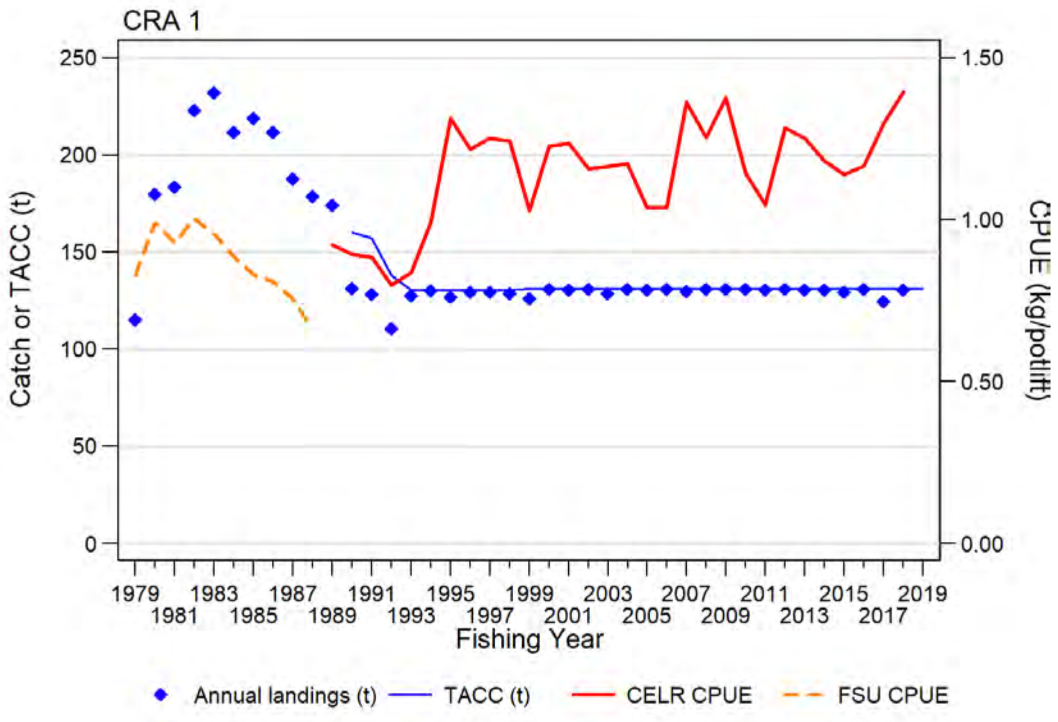
- Explore the utility of implementing standardised length frequencies that employ a methodology similar to that used for standardising CPUE.
- Review the methodology for analysing puerulus data and incorporating it into the model.
- Explore methods for developing a Bayesian version of a likelihood profile.

8. STATUS OF THE STOCKS

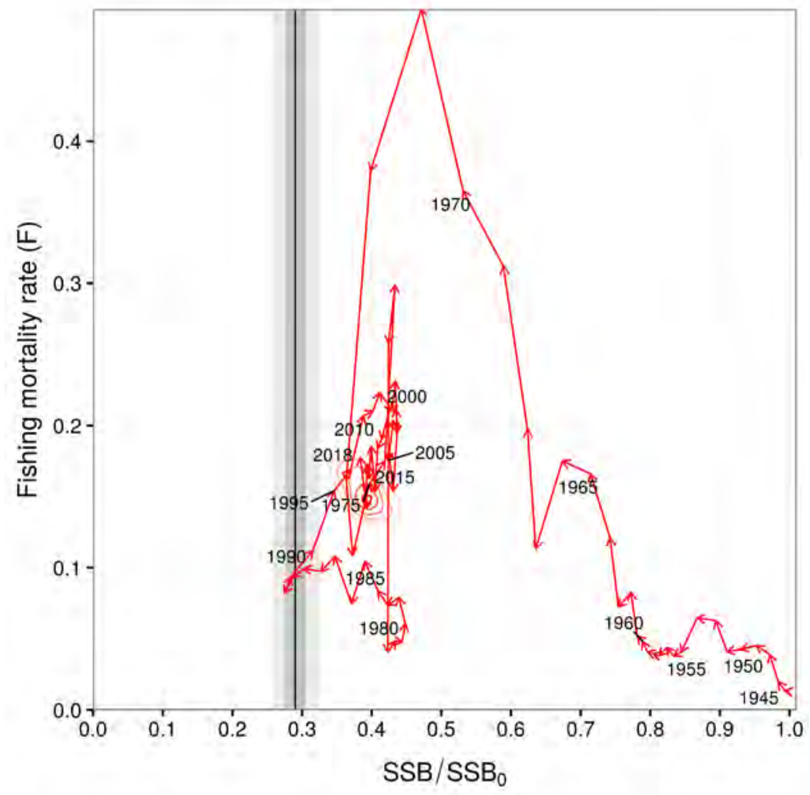
Stock structure assumptions
For the purposes of stock assessment and management, rock lobsters are assumed to constitute separate Fishstocks within each CRA Quota Management Area. There is likely to be some degree of relationship and/or exchange between Fishstocks in these CRA areas, either as a result of migration, larval dispersal or both.

Stock Status	
Year of Most Recent Assessment	2019
Assessment Runs Presented	Base case and 2 MCMC sensitivities
Reference Points	Interim target: VB_{REF}: vulnerable biomass (offset year) corresponding to CPUE of 1.4 kg/potlift (mid-point of plateau for decision rule) = 801 tonnes Soft limit: 20% SSB_0 (default) Hard limit: 10% SSB_0 (default)
Status in relation to Target	Biomass in 2019 was 67% of VB_{REF} VB_{2019} Unlikely (< 40%) to be at or above VB_{REF}
Status in relation to Limits	Very Unlikely (< 10%) that SSB_{2018} is below the soft and hard limits
Status in relation to Overfishing	Overfishing is About as Likely as Not (40–60%) to be occurring.

Historical Stock Status Trajectory and Current Status



Annual landings, TACC and standardised CPUE for CRA 1 from 1979 to 2018.



Snail trail summary of the CRA 1 base case model. The line tracks the median values for each axis from the MCMC posteriors and the cross marks the 90% credibility interval on both axes for the final model year (2013).

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass has been stable in recent years.
Recent Trend in Fishing Intensity or Proxy	Fishing mortality has been stable in recent years.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	Biomass will decline at current levels of catch.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Very Unlikely (< 10%) that $SSB_{2023} < 0.2SSB_0$ Hard Limit: Very Unlikely (< 10%) that $SSB_{2023} < 0.1SSB_0$
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Likely (> 60%)

Assessment Methodology		
Assessment Type	Level 1 – Full Quantitative Stock Assessment	
Assessment Method	Bayesian length-based model with MCMC posteriors	
Assessment Dates	Latest assessment: 2019	Next assessment: 2023
Overall assessment quality rank	1 – High Quality	
Main data inputs	- CPUE - Length-frequency data - Tagging data	1 – High Quality (all)
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	- New model software (LSD) - Added qdrift parameter - Split CPUE data (FSU and CELR) - Single selectivity for all years for each sex - Reinstated CR data	
Major Sources of Uncertainty	- Non-commercial catch (the levels of illegal and recreational catches) - Length frequency samples may not be representative of the fishery throughout all areas (particular issue) - Growth rate (limited tag data) - Model unable to predict sex ratios during spring–summer (SS) - Spatial heterogeneity of the observations throughout statistical areas may not be representative of the population	

Qualifying Comments
-

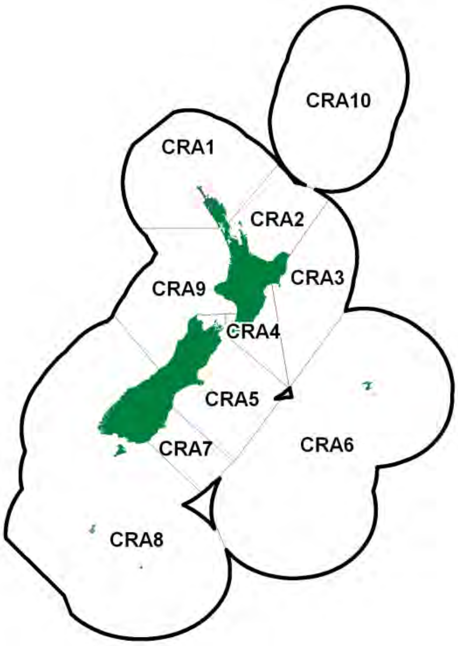
Environmental and Ecosystem Considerations	
Observer coverage	Observer coverage primarily for stock assessment needs.
Non-target fish and invertebrate catch	The levels of incidental catch landed from rock lobster potting ranged from 2–11% of the estimated rock lobster catch weight per QMA for the period 1989–2003. For all QMAs, the most frequently reported incidental species caught are, in decreasing order of catch across all stocks: octopus, conger eel, blue cod, trumpeter, sea perch, red cod, butterfish and leatherjackets.
Incidental catch of seabirds	Small numbers of shags have been reported historically in some CRA areas, but not in recent years.

	Fishers suggest the lack of recent shag captures is attributable to changes in pot design and baiting methodologies.
Incidental catch of marine mammals	From January 2000 until November 2018, 31 entanglements (29 marine mammal individuals, two individuals were entangled twice) were attributed to commercial or recreational rock lobster pot lines from around New Zealand, mainly around Kaikoura (DOC Marine Mammal Database).
Incidental catch of other protected species	There is no known incidental catch of other protected species in rock lobster fisheries.
Benthic interactions	No information exists regarding the benthic impacts of potting in New Zealand.

8. FOR FURTHER INFORMATION

For the list of references refer to the Introduction – Rock Lobster chapter.

ROCK LOBSTER (CRA 2)
(*Jasus edwardsii*) Crayfish, Kōura papatea, Pawharu



1. FISHERY SUMMARY

1.1 Commercial fisheries
Refer to the relevant text, tables and figures in Sections 1, 1.1 and 1.7 of the Introductory Rock Lobster chapter for a presentation of the CRA 2 commercial catches and CPUE.

Historical commercial landings and TACC values can be found in Figure 1. Historical commercial landings, TACC values and CPUE can be found in Table 1.

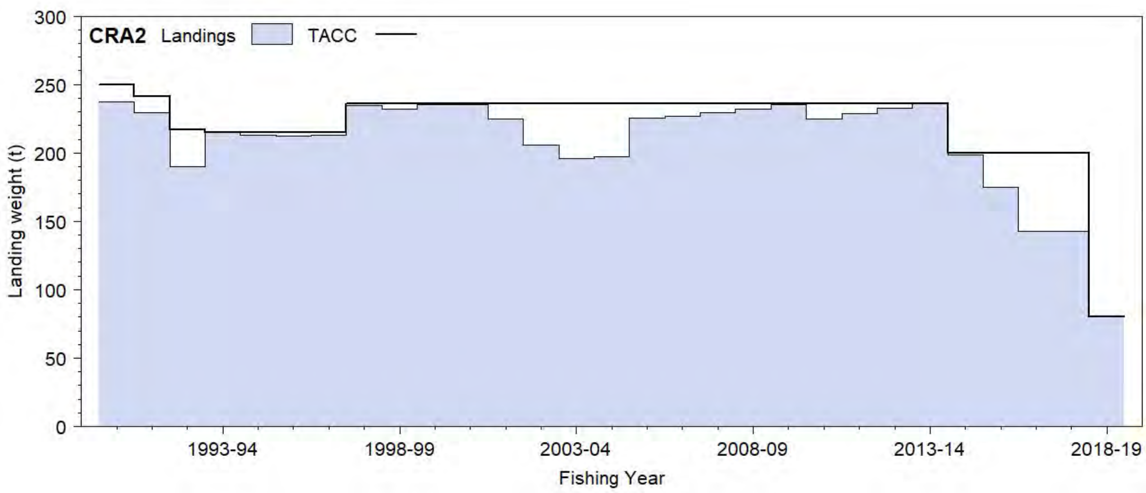


Figure 1: Historical landings and TACC for CRA 2

Table 1: Reported commercial catch (t) from QMRs or MHRs (after 1 October 2001), commercial TACC (t) and standardised CPUE (kg/potlift) (Starr 2019). The commercial catch and commercial TACC are reported for each fishing year since the species was included in the QMS on 1 April 1990. –, TAC not set for QMA or catch not available (current fishing year). The standardised CPUE are reported from 1979–80 to 2018–19. Sources of data: from 1979–80 to 1988–89 from the QMS-held FSU data; from 1989–90 to 2018–19 from the CELR data held by Fisheries New Zealand, using the 'F2' algorithm corrected for 'LFX' destination code landings (see text for definition). The series beginning from 1989–90 has been estimated using a vessel explanatory variable constrained to vessels with at least five years in the fishery. The analysis for the FSU period 1979–88 to 1988–89 does not use a vessel explanatory variable. '–': no data.

Fishing year	Catch	TACC	CPUE
1979–80	–	–	0.522
1980–81	–	–	0.628
1981–82	–	–	0.523
1982–83	–	–	0.436
1983–84	–	–	0.357
1984–85	–	–	0.345
1985–86	–	–	0.400
1986–87	–	–	0.361
1987–88	–	–	0.315
1988–89	–	–	0.343
1989–90	–	–	0.677
1990–91	237.6	249.5	0.564
1991–92	229.7	241.3	0.508
1992–93	190.3	216.6	0.453
1993–94	214.9	214.6	0.516
1994–95	212.8	214.6	0.625
1995–96	212.5	214.6	0.847
1996–97	213.2	214.6	1.030
1997–98	234.4	236.1	1.145
1998–99	232.3	236.1	1.173
1999–00	235.1	236.1	0.891
2000–01	235.4	236.1	0.748
2001–02	225.0	236.1	0.526
2002–03	205.7	236.1	0.395
2003–04	196.0	236.1	0.396
2004–05	197.3	236.1	0.468
2005–06	225.2	236.1	0.437
2006–07	226.5	236.1	0.519
2007–08	229.7	236.1	0.493
2008–09	232.3	236.1	0.465
2009–10	235.2	236.1	0.424
2010–11	224.8	236.1	0.377
2011–12	229.0	236.1	0.347
2012–13	234.3	236.1	0.367
2013–14	235.7	236.1	0.336
2014–15	198.6	200.0	0.299
2015–16	174.7	200.0	0.247
2016–17	142.5	200.0	0.258
2017–18	142.8	200.0	0.246
2018–19	78.1	80.0	0.380
2019–20	–	80.0	–

1.2. Recreational fisheries

For general information on recreational catch refer to the Introduction – Rock Lobster chapter.

Seven annual recreational survey catch estimates are available for CRA 2 (Table 2). Estimates from the two Kingett Mitchell National Surveys (Boyd et al. 2004, Boyd & Reilly 2004) were not accepted by the RLFAWG for the 2013 CRA 2 stock assessment (Starr et al. 2014a) because these survey estimates were considered implausibly high for CRA 2. The earlier 1994 and 1996 surveys, conducted by researchers at the University of Otago, were considered biased in a review of the available recreational surveys (unpublished minutes, Recreational Technical Working Group [NIWA, Auckland, 10–11 June 2004]) because the interview questions possibly underestimated fisher participation rates by allowing for an easy exit from the interview ('soft refusal' bias). These two early surveys continue to be used by the RLFAWG in spite of this advice because the estimates are plausible and no other recreational information is available for these years. Both the Boyd and the Otago surveys were potentially biased high because recreational logbook participants were not closely supervised and may not have accurately recorded their fishing activity. The much higher harvest estimates in the Boyd surveys were a result of higher claimed participation in saltwater fishing over the previous 12 months in the initial screening survey.

A large-scale population-based diary/interview survey was conducted under contract for MPI from 1 October 2011–30 September 2012 (National Panel Survey or NPS), with the intention of estimating FMA- and QMA-specific annual catches for all major finfish and non-finfish species (Heinemann et al. 2015). This survey was based on a design that resembled the New Zealand national census, making use of the census population strata ('mesh blocks') of dwellings as the basis for identifying recreational fishers. A door-to-door survey of households in randomly selected strata was used to select participants who would report their catch for an entire year. A structured and carefully designed Computer Assisted Telephone Interview (CATI) method was used to record harvest in detail from those who had fished. The survey results were thought to be plausible for CRA 2, with 69 fishers providing 168 interviews over the survey period (see table 60 in Wynne-Jones et al. 2014) with a relatively low CV (= 0.24). This survey made estimates of the distribution of fishing platforms used to take lobsters in CRA 2, with motor boats accounting for about three quarters of the effort and only 13% coming from land (Table 3). The primary capture method used to take rock lobster in CRA 2 is diving (83%) followed by potting (16%) (Table 3). The National Panel Survey was repeated in the 2017–18 October fishing year using directly comparable methods (Wynne-Jones et al. 2019).

Table 2: Information used to estimate recreational catch for CRA 2. The Holdsworth (2016) survey estimates are described in Starr (2017).

Survey	Numbers	Mean weight (kg)	Catch weight (t)	Assumed CV
1994 (Otago: Bradford 1997)	142 000	0.672[1]	95.42	1.5×0.24
1996 (Otago: Bradford 1998)	223 000	0.672[1]	149.86	1.5×0.24
2000 (Boyd & Reilly 2004)	324 000	–	235.9[2]	not used
2001 (Boyd et al. 2004)	331 000	–	241.4[2]	not used
2010 (Holdsworth 2016)	55 260	0.741	40.9	1.5×0.24
2011 (Holdsworth 2016)	31 602	0.700	22.1	1.5×0.24
2011 (NPS: Wynne-Jones et al. 2014)	58 413	0.701[3]	40.86	0.24[4]
2017 (NPS: Wynne-Jones et al. 2019)	19 123	0.743[5]	14.21	0.36[6]
Maximum reported s.111 landings (t) (in 2014–15)			2.036	

[1] SS mean weight (kg) calculated from commercial sampling data from 1994–96 assuming recreational minimum legal sizes (Starr et al. 2003). [2]As reported by Boyd & Reilly (2004) and Boyd et al. (2004). [3]Hartill & Davey (2015). [4]Estimate provided in Wynne-Jones et al. (2014). [5]Using data from Davey et al. (2019). [6]Estimate provided in Wynne-Jones et al. (2019).

Table 3: Fishing platform and capture method categories for CRA 2 during 2011–12 estimated by the national NPS recreational survey (Wynne-Jones et al. 2014). The final line shows the 2011–12 CRA 2 total estimates. CV = standard error of the estimate, which does not include error associated with the estimate of mean weight. [Continued on next page]

Category	Numbers	CV	Catch (t)	CV	Distribution (%)
Platform (Appendix 27.3 in Wynne-Jones et al. 2014)					
Trailer motor boat	36 489	0.27	25.49	0.27	62%
Larger motor boat or launch	8 231	0.46	5.76	0.46	14%
Trailer yacht	0		0		0%

Category	**Numbers**	**CV**	**Catch (t)**	**CV**	**Distribution (%)**
Larger yacht or keeler	3 891	0.75	2.73	0.75	7%
Kayak canoe or rowboat	1 771	0.69	1.24	0.69	3%
Off land including beach rocks or jetty	7 855	0.28	5.49	0.28	13%
Something else	218	1.01	0.15	1.01	0%
Capture method (Appendix 27.4 in Wynne-Jones et al. 2014)					
Rod or line (not long line)	0		0		0%
Long-line including set line contiki or kite	0		0		0%
Net (not including landing net used if caught on line)	0		0		0%
Pot (e.g., for crayfish)	9 106	0.60	6.38	0.60	16%
Dredge grapple or rake	0		0		0%
Hand gather or floundering from shore	635	0.94	0.44	0.94	1%
Hand gather by diving	48 714	0.37	34.03	0.37	83%
Spearfishing	0		0		0%
Some other method	0		0		0%
Total	58 455	0.24	40.86[1]	0.24	100%

[1] Uses mean weight estimate of 701 g (Hartill & Davey 2015).

For both NPS surveys (Wynne-Jones et al., 2014 and 2019), panellists provided data in terms of number of fish. Mean recreational catch weights for the most important finfish and non-finfish species QMAs were estimated in parallel projects (Hartill & Davey 2015, Davey et al. 2019).

A recreational catch vector was developed by assuming that recreational catch has been proportional to the CRA 2 SS abundance, as reflected by SS CPUE. By agreement in the RLFAWG, the recreational catch vector was based on five of the seven survey estimates (in tonnes – see Table 2) from 1994 (Otago), 1996 (Otago), 2010 (Holdsworth), 2011 (Holdsworth), and the 2011 NPS survey. The 2011 NPS survey was assumed to be the least biased and most precise so the estimated CV for this survey (0.24) was assumed. The CVs for the remaining surveys were assumed to be 50% higher than that of the NPS survey. A scalar quantity q was estimated by obtaining the best fit to these survey estimates when minimising a lognormal distribution using the CVs indicated in Table 2:

$$W_t = w_t \; N_t$$

$$\hat{W}_t = \hat{q} \;\; CPUE_t \text{ if } t = 1 \text{ (1994 Otago), } = 2 \text{ (1996 Otago), } = 3 \text{ (2010 Holdsworth), } = 4 \text{ (2011 Holdsworth), } = 5 \text{ (2011 LSMS)}$$

$$\mathrm{LL} = \sum_{t=1}^{5} \left(\frac{\left(\mathrm{LN}(W_t) - \mathrm{LN}(\hat{W}_t)\right)^2}{2\sigma_t^2} \right)$$

where

$w_t =$ mean spring/summer weight >= MLS for sampled lobster in year/survey t for CRA2

$N_t =$ mean number lobsters in year/survey t for CRA2

$CPUE_y =$ spring/summer standardised CPUE from 1979 to 2016 for CRA2

$\hat{W}_y =$ estimated recreational catch by weight for year y for CRA2

Recreational catch was estimated as follows:

$$\hat{W}_y = \hat{q} \;\; CPUE_y \text{ if } y >= 1979$$

$$\hat{W}_{1945} = 0.2 * \; \hat{W}_{1979}$$

$$\hat{W}_y = \; \hat{W}_{y-1} + \frac{(\; \hat{W}_{1979} - \; \hat{W}_{1945})}{(1979 - 1945)} \text{ if } y > 1945 \;\&\; y < 1979$$

The recreational catch trajectory closely matches the 2011 NPS and the 2010 Holdsworth observations, while missing the 2011 Holdsworth observation and both Otago observations (Figure 2). This pattern is consistent with the CV assumptions. The *q* parameter is estimated to be 96 t/CPUE-unit and the recreational catch vector accounts for about 2050 t of historical catch from 1979 to 2016. Recreational catch was split between seasons, with 79% assumed taken in the SS and the remainder in AW. The 79%/21% split between seasons is the mean of the seasonal splits observed from the 2011 CRA 2 NPS survey and the 2010/2011 values from the two surveys of the western Bay of Plenty (J. Holdsworth, pers. comm.).

For assessments conducted since 2006, the RLFAWG has included recreational landings made by commercial vessels under Section 111 of the Fisheries Act. Greenweight landings with destination code 'F' were extracted from the CRACE database (Bentley et al. 2005), which showed a maximum annual value of 2036 kg for CRA 2, occurring in 2014–15 t (see table 7 in the Introduction – Rock Lobster chapter). The RLFAWG has agreed to add the maximum catch estimate to the estimated recreational catch in each year since 1979 (Figure 2), increasing the total 1979–2016 recreational catch in the model to 2130 t.

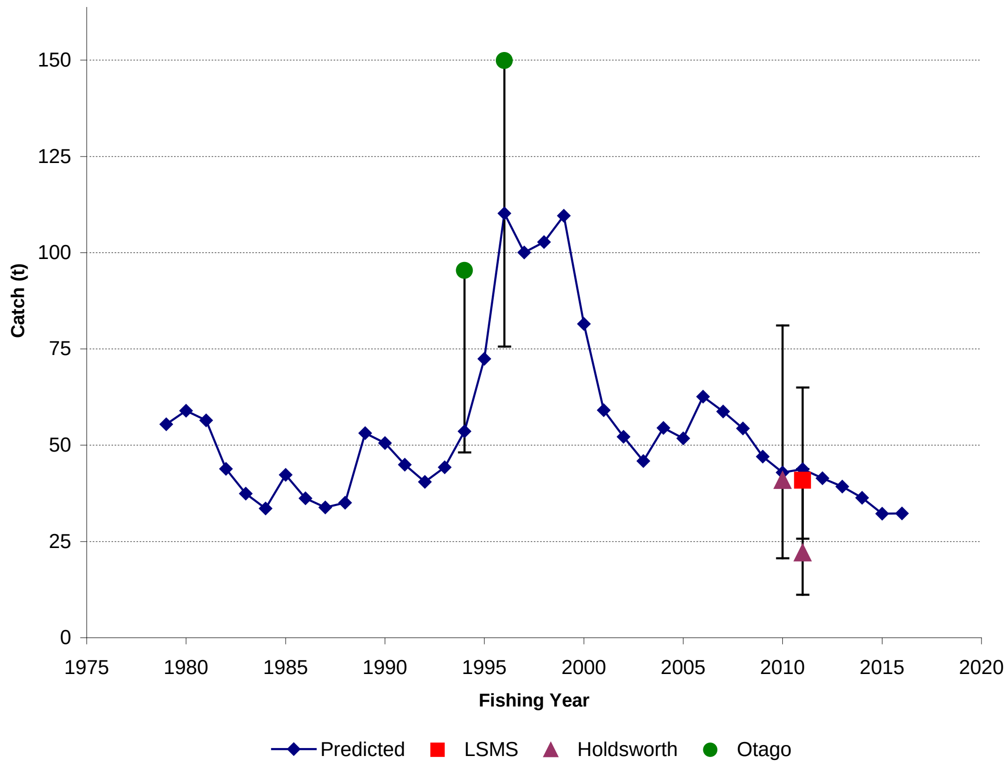


Figure 2: CRA 2 recreational catch trajectory (t) based on the SS seasonal CPUE series fitted to five recreational catch surveys (Table 2). Error bars are ±2 s.e.s, assuming a lognormal distribution, with the upper error bars for the two Otago estimates suppressed.

1.3 Customary non-commercial fisheries

For general information on customary non-commercial catch refer to the Introduction – Rock Lobster chapter.

CRA 2 customary catches were included in the 2013 stock assessment using a constant catch of 10 tonnes/year over the entire reconstruction period of 1945 to 2012 (Starr et al. 2014a). When the RLFAWG discussed the data to be used in the 2017 CRA 2 stock assessment, there was consensus to lower the constant value used for this catch category to 5 tonnes/year in recognition that some customary catch is included in the recreational catch estimate and advice that 10 tonnes/year was likely to be too high (see table 6 in the Introduction – Rock Lobster chapter). Customary catches were split between seasons, with 90% assumed taken in the SS and the balance in the AW.

1.4 Illegal catches

For general information on illegal catch refer to the Introduction – Rock Lobster chapter.

CRA 2 illegal catches from 1990 to 2001 were included in the 2013 stock assessment by using the values provided by MPI Compliance given in table 8 of the Introduction – Rock Lobster chapter. A constant illegal catch of 88 tonnes/year was used to fill in the missing years from 2002 to 2012. Years before 2001 without estimated illegal catches were interpolated. When the RLFAWG discussed the data to be used in the 2017 CRA 2 stock assessment, it was generally agreed that a constant illegal catch of 88 tonnes/year beginning in 1996 was likely to be too large. The RLFAWG also agreed that the value of 88 tonnes (=83+5 tonnes, table 8, Introduction – Rock Lobster chapter) for 1996 was potentially real because of the high CPUE in that year but that illegal catches had been dropping since then. Consequently, the RLFAWG agreed to linearly decrease the illegal catch trajectory from 88 tonnes in 1996 to an assumed value of 40 tonnes in 2016. The MPI 2001 estimate of 88 tonnes for CRA 2 illegal catch was discarded under this assumption.

2. BIOLOGY

Refer to Section 2 in the Introduction – Rock Lobster chapter for a general presentation of rock lobster biological considerations, including growth, natural mortality and puerulus settlement.

3. STOCKS AND AREAS

For information on stocks and areas refer to the Introduction – Rock Lobster chapter.

4. DECISION RULES AND MANAGEMENT PROCEDURES

For information on decision rules and management procedures refer to the Introduction – Rock Lobster chapter.

5. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS

For information on environmental and ecosystem considerations refer to the Introduction – Rock Lobster chapter.

6. STOCK ASSESSMENT

This section describes a stock assessment for CRA 2 that was conducted in 2017. The text reflects the TAC, TACC and allowances that were current at the time each assessment was completed.

The 2017 CRA 2 stock assessment marks the transition from the multi-stock length-based model (MSLM) of Haist et al. (2009) to the new lobster stock dynamics (LSD) model (Webber et al. 2018b). This change was made to consolidate the code in a software environment with fewer constraints than in the previous ADMB software environment. Extensive testing was made to satisfy the stock assessment team that the two models provided equivalent results.

Length-frequency sampling and tagging

The CRA 2 fishing industry made a strong commitment to the voluntary logbook programme when it was first introduced in 1993 and has continued to use this design as the primary source of stock monitoring information in this fishery. CRA 2 was also identified in the mid-1990s as an important region for tagging experiments, which resulted in considerable tagging effort expended in this QMA. There is also an auxiliary observer sampling programme in CRA 2. Twelve sampling days have been assigned to this programme in recent years; the primary purpose of this additional sampling to serve as a check on the voluntary logbook programme. Both sets of data were used in the 2017 stock assessment.

Model structure, including changes from 2013 CRA 2 stock assessment

The 2017 CRA 2 stock assessment made the following modelling changes from the 2013 stock assessment:

- the reconstruction starts in 1979 from a size distribution in equilibrium with R_0 and an initial estimated exploitation rate;
- it was fitted to two CPUE series: FSU from 1979 to 1988 and CELR from 1989 to 2016, with the CELR series standardised by including a vessel explanatory variable based on vessels with at least five years in the fishery;
- no density-dependent growth;
- only fit to the first tag-recapture event, discarding all subsequent recovery events;
- the size distribution sample weights by year, season and sampling source (logbook and catch sampling) are now scaled by the number of size measurements in each of the three sex categories (male, immature female, mature female).

The following assumptions are consistent with those made for the 2013 CRA 2 stock assessment:

- a single-stock model combining all information from Statistical Areas 905, 906, 907 and 908;
- a seasonal time step with autumn–winter (AW, April through to September) and spring–summer (SS) from 1979 through to 2016;
- 93 length bins, 31 for each sex category (males, immature and mature females), each 2 mm TW wide, beginning at left-hand edge 30 mm TW;
- MLS and escape gap regulations are changed over the model reconstruction period. These changes were modelled by incorporating a time series of MLS regulations by sex. Escape gap regulation changes were modelled by estimating separate selectivity functions before and after 1993;
- it was determined from the logbook data that the discarding of large lobsters is not frequent in CRA 2, making it unnecessary to model this process at this time.

Data used and their sources are listed in Table 4 and Figure 3.

The assessment assumed that recreational catch was proportional to SS CPUE from 1979 through to 2016. Estimates from three large-scale 'off-site' CRA 2 recreational surveys in 1994, 1996 and 2011 along with two 'on-site' western Bay of Plenty recreational surveys in 2010 and 2011 were fitted to the SS CPUE indices, assuming a lognormal distribution, to estimate a scaling factor that was used to scale the SS CPUE observations to the total annual CRA 2 recreational catch from 1979–2016.

Table 4: Data types and sources for the 2017 stock assessment of CRA 2. Fishing years are named from the first nine months, i.e., 1998–99 is called 1998. N/A – not applicable or not used; NZ RLIC – NZ Rock Lobster Industry Council Ltd.; FSU: Fisheries Statistics Unit; CELR: catch and effort landing returns.

		CRA 2	
Data type	**Data source**	**Begin year**	**End year**
CPUE	FSU	1979	1988
CPUE	CELR	1989	2016
Observer proportions-at-size	Fisheries New Zealand and NZ RLIC	1986	2016
Logbook proportions-at-size	NZ RLIC	1993	2016
Tag recovery data	NZ RLIC and Fisheries New Zealand	1983	2016
Historical MLS regulations	Fisheries New Zealand	1979	2016
Escape gap regulation changes	Annala (1983), Fisheries New Zealand	1979	2016
Puerulus settlement	Fisheries New Zealand	N/A	N/A
Retention	NZ RLIC	N/A	N/A

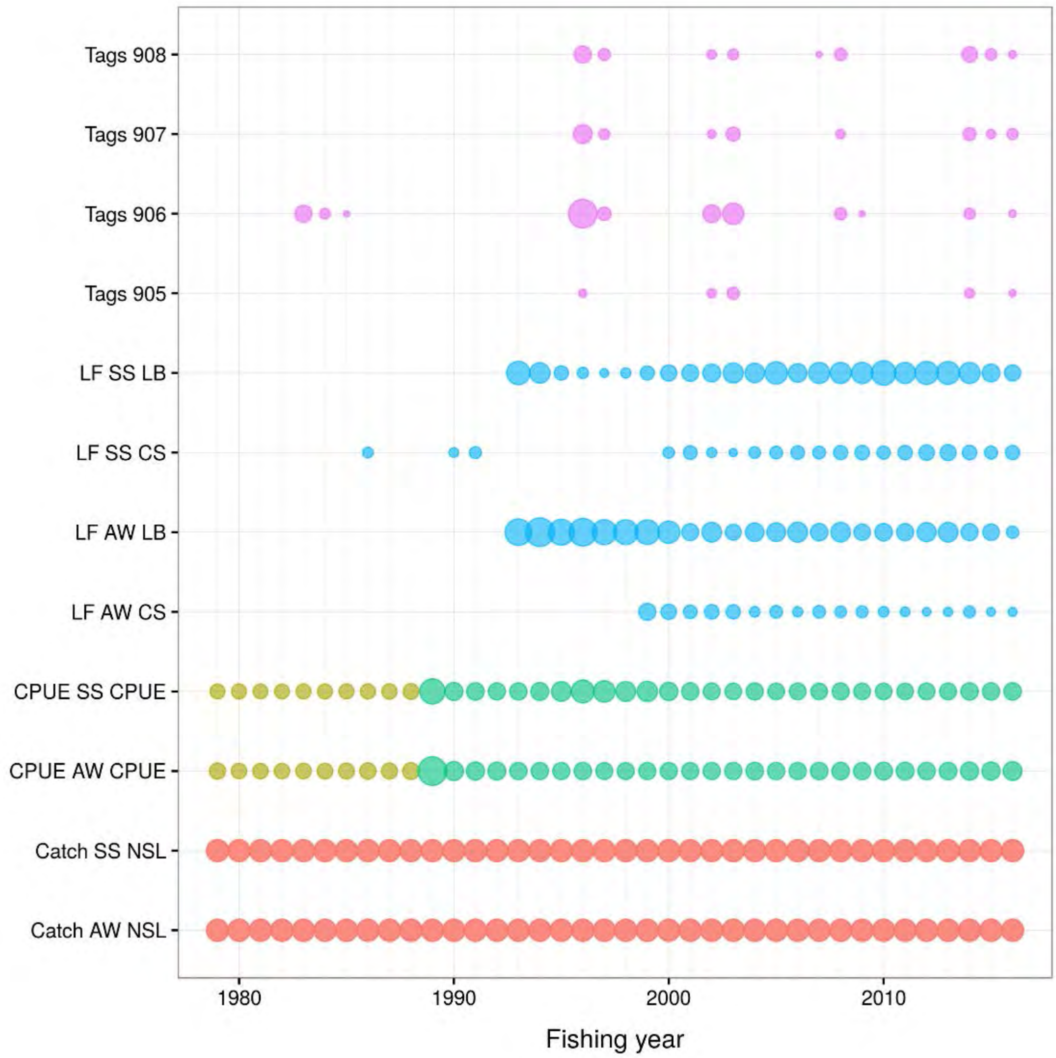


Figure 3: Data extent by fishing year used in the CRA 2 stock assessment. The size of each bubble represents the relative amount of data for each data type.

The numbers of male, immature female and mature female lobsters in each size class were updated in each season as a result of:

a) **Recruitment:** New recruits to the model were added equally for each sex for each season as a normal distribution with a mean size (32 mm) and standard deviation (2 mm), truncated at the smallest size class (30 mm). Recruitment in a specific year was determined by the mean recruitment parameter and the estimated annual deviations from mean recruitment. The vector of recruitment deviations in log space was assumed to be normally distributed with a mean of zero. Recruitment deviations were estimated for 1979 through to 2014. The 2015 and 2016 recruitment deviations were fixed to be the same as the 2014 recruitment deviation.

b) **Mortality:** Natural, fishing and handling mortalities were applied to each sex category in each size class. Natural mortality was assumed to be constant and independent of sex and length. Fishing mortality was determined from observed catch and model biomass, modified by legal sizes, sex-specific vulnerabilities, and selectivity. Handling mortality was assumed to be 10% for lobsters returned to the water before CRA entered the QMS in 1990 and was 5% for discarded lobsters thereafter. Two fisheries were modelled: one that operated only on fish above the MLS, excluding berried females (SL fishery – including legal commercial and recreational) and one that did not respect size limits and restrictions on berried females (NSL fishery – the illegal fishery plus the Maori customary fishery). Selectivity and vulnerability functions were otherwise the same for the SL and NSL fisheries. Vulnerability by sex category and season was estimated relative to males in AW, which were assumed to have the highest vulnerability.

Instantaneous fishing mortality rates for each fishery were calculated using Newton-Raphson iteration (three iterations) from catch, model biomass and natural mortality.

c) **Fishery selectivity:** A three-parameter fishery selectivity function was assumed, with parameters describing the shapes of the ascending and descending limbs and the size at which vulnerability is at a maximum. Selectivity was estimated for two separate epochs, pre-1993 and 1993–2016. As in previous rock lobster stock assessments, the descending limb of the selectivity curve was fixed at a high value to prevent underestimating vulnerability of large lobsters.

d) **Growth and maturation:** For each size class and sex category, a growth transition matrix specified the probability of an individual remaining in the same size class or moving into all other size classes. Maturation of females was estimated as a two-parameter logistic curve.

Model fitting

The best fit to the data was obtained by maximising the total likelihood function using Stan, an 'open-source' modelling language optimised for performing Bayesian analyses. The model was fitted to both standardised CPUE series assuming a lognormal distribution, to proportions-at-length with multinomial distribution, to sex ratios using multinomial distribution, and to tag-recapture data with robust normal distribution. For the CPUE likelihoods, CVs for each index value were initially set at the standard error from the GLM analysis along with an additional 25% of process error.

Proportions-at-length, assumed to be representative of the commercial catch, were available (see Table 4 and Figure 3) from observer catch sampling and voluntary logbooks: data were summarised for each data source by area/month strata and weighted by the commercial catch taken in each stratum, the number of lobsters measured by sex category, and the number of days sampled. Data from observers and logbooks were fitted separately, with proportions normalised and fitted within each sex class, and with the model estimating proportions-at-sex separately using a multinomial distribution. These data were weighted within the model using the iterative method of Francis (2011).

In all model runs, it was assumed that CPUE was directly proportional to vulnerable biomass, that growth was not density-dependent, and that there is no stock-recruit relationship. Parameters estimated, along with the priors, are provided in Table 5. Fixed parameters and their values are given in Table 6.

Table 5: Parameters estimated and priors used in the base case assessment for CRA 2. Prior type abbreviations: U – uniform; N – normal; L – lognormal.

Season	Sex	Par	Lower bound	Upper bound	Prior type	Prior mean	Prior std/CV	Initial value
		R_0	1	7e10				18
		M	0.01	0.35	2	0.12	0.4	0.12
		Rdevs[1]	-2.3	2.3	1	0	*sigmaR*	0
		qFSU	1e-11	1	0			-6
		qCELR	1e-11	1	0			-6
		U_{init}	0	1	0			0
		q-drift	-0.08	0.08	0			0
		mat50	30	80	1	50	15	50
		mat95	1	60	1	10	10	5
	male	*Galpha*	1	20	0			3.5
	male	*Gdiff*	0.001	1	0			0.8
	female	*Galpha*	1	20	0			3.5
	female	*Gdiff*	0.001	1	0			0.5
	male	*Gshape*	0.1	15	1	4.81	1.0	4.8
	male	*GCV*	0.01	2	1	0.59	0.3	0.59
	female	*Gshape*	0.1	15	1	4.51	1.0	4.5
	female	*GCV*	0.01	2	1	0.82	0.3	0.82
		Gobs	0.00001	10	1	1.48	0.074	0.4
	male	*SelLH*	1	50	0			4.1
	female	*SelLH*	1	50	0			9.2
	male	*SelMax*	30	90	0			55
	female	*SelMax*	30	90	0			64
SS	male	*vuln1*	0.01	1	0			0.8
AW	immafem	*vuln2*	0.01	1	0			0.84
SS	imma & matfem	*vuln3*	0.01	1	0			0.8
AW	matfem	*vuln4*	0.01	1	0			0.8

[1] Normal in log space = lognormal (bounds equivalent to –10 to 10).

Table 6: Fixed values used in base case assessment for CRA 2.

Quantity	Value	Quantity	Value
	Weights		**Fixed parameters**
tags	1	*sigmaR*	0.4
CELR CPUE	2.7	*CPUEpow*	1
FSU CPUE	3	*GDD*	0
sex ratio	22.0	*SelRH*	200
length frequencies	7.3	male length-weight *a*	4.16E-06
		male length-weight *b*	2.9354
		female length-weight *a*	1.30E-05
process error FSU/CELR 1979–2016	0.25	female length-weight *b*	2.5452
Newton-Raphson iterations	3		**Other**
last year of estimated *Rdevs*	2014	handling mortality, 1979–89	0.10
years for *Rdev* projections	2005–14	handling mortality, 1990–2016	0.05
		min survival proportion	0.02
		CRA 2 reference years	1979–81
		projected SL catch	184
		projected NSL catch	45
		marine reserve proportion	0
		male bins	4 to 31
		female immature bins	4 to 20
		female mature bins	6 to 31

Bayesian inference

Bayesian inference was used to estimate parameter uncertainty. This procedure was conducted in the following steps:

1. Model parameters were estimated by the LSD model using maximum likelihood and the prior probability distributions. These estimates are called the MAP (maximum a posteriori) estimates.
2. Samples from the joint posterior distribution of parameters were generated with Markov chain Monte Carlo (MCMC) simulations using the Hamiltonian Monte Carlo (HMC) algorithm.
3. Four chains, each with a burn-in period of 500 samples and length of 500 samples, were made, retaining every second sample, for a total of 1000 samples in the posterior distribution.

Performance indicators and results

Vulnerable biomass in the assessment model was determined by the MLS, selectivity, relative sex and seasonal vulnerability, and berried state for mature females. All mature females were assumed to be berried during the AW season, thus not vulnerable to the SL fishery, and not berried and vulnerable in the SS season.

Agreed indicators are summarised in Table 7. B_{REF}, based on the 1979–81 vulnerable biomass calculated with the current MLS and selectivity, was carried over from the 2013 CRA 2 stock assessment. However, this three-year period, which was characterised by an apparently stable and low (relative to peak abundance in 1996) trajectory in the 2013 assessment, shifted in the 2017 assessment to a steeply descending biomass trajectory starting from a level that was as high or higher than the 1996 peak (Figure 4).

Base case results (Figure 4, Figure 5 and Table 8) suggested that the AW biomass decreased to a low point in 1992, increased to a peak in the mid-1990s, and decreased rapidly until 2002. There was a short period of increased biomass to 2007, followed by a steadily decreasing trend to 2016. Median estimated biomass at the beginning of 2017 was about 21% of B_{REF} (90% credibility interval: 17–26%) (Table 8).

Table 7: Reference points, performance indicators and stock status probabilities for the CRA 2 stock assessment.

Reference points	**Description**
H_{2016}	Handling mortality (t) in final fishing year
SSB_0	Female spawning stock biomass during AW season associated with unfished equilibrium
SSB_{2016}	Female spawning stock biomass at end of 2016 AW season
B_{REF}	Beginning of AW season mean vulnerable biomass for the 1979–81 reference period
B_{MIN}	The lowest beginning AW vulnerable biomass in the series
B_{2017}	Beginning of season AW vulnerable biomass for 2017

Performance indicators	**Description**
SSB_{2016} / SSB_0	ratio of SSB_{2016} to SSB_0
B_{2017} / B_{REF}	ratio of B_{2017} to B_{REF}
B_{2017} / B_{MIN}	ratio of B_{2017} to B_{MIN}

Probabilities	**Description**
$P(SSB_{2016} < 0.2\ SSB_0)$	soft limit CRA 2: probability SSB_{2016} < 20% SSB_0
$P(SSB_{2016} < 0.1\ SSB_0)$	hard limit CRA 2: probability SSB_{2016} < 10% SSB_0
$P(B_{2017} > B_{REF})$	probability $B_{2017} > B_{REF}$
$P(B_{2017} > B_{MIN})$	probability $B_{2017} > B_{MIN}$
$P(B_{REF} > B_{MIN})$	probability $B_{REF} > B_{MIN}$

Note that B_{MSY} has been removed from this table as the RLFAWG and Plenary determined that more work needed to be conducted to evaluate how this quantity is determined for rock lobsters.

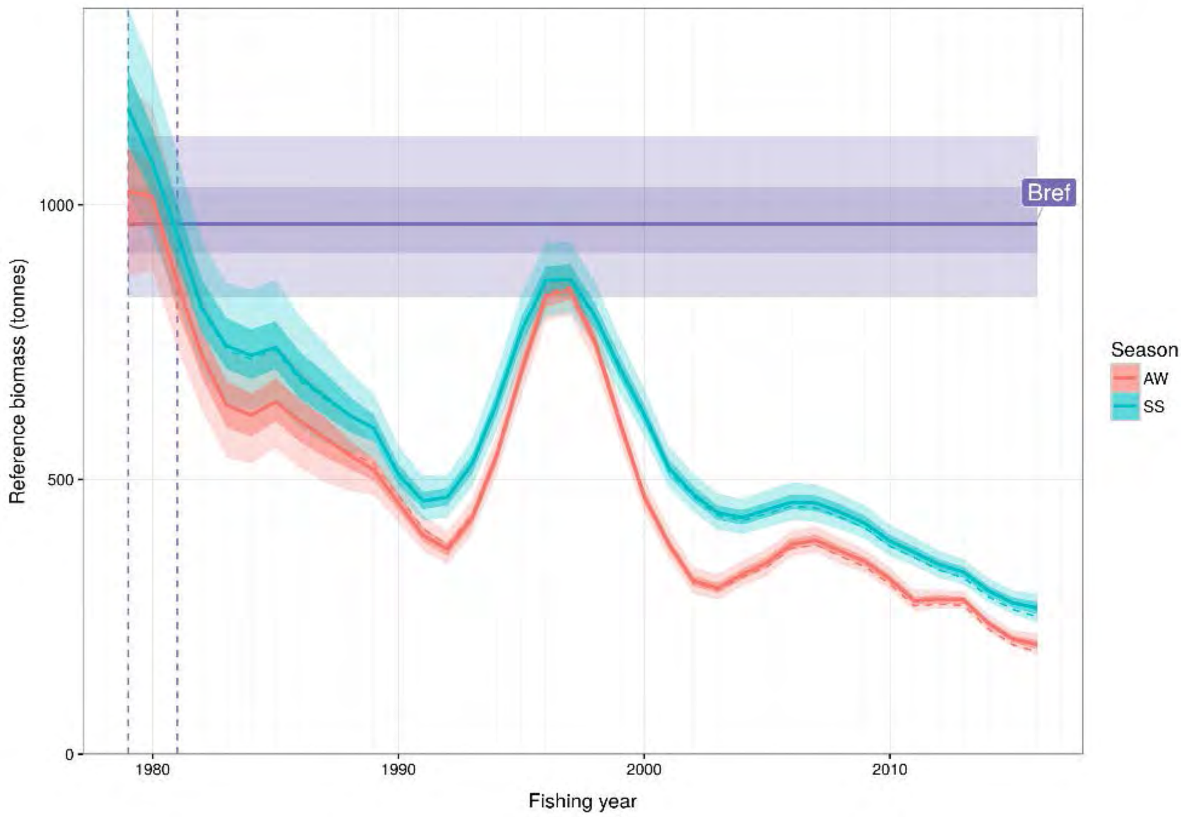


Figure 4: CRA 2 base case vulnerable reference biomass over the model reconstruction period and B_{REF} (the 1979–81 reference period identified using purple vertical dashed lines). Solid lines indicate the median vulnerable biomass by season, shading indicates the 50% and 90% credible intervals for each series, dashed lines indicate the MAP. The biomass in each year uses the final reconstruction year's selectivity and MLS.

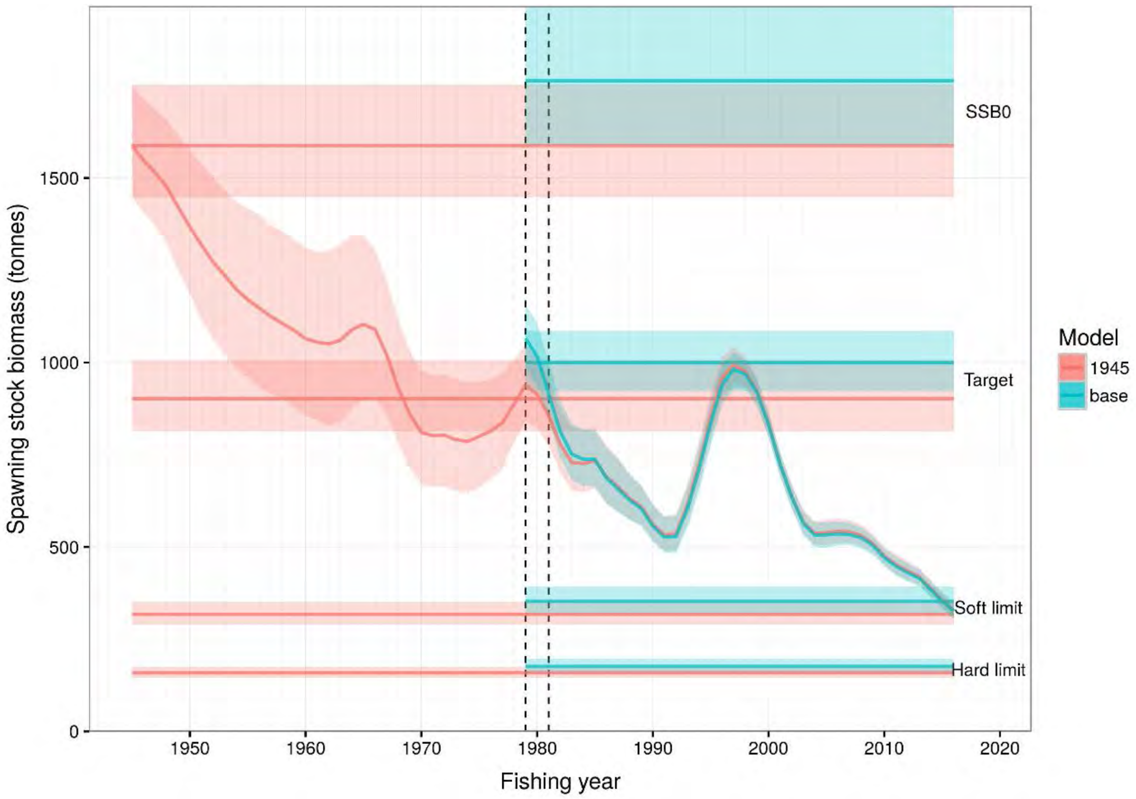


Figure 5: CRA 2 posterior distribution of the spawning stock biomass (*SSB*) trajectory for the base case model run and the model run that begins in 1945. Also plotted for each model run is the posterior distribution of the unfished SSB (SSB_0), the reference biomass (the mean *SSB* between 1979 and 1981), the soft limit (20% SSB_0), and the hard limit (10% SSB_0). The reference period is indicated using vertical dashed black lines.

Table 8: CRA 2 base case and sensitivity run MCMC outputs, reporting the 5%, 50% (median), and 95% quantiles of the posterior distributions. Growth increment values in mm TW, biomass values in t, and R_0 in numbers. '–': not applicable. [Continued over next two pages]

	Base			Start 1945			2× recreational catch			q-drift		
	5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%
Likelihoods and diagnostic statistics												
LFs-sdnr	0.613	0.772	1.126	0.616	0.773	1.143	0.604	0.760	1.053	0.614	0.772	1.091
LFs-MAR	0.101	0.104	0.106	0.101	0.104	0.106	0.101	0.104	0.106	0.101	0.104	0.107
LFs-LL	22 990	23 010	23 020	23 000	23 010	23 020	22 990	23 000	23 010	22 990	23 010	23 020
Tags-sdnr	1.373	1.418	1.467	1.371	1.417	1.463	1.372	1.417	1.462	1.374	1.418	1.465
Tags-MAR	0.662	0.679	0.698	0.662	0.680	0.698	0.663	0.680	0.698	0.662	0.680	0.700
Tags-LL	4 430	4 442	4 455	4 430	4 442	4 456	4 430	4 442	4 456	4 430	4 441	4 453
CELR sdnr	1.078	1.173	1.274	1.065	1.162	1.270	1.060	1.160	1.261	1.066	1.163	1.266
CELR MAR	0.589	0.734	0.876	0.560	0.704	0.841	0.599	0.735	0.883	1.012	1.504	2.289
CELR LL	-99.44	-93.58	-86.34	-100.20	-94.21	-86.91	-100.40	-94.26	-87.44	-100.10	-94.15	-87.17
FSU-sdnr	1.188	1.307	1.436	1.048	1.199	1.382	1.179	1.281	1.408	1.198	1.301	1.438
FSU-MAR	0.660	0.873	1.133	0.665	0.875	1.118	0.656	0.869	1.124	0.662	0.873	1.132
FSU-LL	-35.79	-32.84	-29.20	-38.67	-35.27	-30.70	-36.06	-33.41	-29.84	-35.64	-32.93	-29.32
CR-sdnr	–	–	–	0.969	1.206	1.484	–	–	–	–	–	–
CR-MAR	–	–	–	0.432	0.717	1.091	–	–	–	–	–	–
CR-LL	–	–	–	-25.86	-23.12	-19.19	–	–	–	–	–	–
Sex-sdnr	1.035	1.070	1.112	1.037	1.071	1.109	1.054	1.086	1.121	1.045	1.078	1.118
Sex-MAR	0.566	0.595	0.628	0.565	0.596	0.630	0.573	0.604	0.635	0.569	0.598	0.631
Sex-LL	7 882	7 888	7 894	7 882	7 888	7 894	7 885	7 890	7 895	7 883	7 888	7 895

			Base			**Start 1945**			**2× recreational catch**			**q-drift**
	5%	**50%**	**95%**	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**
Prior	-1.77	7.68	19.40	-15.53	-4.43	9.18	-1.74	7.48	18.75	-1.72	8.18	19.09
Function value	35 210	35 220	35 230	35 170	35 180	35 190	35 200	35 210	35 220	35 210	35 220	35 230
Model parameters												
R_0	559 600	633 000	730 400	522 300	594 200	669 900	571 700	653 300	739 200	564 600	643 500	725 000
M	0.150	0.164	0.179	0.158	0.172	0.189	0.132	0.146	0.161	0.152	0.167	0.182
U_{init}	0.118	0.157	0.203	–	–	–	0.130	0.169	0.216	0.108	0.149	0.192
q-CR	–	–	–	0.0207	0.0278	0.0382	–	–	–	–	–	–
q-FSU	0.0005	0.0006	0.0007	0.0005	0.0006	0.0007	0.0005	0.0006	0.0007	0.0005	0.0006	0.0007
q-CELR	0.0013	0.0014	0.0015	0.0013	0.0014	0.0015	0.0012	0.0013	0.0014	0.0012	0.0013	0.0015
q-drift	–	–	–	–	–	–	–	–	–	-0.0006	0.0043	0.0089
mat50	48.96	49.88	50.71	48.82	49.79	50.60	49.05	49.95	50.82	48.92	49.85	50.65
Model parameters												
mat95Add	8.46	10.50	13.41	8.18	10.46	13.18	8.30	10.61	13.48	8.35	10.42	13.45
GalphaM	6.65	6.82	7.00	6.64	6.80	6.97	6.63	6.81	6.99	6.64	6.81	6.99
GbetaM	2.62	2.88	3.20	2.61	2.84	3.15	2.61	2.87	3.17	2.60	2.85	3.13
GshapeM	2.02	2.55	3.18	1.93	2.457	3.11	1.96	2.53	3.15	1.95	2.51	3.10
GCVM	0.42	0.44	0.46	0.42	0.44	0.46	0.42	0.44	0.46	0.42	0.44	0.46
GalphaF	4.55	4.72	4.88	4.59	4.74	4.90	4.57	4.74	4.90	4.57	4.73	4.89
GbetaF	1.12	1.19	1.27	1.13	1.21	1.30	1.12	1.20	1.28	1.12	1.19	1.28
GshapeF	4.12	4.43	4.71	4.17	4.47	4.77	4.12	4.42	4.69	4.15	4.45	4.74
GCVF	0.74	0.78	0.82	0.73	0.77	0.82	0.73	0.77	0.82	0.73	0.77	0.82
StdObs	0.90	1.00	1.11	0.90	1.01	1.11	0.91	1.01	1.10	0.90	1.01	1.11
vuln1	0.63	0.66	0.69	0.65	0.68	0.71	0.63	0.65	0.68	0.64	0.67	0.70
vuln2	0.51	0.60	0.70	0.50	0.59	0.71	0.49	0.59	0.70	0.50	0.59	0.71
vuln3	0.52	0.56	0.62	0.52	0.57	0.63	0.51	0.56	0.62	0.52	0.57	0.62
vuln4	0.47	0.51	0.56	0.47	0.51	0.56	0.46	0.51	0.56	0.47	0.51	0.56
SelLH1M	2.78	23.42	46.67	2.60	22.04	47.32	3.30	26.39	47.55	3.02	23.20	47.29
SelMax1M	32.00	45.48	67.63	31.64	45.77	67.00	31.16	44.01	67.09	31.97	46.07	66.32
SelLH1F	3.26	11.65	33.01	2.60	11.03	31.90	2.85	12.05	34.28	2.34	10.10	30.87
SelMax1F	49.19	61.77	78.41	48.28	61.20	77.83	48.44	63.15	80.68	47.37	60.22	76.62
SelLH2M	4.38	4.67	4.96	4.38	4.67	4.95	4.42	4.67	4.95	4.41	4.66	4.96
SelMax2M	55.38	55.87	56.37	55.44	55.90	56.40	55.42	55.84	56.33	55.44	55.88	56.39
SelLH2F	6.89	7.26	7.66	6.89	7.26	7.68	6.91	7.35	7.73	6.89	7.27	7.69
SelMax2F	62.51	63.15	63.79	62.52	63.14	63.85	62.53	63.22	63.88	62.50	63.15	63.82
Derived quantities												
H_{2016}	2.251	2.424	2.618	2.213	2.396	2.588	2.586	2.782	3.011	2.272	2.463	2.676
SSB_0	1 582	1 763	1 966	1 444	1 588	1 753	1 954	2 191	2 442	1 555	1 743	1 935
SSB_{REF}	922	999	1 086	813	903	1 006	1 048	1 139	1 234	936	1 017	1 098
SSB_{2016}	306	328	353	304	327	350	344	369	400	293	316	342
B_0	3 391	3 798	4 299	2 883	3 217	3 604	4 149	4 743	5 345	3 283	3 733	4 173
B_{REF}	831	965	1 125	882	1 005	1 160	896	1 044	1 210	864	1 007	1 183
B_{MIN}	182	199	217	182	201	221	203	223	243	171	190	211
B_{2017}	173	203	242	167	197	232	186	222	265	152	184	222
SSB_{2016}/SSB_0	0.163	0.185	0.211	0.183	0.205	0.231	0.148	0.168	0.194	0.162	0.182	0.207
SSB_{2016}/SSB_{REF}	0.297	0.326	0.357	0.322	0.362	0.403	0.294	0.324	0.356	0.283	0.311	0.345
SSB_{REF}/SSB_0	0.503	0.567	0.637	0.489	0.567	0.661	0.452	0.522	0.594	0.517	0.584	0.656
B_{2017}/B_O	0.042	0.052	0.064	0.049	0.061	0.075	0.038	0.047	0.058	0.040	0.049	0.061
B_{2017}/B_{REF}	0.171	0.211	0.261	0.160	0.195	0.240	0.172	0.214	0.264	0.141	0.183	0.234
B_{2017}/B_{MIN}	0.917	1.020	1.174	0.872	0.978	1.118	0.883	0.994	1.135	0.847	0.965	1.107
B_{REF}/B_0	0.204	0.253	0.318	0.260	0.313	0.374	0.174	0.219	0.280	0.215	0.271	0.345

	Base			Start 1945			2× recreational catch			q-drift		
	5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%
Probabilities												
$P(SSB_{2016}<0.2SSB_0)$		0.816			0.340			0.970			0.893	
$P(SSB_{2016}<0.1SSB_0)$		0			0			0			0	
$P(SSB_{2016} > SSB_{REF})$		0			0			0			0	
$P(B_{2017} > B_{REF})$		0			0			0			0	
$P(B_{2017} > B_{MIN})$		0.614			0.391			0.473			0.323	

Three sensitivity runs relative to the base case included:

i. starting the model from 1945 as done in the previous CRA 2 stock assessment;
ii. doubling the recreational catch; and
iii. estimating an additional multiplicative parameter (q-drift), which described increased fishing efficiency over time.

Results from the base case and the three sensitivity trials are compared in Table 8.

B_{2017} was about the same size as B_{MIN} but was smaller than B_{REF} with 100% probability for the base case and all three sensitivity runs (Table 8).

Indicators based on SSB_{REF}

The historical sequence of biomass versus fishing intensity is shown in Figure 6. The plot shows relative spawning biomass on the x-axis and relative fishing intensity on the y-axis; thus high biomass/low fishing intensity is in the lower right-hand corner, where a stock would be when fishing first began, and low biomass/high intensity is in the upper left-hand corner, where an uncontrolled fishery is likely to go. The x-axis is spawning stock biomass SSB in year y as a proportion of the unfished spawning stock (SSB_0). SSB_0 is constant for all years of a run, but varies through the 1000 samples from the posterior distribution.

The y-axis is fishing intensity in year y as a proportion of the fishing intensity (F_{REF}) that results in SSB_{REF} under the fishing pattern in year y. Fishing patterns include MLS, selectivity, the seasonal catch split, and the balance between SL and NSL catches. F_{REF} varies among years because fishing patterns change in each year and is calculated by projecting deterministically for 50 years to reach equilibrium. Each projection is done by holding the NSL catch constant, assuming recruitment at R_0, and applying a range of stepped multipliers to the AW and SS SL fishing mortalities (F_y). The F that results in SSB_{REF} at the end of the projection is F_{REF}. This projection procedure is followed in every year for each sample in the MCMC posterior.

The median track in Figure 6 suggests that fishing intensity has exceeded F_{REF} in every year starting in 1979, the first model year. The only years that the SSB was above SSB_{REF} were 1979 and 1980. As the stock declined from 1979 to 1990 the fishing intensity increased. Stock status then began to improve and fishing intensity declined from 1990 as stock abundance increased. Fishing intensity and relative biomass neared the centre of the figure from 1996 to 1998, as abundance peaked near SSB_{REF} and fishing mortality approached F_{REF}. The trend reversed after 1998, with the stock dropping below 20% SSB_0 in 2015 and fishing mortality exceeding three times F_{REF} after 2001 (Figure 6). Fishing intensity began to drop after 2013 in response to drops in the SL catch but has stayed well above three times F_{REF}. Stock status has continued to decline in spite of the decline in fishing mortality, with the median estimate of SSB_{2016} at 19% SSB_0 (90% credibility interval from 16–21% SSB_0; Table 8).

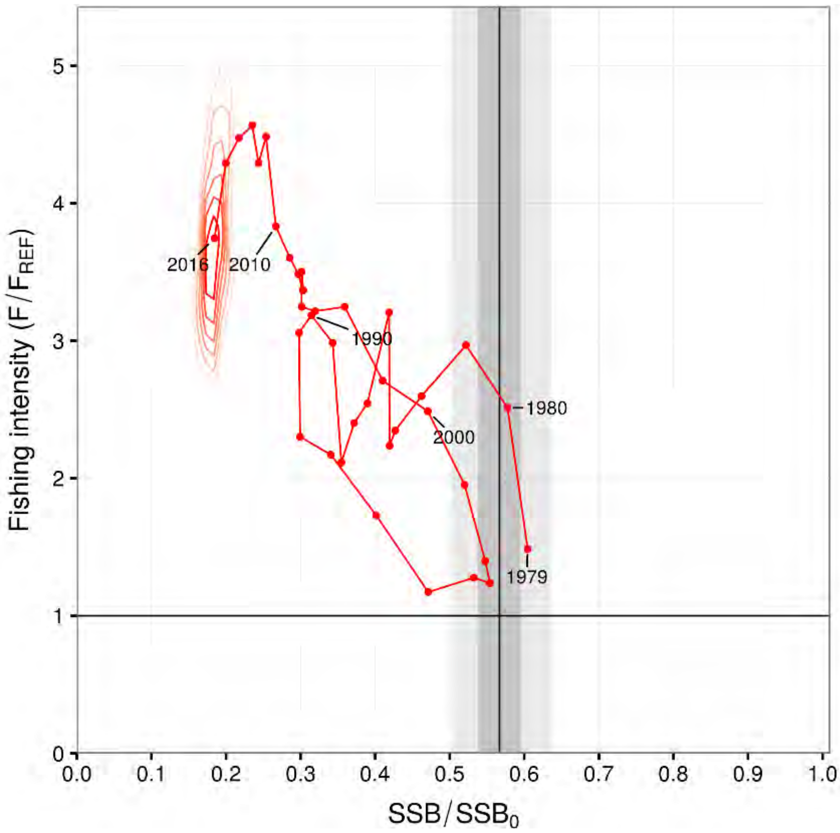


Figure 6: Phase plot summarising the *SSB* history of the CRA 2 stock. The x-axis is the AW spawning stock biomass *SSB* in each year as a proportion of the unfished spawning stock biomass (SSB_0). The y-axis is fishing intensity in each year as a proportion of the fishing intensity (F_{REF}) that gives SSB_{REF} under the fishing patterns in that year. Each point on the figure shows the median of the posterior distributions of biomass ratio and fishing intensity ratio for one year. The vertical line in the figure is the median (line), 70%, and 90% interval (shading) of the posterior distribution of SSB_{REF}. This ratio was calculated using the fishing pattern in 2016. The horizontal line in the figure is drawn at 1, the fishing intensity associated with F_{REF}. The contour density for the final year of the plot (2016) shows the posterior distributions of the two ratios.

Multi-area modelling of CRA 2

An exploratory multi-area CRA 2 stock assessment model was developed in conjunction with the overall CRA 2 stock assessment. Each of the four CRA 2 statistical areas were modelled separately with some independent (e.g., R_0, U_{init}) and some shared parameters (e.g., *M*, vulnerabilities, selectivities split into three areas, growth split into two areas). Summing the vulnerable or spawning stock biomass over all four areas resulted in similar biomass trajectories to the base case assessment model in both shape and overall biomass. However, stock size, trends in abundance, and stock status indicators differed among the four areas with some areas with lower stock status than others. Multi-area models have not yet been used for finer-scale management of rock lobster stocks, but this approach shows considerable potential for such applications.

Future research considerations

The RLFAWG and Plenary identified a number of potentially useful avenues of exploration to evaluate or improve this assessment in the future. Improvements related to the development of the CPUE standardisation (GLM) and its use in the stock assessment model include:

- Include alternative CPUE formulations in the stock assessment model itself as sensitivities to more fully evaluate their consequences.
- Develop logbook CPUE series where possible. Display comparisons of this series with the current CPUE series. Include the logbook series in the model as well.

- Implement vessel as an explanatory variable in all future rock lobster CPUE standardisations. Investigate sequential coding of the same vessel in the model to determine whether there are 'learning' effects, or examine individual vessels for trends in residuals over time.
- Investigate the distribution of the vessel correction factors (VCF) that scale estimated catch into landed greenweight in the F2_LFX algorithm.
- Use a smoother to determine the minimum amount of process error to add and use this (to avoid overfitting) instead of the arbitrary 25% process error that is added at present.

Other improvements include:

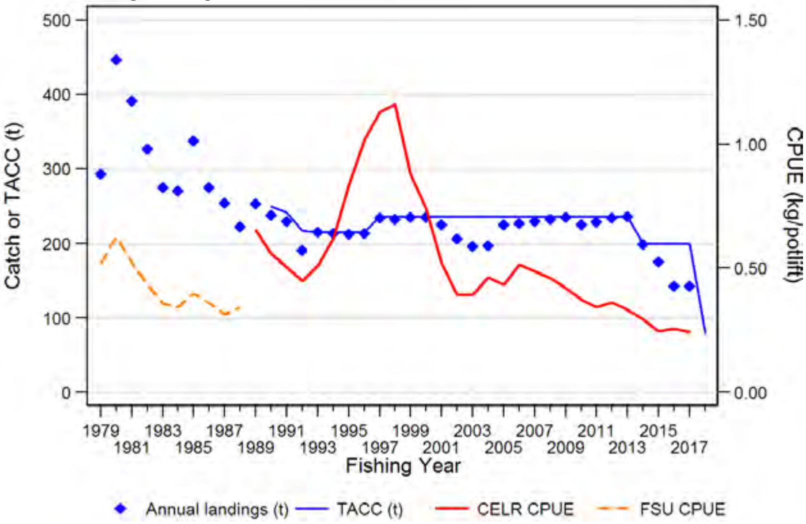
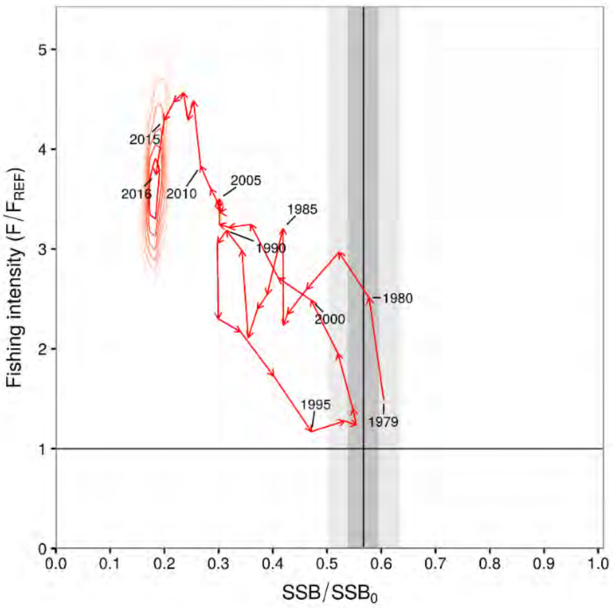
- Explore alternative reference points (targets and limits) for CRA 2 (and rock lobster stocks in general). For example, evaluate the consistency and efficacy of B_{REF} targets, and develop a dynamic B_{MSY}.
- Examine the effects of including a stock-recruitment relationship in the model.
- Investigate the implications of not estimating recruitment deviations for the period with no relevant data or, alternatively, the implications of estimating recruitment deviations for all years.
- Investigate the effects of changing the definition of new recruits from 32 mm, with a standard deviation of 2 mm; for example, what would be the effect of an increase in the standard deviation?
- Develop the computer code to include the effects of density-dependent growth and environmental effects.
- Develop and evaluate alternative growth models.
- Re-evaluate the method used to determine length-frequency weights.
- Develop an option for including random effects for certain parameters (e.g., selectivity parameters) in the model.
- Continue development of the spatial model and develop spatial model management procedures.
- Explore new ways to 'search' for management procedures (e.g., basic optimisation routines, genetic algorithms).

7. STATUS OF THE STOCKS

Stock structure assumptions

For the purposes of stock assessment and management, rock lobsters are assumed to constitute separate Fishstocks within each CRA Quota Management Area. There is likely to be some degree of relationship and/or exchange between Fishstocks in these CRA areas, either as a result of migration, larval dispersal or both.

Stock Status	
Year of Most Recent Assessment	2017
Assessment Runs Presented	Base case and 3 sensitivity runs
Reference Points	Target: B_{REF}: mean of beginning AW vulnerable biomass for the period 1979–81 Soft limit: 20% SSB_0 (default) Hard limit: 10% SSB_0 (default) Overfishing threshold: F_{REF}
Status in relation to Target	Biomass in 2017 is 21% of B_{REF} Exceptionally Unlikely (< 1%) that B_{2017} is above B_{REF}
Status in relation to Limits	Likely (> 60%) that B_{2017} is below the Soft Limit Very Unlikely (< 10%) that B_{2017} is below the Hard limit
Status in relation to Overfishing	Overfishing is Virtually Certain (> 99%) to be occurring

Historical Stock Status Trajectory and Current Status
 **Annual landings, TACC, and two standardised CPUE series for CRA 2 from 1979 to 2016. The CELR CPUE series has been standardised with month, area, and vessel explanatory variables, using vessels at least five years in the fishery. The FSU CPUE series has been standardised with month and area variables.**  **Phase plot for CRA 2. Median values are plotted up to the final (2016) year. The contour density for the final year of the plot (2016) shows the posterior distributions of the two ratios. See Figure 6 caption for detailed explanation of this plot.**

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	AW biomass declined from a peak in the mid-1990s, which was near B_{REF} to near 20% B_{REF} in 2017. There was a short period of increasing biomass to 2007, followed by a steady decline to 2017.
Recent Trend in Fishing Intensity or Proxy	Fishing intensity dropped after 2013, but remains well above F_{REF}.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	2016–17 offset-year CPUE is likely to decline from the 2015–16 level
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Likely (> 60%) Hard Limit: Unknown
Probability of Current Catch or TACC causing Overfishing to continue or commence	Virtually Certain (> 99%) to continue

Assessment Methodology and Evaluation		
Assessment Type	Level 1 – Full Quantitative Stock Assessment	
Assessment Method	Bayesian length-based model	
Assessment dates	Latest assessment: 2017	Next assessment: 2022
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- FSU CPUE data 1979–88 - CELR CPUE data: 1989–2016 - Length-frequency data - Tag-recapture data	1 – High Quality (all)
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	- start model in 1979 instead of 1945 - standardised CELR CPUE with vessel explanatory variable - separate FSU and CELR CPUE series - no density-dependence - only fit to first tag-recapture event - each sex category weighted by the number of size samples	
Major Sources of Uncertainty	- non-commercial catch - lack of size-frequency data before 1993 - lack of puerulus index	

Qualifying Comments
-

Environmental and Ecosystem Considerations	
Observer coverage	Observer coverage primarily for stock assessment needs.
Non-target fish and invertebrate catch	The levels of incidental catch landed from rock lobster potting ranged from 2–11% of the estimated rock lobster catch weight per QMA for the period 1989–2003. For all QMAs, the most frequently reported incidental species caught are, in decreasing order of catch across all stocks: octopus, conger eel, blue cod, trumpeter, sea perch, red cod, butterfish and leatherjackets.
Incidental catch of seabirds	Small numbers of shags have been reported historically in some CRA areas, but not in recent years.
Fishers suggest the lack of recent shag captures is attributable to changes in pot design and baiting methodologies.	
Incidental catch of marine mammals	From January 2000 until November 2018, 31 entanglements (29 marine mammal individuals, two individuals were entangled twice) were attributed to commercial or recreational rock lobster pot lines from around New Zealand,

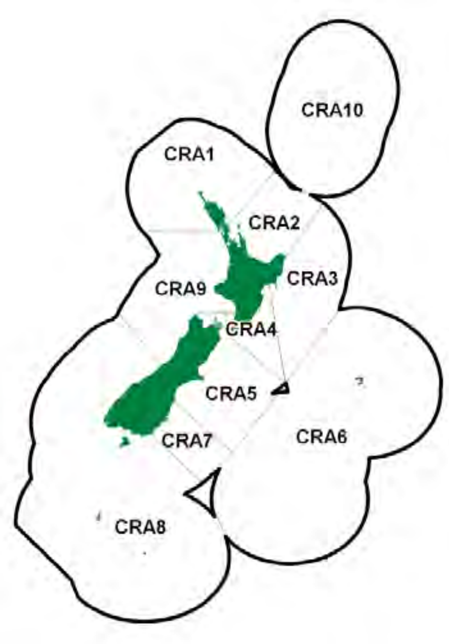
	mainly around Kaikoura (DOC Marine Mammal Database).
Incidental catch of other protected species	There is no known incidental catch of other protected species in rock lobster fisheries.

8. FOR FURTHER INFORMATION

For the list of references refer to the Introduction – Rock Lobster chapter.

ROCK LOBSTER (CRA 3)

(*Jasus edwardsii*) Crayfish, Kōura papatea, Pawharu



1. FISHERY SUMMARY

1.1 Commercial fisheries

Commercial landings and TACC are plotted in Figure 1. Table 1 provides a summary by fishing year of the reported commercial catches, TACCs, and TACs for CRA 3.

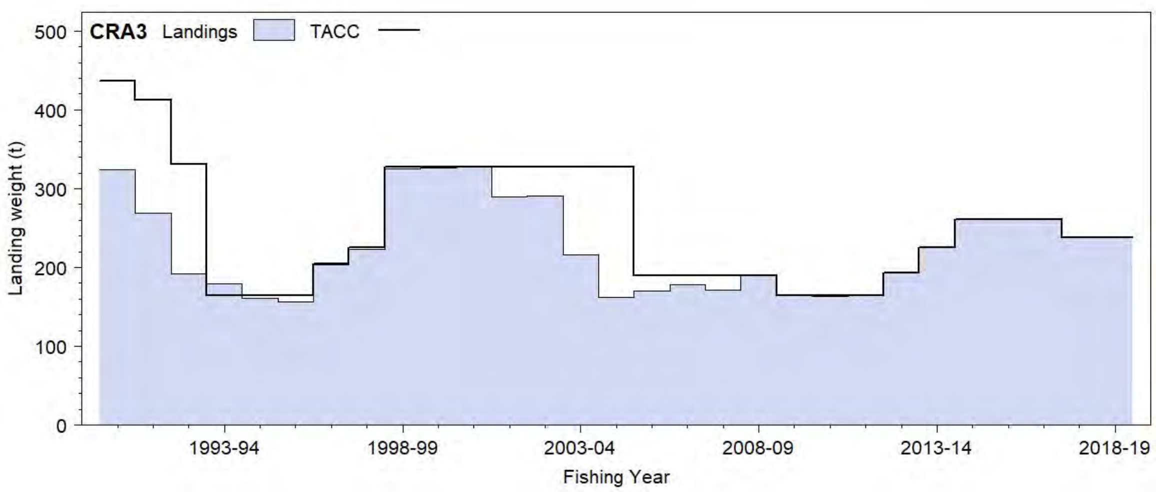


Figure 1: Historical commercial landings and TACC for CRA 3.

Table 1: Reported commercial catch (t) from QMRs or MHRs (after 1 October 2001), commercial TACC (t) and total TAC (t) (where this quantity has been set) for rock lobster, *Jasus edwardsii*, in QMA 3 for each fishing year since the species was included in the QMS on 1 April 1990. –, TAC not set for QMA or catch not available (current fishing year).

			CRA 3
Fishing year	**Catch**	**TACC**	**TAC**
1990–91	324.1	437.1	–
1991–92	268.8	411.9	–
1992–93	191.5	330.9	–
1993–94	179.5	163.9	–
1994–95	160.7	163.9	–
1995–96	156.9	163.9	–
1996–97	203.5	204.9	–
1997–98	223.4	224.9	379.4
1998–99	325.7	327.0	453.0
1999–00	326.1	327.0	453.0
2000–01	328.1	327.0	453.0
2001–02	289.9	327.0	453.0
2002–03	291.3	327.0	453.0
2003–04	215.9	327.0	453.0
2004–05	162.0	327.0	453.0
2005–06	170.1	190.0	319.0
2006–07	178.7	190.0	319.0
2007–08	172.4	190.0	319.0
2008–09	189.8	190.0	319.0
2009–10	164.0	164.0	293.0
2010–11	163.7	164.0	293.0
2011–12	163.9	164.0	293.0
2012–13	193.3	193.3	322.3
2013–14	225.5	225.5	354.5
2014–15	260.4	261.0	390.0
2015–16	260.8	261.0	390.0
2016–17	260.9	261.0	390.0
2017–18	237.7	237.9	366.9
2018–19	240.0	237.9	366.9
2019–20	–	222.9	351.9

1.1.1 Regional commercial catch

The RLFAWG agreed that CRA 3 was best evaluated by separating the QMA into two regions defined by the component statistical areas (Table 2). This decision was based on an analysis of length frequency data specific to each region which showed a consistent difference between the two regions, with Region 911 having larger length distributions than in Region 909+910 for most of the available year/season/sex comparisons (Starr et al in prep). Additionally, the standardised CPUE trends for the two regions diverged after 2012, with Region 911 remaining flat or increasing slightly while Region 909+910 decreased.

Table 2: Sub-stock definitions for CRA 3 multi-area stock assessment, showing the rock lobster statistical area definitions used.

Sub-stock name	Statistical area definition
909+910	Area 909 + Area 911
911	Area 911

Beginning with 1 January 1979, data were allocated to each Region on the basis of the statistical area. This applied to all data: catch, observer and logbook catch sampling, and tagging data. However, assigning catch to a Region before 1979 was more difficult because spatial catch data were only available from 1963 to 1973 and had area definitions which differed from those used in the post-1978 data (Annala & King 1983). Only annual estimates by CRA QMA were available for the periods 1974–1978 and 1945–1962 (Bentley et al. 2005). The Annala & King (1983) areas were resolved into Regions consistent with the Table 2 definitions by noting that a) A & K Area 5 almost perfectly overlapped with the combined Areas 909+910; and b) A & K Area 6 encompassed post-1978 Areas 911 and 912. Catches were assigned to Region 911 by applying a constant proportion of 0.543 to the A & K Area 6 annual catches, where $0.543 = \sum_{1979}^{1983} \text{Area 911} \Big/ \sum_{1979}^{1983} (\text{Area 911+Area 912})$. Catches by Region over the period 1974 to 1978 were assigned by interpolation. Pre-1963 catches were assigned using the mean Regional proportion from 1963–1967 (Starr et al in prep).

1.2. Recreational fisheries

For general information on recreational catch refer to the Introduction – Rock Lobster chapter.

Six annual recreational survey catch estimates are available for CRA 3 (Table 3). Estimates from the two Kingett Mitchell national telephone diary surveys in 1999–2000 and 2000–01 (Boyd et al. 2004; Boyd & Reilly 2004) were not accepted by the RLFAWG for the 2014 CRA 3 stock assessment (Starr et al. 2015b) because these survey estimates were considered implausibly high for CRA 3. The earlier regional 1994 and national 1996 telephone diary surveys, conducted by researchers at the University of Otago, were assessed as being biased, in a review of the available recreational surveys (unpublished minutes: Recreational Technical Working Group [Auckland NIWA, 10–11 June 2004]) because the interview questions possibly underestimated fisher participation rates by allowing for an easy exit from the interview ("soft refusal" bias). These two early surveys continue to be used by the RLFAWG in spite of this advice because the estimates are plausible and no other recreational information is available for these years. Both the Kingett Mitchell and the Otago surveys were potentially biased high because recreational logbook participants were not closely supervised and may not have accurately recorded their fishing activity. The much larger harvest estimates in the Kingett Mitchell surveys were a result of higher claimed participation in saltwater fishing over the previous 12 months in the initial screening survey.

Two large-scale population-based diary/interview surveys (National Panel Survey or NPS) have been conducted by National Research Bureau (NRB) under contract to Fisheries New Zealand from 1 October 2011–30 September 2012 (Wynne-Jones et al. 2014) and from 1 October 2017–30 September 2018 (Wynne-Jones et al. 2019), with the intention of estimating FMA and QMA-specific annual catches for all major finfish and non-finfish species (Heinemann et al. 2015). This survey was based on a design that resembled the New Zealand national census, making use of the census population strata ("mesh blocks" of dwellings as the basis for identifying recreational fishers). A door-to-door survey of households in randomly selected strata was used to select participants who would report their catch for an entire year. A structured and carefully-designed Computer Assisted Telephone Interview (CATI) method was used to record harvest in detail from those who had fished. The survey results were thought to be plausible for CRA 3, with 26 (2011) and 30 (2017) fishers providing details from 47 and 90 trips where rock lobster were caught for respective survey years (see table 60 in Wynne-Jones et al. 2014 and table 51 in Wynne-Jones et al. 2019). These estimates have relatively high CVs (0.33 in 2011 and 0.26 in 2017; Table 4). The 2011 survey provided estimates of the distribution of fishing platforms used to take lobsters in CRA 3, with large and small motor boats accounting for just over three quarters of the catch and 22% coming from land (Table 4). The primary capture method used to take rock lobster in CRA 3 was diving (55%) followed by potting (44%) (Table 4). NPS survey results from logbook participants were in terms of number of fish. Mean recreational catch weights for the most important finfish and non-finfish species QMAs were estimated in a parallel project (Hartill & Davey 2015).

A recreational catch vector was developed by assuming that recreational catch has been proportional to the CRA 3 SS abundance, as reflected in the standardised SS CPUE for all of CRA 3. The standardised SS CPUE vector was calculated using data prepared with the F2-LFX algorithm (see Starr 2019). By agreement in the RLFAWG, the recreational catch vector was based on four of the six survey estimates (in tonnes – see Table 3) from the 1994 and 1996 Otago University surveys and the 2011 and 2017 NPS surveys. The two NPS surveys were assumed to be less biased, so the estimated survey CVs were used. The CVs for the two Otago University surveys were assumed to be 50% higher than that of the mean of the two NPS surveys. A scalar quantity q (Eq. 1) was estimated by obtaining the best fit to these survey estimates when minimising a lognormal distribution using the CVs indicated in Table 3.

Eq. 1

$$W_t = w_t \; N_t$$
$$\hat{W}_t = \hat{q} \; CPUE_t$$
$$\text{LL}=\sum_{t=1}^{5}\left(\frac{\left(\text{LN}(W_t)-\text{LN}(\hat{W}_t)\right)^2}{2\sigma_t^2}\right)$$

where:

t subscripts four recreational survey estimates in Table 1:

1=1994 Otago; 2=1996 Otago; 3=2011 NPS; 4=2017 NPS.

$w_t =$ mean spring/summer weight >= MLS for sampled lobster in year/survey t for CRA 3

$N_t =$ mean number lobsters in year/survey t for CRA 3

$CPUE_t =$ CRA 3 spring/summer standardised CPUE in year t

$\hat{W}_t =$ CRA 3 estimated recreational catch (tonnes) for year t

The estimated recreational catch trajectory (Eq. 2) based on the q estimated in Eq. 1 is a reasonable fit to all four survey estimates in Table 3 (Figure 2). The q parameter is estimated to be 6.0 tonnes/CPUE-unit and the recreational catch vector accounts for 262 tonnes of historical catch from 1979 to 2018.

Eq. 2

$$\hat{W}_y = \hat{q} \; CPUE_y \text{ if } y >= 1979$$
$$\hat{W}_{1945} = 0.2 * \hat{W}_{1979}$$
$$\hat{W}_y = \hat{W}_{y-1} + \frac{(\hat{W}_{1979} - \hat{W}_{1945})}{(1979-1945)} \text{ if } y > 1945 \,\&\, y < 1979$$

For assessments conducted since 2006, the RLFAWG has included recreational landings made by commercial vessels under Section 111 of the Fisheries Act. Greenweight landings with destination code “F” were extracted from the CRACE database (Bentley et al. 2005), which showed a maximum annual value of 3047 kg for CRA 3, occurring in 2016–17 (see table 7 in the Introduction- Rock Lobster chapter). The RLFAWG has agreed to add the maximum catch estimate to the estimated recreational catch in each year since 1979 (Figure 2), increasing the total 1979 to 2018 recreational catch in the model to 384 t.

Table 3: Information used to estimate recreational catch for CRA 3.

Survey	Numbers	Mean weight (kg)	Catch weight (t)	Assumed CV
1994 (Otago: Bradford 1997)	8 000	0.534[1]	4.27	1.5*(0.33+0.26)/2
1996 (Otago: Bradford 1998)	27 000	0.534[1]	14.42	1.5*(0.33+0.26)/2
2000 (Boyd & Reilly 2004)	270 000[2]	–	146.61	not used
2001 (Boyd et al. 2004)	215 000[2]	–	116.75	not used
2011 (NPS: Wynne-Jones et al. 2014)	13 912[3]	0.58	8.07	0.33
2017 (NPS: Wynne-Jones et al. 2019)	22 515[4]	0.54	12.21	0.26
Section 111 reported landings				
Maximum reported landings (t) (in 2016–17)			3.047	

[1] SS mean weight (kg) calculated from commercial sampling data from 1994 to 1996 assuming recreational minimum legal sizes (Starr et al. 2003)

[2] as reported by Boyd & Reilly (2004) and Boyd et al. (2004)

[3] estimate provided in Wynne-Jones et al. (2014)

[4] estimate provided in Wynne-Jones et al. (2019)

Table 4: Fishing platform and capture method categories for CRA 3 during 2011–12 estimated by the national NPS recreational survey (Wynne-Jones et al. 2014). The final line shows the 2011–12 CRA 3 total estimates. CV=standard error of the estimate, which does not include error associated with the estimate of mean weight.

Category	Numbers	CV	Catch (t)[1]	CV	% of Total Catch Weight
Platform (Appendix table 27.3 in Wynne-Jones et al. 2014)					
Trailer motor boat	7 164	0.36	4.16	0.36	52
Larger motor boat or launch	539	1.05	0.31	1.05	4
Trailer yacht	0		0		0
Larger yacht or keeler	0		0		0
Kayak canoe or rowboat	2 914	0.6	1.69	0.60	21
Off land including beach rocks or jetty	3 295	0.48	1.91	0.48	24
Something else	0		0		0
Capture method (Appendix table 27.4 in Wynne-Jones et al. 2014)					
Rod or line (not long line)	0		0		0
Long-line including set line kontiki or kite	0		0		0
Net (not including landing net used if caught on line)	0		0		0
Pot (e.g. for crayfish)	6 660	0.34	3.86	0.34	48
Dredge grapple or rake	0		0		0
Hand gather or floundering from shore	486	0.70	0.28	0.70	3
Hand gather by diving	6 767	0.45	3.92	0.45	49
Spearfishing	0		0		0
Some other method	0		0		0
Total	13 913	0.33	8.07	0.33	100

[1] uses mean weight estimate of 580 grams (Hartill & Davey 2015)

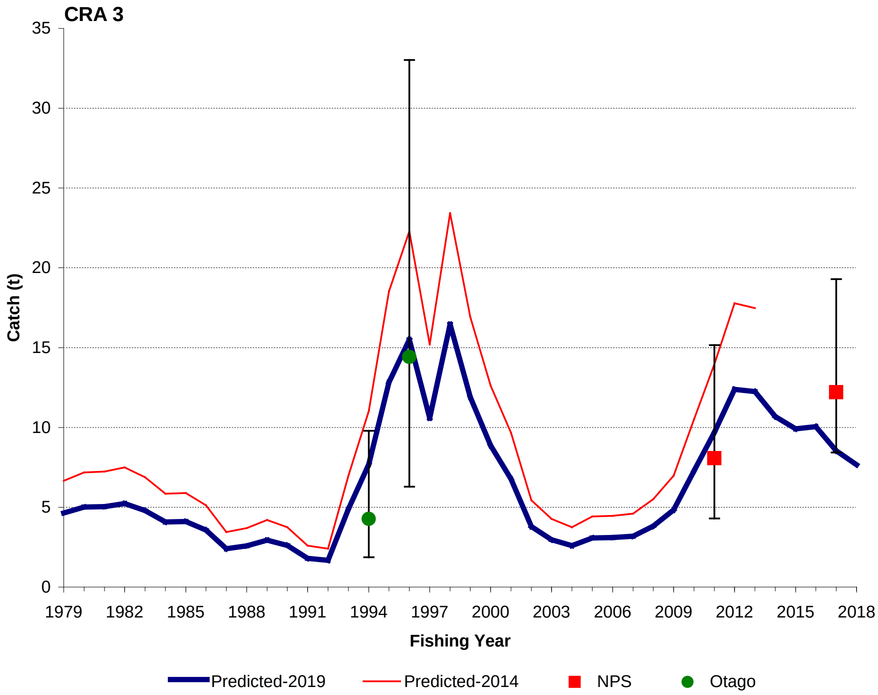


Figure 2: CRA 3 recreational catch trajectory (tonnes) (Eq. 2) from 1979 based on the standardised SS seasonal CRA 3 CPUE series fitted to four recreational catch surveys (Eq. 1 and Table 3). Error bars are ±2 s.e., assuming a lognormal distribution. Also shown is the equivalent recreational catch series used in the 2014 CRA 3 stock assessment.

1.2.2 Customary non-commercial fisheries

For general information on customary non-commercial catch refer to the Introduction – Rock Lobster chapter. Fisheries New Zealand were asked to provide estimates of current and historical customary catches, and an appreciation of their uncertainty. Fisheries New Zealand advised that a constant customary catch of 20 t should be assumed. This was split between seasons with 90% assumed taken in the SS.

1.2.3 Illegal catch

For general information on illegal catch refer to the Introduction – Rock Lobster chapter.

The RLFAWG rejected using the MPI Compliance estimates of illegal catch (see table 8 in the Introduction – Rock Lobster chapter) to generate a time series of illegal catches for CRA 3. This decision was made because members felt that many of the estimates, particularly in the early 1990s, represented a substantial proportion of the legal catch and were not credible. Instead, the RLFAWG agreed to use a fixed percentage of the total commercial catch from 1981 to 2018, with both 10% and 20% selected by the WG. The RLFAWG did not agree to scale the resulting 38 year catch total proportionately to the annual standardised CPUE index because this approach led to very large catches in the years with high CPUE. Instead, a constant average level of illegal catch was assumed (Figure 3). This series was started in 1981 because the McKoy "export discrepancy" procedure ended in 1980 (see following paragraph).

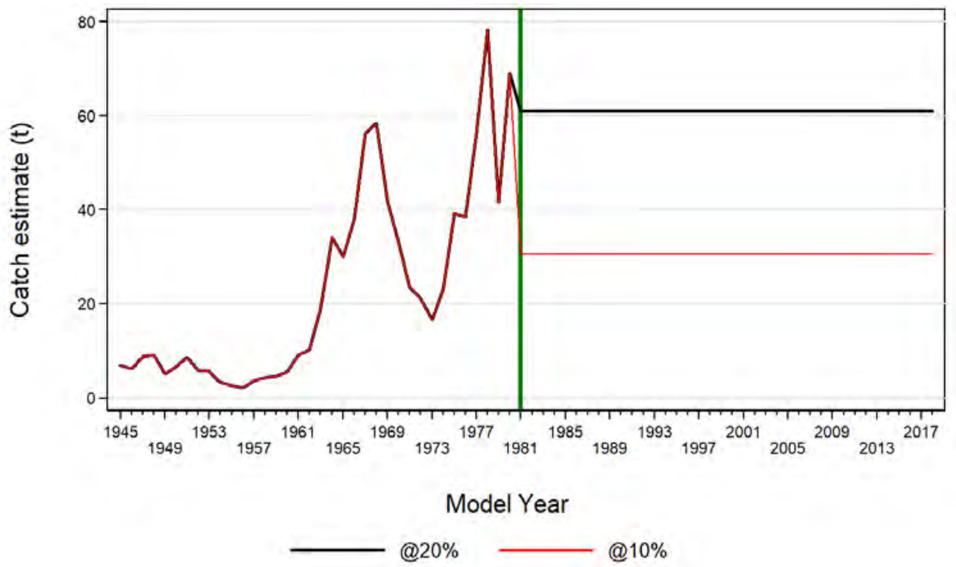


Figure 3: CRA 3 illegal catch trajectories for the 2019 stock assessment. The 10% and 20% labels refer to the percentage of the summed commercial catch from 1981 to 2018 that comprise the illegal catch over the same period. The vertical green line indicates 1981.

The following procedure was used to estimate illegal catch before 1981:

- Starting with the estimates of export discrepancies for all of New Zealand for 1974–80 (McKoy, unpublished data), the CRA 3 illegal catches for each of these seven years were estimated from the ratio of the reported commercial catch in CRA 3 relative to the total New Zealand reported commercial catch for the same years.
- The average ratio of the export discrepancy catch to the reported commercial catch was calculated for the period 1974–80 (see table 9 in the Introduction – Rock Lobster chapter). This ratio was used to generate an illegal catch estimate for all years before 1981 with no data (1945 through to 1973) by multiplying the reported catch by the average ratio. This approach was agreed by the RLFAWG on 15 Aug 2002.

The two annual illegal catch trajectories used in the 2019 CRA 3 stock assessment are plotted in Figure 3. When these annual catch estimates were used in the stock assessment model as seasonal catches, they were assumed to be distributed between seasons in the same proportion as the commercial catch for each year.

2. BIOLOGY

Refer to Section 2 in the Introductory Rock Lobster chapter for a general presentation of rock lobster biological considerations, including growth, natural mortality, and puerulus settlement.

3. STOCKS AND AREAS

For information on stocks and areas refer to the Introduction – Rock Lobster chapter.

4. DECISION RULES AND MANAGEMENT PROCEDURES

For information on decision rules and management procedures refer to the Introduction – Rock Lobster chapter.

5. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS

For information on environmental and ecosystem considerations refer to the Introduction – Rock Lobster chapter.

6. STOCK ASSESSMENT

A new stock assessment was conducted in 2019 for CRA 3 and is summarised below. CRA 3 was last assessed in 2014 (Haist et al. 2015), using two base cases: one that fixed the *Gshape* parameter and the other that fixed the *GCV* parameter. A management procedure was also developed and evaluated from that assessment.

Length-frequency sampling and tagging

The CRA 3 fishing industry made a commitment to the voluntary logbook programme when it was first introduced in 1993 and has used this design as a source of stock monitoring information in this fishery. However, the observer (catch sampling) programme has also been operative in this fishery since the mid-1980s and remains the primary source of biological sampling information. Both sets of data were used in the 2019 stock assessment. CRA 3 has had two stanzas of tagging effort, with one occurring in the late 1970s up to the mid-1980s and a second stanza from the mid-1990s onward, which has resulted in considerable tagging effort expended in this QMA.

Model structure, including changes from 2014 CRA 3 stock assessment

The 2019 CRA 3 stock assessment made the following modelling changes from the 2014 stock assessment:

- the lobster stock dynamics (LSD) model was used;
- a multi-area model that treated 909+910 and 911 as separate sub-areas;
- the model was fitted to three CPUE series: CR from 1963 to 1973, FSU from 1979 to 1988, and CELR from 1989 to 2016, with the CELR series standardised by including a vessel explanatory variable based on vessels with at least five years in the fishery;
- the assessment dropped the CR series for sub-area 911;
- size distribution sample weights by year, season and sampling source (logbook and catch sampling) are now scaled by the number of size measurements in each of the three sex categories (male, immature female, mature female);
- two selectivity curves, pre and post 1993, were estimated for females in sub-area 909+910 (as in the previous assessment), but only one selectivity curve for each sex was estimated in each sub-area otherwise (i.e. a total of five selectivity curves);
- handling mortality was reduced from 10% to 5% from 1990;
- growth was assumed to be sex-specific but constant through time; and
- the reduction in R_0 and stock size due to the marine reserve was set to 3.21% for 909+910 in 1999.

The following assumptions are consistent with those made for the 2014 CRA 3 stock assessment:

- the reconstruction starts in 1945 from a size distribution in equilibrium with growth, R_0, and M;
- a seasonal time step with autumn–winter (AW, April through September) and spring–summer (SS) from 1979 through to 2016;
- 93 length bins, 31 for each sex category (males, immature and mature females), each 2 mm TW wide, beginning at left-hand edge 30 mm TW;
- MLS and escape gap regulations are changed over the model reconstruction period. These changes were modelled by incorporating a time series of MLS regulations by sex;
- no density-dependent growth; and
- it was determined from the logbook data that the discarding of large lobsters is not common in CRA 3, making it unnecessary to model this process at this time.

Data used and their sources are listed in Table 5 and Figure 4.

The assessment assumed that recreational catch was proportional to SS CPUE from 1979 through to 2018. Estimates from four large-scale ‘off-site’ CRA 3 recreational surveys in 1994, 1996, 2011 and 2017 were fitted to the SS CPUE indices, assuming a lognormal distribution, to estimate a scaling factor that was used to scale the SS CPUE observations to the total annual CRA 3 recreational catch from 1979–2018.

Table 5: Data types and sources for the 2019 stock assessment of CRA 3. Fishing years are named from the first nine months, i.e., 1998–99 is called 1998. N/A – not applicable or not used; New Zealand RLIC – New Zealand Rock Lobster Industry Council Ltd.; FSU: Fisheries Statistics Unit; CELR: catch and effort landing returns.

		CRA 3	
Data type	**Data source**	**Begin year**	**End year**
CPUE	CR	1963	1973
CPUE	FSU	1979	1988
CPUE	CELR	1989	2018
Observer proportions-at-size	Fisheries New Zealand and New Zealand RLIC	1986	2018
Logbook proportions-at-size	New Zealand RLIC	1993	2018
Tag recovery data	New Zealand RLIC and Fisheries New Zealand	1975	2018
Historical MLS regulations	Fisheries New Zealand	1945	2018
Escape gap regulation changes	Annala (1983), Fisheries New Zealand	1945	2018
Puerulus settlement	Fisheries New Zealand	N/A	N/A
Retention	New Zealand RLIC	N/A	N/A

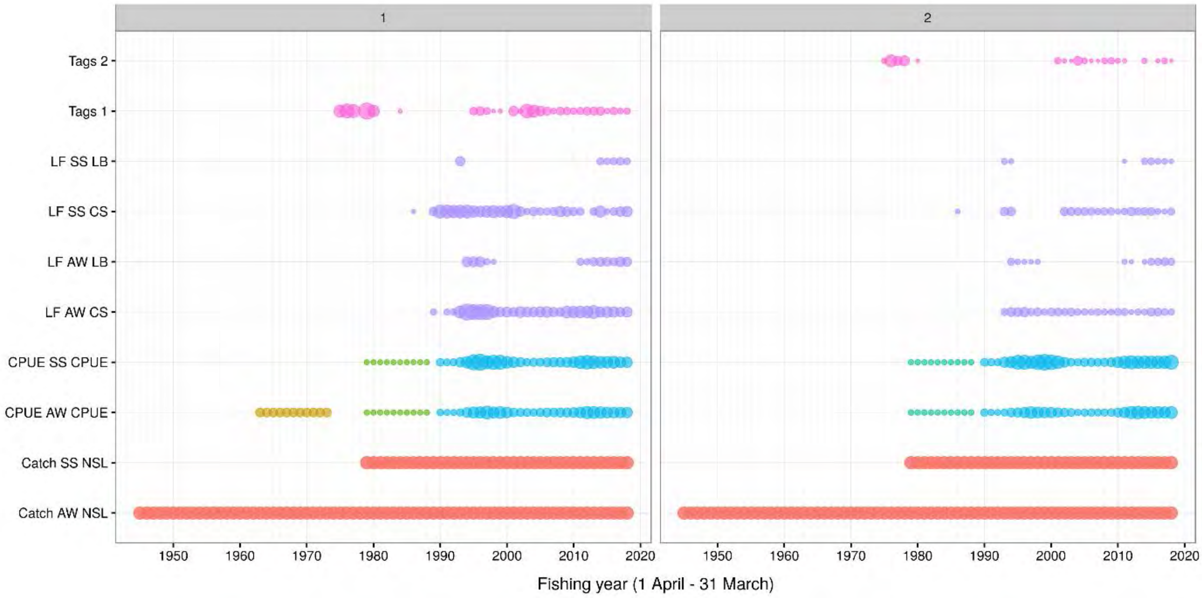


Figure 4: Data extent by fishing year used in the CRA 3 stock assessment. The size of each bubble represents the relative amount of data for each data type.

The numbers of male, immature female and mature female lobsters in each size class were updated in each season as a result of:

a) **Recruitment:** New recruits to the model were added equally for each sex for each season as a normal distribution with a mean size (32 mm) and standard deviation (2 mm), truncated at the smallest size class (30 mm). Recruitment in a specific year was determined by the mean recruitment parameter (R_0) and the estimated annual deviations from mean recruitment. The vector of recruitment deviations in log-space was assumed to be normally distributed with a mean of zero. Recruitment deviations were estimated for 1945 through 2016. The 2017 and 2018 recruitment deviations were fixed to be the same as the 2016 recruitment deviation.

b) **Mortality:** Natural, fishing and handling mortalities were applied to each sex category in each size class. Natural mortality was assumed to be constant and independent of sex and length. Fishing mortality was determined from observed catch and model biomass, modified by legal sizes, sex-specific vulnerabilities, and selectivity. Handling mortality was assumed to be 10% for lobsters returned to the water before CRA entered the QMS in 1990 and was 5% for discarded lobsters thereafter. Two fisheries were modelled: one that operated only on fish above the MLS, excluding berried females (SL fishery – including legal commercial and recreational) and one that did not respect size limits and restrictions on berried females (NSL fishery – the illegal fishery plus the Maori customary fishery). Selectivity and vulnerability functions were otherwise the same for the SL and NSL fisheries. Vulnerability by sex category and season was estimated relative to males in AW, which were assumed to have the highest vulnerability. Instantaneous fishing mortality rates for each fishery were calculated using Newton-Raphson iterations (three iterations) from catch, model biomass and natural mortality.

c) **Fishery selectivity:** A three-parameter fishery selectivity function was assumed, with parameters describing the shapes of the ascending and descending limbs and the size at which vulnerability is at a maximum. Five selectivity curves were assumed: two separate periods (pre-1993 and 1993–2018) for females in 909+910, otherwise one selectivity period was assumed for each sex in each region. As in previous rock lobster stock assessments, the descending limb of the selectivity curve was fixed at a high value (200) assuming high vulnerability of large lobsters.

d) **Growth and maturation:** For each size class and sex category, a growth transition matrix specified the probability of an individual remaining in the same size class or moving into other size classes. Maturation of females was estimated as a two-parameter logistic curve.

Model fitting

The best fit to the data was obtained by finding the maximum *a posteriori* (MAP) using Stan, an 'open-source' modelling language. The model was fitted to: all CPUE series assuming a lognormal distribution, to proportions-at-length with a multinomial distribution, to sex ratios using a multinomial distribution, and to tag-recapture data with a robust normal distribution. For the CPUE likelihoods, CVs for each index value were initially set at the standard error from the GLM analysis along with an additional 25% process error.

Proportions-at-length, assumed to be representative of the commercial catch, were available (see Table 5 and Figure 4) from observer catch sampling and voluntary logbooks. These data were summarised for each data source by area/month strata and weighted by the commercial catch taken in each stratum, the number of lobsters measured by sex category, and the number of days sampled. Data from observers and logbooks were fitted separately, with proportions normalised and fitted within each sex class, and with the model estimating proportions-at-sex separately using a multinomial distribution. These data were weighted within the model using the iterative method of Francis (2011).

In all model runs it was assumed that CPUE was directly proportional to vulnerable biomass, that growth was not density-dependent, and that there is no stock-recruit relationship. Parameters estimated, along with their priors, are listed in Table 6. Fixed parameters and their values are listed in Table 7.

Table 6: Specifications for estimated parameters in the CRA 3 models including the upper and lower bounds, prior type, and prior parameters.

	Bounds		Priors		
Parameters	**lower**	**upper**	**type**	**par1**	**par2**
R_0	exp(1)	exp(25)	uniform		
*Rdev*s	-2.3	2.3	normal	0	*SigmaR*
M	0.01	0.35	lognormal	0.12	0.4
qCR	exp(-25)	exp(0)	uniform		
qFSU	exp(-25)	exp(0)	uniform		
qCELR	exp(-25)	exp(0)	uniform		
Mat50	10	80	normal	50	50
Mat95add	1	60	normal	10	10
Galpha	1	15	normal	5	3
Gdiff	0.001	0.99	beta	1	5
GCV (males)	0.01	2	normal	0.59	1
GCV (females)	0.01	2	normal	0.82	1
Gobs	0.0001	10	normal	1.48	1
Gdd	0	1	beta	1	1
SelL	1	50	normal	20	100
SelM	30	90	normal	50	50
vuln	0.01	1	beta	3	3
U_0	0	0.99	beta	1	1
qdrift	-0.08	0.08	normal	0	1

Table 7: Fixed values used in base case assessment for CRA 3.

Quantity	**Value**	**Quantity**	**Value**
Projected catches		**Fixed parameters**	
commercial (909+910)	135.78 t	*sigmaR*	0.4
commercial (911)	104.18 t	*Gshape*	5.0
recreational (909+910)	6.06 t	*Gmin*	0.5
recreational (911)	4.66 t	*alpha (for Galpha)*	30 mm
illegal (909+910)	34.46 t	*beta (for Gbeta)*	80 mm
illegal (911)	26.44 t	*SelR*	200
customary (909+910)	11.32 t	**Length-weight**	
customary (911)	8.68 t	male length-weight *a*	4.16e-6
Handling mortality rates		male length-weight *b*	2.9354
handling mortality (1945–1989)	0.10	female length-weight *a*	1.30e-5
handling mortality (1990–2017)	0.05	female length-weight *b*	2.5452
Other		**Recruitment**	
Newton-Raphson iterations	3	last year of estimated *Rdevs*	2016
Tail compression: male bins	4 to 23	years for estimating *Rdev*'s for	2007–
Tail compression: female immature	4 to 17	years for estimating autocorrelation	1986–
Tail compression: female mature bins	4 to 24	recruitment size mean	32 mm
		recruitment size SD	2 mm

Bayesian inference

Bayesian inference was used to estimate parameter uncertainty. Sensitivity runs were done to evaluate structural uncertainty. Samples from the joint posterior distribution were generated with Markov chain Monte Carlo (MCMC) simulations using the Hamiltonian Monte Carlo (HMC) algorithm. Four chains, each with a warm-up phase of 500 samples and length of 500 samples were done, retaining every second sample, for a total of 1000 samples of the posterior distribution.

Two base case MCMCs were done:

1. using a reduced tag data set, based on recoveries that were at liberty for greater than 365 days; and
2. using the complete tag data set, without filtering for days at liberty.

Two MCMC sensitivity runs that fixed the q-drift parameter to zero were also completed.

Performance indicators and results

Agreed indicators are summarised in Table 8. Results from the two base cases are compared in Table 9.

The base case results suggested that the spawning stock biomass (SSB) was steady until the mid-1960s when it declined slowly to the mid-1970s, then increased rapidly above SSB_0 to its peak in 1981. From 1982 to 1990, the SSB declined to its lowest point, then increased to 1997, declined to 2005, and in recent years has increased steadily. The current SSB is predicted to be well above the default soft and hard limits (Figure 6 and Table 9). The SSB is projected to decline over the next five years with current catches and recent recruitment but will remain well above the soft and hard limits.

Vulnerable biomass in the assessment model was determined by the MLS, selectivity, relative sex and seasonal vulnerability, and berried state for mature females. All mature females were assumed to be berried during the AW season, thus not vulnerable to the SL fishery, and not berried and vulnerable in the SS season. The base case results (Figure 5, Figure 6, and Table 9) suggested that the AW vulnerable reference biomass decreased to a low point in 1992, increased to a peak in the mid-1990s, and decreased rapidly until 2004. There was a short period of increased biomass to 2013, followed by a steadily decreasing trend to 2018. B_{2019} is predicted to be well above B_{min} but the AW vulnerable biomass is projected to continue to decline with current catches and recent recruitment.

VB_{REF} was calculated as the biomass level corresponding to the offset year CPUE of 1.5 kg/potlift (this is the mid-point of the second slope of the decision rule from the previous CRA 3 MP) multiplied by the median catchability coefficient (q) from the 2014 assessment. The median estimated offset year vulnerable biomass at the beginning of 2019 was about 91% (r1 base) or about104% (r2 base) of VB_{REF} (Table 9).

Table 8: Reference points, performance indicators and stock status probabilities for the CRA 3 stock assessment. [Continued on next page]

Type	Description
Reference Points	
B_0	beginning of season AW vulnerable biomass before fishing
B_{0now}	equilibrium vulnerable biomass using mean 2007–2016 recruitment
B_{min}	the lowest beginning AW vulnerable biomass in the series
B_{2019}	beginning of season AW vulnerable biomass for 2019
B_{2023}	beginning of season AW vulnerable biomass for 2023
SSB_0	female AW spawning stock biomass before fishing began (1945)
SSB_{0now}	equilibrium female spawning biomass using mean 2007–2016 recruitment
SSB_{2019}	female spawning stock biomass at beginning of 2019 AW season
SSB_{2023}	female spawning stock biomass at beginning of 2023 AW season
$Btot_0$	equilibrium total biomass
$Btot_{2019}$	beginning of season AW total biomass for 2019
VB_{2019}	Average of vulnerable biomass for season SS in 2018 and AW in 2019
VB_{2023}	Average of vulnerable biomass for season SS in 2022 and AW in 2023
$CPUE_{2018}$	AW CPUE at beginning of 2019 (in kg/potlift)
$CPUE_{2023}$	AW CPUE at beginning of 2023 (in kg/potlift)
H_{2018}	total handling mortality for 2018 (tonnes)
H_{2023}	total handling mortality for 2022 (tonnes)
VB_{REF}	Interim target vulnerable biomass associated with the CPUE midpoint on the second slope of the control rule and the median q estimated in 2014
Performance indicators	
B_{2019}/B_0	ratio of B_{2019} to B_0
B_{2023}/B_0	ratio of B_{2023} to B_0
B_{2023}/B_{2019}	ratio of B_{2023} to B_{2019}
SSB_{2019}/SSB_0	ratio of SSB_{2019} to SSB_0
SSB_{2023}/SSB_0	ratio of SSB_{2023} to SSB_0
SSB_{2023}/SSB_{2018}	ratio of SSB_{2023} to SSB_{2019}
$Btot_{2019}/Btot_0$	ratio of $Btot_{2019}$ to $Btot_0$
$Btot_{2023}/Btot_0$	ratio of $Btot_{2023}$ to $Btot_0$
$Btot_{2023}/Btot_{2019}$	ratio of $Btot_{2023}$ to $Btot_{2019}$

Performance Indicators

VB_{2019}/VB_{REF}	ratio of VB_{2019} to VB_{REF}
VB_{2023}/VB_{REF}	ratio of VB_{2023} to VB_{REF}
$Btot_{0M}/Btot_{0F}$	ratio of male to female total biomass at equilibrium
$Btot_{2019M}/Btot_{2019F}$	ratio of male to female total biomass for 2019

Probabilities

$P(B_{2019}>B_{min})$	probability B_{2019} is greater than B_{min}
$P(SSB_{2019}<20\%SSB_0)$	probability SSB_{2019} is less than 20% SSB_0
$P(SSB_{2019}<10\%SSB_0)$	probability SSB_{2019} is less than 10% SSB_0
$P(VB_{2019}>VB_{REF})$	probability VB_{2019} is greater than VB_{REF}
$P(VB_{2023}\geq VB_{REF})$	probability VB_{2023} is greater than VB_{REF}

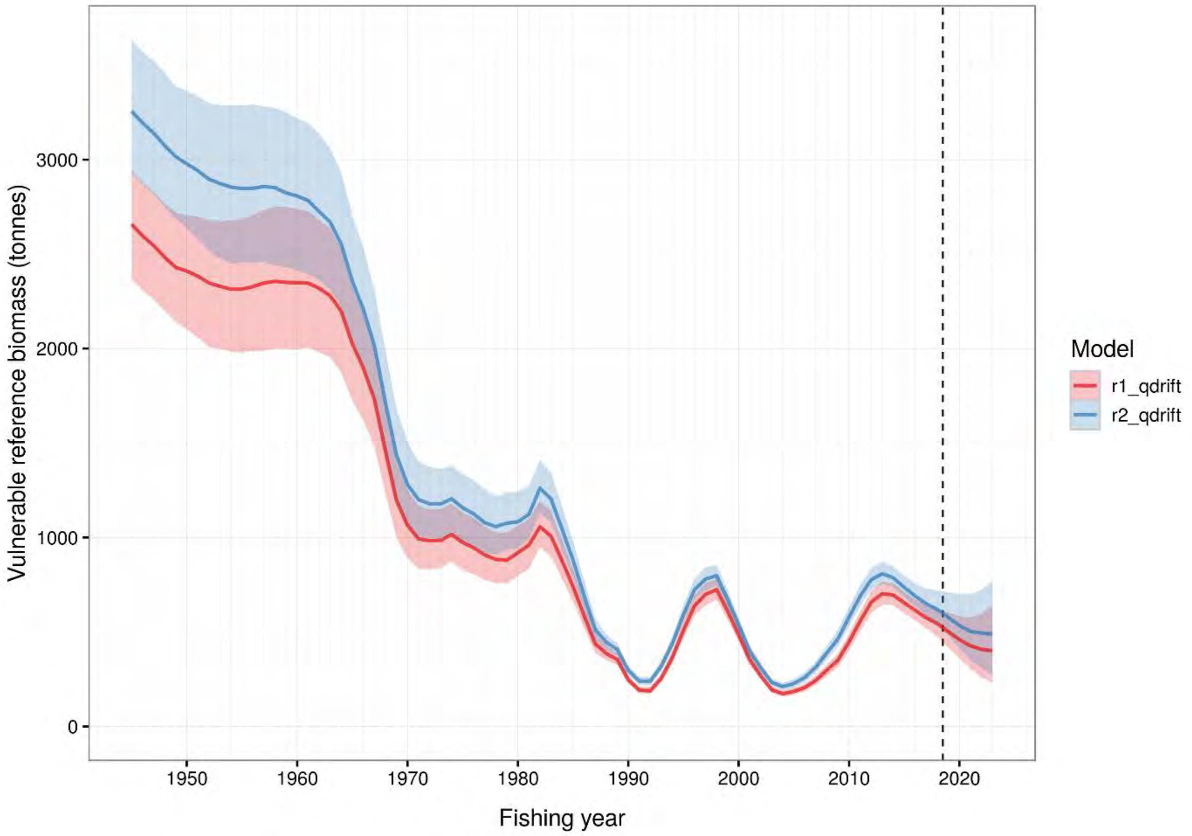


Figure 5: CRA 3 AW vulnerable reference biomass over the model reconstruction period for the model runs that fit to tags at liberty for longer than 365 days (r1_base) and fit to all tags (r2_base). Solid lines indicate the median vulnerable reference biomass; shading indicates the 90% credible intervals for each series. The biomass in each year uses the final reconstruction year's selectivity and MLS.

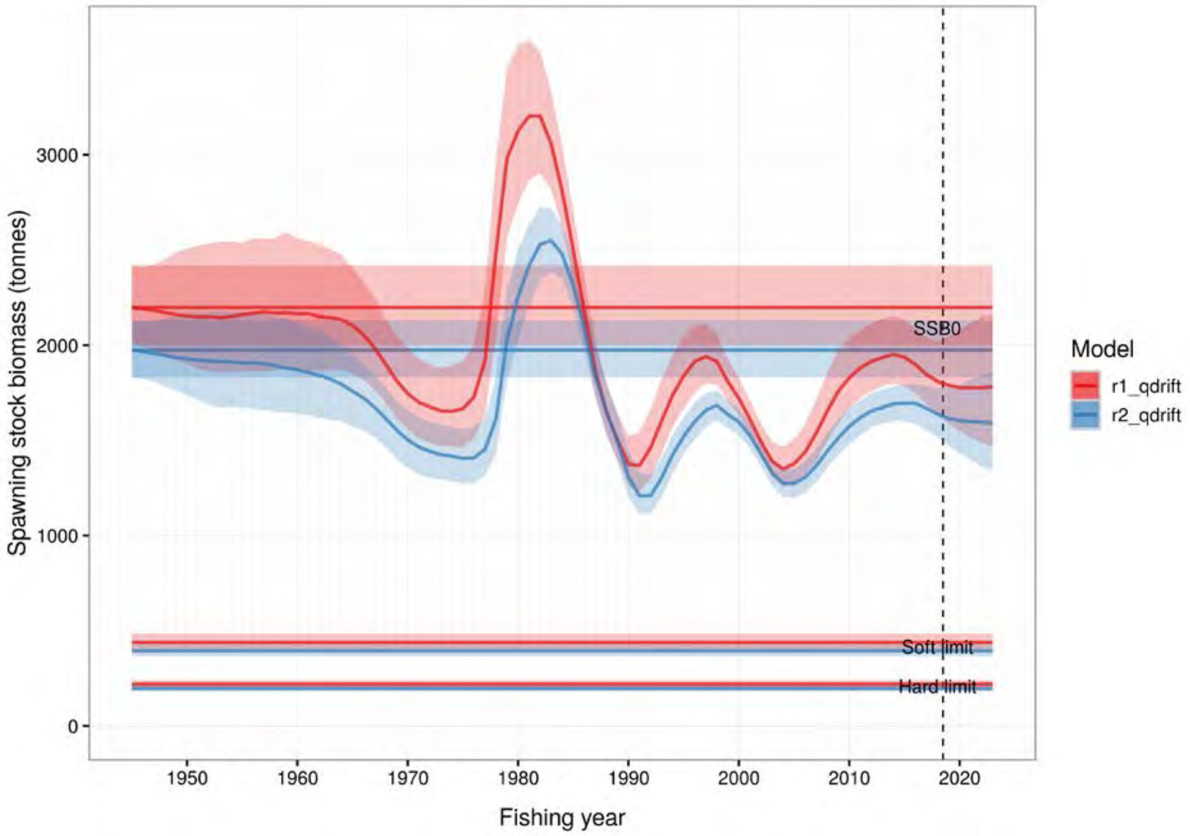


Figure 6: CRA 3 posterior distribution of the spawning stock biomass (*SSB*) trajectory for the model runs that fit to tags at liberty for longer than 365 days (r1_base) and fit to all tags (r2_base). Solid lines indicate the median vulnerable reference biomass; shading indicates the 90% credible intervals for each series. Also plotted for each model run is the posterior distribution of the unfished SSB (SSB_0), the soft limit (20% SSB_0), and the hard limit (10% SSB_0).

Table 9: CRA 3 base case MCMC outputs, reporting the 5%, 50% (median), and 95% quantiles of the posterior distribution. Growth increment values in mm TW, biomass values in t, and R_0 in numbers. '–': not applicable.

	r1_base			r2_base		
	5%	50%	95%	5%	50%	95%
Likelihoods						
Total	21 744.0	21 758.9	21 774.9	25 461.1	25 475.2	25 490.4
Prior	20.8	35.0	48.2	22.0	34.6	49.7
Tag	2 008.5	2 016.7	2 025.7	6 653.8	6 668.3	6 684.4
Sex-ratio	2 526.4	2 532.9	2 540.8	2 532.2	2 539.9	2 549.9
LFs	17 297.2	17 309.4	17 324.4	16 329.9	16 349.2	16 367.1
CR	21 744.0	21 758.9	21 774.9	25 461.1	25 475.2	25 490.4
FSU[909+910]	20.8	35.0	48.2	22.0	34.6	49.7
FSU[911]	2 008.5	2 016.7	2 025.7	6 653.8	6 668.3	6 684.4
CELR	2 526.4	2 532.9	2 540.8	2 532.2	2 539.9	2 549.9
Standard deviation normalised residuals (SDNR)						
Tag	1.17	1.22	1.26	5.29	5.54	5.78
Sex-ratio	0.94	0.98	1.02	0.97	1.00	1.05
CR	0.98	1.07	1.24	1.00	1.06	1.22
FSU[909+910]	0.92	1.12	1.34	0.86	1.07	1.30
FSU[911]	0.95	1.07	1.25	0.96	1.10	1.30
CELR	1.16	1.23	1.32	1.13	1.22	1.30
Median absolute residual (MAR)						
Tag	0.65	0.68	0.71	0.70	0.72	0.73
Sex-ratio	0.46	0.51	0.56	0.49	0.53	0.57
CR	0.42	0.71	1.11	0.40	0.66	1.03
FSU[909+910]	0.62	0.89	1.13	0.56	0.80	1.05
FSU[911]	0.49	0.70	0.93	0.50	0.73	0.97
CELR	0.61	0.71	0.81	0.68	0.76	0.87
Parameters						

	r1_base			r2_base		
	5%	**50%**	**95%**	**5%**	**50%**	**95%**
R₀[909+910]	1 173 200	1 422 330	1 749 880	734 761	845 445	981 710
R₀[911]	672 448	814 417	1 024 670	410 541	481 193	562 359
M	0.213	0.235	0.262	0.162	0.179	0.197
Galpha[909+910]	6.81	7.35	7.89	9.91	10.16	10.39
Galpha[911]	7.08	7.59	8.11	7.20	7.65	8.10
Gbeta[909+910]	2.41	2.61	2.82	1.17	1.27	1.37
Gbeta[911]	0.64	0.74	0.86	0.42	0.49	0.56
GCV[909+910]	0.750	0.795	0.844	0.703	0.724	0.744
GCV[911]	1.14	1.26	1.40	1.22	1.32	1.43
Gobs	0.0298	0.2740	0.6724	0.0012	0.0091	0.0269
Mat50	35.4	40.2	43.4	36.6	41.1	44.5
Mat95add	9.4	20.9	34.2	11.9	23.2	36.4
selL (M[909+910])	4.5	4.6	4.8	4.7	4.8	5.0
selL (F[909+910]period2)	13.3	15.8	18.1	15.6	18.3	20.9
selL (M[911])	5.3	5.7	6.1	5.5	6.0	6.5
selL (F[911])	5.9	6.3	6.8	6.0	6.5	6.9
selL (F[909+910]period1)	5.2	6.7	8.9	5.3	7.2	9.6
selM (M[909+910])	54.3	54.6	55.0	53.5	53.8	54.1
selM (F[909+910]period2)	73.7	79.7	86.1	76.4	82.9	88.8
selM (M[911])	58.9	59.7	60.5	58.0	58.9	60.0
selM (F[911])	64.9	65.8	66.8	64.4	65.3	66.3
selM (F[909+910]period1)	56.6	59.5	64.4	55.6	58.9	63.4
vuln1 (M/SS[909+910])	0.893	0.941	0.977	0.883	0.938	0.975
vuln2 (F/AW[909+910])	0.056	0.087	0.138	0.062	0.094	0.137
vuln3 (F/SS[909+910])	0.206	0.303	0.467	0.222	0.321	0.463
vuln4 (M/SS[911])	0.859	0.914	0.964	0.824	0.885	0.938
vuln5 (F/AW[911])	0.339	0.417	0.505	0.371	0.451	0.555
vuln6 (F/SS[911])	0.783	0.893	0.964	0.823	0.914	0.976
qCR	0.13815	0.17356	0.21772	0.11508	0.14264	0.17450
qFSU [909+910]	0.00178	0.00222	0.00283	0.00152	0.00191	0.00239
qFSU [911]	0.00250	0.00314	0.00394	0.00198	0.00239	0.00300
qCELR	0.00433	0.00501	0.00581	0.00313	0.00359	0.00410
qdrift	0.00469	0.01240	0.01958	0.00859	0.01612	0.02374
Derived quantities: vulnerable biomass						
B_0[909+910]	1 549	1 765	1 991	1 896	2 139	2 426
B_0[911]	780	896	1 014	973	1 111	1 261
B_0[CRA 3]	2 367	2 658	2 940	2 929	3 257	3 635
B_{0now}[909+910]	1 457	1 690	1 952	1 905	2 155	2 455
B_{0now}[911]	713	850	1 014	839	998	1 183
B_{0now}[CRA 3]	2 219	2 551	2 919	2 795	3 154	3 577
B_{min}[909+910]	109	118	128	126	138	150
B_{min}[911]	44	50	57	56	65	74
B_{min}[CRA 3]	155	168	182	185	202	219
B_{2019}[909+910]	208	257	323	238	307	403
B_{2019}[911]	186	240	310	201	266	340
B_{2019}[CRA 3]	419	501	602	476	575	706
B_{2023}[909+910]	109	266	511	149	346	637
B_{2023}[911]	47	126	250	45	126	273
B_{2023}[CRA 3]	209	400	673	254	489	798
B_{2019}/B_0[909+910]	0.11	0.15	0.19	0.11	0.14	0.19
B_{2019}/B_0[911]	0.20	0.27	0.36	0.18	0.24	0.31
B_{2019}/B_0[CRA 3]	0.15	0.19	0.23	0.14	0.18	0.22
B_{2023}/B_0[909+910]	0.06	0.15	0.29	0.07	0.16	0.30
B_{2023}/B_0[911]	0.05	0.14	0.28	0.04	0.11	0.24
B_{2023}/B_0[CRA 3]	0.08	0.15	0.26	0.08	0.15	0.25
B_{2023}/B_{2019}[909+910]	0.47	1.03	1.85	0.53	1.10	1.91
B_{2023}/B_{2019}[911]	0.23	0.52	0.90	0.20	0.47	0.90
B_{2023}/B_{2019}[CRA 3]	0.45	0.80	1.25	0.47	0.83	1.29
Derived quantities: spawning stock biomass (females only)						
SSB_0[909+910]	1 243	1 394	1 546	1 149	1 254	1 397
SSB_0[911]	718	802	910	643	713	787
SSB_0[CRA 3]	2 002	2 198	2 419	1 829	1 974	2 130
SSB_{0now}[909+910]	1 168	1 289	1 446	1 131	1 240	1 363
SSB_{0now}[911]	636	741	871	544	632	739
SSB_{0now}[CRA 3]	1 840	2 029	2 262	1 712	1 878	2 044
SSB_{2019}[909+910]	958	1 099	1 306	935	1 036	1 162
SSB_{2019}[911]	546	659	804	480	551	646
SSB_{2019}[CRA 3]	1 560	1 765	2 047	1 452	1 589	1 755

			r1_base			**r2_base**
	5%	**50%**	**95%**	**5%**	**50%**	**95%**
SSB_{2023}[909+910]	898	1 144	1 452	896	1 083	1 312
SSB_{2023}[911]	460	623	835	374	498	650
SSB_{2023}[CRA 3]	1 464	1 781	2 162	1 338	1 590	1 863
SSB_{2018}/SSB_0[909+910]	0.69	0.79	0.92	0.73	0.82	0.92
SSB_{2018}/SSB_0[911]	0.69	0.82	1.00	0.67	0.77	0.90
SSB_{2018}/SSB_0[CRA 3]	0.72	0.80	0.91	0.74	0.80	0.89
SSB_{2023}/SSB_0[909+910]	0.65	0.82	1.04	0.70	0.86	1.05
SSB_{2023}/SSB_0[911]	0.59	0.78	1.02	0.53	0.70	0.91
SSB_{2023}/SSB_0[CRA 3]	0.67	0.81	0.96	0.68	0.80	0.94
SSB_{2023}/SSB_{2019}[909+910]	0.87	1.02	1.22	0.90	1.02	1.18
SSB_{2023}/SSB_{2019}[911]	0.78	0.94	1.12	0.74	0.89	1.06
SSB_{2023}/SSB_{2019}[CRA 3]	0.88	0.99	1.13	0.88	0.98	1.09
Derived quantities: total biomass						
$Btot_0$[909+910]	4 051	4 487	4 877	3 826	4 186	4 644
$Btot_0$[911]	2 327	2 576	2 866	2 152	2 382	2 605
$Btot_0$[CRA 3]	6 524	7 051	7 585	6 103	6 582	7 090
$Btot_{0now}$[909+910]	3 879	4 276	4 723	3 874	4 236	4 680
$Btot_{0now}$[911]	2 132	2 448	2 836	1 872	2 163	2 504
$Btot_{0now}$[CRA 3]	6 161	6 723	7 381	5 907	6 414	6 994
$Btot_{2019}$[909+910]	2 063	2 522	3 101	1 803	2 115	2 518
$Btot_{2019}$[911]	1 377	1 708	2 168	1 080	1 314	1 628
$Btot_{2019}$[CRA 3]	3 631	4 264	5 030	3 028	3 441	4 001
$Btot_{2023}$[909+910]	2 017	2 643	3 565	1 683	2 247	2 938
$Btot_{2023}$[911]	1 168	1 585	2 209	825	1 156	1 635
$Btot_{2023}$[CRA 3]	3 449	4 248	5 388	2 763	3 410	4 301
$Btot_{2019}/Btot_0$[909+910]	0.46	0.56	0.69	0.42	0.50	0.61
$Btot_{2019}/Btot_0$[911]	0.54	0.67	0.85	0.45	0.55	0.69
$Btot_{2019}/Btot_0$[CRA 3]	0.52	0.61	0.71	0.45	0.52	0.61
$Btot_{2023}/Btot_0$[909+910]	0.44	0.59	0.80	0.40	0.53	0.71
$Btot_{2023}/Btot_0$[911]	0.46	0.62	0.84	0.35	0.48	0.69
$Btot_{2023}/Btot_0$[CRA 3]	0.49	0.60	0.76	0.41	0.52	0.65
$Btot_{2023}/Btot_{2019}$[909+910]	0.86	1.04	1.32	0.87	1.05	1.30
$Btot_{2023}/Btot_{2019}$[911]	0.78	0.92	1.12	0.72	0.87	1.07
$Btot_{2023}/Btot_{2019}$[CRA 3]	0.87	1.00	1.18	0.86	0.98	1.16
Other derived quantities						
$R_{2007-2016}$[909+910]	1 158 150	1 368 720	1 642 220	771 264	865 708	981 717
$R_{2007-2016}$ [911]	630 441	783 201	1 010 260	370 070	442 804	533 574
H_{2018}[909+910]	6.4	7.2	8.2	5.9	6.8	7.7
H_{2018}[911]	2.3	2.7	3.0	2.4	2.8	3.2
H_{2018}[CRA 3]	9.0	9.9	10.9	8.7	9.6	10.7
H_{2023}[909+910]	4.6	8.3	25.7	3.7	6.7	17.2
H_{2023}[911]	2.9	5.1	15.9	3.3	5.7	21.0
H_{2023}[CRA 3]	8.7	14.3	34.2	8.2	13.3	31.2
$Btot_{0M}/Btot_{0F}$[909+910]	1.60	1.71	1.83	1.85	1.94	2.05
$Btot_{0M}/Btot_{0F}$[911]	1.60	1.71	1.83	1.85	1.94	2.05
$Btot_{2019M}/Btot_{2019F}$[909+910]	0.73	0.81	0.89	0.60	0.69	0.78
$Btot_{2019M}/Btot_{2019F}$[911]	1.06	1.11	1.16	0.97	1.05	1.13
$CPUE_{2018}$[909+910]	1.13	1.36	1.63	1.11	1.35	1.67
$CPUE_{2018}$[911]	1.23	1.56	1.97	1.12	1.43	1.81
$CPUE_{2023}$[909+910]	0.16	1.31	2.78	0.42	1.51	3.03
$CPUE_{2023}$[911]	0.12	0.71	1.44	0.07	0.62	1.36
VB_{2019}	425	502	591	481	572	686
VB_{2023}	225	381	590	261	463	707
VB_{REF}	–	551	–	–	551	–
VB_{2019}/VB_{REF}	0.773	0.911	1.07	0.875	1.040	1.240
VB_{2023}/VB_{REF}	0.412	0.692	1.07	0.486	0.833	1.280
Probabilities						
$P(B_{2019}>B_{min})$[909+910]		1			1	
$P(B_{2019}>B_{min})$[911]		1			1	
$P(B_{2019}>B_{min})$[CRA 3]		1			1	
$P(SSB_{2019}<20\%SSB_0)$[909+910]		0			0	
$P(SSB_{2019}<20\%SSB_0)$[911]		0			0	
$P(SSB_{2019}<20\%SSB_0)$[CRA 3]		0			0	
$P(SSB_{2019}<10\%SSB_0)$[909+910]		0			0	
$P(SSB_{2019}<10\%SSB_0)$[911]		0			0	
$P(SSB_{2019}<10\%SSB_0)$[CRA 3]		0			0	
$P(Btot_{2023}>Btot_{2019})$[909+910]		0.611			0.661	
$P(Btot_{2023}>Btot_{2019})$[911]		0.268			0.138	

	r1_base			r2_base		
	5%	50%	95%	5%	50%	95%
P($Btot_{2023}$>$Btot_{2019}$)[CRA 3]		0.493			0.444	
P(B_{2023}>B_{2019})[909+910]		0.527			0.606	
P(B_{2023}>B_{2019})[911]		0.028			0.023	
P(B_{2023}>B_{2019})[CRA 3]		0.204			0.268	
P(SSB_{2023}>SSB_{2019})[909+910]		0.588			0.604	
P(SSB_{2023}>SSB_{2019})[911]		0.253			0.149	
P(SSB_{2023}>SSB_{2019})[CRA 3]		0.470			0.382	
P(VB_{2019}>VB_{REF})		0.189			0.626	
P(VB_{2023}>VB_{REF})		0.080			0.250	

7. FUTURE RESEARCH CONSIDERATIONS

Future research considerations are similar for CRA 1 and CRA 3 and are therefore duplicated in each chapter. They include:

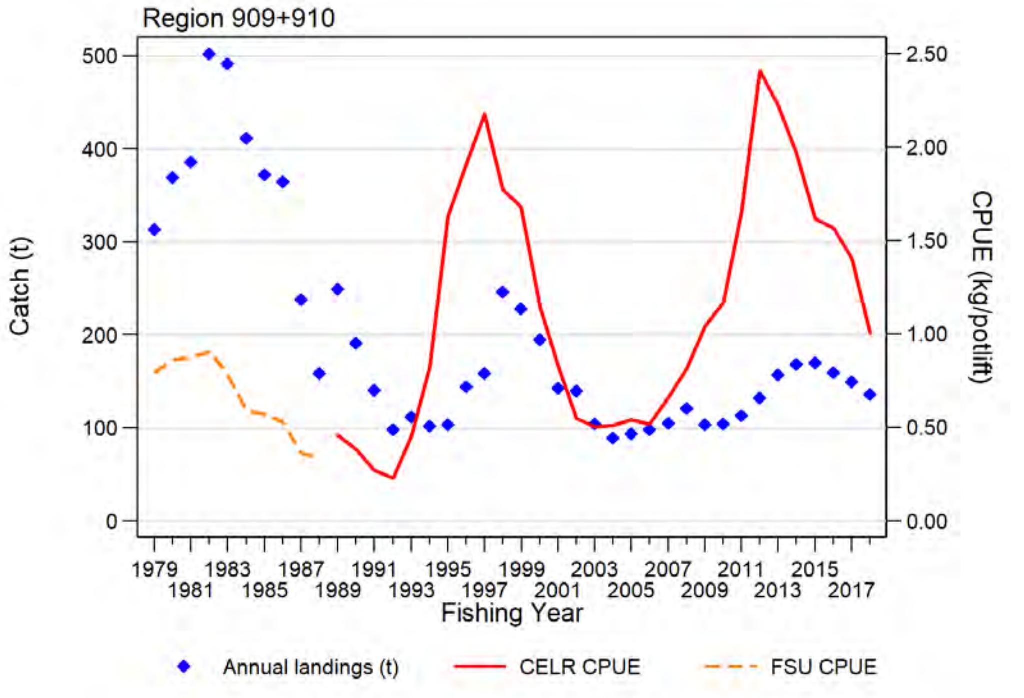
- Further develop a new method to derive target reference points for rock lobsters where, in the absence of a Management Procedure, catch may need to be held constant between full stock assessments.
- Re-evaluate the method used to determine Effective Sample Sizes for length composition data.
- Explore the potential to develop alternative growth models with fewer parameters, especially for cases when there are a limited number of datasets.
- Consider further analysing the potential for a bias in the estimation of growth that could result from the timing of tagging with respect to the timing of moulting.
- Review the validity of the prior for M.
- Explore the utility of implementing standardised length frequencies that employ a methodology similar to that used for standardising CPUE.
- Review the methodology for analysing puerulus data and incorporating it into the model.
- Explore methods for developing a Bayesian version of a likelihood profile.

8. STATUS OF THE STOCKS

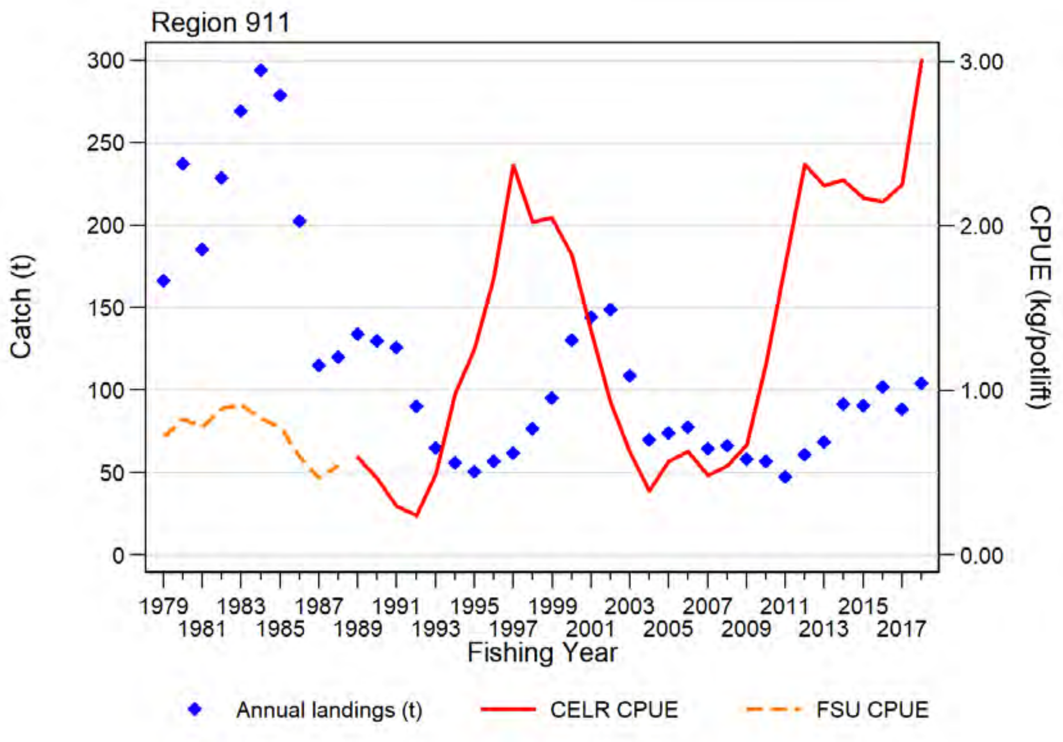
Stock structure assumptions
For the purposes of stock assessment and management, rock lobsters are assumed to constitute separate Fishstocks within each CRA Quota Management Area. There is likely to be some degree of relationship and/or exchange between Fishstocks in these CRA areas, either as a result of migration, larval dispersal or both.

Stock Status	
Year of Most Recent Assessment	2019
Assessment Runs Presented	Two base case MCMCs (r1 and r2)
Reference Points	Interim target: reported against VB_{REF}: offset year vulnerable biomass associated with mid-point of the second slope of the decision rule (CPUE of 1.5 kg/potlift) = 551 t Soft limit: 20% SSB_0 (default) Hard limit: 10% SSB_0 (default)
Status in relation to Target	Biomass in 2019 was 91% (r1) or 104% (r2) of VB_{REF} for the two base cases VB_{2019} About as Likely as Not (40–60%) to be at or above VB_{REF}
Status in relation to Limits	Exceptionally Unlikely (< 1%) that SSB_{2019} is below soft and hard limits
Status in relation to Overfishing	Overfishing is About as Likely as Not (40–60%) to be occurring

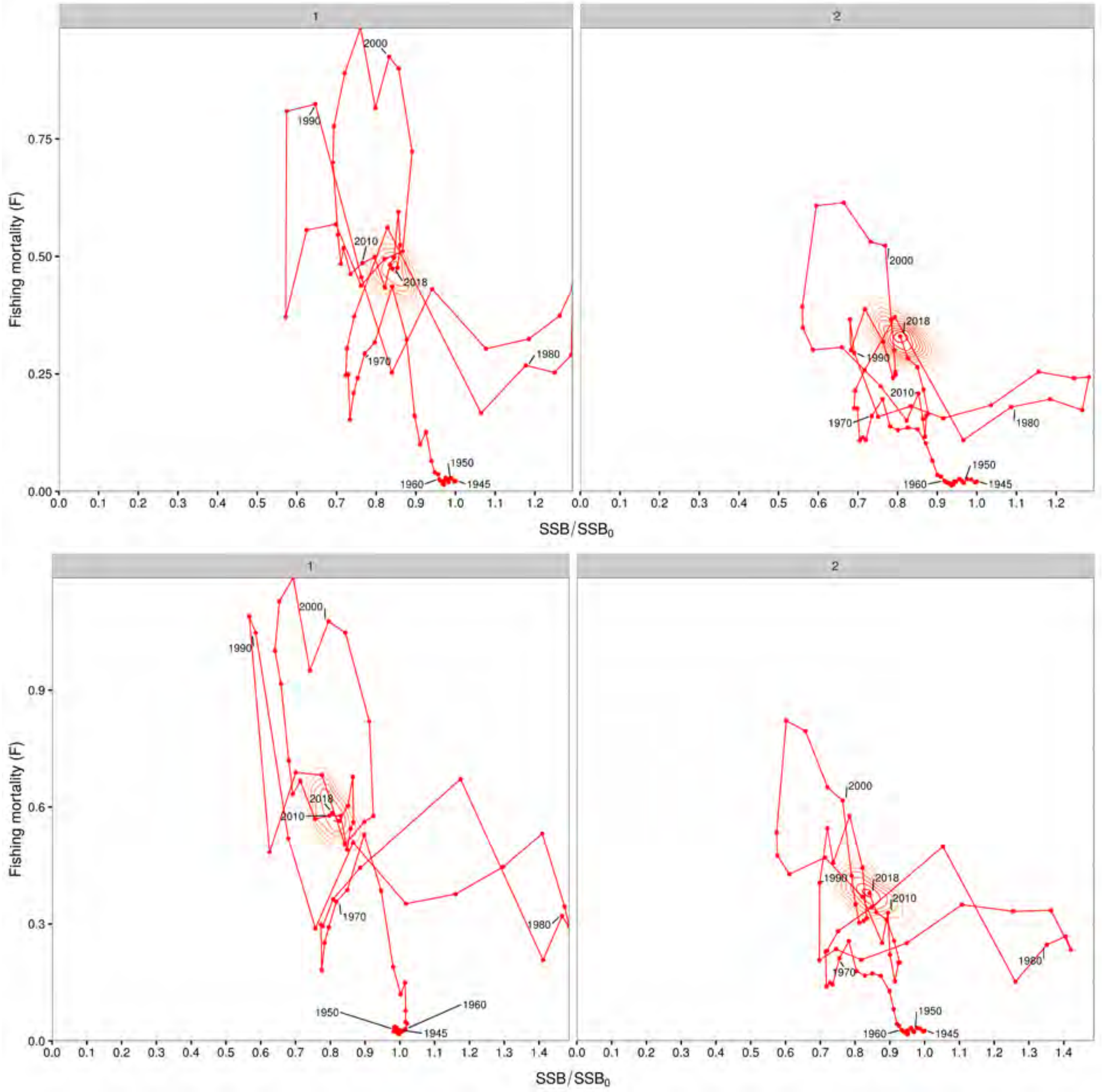
Historical Stock Status Trajectory and Current Status



Annual landings and standardised CPUE for CRA 3 Region 909+910 from 1979 to 2018.



Annual landings and standardised CPUE for CRA 3 Region 911 from 1979 to 2018.



Snail trails from the two CRA 3 base case MCMCs: r1_base and r2_base. The figures show the median of the posterior distribution of the AW spawning stock biomass (*SSB)* as a proportion of *SSB₀* each year versus the AW fishing mortality (line and points), for each region (1=909+910, 2=911). The contours at the final year of the plot show the posterior distribution of the biomass ratio and fishing mortality. The size-limited (SL) and non-size-limited (NSL) fishing mortalities are summed to get total fishing mortality in AW for each panel.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass declined steadily from 1997 to 2003 and then increased strongly after 2009. CPUE shows the same pattern until 2012 after which CPUE declined in 909+910 and plateaued in 911.
Recent Trend in Fishing Mortality or Proxy	Size-limited and non-size-limited exploitation rates have declined since 2002.
Other Abundance Indices	- Puerulus not fitted in base case
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	Biomass will continue to decline at current levels of catch.

Probability of Current Catch or TACC causing decline below Limits	Very Unlikely (< 10%)
Probability of Current Catch or TACC causing Overfishing to continue or commence	About as Likely as Not (40–60%)

Assessment Methodology		
Assessment Type	Level 1 – Full Quantitative Stock Assessment	
Assessment Method	Bayesian Lobster stock dynamics (LSD) model (Webber et al. 2018)	
Assessment Dates	Latest assessment: 2019	Next assessment: 2023
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- CPUE - Length frequency - Tagging data	1 – High Quality (all)
Data not used (rank)	- Puerulus not fitted in base case	
Changes to Model Structure and Assumptions	- LSD model used - Two-area model fitted to sub-areas 909+910 and 911 - Extra selectivity added for females in sub-area 909+910 before 1993 - Reduction in handling mortality from 10% to 5% from 1990 - Changes to LF weighting - One growth period - Split CPUE (FSU and CELR) - Omitted 911 CR data - Marine reserve reduction in R_0 and stock size changed to 3.21% for 909+910 in 1999	
Major Sources of Uncertainty	- Estimates of illegal catches are unreliable - Assumption of constant growth rate over time - Tag-based growth may not represent growth of underlying population	

Qualifying Comments
-

Environmental and Ecosystem Considerations	
Observer coverage	Observer coverage primarily for stock assessment needs.
Non-target fish and invertebrate catch	The levels of incidental catch landed from rock lobster potting ranged from 2 to 11% of the estimated rock lobster catch weight per QMA for the period 1989–2003. For all QMAs, the most frequently reported incidental species caught are, in decreasing order of catch across all stocks: octopus, conger eel, blue cod, trumpeter, sea perch, red cod, butterfish and leatherjackets.
Incidental catch of seabirds	Small numbers of shags have been reported historically in some CRA areas, but not in recent years. Fishers suggest the lack of recent shag captures is attributable to changes in pot design and baiting methodologies.
Incidental catch of marine mammals	From January 2000 until November 2018, 31 entanglements (29 marine mammal individuals, two individuals were entangled twice) were attributed to commercial or recreational rock lobster pot lines from around New Zealand, mainly around Kaikoura (DOC Marine Mammal Database).

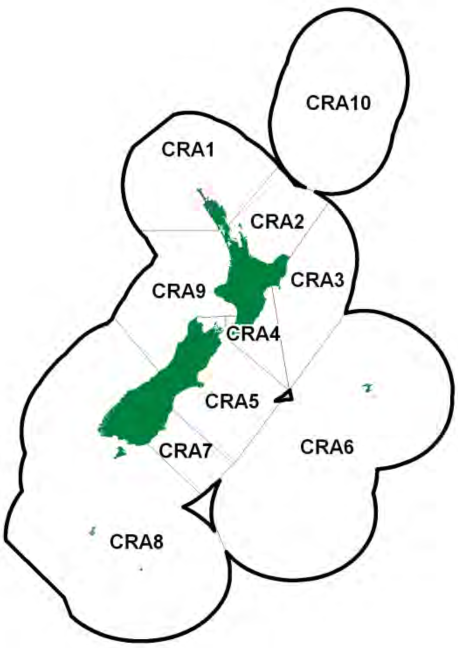
Incidental catch of other protected species	There is no known incidental catch of other protected species in rock lobster fisheries.
Benthic interactions	No information exists regarding the benthic impacts of potting in New Zealand.

8. FOR FURTHER INFORMATION

For the list of references refer to the Introduction – Rock Lobster chapter.

ROCK LOBSTER (CRA 6)

(*Jasus edwardsii*) Crayfish, Kōura papatea, Pawharu



1. FISHERY SUMMARY

1.1 Commercial fisheries

Refer to the relevant text, tables and figures in Sections 1, 1.1 and 1.7 of the Introductory Rock Lobster chapter for a presentation of the CRA 6 commercial catches and CPUE.

Historical commercial landings and TACC values can be found in Figure 1. Historical commercial landings, TACC values and CPUE can be found in Table 1.

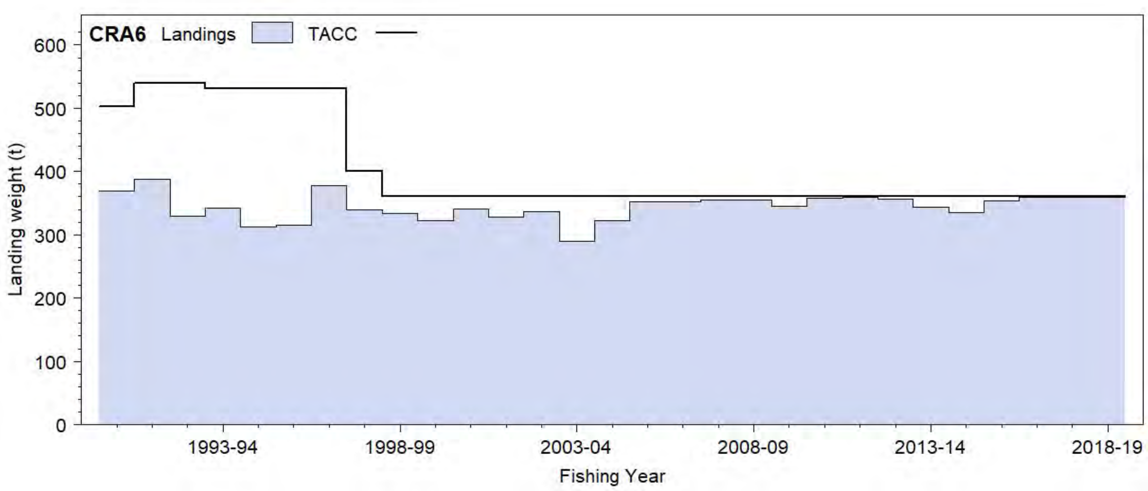


Figure 1: Historical landings and TACC for CRA 6.

Table 1: Reported commercial catch (t) from QMRs or MHRs (after 1 October 2001), commercial TACC (t) and standardised CPUE (kg/potlift) (Starr 2019). The commercial catch and commercial TACC are reported for each fishing year since the species was included in the QMS on 1 April 1990. –, TAC not set for QMA or catch not available (current fishing year). The standardised CPUE are reported from 1979–80 to 2018–19. Sources of data: from 1979–80 to 1988–89 from the QMS-held FSU data; from 1989–90 to 2018–19 from the CELR data held by Fisheries New Zealand, using the 'F2' algorithm corrected for 'LFX' destination code landings (see text for definition). The series beginning from 1989–90 has been estimated using a vessel explanatory variable constrained to vessels with at least five years in the fishery. The analysis for the FSU period 1979–88 to 1988–89 does not use a vessel explanatory variable. '–': no data.

Fishing year	Catch	TACC	CPUE
1979–80	–	–	2.182
1980–81	–	–	2.013
1981–82	–	–	2.292
1982–83	–	–	1.659
1983–84	–	–	1.630
1984–85	–	–	1.300
1985–86	–	–	1.370
1986–87	–	–	1.500
1987–88	–	–	1.320
1988–89	–	–	1.269
1989–90	–	–	1.304
1990–91	369.7	503.0	1.388
1991–92	388.3	539.6	1.315
1992–93	329.4	539.6	1.207
1993–94	341.8	530.6	1.095
1994–95	312.5	530.6	1.049
1995–96	315.3	530.6	1.078
1996–97	378.3	530.6	1.097
1997–98	338.7	400.0	1.095
1998–99	334.2	360.0	1.268
1999–00	322.4	360.0	1.252
2000–01	342.7	360.0	1.186
2001–02	328.7	360.0	1.151
2002–03	336.3	360.0	1.260
2003–04	290.4	360.0	1.198
2004–05	323.0	360.0	1.340
2005–06	351.7	360.0	1.418
2006–07	352.1	360.0	1.634
2007–08	356.0	360.0	1.418
2008–09	355.3	360.0	1.538
2009–10	345.2	360.0	1.352
2010–11	357.4	360.0	1.438
2011–12	359.7	360.0	1.436
2012–13	355.9	360.0	1.450
2013–14	343.6	360.0	1.416
2014–15	334.5	360.0	1.343
2015–16	353.3	360.0	1.341
2016–17	359.5	360.0	1.706
2017–18	359.1	360.0	1.767
2018–19	359.9	360.0	2.027
2019–20	–	360.0	–

1.2. Recreational fisheries

Davey et al (2011) conducted a Chatham Islands recreational harvest survey from 1 October 2008 to 30 September 2009. This survey consisted of a pool of 79 diarists, representing local residents and tourists, who recorded their recreational catches over the period. The primary species taken by both sectors were blue cod, hapuku, rock lobster, and paua, with blue cod having the greatest estimated catch of around 15 t, followed by 9 t of hapuku, 4 t of paua and 3 t of rock lobster. The latter two species were mainly taken by local residents while the two finfish species were targeted by both tourists and local residents. The RLFAWG discussed this survey and agreed to include a constant 5 t/year of recreational catch in the catch history.

For assessments since 2006, the RLFAWG has included recreational landings made by commercial vessels under Section 111 of the Fisheries Act. Greenweight landings with destination code “F” were extracted in 2018 from the CRACE database (Bentley et al. 2005), which showed a maximum annual value of 1.03 t[1] for CRA 6, occurring in 2012–13. The RLFAWG has agreed to add the maximum catch estimate to the estimated recreational catch in each year since 1979, increasing the total 1979 to 2017 recreational catch in the model to 1195 t.

1.3 Customary non-commercial fisheries

The RLFAWG discussed this component of the CRA 6 catch and agreed to use a constant 4 t/year which is the value currently used by Fisheries New Zealand to represent this fishery in CRA 6.

1.4 Illegal catch

CRA 6 illegal catches from 1990 to 2001 (Figure 2) were based on values provided by MPI Compliance, with values of 85 t in 1990, dropping to 70 t in 1992 and ending at 10 t in 2001 (see table 8 in the Introduction – Rock Lobster chapter). Illegal catch was set at a constant 10 t/year from 2001, where it remains. Years before 2001 without estimated illegal catches were filled by interpolation.

CRA 6 illegal catch estimates before 1990 (Figure 2) were derived from unpublished estimates of discrepancies between reported catch totals and total exported weight that were developed for the period 1974 to 1980 (see table 9 in the Introduction – Rock Lobster chapter; McKoy, unpublished). For years before 1972–73 and from 1981–82 to 1989–90, illegal catch was estimated by multiplying the average 1974–1980 discrepancy ratio by QMA with the reported catch in each QMA (table 9 in the Introduction – Rock Lobster chapter).

MPI Compliance estimates of illegal catch are often provided in two categories (“reported” or “R” and “not reported” or “NR”). Previously, the RLFAWG agreed to treat CRA 6 illegal estimates, beginning in 1990, as if they were in the “R” category. This implied that these catches were eventually landed legally and needed to be subtracted from the legal landings to avoid double counting. The reasoning behind this decision was that it would be difficult to export large amounts of illegal lobsters from a small community with limited transport options without others being aware. When this decision was reviewed for the 2018 CRA 6 stock assessment, it was agreed that the original reasoning was sound, but that it was incongruous to treat the pre-1990 catches as “unreported” (or “NR”), which would be added to the overall catch history. By agreement, the CRA 6 illegal catches were treated in the following manner:

- From 2001 onwards, the Fisheries New Zealand estimate for CRA 6 illegal catch has been 10 t/year (table 8 in the Introduction – Rock Lobster chapter). This implies a nominal amount of 250 kg of “unreported” illegal catch per operating vessel in a year, given that there were 40 vessels operating in CRA 6 in 2017–18. Estimates of vessel numbers are available in the FSU and CELR data from 1979 to 2017 as well as from 1965 to 1974 (the latter estimates are undocumented). The estimated “unreported illegal” (NR) catches for every year were determined by multiplying the annual number of vessels by the nominal value of 250 kg per

[1] Note that the maximum value shown in table 7 in the Introduction – Rock Lobster chapter is 1.68 t for 2018–19, which wasn’t available in 2018 when this stock assessment was completed.

vessel-year. Vessel numbers for 1975–1978, which have no estimates, were obtained by interpolating between the 1974 and 1979 values.

- The "reported illegal" (R) catches by year were obtained by subtracting the "unreported illegal" (NR) catches, calculated from vessel numbers, from the total annual illegal catch estimates.

Figure 2 plots the trajectory of illegal catches, showing the relative size of the "illegal unreported" and "reported illegal" components. Catches in the "reported illegal" category were subtracted from the reported landings in the catches used in the CRA 6 stock assessment. The RLFAWG members have little confidence in the estimates of illegal catch because the estimates cannot be verified.

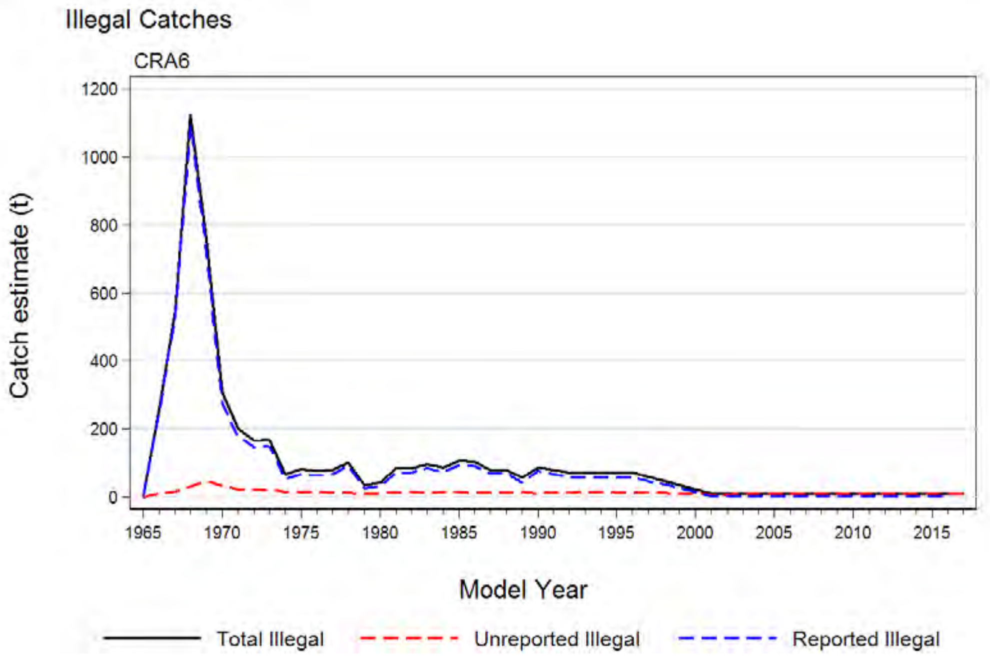


Figure 2: CRA 6 illegal catch trajectory: 'unreported illegal' catches are added to the catch history while 'reported illegal' catches are subtracted from the commercial catch.

2. BIOLOGY

Refer to Section 2 in the Introductory Rock Lobster chapter for a general presentation of rock lobster biological considerations, including growth, natural mortality and puerulus settlement.

3. STOCKS AND AREAS

For information on stocks and areas refer to the Introduction – Rock Lobster chapter.

4. DECISION RULES AND MANAGEMENT PROCEDURES

For information on decision rules and management procedures refer to the Introduction – Rock Lobster chapter.

5. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS

For information on environmental and ecosystem considerations refer to the Introduction – Rock Lobster chapter.

6. STOCK ASSESSMENT

The previous stock assessment for CRA 6 was done in 1996 and was based on a surplus production model using catches and abundance indices up to the 1995–96 fishing year. That model did not reliably assess the stock status, but concluded that the stock was stable or increasing after an initial fishing down period. However, examination of mid–1990s size-frequency distributions from the lobster commercial catch led to the conclusion that these distributions had not changed as much as would have been expected in a stock declining under fishing pressure, which in turn led to a further conclusion that there might be immigration of large lobsters into the area being fished. MCY was estimated to lie in the range 300–380 t and B_0 was estimated to be about 20 000 t.

This section describes a length-based stock assessment for CRA 6 conducted in 2018, using the lobster stock dynamics (LSD) model (Webber et al. 2018). This platform reproduces the dynamics of the previous MSLM code (Haist et al. 2009) in a software environment with fewer constraints than in the previous ADMB environment. Extensive testing was made to satisfy the stock assessment team that the previous and current models provided equivalent results.

The early Chatham Islands rock lobster fishery (now called CRA 6) was characterised by very high catches, intense fishing from a large number of vessels, and a rapid decline in CPUE over a short period of time. Catch estimates are uncertain, but it is thought that over 17 000 tonnes of lobsters were harvested from CRA 6 from 1966 to 1970. An early paper by Kensler (1969), who worked for the Fisheries Research Division, Marine Department, Wellington, documents the capture of 3 000 tonnes (6 600 000 pounds) of lobsters from September 1966 to August 1967 or 40% of the total harvest of NZ lobsters during that 12 month period. A significant fraction of that catch was taken by bottom trawling.

Length-frequency (LF) sampling and tagging

Kensler (1969) plots a frequency histogram of 1152 male and 1339 female lobsters measured in October 1966. These plots were converted to LFs for use as input data to the stock assessment model, as were four 1982 LF samples found in the *rlcs* (observer) database. Intermittent observer sampling during the early 1990s, including a two-year directed CRA 6 sampling project spanning the summers of 1995–96 and 1996–97, rounded out the available observer catch sampling. A fisher-based logbook programme was started in 2001 with 2 participants, rapidly expanding to 17 participants by 2005. Participation then declined with 5 to 8 participants in the years from 2012 to 2017. Although these LFs do not constitute a large sample, they represent an important component of the stock assessment by providing consistent annual estimates of the length distribution for captured lobsters.

The mid-1990s Chatham Islands sampling project also released about 5000 CRA 6 tags in 1996 and 1997. Only 183 usable recoveries (21 males and 162 females) have been obtained from these releases, with the males all being under 60 mm TW. This number of release/recovery pairs is inadequate to operate a length-based stock assessment, given the high variability in growth observed in NZ red rock lobsters. CRA 8 seemed to be the most likely source of tags that would be comparable with CRA 6, given the lower productivity of lobsters from this QMA and the large size of resident lobsters. Preliminary model fits to the CRA 6 data, including the CRA 8 tagging data to estimate growth, showed that the patterns of tag residuals by statistical area were similar to the CRA 6 residuals for tags released in Statistical Areas 926, 927 and 928 (Fiordland) while tag residuals for Areas 922, 923 (Foveaux Strait), 924 (Stewart Island) and 925 (Snares Island) differed from those for CRA 6. Accordingly, tags from Areas 926, 927 and 928 were used to augment the few available CRA 6 tags.

Base case model structure

The 2018 CRA 6 stock assessment had the following structure:

- the reconstruction starts in 1965, which is the beginning of the fishery, from a size distribution in equilibrium with estimated R_0 and M;

- it was fitted to three CPUE series: daily catch rate CR from 1966 to 1972 (Annala & King 1983), FSU from 1979 to 1988 and CELR from 1989 to 2017, with the CELR series standardised by including a vessel explanatory variable based on vessels with at least five years in the fishery;
- no density-dependent growth;
- only fit to the first tag-recapture event, discarding all subsequent recovery events;
- size distribution sample weights by year, season and sampling source (logbook and catch sampling) are scaled by the number of size measurements in each of the three sex categories (male, immature female, mature female).
- a single-stock model combining all information from Statistical Areas 940, 941, 942 and 943;
- a seasonal time step with autumn–winter (AW, April through to September) and spring–summer (SS) from 1965 through to 2017;
- 138 length bins, 46 for each sex category (males, immature and mature females), each 2 mm TW wide, beginning at left-hand edge 30 mm TW and continuing to a plus bin at 120 mm TW;
- MLS regulations change over the model reconstruction period by incorporating a time series of MLS regulations by sex.
- a single set of selectivity functions estimated by the base case;
- the discarding of large lobsters appears to be infrequent in CRA 6, given the low use made of Destination X in this QMA; it is not known if this reflects a lack of discarding or a failure to record discards but discarding was not modelled in this stock assessment.

Data used and their sources are listed in Table 2 and the temporal extent is shown in Figure 3.

The assessment assumed constant recreational and customary catch of 6.03 t and 4 t respectively. The sources of these catch estimates are documented in table 6 in Section 1.2 of the Rock Lobster Introduction chapter. The derivation of illegal catches used in this stock assessment is described in Section 1.5. A CRA 6-specific length-weight relationship was used, based on 532 length-weight pairs collected in 1996 (351 males, 181 females).

Table 2: Data types and sources for the 2018 stock assessment of CRA 6. Fishing years are named from the first nine months, i.e., 1998–99 is called 1998. N/A – not applicable or not used; NZ RLIC – NZ Rock Lobster Industry Council Ltd.; FSU: Fisheries Statistics Unit; CELR: catch and effort landing returns.

		CRA 6	
Data type	**Data source**	**Begin year**	**End year**
CR	Annala & King (1983)	1966	1972
CPUE	FSU	1979	1988
CPUE	CELR	1989	2017
Early proportions at size	Kensler (1969) & sampling	1966	1982
Observer proportions-at-size	Fisheries New Zealand	1989	1997
Logbook proportions-at-size	NZ RLIC	2001	2017
Tag recovery data	Fisheries New Zealand	1983	2017
Historical MLS regulations	Fisheries New Zealand	1979	2017
Escape gap regulation changes	Annala (1983), Fisheries New Zealand	1979	2017
Puerulus settlement	Fisheries New Zealand	N/A	N/A
Retention	NZ RLIC	N/A	N/A

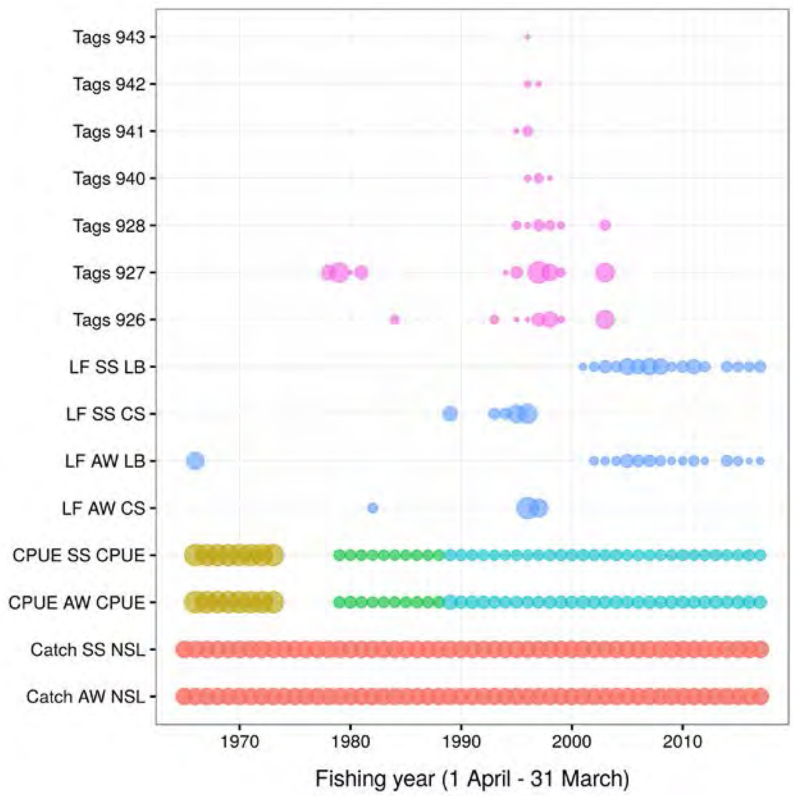


Figure 3: Data extent by fishing year used in the CRA 6 stock assessment. The size of each bubble represents the relative amount of data for each data type.

The numbers of male, immature female and mature female lobsters in each size class were updated in each season as a result of:

a) **Recruitment:** New recruits to the model were added equally for each sex for each season as a normal distribution with a mean size (32 mm) and standard deviation (2 mm), truncated at the smallest size class (30 mm). Recruitment in a specific year was determined by the mean recruitment parameter and the estimated annual deviations from mean recruitment. The vector of recruitment deviations in log space was assumed to be normally distributed with a mean of zero. Recruitment deviations were estimated for 1965 through to 2015. The 2016 and 2017 recruitment deviations were fixed to be the same as the 2015 recruitment deviation during the reconstruction phase.

b) **Mortality:** Natural, fishing and handling mortalities were applied to each sex category in each size class. Natural mortality was assumed to be constant and independent of sex and length. Fishing mortality was determined from observed catch and model biomass, modified by legal sizes, sex-specific vulnerabilities, and selectivity. Handling mortality was assumed to be 10% for lobsters returned to the water before CRA entered the QMS in 1990 and was 5% for discarded lobsters thereafter. Two fisheries were modelled: one that operated only on fish above the MLS, excluding berried females (SL fishery – including legal commercial and recreational) and one that did not respect size limits and restrictions on berried females (NSL fishery – the illegal fishery plus the Maori customary fishery). Selectivity and vulnerability functions were otherwise the same for the SL and NSL fisheries. Vulnerability by sex category and season was estimated relative to males in AW, which were assumed to have the highest vulnerability. Instantaneous fishing mortality rates for each fishery were calculated iteratively from the catch, model biomass, and natural mortality using the Newton-Raphson algorithm (three iterations).

c) **Fishery selectivity:** A three-parameter fishery selectivity function was assumed, with parameters describing the shapes of the ascending and descending limbs and the size at which vulnerability is at a maximum. Only one selectivity for each sex was used: 1965–2017. Unlike previous rock lobster stock assessments, the descending limb of the selectivity curve was estimated because of the preponderance of large lobsters.

d) **Growth and maturation:** For each size class and sex category, a growth transition matrix specified the probability of an individual remaining in the same size class or moving into other size classes. Maturation of females was estimated as a two-parameter logistic curve.

Model fitting

The best fit to the data was obtained by maximising the total likelihood function using Stan, an 'open-source' modelling language optimised for performing Bayesian analyses. The model was fitted to two standardised CPUE series and an early unstandardised series representing catch per day, all assuming a lognormal distribution. The model was also fitted to proportions-at-length using the multinomial distribution, to sex ratios using the multinomial distribution, and to tag-recapture data using the robust normal distribution.

For the CPUE likelihoods, CVs for each index value were initially set at the standard error from the GLM analysis. Data set weights were used to specify the relative importance of each data set. The CELR CPUE series was deliberately overfitted because it was considered the most reliable information among the CRA 6 data sources.

Proportions-at-length, assumed to be representative of the commercial catch, were available (see Table 2 and Figure 3) from observer catch sampling and voluntary logbooks: data were summarised for each data source by area/month strata and weighted by the commercial catch taken in each stratum, the number of lobsters measured by sex category, and the number of days sampled. Data from observers and logbooks were fitted separately, with proportions normalised and fitted within each sex class, and with the model estimating proportions-at-sex separately using a multinomial distribution. These data were weighted within the model using the iterative method of Francis (2011).

In all model runs, it was assumed that CPUE was directly proportional to vulnerable biomass, that growth was not density-dependent, and that there was no stock-recruit relationship. Parameters estimated, along with the priors, are provided in Table 3. Fixed parameters and their values are given in Table 4.

Table 3: CRA 6 base case MAP, showing estimated parameters, upper and lower bounds, prior type (blank if uniform), prior mean, and prior standard deviation or CV. [Continued on next page]

Season	Sex	par	lower bound	upper bound	prior type	prior mean	prior std/CV
		R_0	exp(1)	exp(25)			
		M	0.01	0.35	lognormal	0.12	0.4
		*Rdev*s	-2.3	2.3	normal	0	*sigmaR*
		qCR	exp(-25)	exp(0)			
		qFSU	exp(-25)	exp(0)			
		qCELR	exp(-25)	exp(0)			
		Mat50	10	80	normal	50	15
		Mat95	1	60	normal	10	10
	male	*Galpha*	1	15	normal	5	30
	male	*Gdiff*	0.001	0.7			
	male	*Gshape*	0.1	12	normal	4.81	5
	male	*GCV*	0.1	2	normal	0.59	1
	female	*Galpha*	1	15	normal	5	30
	female	*Gdiff*	0.001	0.7			
	female	*Gshape*	0.1	12	normal	4.51	5
	female	*GCV*	0.1	2	normal	0.82	1
		Gobs	0.00001	10	normal	1.48	1

Season	Sex	par	lower bound	upper bound	prior type	prior mean	prior std/CV
	male	*SelLH*	1	50	normal	20	10
	female	*SelLH*	1	50	normal	20	10
	male	*SelMax*	10	100	normal	50	25
	female	*SelMax*	10	100	normal	50	25
	male	*SelRH*	1	2000	normal	30	500
	female	*SelRH*	1	2000	normal	30	500
SS	male	*vuln1*	0.01	1			
AW	immafem	*vuln2*	0.01	1			
SS	imma & matfem	*vuln3*	0.01	1			
AW	matfem	*vuln4*	0.01	1			

Table 4: Fixed values used in base case assessment for CRA 6.

Quantity	Value	Quantity	Value
	weights		**fixed parameters**
tags	1	*sigmaR*	0.4
CELR CPUE	0.86	male length-weight *a*	6.6302e-7
FSU CPUE	0.28	male length-weight *b*	3.3629
CR CPUE	0.945	female length-weight *a*	1.0495e-5
sex ratio	22.83	female length-weight *b*	2.6025
LFs	5.70		**other**
	catch and handling	Newton-Raphson iterations	3
handling mortality, 1945–1989	0.10	last year of estimated *Rdevs*	2015
handling mortality, 1990–2017	0.05	years for *Rdev* projections	2006-2015
projected SL commercial catch	359.07	Bin compression: male bins	4 to 40
projected SL recreational catch	6.02	Bin compression: female immature bins	4 to 20
Projected NSL illegal catch	10.0	Bin compression: female mature bins	6 to 40
Projected NSL customary catch	4.0		

Bayesian inference

Bayesian inference was used to estimate parameter uncertainty. This procedure was conducted in the following steps:

1. Model parameters were estimated by the LSD model using maximum likelihood and the prior probability distributions. These estimates are called the MAP (maximum *a posteriori*) estimates.
2. Samples from the joint posterior distribution of parameters were generated with Markov chain Monte Carlo (MCMC) simulations using the Hamiltonian Monte Carlo (HMC) algorithm.
3. Up to eight chains, each with a burn-in period of 500 iterations and length of 286 iterations, were made, retaining every second sample, for a total of approximately 1000 samples from the posterior distribution. The number of iterations achieved was variable because some of the chains did not complete, stalling during the warm-up phase of the HMC algorithm. This occurred because the observed biomass decline from 1966 to 1970 occasionally led to a conflict between the large initial catches and the requirement to have a sufficient vulnerable biomass from which to remove the catches.

Performance indicators, projections and results

Vulnerable biomass in the assessment model was determined by the MLS, selectivity, relative sex and seasonal vulnerability, and berried state for mature females. All mature females were assumed to be berried during the AW season, thus not vulnerable to the SL fishery, and not berried and vulnerable in the SS season.

Agreed indicators are summarised in Table 5. There is no agreed B_{REF} for CRA 6, so this reference level is not reported. B_0, B_{MIN}, B_{2018} and B_{2022} are all based on the vulnerable biomass calculated with the current MLS and selectivity. SSB_0, SSB_{2018}, and SSB_{2022} report female mature biomass. B_0^{tot}, B_{2018}^{tot} and B_{2022}^{tot} report total model biomass over all sex categories, regardless of maturity state. B_0^{now} and SSB_0^{now} report vulnerable and spawning equilibrium biomass based on the mean of the final 10 years of recruitment (2006–2015).

Projections extend from 2018 to 2021 with simulated recruitment from 2016 to 2022 (i.e., the final two years recruitment deviations that were fixed at the 2015 recruitment deviation estimate were overwritten). Recruitment deviations were simulated from a normal distribution with mean and standard deviation calculated from the last 10 years of estimated recruitment deviations (2006–2015) with autocorrelation calculated from 1965–2015. Projections assumed 2017 catch levels (359.07 t commercial, 6.02 t recreational, 4 t customary, 10 t illegal) where the proportion of the catch taken during the AW was simulated from a logit regression of AW CPUE (with normally distributed error in logit-space) with parameters estimated from the relationship between the proportion of catch taken during AW and the AW CPUE from 1993 to 2017.

Table 5: Reported reference points, performance indicators and probabilities for the CRA 6 stock assessment MCMC results.

Type	Description
Reference Points	
B_0	beginning of season AW vulnerable biomass before fishing (1965)
SSB_0	female AW spawning stock biomass before fishing began (1965)
B_0^{now}	equilibrium vulnerable biomass using mean 2006–2015 recruitment
SSB_0^{now}	equilibrium female spawning biomass using mean 2006–2015 recruitment
B_0^{tot}	equilibrium total biomass
B_{MIN}	the lowest beginning AW vulnerable biomass in the series
B_{2018}	beginning of season AW vulnerable biomass for 2018
B_{2022}	beginning of season AW vulnerable biomass for 2022
SSB_{2018}	female spawning stock biomass at beginning of 2018 AW season
SSB_{2022}	female spawning stock biomass at beginning of 2022 AW season
B_{2018}^{tot}	beginning of season AW total biomass for 2018
B_{2022}^{tot}	beginning of season AW total biomass for 2022
$CPUE_{2018}$	AW CPUE at beginning of 2018 (in kg/potlift)
$CPUE_{2022}$	AW CPUE at beginning of 2022 (in kg/potlift)
$Hmort_{2017}$	total handling mortality for 2017 (tonnes)
$Hmort_{2021}$	total handling mortality for 2021 (tonnes)
Performance indicators	
B_{2018} / B_0	ratio of B_{2018} to B_0
B_{2022} / B_0	ratio of B_{2022} to B_0
B_{2022} / B_{2018}	ratio of B_{2022} to B_{2018}
SSB_{2018}/SSB_0	ratio of SSB_{2018} to SSB_0
SSB_{2022}/SSB_0	ratio of SSB_{2022} to SSB_0
SSB_{2022}/SSB_{2018}	ratio of SSB_{2022} to SSB_{2018}
B_{2018}^{tot}/B_0^{tot}	ratio of B_{2018}^{tot} to B_0^{tot}
B_{2022}^{tot}/B_0^{tot}	ratio of B_{2022}^{tot} to B_0^{tot}
$B_{2022}^{tot}/B_{2018}^{tot}$	ratio of B_{2022}^{tot} to B_{2018}^{tot}
Probabilities	
P($B_{2018}>B_{MIN}$)	probability B_{2018} is greater than B_{MIN}
P($SSB_{2018}<20\%SSB_0$)	probability SSB_{2018} is less than 20%SSB_0
P($SSB_{2018}<10\%SSB_0$)	probability SSB_{2018} is less than 10%SSB_0

Note that B_{MSY} has been removed from this table as the RLFAWG and Plenary determined in 2017 that more work needed to be conducted to evaluate how this quantity is determined for rock lobsters.

Stock assessment results

A stock assessment consisting of a base case and three sensitivity runs relative to the base case was reviewed by the Fisheries New Zealand stock assessment Plenary in November 2018. The base case and two of the sensitivity runs were accepted because they encompassed a credible range of model structure uncertainty. These runs had the following definitions:

Model name	**Model description**	**Number of usable chains**	**Number of MCMC samples**
base	Defined above under "**Base case model structure**"	7	1 001
catch_hi	Catch from 1965-1970 was 30% higher than the base case	7	1 001
q-drift	Estimate q-drift parameter with uniform prior	8	1 144
combined	Stack the posterior distributions of the three accepted runs	21	3 003

The *q-drift* and *catch_hi* runs were considered by the Plenary to be credible alternative scenarios (relative to the *base* run) while a third sensitivity run (*catch_lo*), which explored the possibility that the early catch history was 30% lower than the *base* run, was not accepted because it was unlikely that catches had been overestimated during the early years of the fishery. The Plenary concluded that none of the three accepted runs captured the full range of uncertainty associated with this stock assessment and requested that a combined model consisting of the stacked posterior distributions of the three runs be used to provide CRA 6 management advice. Results from the *base*, *catch_hi* and *q_drift* runs are compared in Table 6, along with the results from the model which combines the posterior distributions of these three runs (i.e., model estimates calculated from the 3003 samples from the 21 combined chains). The discussion below applies to the *combined* model.

This stock assessment, unlike all other CRA stock assessments, estimated a descending limb for the selectivity curve. This was considered justified given the preponderance of large individuals in this population, especially at the beginning of the fishery. Model estimates of the descending limb are credible (Figure 4; Table 6), encompassing the value of the fixed parameters used in other CRA stock assessments (e.g., a value of 200 was used in the 2017 CRA 2 stock assessment: table 7 in the CRA 2 chapter).

Three strong recruitment events are estimated, one in the mid-1990s, the second in the early 2000s and the most recent (and largest) in the early 2010s (Figure 5). This recruitment pattern is unlike that seen in any of the other assessed CRA QMAs and supports the hypothesis that this population is independent of rock lobster populations on either the North or the South Islands. Recent mean (2006–2015) recruitment is estimated to be above R_0, as indicated by the derived parameters B_0^{now} and SSB_0^{now} being larger than the equivalent parameters B_0 and SSB_0, which are based on the mean recruitment (i.e. R_0) from 1965–2015 (Table 6).

Fishing mortality was high in the initial years of this fishery, followed by substantial reductions as catches moved to a more sustainable level. Vulnerable biomass decreased rapidly in the initial years of the fishery, dropping to low levels in the mid-1990s (Figure 6). Vulnerable biomass has since slowly increased and is projected to continue to increase over the next five years, given recent recruitment. A similar trajectory is seen for the spawning biomass (Figure 7), with the lowest levels near the soft limit and gradually increasing trend since then. Current (2018) spawning biomass is estimated to be at 32% of SSB_0 (SSB_{2018}/ SSB_0 = 0.32 [90% credible interval (CI) = 0.24–0.39]; Table 6) and is projected to increase to 35% of SSB_0 (SSB_{2022}/ SSB_0 = 0.35 [90% CI = 0.25–0.44]; Table 6). There is zero probability of the *combined* model being below the soft limit (20%SSB_0) and 100% probability of being above B_{MIN} (Table 6).

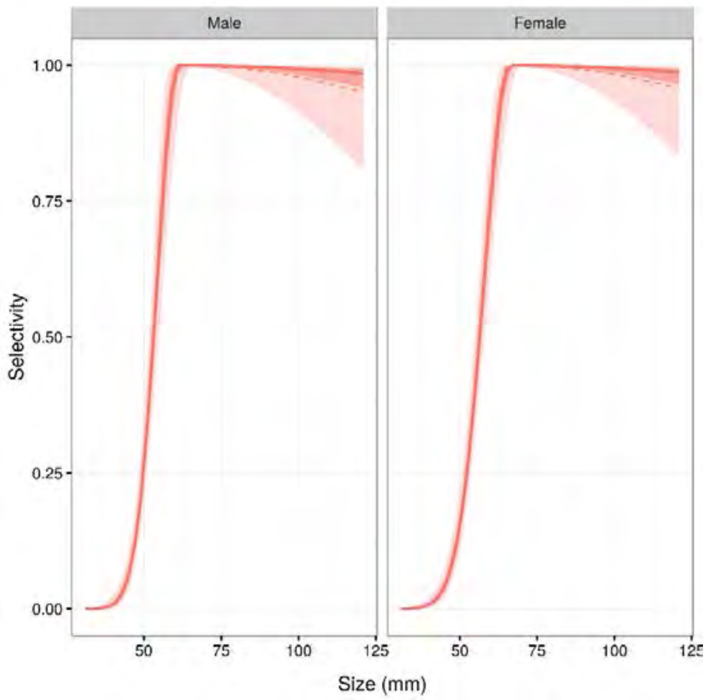


Figure 4: CRA 6 *combined* model selectivity by sex, with the solid line indicating the posterior median and the variable intensity coloured bands showing the 50% and 90% credible intervals. Dashed lines indicate the corresponding MAP estimates from the *base* run.

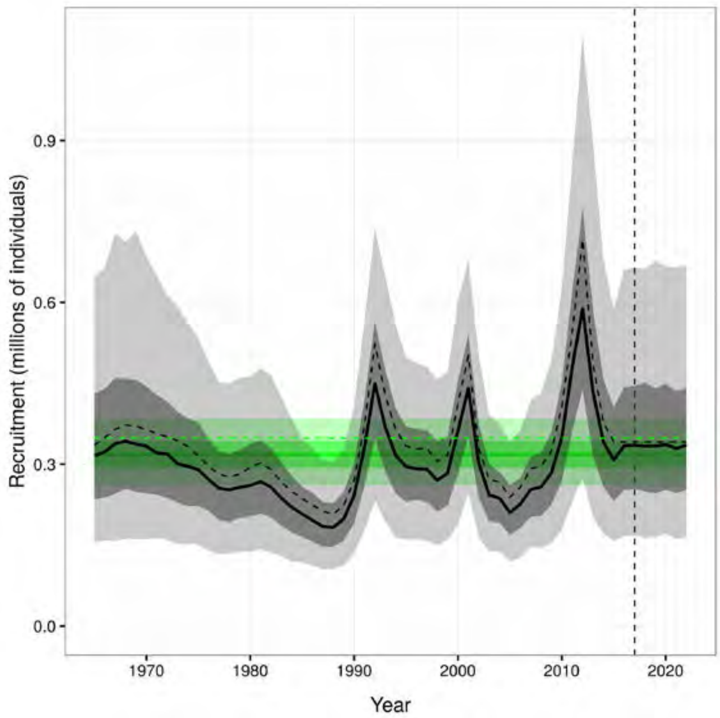


Figure 5: CRA 6 *combined* model recruitment in 000 000's, where the dashed black line indicates the MAP, the solid black line indicates the median of the posterior, and variable shading intensity indicates the 50% and 90% credible intervals. The horizontal solid green line is the median of the posterior for R_0 with green shading indicating the 50% and 90% credible intervals for R_0. The dashed green line is the MAP for R_0 from the *base* run. The vertical dashed line is the final year of the reconstruction period. Projection recruitments (plotted to the right of the vertical dashed line) are based on the mean and standard deviation of the 2006–2015 recruitment and the 1965–2015 estimated autocorrelation. Projection recruitment for the MAP is fixed at the 2015 estimate.

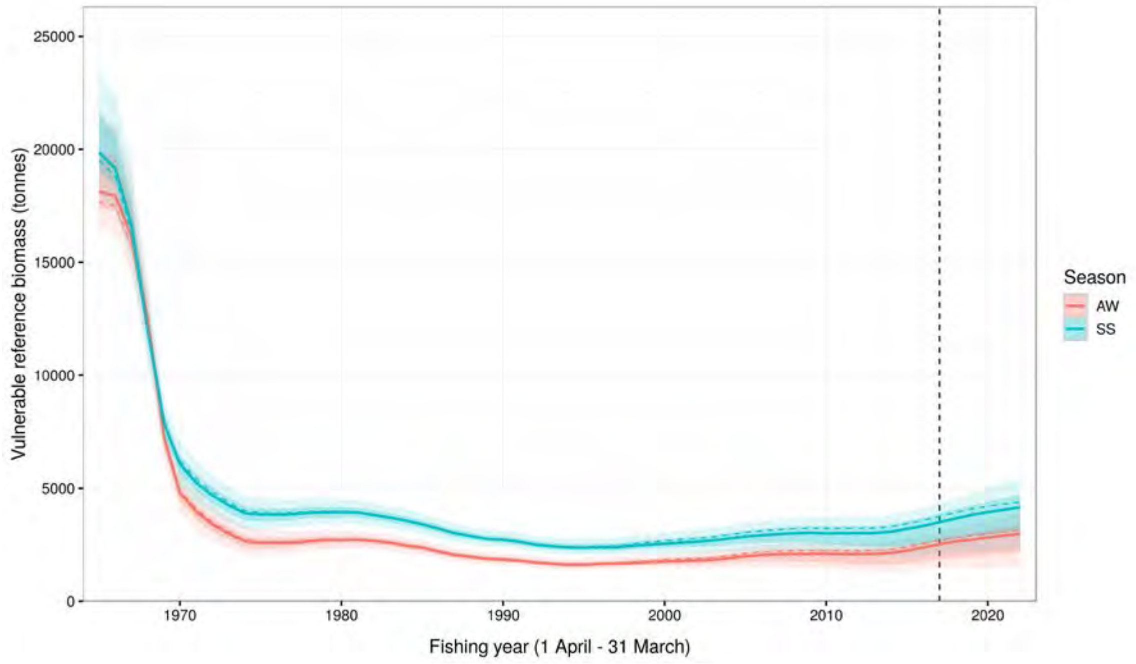


Figure 6: CRA 6 *combined* model vulnerable reference biomass over the model reconstruction period. Solid lines indicate the median vulnerable biomass by season, shading indicates the 50% and 90% credible intervals for each series, and dashed lines indicate the MAP from the *base* run. The biomass in each year uses the final reconstruction year's selectivity and MLS.

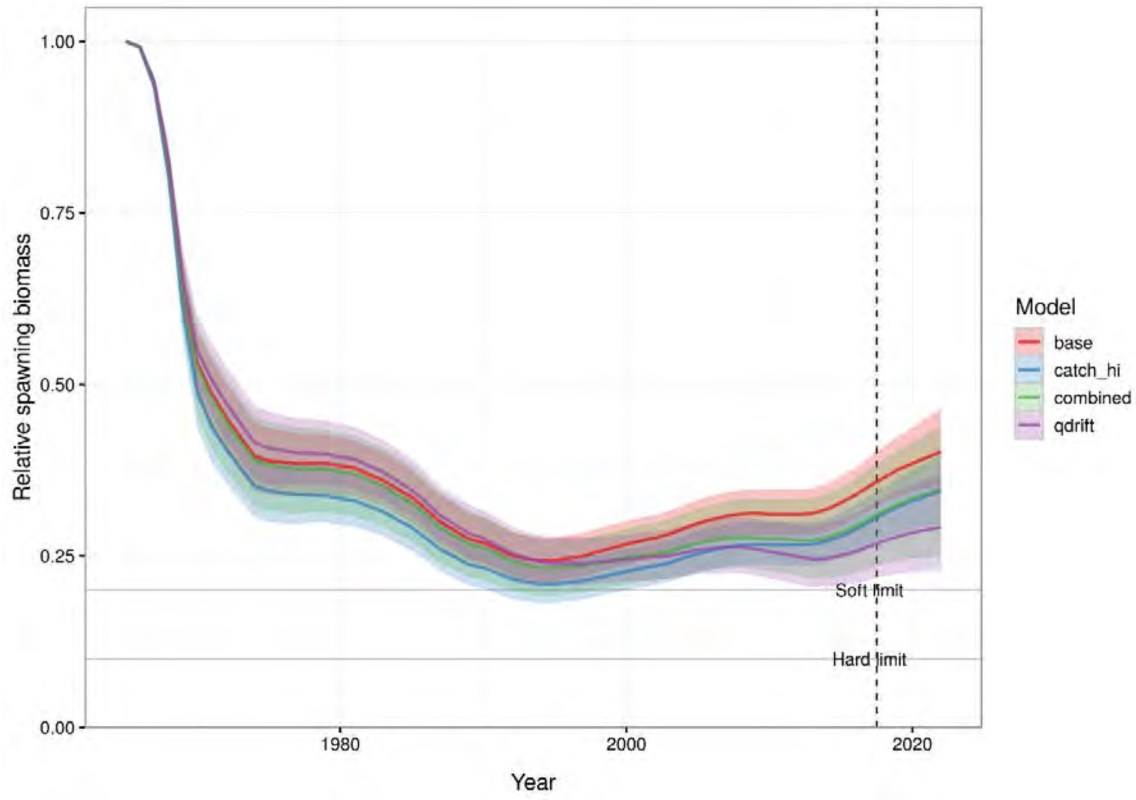


Figure 7: Comparison of the relative spawning stock biomass trajectories between the *base*, *catch_hi* and *q_drift* runs with the *combined* model. The vertical dashed line indicates the last year of the reconstruction period, after which the projected biomass is shown.

Table 6: MCMC outputs for the CRA 6 *base*, *catch_hi* and *q_drift* runs, along with the stacked *combined* model, reporting the 5th, 50th (median), and 95th quantiles of the posterior distributions. Growth increment values in mm TW, biomass values in tonnes and R_0 in numbers. Handling mortality (*Hmort*) in tonnes and CPUE in kg/potlift. '–': not applicable.

	base			catch_hi			q-drift			combined		
	5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%
Likelihood components												
LFs-sdnr	0.412	0.475	0.706	0.413	0.477	0.689	0.410	0.468	0.654	0.411	0.473	0.680
LFs-MAR	0.064	0.072	0.080	0.064	0.071	0.080	0.063	0.071	0.080	0.064	0.071	0.080
LFs-LL	3 295.8	3 301.0	3 307.4	3 319.4	3 324.9	3 331.1	3 312.1	3 317.9	3 324.7	3 297.3	3 317.8	3 328.8
Tags-sdnr	1.991	2.071	2.160	1.984	2.073	2.162	1.998	2.079	2.171	1.992	2.074	2.166
Tags-MAR	0.714	0.729	0.746	0.713	0.730	0.745	0.715	0.731	0.747	0.714	0.730	0.746
Tags-LL	5 854.1	5 856.4	5 860.5	5 853.8	5 856.2	5 860.5	5 853.8	5 856.2	5 860.2	5 853.9	5 856.3	5 860.5
CELR sdnr	1.473	1.536	1.608	1.483	1.543	1.613	1.484	1.552	1.629	1.479	1.544	1.620
CELR MAR	0.825	0.946	1.079	0.836	0.953	1.078	0.843	0.986	1.133	0.835	0.960	1.107
CELR LL	- 99.9	- 94.3	- 87.7	- 99.1	- 93.8	- 87.3	- 99.1	- 93.0	- 85.9	- 99.3	- 93.7	- 86.6
FSU-sdnr	0.886	0.993	1.133	0.895	0.995	1.141	0.875	0.964	1.084	0.883	0.982	1.124
FSU-MAR	0.466	0.606	0.886	0.481	0.628	0.896	0.435	0.563	0.843	0.454	0.596	0.877
FSU-LL	- 29.5	- 27.5	- 24.3	- 29.4	- 27.4	- 24.3	- 29.7	- 28.0	- 25.3	- 29.6	- 27.7	- 24.5
CR-sdnr	0.923	1.038	1.150	0.810	0.890	0.980	0.949	1.071	1.191	0.840	1.009	1.163
CR-MAR	0.651	0.825	0.941	0.491	0.659	0.816	0.698	0.855	1.006	0.539	0.792	0.959
CR-LL	- 11.7	- 9.8	- 7.6	- 13.3	- 12.0	- 10.1	- 11.3	- 9.3	- 6.9	- 12.8	- 10.3	- 7.4
Sex-sdnr	1.022	1.065	1.123	1.013	1.051	1.112	1.017	1.051	1.106	1.016	1.055	1.116
Sex-MAR	0.651	0.825	0.941	0.491	0.659	0.816	0.698	0.855	1.006	0.539	0.792	0.959
Sex-LL	1 080.5	1 082.8	1 086.5	1 076.6	1 078.7	1 081.9	1 076.6	1 078.5	1 081.6	1 076.8	1 079.5	1 084.9
Prior	10.8	18.2	27.4	11.0	18.5	28.5	11.3	18.7	28.0	11.0	18.5	28.0
Function value	10 139.2	10 127.7	10 118.9	10 157.6	10 146.5	10 137.0	10 153.5	10 142.2	10 133.5	10 154.4	10 140.5	10 122.2
Parameters												
R0	285 484	337 830	407 218	270 557	320 682	378 933	249 420	296 374	357 186	261 501	317 884	384 401
M	0.0416	0.0475	0.0542	0.0361	0.0416	0.0474	0.0369	0.0428	0.0495	0.0370	0.0437	0.0516
q-drift	–	–	–	–	–	–	0.0088	0.0184	0.0274	–	–	–
qCPUE	4.19E-04	4.83E-04	5.60E-04	4.42E-04	5.15E-04	5.89E-04	4.05E-04	4.62E-04	5.34E-04	4.16E-04	4.86E-04	5.70E-04
qFSU	4.55E-04	5.27E-04	6.08E-04	4.90E-04	5.61E-04	6.44E-04	4.57E-04	5.22E-04	5.98E-04	4.64E-04	5.35E-04	6.24E-04
qCR	3.75E-02	4.55E-02	5.49E-02	3.65E-02	4.44E-02	5.42E-02	3.65E-02	4.38E-02	5.31E-02	3.67E-02	4.46E-02	5.42E-02
mat50	51.9	54.1	56.8	52.0	54.1	56.5	52.0	54.1	56.9	51.9	54.1	56.7
mat95Add	10.1	18.3	30.2	10.5	18.8	30.1	10.4	19.0	30.2	10.3	18.7	30.1
GalphaM	5.1	5.3	5.4	5.1	5.3	5.4	5.2	5.3	5.4	5.2	5.3	5.4
GbetaM	2.4	2.5	2.7	2.4	2.5	2.7	2.4	2.5	2.7	0.0	2.4	2.6
GshapeM	1.6	2.0	2.3	1.6	2.0	2.4	1.6	2.0	2.3	1.6	2.0	2.3
GCVM	0.444	0.458	0.473	0.443	0.458	0.473	0.442	0.457	0.472	0.443	0.458	0.473
GalphaF	3.9	4.0	4.2	3.9	4.0	4.2	3.9	4.0	4.2	3.9	4.0	4.2
GbetaF	1.5	1.5	1.6	1.5	1.5	1.6	1.5	1.5	1.6	1.5	1.6	2.6
GshapeF	2.9	3.2	3.6	2.9	3.2	3.6	2.9	3.2	3.5	2.9	3.2	3.6
GCVF	0.500	0.520	0.540	0.501	0.521	0.540	0.500	0.520	0.540	0.500	0.520	0.540
StdObs	0.283	0.330	0.384	0.283	0.330	0.387	0.283	0.330	0.385	0.283	0.330	0.385
vuln1	0.840	0.870	0.899	0.822	0.852	0.885	0.816	0.846	0.881	0.822	0.856	0.892
vuln2	0.413	0.686	0.963	0.419	0.683	0.951	0.387	0.669	0.944	0.409	0.678	0.951
vuln3	0.569	0.673	0.792	0.550	0.656	0.781	0.529	0.642	0.757	0.544	0.656	0.781
vuln4	0.317	0.388	0.469	0.302	0.372	0.447	0.283	0.353	0.435	0.293	0.369	0.453
SelLH1M	6.1	7.9	10.1	6.2	7.9	9.9	6.6	8.3	10.7	6.3	8.0	10.3
SelMax1M	58.0	61.0	64.1	58.0	60.8	63.9	59.0	61.7	65.6	58.3	61.2	64.7
SelLH1F	8.3	10.0	12.2	8.2	9.9	12.0	8.3	9.9	12.1	8.3	9.9	12.1

	base			catch_hi			q-drift			combined		
	5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%
SelMax1F	63.7	66.4	69.6	63.5	66.2	69.2	63.9	66.4	69.7	63.7	66.3	69.5
SelRH1	109	416	1 014	88	372	943	125	420	1 038	107	401	995
Reference points												
B_0	16 057	17 472	18 550	18 117	20 645	21 786	16 584	17 923	18 994	16 392	18 129	21 348
B_0^{now}	17 785	21 058	24 859	19 967	24 079	28 555	17 050	20 215	23 932	17 636	21 559	26 834
SSB_0	6 282	6 695	7 111	7 191	7 741	8 265	6 263	6 762	7 211	6 337	6 886	8 049
SSB_0^{now}	6 927	8 046	9 418	7 764	9 099	10 745	6 533	7 609	9 009	6 801	8 187	10 095
B_0^{tot}	23 802	24 974	26 125	28 008	29 282	30 368	24 133	25 368	26 561	24 048	25 654	29 983
B_{MIN}	1 438	1 680	1 953	1 360	1 575	1 842	1 201	1 473	1 762	1 279	1 572	1 883
B_{2018}	2 502	2 912	3 403	2 374	2 762	3 236	1 369	1 769	2 397	1 482	2 635	3 261
B_{2022}	3 786	4 663	5 729	3 567	4 424	5 457	1 997	2 773	3 845	2 206	4 136	5 460
SSB_{2018}	2 195	2 442	2 733	2 156	2 403	2 696	1 518	1 836	2 223	1 618	2 310	2 669
SSB_{2022}	2 356	2 685	3 106	2 328	2 659	3 082	1 561	1 966	2 462	1 695	2 519	3 035
B_{2018}^{tot}	10 660	11 933	13 613	10 241	11 484	13 066	6 776	8 274	10 238	7 195	11 084	13 102
B_{2022}^{tot}	11 422	13 314	15 874	10 926	12 817	15 188	6 735	8 799	11 376	7 337	12 121	15 083
$CPUE_{2018}$	1.27	1.42	1.57	1.28	1.42	1.60	0.65	0.85	1.15	0.71	1.35	1.57
$CPUE_{2022}$	1.45	1.71	2.06	1.47	1.75	2.10	0.67	0.97	1.39	0.75	1.60	2.02
$Hmort_{2017}$	2.3	2.6	3.0	2.3	2.6	3.0	2.6	3.0	3.5	2.3	2.8	3.3
$Hmort_{2021}$	1.5	1.9	2.5	1.5	1.9	2.4	1.8	2.4	3.2	1.5	2.0	2.9
B_{2018} / B_0	0.140	0.167	0.201	0.113	0.135	0.165	0.075	0.099	0.136	0.082	0.134	0.187
B_{2022} / B_0	0.215	0.268	0.331	0.172	0.216	0.277	0.110	0.155	0.222	0.122	0.213	0.309
B_{2022} / B_{2018}	1.456	1.596	1.783	1.448	1.589	1.784	1.364	1.558	1.800	1.409	1.582	1.791
SSB_{2018}/SSB_0	0.327	0.364	0.409	0.276	0.312	0.351	0.220	0.272	0.335	0.238	0.315	0.391
SSB_{2022}/SSB_0	0.352	0.402	0.465	0.297	0.345	0.401	0.229	0.292	0.370	0.249	0.347	0.439
SSB_{2022}/SSB_{2018}	1.036	1.101	1.187	1.041	1.104	1.185	0.987	1.072	1.171	1.009	1.092	1.181
B_{2018}^{tot}/B_0^{tot}	0.425	0.478	0.548	0.348	0.393	0.448	0.264	0.327	0.406	0.281	0.394	0.518
B_{2022}^{tot}/B_0^{tot}	0.452	0.531	0.636	0.372	0.438	0.526	0.260	0.347	0.457	0.287	0.439	0.592
$B_{2022}^{tot}/B_{2018}^{tot}$	1.040	1.111	1.196	1.049	1.114	1.198	0.969	1.064	1.166	0.996	1.098	1.189
Probabilities												
P(B_{2018}>B_{MIN})	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
P(SSB_{2018}<20%SSB_0)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P(SSB_{2018}<10%SSB_0)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Comparative trajectories of the relative spawning biomass for the *base*, *catch_hi* and *q_drift* runs are presented in Figure 7.

The *catch_hi* run estimates a larger stock size, a lower stock status and lower productivity than the *base* run (Figure 7; Table 6). The *q-drift* run estimates an 1.8% increasing efficiency per year (Table 6). This converts to an increase in the CELR *q* of about 60% over the 29-year period of the CELR series. The credibility of this increase is unknown. This run results in a similar stock size as in the *base* run but with lower stock status and lower productivity. All three runs show the same three recruitment peaks and have similar estimated selectivity functions.

The *base*, *catch_hi* and *q_drift* runs have zero probability of being below the soft limit (20% SSB_0) and 100% probability of being above B_{MIN} (Table 6).

7. FUTURE RESEARCH CONSIDERATIONS

The RLFAWG and Plenary identified a number of potentially useful avenues of exploration to evaluate or improve this assessment in the future. Improvements related to the development of the CPUE standardisation (GLM) and its use in the stock assessment model include:

- Use alternative CPUE series, from different standardisation models, in the stock assessment model as sensitivities.
- Develop logbook CPUE series where possible. Display comparisons of this series with the current CPUE series. Include the logbook series in the model as well.
- Implement vessel as an explanatory variable in all future rock lobster CPUE standardisations. Investigate sequential coding of the same vessel in the model to determine whether there are 'learning' effects, or examine individual vessels for trends in residuals over time.
- Investigate the distribution of the vessel correction factors (VCF) that scale estimated catch into landed greenweight in the F2_LFX algorithm.

Other improvements that apply to most if not all rock lobster stocks include:

- Explore alternative reference points (targets and limits) for CRA 6 (and rock lobster stocks in general). For example, evaluate the consistency and efficacy of B_{REF} targets; develop a dynamic B_{MSY}; decide on appropriate targets and whether these should be expressed in terms of vulnerable biomass, spawning stock biomass, or total biomass, and which time of the year should be used; and determine how to apply the targets.
- Conduct additional morphometric work for all stocks; for example, collect and analyse data such as tail width, carapace length, weight, sex and condition.
- More tag-recapture data to estimate growth are required for all rock lobster stocks but especially for CRA 6, for which CRA 8 data had to be borrowed in order to obtain a viable assessment.
- Investigate the utility of estimating independent *M* parameters for each sex.
- Investigate potential fisheries-independent survey designs.
- Improve estimates of non-commercial catch.
- Investigate the effects of changing the definition of new recruits from 32 mm, with a standard deviation of 2 mm; for example, what would be the effect of an increase in the standard deviation?
- Develop computer code to include the effects of density-dependent growth and environmental effects in the LSD model.
- Develop and evaluate alternative growth models.
- Evaluate a statistically rigorous method to determine length-frequency weights.
- Included random effects for certain LSD model parameters (e.g., selectivity parameters).
- Continue development of spatial models and develop spatial model management procedures.
- Continue strong support for the logbook sampling programme.

8. STATUS OF THE STOCKS

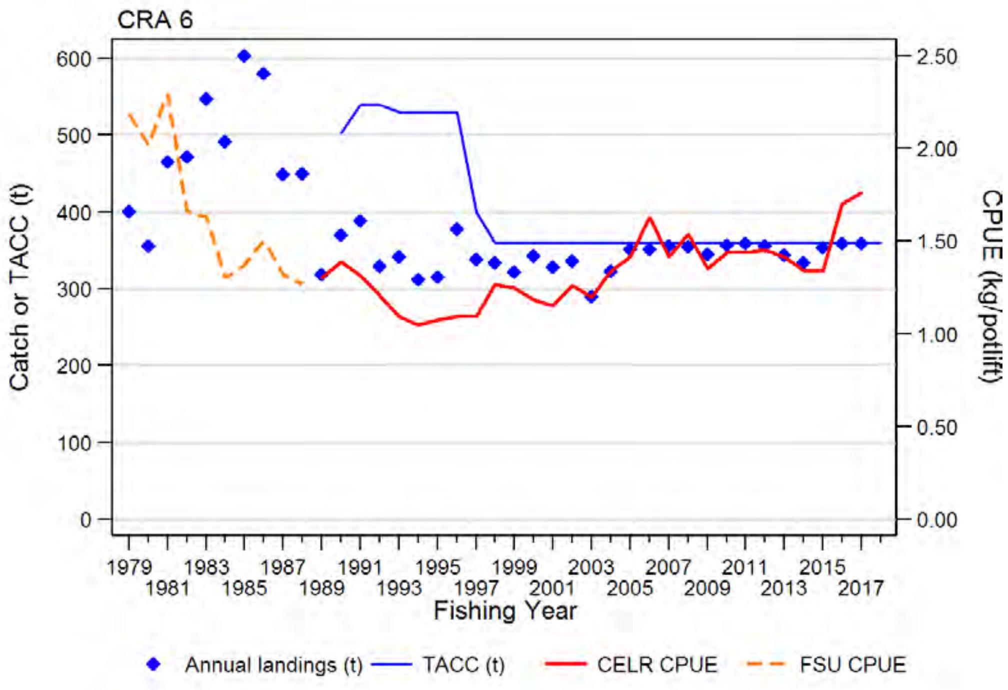
Stock structure assumptions

For the purposes of stock assessment and management, rock lobsters are assumed to constitute separate Fishstocks within each CRA Quota Management Area. There is likely to be some degree of relationship and/or exchange between Fishstocks in these CRA areas, either as a result of migration, larval dispersal or both.

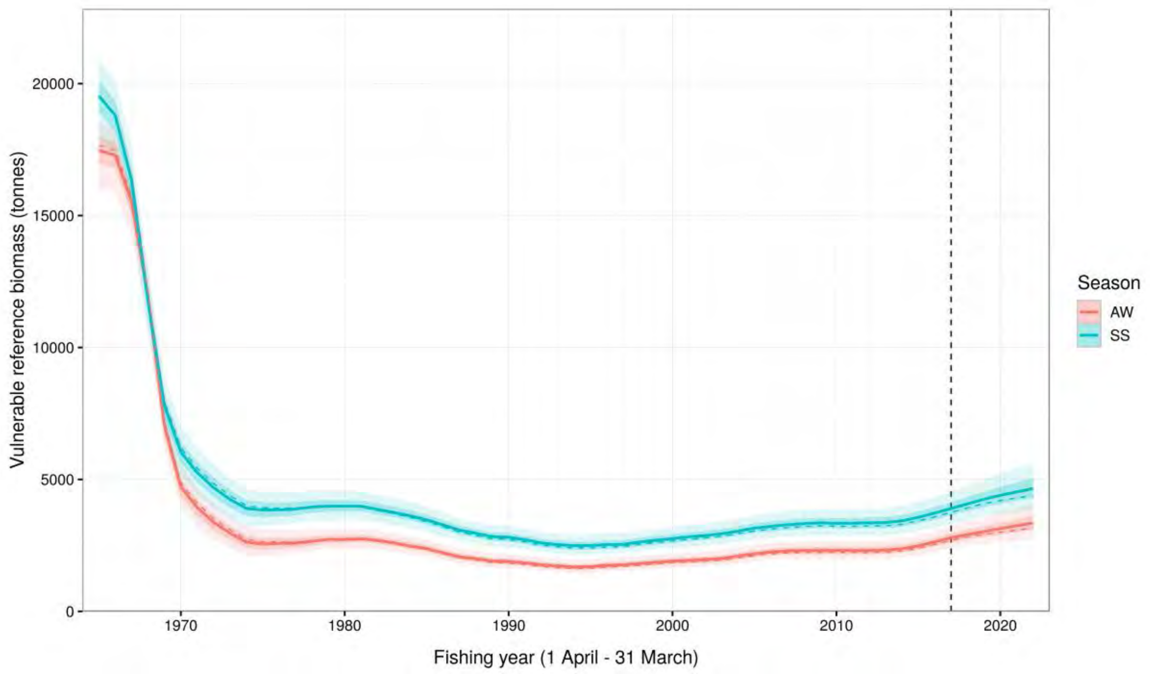
Stock Status	
Year of Most Recent Assessment	2018
Assessment Runs Presented	Combined model
Reference Points	Default target: 40% SSB_0 Soft limit: 20% SSB_0 (default)

	Hard limit: 10% SSB_0 (default) Overfishing threshold: Not established
Status in relation to Target	SSB_{2018} is Unlikely (< 40%) to be at or above the default target
Status in relation to Limits	SSB_{2018} is Unlikely (< 40%) to be below the soft limit SSB_{2018} is Very Unlikely (< 10%) to be below the hard limit
Status in relation to Overfishing	Unknown

Historical Stock Status Trajectory and Current Status



Annual landings, TACC and standardised CPUE for CRA 6 from 1979 to 2017.



CRA 6 vulnerable reference biomass trajectory: 1965–2022, with 2019–2022 projection years.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Vulnerable and spawning biomass have been increasing since the mid-1990s.
Recent Trend in Fishing Intensity or Proxy	Unknown
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	There was a recruitment pulse in the early 2010s and the recent (2006–2015) average recruitment is greater than R_0.

Projections and Prognosis	
Stock Projections or Prognosis	The stock is projected to increase under current catch levels assuming average 2006–2015 recruitment.
Probability of Current Catch or TACC causing Biomass to remain or to decline below Limits	Soft Limit: SSB_{2022} is Very Unlikely (< 10%) to be below the soft limit Hard Limit: SSB_{2022} is Very Unlikely (< 10%) to be below the hard limit
Probability of Current Catch or TACC causing Overfishing to continue or commence	Unknown

Assessment Methodology and Evaluation		
Assessment Type	Level 1 – Full Quantitative Stock Assessment	
Assessment Method	Bayesian length-based model	
Assessment dates	Last assessment: 2018	Next assessment: 2023
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- FSU CPUE data 1979–88 - CELR CPUE data: 1989–2017 - Length-frequency data - Tag-recapture data post-1978 commercial catch	1 – High Quality 1 – High Quality 1 – High Quality 1 – High Quality
	- CR CPUE data 1966–1972 - pre-1979 commercial catch data - non-commercial catch (recreational, customary, illegal)	2 – Medium or Mixed Quality: lacks detail, unstandardised 2 – Medium or Mixed Quality: great potential for misreporting early catches 2 – Medium or Mixed Quality: non-commercial catches inferred or assumed
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	- new length-based model: never before attempted for CRA 6	
Major Sources of Uncertainty	- growth estimates are driven by Fiordland tag-recovery data - length-frequency data are relatively sparse and may not be representative of the catch in some years; - there is considerable uncertainty in the early catch history - the model estimate of M is low compared to other rock lobster stocks - there are possible changes in catchability over time - the effective area of the stock may be larger than the area being fished	

Qualifying Comments
-

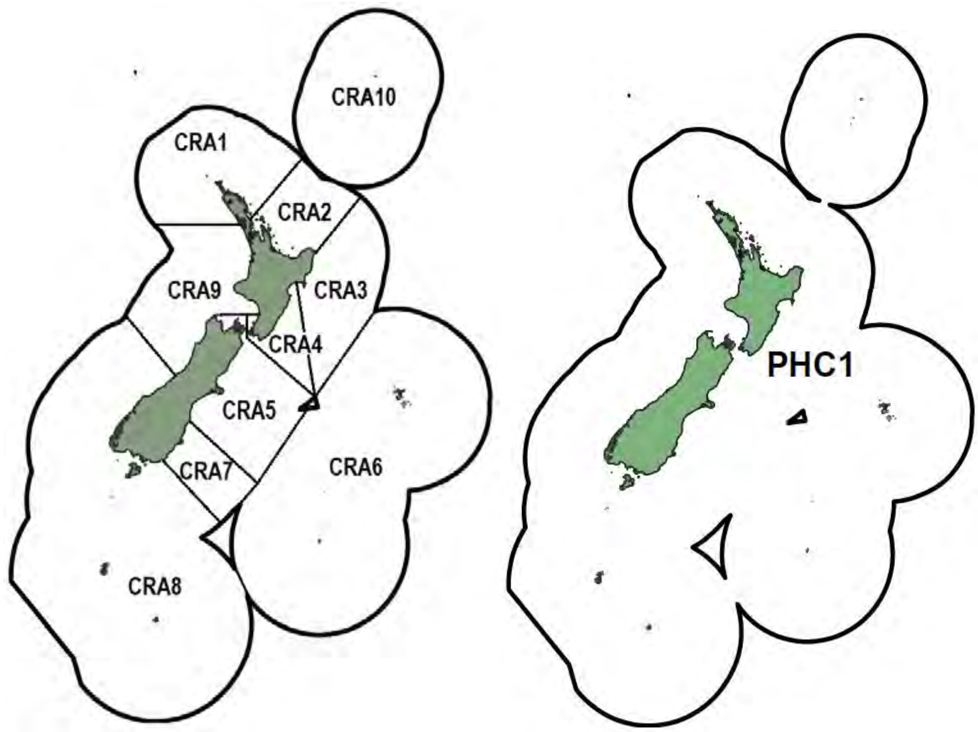
Environmental and Ecosystem Considerations	
Observer coverage	Observer coverage primarily for stock assessment needs.
Non-target fish and invertebrate catch	The levels of incidental catch landed from rock lobster potting ranged from 2–11% of the estimated rock lobster catch weight per QMA for the period 1989–2003. For all QMAs, the most frequently reported incidental species caught are, in decreasing order of catch across all stocks: octopus, conger eel, blue cod, trumpeter, sea perch, red cod, butterfish and leatherjackets.
Incidental catch of seabirds	Small numbers of shags have been reported historically in some CRA areas, but not in recent years.
A survey of rock lobster fishers on the Chatham Islands reported no shag bycatch in the past five years (2007–08 to 2011–12 fishing season), only 2 shag captures between five and ten years ago (2001–02 to 2006–07 fishing season), and 18 shags caught more than 10 years ago (prior to 2000–01 season).	
Fishers suggest the lack of recent shag captures is attributable to changes in pot design and baiting methodologies.	
Incidental catch of marine mammals	From January 2000 until November 2018, 31 entanglements (29 marine mammal individuals, two individuals were entangled twice) were attributed to commercial or recreational rock lobster pot lines from around New Zealand, mainly around Kaikoura (DOC Marine Mammal Database).

9. FOR FURTHER INFORMATION

For the list of references refer to the Introduction – Rock Lobster chapter.

ROCK LOBSTER (CRA 4, CRA 5, CRA 7, CRA 8 AND CRA 9)

(*Jasus edwardsii*, *Sagmariasus verreauxi*)
Crayfish, Kōura papatea, Pawharu



1. FISHERY SUMMARY

1.1 Commercial fisheries
Refer to the relevant text, tables and figures in Sections 1, 1.1 and 1.7 of the Introductory Rock Lobster Chapter for a presentation of the CRA commercial catches and CPUE.

1.2 Recreational fisheries
For general information on recreational catch refer to the Introductory Rock Lobster chapter.

1.3 Customary non-commercial fisheries
For general information on customary non-commercial catch refer to the Introductory Rock Lobster chapter.

1.4 Illegal catch
For general information on customary non-commercial catch refer to the Introductory Rock Lobster chapter.

2. BIOLOGY

Refer to Section 2 in the Introductory Rock Lobster chapter for a general presentation of rock lobster biological considerations, including growth, natural mortality and puerulus settlement.

3. STOCKS AND AREAS

For information on stocks and areas refer to the Introductory Rock Lobster chapter.

4. DECISION RULES AND MANAGEMENT PROCEDURES

For information on decision rules and management procedures refer to the Introductory Rock Lobster chapter.

5. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS

For information on environmental and ecosystem considerations refer to the Introductory Rock Lobster chapter.

6. STOCK ASSESSMENT

This section repeats stock assessment results for CRA 4, CRA 5, CRA 7, CRA 8 and CRA 9 from previous mid-year Plenary documents; the text has not been updated from the originals and reflects the TAC, TACC and allowances that were current at the time each assessment was completed.

6.1 CRA 4

This section reports the assessment for CRA 4 conducted in 2016.

Models and model structure

The stock assessment is based on a single-stock version of the multi-stock length-based model (MSLM) (Haist et al. 2009). During the stock assessment workshop, a new single-stock model (Webber et al. 2018a) was also fitted in parallel and its estimates were verified against the MSLM results. Also during the workshop, multi-stock versions of both models were fitted to four sets of statistical area data on an experimental basis. Only the single-stock MSLM model results are discussed here.

The model was fitted to two series of catch rate indices from different periods, and to size frequency, puerulus settlement and tagging data. The model used an annual time step from 1945 to 1978 and then switched to a seasonal time step with AW and SS from 1979 through to 2015. The model had 93 length bins, 31 for each sex group (males, immature and mature females), each 2 mm TW wide, beginning at left-hand edge 30 mm TW.

Significant catches occurred in the historical series for CRA 4. Different MLS regulations existed in the past and pots were not required to have escape gaps. The model incorporated a time series of sex-specific MLS regulations. Data and their sources are listed in Table 1.

Non-commercial catches for CRA 4 are described in Section 1.2 (recreational catch), Section 1.3 (Section 111 recreational catches), Section 1.4 (customary catch) and Section 1.5 (illegal catch) of the Introductory Rock Lobster chapter.

MPI (now Fisheries New Zealand), in its response to the request from the Rock Lobster Stock Assessment team for guidance on setting recreational catches, recommended the following for the CRA 4 recreational fishery:

> ‘All available estimates of recreational rock lobster harvest by Quota Management Area are presented in the November 2015 Fisheries Assessment Plenary. The harvest estimates provided by the historical telephone diary surveys (1992, 1993, 1994, 1996, 2000 and 2001) are no longer considered reliable by the MPI Marine Amateur Fisheries Working Group.

A recreational harvest estimate is available for CRA 4 from the 2011–12 National Panel Survey (NPS), which includes any charter fishing activity.

MPI recommends that the 2011/12 NPS estimate for CRA 4 is used in the upcoming stock assessment. Given that there were a number of panellists making quite a few trips and the CV is relatively low, the NPS estimate for CRA 4 is considered reasonably robust. However, this is said in recognising that the NPS is unlikely to be reaching a high proportion of rock lobster fishers as finfish fishers, which could mean there is a negative bias in the catch estimates, but this has not been tested or quantified.'

The RLFAWG agrees that, because there were a number of panellists making quite a few trips and the CV is relatively low, the NPS estimate for CRA 4 would be considered reasonably robust. However, it is also recognised that the NPS was unlikely to be reaching as high a proportion of rock lobster fishers as finfish fishers, which could mean there is a negative bias in the rock lobster catch estimates, but this has not been tested or quantified. Apart from the NPS, recreational catches of rock lobster are poorly known throughout New Zealand, but it seems unlikely that recreational catch in CRA 4 would have been constant, given its proximity to Wellington and Hawke's Bay. The RLFAWG agreed for the 2003 CRA 4 stock assessment (Kim et al. 2004) to use a catch trajectory that reflected the changing abundance of lobster in this QMA, based on SS CPUE. This stock assessment calculated the ratios of the CPUE relative to the recreational survey catch weight, took the mean of these ratios, and applied it to the observed SS CPUE in all other years from 1979. All rock lobster stock assessments that use this procedure since 2003 have used the standardised SS CPUE from the entire QMA except for the 2014 CRA 1 stock assessment and the 2010 and 2015 CRA 5 stock assessments, which used unstandardised CPUE from statistical areas where the majority of the recreational catch was thought to be taken (see Table 6 in the Introductory Rock Lobster chapter for details). When this method was implemented for the 2016 CRA 4 stock assessment (using the survey estimates in Table 6 in the Introductory Rock Lobster chapter), the estimated recreational catches were consistent with the 2011 NPS survey and the values used in the 2011 CRA 4 stock assessment.

$$
\begin{aligned}
{}^{q}W_y &= {}^{q}w_y \; {}^{q}N_y \\
{}^{q}S &= \left({}^{q}W_{94} / {}^{q}CPUE_{94} + {}^{q}W_{96} / {}^{q}CPUE_{96} + {}^{q}W_{11} / {}^{q}CPUE_{11} \right) / 3 \\
{}^{q}\hat{W}_i &= {}^{q}S * {}^{q}CPUE_i \text{ if } i >= 1979 \\
{}^{q}\hat{W}_{1945} &= 0.2 * {}^{q}\hat{W}_{1979} \\
{}^{q}\hat{W}_i &= {}^{q}\hat{W}_{i-1} + \frac{({}^{q}\hat{W}_{1979} - {}^{q}\hat{W}_{1945})}{(1979 - 1945)} \text{ if } i > 1945 \,\&\, i < 1979
\end{aligned}
$$

Eq. 1 where

y: subscripts 1994, 1996 and 2011

${}^{q}w_y =$ mean spring/summer weight >= MLS for sampled lobster in year y for QMA q

${}^{q}N_y =$ mean numbers lobster in survey year y for QMA q

${}^{q}CPUE_i =$ spring/summer standardised CPUE from 1979 to 2015 for QMA q

${}^{q}\hat{W}_i =$ estimated recreational catch by weight for year i for QMA q

${}^{q}S$ = 45.833 t was used when Eq.1 was fitted to the survey estimates in Table 6 in the Introductory Rock Lobster chapter and the estimated recreational catch trajectory is plotted in Figure 1. Recreational catch is split between seasons, with 90% assumed taken in the SS and the remainder in AW.

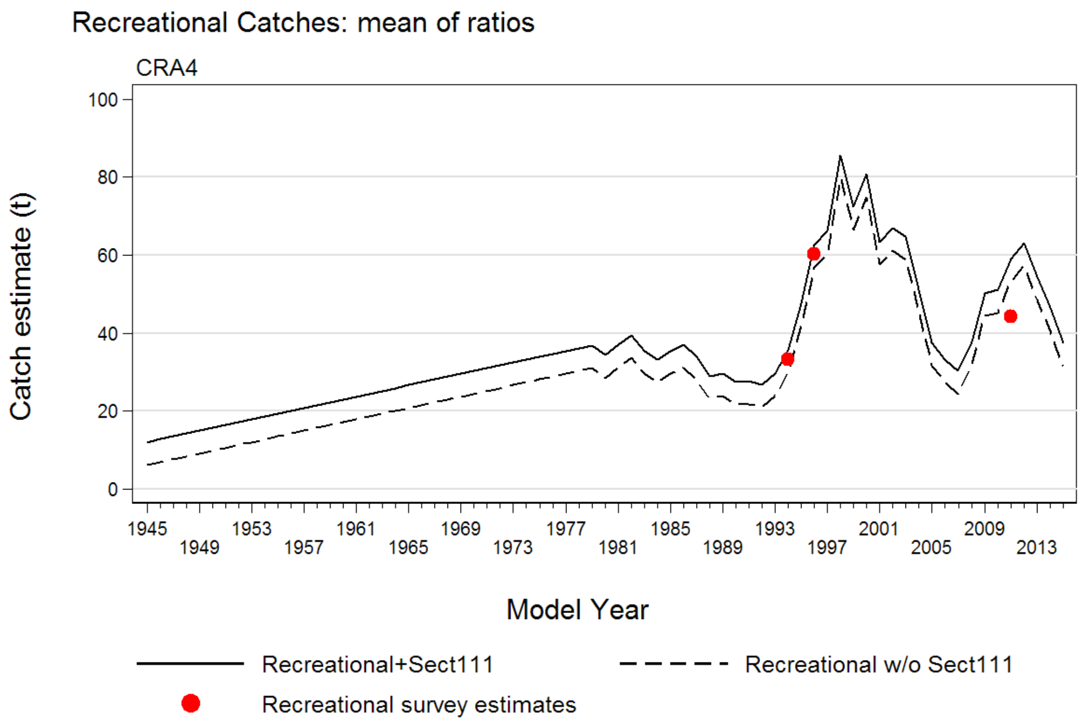


Figure 1: Recreational catch trajectories (t) for the 2016 stock assessment of CRA 4. Trajectories with and without the additional Section 111 catches are shown.

Table 1: Data types and sources for the 2016 assessment for CRA 4. Year codes apply to the first nine months of each fishing year, i.e., 1998–99 is called 1998. NZ RLIC – NZ Rock Lobster Industry Council.

Data type	Data source	Begin year	End year
Historical catch rate CR	Annala & King (1983)	1963	1973
CPUE	FSU & CELR	1979	2015
Observer proportions-at-size	Fisheries New Zealand and NZ RLIC	1986	2015
Logbook proportions-at-size	NZ RLIC	1997	2015
Tag recovery data	NZ RLIC & Fisheries New Zealand	1982	2015
Historical MLS regulations	Annala (1983), Fisheries New Zealand	1945	2015
Escape gap regulation changes	Annala (1983), Fisheries New Zealand	1945	2015
Puerulus settlement	Fisheries New Zealand	1979	2015

The initial population in 1945 was assumed to be in equilibrium with average recruitment and with no fishing mortality. Each season the number of male, immature female and mature female lobsters within each size class was updated as a result of:

a) **Recruitment:** Each year, new recruits to the model were added equally for each sex for each season, as a normal distribution with a mean size (32 mm) and standard deviation (2 mm), truncated at the smallest size class (30 mm). Recruitment in a specific year was determined by the parameter for base recruitment and a parameter for the deviation from base recruitment. The vector of log recruitment deviations was assumed to be normally distributed with a mean of zero. Recruitment deviations were estimated for 1945 through 2017 when fitting to the puerulus index.

b) **Mortality:** Natural, fishing and handling mortalities were applied to each sex category (male, immature female and mature female) in each size class. Natural mortality was estimated, but was assumed to be constant and independent of sex and length. Fishing mortality was determined from observed catch and model biomass, modified by legal sizes, sex-specific vulnerabilities and selectivity curves. Handling mortality was assumed to be 10% of fish returned to the water until 1990, then reduced to 5%. Two fisheries were modelled: one fishery that operated only on fish above the size limit (SL fishery – including legal commercial and recreational) and one that did not (NSL fishery – all of the illegal fishery plus the Maori customary fishery). It was assumed that size limits and the prohibition on berried females applied only to the SL fishery. Otherwise, the selectivity and vulnerability functions were the same for the SL and NSL fisheries. Relative vulnerability was calculated by assuming (after experimentation) that immature females in the AW had the highest vulnerability and that the vulnerabilities of all other sex categories by season were less. Instantaneous fishing mortality rates for each fishery were calculated using Newton-Raphson iteration (three iterations after experiment) based on catch and model biomass.

c) **Fishery selectivity:** A three-parameter fishery selectivity function was assumed, with parameters describing the shapes of the ascending and descending limbs and the size at which vulnerability is at a maximum. Changes in regulations over time (for instance, changes in escape gap regulations) were modelled by estimating two separate selectivity epochs, pre-1993 and 1993–2010. As in previous assessments for the past decade, the descending limb of the selectivity curve was fixed to prevent underestimation of selection for large lobsters.

d) **Growth and maturity:** For each size class and sex category, a growth transition matrix specified the probability of an individual remaining in the same size class or growing into each of the other size classes. Maturation of females was estimated as a two-parameter logistic curve from the maturity-at-size information in the size-frequency data.

Model fitting

A total negative log likelihood function was minimised using AD Model Builder™. The model was fitted to historical catch rate and standardised CPUE data using lognormal likelihood. Puerulus settlement data were fit with normal-log likelihood. The model was fitted to proportions-at-length with multinomial likelihood and tag-recapture data with robust normal likelihood (after experimentation with normal likelihood). For the CPUE and puerulus likelihoods, CVs for each index value were initially set at the standard error from the GLM analysis. Process error was subsequently added to these CVs. A fixed CV of 0.3 was used for the historical catch rate data. The robust normal likelihood was used for the tagging data. Proportions-at-length, assumed to be representative of the commercial catch, were available from observer catch sampling for all years after 1985 and from voluntary logbooks for some years from 1997. Data were summarised by area/month strata and weighted by the commercial catch taken in each stratum, the number of lobsters measured and the number of days sampled with the size data from each source (research sampling or voluntary logbooks) fitted independently. Seasonal proportions-at-length summed to one for each of males, immature and mature females and the sex ratios by season were fitted using a multinomial likelihood. Randomisation trials were conducted to establish that puerulus settlement data contained a recruitment signal; these established that the puerulus data contributed recruitment information to the model with lags of 1 or 2 years.

Uniform priors with wide bounds were used for most estimated parameters. Informed priors on the growth shape, growth CV and growth observation error were based on a meta-analysis of all rock lobster growth data in 2015 (Webber et al. 2018a). The CVs of these priors were experimentally increased when the search for a base case was conducted.

Table 2: Parameters estimated and priors used in the base case CRA 4 stock assessment. Prior type abbreviations: U – uniform; N – normal; L – lognormal. [Continued on next page]

Par	Lower bound	Upper bound	Prior type	Prior mean	Prior std/CV
ln(*R0*)	1	25			
M	0.01	0.35	2	0.12	0.4
*Rdev*s	-2.3	2.3	1	0	0.4
ln(*qCPUE*)	-25	0	0		
ln(*qCR*)	-25	2	0		
ln(*qpuerulus)*	-25	0	0		
size at 50% maturation	30	80	0		
increment at 50 mm TW	1	20	0		
ratio of increments at 80 and 50 mm	0.001	1	0		

Par	Lower bound	Upper bound	Prior type	Prior mean	Prior std/CV
growth shape - male	0.1	15	1	4.81	0.38
growth CV - male	0.01	2	1	0.59	0.0076
growth shape - female	0.1	15	1	4.51	0.24
growth CV - female	0.01	2	1	0.82	0.013
growth observation error	0.00001	10	1	1.48	0.015
selectivity left limb	1	50	0		
size at maximum selectivity	30	90	0		
sex-seasonal vulnerability	0.01	1	0		

In the base case, it was assumed that biomass was proportional to CPUE, that growth is not density-dependent and that there is no stock-recruit relationship. Base case explorations involved experimentally weighting the datasets and inspecting the resulting standard deviations of normalised residuals and medians of absolute residuals, experimentally increasing the CVs of the informed growth priors, experimenting with the sex and season for maximum vulnerability, experimenting with fixing the shape of the maturation ogive and exploring other model options such as density-dependence and selectivity curves. Recruitment deviations were estimated for 1945–2017. CPUE process error was decreased for 2014–15 to force a good fit to the 2015 observed CPUE.

Parameters estimated in each model and their priors are provided in Table 2; fixed values used in the assessment are provided in Table 3. CPUE, the historical catch rate, proportions-at-length and tagging data were given relative weights directly by a relative weighting factor.

Table 3: Fixed values used in base case assessment for CRA 4.

Value	CRA 4
shape parameter for CPUE vs biomass	1.0
maturation shape parameter	3.26
minimum std. dev. of growth increment	0.0001
Std dev of historical catch per day	0.30
Handling mortality before 1990	10%
Handling mortality from 1990	5%
Process error for CPUE before 2014	0.25
Process error for CPUE from 2014	0.075
Year of selectivity change	1993
Current male size limit	54
Current female size limit	60
First year for recruitment deviations	1945
Last year for recruitment deviations	2017
Relative weight for length frequencies: male	3.15
Relative weight for length frequencies: immature female	1.0
Relative weight for length frequencies: mature female	1.814
Relative weight for sex proportions	3.09
Relative weight for CPUE	2.8
Relative weight for CR	4
Relative weight for puerulus	0.683
Relative weight for tag-recapture data	1

Model projections

Bayesian estimation procedures were used to estimate the uncertainty in model estimates and short-term projections. This procedure was conducted in the following steps:

1. Model parameters were estimated by AD Model Builder™ using maximum likelihood and the prior probabilities. The point estimates are called MPD (mode of the joint posterior) estimates.
2. Samples from the joint posterior distribution of parameters were generated with Markov chain Monte Carlo (MCMC) simulations using the Hastings-Metropolis algorithm; five million simulations were made, starting from the base case MPD, and 1000 samples were saved. From

each sample of the posterior, three-year projections (2016–19) were generated with an assumed current-catch scenario (Table 4).

3. Future annual recruitment was randomly sampled with replacement from the model's estimated recruitments from 2008–17.

Table 4: Catches (t) used in the three-year projections. Projected catches are based on the current TACC for CRA 4, and the current estimates of recreational, customary and illegal catches. SL = commercial + recreational - reported illegal; NSL = reported illegal + unreported illegal + customary.

Commercial	Recreational	Reported illegal	Unreported illegal	Customary	SL	NSL
397	37	0	40	20	434	60

Performance indicators and results

Vulnerable biomass in the assessment model was determined by the MLS, selectivity, relative sex and seasonal vulnerability and berried state for mature females. All mature females were assumed to be berried (and not vulnerable to the fishery) in AW and not berried (thus vulnerable) in SS.

Results from agreed indicators are summarised in Table 6. Base case results (Table 6) suggested that biomass decreased to a low point in 1991, then increased to a high in 1998 (Figure 2), decreased to 2006 and has increased again. The current vulnerable stock size (AW) is about 0.75 times the reference biomass and the spawning stock biomass is close to SSB_{MSY} (Table 6). Projected biomass would decrease at the level of current catches over the next four years (Figure 2).

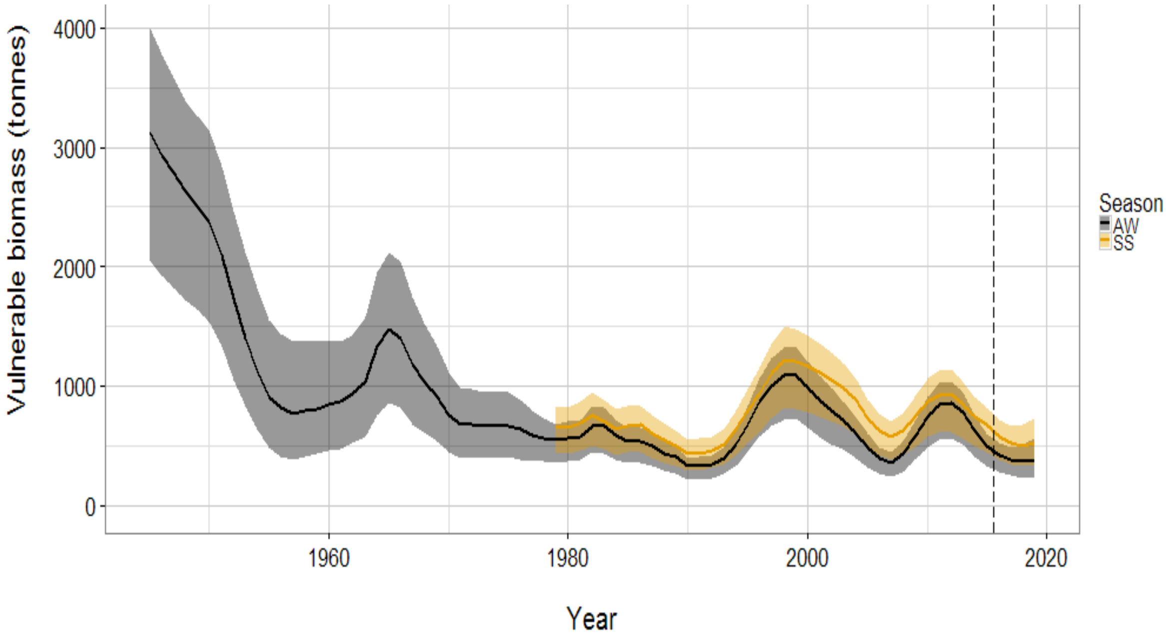


Figure 2: Posterior distribution of the CRA 4 base case MCMC biomass vulnerable trajectory. Before 1979 there was a single time step, shown in AW. For each year the black line represents the median, the shaded area spans the 5th and 95th quantiles.

Table 5: Performance indicators used in the CRA 4 stock assessment. [Continued on next page]

Reference points	Description
B_{MIN}	The lowest beginning AW vulnerable biomass in the series
B2016	Beginning of season AW vulnerable biomass
B_{REF}	Beginning of AW season mean vulnerable biomass for 1979–88
B2019	Projected beginning of season AW 2019 vulnerable biomass
B_{MSY}	Beginning of season AW vulnerable biomass associated with MSY, calculated by doing deterministic forward projections with recruitment *R0* and current fishing patterns
MSY	Maximum sustainable yield (sum of AW and SS SL catches) found by searching a across a range of multipliers on F.

Reference points	Description
Fmult	The multiplier that produced *MSY*
SSB2016	spawning stock biomass at start of AW 2016 season
SSB2019	Projected spawning stock biomass at start of AW 2019 season
SSB_{MSY}	Spawning stock biomass at start of AW season associated with *MSY*

CPUE indicators	Description
CPUE2015	CPUE predicted for AW 2015
CPUE2019	CPUE predicted for AW 2019
CPUEmsy	CPUE at B_{MSY}

Performance indicators	Description
$B2016 / B_{MIN}$	ratio of *B2016* to B_{MIN}
$B2016 / B_{REF}$	ratio of *B2016* to B_{REF}
$B2016 / B_{MSY}$	ratio of *B2016* to B_{MSY}
B2019 / B2016	ratio of *B2019* to *B2016*
$B2019 / B_{REF}$	ratio of *B2019* to B_{REF}
$B2019 / B_{MSY}$	ratio of *B2019* to B_{MSY}
$SSB2016/ SSB_0$	ratio of *SSB2016* to SSB_0
$SSB2019/ SSB_0$	ratio of *SSB2019* to SSB_0
$SSB2016/SSB_{MSY}$	ratio of *SSB2016* to SSB_{MSY}
$SSB2019/SSB_{MSY}$	ratio of *SSB2019* to SSB_{MSY}
SSB2019/SSBcurr	ratio of *SSB2019* to *SSBcurrent*
USL2015	The 2015 exploitation rate for SL catch in AW
USL2019	Projected 2019 exploitation rate for SL catch in AW
USL2019/USL2015	ratio of SL 2019 exploitation rate to 2015 SL exploitation rate
Btot2016	total biomass at start of 2016 AW season
Btot2016/Btot0	*Btot2016* divided by total biomass at the start
Ntot2016	total numbers at start of 2016 AW season
Ntot2016/Ntot0	*Ntot2016* divided by total numbers at the start
minHandMort	minimum tonnage of mortality caused by handling
HandMort2016	2016 tonnage of mortality caused by handling
HandMort2019	2019 tonnage of mortality caused by handling

Probabilities	Description
$P(B2016 > B_{MIN})$	probability $B2016 > B_{MIN}$
$P(B2016 > B_{REF})$	probability $B2016 > B_{REF}$
$P(B2016 > B_{MSY})$	probability $B2016 > B_{MSY}$
$P(B2019 > B_{MIN})$	probability $B2019 > B_{MIN}$
$P(B2019 > B_{REF})$	probability $B2019 > B_{REF}$
$P(B2019 > B_{MSY})$	probability $B2019 > B_{MSY}$
$P(B2019 > B2016)$	probability $B2019 > B2016$
$P(SSB2016>SSB_{MSY})$	probability $SSB2016>SSB_{MSY}$
$P(SSB2019>SSB_{MSY})$	probability $SSB2019>SSB_{MSY}$
$P(USL2019>USL2015)$	probability 2019 SL exploitation rate > 2015 SL exploitation rate
$P(SSB2016<0.2\ SSB_0)$	soft limit: probability $SSB2016$ < 20% SSB_0
$P(SSB2019<0.2\ SSB_0$	soft limit: probability $SSB2019$ < 20% SSB_0
$P(SSB2016<0.1\ SSB_0)$	hard limit: probability $SSB2016$ < 10% SSB_0
$P(SSB2019<0.1\ SSB_0)$	hard limit: probability $SSB2019$ < 10% SSB_0

A series of MCMC sensitivity trials were also made. The assessment results from the base case and sensitivity trials calculated as a series of agreed indicators (Table 5) are shown in Table 6.

The sensitivity trials run were:

- *3-sexlag1*: same as the base but with lag 1 year for puerulus
- *2-sex*: fitted to males and aggregated females with fixed maturation parameters
- *normaltag*: using normal likelihood instead of robust normal for fitting to tags
- *estMat95*: with fixed growth shape and growth CV parameters and the maturation shape parameter estimated

- *fixMat95*: with fixed growth shape and growth CV parameters and the maturation shape parameter fixed.

Indicators based on vulnerable biomass and B_{MSY}

In all trials the median B_{REF} was larger than B_{MSY} and B_{MIN}. In all trials median current and projected biomass was smaller than B_{REF} but larger than B_{MSY}. Projected biomass, using current catches, decreased in the base case but increased in some of the sensitivity trials. Projected biomass remained below B_{REF} except in the estMat95 and fixMat95 trials.

Table 6: Assessment results – medians of indicators described in Table 5 from the base case and sensitivity trials; the lower part of the table shows the probabilities that events are true; biomass in t and CPUE in kg/potlift.

Indicator	3-sex base	3-sex lag1	2-sex	normaltag	estMat95	fixMat95
B_{MIN}	324.2	307.1	391.4	248.8	270.2	270.2
B_{2016}	416.0	399.3	493.9	316.8	347.1	346.8
B_{REF}	560.9	542.6	672.4	423.1	494.0	493.1
B_{2019}	384.3	412.6	449.5	272.9	509.3	509.6
B_{MSY}	283.6	269.3	351.1	227.1	305.4	304.8
MSY	638.8	642.2	643.0	620.9	634.8	635.0
Fmult	3.11	3.23	2.97	2.72	2.31	2.33
SSB_{2016}	1 601.2	1 635.8	1 669.2	1 526.4	1 081.1	1 072.8
SSB_{2019}	1 649.3	1 750.3	1 691.1	1 514.4	1 040.5	1 020.7
SSB_{MSY}	1 889.9	1 940.1	2 018.5	1 815.0	1 101.4	1 088.6
$CPUE_{2015}$	0.737	0.741	0.733	0.742	0.747	0.747
$CPUE_{2019}$	0.584	0.646	0.555	0.544	1.028	1.017
CPUEmsy	0.339	0.327	0.353	0.375	0.461	0.459
B_{2016}/B_{MIN}	1.295	1.309	1.263	1.279	1.279	1.280
B_{2016}/B_{REF}	0.749	0.741	0.735	0.751	0.701	0.700
B_{2016}/B_{MSY}	1.471	1.497	1.414	1.389	1.131	1.137
B_{2019}/B_{2016}	0.942	1.043	0.914	0.884	1.483	1.473
B_{2019}/B_{REF}	0.708	0.773	0.669	0.664	1.035	1.030
B_{2019}/B_{MSY}	1.385	1.568	1.282	1.239	1.666	1.668
SSB_{2016}/SSB_0	0.508	0.510	0.508	0.509	0.473	0.475
$SSB2019/SSB_0$	0.518	0.545	0.512	0.503	0.454	0.452
SSB_{2016}/SSB_{MSY}	0.850	0.841	0.827	0.835	0.981	0.985
SSB_{2019}/SSB_{MSY}	0.867	0.901	0.833	0.827	0.941	0.944
SSB_{2019}/SSB_{2016}	1.021	1.065	1.014	0.989	0.964	0.957
USL_{2015}	0.229	0.236	0.193	0.302	0.285	0.285
USL_{2019}	0.267	0.249	0.229	0.376	0.202	0.202
USL_{2019}/USL_{2015}	1.134	1.045	1.181	1.209	0.707	0.709
$Btot_{2016}$	4 056.8	4 465.0	4 415.5	4 429.6	2 162.9	2 154.7
$Btot_{2016}/Btot_0$	0.406	0.441	0.415	0.418	0.291	0.293
$Ntot_{2016}$	14 152 350	17 139 950	16 166 500	16 750 850	6 452 725	6 433 990
$Ntot_{2016}/Ntot_0$	0.500	0.584	0.512	0.531	0.393	0.394
minHandMort (t)	14.25	14.42	14.44	14.62	10.99	11.00
$HandMort_{2016}$ (t)	18.14	17.90	18.54	18.95	19.18	19.23
$HandMort_{2019}$ (t)	25.88	24.22	26.78	26.87	16.65	16.70

Indicators based on SSB_{MSY}

The historical track of biomass versus fishing intensity is shown in Figure 3. This ‘snail trail’ shows the median spawning biomass on the x-axis and median fishing intensity on the y-axis; thus high biomass/low fishing intensity is in the lower right-hand corner, where a stock would be when fishing first began, and low biomass/high intensity is in the upper left-hand corner, where an uncontrolled fishery would be likely to go. Specifically, the x-axis is spawning stock biomass *SSB* as a proportion of the unfished spawning stock SSB_0. Estimated *SSB* changes every year; SSB_0 is constant for all years of a simulation, but varies among the 1000 samples from the posterior distribution.

The y-axis is fishing intensity as a proportion of the fishing intensity that would have given MSY (F_{MSY}) under the fishing patterns in year *y*; fishing patterns include MLS, selectivity, the seasonal catch split and the balance between SL and NSL catches. F_{MSY} varies among years because the fishing patterns change. It was calculated with a 50-year projection for each year in each simulation, with the NSL catch held constant at that year's value, deterministic recruitment at *R0* and a range of multipliers on the SL catch *F*s estimated for year *y*. The *F* (actually *F*s for two seasons) that gave MSY was F_{MSY}, and the multiplier was *Fmult*.

Each point on the figure was plotted as the median of the posterior distributions of biomass ratio and fishing intensity ratio. The vertical line in the figure is the median (line) and 90% interval (shading) of the posterior distribution of SSB_{MSY} as a proportion of SSB_0; this ratio was calculated using the fishing pattern in 2015. The horizontal line in the figure is drawn at 1, the fishing intensity associated with *Fmsy*. The bars at the final year of the plot show the 90% intervals of the posterior distributions of biomass ratio and fishing intensity ratio.

Both current and projected spawning biomass are well above 40% SSB_0.

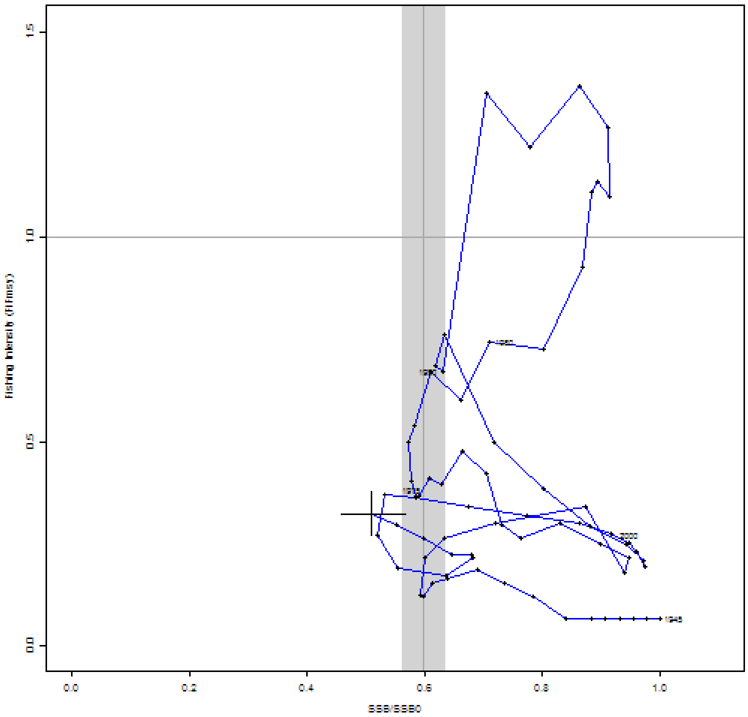


Figure 3: 'Snail trail' showing the median spawning biomass on the x-axis and median fishing intensity on the y-axis.

This year two new models were tested alongside the CRA 4 stock assessment: an experimental CRA 4 sub-area stock assessment and a new rock lobster stock assessment model called Lobster Stock Dynamics (LSD). The experimental CRA 4 sub-area assessment was not completed this year but the approach looks promising and is likely to be a credible approach to investigate in the future. Not only do sub-area models like this provide an understanding of stock status as a whole, they may also provide more disaggregated results that can be used to voluntarily manage fisheries at smaller spatial scales (e.g., apportioning more catch to statistical areas that have the highest abundance or productivity). The new assessment model aimed to emulate the MLSM model (Haist et al. 2009) as closely as possible this year, so few new features were added to the code. The model was written in the state-of-the-art Bayesian programming language, Stan, and several benefits have already been identified. For example, LSD/Stan does not require that the Hessian be positive definite to begin MCMC sampling. Also, Stan uses Hamiltonian Monte Carlo (HMC), which is a much more efficient MCMC sampler and mixes much faster than standard Metropolis-Hastings MCMC samplers. This greatly speeds up the exploration of different model structures and allows for faster Bayesian inference (or more complex models to be explored). Due to its speed, LSD could be an excellent platform for finer-scale spatial modelling in the future.

Future research considerations

- Continued development of the sub-area model:
  - more flexible data processing code is needed;
  - the new model should have the capability to fit to data that have different spatial or temporal scales (e.g., catch data pre-1979 are by QMA and are only available by statistical area from 1979);
  - the new model should have the capability to specify some parameters as random effects (e.g., natural mortality, selectivity);
- investigation of methods for collecting growth data for sub-45 mm TW lobsters;
- further exploration of relative weightings of length frequencies;
- improved estimates of non-commercial catch;
- more tagging in Statistical Areas 912 and 915.

6.2 CRA 5

This section reports the assessment for CRA 5 conducted in 2015.

Model structure

A single-stock version of the multi-stock length-based model (MSLM) (Haist et al. 2009) was fitted to two series of catch rate indices from different periods, and to size frequency, puerulus settlement and tagging data. The model used an annual time step for 1945–78 and then a seasonal time step (autumn–winter (AW): April to September; and spring–summer (SS): October to March).

Significant catches occurred in the early part of the time series for CRA 5. Different MLS regulations existed at this time and pots were not required to have escape gaps. The model incorporated a time series of sex-specific MLS regulations. Data and sources available to the model are listed in Table 7.

The assessment assumed that recreational catch was equal to survey estimates in 1994, 1996 and an assumed value of 80 t in 2011, fitted to an exponential model driven by the Statistical Area 917 AW CPUE from 1979–2009, and increased linearly from 20% of the 1979 value in 1945 up to the 1979 value (see Section 1.4 for a description of the procedure followed).

The initial population in 1945 was assumed to be in equilibrium with average recruitment and with no fishing mortality. Each season the number of male, immature female and mature female lobsters within each size class is updated as a result of:

a) **Recruitment:** Each year, new recruits were added equally for each sex season, as a normal distribution with a mean size (32 mm) and standard deviation (2 mm), truncated at the smallest size class (30 mm). Recruitment in a specific year was determined by the parameter for base recruitment and a parameter for the deviation from base recruitment. The vector of recruitment deviations was assumed to be normally distributed with a mean of zero with standard deviation of 0.4. It was assumed that stock size has no influence on recruitment because of the long duration of the pelagic larval phase coupled with long-distance movements during this phase.

b) **Mortality:** Natural, fishing and handling mortalities were applied to each sex category (male, immature female and mature female) in each size class. Natural mortality was estimated, but was assumed to be constant and independent of sex and length. Fishing mortality was determined from observed catch and model biomass, modified by legal sizes, sex-specific vulnerabilities and selectivity curves. A constant handling mortality of 10% was applied to all discarded lobsters, independent of size. Two fisheries were modelled: one fishery that operated only on fish above the size limit (SL fishery – consisting of legal commercial and recreational) and one that did not (NSL fishery – all of the illegal fishery plus the Maori customary fishery). It was assumed that size limits and the prohibition on berried females applied only to the SL fishery. Otherwise, the selectivity and vulnerability functions were the same for the SL and NSL fisheries. Relative vulnerability was calculated by assuming that the males in the AW had the highest vulnerability and that the vulnerability of all other sex categories by season are equal to or less than the AW males. Instantaneous fishing mortality rates for each fishery were calculated using Newton-Raphson iteration based on catch and model biomass.

c) **Fishery selectivity:** A three-parameter fishery selectivity function was assumed, with parameters describing the shapes of the ascending and descending limbs and the size at which vulnerability is at a maximum (the right-hand limb was fixed at a high value for the base case and most sensitivity runs to avoid the creation of cryptic biomass). Changes in regulations over time (for instance, changes in escape gap regulations) were modelled by estimating two separate selectivity epoch, pre-1993 and 1993–2014.

d) **Growth and maturity:** For each size class and sex category, a growth transition matrix specified the probability of an individual remaining in the same size class or growing into each of the other size classes. Maturation of females was estimated as a two-parameter logistic curve from the maturity-at-size information in the size-frequency data.

Model fitting

A total negative log likelihood function was minimised using AD Model Builder™. The model was fitted to historical catch rate, standardised CPUE and puerulus settlement data using lognormal likelihood. The model was fitted to proportions-at-length with multinomial likelihood and tag-recapture data with a normal likelihood. For the CPUE and puerulus lognormal likelihoods, CVs for each index value were initially set at the standard error from the GLM analysis. Process error was subsequently added to these CVs so that the overall standard deviation of the standardised (Pearson) residuals was near 1.0. A fixed CV of 0.3 was used for the historical catch rate data. Outliers (defined as lying in the ±0.2% quantiles of the standardised residuals when fitting to the tag data without other model data) were dropped. Proportions-at-length, assumed to be representative of the commercial catch, were available from both observer catch sampling and voluntary logbooks; these were fitted separately. Data were summarised by area/month strata and weighted by the commercial catch taken in each stratum, the number of lobsters measured and the number of days sampled with the size data from each source (research sampling or voluntary logbooks) fitted independently. Seasonal proportions-at-length summed to one for each sex category (males, immature and mature females) and the sex ratios by season were fitted using a multinomial likelihood. Randomisation trials were conducted to establish that puerulus settlement data contained a recruitment signal; these established that the puerulus data contributed recruitment information to the model with a lag of a single year.

Two base case models were accepted by the RLFAWG: both included the puerulus settlement indices but differed by the inclusion/exclusion of density-dependent growth. The RLFAWG was not able to choose between these two models because it was felt that each was equally plausible. The remaining aspects of the base case were the same, with the same weighting assumptions made for each model. Recruitment deviations were estimated for the entire period: 1945–2015, given that the final 2014 puerulus index applies to 2015 with a one-year lag.

Table 7: Data types and sources for the 2015 assessment for CRA 5. Year codes apply to the first nine months of each fishing year (i.e., 1998–99 is called 1998). NZRLIC – NZ Rock Lobster Industry Council.

Data type	Data source	Begin year	End year
Historical catch rate CR	Annala & King (1983)	1963	1973
CPUE	FSU & CELR	1979	2014
Observer proportions-at-size	Fisheries New Zealand	1989	2010
Logbook proportions-at-size	NZRLIC	1994	2014
Tag recovery data	NZRLIC & Fisheries New Zealand	1974	2014
MLS regulations	Annala (1983), Fisheries New Zealand	1945	2014
Escape gap regulation changes	Annala (1983), Fisheries New Zealand	1945	2014
Puerulus settlement	Fisheries New Zealand	1980	2014

Parameters estimated in each model and their priors are provided in Table 8. Fixed parameters and their values are given in Table 9.

CPUE, the historical catch rate, proportions-at-length and tagging data were given relative weights directly by a relative weighting factor. The weights were varied to obtain standard deviations of standardised residuals for each dataset that were close to one.

Table 8: Parameters estimated and priors used in basecase assessments for CRA 5. Prior type abbreviations: U – uniform; N – normal; L – lognormal.

	Prior type	Bounds	Mean	SD	CV
ln(*R0*) (mean recruitment)	U	1–25	–		–
M (natural mortality)	L	0.01–0.35	0.12		0.4
Recruitment deviations	N[1]	-2.3–2.3	0	0.4	
ln(*qCPUE*)	U	-25–0	–		–
ln(*qCR*)	U	-25–2	–		–
ln(*qPuerulus*)	U	-25–0	–		–
Increment at TW=50 (male & female)	U	0.1–20.0	–		–
shape of growth curve (male)	N	0.1–15.0	4.81	0.38	
shape of growth curve (female)	N	0.1–15.0	4.51	0.24	
CV of growth increment (male)	N	0.01–2.0	0.59	.0076	
CV of growth increment (female)	N	0.01–2.0	0.82	.013	
growth observation std.dev. (male & female)	N	0.00001–10.0	1.48	.0015	
TW at 50% probability female maturation	U	30–80	–		–
(TW at 95% probability female maturity) – (TW at 50% probability female maturity)	U	1–60	–		–
density-dependence parameter	U	0–1	–	–	
Relative vulnerability (all sexes and seasons)[2]	U	0–1	–		–
Shape of selectivity left limb (males & females)	U	1–50	–		–
Size at maximum selectivity (males & females)	U	30–80	–		–
Size at maximum selectivity females	U	30–80	–		–

[1] Normal in natural log space = lognormal (bounds equivalent to –10 to 10).
[2] Relative vulnerability of males in autumn–winter was fixed at one.

Table 9: Fixed values used in base case assessment for CRA 5.

Parameter/description	CRA 5
shape parameter for CPUE vs biomass	1
minimum std. dev. of growth increment	0.0001
Std dev of historical catch per day	0.30
Handling mortality	10%
Process error for CPUE	0.25
Year of selectivity change	1993
Current male size limit	54
Current female size limit	60
First year for recruitment deviations	1945
Last year for recruitment deviations	2015
Relative weight for length frequencies	4
Relative weight for CPUE	2.6
Relative weight for CR	4
Relative weight for puerulus	0.3
Relative weight for tag-recapture data	1.0

Model projections

Bayesian estimation procedures were used to estimate the uncertainty in model estimates and short-term projections. This procedure was conducted in the following steps:

1. Model parameters were estimated by AD Model Builder™ using maximum likelihood and the prior probabilities. These point estimates are called MPD (mode of the joint posterior) estimates.

2. Samples from the joint posterior distribution of parameters were generated with Markov chain Monte Carlo (MCMC) simulations using the Hastings-Metropolis algorithm; five million simulations were made, starting from the base case MPD, and 1000 samples were saved. From each sample of the posterior, four-year projections (2015–18) were generated with an agreed catch scenario (Table 10).

3. Future annual recruitment was randomly sampled with replacement from the model's estimated recruitments from 2006–15 (except for the no puerulus sensitivity trial, which resampled from 2003–12).

Table 10: Catches (t) used in the four-year projections. Projected catches are based on the current TACC for CRA 5, and the current estimates of recreational, customary and illegal catches.

Commercial	Recreational	Reported illegal	Unreported illegal	Customary
350	82.8	0	30	10

Vulnerable biomass in the assessment model was determined by the MLS, selectivity, relative sex and seasonal vulnerability and berried state for mature females. All mature females were assumed to be berried (and not vulnerable to the fishery) in AW and not berried (and vulnerable) in SS.

Base case results suggested that biomass decreased to a low level in the late 1980s, remained low through to about 1995, and then increased (Figure 4) to a peak around 2010. The current vulnerable stock size (AW) is about twice the reference biomass and the spawning stock biomass is well above B_{MSY} (Table 12). However, projected biomass would decrease at the level of current catches over the next four years (Figure 4).

A series of MCMC sensitivity trials was also made, including exclusion of puerulus data, using an alternative (higher) recreational catch vector, wider CVs on the growth priors, stronger CVs on the CPUE indices (to obtain a better fit), and a descending right-hand limb to the selectivity functions. The assessment results from the base case and sensitivity trials calculated as a series of agreed indicators (Table 11) are shown in Table 12.

Table 11: Performance indicators used in the CRA 5 stock assessment (SL = size limited fishery; AW = autumn–winter season; SS = spring–summer season).

Reference points	**Description**
B_{MIN}	The lowest beginning AW vulnerable biomass in the series
B2015	Beginning of season AW vulnerable biomass for 2015
B_{REF}	Beginning of AW season mean vulnerable biomass for 1979–81
B2018	Projected beginning of season AW vulnerable biomass in 2018
B_{MSY}	Beginning of season AW vulnerable biomass associated with MSY, calculated by doing deterministic forward projections with recruitment *R0* and current fishing patterns
MSY	Maximum sustainable yield (sum of AW and SS SL catches) found by searching a across a range of multipliers on *F*.
Fmult	The multiplier that produced MSY
SSB2015	Current spawning stock biomass at start of AW season
SSB2018	Projected spawning stock biomass at start of AW season
SSB_{MSY}	Spawning stock biomass at start of AW season associated with MSY
CPUE indicators	**Description**
CPUE2014	CPUE predicted for AW 2014
CPUE2018proj	CPUE predicted for AW 2018
CPUEmsy	CPUE at B_{MSY}
Performance indicators	**Description**
$B2015 / B_{MIN}$	ratio of *B2015* to B_{MIN}
$B2015/ B_{REF}$	ratio of *B2015* to B_{REF}
$B2015 / B_{MSY}$	ratio of *B2015* to B_{MSY}
B2018 / B2015	ratio of *B2018* to *B2015*
$B2018/ B_{REF}$	ratio of *B2018* to B_{REF}
$B2018/ B_{MSY}$	ratio of *B2018* to B_{MSY}
$SSB2015/ SSB_0$	ratio of *SSB2015* to SSB_0
$SSB2018/ SSB_0$	ratio of *SSB2018* to SSB_0
$SSB2015/SSB_{MSY}$	ratio of *SSB2015* to SSB_{MSY}
$SSB2018/SSB_{MSY}$	ratio of *SSB2018* to SSB_{MSY}
SSB2015/SSB2015	ratio of *SSB2018* to *SSB2015ent*
USL2015	The 2015 exploitation rate for SL catch in AW
Performance indicators	**Description**
USL2018/USL2015	ratio of SL 2018 exploitation rate to 2015 SL exploitation rate
Btot2014	total biomass in 2014

Ntot2014	total numbers in 2014
Btot0	total biomass without fishing
Ntot0	total numbers without fishing

Probabilities	**Description**
P$(B2015 > B_{MIN})$	probability $B2015 > B_{MIN}$
P$(B2015 > B_{REF})$	probability $B2015 > B_{REF}$
P$(B2015 > B_{MSY})$	probability $B2015 > B_{MSY}$
P$(B2018 > B_{MIN})$	probability $B2018 > B_{MIN}$
P$(B2018 > B_{REF})$	probability $B2018 > B_{REF}$
P$(B2018 > B_{MSY})$	probability $B2018 > B_{MSY}$
P$(B2018 > B2015)$	probability $B2018 > B2015$
P$(SSB2015>SSB_{MSY})$	probability $SSB2015>SSB_{MSY}$
P$(SSB2018>SSB_{MSY})$	probability $SSB2015>SSB_{MSY}$
P$(USL2018>USL2015)$	probability SL exploitation rate *2018* > SL exploitation rate *2015*
P$(SSB2015<0.2\ SSB_0)$	soft limit CRA 8: probability $SSB2015<$ 20% SSB_0
P$(SSB2018<0.2\ SSB_0$	soft limit CRA 8: probability $SSB2018$ < 20% SSB_0
P$(SSB2015\ <0.1\ SSB_0)$	hard limit CRA 8: probability $SSB2015<$ 10% SSB_0
P$(SSB2018<0.1\ SSB_0)$	hard limit CRA 8: probability $SSB2018<$ 10% SSB_0

Indicators based on vulnerable biomass (AW) and B_{MSY}

In the base case and for all trials, current and projected biomass levels were larger than B_{REF} and B_{MSY} reference levels by substantial amounts for both catch projection scenarios (Table 12). Projected biomass decreased in most runs but remained well above the reference levels in the base case and for all trials.

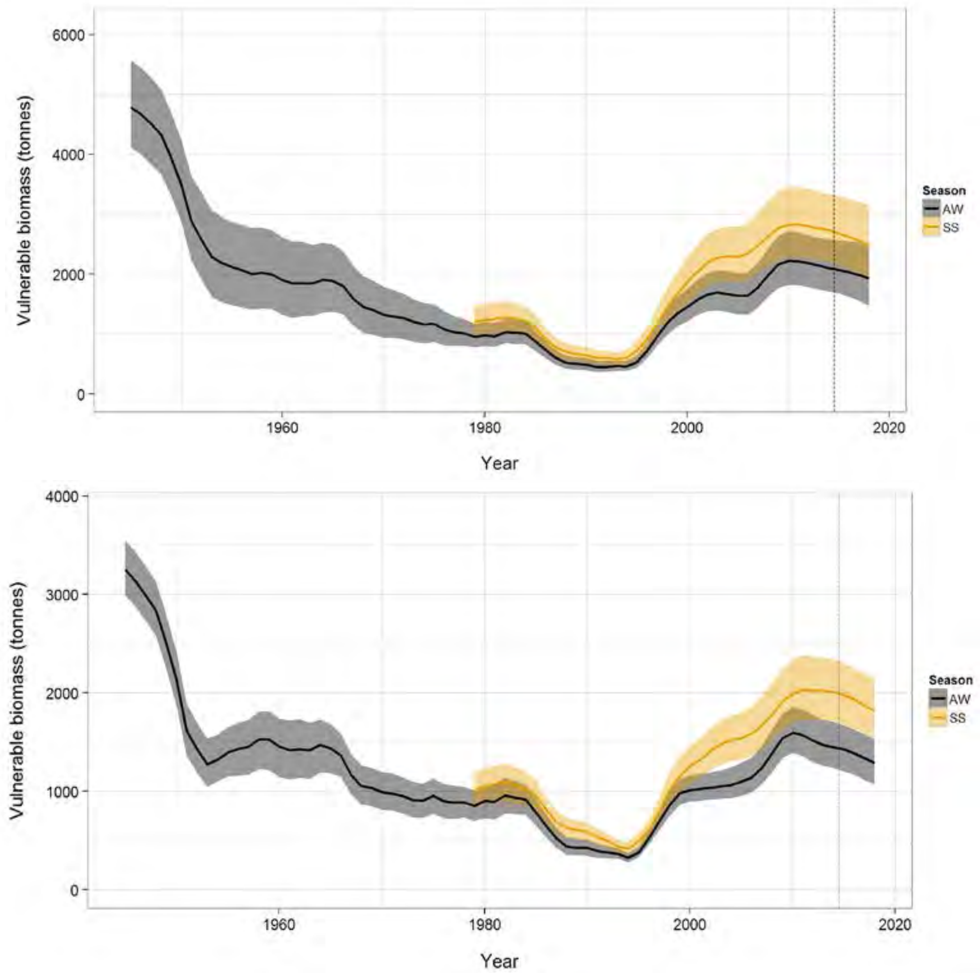


Figure 4: Posterior distributions of the two base case MCMCs biomass vulnerable trajectory (without (top) and with (bottom) density-dependence [DD]). Before 1979 there was a single time step, shown in AW. The trajectory to the right of the vertical dotted catches are projections based on the catches in Table 10. For each year the horizontal line represents the median and the coloured envelope represents the 5% and 95% quantiles.

Indicators based on SSB_{MSY}

SSB_{MSY} is biomass of mature females associated with B_{MSY}. The historical track of biomass versus fishing intensity is shown in Figure 5. The phase space in the plot shows biomass on the x-axis and fishing intensity on the y-axis. High biomass/low intensity is in the lower right-hand corner, the location of the stock when fishing first began, and low biomass/high intensity is in the upper left-hand corner, in a period when the fishery was largely uncontrolled. Note that fishing patterns include MLS, selectivity and the seasonal catch split and that *Fmsy* varies in each year because fishing patterns change. The reference SSB_{MSY} in Figure 5 has been calculated using the 2014 fishing pattern.

In 1945, the fishery was near the lower right-hand corner of the plot, in the high biomass/low fishing intensity region. It climbed towards the low biomass/high intensity region, reaching highest fishing intensity in 1985 and lowest biomass in 1989–91. After 1991, the fishery moved quite steadily back towards lower fishing intensity and higher biomass. The current biomass on this scale is near that of 1951, and current fishing intensity is near that of 1952.

Table 12: Assessment results –medians of indicators described in Table 11 from the base case and sensitivity trials under catches given in the lower part of the table shows the probabilities that events are true (DD = density-dependence). The last four models were all run without density-dependence. [Continued on next page]

Indicator	Base case: no DD	Base case: with DD	Base case: no DD and no puerulus	Base case: with DD and no puerulus	Alternative recreational catch	Estimate R-H selectivity	Growth prior CV=30%	Double weight to CPUE series
B_{MIN}	438.8	323.9	425.9	319.1	431.6	450.3	370.3	378.0
B2015	2 070.0	1 428.8	2 086.2	1 373.1	2 019.0	2 020.2	1 650.7	1 686.0
B_{REF}	871.0	788.6	841.2	744.7	857.5	903.6	760.2	755.2
B2018	1 935.6	1 290.3	2 250.7	1 257.9	1 844.6	1 869.0	1 548.4	1 594.4
B_{MSY}	505.2	483.6	503.8	481.9	517.1	568.3	474.6	498.1
MSY	536.6	560.1	545.3	564.5	540.2	591.6	504.2	494.5
Fmult	6.18	4.78	6.30	4.72	5.17	6.01	4.93	4.66
SSB2015	2 926.2	2 250.3	3 022.4	2 195.8	2 867.6	3 556.2	2 406.1	2 541.6
SSB2018	2 669.6	2 018.0	3 139.5	2 016.8	2 574.5	3 313.0	2 218.0	2 335.5
SSB_{MSY}	1 500.4	1 094.2	1 511.8	1 086.8	1 456.2	1 736.2	1 267.6	1 411.4
CPUEcurrent	1.54	1.54	1.54	1.52	1.53	1.49	1.50	1.46
CPUEproj	1.40	1.36	1.68	1.35	1.34	1.33	1.36	1.36
CPUEmsy	0.267	0.362	0.266	0.364	0.291	0.296	0.311	0.318
$B2015/B_{MIN}$	4.74	4.40	4.90	4.27	4.65	4.47	4.43	4.42
$B2015/B_{REF}$	2.40	1.82	2.51	1.84	2.36	2.25	2.16	2.22
$B2015/B_{MSY}$	4.11	2.94	4.14	2.85	3.89	3.57	3.46	3.41
B2018/B2015	0.92	0.90	1.07	0.92	0.91	0.92	0.93	0.94
$B2018/B_{REF}$	2.22	1.65	2.69	1.68	2.12	2.05	2.02	2.11
$B2018/B_{MSY}$	3.84	2.67	4.46	2.62	3.53	3.27	3.25	3.20
$SSB2015/SSB_0$	0.781	0.970	0.805	0.965	0.751	0.779	0.701	0.702
$SSB2018/SSB_0$	0.707	0.871	0.837	0.888	0.668	0.720	0.649	0.642
$SSB2015/SSB_{MSY}$	1.96	2.05	2.00	2.02	1.97	2.05	1.89	1.81
$SSB2018/SSB_{MSY}$	1.78	1.84	2.08	1.86	1.75	1.90	1.74	1.66
SSB2018/SSB2015	0.905	0.897	1.032	0.918	0.889	0.928	0.921	0.916
USL2014	0.113	0.164	0.115	0.170	0.118	0.115	0.142	0.140
USL2018	0.123	0.184	0.106	0.189	0.132	0.127	0.154	0.149
USL2018/USL2014	1.10	1.12	0.93	1.11	1.12	1.11	1.10	1.07
Btot2015	6 986.9	5 193.8	7 448.8	5 109.5	6 835.4	8 463.3	5 558.3	5 952.1
Btot2015/Btot0	0.673	0.668	0.720	0.667	0.645	0.668	0.577	0.588
Ntot2015	16 854 400	12 830 400	19 078 650	12 767 250	16 562 000	18 648 300	13 185 100	14 581 600
Ntot2015/Ntot0	0.832	0.698	0.927	0.699	0.823	0.829	0.771	0.781
$P(B2015> B_{MIN})$	1	1	1	1	1	1	1	1
$P(B2015> B_{REF})$	1	1	1	1	1	1	1	1
$P(B2015> B_{MSY})$	1	1	1	1	1	1	1	1
$P(B2018> B_{MIN})$	1	1	1	1	1	1	1	1
$P(B2018> B_{REF})$	1	0.999	1	1	1	1	1	1
$P(B2018> B_{MSY})$	1	1	1	1	1	1	1	1
$P(B2018>B2015)$	0.188	0.026	0.726	0.081	0.133	0.189	0.24	0.281

Indicator	Base case: no DD	Base case: with DD	Base case: no DD and no puerulus	Base case: with DD and no puerulus	Alternative recreational catch	Estimate R-H selectivity	Growth prior CV=30%	Double weight to CPUE series
P($SSB2015>SSB_{MSY}$)	1	1	1	1	1	1	1	1
P($SSB2018>SSB_{MSY}$)	1	1	1	1	1	1	1	1
P($USL2018>USL2014$)	0.822	0.985	0.281	0.956	0.871	0.833	0.788	0.705
P($SSB2015<0.2\ SSB_0$)	0	0	0	0	0	0	0	0
P($SSB2018<0.2\ SSB_0$)	0	0	0	0	0	0	0	0
P($SSB2015<0.1SSB0$)	0	0	0	0	0	0	0	0
P($SSB2018<0.1\ SSB_0$)	0	0	0	0	0	0	0	0

Two alternative base case models were investigated for CRA 5: one that assumed that growth was faster at low abundance (density-dependent growth) and another that assumed a constant average growth rate regardless of abundance. The model that assumed density-dependent growth had lower productivity and smaller average biomass than the model without density-dependence. However, biomass at the end of 2015–16 was estimated by both models to be well above all reference points (B_{MIN}, B_{MSY} and B_{REF}), with a nearly certain expectation that biomass would remain above these reference points at the end of the next four years. However, both models predict with a high probability (about 90%) that biomass will have declined by the end of the four-year projection period.

Future research considerations

- For the new growth analysis:
  - Investigate potential seasonal effects such as seasonal patterns in growth and the probability of recapture;
  - Modify the ‘Q’ matrix (matrix of similarities between areas) to determine how much assumptions about similarities matter;
  - Further work with alternative error distributions would be useful;
  - Explore the utility of contamination models.
- Recreational catch estimates are highly uncertain and improving them should be a high priority for the future. Estimates of illegal catch are also large and uncertain.
- CPUE is used as a continuous series from 1979 to 2014, yet there have been substantial technological changes over that time; the potential effects of changes in CPUE should be investigated by breaking the series in one or two places – e.g., around 1992 or 1993, when the species was introduced into the Quota Management System and when GPS began to be widely used.
- Plot the expected growth increment as a function of $\%SSB_0$, in order to determine the effect of density-dependence.
- There are few data available to estimate *a50* for females in the first epoch; therefore, examine alternative approaches other than estimating it – e.g., setting the value to the same as that estimated for the second epoch.
- Estimates of the size-at-maturity are uncertain; consider conducting a maturity ogive meta-analysis using all rock lobster data.
- Examine the effect of returning large females in influencing sex ratios.
- Examine the sensitivity of the model to the assumption of 10% mortality for rock lobsters returned to the sea.

(a) Base case without DD **(b) Base case with DD**

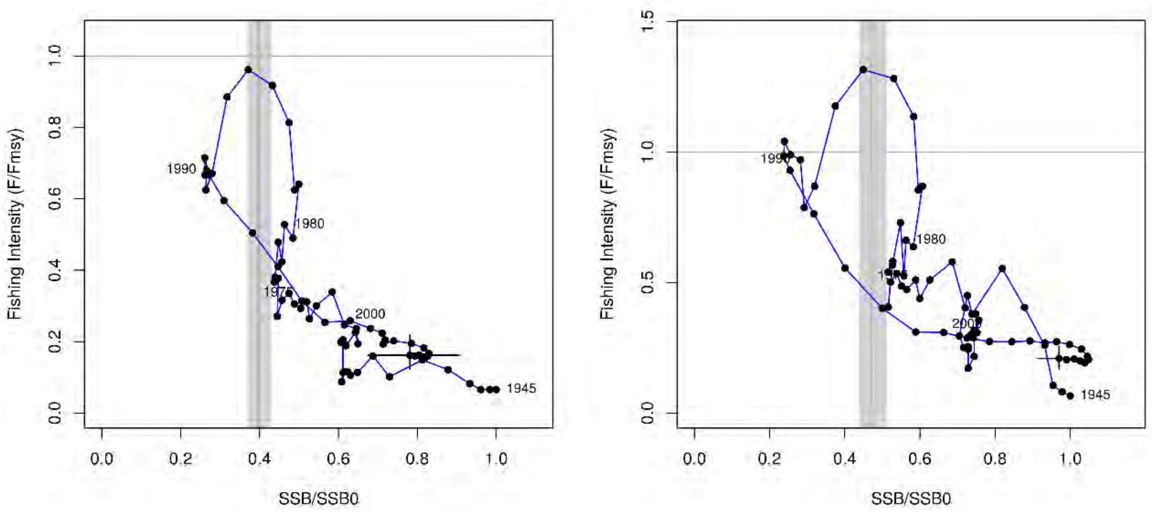


Figure 5: Phase plots that summarise the history of the CRA 5 fishery for the two base cases. The x-axis is the spawning biomass (*SSB*) as a proportion of B_0 (SSB_0); the y-axis is the ratio of the fishing intensity (F) relative to Fmsy. Each point is the median of the posterior distributions, and the bars associated with 2009 show the 90% confidence intervals. The vertical reference line shows SSB_{MSY} as a proportion of SSB_0, with the grey band indicating the 90% confidence interval. The horizontal reference line is F_{MSY}.

6.4 CRA 7 and CRA 8

This section describes stock assessments for CRA 7 and CRA 8 conducted in 2015.

Model structure

A two-stock version of the multi-stock length-based model (MSLM) (Haist et al. 2009) was fitted to data from CRA 7 and CRA 8: seasonal standardised CPUE from 1979–2014, older catch rate data (CR), length frequencies from observer and voluntary (logbook) catch sampling, and tag-recapture data. Puerulus settlement data are available from Halfmoon Bay, Chalky Inlet and Jackson Bay for different periods, but they showed differing trends. Because the puerulus indices appeared to have limited predictive power in the 2012 assessment, they were not used. The model used an annual time step from 1963 through to 1978 and then switched to a seasonal time step with autumn–winter (AW, April through to September) and spring–summer (SS, October through to March) from 1979 through 2014. The model had 93 length bins, 31 for each sex group (males, immature and mature females), each 2 mm TW wide, beginning at left-hand edge 30 mm TW.

Significant catches occurred in the historical series for both CRA 7 and CRA 8 before the beginning of the model and the reconstruction assumed that the population began from an exploited state. MLS and escape gap regulations in place at the beginning of the reconstruction differed from the current ones. To accommodate these differences, the model incorporated stock-specific time series of MLS regulations by sex and modelled escape gap regulation changes by estimating separate selectivity functions before 1993. The model simulated the return of large legal lobsters to the sea in CRA 8, where this practice is prevalent. Smaller males are retained in preference to larger males, and the model used annual fitted retention curves from 2000 onwards to simulate this in the fishing dynamics. Data and their sources are listed in Table 13.

Historical and recent recreational catch surveys were examined and the stock assessment assumed that recreational catch was constant from 1979 (see Section 1.2) and that it increased linearly from 20% of the 1979 value in 1945 up to the 1979 value.

Table 13: Data types and sources for the 2015 assessment for CRA 7 and CRA 8. Year codes are from the first nine months of each fishing year, i.e., 1998–99 is called 1998. N/A – not applicable or not used; NZ RLIC – NZ Rock Lobster Industry Council; FSU: Fisheries Statistics Unit; CELR: catch and effort landing returns.

		CRA 7		CRA 8	
Data type	**Data source**	**Begin year**	**End year**	**Begin year**	**End year**
CPUE	FSU & CELR	1979	2014	1979	2014
Older catch rate (CR)	Annala & King (1983)	1963	1973	1963	1973
Observer proportions-at-size	Fisheries New Zealand and NZ RLIC	1988	2014	1987	2010
Logbook proportions-at-size	NZ RLIC	N/A	N/A	1993	2014
Tag recovery data	NZ RLIC & MFish	1965	2013	1966	2011
Historical MLS regulations	Annala (1983), Fisheries New Zealand	1974	2014	1974	2014
Escape gap regulation changes	Annala (1983), Fisheries New Zealand	1974	2014	1974	2014
Puerulus settlement (not used)	Fisheries New Zealand	1990	2014	1980	2014
Retention	NZ RLIC	N/A	N/A	2000	2014

The initial populations in 1963 were assumed to be in equilibrium with estimated exploitation rates for each stock. Each season, numbers of male, immature female and mature female lobsters in each size class were updated as a result of:

a) **Recruitment:** Each year, new recruits to the model were added equally for each sex for each season for each stock, as a normal distribution with a mean size (32 mm) and standard deviation (2 mm), truncated at the smallest size class (30 mm). Recruitment in a specific year was determined by the parameters for base recruitment and parameters for the deviations from base recruitment; all recruitment parameters were stock-specific. The vector of recruitment deviations in natural log space was assumed to be normally distributed with a mean of zero. Recruitment deviations were estimated for 1963 through to 2012. It was assumed that stock size has no influence on recruitment because of the long duration of the pelagic larval phase coupled with long-distance movements during this phase.

b) **Mortality:** Natural, fishing and handling mortalities were applied to each sex category in each size class. Natural mortality was assumed to be constant and independent of sex and length; a value was estimated for each stock. Fishing mortality was determined from observed catch and model biomass in each stock, modified by legal sizes, sex-specific vulnerabilities and selectivity curves in each stock and, for CRA 8, retention curves for 2000 and later. Handling mortality was assumed to be 10% for fish returned to the water. Two fisheries were modelled for each stock: one that operated only on fish above the size limit, excluding berried females (SL fishery – including legal commercial and recreational) and one that did not respect size limits and restrictions on berried females (NSL fishery – all of the illegal fishery plus the Maori customary fishery). Selectivity and vulnerability functions were otherwise the same for the SL and NSL fisheries. Vulnerability in each stock by sex category and season was estimated relative to males in AW, which were assumed to have the highest vulnerability. Instantaneous fishing mortality rates for each fishery were calculated using Newton-Raphson iterations (four iterations) based on catch and model biomass.

c) **Fishery selectivity:** A three-parameter fishery selectivity function was assumed, with parameters for each stock describing the shapes of the ascending and descending limbs and the size at maximum selectivity. Changes in MLS and escape gap regulations were accommodated for CRA 8 only (in CRA 7 there have been no MLS changes) by estimating selectivity in two separate epochs, pre-1993 and 1993–2014. As in all recent stock assessments the descending limb of the selectivity curve was fixed to prevent underestimation of selectivity of large lobsters.

d) **Growth and maturation:** For each size class and sex category in each stock, a growth transition matrix specified the probability of an individual remaining in the same size class or growing into each of the other size classes. The growth parameters for shape, CV and observation error were estimated with priors based on exploratory fits using only the growth model (Webber, unpublished data); these stabilised the estimation considerably. Maturation of females was estimated as a two-parameter logistic curve from the maturity-at-size information in the size-frequency data. Maturation parameters were estimated as common parameters for both stocks (all other estimated parameters were stock-specific).

e) **Movements between stocks:** For each year from 1985–2014, the model estimated the proportion of fish of sizes 45–60 mm TW that moved each season from CRA 7 to CRA 8. Mean movement was assumed for all other years.

Model fitting:
A total negative log likelihood function was minimised using AD Model Builder™. The model was fitted to standardised CPUE and CR using lognormal likelihood, to proportions-at-length with multinomial likelihood and to tag-recapture data with normal likelihood after removal of outliers based on tag-only fits. For the CPUE lognormal likelihoods, CVs for each index value were initially set at the standard error from the GLM analysis. Process error was subsequently added to these CVs.

Proportions-at-length, assumed to be representative of the commercial catch, were available (see Table 13) from observer catch sampling and voluntary logbooks: data were summarised by area/month strata and weighted by the commercial catch taken in each stratum, the number of lobsters measured and the number of days sampled. Size data from each source were fitted separately. Seasonal proportions-at-length summed to one across each sex category. These data were weighted within the model using the method of Francis (2011).

In the base case, it was assumed that biomass was proportional to CPUE, that growth was not density-dependent but for CRA 8 had changed between the pre-1993 and 1993 onwards periods, there was no stock-recruit relationship and there was migration between CRA 7 and CRA 8, involving fish 45–60 mm TW. Base case explorations involved experimentally weighting the datasets and inspecting the resulting standard deviations of normalised residuals and medians of absolute residuals, exploring the effect of the start year (1963 was chosen), exploring the effect of excluding SS length-frequency data from CRA 7 (it was not excluded), and changing the prior on *M* (a prior with a smaller CV was chosen).

Parameters estimated in the base case and their priors are provided in Table 14. Fixed parameters and their values are given in Table 15.

Table 14: Parameters estimated and priors used in the base case assessments for CRA 7 and CRA 8. Prior type abbreviations: U – uniform; N – normal; L – lognormal.

Parameter	Prior type	Number of parameters	Bounds	Mean	SD	CV
ln(*R0*) (mean recruitment)	U	2	1–25	–	–	–
M (natural mortality)	L	2	0.01–0.35	0.12	–	0.10
Initial exploitation rate	U	2	0.00–0.99	–	–	–
Recruitment deviations	N [1]	100	-2.3–2.3	0	0.4	
ln(*qCPUE*)	U	2	-25–0	–	–	–
ln(*qCR*)	U	2	-25-2.0	–	–	–
Increment at TW=50 (male & female)	U	6	1–20	–	–	–
ratio of TW=80 increment at TW=50 (male & female)	U	6	0.001–1.000	–	–	–
shape of growth curve (male)	N	2	0.1–15.0	4.812	0.384	–
shape of growth curve (female)	N	2	0.1–15.0	4.508	0.236	
growth CV (male)	N	2	0.01–5.0	0.587	0.0076	
growth CV (female)	N	2	0.01–5.0	0.820	0.0131	
growth observation error (male and female)	N	1	1E-5-10.0	1.482	0.0152	
TW at 50% probability female maturation	U	1	30–80	–	–	–
difference between TWs at 95% and 50% probability female maturation	U	1	3–60	–	–	–
Relative vulnerability (all sexes and seasons)	U	8	0.01–1.0	–	–	–
Shape of selectivity left limb (males & females)	U	6	1–50	–	–	–
Size at maximum selectivity (males & females)	U	6	30–70	–	–	–
Movement parameters	U	30	0.00–0.50	–	–	–

[1] Normal in natural log space = lognormal (bounds equivalent to –10 to 10).

Table 15: Fixed values used in base case assessment for CRA 7 and CRA 8.

Value	CRA 7	CRA 8
Shape parameter for CPUE vs biomass	1.0	1.0
Minimum std. dev. of growth increment	0.001	0.001
Handling mortality	10%	10%
Process error for CPUE	0.25	0.25
process error for CR	0.3	0.3
Year of selectivity change	1993	1993
Current male size limit (mm TW)	47	54
Current female size limit (mm TW)	49	57
First year for recruitment deviations	1963	1963
Last year for recruitment deviations	2012	2012
Relative weight for male length frequencies	0.227	1.849
Relative weight for immature female LFs	0.239	5.145
Relative weight for mature female LFs	0.422	1.272
relative weight for proportion-at-sex	3.645	3.645
Relative weight for CPUE	1.251	1.251
relative weight for CR	1.062	1.062
Relative weight for tag-recapture data*	1	1
length-weight intercept (male)	3.39E-6	3.39E-6
length-weight intercept (female)	1.04E-5	1.04E-5
length-weight slope (male)	2.9665	2.9665
length-weight slope (female)	2.6323	2.6323

* For CRA 7 the weight for tag-recapture data was increased by doubling the dataset.

Model projections

Bayesian estimation procedures were used to estimate the uncertainty in model estimates and short-term projections. This procedure was conducted in the following steps:

1. Model parameters were estimated by AD Model Builder™ using maximum likelihood and the prior probabilities. The point estimates are called the MPD (mode of the joint posterior) estimates.
2. Samples from the joint posterior distribution of parameters were generated with Markov chain Monte Carlo (MCMC) simulations using the Hastings-Metropolis algorithm; five million simulations were made starting from the base case MPD and 1000 samples were saved.
3. From each sample of the posterior, four-year projections (2015–18) were generated using the 2014 catches, with annual recruitment randomly sampled from the model's estimated recruitments from 2003–12, and with annual movement resampled from the estimated values.

Performance indicators and results

The definition of the 'current fishing pattern', used to calculate MSY statistics, was modified to include the retention pattern. That is, for CRA 8 the estimated 2015 retention pattern was included in the definition of *Fmsy* (for other CRA QMAs retention is assumed to be 1, so does not influence *Fmsy*). This is somewhat anomalous because fishing at *Fmsy* would result in lower biomass and it would be expected that there would be full retention of all legal rock lobster. The alternative, to ignore retention in the definition of *Fmsy*, is also problematic because it results in the conclusion that the current fishing intensity exceeds *Fmsy* (which is not the case because greater than 40% of the biomass of legal rock lobster is returned to the sea). The retention pattern was not included in the definitions of 'vulnerable biomass' used to calculate B_{MSY} and B_{REF}, because that would also lead to inconsistency between the retention pattern used to define those reference levels and the retention pattern expected at the biomass levels.

Vulnerable biomass in the assessment model was determined by the MLS, selectivity, relative sex and seasonal vulnerability and berried state for mature females. All mature females were assumed to be berried (ovigerous) and not legally available to the fishery in AW and not berried, thus vulnerable, in SS.

Agreed indicators are summarised in Table 16.

For CRA 7, base case results (Figure 6 and Table 17) suggested that AW biomass decreased to a low point in 1997, increased to a high in the late 2000s, decreased and then increased again. *B2015* was about twice B_{REF}. Median projected biomass was 8% less than current biomass at the level of current catches over the next four years, but indicators remained above reference levels. Neither current nor projected biomass was anywhere near the soft limit. Note that MSY from CRA 7 was estimated as a high proportion of B_{MSY}, thus that fishing intensity *Fmsy* is very high.

For CRA 8, base case results (Figure 7 and Table 18) suggested that AW biomass decreased to a low point in 1990, remained relatively low until 2000, then increased strongly and has remained relatively high. *B2015* was well above B_{MSY} and 35% above B_{REF} (mean biomass for 1979–81). Biomass was projected to remain about the same in four years at the current level of catches and was projected to remain well above both B_{REF} and B_{MSY}. Spawning biomass was a high proportion (43%) of the unfished level. Neither current nor projected biomass was anywhere near the soft limit.

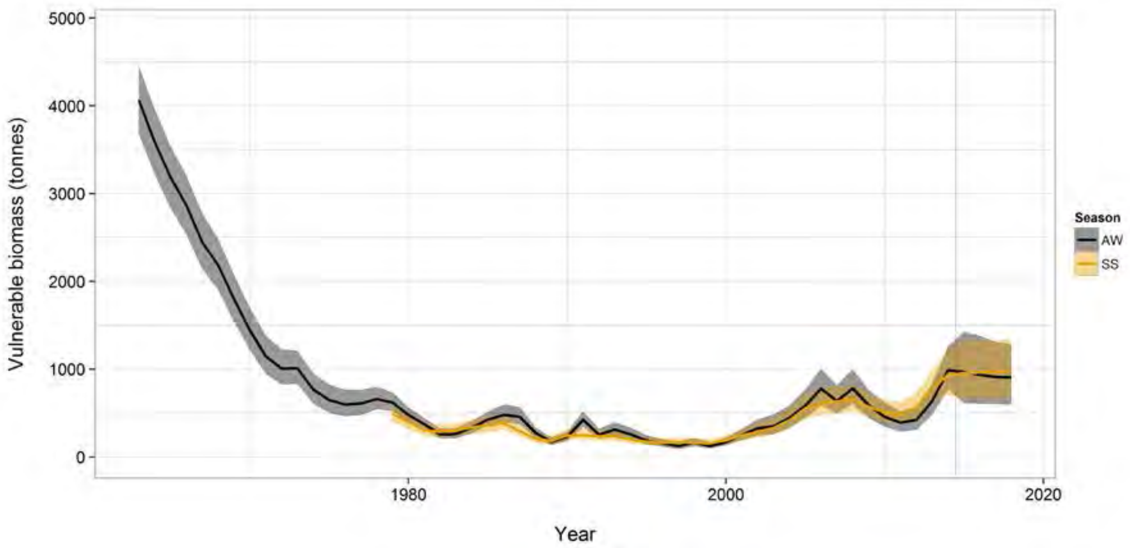


Figure 6: Posterior distribution of the CRA 7 base case MCMC vulnerable biomass trajectory. Before 1979 there was a single time step, shown in AW. The shaded areas span the 5th and 95th quantiles.

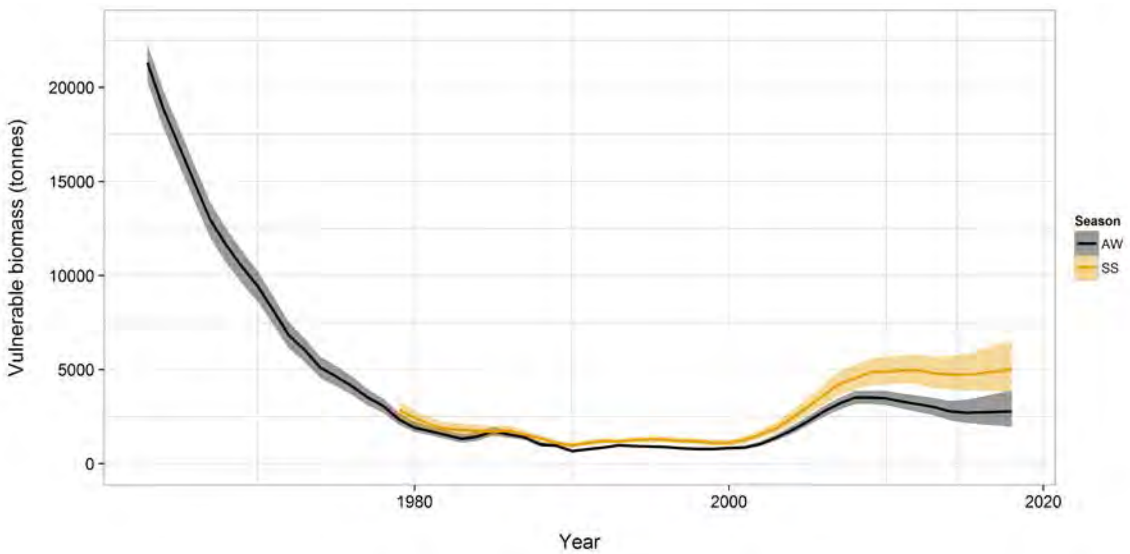


Figure 7: Posterior distribution of the CRA 8 base case MCMC vulnerable biomass trajectory. Before 1979 there was a single time step, shown in AW. The shaded areas span the 5th and 95th quantiles.

Table 16: Performance indicators used in the CRA 7 and CRA 8 stock assessments.

Reference points	**Description**
B_{MIN}	The lowest beginning AW vulnerable biomass in the series
B2015	Beginning of season AW vulnerable biomass for 2015
B_{REF}	Beginning of AW season mean vulnerable biomass for 1979–81
B2018	Projected beginning of season AW vulnerable biomass in 2018
B_{MSY}	Beginning of season AW vulnerable biomass associated with MSY, calculated by doing deterministic forward projections with recruitment *R0* and current fishing patterns
MSY	Maximum sustainable yield (sum of AW and SS SL catches) found by searching a across a range of multipliers on *F*.
Fmult	The multiplier that produced MSY
SSB2015	Current spawning stock biomass at start of AW season
SSB2018	Projected spawning stock biomass at start of AW season
SSB_{MSY}	Spawning stock biomass at start of AW season associated with MSY
CPUE indicators	**Description**
CPUE2014	CPUE predicted for AW 2014
CPUE2018proj	CPUE predicted for AW 2018
CPUEmsy	CPUE at B_{MSY}
Performance indicators	**Description**
$B2015 / B_{MIN}$	ratio of *B2015* to B_{MIN}
$B2015/ B_{REF}$	ratio of *B2015* to B_{REF}
$B2015 / B_{MSY}$	ratio of *B2015* to B_{MSY}
B2018 / B2015	ratio of *B2018* to *B2015*
$B2018/ B_{REF}$	ratio of *B2018* to B_{REF}
$B2018/ B_{MSY}$	ratio of *B2018* to B_{MSY}
$SSB2015/ SSB_0$	ratio of *SSB2015* to SSB_0
$SSB2018/ SSB_0$	ratio of *SSB2018* to SSB_0
$SSB2015/SSB_{MSY}$	ratio of *SSB2015* to SSB_{MSY}
$SSB2018/SSB_{MSY}$	ratio of *SSB2018* to SSB_{MSY}
SSB2015/SSB2015	ratio of *SSB2018* to *SSBcurrent*
USL2015	The 2015 exploitation rate for SL catch in AW
USL2018	2018 exploitation rate for SL catch in AW
USL2018/USL2015	ratio of SL 2018 exploitation rate to 2015 SL exploitation rate
Btot2014	total biomass in 2014
Ntot2014	total numbers in 2014
Btot0	total biomass without fishing
Ntot0	total numbers without fishing
Probabilities	**Description**
$P(B2015 > B_{MIN})$	probability $B2015 > B_{MIN}$
$P(B2015 > B_{REF})$	probability $B2015 > B_{REF}$
$P(B2015 > B_{MSY})$	probability $B2015 > B_{MSY}$
$P(B2018 > B_{MIN})$	probability $B2018 > B_{MIN}$
$P(B2018 > B_{REF})$	probability $B2018 > B_{REF}$
$P(B2018 > B_{MSY})$	probability $B2018 > B_{MSY}$
$P(B2018 > B2015)$	probability $B2018 > B2015$
$P(SSB2015>SSB_{MSY})$	probability $SSB2015>SSB_{MSY}$
$P(SSB2018>SSB_{MSY})$	probability $SSB2015>SSB_{MSY}$
$P(USL2018>USL2015)$	probability SL exploitation rate *2018* > SL exploitation rate *2015*
$P(SSB2015<0.2\ SSB_0)$	soft limit CRA 8: probability $SSB2015< 20\%\ SSB_0$
$P(SSB2018<0.2\ SSB_0$	soft limit CRA 8: probability $SSB2018 < 20\%\ SSB_0$
$P(SSB2015 <0.1\ SSB_0)$	hard limit CRA 8: probability $SSB2015< 10\%\ SSB_0$
$P(SSB2018<0.1\ SSB_0)$	hard limit CRA 8: probability $SSB2018< 10\%\ SSB_0$
$P(B2015 <50\%\ B_{REF})$	soft limit CRA 7: probability $B2015 < 50\%\ B_{REF}$
$P(B2015 <25\%\ B_{REF})$	hard limit CRA 7: probability $B2015 < 25\%\ B_{REF}$
$P(B2018<50\%\ B_{REF})$	soft limit (CRA 7): probability $B2015 < 50\%\ B_{REF}$
$P(B2018<25\%\ B_{REF})$	hard limit (CRA 7): probability $B2015 < 25\%\ B_{REF}$

MCMC sensitivity trials were also run:

- *d-d*: estimating growth density-dependence, and using a single tag data file for CRA 8 instead of two (as in the base case);
- *wideG*: using priors on the growth parameters for shape, CV and observation error with CVs that were 30% of the mean;
- *noMoves*: with no estimated movements from CRA 7 to CRA 8;
- *rawLFs*: using the calculated weights on length-frequency records, instead of truncating them between 1 and 10;
- *wideM*: with the CV of the prior on *M* 0.40 instead of 0.10.

Results from base case and sensitivity trials are compared for CRA 7 (Table 17) and CRA 8 (Table 18).

Table 17: Assessment results: median and probability indicators for CRA 7 from the base case MCMC and sensitivity trials; biomass in t and CPUE in kg/pot.

	Base median	d-d median	wideG prior median	noMoves median	rawLFs median	wideM prior median
B_{MIN}	114.7	118.3	102.8	125.9	113.2	104.1
B2015	965.7	994.4	755.1	931.2	940.3	962.3
B_{REF}	489.2	510.3	443.3	455.7	477.6	453.1
B2018	905.3	858.7	604.3	1 118.5	891.1	916.8
B_{MSY}	241.1	268.0	265.5	770.9	232.0	223.4
MSY	192.1	208.6	248.7	219.5	187.9	183.6
Fmult	15.2	15.2	15.2	3.25	15.2	15.2
SSB2014	413.5	419.6	464.1	505.7	400.1	427.3
SSB2018	575.1	567.0	541.1	723.0	568.2	636.2
SSB_{MSY}	43.1	50.2	74.9	660.8	39.4	43.3
CPUE2014	2.121	2.172	2.088	1.911	2.112	2.254
CPUE2018	1.900	1.724	1.360	2.658	1.966	2.206
CPUEmsy	0.375	0.412	0.463	1.700	0.367	0.387
$B2015/B_{MIN}$	8.440	8.251	7.282	7.386	8.374	9.263
$B2015/B_{REF}$	1.974	1.940	1.712	2.050	1.956	2.130
$B2015/B_{MSY}$	4.002	3.719	2.873	1.220	4.042	4.345
B2018/B2015	0.925	0.851	0.789	1.202	0.946	0.948
$B2018/B_{REF}$	1.833	1.677	1.384	2.463	1.861	2.021
$B2018/B_{MSY}$	3.697	3.180	2.300	1.465	3.831	4.126
$SSB2014/SSB_0$	0.167	0.178	0.222	0.191	0.161	0.134
$SSB2018/SSB_0$	0.234	0.244	0.257	0.273	0.229	0.195
$SSB2014/SSB_{MSY}$	9.577	8.266	6.209	0.760	10.149	10.084
$SSB2018/SSB_{MSY}$	13.307	10.982	7.276	1.087	14.416	14.905
SSB2018/SSB2014	1.384	1.346	1.153	1.423	1.411	1.513
USL2014	0.048	0.046	0.053	0.060	0.050	0.052
USL2018	0.076	0.080	0.113	0.061	0.077	0.075
USL2018/USL2014	1.575	1.758	2.129	1.030	1.500	1.424
Btot2014	2 445.7	2 723.1	3 561.0	1 777.7	2 315.2	2 343.9
Btot2014/Btot0	0.320	0.369	0.540	0.232	0.304	0.254
Ntot2014	7.7E+06	9.0E+06	1.4E+07	4.4E+06	7.3E+06	7.3E+06
Ntot2014/Ntot0	0.661	0.681	0.815	0.468	0.648	0.581
$P(B2015> B_{MIN})$	1.000	1.000	1.000	1.000	1.000	1.000
$P(B2015> B_{REF})$	0.998	0.999	0.994	1.000	0.998	1.000
$P(B2015> B_{MSY})$	1.000	1.000	1.000	0.934	1.000	0.997
$P(B2018> B_{MIN})$	1.000	1.000	1.000	1.000	1.000	1.000
$P(B2018> B_{REF})$	0.991	0.981	0.911	1.000	0.996	0.998
$P(B2018> B_{MSY})$	1.000	1.000	1.000	0.993	1.000	0.997
P(B2018>B2015	0.236	0.101	0.104	0.999	0.327	0.300
$P(SSB2014>SSB_{MSY})$	1.000	1.000	1.000	0.007	1.000	0.968
$P(SSB2018>SSB_{MSY})$	1.000	1.000	1.000	0.747	1.000	0.982
P(USL2018>USL2014	0.993	0.999	1.000	0.615	0.994	0.987
$P(SSB2014<0.2\ SSB_0)$	0.919	0.716	0.233	0.674	0.948	0.992
$P(SSB2018<0.2\ SSB_0)$	0.213	0.182	0.069	0.002	0.240	0.536
$P(SSB2014<0.1\ SSB_0)$	0.000	0.000	0.000	0.000	0.000	0.274
$P(SSB2018<0.1\ SSB_0)$	0.000	0.000	0.000	0.000	0.000	0.120

Table 18: Assessment results: median and probability indicators for CRA 8 from base case MCMC and sensitivity trials; biomass in t and CPUE in kg/pot.

	Base median	d-d median	wideG prior median	noMoves median	rawLFs median	wideM prior median
B_{MIN}	658.2	674.2	550.9	651.5	635.9	601.8
B2015	2 698.1	2 529.9	2 362.5	2 624.9	2 175.2	2 506.1
B_{REF}	1 983.4	1 873.9	1 687.1	2 024.7	1 902.7	1 781.7
B2018	2 770.6	2 383.3	2 971.5	2 334.1	2 004.4	2 674.3
B_{MSY}	1 464.9	1 170.9	1 393.0	1 494.3	1 410.9	1 949.5
MSY	1 091.3	1 072.6	1 104.79	1 117.5	1 015.5	1 047.2
Fmult	1.59	2	1.6	1.57	1.23	1.17
SSB2014	5 043.3	4 815.6	4 631.9	4 974.7	4 974.5	5 525.7
SSB2018	5 321.6	4 868.4	5 345.3	5 003.0	4 950.2	6 176.7
SSB_{MSY}	3 103.6	2 364.0	2 937.370	3 093.9	3 399.4	4 878.0
CPUE2014	2.504	2.468	2.524	2.441	2.173	2.494
CPUE2018	2.539	2.181	3.391	2.075	1.879	2.654
CPUEmsy	1.147	0.867	1.325	1.159	1.185	1.774
$B2015/B_{MIN}$	4.104	3.772	4.289	3.990	3.399	4.148
$B2015/B_{REF}$	1.352	1.358	1.389	1.288	1.140	1.404
$B2015/B_{MSY}$	1.834	2.161	1.701	1.746	1.536	1.317
B2018/B2015	1.024	0.935	1.257	0.895	0.926	1.071
$B2018/B_{REF}$	1.399	1.269	1.747	1.159	1.055	1.505
$B2018/B_{MSY}$	1.889	2.043	2.140	1.571	1.425	1.421
$SSB2014/SSB_0$	0.438	0.774	0.391	0.432	0.393	0.253
$SSB2018/SSB_0$	0.462	0.789	0.450	0.436	0.391	0.285
$SSB2014/SSB_{MSY}$	1.620	2.028	1.572	1.611	1.462	1.132
$SSB2018/SSB_{MSY}$	1.711	2.060	1.812	1.622	1.453	1.270
SSB2018/SSB2014	1.055	1.019	1.152	1.003	0.994	1.115
USL2014	0.181	0.187	0.218	0.183	0.217	0.196
USL2018	0.182	0.211	0.169	0.216	0.251	0.188
USL2018/USL2014	1.002	1.137	0.8	1.184	1.168	0.962
Btot2014	9 749.9	9 689.3	8 030.890	1 0038.7	9 020.7	9 729.8
Btot2014/Btot0	0.269	0.403	2.3E-01	0.273	0.235	0.157
Ntot2014	1.6E+07	1.7E+07	1.2E+07	1.8E+07	1.5E+07	1.5E+07
Ntot2014/Ntot0	0.415	0.405	0.352	0.423	0.372	0.294
$P(B2015> B_{MIN})$	1.000	1.000	1.000	1.000	1.000	1.000
$P(B2015> B_{REF})$	0.995	0.999	0.997	0.975	0.862	0.990
$P(B2015> B_{MSY})$	1.000	1.000	1.000	1.000	1.000	0.954
$P(B2018> B_{MIN})$	1.000	1.000	1.000	1.000	1.000	1.000
$P(B2018> B_{REF})$	0.942	0.916	0.999	0.724	0.602	0.961
$P(B2018> B_{MSY})$	0.998	1.000	1.000	0.961	0.944	0.932
P(B2018>B2015	0.575	0.203	0.974	0.241	0.275	0.711
$P(SSB2014>SSB_{MSY})$	1.000	1.000	1.000	1.000	1.000	0.855
$P(SSB2018>SSB_{MSY})$	1.000	1.000	1.000	1.000	1.000	0.970
P(USL2018>USL2014	0.510	0.893	0.045	0.804	0.824	0.395
$P(SSB2014<0.2\ SSB_0)$	0.000	0.000	0.000	0.000	0.000	0.056
$P(SSB2018<0.2\ SSB_0$	0.000	0.000	0.000	0.000	0.000	0.017
$P(SSB2014<0.1\ SSB_0)$	0.000	0.000	0.000	0.000	0.000	0.000
$P(SSB2018<0.1\ SSB_0)$	0.000	0.000	0.000	0.000	0.000	0.000

Indicators based on vulnerable biomass (AW) and B_{MSY}

For both stocks, median current and projected biomass were above medians of B_{REF} and B_{MSY}. Projected biomass decreased in 76% of runs for CRA 7 and decreased in 42% of runs for CRA 8 but remained well above the reference levels in both stocks.

Indicators based on SSB_{MSY}

The historical track of biomass versus fishing intensity is shown in Figure 8 for the CRA 7 stock. The phase space in the plot shows biomass on the x-axis and fishing intensity on the y-axis. High biomass/low intensity is in the lower right-hand corner, the location of the stock when fishing first began, and low biomass/high intensity is in the upper left-hand corner, in a period when the fishery was largely uncontrolled. *Fmsy* varies among runs because of parameter variations and among years because of variation in fishing patterns, which include MLS, selectivity and the seasonal catch split. Figure 8 was calculated using the 2014 fishing pattern.

Fmsy was calculated with a 50-year projection for each year in each run, with the NSL catch held constant at that year's value, deterministic recruitment at *R0* and a range of multipliers on the SL catch *F*s estimated for year *y*. The *F* (actually separate *F*s for two seasons) that gives MSY is *Fmsy* and the multiplier is *Fmult*. Each point on the figure was plotted as the median of the posterior distributions of biomass ratio and fishing intensity ratio.

Figure 8 suggests that for CRA 7, SSB_{MSY} was estimated as a very small fraction of SSB_0, and that, while the fishery has driven the stock to low levels of SSB_0 in the past, the stock has never gone below SSB_{MSY} and has recovered to 20% of SSB_0 over the past decade. As noted above, the fishing intensity associated with MSY was very high, and similarly the fishery has never exceeded *Fmsy*. The figure suggests that fishing intensity is now lower than in 1963 and far below its peak in 1979.

For CRA 8, Figure 9 shows declining biomass after 1963 and increasing fishing intensity after 1975. After 1970, until 2005, fishing intensity exceeded *Fmsy*. *SSB* was below SSB_{MSY} from 1979 until 2009. The current position of the stock is relatively good, well above SSB_{MSY} and with fishing intensity well below *Fmsy*.

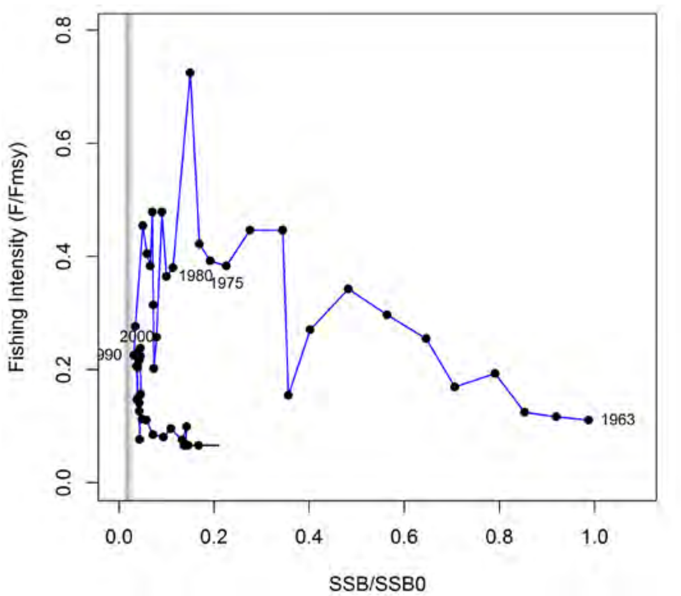


Figure 8: Phase plot (base case MCMC) for CRA 7, showing median spawning stock biomass for each year on the x-axis and median fishing intensity for each year on the y-axis; thus, high biomass/low fishing intensity is in the lower right-hand corner, where a stock would be when fishing first began, and low biomass/high intensity is in the upper left-hand corner, where an uncontrolled fishery would be likely to go. Specifically, the x-axis is spawning stock biomass *SSB* as a proportion of the unfished spawning stock SSB_0. SSB_0 is constant for all years of a simulation, but varies among the 1000 samples from the posterior distribution. The y-axis is fishing intensity as a proportion of the fishing intensity that would have given *MSY* (*Fmsy*) under the fishing patterns in year y; fishing patterns include MLS, selectivity, the seasonal catch split, retention curves and the balance between SL and NSL catches. *Fmsy* varies among years because the fishing patterns change. It was calculated with a 50-year projection for each year in each simulation, with the NSL catch held constant at that year's value, deterministic recruitment at R0 and a range of multipliers on the SL catch *F*s estimated for year y. The *F* (actually *F*s for two seasons) that gave *MSY* was F_{MSY}, and the multiplier was *Fmult*. Each point on the figure was plotted as the median of the posterior distributions of biomass ratio and fishing intensity ratio. The vertical line in the figure is the median (line) and 90% interval (shading) of the posterior distribution of SSB_{MSY} as a proportion of SSB_0; this ratio was calculated using the fishing pattern in 2013. The horizontal line in the figure is drawn at 1, the fishing intensity associated with *Fmsy*. The bars at the final year of the plot show the 90% intervals of the posterior distributions of biomass ratio and fishing intensity ratio.

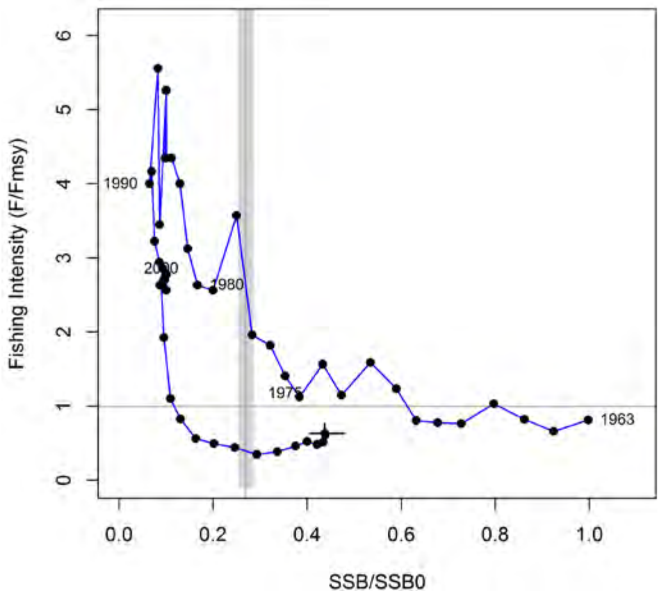


Figure 9: Phase plot for CRA 8; see the caption for Figure 8.

Future research considerations

- For the new growth analysis:
  - o Investigate potential seasonal effects such as seasonal patterns in growth and the probability of recapture
  - o Modify the 'Q' matrix (matrix of similarities between areas) to determine how much assumptions about similarities matter
  - o Further work with alternative error distributions would be useful
  - o Explore the utility of contamination models.
- The uncertainty of the length-frequency datasets needs further investigation (by, for example, bootstrapping to obtain appropriate estimates of uncertainty).
- Further work is needed on the influence of returning a high proportion of large lobsters to the sea on the calculation and interpretation of reference points.
- Examine the sensitivity of the model to the assumption of 10% mortality for lobsters returned to the sea.

6.5 CRA 9

A management procedure for CRA 9, based on a Fox surplus-production stock assessment model and MPEs, was used for the 2014–15 fishing year. However, an audit of the CRA 9 CPUE data in 2015 suggested that the CRA 9 CPUE index was not a reliable indicator of abundance in CRA 9 because of the small number of vessels fishing in recent years (six or fewer), problems with reporting and the large size of the CRA 9 area, in which changes in fished area could affect CPUE substantially. The NRLMG (National Rock Lobster Management Group) agreed to reject the CRA 9 management procedure. There is currently no accepted stock assessment for CRA 9.

7. STATUS OF THE STOCKS

Stock structure assumptions

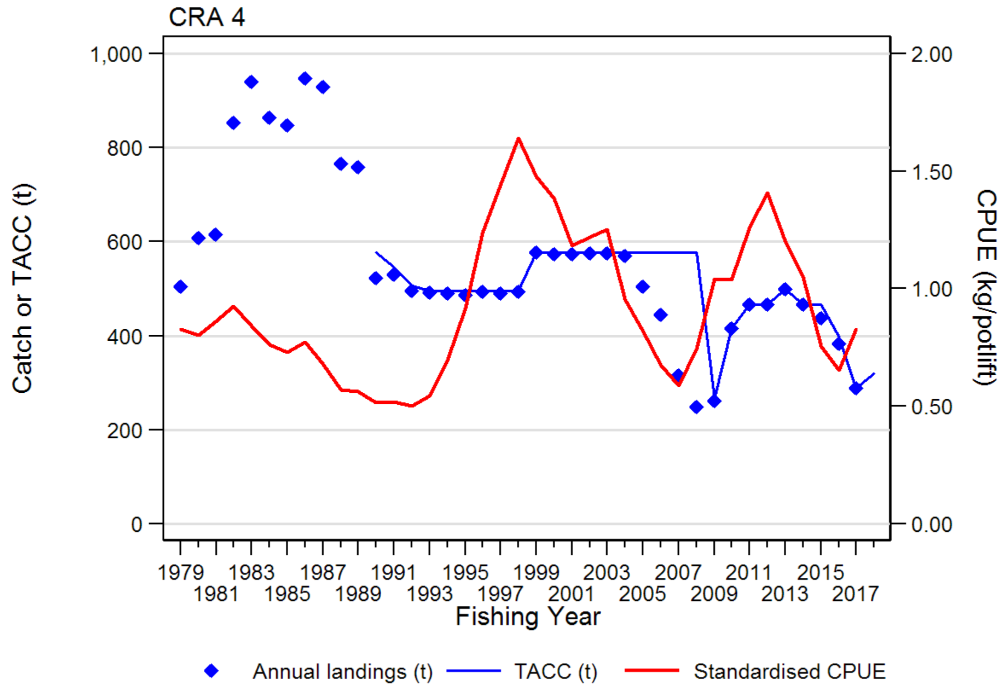
For the purposes of stock assessment and management, rock lobsters are assumed to constitute separate Fishstocks within each CRA Quota Management Area. There is likely to be some degree of relationship and/or exchange between Fishstocks in these CRA areas, either as a result of migration, larval dispersal or both.

7.1 *Jasus edwardsii*

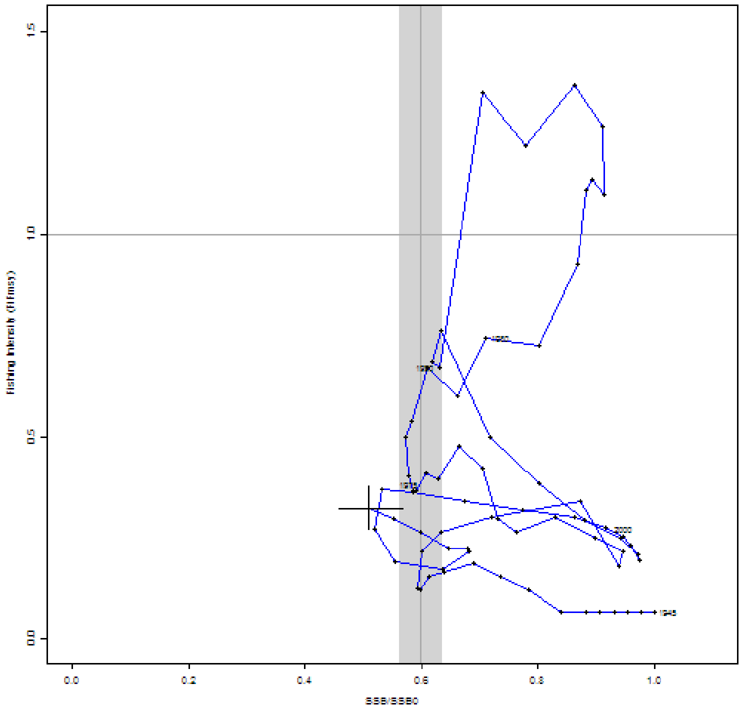
- **CRA 4 Wellington – Hawke's Bay**

Stock Status	
Year of Most Recent Assessment/Evaluation	Assessment 2016; MP update 2019
Assessment Runs Presented	2016 assessment: MCMC base case; 2019: MP evaluated
Reference Point	Target: B_{REF}: mean of beginning AW vulnerable biomass for the period 1979–88 Soft limit: 20% SSB_0 (default) Hard limit: 10% SSB_0 (default) Overfishing threshold: F_{MSY}
Status in relation to Target	Biomass in 2016 was 75% of B_{REF}; MP update in 2019 indicates that standardised CPUE in 2019 is higher than that in 2016 by about 30% and biomass may therefore be close to the target Very Unlikely (< 10%) that B_{2016} is at or above B_{REF} and About as Likely as Not (40-60%) that B_{2019} is at or above B_{REF}
Status in relation to Limits	Exceptionally Unlikely (< 1%) to be below the soft and hard limits
Status in relation to Overfishing	Overfishing was Likely (> 60%) to be occurring in 2016

Historical Stock Status Trajectory and Current Status



Annual landings, TACC and standardised CPUE for CRA 4 from 1979 to 2018.



Snail trail summary of the CRA 4 base case model. The line tracks the median values for each axis from the MCMC posteriors and the cross marks the 90% credibility interval on both axes for the final model year (2016). The vertical line in the figure is the median (line) and 90% interval (shading) of the posterior distribution of SSB_{MSY}. This ratio was calculated using the fishing pattern in 2015. The horizontal line in the figure is drawn at 1, the fishing intensity associated with F_{MSY}.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass has been decreasing since 2012; standardised CPUE increased in 2018 and 2019.
Recent Trend in Fishing Intensity or Proxy	Fishing intensity has been increasing since 2012, but may have dropped in 2017–18 due to a drop in landings (resulting from a TACC reduction) combined with an increase in standardised CPUE.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	Biomass was projected to decrease over the next three years at the level of the 2016 TACC (397 t); standardised CPUE increased in 2018 and 2019
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Likely (> 60%)
Probability of Current Catch or TACC causing Overfishing to continue or commence	Likely (> 60%)

Assessment Methodology		
Assessment Type	Level 1 – Full Quantitative Stock Assessment	
Assessment Method	Bayesian length based model	
Assessment Dates	Latest assessment: 2016	Next assessment: 2021

Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	CPUE, length frequency, tagging data, puerulus settlement indices	1– High Quality (all)
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	- informed priors on some growth parameters, fitting LFs separately by sex and estimating sex ratios; change to estimate of handling mortality	
Major Sources of Uncertainty	- level of non-commercial catches, including recreational and illegal catches, modelling of growth, estimation of productivity, vulnerability of immature females; estimated recent recruitment.	

Qualifying Comments
-

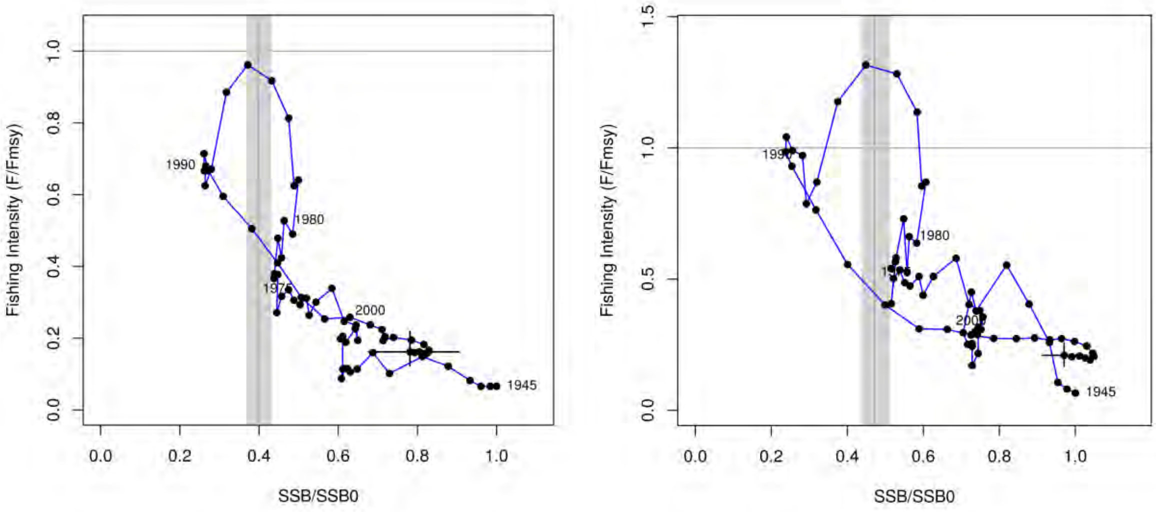
Environmental and Ecosystem Considerations	
Observer coverage	Observer coverage limited to stock assessment needs.
Non-target fish and invertebrate catch	The levels of incidental catch landed from rock lobster potting ranged from 2 to 11% of the estimated rock lobster catch weight per QMA for the period 1989–2003. For all QMAs, the most frequently reported incidental species caught are, in decreasing order of catch across all stocks: octopus, conger eel, blue cod, trumpeter, sea perch, red cod, butterfish and leatherjackets.
Incidental catch of seabirds	Small numbers of shags have been reported historically in some CRA areas, but not in recent years. Fishers suggest the lack of recent shag captures is attributable to changes in pot design and baiting methodologies.
Incidental catch of mammals	From January 2000 until November 2018, 31 entanglements (29 marine mammal individuals, two individuals were entangled twice) were attributed to commercial or recreational rock lobster pot lines from around New Zealand, mainly around Kaikoura (DOC Marine Mammal Database).
Incidental catch of other protected species	There is no known incidental catch of other protected species in rock lobster fisheries.
Benthic interactions	No information exists regarding the benthic impacts of potting in New Zealand.

- **CRA 5 Canterbury – Marlborough**

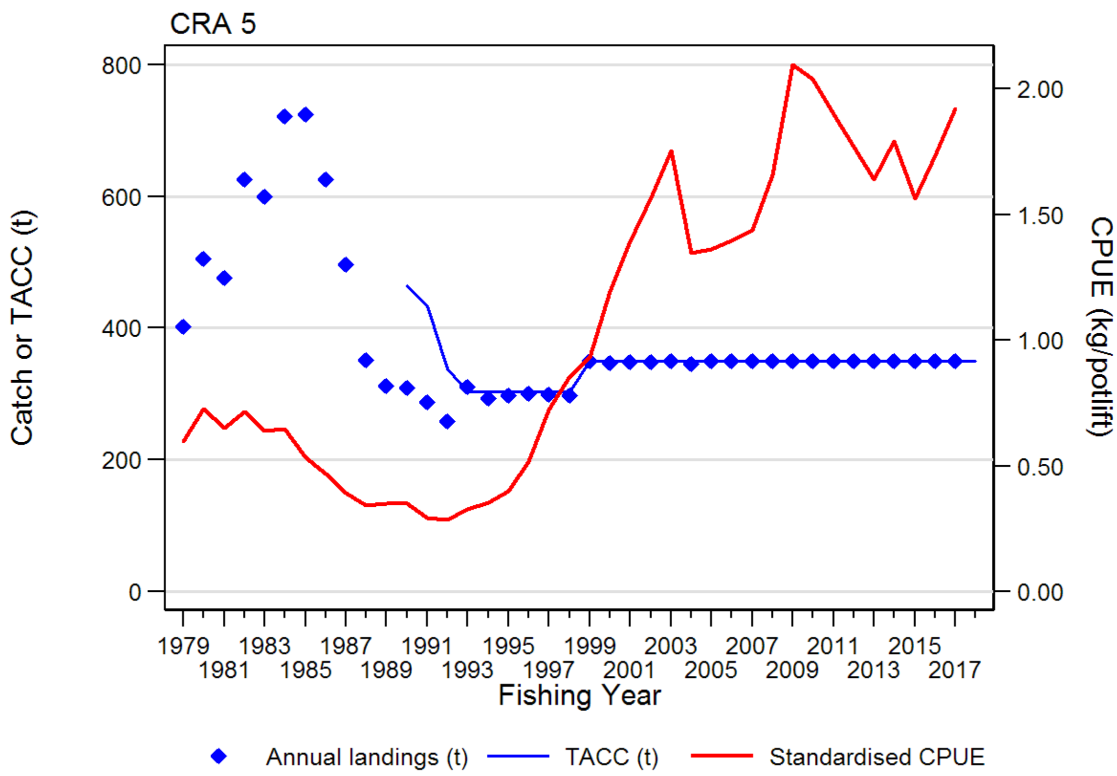
Stock Status	
Year of Most Recent Assessment/Evaluation	Assessment 2015; MP update 2019
Assessment Runs Presented	2015 assessment: two base cases; 2019: MP evaluated
Reference Points	Target: B_{REF}: mean of beginning AW vulnerable biomass for the period 1979–81 Soft limit: 20% SSB_0 (default) Hard limit: 10% SSB_0 (default) Overfishing threshold: F_{MSY}
Status in relation to Target	Biomass in 2015 was 182% or 240% B_{REF} for the two base cases; MP update indicates standardised CPUE in 2019 is only slightly lower (2%) than that from 2015, so stock status is likely to be similar; B_{2015} and B_{2019} Virtually Certain (> 99%) to be above B_{REF}

Status in relation to Limits	B_{2015} and B_{2019} Exceptionally Unlikely (< 1%) to be below the soft and hard limits
Status in relation to Overfishing	Overfishing is Very Unlikely (< 10%) to be occurring

Historical Stock Status Trajectory and Current Status



Phase plots for the two base case runs (without and with density-dependence).



Annual landings, TACC and standardised CPUE for CRA 5 from 1979 to 2016.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	CPUE has decreased since 2009, the highest level observed in the 36-year series, but remains at high levels.

Recent Trend in Fishing Intensity or Proxy	Fishing mortality has remained well below the overfishing threshold in recent years.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	Biomass is expected to decrease from 2015–18 but will remain above all reference levels for either of the two base case results.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Very Unlikely (< 10%)
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Very Unlikely (< 10%)

Assessment Methodology		
Assessment Type	Level 1 – Full Quantitative Stock Assessment	
Assessment Method	Bayesian length based model	
Assessment Dates	Latest assessment: 2015	Next assessment: 2020
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	CPUE, length frequency, tagging data, puerulus data	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	- new growth priors - addition of a density-dependence parameter	
Major Sources of Uncertainty	- level of non-commercial catches, illegal catches, validity of the assumption of constant catchability since 1979 in the CPUE series.	

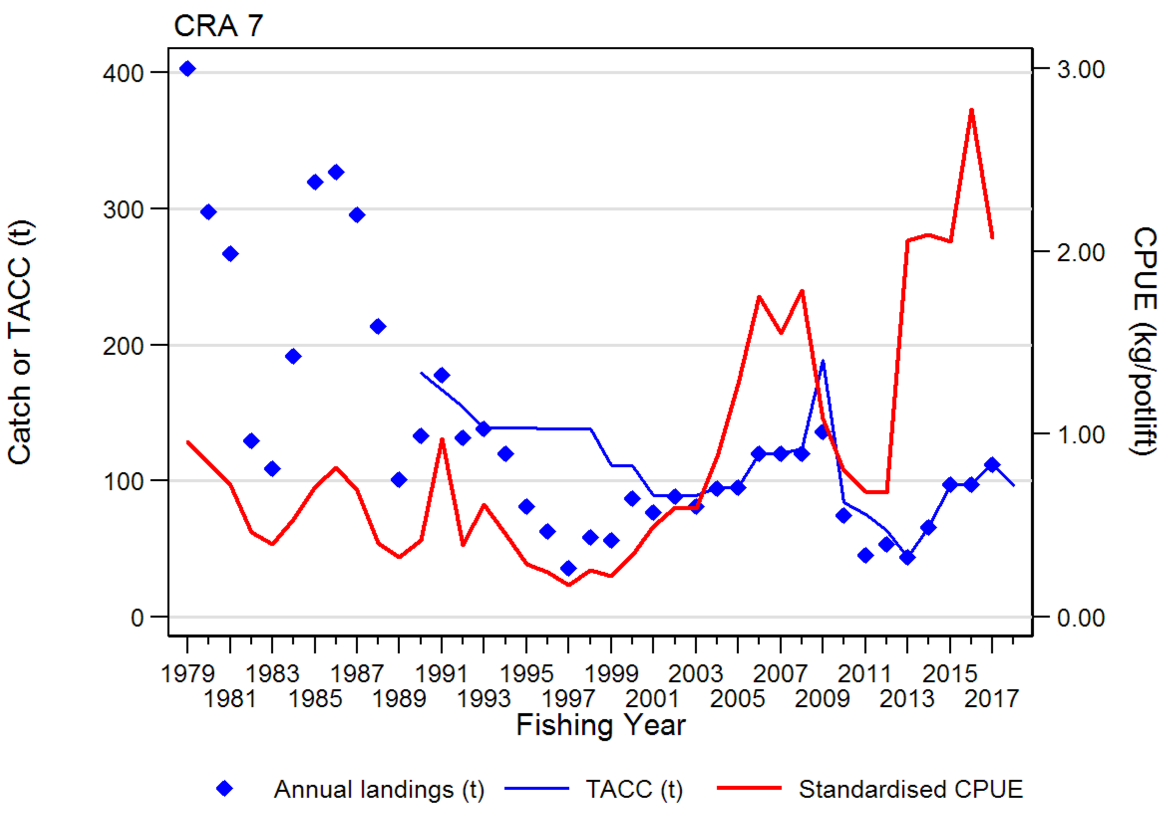
Qualifying Comments
-

Environmental and Ecosystem Considerations	
Observer coverage	Observer coverage limited to stock assessment needs.
Non-target fish and invertebrate catch	The levels of incidental catch landed from rock lobster potting ranged from 2 to 11% of the estimated rock lobster catch weight per QMA for the period 1989–2003. For all QMAs, the most frequently reported incidental species caught are, in decreasing order of catch across all stocks: octopus, conger eel, blue cod, trumpeter, sea perch, red cod, butterfish and leatherjackets.
Incidental catch of seabirds	Small numbers of shags have been reported historically in some CRA areas, but not in recent years. Fishers suggest the lack of recent shag captures is attributable to changes in pot design and baiting methodologies.
Incidental catch of mammals	From January 2000 until November 2018, 31 entanglements (29 marine mammal individuals, two individuals were entangled twice) were attributed to commercial or recreational rock lobster pot lines from around New Zealand, mainly around Kaikoura (DOC Marine Mammal Database).
Incidental catch of other protected species	There is no known incidental catch of other protected species in rock lobster fisheries.
Benthic interactions	No information exists regarding the benthic impacts of potting in New Zealand.

- **CRA 7 Otago**

Stock Status	
Year of Most Recent Assessment/Evaluation	Assessment 2015; MP update 2019
Assessment Runs Presented	2015 assessment: MCMC base case; 2019: MP evaluated
Reference Point	Target: B_{REF}: mean of beginning AW vulnerable biomass for the period 1979–81 Soft limit: ½*B_{REF} (default) Hard limit: ¼*B_{REF} (default) Overfishing threshold: F_{MSY}
Status in relation to Target	B_{2015} Very Likely (> 90%) to be at or above B_{REF}; MP update indicates standardised CPUE in 2019 is considerably higher (45%) than that in 2015 and therefore B_{2019} also Very Likely (> 90%) to be at or above B_{REF}
Status in relation to Limits	B_{2015} and B_{2019} Unlikely (< 40%) to be below soft or hard limits
Status in relation to Overfishing	Overfishing is Very Unlikely (< 10%) to be occurring

Historical Stock Status Trajectory and Current Status



Annual landings, TACC and standardised CPUE for CRA 7 from 1979 to 2016.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass levels have increased since the mid-2000s to a level well above the reference period.
Recent Trend in Fishing Intensity or Proxy	Stable over the past decade

Other Abundance Indices	-

Projections and Prognosis	
Stock Projections or Prognosis	Four-year projections from 2015 suggest median biomass will decline by 8% but will remain well above reference levels.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Unlikely (< 40%)
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Very Unlikely (< 10%)

Assessment Methodology		
Assessment Type	Level 1 – Full Quantitative Stock Assessment	
Assessment Method	Bayesian length based model	
Assessment Dates	Latest assessment: 2015	Next assessment: 2020
Overall assessment quality rank	1– High Quality	
Main data inputs (rank)	CPUE, historic catch rate, length frequency, tagging data	1– High Quality
Data not used (rank)	Puerulus indices	3 – Low quality: three indices in CRA 7 and CRA 8, with conflicting trends
Changes to Model Structure and Assumptions	- average movement used for years without movement estimated - Francis (2011) weights for composition data - change in tag-recapture likelihood - no density-dependent growth	
Major Sources of Uncertainty	- variation in length-frequency data - uncertain movement patterns out of CRA 7 (with potential change over time) - lack of mature females.	

Qualifying Comments
-

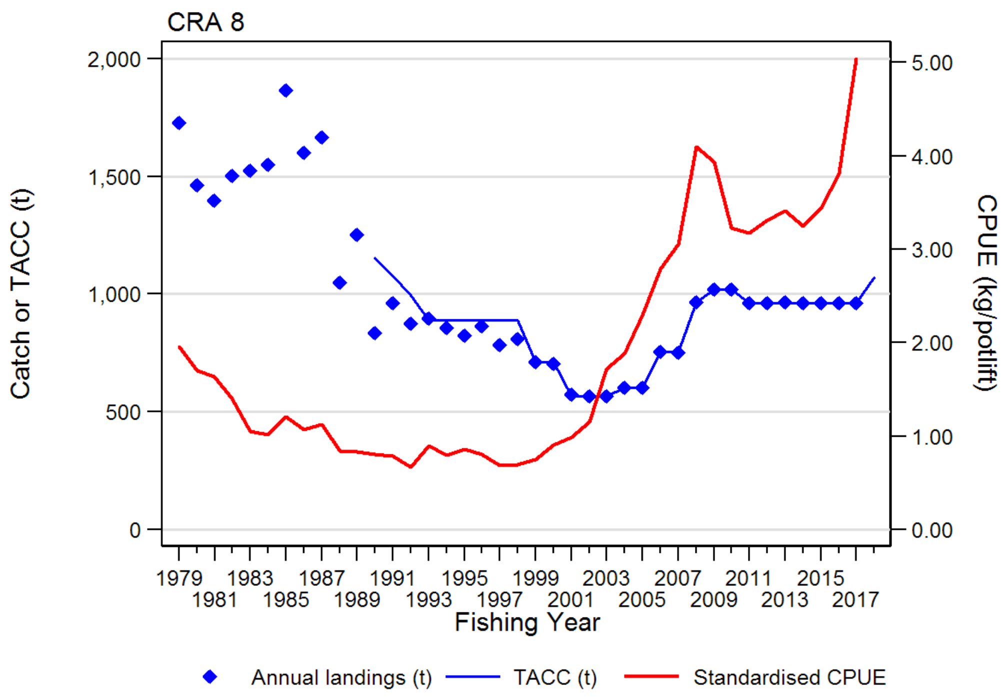
Environmental and Ecosystem Considerations	
Observer coverage	Observer coverage limited to stock assessment needs.
Non-target fish and invertebrate catch	The levels of incidental catch landed from rock lobster potting ranged from 2 to 11% of the estimated rock lobster catch weight per QMA for the period 1989–2003. For all QMAs, the most frequently reported incidental species caught are, in decreasing order of catch across all stocks: octopus, conger eel, blue cod, trumpeter, sea perch, red cod, butterfish and leatherjackets.
Incidental catch of seabirds	Small numbers of shags have been reported historically in some CRA areas, but not in recent years. Fishers suggest the lack of recent shag captures is attributable to changes in pot design and baiting methodologies.
Incidental catch of mammals	From January 2000 until November 2018, 31 entanglements (29 marine mammal individuals, two individuals were entangled twice) were attributed to commercial or recreational rock lobster pot lines from around New Zealand, mainly around Kaikoura (DOC Marine Mammal Database).

Incidental catch of other protected species	There is no known incidental catch of other protected species in rock lobster fisheries.
Benthic interactions	No information exists regarding the benthic impacts of potting in New Zealand.

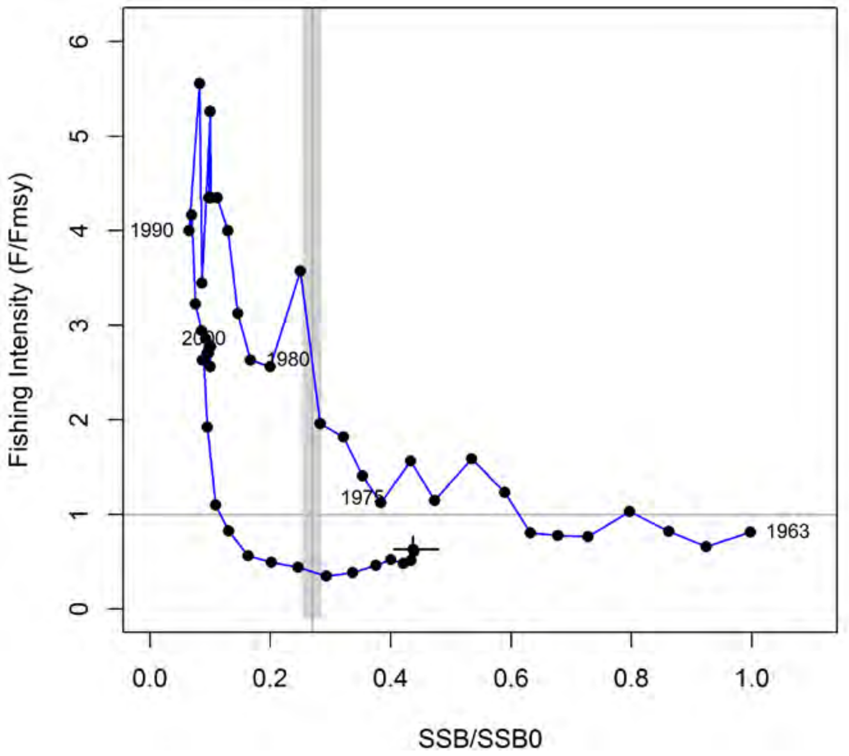
- **CRA 8 Southern**

Stock Status	
Year of Most Recent Assessment/Evaluation	Assessment 2015; MP update 2019
Assessment Runs Presented	2015 assessment: MCMC base case; 2019: MP evaluated
Reference Point	Target: B_{REF}: mean of beginning AW vulnerable biomass for the period 1979–81 Soft limit: 20% SSB_0 (default) Hard limit: 10% SSB_0 (default) Overfishing threshold: F_{MSY}
Status in relation to Target	Standardised CPUE in 2015 well above the levels during the reference period; MP update indicates standardised CPUE in 2019 is even higher (by 59%); B_{2015} and B_{2019} Virtually Certain (> 99%) to be at or above B_{REF}
Status in relation to Limits	B_{2015} and B_{2019} Exceptionally Unlikely (< 1%) to be below both the soft and hard limits
Status in relation to Overfishing	Overfishing is Very Unlikely (< 10%) to be occurring

Historical Stock Status Trajectory and Current Status



Annual landings, TACC and standardised CPUE for CRA 8 from 1979 to 2016



Phase plot that summarises the history of the CRA 8 fishery.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass has been increasing steadily in recent years.
Recent Trend in Fishing Intensity or Proxy	Relatively stable and well below F_{MSY}
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	2015 projections suggested the stock will remain near its current level.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Exceptionally Unlikely (< 1%)
Probability of Current Catch or TACC causing Overfishing to continue or commence	Very Unlikely (< 10%)

Assessment Methodology and Evaluation		
Assessment Type	Level 1 – Full Quantitative Stock Assessment	
Assessment Method	Bayesian length based model	
Assessment Dates	Latest assessment: 2015	Next assessment: 2020
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	CPUE, historic catch rate, length frequency, tagging data	1 – High Quality
Data not used (rank)	Puerulus indices	3 – Low quality: three indices in CRA 7 and CRA 8, with conflicting trends

Changes to Model Structure and Assumptions	- Francis (2011) weights for composition data; change in tag-recapture likelihood.
Major Sources of Uncertainty	- Effect of returning a high proportion of large lobsters to the sea (including for the calculation of reference points); assumption of constant catchability over the entire CPUE time series.

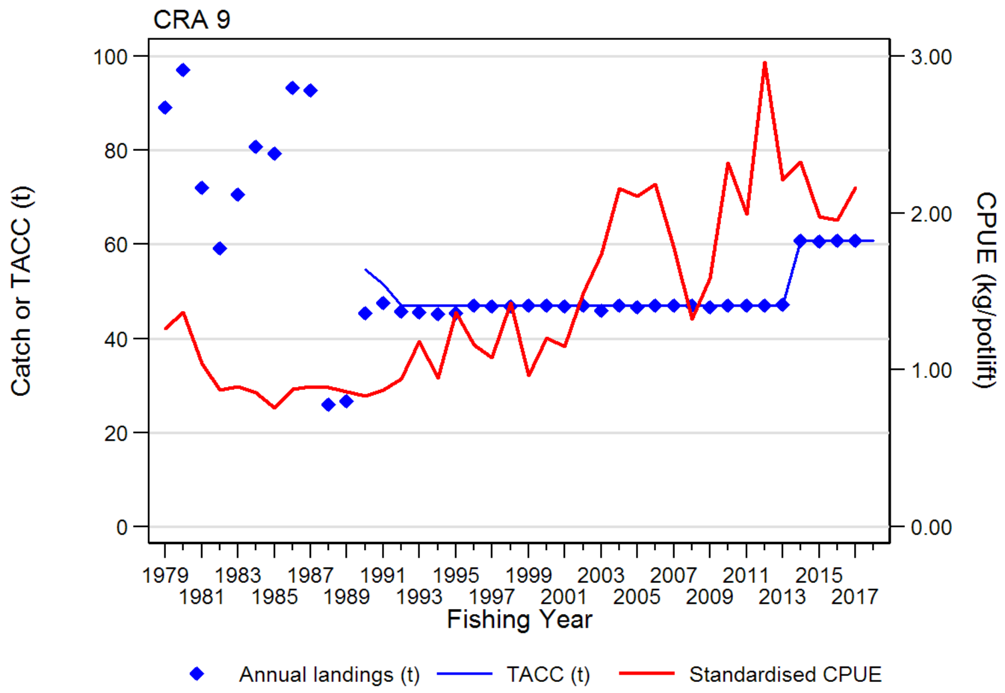
Qualifying Comments
-

Environmental and Ecosystem Considerations	
Observer coverage	Observer coverage limited to stock assessment needs.
Non-target fish and invertebrate catch	The levels of incidental catch landed from rock lobster potting ranged from 2 to 11% of the estimated rock lobster catch weight per QMA for the period 1989–2003. For all QMAs, the most frequently reported incidental species caught are, in decreasing order of catch across all stocks: octopus, conger eel, blue cod, trumpeter, sea perch, red cod, butterfish and leatherjackets.
Incidental catch of seabirds	Small numbers of shags have been reported historically in some CRA areas, but not in recent years. Fishers suggest the lack of recent shag captures is attributable to changes in pot design and baiting methodologies.
Incidental catch of mammals	From January 2000 until November 2018, 31 entanglements (29 marine mammal individuals, two individuals were entangled twice) were attributed to commercial or recreational rock lobster pot lines from around New Zealand, mainly around Kaikoura (DOC Marine Mammal Database).
Incidental catch of other protected species	There is no known incidental catch of other protected species in rock lobster fisheries.
Benthic interactions	No information exists regarding the benthic impacts of potting in New Zealand.

- **CRA 9 Westland–Taranaki**

Stock Status	
Year of Most Recent Assessment/Evaluation	Stock assessment and MP suspended in 2015; CPUE updated to 2015
Assessment Runs Presented	-
Reference Points	Target: Not established Soft limit: 20% *K* (default) Hard limit: 10% *K* (default) Overfishing threshold: F_{MSY}
Status in relation to Target	Unknown
Status in relation to Limits	Unknown
Status in relation to Overfishing	Unknown

Historical Stock Status Trajectory and Current Status



Annual landings, TACC and standardised CPUE for CRA 9 from 1979 to 2016.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	CPUE has risen steadily since the early 1990s.
Recent Trend in Fishing Intensity or Proxy	Size data from commercial fisheries suggests low exploitation rates in all statistical areas.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	-
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Unknown
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unknown

Assessment Methodology		
Assessment Type	N/A	
Assessment Method	N/A	
Assessment Dates	Latest assessment: 2013	Next assessment: Unknown
Overall quality assessment rank	3 – Low Quality: assessment and MP rejected	
Main data inputs (rank)	Catch and CPUE	1 – High Quality
Data not used (rank)	-	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	Catch and CPUE data from small number of participants	

Qualifying Comments
-

Environmental and Ecosystem Considerations	
Observer coverage	Observer coverage limited to stock assessment needs.
Non-target fish and invertebrate catch	The levels of incidental catch landed from rock lobster potting ranged from 2 to 11% of the estimated rock lobster catch weight per QMA for the period 1989–2003. For all QMAs, the most frequently reported incidental species caught are, in decreasing order of catch across all stocks: octopus, conger eel, blue cod, trumpeter, sea perch, red cod, butterfish and leatherjackets.
Incidental catch of seabirds	Small numbers of shags have been reported historically in some CRA areas, but not in recent years. Fishers suggest the lack of recent shag captures is attributable to changes in pot design and baiting methodologies.
Incidental catch of mammals	From January 2000 until November 2018, 31 entanglements (29 marine mammal individuals, two individuals were entangled twice) were attributed to commercial or recreational rock lobster pot lines from around New Zealand, mainly around Kaikoura (DOC Marine Mammal Database).
Incidental catch of other protected species	There is no known incidental catch of other protected species in rock lobster fisheries.
Benthic interactions	No information exists regarding the benthic impacts of potting in New Zealand.

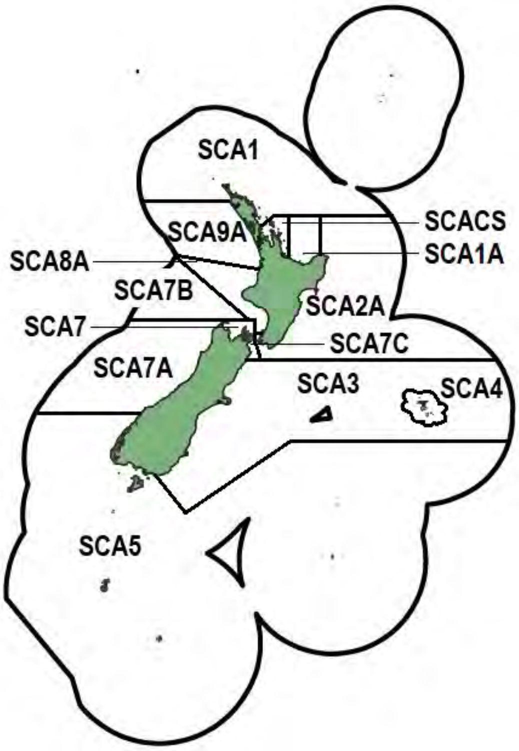
7.2 *Sagmariasus verreauxi*, PHC stock
The status of this stock is unknown.

8. FOR FURTHER INFORMATION

For the list of references refer to the Introductory Rock Lobster chapter.

SCALLOPS (SCA)

(*Pecten novaezelandiae*)
Kuakua



1. INTRODUCTION

Scallops are important shellfish both commercially and to non-commercial (customary and recreational) fishers.

For each stock, the Total Allowable Catch (TAC), allowances for customary and recreational fisheries and other sources of mortality, and Total Allowable Commercial Catch (TACC) can be found in Table 1 (all values in meatweight – muscle plus attached roe).

Table 1: TAC, customary allowance, recreational allowance, other sources of mortality allowance and TACC (t) for all scallop stocks.

Fishstock	TAC	Customary allowance	Recreational allowance	Other mortality	TACC
SCA 1 (Northland)	75	7.5	7.5	20	40
SCA 1A (Eastern Bay of Plenty)	8	3	3	1	1
SCA CS (Coromandel)	81	10	10	11	50
SCA 2A (part Central (East))	4	1	1	1	1
SCA 3 (South-East and part Chatham Rise)	4	1	1	1	1
SCA 4 (Chatham Islands)	26	1	1	1	23
SCA 5 (Southland and Sub-Antarctic)	8	3	3	1	1
SCA 7 (Nelson/Marlborough)	520	40	40	40	400
SCA 7A (West Coast)	4	1	1	1	1
SCA 7B (North and West of Farewell Spit)	2	0	0	1	1
SCA 7C (Clarence Pt to West Head, Tory Channel)	4	1	1	1	1
SCA 8A (part Central (Egmont))	4	1	1	1	1
SCA 9A (part Auckland (West))	26	12	12	1	1

Specific Working Group reports are given separately for SCA 1, SCA CS and SCA 7.

1.1 Commercial fisheries

All scallop stocks are managed under the QMS using individual transferable quotas (ITQ). In October 1995, legislation was passed in which annual catch entitlement was determined as a fixed proportion of the Total Allowable Commercial Catch (TACC) rather than being allocated as a fixed tonnage.

The Minister can decide to increase or decrease the Total Allowable Catch (TAC) and/or the TACC that applies each fishing year, after considering certain matters. All scallop stocks, other than SCA 7, are also gazetted on the Second Schedule of the Fisheries Act 1996, which specifies that, for certain 'highly variable' stocks, the TAC and the amount of Annual Catch Entitlement (ACE) can be increased within a fishing season after considering information about abundance during that fishing year. The TACC is not changed by an "in-season increase" and the ACE reverts to the 'base' level of the TACC the following fishing year. There have not been any in-season TAC increases for scallop stocks since 2012.

In 1996, because of the rotational fishing and stock enhancement management strategy being used to manage the stocks in SCA 7, the fishery was placed on the Third Schedule of the Fisheries Act 1996, and was, therefore, able to have an alternative TAC set under s14 of the Act.

Some harbours and enclosed waters are closed to commercial dredging but remain open to recreational fishers. Some other areas are closed to both commercial and recreational fishers. Closures by area have a considerable history of use in New Zealand scallop fisheries, for both allocation issues and more general issues in scallop management.

The fishing year for scallops is from 1 April to 31 March. The commercial fishing seasons and minimum legal sizes can be found in Table 2. The period of fishing within the season may vary from year to year depending on when the industry decides to operate.

Table 2: Commercial fishing seasons and minimum legal sizes (MLS).

Fishstock	Commercial fishing season	MLS (mm)
SCA 1 (Northland)	15 July to 14 February	100
SCA CS (Coromandel)	15 July to 21 December	90
SCA 7 (Nelson/Marlborough) (until closure in 2016–17)	15 July to 14 February	90

Historical landings for the three major commercial fisheries are shown in Figure 1.

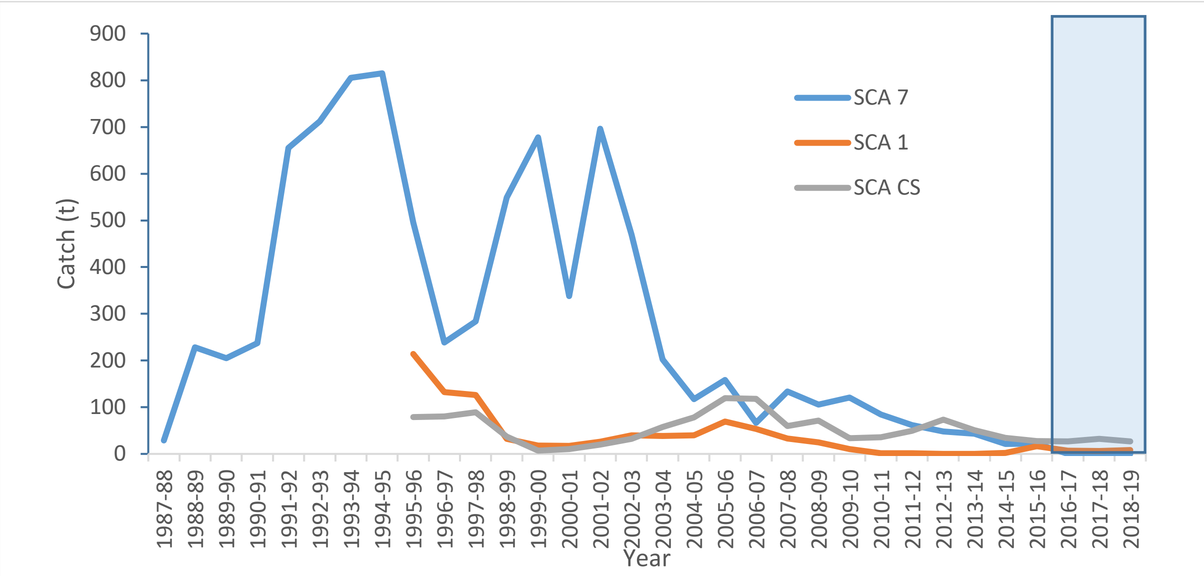


Figure 1: Historical landings for Nelson/Marlborough (SCA 7), Northland (SCA 1) and Coromandel (SCA CS) scallop fisheries. Blue box indicates the closure of the SCA 7 fishery.

All commercial fishing is by dredge. In the Northland and Coromandel fisheries, fishers use a self-tipping ‘box’ dredge (up to 2.4 m wide, fitted with a rigid tooth bar on the leading bottom edge). Until the fishery closed in 2016–17, vessels in the SCA 7 fishery towed one or two ring-bag dredges up to 2.4 m in width with heavy tickler chains (there are no teeth or tines on the leading bottom edge of the dredges, unlike those of the fixed tooth bars used on dredges in the northern fisheries).

1.2 Recreational fisheries

There is a strong non-commercial interest in scallops in suitable areas throughout the country, mostly in enclosed bays and harbours. Scallops are usually taken by diving using snorkel or scuba, although the use of small dredges is also common practice. In some areas, for example in some harbours, scallops can be taken by hand from the shallow subtidal and even the low intertidal zones (on spring tides) and, in storm events, scallops can be cast onto beaches in large numbers.

Some harbours and enclosed waters are closed to commercial dredging but remain open to recreational fishers in the Northland and Coromandel scallop fisheries. Some other areas are closed to both commercial and recreational fishers. Closures by area have a considerable history of use in New Zealand scallop fisheries, for both scallop allocation issues and more general issues in scallop management.

The Kaipara harbour was surveyed most recently in 2017 and led to the closure of the harbour to recreational fishers following the severe decline of the stock (Williams et al. 2018). Commercial fishing for scallops in the harbour was already prohibited (Regulation 21(1)(a) Fisheries (Auckland and Kermadec Areas Commercial Fishing) Regulations 1986).

Regulations governing the recreational harvest of scallops include a minimum legal size, a restricted daily harvest (bag limit) and a recreational fishing season (Table 3). A change to the recreational fishing regulations in 2005 allowed divers operating from a vessel to take scallops for up to two nominated safety people on board the vessel, in addition to the catch limits for the divers.

Table 3: Recreational scallop fishing regulations.

Fishstock	Minimum legal size (mm)	Daily bag limit (# of scallops per person)	Recreational fishing season
SCA 1 (Northland)	100	20	1 September to 31 March
SCA CS (Coromandel)	100	20	1 September to 31 March
SCA 5 (Stewart Island: Fiordland Paterson Inlet and Port Pegasus)	100	10	1 October to 15 March
SCA 7 (Nelson/Marlborough) (until closure in 2016–17)	90	50	15 July to 14 February

1.3 Customary fisheries

Scallops were undoubtedly used traditionally as food by Maori. Limited quantitative information on the level of customary take is available from Fisheries New Zealand. Details are provided in the respective Working Group reports.

1.4 Illegal catch

There is no quantitative information on the level of illegal catch for the scallop stocks.

1.5 Other sources of fishing mortality

Dredging results in incidental mortality of scallops.

An experimental study conducted on predominantly sandy substrates in the Coromandel fishery found that a box dredge (with teeth or ‘tines’) caused more breakage and incidental mortality in scallops than a ring-bag dredge, although the ring-bag dredge showed poor efficiency on this substrate type in comparison with the box dredge (Cryer & Morrison 1997). Scallops retained by dredges were more likely to be killed than those that were left on the seabed, and there was increasing mortality with increasing scallop size. Total mortality was 20–30% but potentially as high as 50% for scallops that were returned to the water, i.e., those just under the MLS. The incidental mortality caused by dredging substantially changed the shape of yield-per-recruit curves for Coromandel scallops, causing generally asymptotic curves to become domed, and decreasing estimates of F_{max} and $F_{0.1}$. More recent field experiments (Talman et al. 2004) and modelling (Cryer et al. 2004) suggest that dredging reduces habitat heterogeneity, increases juvenile mortality, makes yield-per-recruit curves even more domed, and decreases estimates of F_{max} and $F_{0.1}$ even further (Cryer & Parkinson 2006).

The applicability of these findings to the use of the ring-bag dredge in the sand/silt substrates in the SCA 7 fishery is unknown.

The extent of other sources of fishing mortality is unknown. Dredging results in incidental mortality of scallops.

2. BIOLOGY

Pecten novaezelandiae is one of several species of 'fan shell' bivalve molluscs found in New Zealand waters. Others include queen scallops and some smaller species of the genus *Chlamys*. *P. novaezelandiae* is endemic to New Zealand, but is very closely related to the Australian species *P. fumatus* and *P. modestus*. Scallops of various taxonomic groups are found in all oceans and support many fisheries worldwide; most scallop populations undergo large fluctuations. *Pecten novaezelandiae rakiura* is a sub-species found around Stewart Island.

Scallops are found in a variety of coastal habitats, but particularly in semi-enclosed areas where circulating currents are thought to retain larvae.

Scallops are functional hermaphrodites and become sexually mature at a size of about 70 mm shell length (Williams & Babcock 2005). They are extremely fecund and may spawn several times each year. They breed most prolifically in early summer (although partial spawning can occur from at least August to February). Most scallops mature by the end of their first year, but they contribute little to the spawning pool until the end of their second year. Year 1 scallops contain about 500 000 eggs, whereas year 4 and 5 scallops can contain over 40 million. Like other broadcast spawning marine invertebrates, scallops need to be in close proximity during spawning to ensure that sperm concentrations are sufficiently high to fertilise the eggs released; high density beds of scallops are disproportionately more important for fertilisation success during spawning. Scallop veliger larvae spend about three weeks in the plankton. They then attach to algae or some other filamentous material with fine byssus threads. When the spat reach about 5 mm they detach and take up the free-living habit of adults, usually lying in depressions on the seabed and often covered by a layer of silt. Although adult scallops can swim, they appear to move very little (based on underwater observations, the recovery of tagged scallops, and the persistence of morphological differences between adjacent sub-populations). They may, however, be moved considerable distances by currents and storms and are sometimes thrown up in large numbers on beaches.

The very high fecundity of this species, and likely variability in the mortality of larvae and pre-recruits, could lead to high variability in natural annual recruitment. This, combined with variable mortality and growth rate of adults, leads to scallop populations being highly variable from one year to the next, especially in areas of rapid growth and high fishing mortality where the fishery may be supported by only one or two year classes. This variability is characteristic of most scallop populations worldwide, and often occurs independently of fishing pressure.

For more specific information on individual stocks, please refer to the relevant scallop Working Group reports.

3. STOCKS AND AREAS

Scallops inhabit waters of up to about 60 m deep (apparently up to 85 m at the Chatham Islands), but are more common in depths of 10 to 50 m on substrates of shell gravel, sand or, in some cases, silt. Scallops are typically patchily distributed at a range of spatial scales. Some of the beds are persistent and others are ephemeral. The extent to which the various beds or populations are reproductively or functionally separate is not known.

Some work has been conducted on the spatial and temporal genetic structure of the New Zealand scallop. Samples were collected from 15 locations to determine the genetic structure across the distribution range of scallops. The low genetic structure detected was expected given the recent evolutionary history, the large reproductive potential and the pelagic larval duration of the species (approximately 3 weeks). A significant isolation by distance signal and a degree of differentiation from north to south was apparent, but this structure conflicted with some evidence of panmixia. A latitudinal genetic diversity gradient was observed that might reflect colonisation and extinction events and insufficient time to reach migration-drift equilibrium during a recent range expansion (Silva 2015, Silva & Gardner 2015).

A seascape genetic approach was used to test for associations between patterns of genetic variation in scallops and environmental variables (three geospatial and six environmental variables). Although the geographic distance between populations was an important variable explaining the genetic variation among populations, it appears that levels of genetic differentiation are not a simple function of distance. Evidence suggests that some environmental factors such as freshwater discharge and suspended particulate matter can be contributing to the patterns of genetic differentiation of scallops (Silva 2015, Silva & Gardner 2016).

For more specific information on individual stocks, please refer to the relevant scallop Working Group reports.

4. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS

4.1 Role in the ecosystem

Scallops (*Pecten novaezelandiae*) are subtidal, benthic, epifaunal, sedentary, bivalve molluscs, which have a pelagic larval dispersal phase. They are found patchily distributed at a range of scales in particular soft sediment habitats in inshore waters of depths generally to 50 m and exceptionally up to 85 m. They exhibit relatively fast growth, high mortality, and variable recruitment. The rates of these processes probably vary in relation to environmental conditions (e.g., temperature, water flow, turbidity and salinity), ecological resources (e.g., food, oxygen and habitat), and with intra- and inter-specific interactions (e.g., competition, predation, parasitism and mutualism), and the combination of these factors determines the species distribution and abundance (Begon et al. 1990). Scallops are considered to be a key component of the inshore coastal ecosystem, acting both as consumers of primary producers and as prey for many predators. Scallops themselves can also provide structural habitat for other epifauna (e.g., sponges, ascidians and algae).

A two-year project (2017–2019) has been funded to survey the environmental factors correlated with scallop survival and growth in scallop 7.

4.2 Trophic interactions

Scallops are active suspension feeders, consuming phytoplankton and other suspended material (benthic microalgae and detritus) as their food source (Macdonald et al. 2006). Their diet is the same as, or similar to, that of many other suspension-feeding taxa, including other bivalves such as oysters, clams and mussels.

Scallops are prey to a range of invertebrate and fish predators, whose dominance varies spatially. Across all areas, reported invertebrate predators of scallops include starfish (*Astropecten polyacanthus*, *Coscinasterias muricata* and *Luidia maculata*), octopus (*Pinnoctopus cordiformis*) and hermit crabs (*Pagurus novaezelandiae*), and suspected invertebrate predators include various carnivorous gastropods (e.g., *Cominella adspersa* and *Alcithoe arabica*); reported fish predators of scallops include snapper (*Pagrus auratus*), tarakihi (*Nemadactylus macropterus*) and blue cod (*Parapercis colias*), and suspected fish predators include eagle rays (*Myliobatis tenuicaudatus*) and stingrays (*Dasyatis* sp.) (Morton & Miller 1968, Bull 1976, Morrison 1998, Nesbit 1999). Predation varies with scallop size, with small scallops being generally more susceptible to a larger range of predators.

4.3 Non-target fish and invertebrate catch

A range of non-target fish and invertebrate species are caught and discarded by dredge fisheries for *P. novaezelandiae* scallops. No data are available on the level or effect of this incidental catch and discarding by the fisheries. Non-target fish and invertebrate species catch data are available, however, from various dredge surveys of the scallop stocks, and the non-target catch of the fisheries is likely to be similar to that of the survey tows conducted in areas that support commercial fishing.

Species or groups that have been caught as incidental catch in the box dredges and ring-bag dredges used in surveys of commercial scallop (*P. novaezelandiae*) fishery areas in New Zealand are shown in Table 4. Catch composition varies among the different fishery locations and through time.

In the Coromandel scallop stock (SCA CS), a photographic approach was used in the 2006 dredge survey to provisionally examine non-target catch groups (Tuck et al. 2006), but a more quantitative and comprehensive study was conducted using non-target catch data collected in the 2009 dredge survey (Williams et al. 2010), with survey catches quantified by volume of different component categories. Over the whole 2009 survey, scallops formed the largest live component of the total catch volume (26%), followed by assorted seaweed (11%), starfish (4%), other live bivalves (4%), coralline turfing algae (1%) and other live components not exceeding 0.5%. Dead shell (identifiable and hash) formed the largest overall component (45%), and rock, sand and gravel formed 8%. Categories considered to be sensitive to dredging were caught relatively rarely. Data on the non-target catch of the 2010 and 2012 surveys of SCA CS were also collected but not analysed; those data have been loaded to the Fisheries New Zealand database ‘scallop’ for potential future analysis (Williams & Parkinson 2010, Williams et al. 2013).

In the Northland scallop stock (SCA 1), analysis of historical survey non-target catch from a localised deep area within Spirits Bay showed an unusually high abundance and species richness of sponges (Cryer et al. 2000), and led to the voluntary and subsequent regulated closure of that area to commercial fishing.

In the Southern scallop stock (SCA 7), data on the non-target catch of the 1994–2013 surveys have been collected but not analysed, except for preliminary estimation of the 1998–2013 non-target catch trajectories (Williams et al. 2014).

Table 4: Species or groups categorised by non-target catch type caught as incidental catch in dredge surveys of commercial scallop (*P. novaezelandiae*) fishery areas in New Zealand.

Type	Species or groups
Habitat formers	sponges, tubeworms, coralline algae (turf, maerl), bryozoa
Starfish	*Astropecten*, *Coscinasterias*, *Luidia*, *Patiriella*
Bivalves	dog cockles, horse mussels, oysters, green-lipped mussels, *Tawera*
Other invertebrates	anemones, crabs, gastropods, polychaetes, octopus, rock lobster
Fish	gobie, gurnard, John dory, lemon sole, pufferfish, red cod, sand eel, snake eel, stargazer, yellowbelly flounder
Seaweed	*Ecklonia,* other brown algae, green algae, red algae
Shell	whole shells, shell hash
Substrate	mud, sand, gravel, rock
Other	rubbish

4.4 Incidental catch (seabirds, mammals and protected fish)

There is no known capture of seabirds, mammals or protected fish species from *P. novaezelandiae* scallop fisheries.

4.5 Benthic interactions

It is well known that fishing with mobile bottom contact gears such as dredges has impacts on benthic populations, communities and their habitats (e.g., Kaiser et al. 2006, Rice 2006). The effects are not uniform, but depend on at least: 'the specific features of the seafloor habitats, including the natural disturbance regime, the species present, the type of gear used, the methods and timing of deployment of the gear and the frequency with which a site is impacted by specific gears; and the history of human activities, especially past fishing, in the area of concern' (Department of Fisheries and Oceans 2006). The effects of scallop dredging on the benthos are relatively well studied, and include several New Zealand studies carried out in areas of the northern fisheries (SCA 1 and SCA CS) (Thrush et al. 1995, Thrush et al. 1998, Cryer et al. 2000, Tuck et al. 2009, Tuck & Hewitt 2012) and the Golden/Tasman Bays region of the southern fishery (SCA 7) (Tuck et al. 2017). The results of these studies are summarised in the Aquatic Environment and Biodiversity Annual Review (Ministry for Primary Industries 2019), and are consistent with the global literature: generally, with increasing fishing intensity there are decreases in the density and diversity of benthic communities and, especially, the density of emergent epifauna that provide structured habitat for other fauna.

4.6 Other considerations

4.6.1 Spawning disruption

Scallop spawning occurs mainly during spring and summer (Bull 1976, Williams & Babcock 2004). Scallop fishing also occurs during these seasons, and is particularly targeted in areas with scallops in good condition (reproductively mature adults ready to spawn). Fishing also concentrates on high density beds of scallops, which are disproportionately more important for fertilisation success during spawning (Williams 2005). Fishing may therefore disrupt spawning by physically disturbing scallops that are either caught and retained (removal), caught and released, not caught but directly contacted by the dredge, or not caught but indirectly affected by the effects of dredging (e.g., suspended sediments).

4.6.2 Habitat of particular significance to fisheries management

Habitat of particular significance for fisheries management (HPSFM) does not have a policy definition (Ministry for Primary Industries 2019). Certain features of the habitats with which scallops are associated are known to influence scallop productivity by affecting the recruitment, growth and mortality of scallops, and therefore may in the future be useful in terms of identifying HPSFM. Scallop larval settlement requires the presence of fine filamentous emergent epifauna on the seabed, such as tubeworms, hydroids and filamentous algae, hence the successful use of synthetic mesh spat bags held in the water column as a method for collecting scallop spat. Survival of juveniles has been shown to vary with habitat complexity, being greater in more complex habitats (with more emergent epifauna) than in more homogeneous areas (Talman et al. 2004). The availability of suspended microalgae and detritus affects growth and condition (Macdonald et al. 2006). Suspended sediments can reduce rates of respiration and growth, the latter by 'diluting' the food available. Scallops regulate ingestion by reducing clearance rates rather than increasing pseudofaeces production. Laboratory studies have demonstrated that suspended sediments disrupt feeding, decrease growth and increase mortality in scallops (Stevens 1987, Cranford & Gordon 1992, Nicholls et al. 2003).

5. STOCK ASSESSMENT

The stock assessments of scallop stocks SCA 1, SCA CS and SCA 7 are provided in the relevant Working Group reports.

6. STATUS OF THE STOCKS

The status of scallop stocks SCA 1, SCA CS and SCA 7 are given in the relevant Working Group reports.

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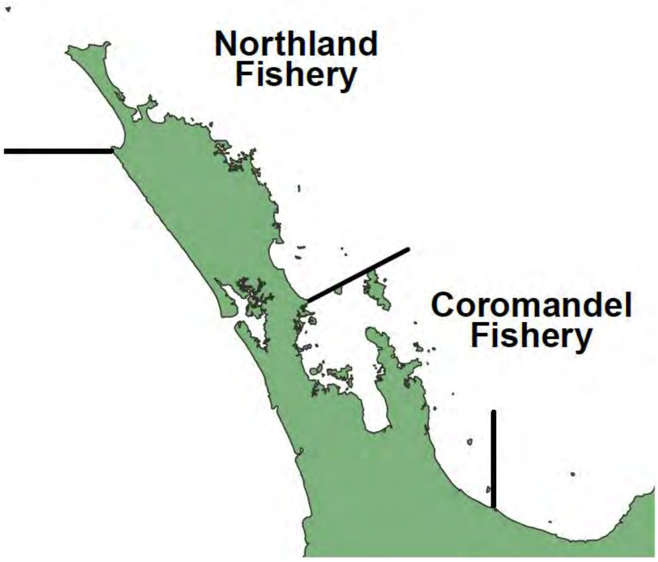
SCALLOPS NORTHLAND (SCA 1)

(*Pecten novaezelandiae*)
Kuakua, Tipa



1. FISHERY SUMMARY

Northland scallops (SCA 1) were introduced into the Quota Management System (QMS) on 1 April 1997. The Northland Total Allowable Catch (TAC) is 75 t, comprising a Total Allowable Commercial Catch (TACC) of 40 t, allowances of 7.5 t for recreational and customary fisheries, and an allowance of 20 t for other sources of mortality (Table 1; all values in meatweight – muscle plus attached roe).

Table 1: TAC, customary allowance, recreational allowance, other sources of mortality allowance and TACC (t) for SCA 1.

Year	TAC	Customary	Recreational	Other mortality	TACC
1996–present	75	7.5	7.5	20	40

1.1 Commercial fisheries

SCA 1 has supported a regionally important commercial fishery situated between Reef Point at Ahipara on the west coast and Cape Rodney at Leigh on the east coast. Fishing has been conducted within discrete beds in Spirits Bay, Tom Bowling Bay, Great Exhibition Bay, Rangaunu Bay, Doubtless Bay, Stevenson's Island, the Cavalli Passage, Bream Bay, and the coast between Mangawhai and Pakiri Beach. All commercial fishing is by dredge, with fishers preferring self-tipping 'box' dredges (up to 2.4 m wide, fitted with a rigid tooth bar on the leading bottom edge) to the 'ring bag' designs used in Challenger and Chatham Island fisheries. The fishing year for SCA 1 is from 1 April to 31 March. The Northland commercial scallop season runs from 15 July to 14 February. The minimum legal size (MLS) is 100 mm.

Between 1980–81 and 2009–10, landings varied more than 10-fold from 80 t to over 1600 t greenweight. There was a gradual decline in landings from 68 t meatweight in 2005–06 to only 1 and 2 t in 2010–11 and 2011–12, respectively. There was no fishing in 2012–13, as voluntarily agreed by members of the Northland Scallop Enhancement Company (NSEC, representing the SCA 1 commercial scallop fishing industry), and only 86 kg and 2 t of meatweight were landed in 2013–14 and 2014–15 respectively. Significant fishing has occurred again in Bream Bay since 2015, with landings of 16 t, 7 t, 6 t and 8 t meatweight over the last 4 fishing years.

SCA 1 is managed under the QMS using individual transferable quotas (ITQ) that are proportions of the Total Allowable Commercial Catch (TACC). Catch limits and landings from the Northland fishery are shown in Table 2 and Figure 1. SCA 1 is gazetted on the Second Schedule of the Fisheries Act 1996, which specifies that, for certain 'highly variable' stocks, the Annual Catch Entitlement (ACE) can be increased within a fishing season. The TACC is not changed by this process and the ACE reverts to the base level of the TACC the following fishing year. Increases occurred in 2005–06 and 2006–07 supported by estimates of biomass derived from annual surveys.

Table 2: Catch limits and landings (t meatweight or greenweight) from the Northland fishery since 1980. Data before 1986 are from Fisheries Statistics Unit (FSU) forms. Landed catch figures come from Quota Management Returns (QMRs), Monthly Harvest Returns (MHRs), and from the landed section of Catch Effort and Landing Returns (CELRs), whereas estimated catch figures come from the effort section of CELRs and are pro-rated to sum to the total CELR landed greenweight. Catch limits for 1996 were specified on permits as meatweights, and, since 1997, were specified as a formal TACC in meatweight (Green1 assumes the gazetted meatweight recovery conversion factor of 12.5% and probably overestimates the actual greenweight taken in most years). In seasons starting in 1999 and 2000, voluntary catch limits were set at 40 and 30 t, respectively. * split by area not available; – no catch limits set, or no reported catch (Spirits).

								Landings (t)
	Catch limits (t)		QMR/ MHR	CELR and FSU		Scaled estimated catch (t green)		
Fishing year	Meat	Green	Meat	Meat	Green	Whangarei	Far North	Spirits
1980–81	–	–	–	–	238	*	*	*
1981–82	–	–	–	–	560	*	*	*
1982–83	–	–	–	–	790	*	*	*
1983–84	–	–	–	–	1 171	78	1 093	–
1984–85	–	–	–	–	541	183	358	–
1985–86	–	–	–	–	343	214	129	–
1986–87	–	–	–	–	675	583	92	–
1987–88	–	–	–	–	1 625	985	640	–
1988–89	–	–	–	–	1 121	1 071	50	–
1989–90	–	–	–	–	781	131	650	–
1990–91	–	–	–	–	519	341	178	–
1991–92	–	–	–	168	854	599	255	–
1992–93	–	–	–	166	741	447	294	–
1993–94	–	–	–	110	862	75	787	1
1994–95	–	–	–	186	1 634	429	1 064	142
1995–96	–	–	–	209	1 469	160	810	499
1996–97	188	1 504	–	152	954	55	387	512
1997–98	188	1 504	–	144	877	22	378	477
1998–99	106	848	28	29	233	0	102	130
1999–00	106	785	22	20	132	0	109	23
2000–01	60	444	15	16	128	0	88	40
2001–02	40	320	38	37	291	14	143	134
2002–03	40	320	40	42	296	42	145	109
2003–04	40	320	38	38	309	11	228	70
2004–05	40	320	40	37	319	206	77	37
2005–06	70	560	69	68	560	559	1	0
2006–07	70	560	53	50	405	404	1	0
2007–08	40	320	33	32	242	9	197	35
2008–09	40	320	25	25	197	0	171	26
2009–10	40	320	10	10	80	0	80	0
2010–11	40	320	1	1	8	0	8	0
2011–12	40	320	2	2	16	0	16	0
2012–13	40	320	0	0	0	0	0	0
2013–14	40	320	0.01	0.01	0.086	0.086	0	0
2014–15	40	320	2	2	3	3	0	0
2015–16	40	320	16	16	83	83	0	0
2016–17	40	320	7	7	36	36	0	0
2017–18	40	320	6	6	15	15	0	0
2018–19	40	320	8	8	-	-	-	-

1.2 Recreational fisheries

Until 2006, the recreational scallop season ran from 15 July to 14 February, but in 2007 the season was changed to run from 1 September to 31 March. Fishers may take up to 20 scallops per day with a minimum legal size of 100 mm shell width. Estimates of the recreational scallop harvest from SCA 1 are shown in Table 3. The harvest estimates provided by telephone-diary surveys between 1993 and 2001 are no longer considered reliable for various reasons. A Recreational Technical Working Group concluded that these harvest estimates should be used only with the following qualifications: a) they may be very inaccurate; b) the 1996 and earlier surveys contain a methodological error; and c) the 2000 and 2001 estimates are implausibly high for many important fisheries. In response to these problems and the cost and scale challenges associated with onsite methods, a National Panel Survey was conducted for the first time throughout the 2011–12 fishing year. The panel survey used face-to-face interviews of a random sample of 30 390 New Zealand households to recruit a panel of fishers and non-fishers for a full year. The panel members were contacted regularly about their fishing activities and harvest information collected in standardised phone interviews. The panel survey was repeated in 2017–18 using directly comparable methods (Wynne-Jones et al. 2019). The annual recreational harvest level is likely to vary substantially through time.

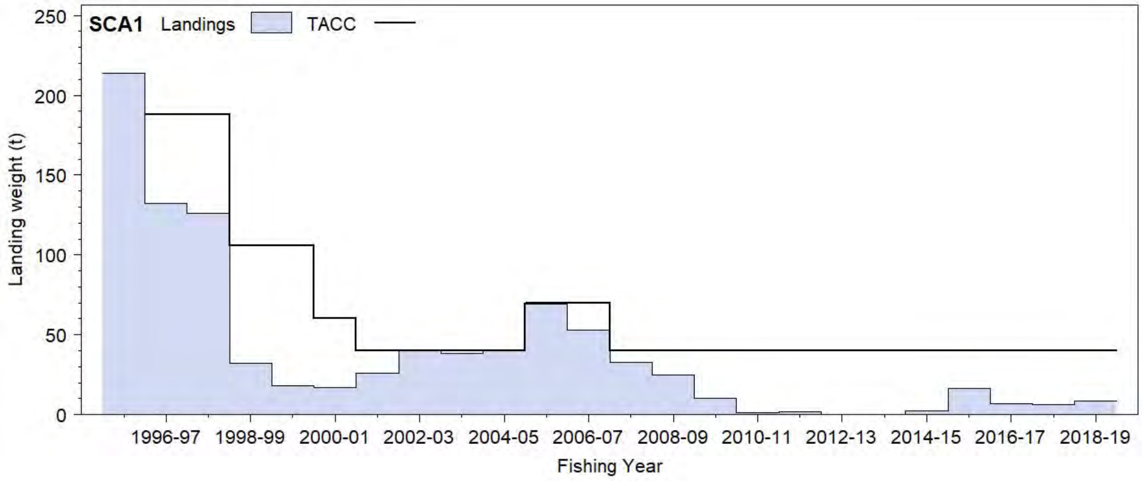


Figure 1: Landings and catch limits for SCA 1 (Northland) since 1995–96. TACC refers to the base TACC and any in-season increase in Annual Catch Entitlement and 'Weight' refers to meatweight.

Table 3: Estimates of the recreational harvest of scallops from SCA 1. Number, number of scallops; green, greenweight; meat, meatweight (assuming 12.5% recovery of meatweight from green weight).

Year	Area	Survey method	Number	CV	Green (t)	Meat (t)	Reference
1991–93	SCA 1	Phone-diary	391 000	0.17	40–60	5–8	Teirney et al. (1997)
1996	SCA 1	Phone-diary	272 000	0.18	32	4	Bradford (1998)
1999-2000	SCA 1	Phone-diary	322 000	0.32	33	4	Boyd & Reilly (2004)
2000–01	SCA 1	Phone-diary	283 000	0.49	29	4	Boyd et al. (2004)
2011–12	SCA 1	Panel survey	148 905	0.36	16	2	Wynne-Jones et al. (2014)
2017–18	SCA 1	Panel survey	148 905	0.36	16	2	Wynne-Jones et al. (2019)

For further information on recreational fisheries refer to the introductory SCA Working Group report.

1.3 Customary fisheries

Limited quantitative information on the level of customary take is available from Fisheries New Zealand. The kilograms and numbers of scallops harvested under customary permits is given in Table 4, and is likely to be an underestimate of customary harvest.

Table 4: Fisheries New Zealand records of customary harvest of scallops (reported as greenweight and numbers) taken from the Northland scallop fishery, 2006–07 to 2013–14. – no data.

	Weight (kg		Numbers	
Fishing year	Approved	Harvested	Approved	Harvested
2006–07	–	–	1 650	1 650
2007–08	–	–	1 780	1 780
2008–09	–	–	120	120
2009–10	–	–	1 200	1 200
2010–11	–	–	–	–
2011–12	130	130	600	480
2012–13	80	80	2 950	2 640
2013–14	8	8	450	450

For further information on customary fisheries refer to the introductory SCA Working Group report.

1.4 Illegal catch
For information on illegal catch refer to the introductory SCA Working Group report.

1.5 Other sources of mortality
For information on other sources of mortality refer to the introductory SCA Working Group report.

2. BIOLOGY

Little detailed information is available on the growth and natural mortality of Northland scallops, although the few tag returns from Northland indicate that growth rates in Bream Bay are similar to those in the nearby Coromandel fishery (see the Working Group report for SCA CS). The large average size of scallops in the northern parts of the Northland fishery and the consistent lack of small animals there suggests that growth rates may be high in the Far North.

For further information on biology refer to the introductory SCA Working Group report.

3. STOCKS AND AREAS

It is currently assumed for management purposes that the Northland stock is separate from the adjacent Coromandel stock, from the various west coast harbours stocks and also from the Golden Bay, Tasman Bay, Marlborough Sounds, Stewart Island and Chatham Island stocks.

For further information on stocks and areas refer to the introductory SCA Working Group report.

4. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS

In the Northland scallop stock (SCA 1), analysis of historical survey non-target catch from a localised deep area within Spirits Bay showed an unusually high abundance and species richness of sponges (Cryer et al. 2000), and led to the voluntary and subsequent regulated closure of that area to commercial fishing. There is no other local information on non-target fish and invertebrate catch for SCA1.

Refer to the introductory SCA Working Group report for general information on environmental and ecosystem considerations.

5. STOCK ASSESSMENT

Northland scallops are managed using a TACC of 40 t meatweight, which can be augmented with additional ACE after considering information about the abundance during the current fishing year. Previous in-season increases were based on the results from a pre-season biomass survey and the subsequent Current Annual Yield (CAY) estimates, using $F_{0.1}$ as a reference point. The last comprehensive biomass survey conducted in SCA 1 was in 2007. However, industry-based surveys of scallops in core commercial fishery areas have been conducted annually between 2012 and 2017 (Williams et al. 2017).

5.1 Estimates of fishery parameters and abundance
Over all of SCA 1, estimated fishing mortality on scallops 100 mm or more was in the range F_{est} = 0.33–0.78 y^{-1} (mean F_{est} = 0.572 y^{-1}) between 1997–98 and 2003–04, but was lower in the period 2005–07 (mean F_{est} = 0.203 y^{-1}) (Table 5). The level of fishing mortality in more recent years is unknown

because of the lack of surveys to estimate biomass. There is no known stock-recruit relationship for Northland scallops.

CPUE is not usually presented for scallops because it is not considered to be a reliable index of abundance (Cryer 2001). However, Management Strategy Evaluation (MSE) modelling suggested the potential for CPUE to be used as a basis for some management areas (Haist & Middleton 2010). This may or may not apply to the Northland scallop fishery.
In the absence of survey estimates of abundance from 2007 to 2011, CPUE indices were generated for SCA 1 based on the available data for the period 1991–2011 (Hartill & Williams 2014). Almost all commercial fishing during this period has taken place in three statistical reporting areas, but none of these areas has been fished continuously. In any given year, fishers tend to select the most productive area(s). A stock-wide CPUE index, produced by combining data from the different areas, suggests that the abundance of scallops throughout SCA 1 declined in the late 1990s, and then steadily increased substantially until 2005–06, after which there has been a steady decline. Such an index, however, must be regarded with caution. The limitations of CPUE as an index of abundance are well understood, but are particularly severe for sedentary species like scallops. The nature of the relationship between CPUE and abundance is unclear, but is likely to be hyperstable.

Since 2012, the SCA 1 commercial scallop fishing industry (represented by NSEC, the Northland Scallop Enhancement Company Ltd.) has worked with NIWA to conduct industry-based stratified random dredge surveys of scallops annually in Bream and Rangaunu Bays, two of the core areas for commercial scallop fishing in SCA 1 (Williams et al. 2017). In 2017, only Bream Bay was surveyed (J. Williams, NIWA, unpublished data). Estimates of scallop population density in the surveyed areas are shown in Figure 2.

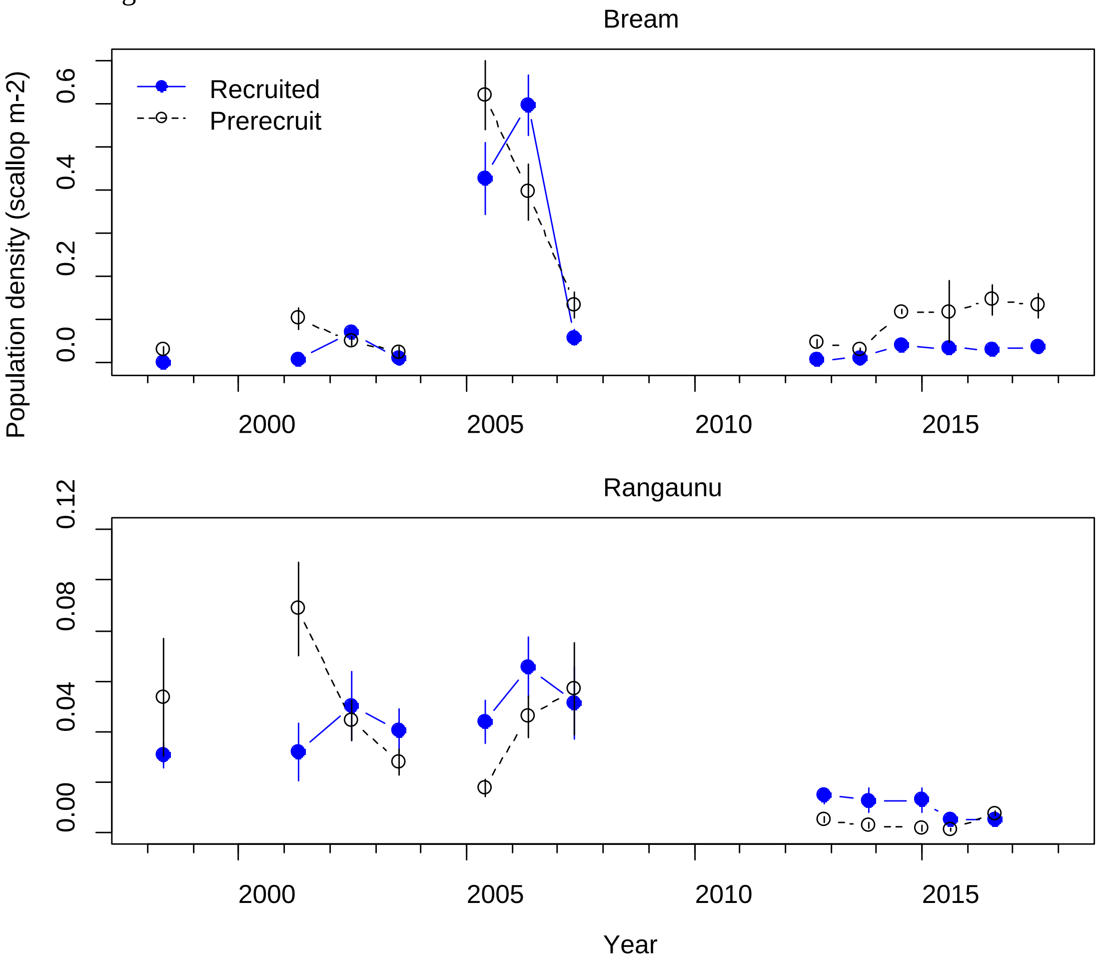


Figure 2: Scallop population density time series, 1998 to 2017. Values plotted are mean density +/- CV. Corrected for historical average dredge efficiency.

The 2012–17 surveys at Bream Bay show there has been an increasing trend in the abundance of pre-recruit sized scallops (< 100 mm) since 2013, but this has not resulted in substantive increases in recruited scallops (100 mm or larger), suggesting relatively slow growth and/or high mortality of these scallops has occurred in recent years. The relatively high commercial landings in 2015 (16 t meatweight, about 36% of the estimated total recruited biomass) in particular may explain why the recruited biomass at the time of the surveys has not increased markedly in response to increasing recruitment. Incidental mortality of undersized scallops caused by dredging may have also contributed. At Rangaunu, there has been no commercial scallop fishing since 2011. The surveys show that recruited abundance at Rangaunu was fairly stable (albeit at a low level) from 2012 to 2015, but had decreased by 2016. This may be expected given the low level of recruitment (large pre-recruits) observed in the 2012 to 2015 surveys. An increase in the abundance of large pre-recruits was evident in 2016. At Bream and especially at Rangaunu, scallop densities in the 2012–17 survey time series were low compared with peak levels previously observed in surveys from 1998 to 2007 (Williams et al. 2017).

5.2 Biomass estimates

Virgin biomass, B_0, and the biomass that will support the maximum sustainable yield, B_{MSY}, have not been estimated and are probably not appropriate reference points for a stock with highly variable recruitment and growth such as scallops.

There were reasonably regular assessments of the Northland scallop stock between 1992 and 2007 (Tables 5 and 6), in support of a CAY management strategy. Assessments were based on pre-season biomass surveys conducted by diving and/or dredging. Composite dive-dredge surveys were conducted annually from 1992 to 1997, except in 1993 when only divers were used. From 1998, surveys were conducted using dredges only. The Northland stock was not surveyed in 1999, 2000, 2004, or since 2007. Where dredges have been used, absolute biomass must be estimated by correcting for the efficiency of the particular dredges used. Previously, estimates were corrected for dredge efficiency using scalars (multipliers), which were estimated by directly comparing dredge counts with diver counts in experimental areas (e.g., Cryer & Parkinson 1999). However, different vessels were used in the most recent surveys and no trials were conducted on the efficiency of the particular dredges used. Estimating start-of-season biomass (Table 5) and yield is, therefore, difficult and contains unmeasurable as well as measurable uncertainty. For some years, the highest recorded estimate of dredge efficiency has been used, but more recent surveys have had a range of corrections applied from no correction (the most conservative) to the historical average across all studies (the least conservative). A model for estimating scallop dredge efficiency in SCA CS was developed by Bian et al. in 2012 but has not yet been used to reanalyse the historical survey time series for SCA 1.

Biomass estimates at the time of the survey for the Northland fishery are shown in Table 6. These estimates were calculated using historical average dredge efficiency for scallops 95 mm or more in shell length. Estimates of current biomass for the Northland stock are not available (the last biomass survey of the Northland fishery was in 2007), and there are no estimates of reference biomass with which to compare historical estimates of biomass. A substantial increase in biomass was observed between 2003 and 2006, which resulted in the 2006 biomass estimate being the highest recorded for Northland. In 2005 and 2006, estimates of biomass were considerably higher than those in 2003 for some beds (notably Bream Bay), but similar or lower in others. There appeared to have been a ‘shift’ in biomass away from the Far North and towards Bream Bay and Mangawhai/Pakiri Beach. This was the ‘reverse’ of the shift towards the Far North that occurred in the early 1990s. However, the 2007 survey results suggested that the biomass in Bream Bay and Mangawhai/Pakiri had declined markedly since 2006, and, consequently, the overall fishery biomass was far lower in 2007 than in previous years. The beds in Rangaunu Bay seem more consistent between years, although the 2007 biomass estimate was the highest on record. The biomass in Spirits/Tom Bowling Bays was higher in 2007 than 2006 but was low compared with historical levels.

Table 5: Estimated start of season abundance and biomass of scallops of 100 mm or more shell length in SCA 1 from 1997 to 2007 using historical average dredge efficiency; for each year the catch (reported on the 'Landed' section of CELRs), exploitation rate (catch to biomass ratio), and estimated fishing mortality (F_{est}) are also given. F_{est} was estimated by iteration using the Baranov catch equation where t = 7/12 and M = 0.50 spread evenly through the year. Abundance and biomass estimates are mean values up to and including 2003, and median values from 2005, when the analytical methodology for producing the estimates was modified. This, together with changes to survey coverage each year, make direct comparisons among years difficult. – no data. There were no surveys in 1999, 2000, 2004 or 2008–11. Estimates from the 2012–17 industry-based surveys of scallops at Bream and Rangaunu Bays are not included here.

Year	Abundance		Biomass				Exploitation rate	F_{est}
	(millions)	C.V.	(t green)	C.V.	(t meat)	C.V.	(catch/biomass)	≥100 mm
1997	34.9	0.22	3 520	0.22	475	0.22	0.27	0.62
1998	13.9	0.13	1 547	0.13	209	0.13	0.15	0.33
1999	–	–	–	–	–	–	–	–
2000	–	–	–	–	–	–	–	–
2001	8.9	0.27	871	0.27	118	0.27	0.32	0.78
2002	13.2	0.19	1 426	0.19	193	0.19	0.21	0.46
2003	9.3	0.19	1 031	0.19	139	0.19	0.28	0.66
2004	–	–	–	–	–	–	–	–
2005	51.3	0.72	5 565	0.70	753	0.71	0.09	0.19
2006	66.6	0.45	7 280	0.43	984	0.44	0.05	0.11
2007	15.1	0.47	1 637	0.45	208	0.46	0.14	0.31

Table 6: Estimated biomass (t greenweight) of scallops of 95 mm or more shell length at the time of the surveys in various component beds of the Northland scallop fishery from 1992 to 2007, assuming historical average dredge efficiency. – indicates no survey in a given year; there have been no surveys of SCA 1 since 2007. Estimates of biomass given for 1993 are probably negatively biased, especially for Rangaunu Bay (*), by the restriction of diving to depths under 30 m, and all estimates before 1996 are negatively biased by the lack of surveys in Spirits Bay (†). Totals also include biomass from less important beds at Mangawhai, Pakiri, around the Cavalli Passage, in Great Exhibition Bay, and Tom Bowling Bay when these were surveyed. Commercial landings in each year for comparison can be seen in Table 2, wherein 'Far North' landings come from beds described here as 'Whangaroa', 'Doubtless', and 'Rangaunu'. The biomass of scallops 95 mm or larger shell length has not been estimated since 2007.

						Biomass (t)
	Bream Bay	Whangaroa	Doubtless	Rangaunu	Spirits Bay	Total
1992	1 733	–	78	766	–	3 092 †
1993	569	172	77	170 *	–	1 094 *
1994	428	66	133	871	–	1 611 †
1995	363	239	103	941	–	1 984 †
1996	239	128	32	870	3 361	5 098
1997	580	117	50	1 038	1 513	3 974
1998	18	45	37	852	608	1 654
1999	–	–	–	–	–	–
2000	–	–	–	–	–	–
2001	110	8	0	721	604	1 451
2002	553	10	–	1 027	1 094	2 900
2003	86	33	3	667	836	1 554
2004	–	–	–	–	–	–
2005	2 945	–	–	719	861	4 676
2006	5 315	–	–	1 275	261	7 539
2007	795	–	–	1 391	432	2 694

Substantial uncertainty stemming from assumptions about the dredge efficiency during the surveys, rates of growth and natural mortality between the survey and the start of the fishing season, and predicting the average recovery of meatweight from greenweight remain in these stock assessments. A new model of scallop dredge efficiency (Bian et al. 2012) has helped to reduce this uncertainty, as should any future research aimed at collecting more data on scallop growth and mortality. Managing the fisheries based on the number of recruited scallops at the start of the season as opposed to recruited biomass (the current approach) could remove the uncertainty associated with converting estimated numbers of scallops to estimated meatweight.

Diver surveys of scallops were conducted in June 2006 and June–July 2007 at selected scallop beds in Northland recreational fishing areas (Williams et al. 2008, Williams 2009). For the four small beds (total area of 4.35 km^2) surveyed, start-of-season biomass of scallops over 100 mm shell length was estimated to be 49.7 t greenweight (CV of 23%) or 6.2 t meatweight in 2006, and 42 t greenweight (CV of 25%) or 5 t meatweight (CV of 29%) in 2007.

Time series of biomass estimates have also been generated for 1998–2017 from the available data collected during the industry-based surveys in 2012–16 (Williams et al. 2017) and Bream Bay in 2017 (J. Williams, NIWA, unpublished data), and the 1998–2017 surveys (Table 7).

5.3 Estimation of Maximum Constant Yield (MCY)

MCY has not been estimated for Northland scallops because it is not thought to be a reasonable management approach for highly fluctuating stocks such as scallops.

Table 7: Estimated biomass (t greenweight) of recruited scallops 100 mm or more shell length at the time of the surveys at Bream and Rangaunu Bays from 1998 to 2017, assuming historical average dredge efficiency. – indicates no survey in a given year or bay.

Year	Recruited biomass (t green)	
	Bream	Rangaunu
1998	211	475
1999	–	–
2000	–	–
2001	498	1 024
2002	259	564
2003	153	342
2004	–	–
2005	3 326	192
2006	2 514	596
2007	509	652
2008	–	–
2009	–	–
2010	–	–
2011	–	–
2012	317	36
2013	207	21
2014	394	15
2015	600	6
2016	911	61
2017	821	–

5.4 Estimation of Target Harvest (Exploitation) Rate

The estimation of Provisional Yield (PY) is no longer accepted as appropriate, and assessments since 1998 have used a CAY approach.

Yield estimates are generally calculated using reference rates of fishing mortality applied in some way to an estimate of current or reference biomass. Cryer & Parkinson (2006) reviewed reference rates of fishing mortality and summarised modelling studies by Cryer & Morrison (1997) and Cryer et al. (2004). The Shellfish Working Group recommend $F_{0.1}$ as the most appropriate reference rate (target) of fishing mortality for scallops.

Management of Northland scallops is based on a CAY approach. Since 1998, in years when biomass surveys have been conducted, catch limits have been adjusted in line with estimated start-of-season recruited biomass and an estimate of CAY made using the Baranov catch equation:

$$CAY = \frac{F_{ref}}{F_{ref} + M}(1 - e^{-(F_{ref}+M)t})B_{beg}$$

where t = 7/12 years, F_{ref} is a reference fishing mortality ($F_{0.1}$) and B_{beg} is the estimated start-of-season (15 July) recruited biomass (scallops of 90 mm or more shell length). Natural mortality is assumed to act in tandem with fishing mortality for the first seven months of the fishing season, the length of the current Northland commercial scallop season. B_{beg} is estimated assuming historical average dredge efficiency at length, average growth (from previous tagging studies), M = 0.5 spread evenly through the year, and historical average recovery of meatweight from greenweight. Because of the uncertainty over biomass estimates, growth and mortality in a given year, and appropriate reference rates of fishing mortality, yield estimates must be treated with caution.

Modelling studies for Coromandel scallops (Cryer & Morrison 1997, Cryer et al. 2004) indicate that $F_{0.1}$ is sensitive not only to the direct incidental effects of fishing (reduced growth and increased mortality on essentially adult scallops), but also to indirect incidental effects (such as additional juvenile mortality related to reduced habitat heterogeneity in dredged areas). Cryer & Morrison's (1997) yield-per-recruit model for the Coromandel fishery was modified to incorporate growth parameters more suited to the Northland fishery and estimate reference fishing mortality rates. Including direct incidental effects of fishing only, and for an assumed rate of natural mortality of M = 0.50, $F_{0.1}$ was estimated as $F_{0.1}$ = 0.943 y^{-1} (reported by Cryer et al. 2004, as 7/12 * $F_{0.1}$ = 0.550) for SCA 1, but estimates of $F_{0.1}$ including direct and indirect incidental effects of fishing were not estimated.

Consequently, the most recent CAY estimates were derived in 2007 (the year of the last biomass survey) for one scenario only.

5.4.1 CAY including direct effects on adults

By including only the direct incidental effects of fishing on scallops, Cryer et al. (2004) derived an estimate of $F_{0.1}$ = 0.943 y^{-1} (reported by Cryer et al. 2004, as 7/12 * $F_{0.1}$ = 0.550). Using this value and the 2007 start-of-season biomass estimates (median projected values), CAY for 2007–08 was estimated to be 609 t greenweight or 77 t meatweight.

These estimates of CAY would have a CV at least as large as that of the estimate of start-of-season recruited biomass (50–51%), are sensitive to assumptions about dredge efficiency, growth and expected recovery of meatweight from greenweight, and relate to the surveyed beds only. The sensitivity of these yield estimates to excluding areas of low density has not been calculated, but excluding stations with scallop density less than 0.02 m^{-2} and 0.04 m^{-2} reduced the fishery-wide time-of-survey biomass estimate by 95% and 100%, respectively. It should be noted that these low-density exclusions were calculated before correcting for average historical dredge efficiency, so these estimates are conservative. However, even if corrections for dredge efficiency were applied and no exclusions were made, the density of scallops 100 mm or more was low in all areas of the fishery surveyed in 2007. There is also additional uncertainty associated with using a point estimate of $F_{0.1}$ (i.e., variance associated with the point estimate of $F_{0.1}$ was not incorporated in the analysis).

6. STOCK STATUS

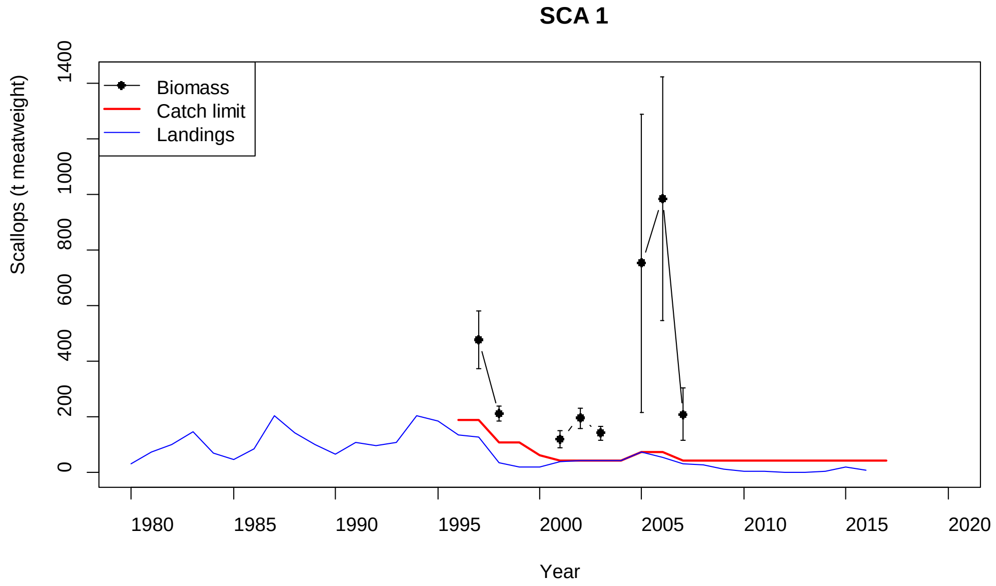
Stock structure assumptions

The stock structure of scallops in New Zealand waters is uncertain. For the purposes of the SCA 1 assessments, SCA 1 is assumed to be a single biological stock, although the extent to which the various beds or populations are separate reproductively or functionally is not known.

Stock Status	
Year of Most Recent Assessment	2007
Assessment Runs Presented	Estimate of CAY for 2007
Reference Points	Target: Fishing mortality at or below $F_{0.1}$ ($F_{0.1}$ = 0.943 y^{-1} including direct incidental effects of fishing only) Soft Limit: 20% B_0

	Hard Limit: 10% B_0 Overfishing threshold: F_{MSY} as approximated by $F_{0.1}$
Status in relation to Target	Likely (> 60%) to be at or below the target (in 2007–08, F_{est} = 0.31 y^{-1}) in 2007–08; unknown for 2018–19.
Status in relation to Limits	Unknown
Status in relation to Overfishing	Overfishing was Unlikely (< 40%) in 2007–08; unknown in 2018–19.

Historical Stock Status Trajectory and Current Status



Estimated biomass (mean and CV), catch limits, and reported landings of recruited scallops (100 mm or larger shell length) in t meatweight for SCA 1 since 1980. Biomass estimates from the annual 2012–17 industry-based surveys at Bream and Rangaunu Bays are not presented here because the surveys did not cover the full extent of the SCA 1 fishery.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	The trend in stock biomass since 2007 is unknown. Industry surveys of core fishery areas, Bream Bay and Rangaunu Bay, in 2012–17 suggest biomass in those areas was low compared with estimates from the 2005–07 surveys, but biomass in Bream Bay followed an increasing trend from 2013 to 2016.
Recent Trend in Fishing Intensity or Proxy	F_{est} cannot be estimated for this fishery for recent years. Landings between 2010–11 and 2014–15 were low (between 0 and 2 t). Fishing intensity has increased in Bream Bay since 2015 (7 to 16 t).
Other Abundance Indices	CPUE is not a reliable index of abundance (Cryer 2001).
Trends in Other Relevant Indicator or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	Stock projections are not available
Probability of Current Catch causing Biomass to remain below or to decline below Limits	Soft Limit: Unknown Hard Limit: Unknown

Probability of Current TACC causing Biomass to remain below or to decline below Limits	Very Likely (> 90%) for the TACC
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Very Likely (> 90%) for the TACC

Assessment Methodology and Evaluation		
Assessment Type	Level 2: Partial quantitative stock assessment	
Assessment Method	Biomass surveys and CAY management strategy	
Assessment Dates	Latest assessment: 2007	Next assessment: Unknown
Overall Assessment Quality Rank	1 – High Quality	
Main data inputs (rank)	Biomass survey: 2007	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	Current model has been in use since 2005	
Major Sources of Uncertainty	- dredge efficiency during the survey - growth rates and natural mortality between the survey and the start of the fishing season - predicting the average recovery of meatweight from greenweight - the extent to which dredging causes incidental mortality and affects recruitment.	

Qualifying Comments
In the Northland fishery some scallop beds are persistent and others are ephemeral. The extent to which the various beds or populations are reproductively or functionally separate is not known. This fishery is managed with a CAY management strategy with a base TACC. However, the management strategy currently resembles a constant catch strategy because there have been no surveys since 2007.

Environmental and Ecosystem Considerations	
Observer coverage	No observer coverage
Non-target fish and invertebrate catch	No local information on non-target fish and invertebrate catch. A historical analysis of survey data from a deep area within Spirits Bay highlighted extreme biodiversity, and led to the closure of that area to commercial fishing (including scallop dredging).
Incidental catch of seabirds	There is no known incidental catch of seabirds from *P. novaezelandiae* scallop fisheries.
Incidental catch of mammals	There is no known incidental catch of mammals from *P. novaezelandiae* scallop fisheries.
Incidental catch of other protected species	There is no known incidental catch of protected species from *P. novaezelandiae* scallop fisheries.
Benthic interactions	There have been several studies in New Zealand to assess effects of scallop dredging on benthic habitats. Generally with increasing fishing intensity there are decreases in the density and diversity of benthic communities and, especially, the density of emergent epifauna that provide structured habitat for other fauna.

7. FOR FURTHER INFORMATION

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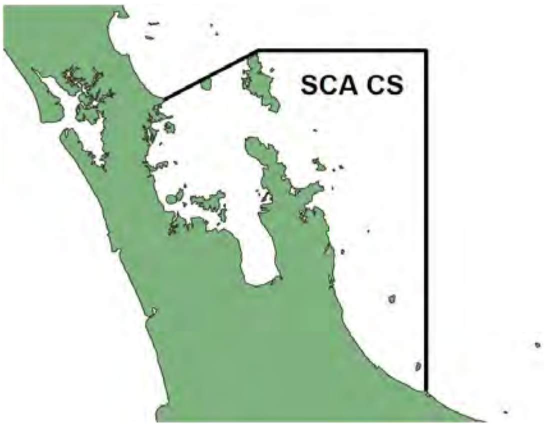
SCALLOPS COROMANDEL (SCA CS)

(*Pecten novaezelandiae*)
Kuakua, Tipa



1. FISHERY SUMMARY

Coromandel scallops (SCA CS) were introduced into the QMS on 1 April 2002 with a TAC of 48 t, comprising a TACC of 22 t, allowances of 7.5 t for recreational and customary fisheries, and an allowance of 11 t for other sources of mortality. Following a review of the TAC in 2012–13 (Ministry for Primary Industries 2013), on 1 April 2013 the TAC was changed to 131 t, comprising a TACC of 100 t, allowances of 10 t for recreational and customary fisheries, and 11 t for other sources of mortality. Following a further review (Ministry for Primary Industries 2016), on 1 April 2016 the TAC was reduced to 81 t, and the TACC was reduced to 50 t (allowances for recreational, customary and other mortality were not changed) (Table 1; values all in meatweight: adductor muscle plus attached roe).

Table 1: Total Allowable Commercial Catch (TACC, t) declared for SCA CS since introduction into the QMS.

Year	TAC	Customary	Recreational	Other mortality	TACC
2002–12	48	7.5	7.5	11	22
2013–15	131	10	10	11	100
2016–present	81	10	10	11	50

1.1 Commercial fisheries

SCA CS supports a regionally important commercial fishery situated between Cape Rodney at Leigh in the north and Town Point near Tauranga in the south. Fishing has been conducted within discrete beds around Little Barrier Island, east of Waiheke Island (though not in recent years), at Colville, north of Whitianga (to the west and south of the Mercury Islands), and in the Bay of Plenty (principally off Waihi, and around Motiti and Slipper Islands). In 2011, fishers discovered that a large area of the Hauraki Gulf contained good densities of large scallops, which supported a large proportion of the fishing from 2011 to 2013. This new, deeper (45–50 m water depth) bed was found mainly within statistical reporting area 2W and a smaller portion in 2S, and was surveyed for the first time in 2012. However, fishing of this area ceased soon after, despite catches below the catch limits informed by the survey. Results of an industry-based survey suggested biomass in the surveyed part of that area was very low in 2015.

All commercial fishing is by dredge, with fishers preferring self-tipping ‘box’ dredges (1.5–2.4 m wide, fitted with a rigid tooth bar on the leading bottom edge) to the ‘ring bag’ designs used in the Challenger and Chatham Island fisheries. The fishing year applicable to this fishery is from 1 April to 31 March. The Coromandel commercial scallop fishing season runs from 15 July to 21 December each year. Until the 1994 season, the minimum legal size was 100 mm shell length. From 1995 onwards, a new minimum legal size of 90 mm shell length was applied in the commercial fishery (but not the recreational or customary fisheries) as part of a management plan comprising several new measures.

A wide variety of effort controls (e.g., dredge size, fishing hours or non-fishing days) and daily/explicit seasonal catch limits specified in meatweight (adductor muscle with roe attached) have been imposed over the years. In 2017, six vessels were operating in the commercial fishery.

The SCA CS commercial fishing industry is represented by the Coromandel Scallop Fishermen's Association (CSFA). Since 2010, in addition to CELR reporting, CSFA has implemented a voluntary management strategy, the 'CPUE limit rule' that aims to ensure that scallop beds will not be fished below a specified level of CPUE. Once a specified lower CPUE limit has been reached, fishing within that area of the fishery ceases for the remainder of the season. To inform this approach, CSFA have carried out a logbook programme that involves recording fishery data (catch and effort) at a fine spatial scale within the broader CELR statistical reporting areas. Meatweight recovery, and the proportion of legal size scallops in the catch, are also monitored and used to determine fishing patterns. In addition, the fishery is open for five days per week and daily catch limits apply, by agreement of the quota holders.

Catch and catch rates from the Coromandel fishery are variable both within and among years, a characteristic typical of most scallop fisheries worldwide. Catch rates typically decline as each season progresses, but such declines are highly variable and depletion analysis has not been successfully used to assess start-of-season biomass. Since 1980 when the fishery was considered to be fully developed, landings have varied more than 30-fold from less than 6 t to over 188 t (meatweight). The two lowest recorded landings were in 1999 and 2000.

SCA CS is managed under the QMS using individual transferable quotas (ITQ) that are proportions of the Total Allowable Commercial Catch (TACC). Catch limits and landings from the Coromandel fishery are shown in Table 2 and Figure 1. SCA CS is gazetted on the Second Schedule of the Fisheries Act 1996, which specifies that, for certain 'highly variable' stocks, the Annual Catch Entitlement (ACE) can be increased within a fishing season. The TACC is not changed by this process and the ACE reverts to the base level of the TACC at the end of each season. From 1992 up to and including the 2012 fishing year, the base TACC for SCA CS was 22 t; requests from the commercial fishers for an increase in ACE were usually supported by estimates of biomass derived from (mostly) annual surveys, and also required a consultation process with all relevant stakeholders, prior to being implemented. In 2013, the base TACC was raised from 22 t to 100 t. The purpose of the increase was to reduce management and research costs by reducing the need for the annual survey and consultation processes that were required to support requests for increases in TACC. In 2016 the TACC was reduced to 50 t.

Table 2: Catch limits and landings (t meatweight or greenweight) from the Coromandel fishery since 1974. Data before 1986 are from Fisheries Statistics Unit (FSU) forms. Landed catch figures come from Monthly Harvest Return (MHR) forms, Licensed Fish Receiver Return (LFRR) forms, and from the 'Landed' section of Catch Effort and Landing Return (CELR) forms, whereas estimated catch figures come from the effort section of CELRs and are pro-rated to sum to the total CELR greenweight. 'Hauraki' = 2X and 2W, 'Mercury' = 2L and 2K, 'Barrier' = 2R, 2S and 2Q, 'Plenty' = 2A–2I. Seasonal catch limits (since 1992) have been specified as ACE or on permits in meatweight (Green[1] assumes the gazetted meatweight recovery conversion factor of 12.5% and probably overestimates the actual greenweight taken in most years). * 1991 landings include about 400 t from Colville; # a large proportion of the 2011, 2012 and 2013 landings were from a relatively deep (45–50 m) area of 2W fished for the first time in 2011; – indicates no catch limits set, or no reported catch. [Continued on next page]

			Landings (t)						
	Catch limits (t)		MHR	CELR		Scaled estimated catch (t green)			
Season	Meat	Green[1]	Meat	Meat	Green	Hauraki	Mercury	Barrier	Plenty
1974	–	–	–	–	26	0	26	0	0
1975	–	–	–	–	76	0	76	0	0
1976	–	–	–	–	112	0	98	0	14
1977	–	–	–	–	710	0	574	0	136
1978	–	–	–	–	961	164	729	3	65
1979	–	–	–	–	790	282	362	51	91
1980	–	–	–	–	1 005	249	690	23	77
1981	–	–	–	–	1 170	332	743	41	72
1982	–	–	–	–	1 050	687	385	49	80
1983	–	–	–	–	1 553	687	715	120	31
1984	–	–	–	–	1 123	524	525	62	12

			Landings (t)						
	Catch limits (t)		MHR	CELR		Scaled estimated catch (t green)			
Season	Meat	Green[1]	Meat	Meat	Green	Hauraki	Mercury	Barrier	Plenty
1985	–	–	–	–	877	518	277	82	0
1986	–	–	–	–	1 035	135	576	305	19
1987	–	–	–	–	1 431	676	556	136	62
1988	–	–	–	–	1 167	19	911	234	3
1989	–	–	–	–	360	24	253	95	1
1990	–	–	–	–	903	98	691	114	0
1991	–	–	–	–	1 392	*472	822	98	0
1992–93	154	1 232	–	–	901	67	686	68	76
1993–94	132	1 056	–	–	455	11	229	60	149
1994–95	66	528	–	–	323	17	139	48	119
1995–96	86	686	–	79	574	25	323	176	50
1996–97	88	704	–	80	594	25	359	193	18
1997–98	105	840	–	89	679	26	473	165	15
1998–99	110	880	–	37	204	1	199	2	1
1999–00	31	248	–	7	47	0	12	17	18
2000–01	15	123	–	10	70	0	24	2	44
2001–02	22	176	–	20	161	1	63	85	12
2002–03	35	280	32	31	204	0	79	12	112
2003–04	58	464	58	56	451	63	153	13	223
2004–05	78	624	78	78	624	27	333	27	237
2005–06	118	944	119	121	968	21	872	75	0
2006–07	118	944	118	117	934	28	846	60	0
2007–08	108	864	59	59	471	51	373	45	2
2008–09	95	760	71	72	541	12	509	15	5
2009–10	100	800	33	33	267	12	184	71	0
2010–11	100	800	35	35	281	11	110	160	1
2011–12	50	400	50	50	402	#220	160	20	0
2012–13	325	2600	73	73	584	#572	1	11	0
2013–14	100	800	51	68	545	#344	133	68	0
2014–15	100	800	34	35	280	27	186	64	4
2015–16	100	800	27	33	264	11	153	32	0
2016–17	50	400	27	27	216	0	94	152	0
2017–18	50	400	32	32	307	22	204	81	
2018–19	50	400	27	27	-	-	-	-	-

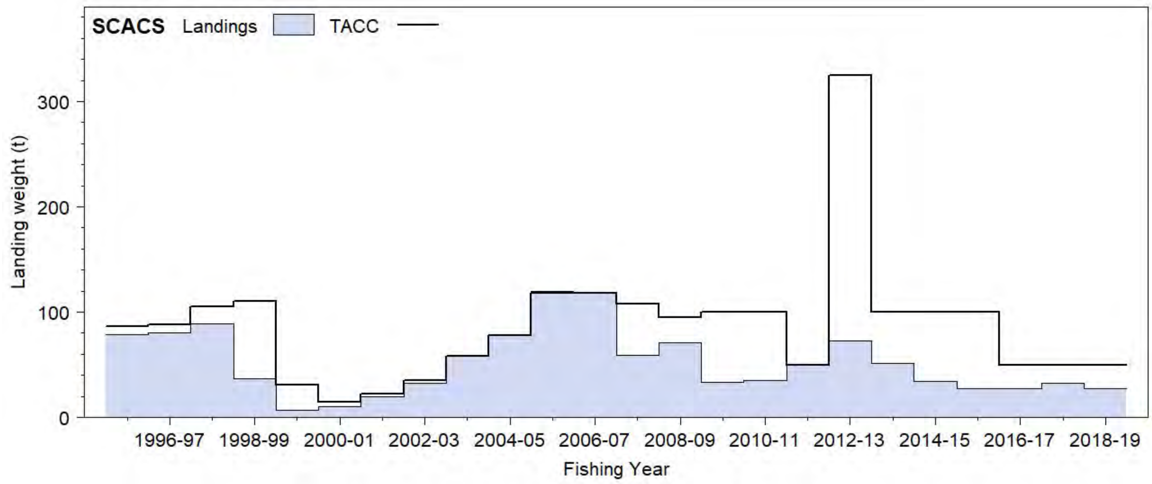


Figure 1: Landings and catch limits for SCA CS (Coromandel) from 1995–98 to 2018–19. TACC refers to catch limit, and Weight refers to meatweight.

1.2 Recreational fisheries

Until 2006, the recreational scallop season ran from 15 July to 14 February, but in 2007 the season was changed to run from 1 September to 31 March. Fishers may take up to 20 scallops per day with a minimum legal size of 90 mm shell width. Estimates of the recreational scallop harvest from SCA CS are shown in Table 3. The harvest estimates provided by telephone-diary surveys between 1993 and 2001 are no longer considered reliable for various reasons. A Recreational Technical Working Group concluded that these harvest estimates should be used only with the following qualifications: a) they may be very inaccurate; b) the 1996 and earlier surveys contain a methodological error; and c) the 2000 and 2001 estimates are implausibly high for many important fisheries. In response to these problems and the cost and scale challenges associated with onsite methods, a National Panel Survey was conducted for the first time throughout the 2011–12 fishing year. The panel survey used face-to-face interviews of a random sample of 30 390 New Zealand households to recruit a panel of fishers and non-fishers for a full year. The panel members were contacted regularly about their fishing activities and harvest information collected in standardised phone interviews. The panel survey was repeated in 2017–18 using directly comparable methods (Wynne-Jones et al. 2019). A creel survey was conducted in 2007–08 to assess the feasibility of estimating the recreational catch in that part of the Coromandel scallop fishery from Cape Colville to Hot Water Beach (Holdsworth & Walshe 2014). The study was based on an access point (boat ramp) survey using interviewers to collect catch and effort information from returning fishers, and was conducted from 1 December 2007 to 28 February 2008 (90 days) during the peak of the scallop season. The annual recreational harvest level is likely to vary substantially through time.

Table 3: Estimates of the recreational harvest of scallops from SCA CS. Number, number of scallops; green, greenweight; meat, meatweight (assuming 12.5% recovery of meatweight from greenweight). The 2007–08 estimates are for a 90-day period of the summer in a defined area (Coromandel peninsula) within SCA CS only.

Year	Area	Survey method	Number	CV	Green (t)	Meat (t)	Reference
1991–93	SCA CS	Phone-diary	654 000	0.14	60–70	8–9	Teirney et al. (1997)
1996	SCA CS	Phone-diary	614 000	0.12	62	8	Bradford (1998)
99–2000	SCA CS	Phone-diary	257 000	1.01	30	4	Boyd & Reilly (2004)
2000–01	SCA CS	Phone-diary	472 000	0.47	55	7	Boyd et al. (2004)
2007–08	Coro. peninsula	Creel survey	205 400	0.09	24	3	Holdsworth & Walshe (2014)
2011–12	SCA CS	Panel survey	605 466	0.27	67	8	Wynne-Jones et al. (2014)
2017–18	SCA CS	Panel survey	335 864	0.18	37	5	Wynne-Jones et al. (2019)

For further information on recreational fisheries refer to the introductory SCA Working Group report.

1.3 Customary fisheries

Limited quantitative information on recent levels of customary take is available from Fisheries New Zealand (Table 4).

Table 4: Fisheries New Zealand records of customary harvest of scallops (reported on customary permits as numbers or greenweight, or units unspecified) taken from the Coromandel scallop fishery, 2003–04 to 2017–18. – indicates no data.

SCA CS	Quantity approved, by unit type				Actual quantity harvested, by unit type			
Fishing year	Weight (kg)	Number	Bin/Bucket/ Bag/Sack	Unspecified	Weight (kg)	Number	Bin/Bucket/ Bag/Sack	Unspecified
2005–06		600				500		
2006–07	60	290	19	6 340	0	180	2	1 579
2007–08	370	3 190	950	13 825	310	1 340	500	4 410
2008–09	370	2 390	11	13 550	82	2 090	4	4 476
2009–10	150	1 260	1	15 510	65	1 000	202	4 500
2010–11	555	2 300		18 800	190	1 400		6 485
2011–12	125	640		22 080	125	0		10 270
2012–13	125	80	3	30 200	75	80	200	11 440
2013–14				23 080				7 315
2014–15	80			12 850	35			6 948
2015–16				21 750				12 234
2016–17				19 977				11 767
2017–18	–			24 110				11 226

For further information on customary fisheries refer to the introductory SCA Working Group report.

1.4 Illegal catch

For information on illegal catch refer to the introductory SCA Working Group report.

1.5 Other sources of mortality

Research on the incidental effects of commercial scallop dredges in the Coromandel scallop fishery showed that scallops encountered by box dredges compared with scallops collected by divers had quite high mortality (about 20–30% mortality but potentially as high as 50% for scallops that are returned to the water; i.e., those just under the MLS) (Cryer & Morrison 1997). The incidental mortality caused by dredging substantially changed the shape of yield-per-recruit curves for Coromandel scallops, causing generally asymptotic curves to become domed, and decreasing estimates of F_{max} and $F_{0.1}$. More recent field experiments (Talman et al. 2004) and modelling (Cryer et al. 2004) suggest that dredging reduces habitat heterogeneity, increases juvenile mortality, makes yield-per-recruit curves even more domed, and decreases estimates of F_{max} and $F_{0.1}$ even further (Cryer & Parkinson 2006).

2. BIOLOGY

The growth of scallops within the Coromandel fishery is variable among areas, years, seasons and depths, and probably among substrates. In the Hauraki Gulf, scallops have been estimated to grow to 100 mm shell length in 18 months or less, whereas this can take three or more years elsewhere (Table 5). There is a steep relationship with depth and scallops in shallow water grow much faster than those in deeper water. This is not a simple relationship, however, as scallops in some very deep beds (e.g., Rangaunu Bay and Spirits Bay in the Far North, both deeper than 40 m) appear to grow at least as fast as those in favourable parts of the Coromandel fishery. Food supply undoubtedly plays a role.

A variety of studies suggest that average natural mortality in the Coromandel fishery is quite high at $M = 0.50\ y^{-1}$ (instantaneous rate), and maximum age in unexploited populations is thought to be about 6 or 7 years.

Table 5: Estimates of biological parameters.

Stock	Estimates		Source
1. Natural mortality, *M*			
Motiti Island	0.4–0.5		Walshe 1984
2. Weight = a(length)^b			
	a	b	
Coromandel fishery	0.00042	2.662	Cryer & Parkinson 1999
3. von Bertalanffy parameters			
	L_∞	K	
Motiti Island (1981–82)	140.6	0.378	Walshe 1984
Hauraki Gulf (1982–83)	115.9	1.200	Walshe 1984
Whitianga (1982)	114.7	1.210	Data of L.G. Allen, analysed by Cryer & Parkinson 1999
Whitianga (1983)	108.1	1.197	Data of L.G. Allen, analysed by Cryer & Parkinson 1999
Whitianga (1984)	108.4	0.586	Data of L.G. Allen, analysed by Cryer & Parkinson 1999
Coromandel fishery (1992–97)	108.8	1.366	Cryer & Parkinson 1999
Whitianga mean depth 10.6 m	113.5	1.700	Cryer & Parkinson 1999
Whitianga mean depth 21.1 m	109.0	0.669	Cryer & Parkinson 1999
Whitianga mean depth 29.7 m	110.3	0.588	Cryer & Parkinson 1999

For further information on biology refer to the introductory SCA Working Group report.

3. STOCKS AND AREAS

It is currently assumed for management that the Coromandel stock is separate from the adjacent Northland stock and from the various west coast harbours, Golden Bay, Tasman Bay, Marlborough Sounds, Stewart Island and Chatham Island areas.

Dispersal of scallops was investigated at a small spatial and temporal scale in the Coromandel fishery using genetic markers integrated with hydrodynamic modelling. Results showed small but significant spatial and temporal genetic differentiation, suggesting that the Coromandel fishery does not form a single panmictic unit with free gene flow and supporting a model of source-sink population dynamics (Silva 2015).

For further information on stocks and areas refer to the introductory SCA Working Group report.

4. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS

In the Coromandel scallop stock (SCA CS), a photographic approach was used in the 2006 dredge survey to provisionally examine non-target catch groups (Tuck et al. 2006), but a more quantitative and comprehensive study was conducted using non-target catch data collected in the 2009 dredge survey (Williams et al. 2010) with survey catches quantified by volume of different component categories. Over the whole 2009 survey, scallops formed the largest live component of the total catch volume (26%), followed by assorted seaweed (11%), starfish (4%), other live bivalves (4%), coralline turfing algae (1%) and other live components not exceeding 0.5%. Dead shell (identifiable and hash) formed the largest overall component (45%), and rock, sand and gravel formed 8%. Categories considered to be sensitive to dredging were caught relatively rarely. Data on non-target catch of the 2010 and 2012 surveys of SCA CS were also collected but not analysed; those data have been loaded to the Fisheries New Zealand database ‘scallop’ for potential future analysis (Williams & Parkinson 2010, Williams et al. 2013).

Refer to the introductory SCA Working Group report for general information on environmental and ecosystem considerations.

5. STOCK ASSESSMENT

Coromandel scallops are managed using a TACC of 50 t meatweight, which could be augmented with additional ACE after considering information about the abundance during the current fishing year. Previous in-season increases were based on the results from a pre-season biomass survey and the subsequent Current Annual Yield (CAY) estimates, using $F_{0.1}$ as a reference point.

From 1992 to 2010, biomass surveys of selected scallop beds in the fishery were conducted annually (excluding 2000 when no survey was conducted), as a means of estimating stock size and informing management decisions on potential increases in the annual TACC.

A survey was not conducted in 2011; instead, biomass estimates were calculated using estimates of projected biomass generated by projecting the 2010 survey data forward to the start of the 2011 fishing season. The projection approach used a length-based growth transition matrix (based on tag return data) to grow the scallops from the time of the survey (May 2010) to the start of the fishing season the following year (July 2011), correcting for dredge efficiency, and allowing for natural mortality and fishing mortality (catch and incidental mortality). Uncertainty was incorporated during the projection process by bootstrapping (resampling with replacement) from the various data sources (Tuck 2011).

In 2012, a comprehensive survey was conducted (Williams et al. 2013) that aimed to provide an estimate of abundance representative of the status of the overall SCA CS stock. The survey coverage was more extensive than used previously, with the stratification comprising ‘core’ strata (those surveyed and fished consistently in the past), ‘background’ strata (areas of lower densities outside the core strata that formed part of the survey coverage in the past), and ‘new’ strata (those in Hauraki Gulf that had never been surveyed before).

There was no survey conducted in 2013. Industry-based surveys were conducted in 2014 (D. Middleton, unpublished data) and 2015 (Williams 2015), with design and analytical assistance provided by research providers. Surveys have not been conducted since 2016.

5.1 Estimates of fishery parameters and abundance

Fishing mortality has been variable over time in the Coromandel fishery (Table 6).

Standardised CPUE from the statutory catch and effort returns is not considered a reliable index of abundance at the stock level (Cryer 2001). Simulation studies have, however, examined the use of local area CPUE as a basis for some management strategies (Haist & Middleton 2014) and this approach has subsequently informed a voluntary management approach in the commercial fishery.

5.2 Biomass estimates

From 1992 to 2012, biomass surveys were conducted almost annually (Tables 6 and 7). Average biomass in the absence of fishing, B_0, and the biomass that will support the maximum sustainable yield, B_{MSY}, have not been estimated and are probably not appropriate reference points for a stock with highly variable recruitment and growth such as scallops.

Assessments of current yields were based on pre-season biomass surveys done by diving and/or dredging (Tables 6 and 7). Bian et al. (2012) modelled the efficiency of box dredges used in northern New Zealand scallop fisheries, and the results suggest the efficiency of these dredges was underestimated previously (2004 to 2010), resulting in overestimation of biomass and yield. The estimates of abundance and biomass for 2012 (Williams et al. 2013) and 2015 (Williams 2015) were made using the new parametric model of dredge efficiency (Bian et al. 2012) that estimates efficiency with respect to scallop length, water depth, substrate type and tow termination.

Discerning trends in the abundance and biomass of recruited scallops is complicated by changes to survey coverage, the establishment of closed areas, and uncertainty about dredge efficiency in any particular year. Time series of abundance and biomass estimates of scallops 90 mm or more shell length are shown in Table 7. It is important to note that these time series were produced by correcting for dredge efficiency using the method of Cryer & Parkinson (2006); the 2012 values were generated using that same method so that all years are comparable. For 2012, the estimates were generated using data from the 'core' strata only (i.e., the 'background' strata, and 'new' strata in the Hauraki Gulf region, were excluded, the latter because there was no survey from the past; it was surveyed for the first time in 2012).

Table 6: Estimated start of season abundance and biomass of scallops of 90 mm or more shell length in the Coromandel fishery since 1998 using historical average dredge efficiency; for each year, the catch (reported on the 'Landed' section of CELRs), exploitation rate (catch to biomass ratio), and the estimated fishing mortality (F_{est}) are also given. F_{est} was estimated by iteration using the Baranov catch equation where t = 5/12 and M = 0.50 spread evenly through the year. Abundance and biomass estimates are mean values up to and including 2003, and median values from 2004, when the analytical methodology for producing the estimates was modified. Note the estimates for 1998–2010 were produced by correcting for dredge efficiency using the method of Cryer & Parkinson (2006), which was replaced by the method of Bian et al. (2012) in 2012 (a preliminary version of that method was used in 2011). This, together with changes to survey coverage each year, makes direct comparisons among years difficult. There was no survey in 2000, 2011, 2013, 2016, 2017 or 2018. The 2011 values are projected estimates generated by projecting forward the 2010 survey data to the start of the 2011 fishing season. Estimates of abundance in numbers (millions) of scallops were not reported in 2011. Industry-based surveys were conducted in 2014 and 2015, although estimates from the 2014 survey were unavailable for inclusion in this table. – indicates no data. [Continued on next page]

Year	Abundance		Biomass				Catch	Exploitation rate	F_{est}
	(millions)	CV	(t green)	CV	(t meat)	CV	(t meat)	(catch/biomass)	≥90 mm
1998	35.4	0.16	2 702	0.16	365	0.16	31	0.08	0.237
1999	10.3	0.18	752	0.18	102	0.18	7	0.07	0.189
2000	–	–	–	–	–	–	10	–	–
2001	8.3	0.26	577	0.27	78	0.27	20	0.26	0.796
2002	10.3	0.20	768	0.20	104	0.20	31	0.30	0.954
2003	16.0	0.18	1 224	0.18	165	0.18	56	0.34	1.131

Year	Abundance		Biomass				Catch	Exploitation rate	F_{est}
	(millions)	CV	(t green)	CV	(t meat)	CV	(t meat)	(catch/biomass)	≥90 mm
2005	169.3	0.24	14 374	0.23	1 795	0.27	121	0.07	0.185
2006	143.1	0.21	12 302	0.21	1 531	0.25	117	0.08	0.212
2007	101.6	0.20	8 428	0.20	1 061	0.23	59	0.06	0.152
2008	94.0	0.29	6 900	0.28	868	0.31	72	0.08	0.232
2009	64.5	0.23	4 676	0.22	595	0.24	33	0.06	0.154
2010	58.8	0.20	4 442	0.19	540	0.21	35	0.07	0.180
2011	–	–	5 426	0.85	658	0.87	50	0.08	0.211
2012	140.0	0.15	11 423	0.15	1 380	0.18	73	0.05	0.145
2013	–	–	–	–	–	–	–	–	–
2014	–	–	–	–	–	–	–	–	–
2015	14.5	0.17	1 065	0.18	128	0.20			
2016	–	–	–	–	–	–	–	–	–
2017	–	–	–	–	–	–	–	–	–
2018	–	–	–	–	–	–	–	–	–

The 2012 estimates were produced from a comprehensive survey coverage that included previously unsurveyed areas of the SCA CS stock (e.g., the 40–50 m deep region of Hauraki Gulf, which contained a considerable biomass in 2012).

Table 7: Estimated abundance and biomass of scallops 90 mm or more shell length at the time of surveys in the five main regions of the Coromandel fishery since 1998. It excludes the 'new', deep fishery region in Hauraki Gulf, which was fished for the first time in 2011, and surveyed for the first time in 2012 (estimated 148.5 million scallops or 13 278 t greenweight biomass). Survey data were analysed using a non-parametric re-sampling with replacement approach to estimation (1000 bootstraps). Note these estimates were produced by correcting for dredge efficiency using the method of Cryer & Parkinson (2006), which has now been replaced by the method of Bian et al. (2012). Figures are not necessarily directly comparable among years because of changes to survey coverage. – indicates no survey in a region or year. The 2001 survey totals include scallops surveyed in 7 km² strata at both Kawau (0.5 million, 3 t) and Great Barrier Island (0.8 million, 62 t).

Year	Abundance (millions)						Area surveyed
	Barrier	Waiheke	Colville	Mercury	Plenty	Total fishery	(km²)
1998	2.0	9.0	0.4	21.3	2.2	36.1	341
1999	0.5	0.5	0.0	7.3	2.7	11.2	341
2000	–	–	–	–	–	–	–
2001	7.4	0.4	–	6.9	2.1	18.1	125
2002	1.8	4.0	–	6.6	2.0	14.7	119
2003	2.5	4.0	4.3	12.3	4.9	28.6	130
2004	4.5	9.8	0.4	58.5	8.2	82.6	149
2005	6.2	3.3	3.0	118.8	12.6	145.3	174
2006	5.6	–	10.3	101.6	6.5	125.3	160
2007	4.2	1.3	4.4	59.9	14.3	84.6	175
2008	2.0	–	1.7	56.3	4.8	65.0	144
2009	10.4	–	3.1	31.8	1.3	46.9	144
2010	9.6	0.8	2.6	28.0	3.9	45.6	149
2011	–	–	–	–	–	–	–
2012	7.7	0.4	2.4	22.8	2.9	36.8	180
2013	–	–	–	–	–	–	–
2014	–	–	–	–	–	–	–
2015	1.9	–	0.4	9.6	–	11.8	60
2016	–	–	–	–	–	–	–
2017	–	–	–	–	–	–	–
2018	–	–	–	–	–	–	–
1998	173	731	30	1 674	205	2 912	341
1999	42	34	1	559	224	873	341
2000	–	–	–	–	–	–	–
2001	554	32	–	525	165	1 362	125
2002	150	289	–	538	163	1 156	119
2003	225	302	387	995	406	2 355	130
2004	348	737	30	4 923	676	6 794	149
2005	544	274	316	10 118	1 058	12 404	174
2006	519	–	1 041	8 731	534	10 902	160
2007	376	96	409	5 498	1 110	7 539	175
2008	166	–	150	4 575	367	5 265	144
2009	823	–	257	2 512	102	3 725	144
2010	764	59	219	2 299	291	3 671	149
2011	–	–	–	–	–	–	–
2012	629	32	250	1 855	225	3 027	180
2013	–	–	–	–	–	–	–
2014	–	–	–	–	–	–	–
2015	136	–	27	698	–	861	60
2016	–	–	–	–	–	–	–
2017	–	–	–	–	–	–	–
2018	–	–	–	–	–	–	–

Uncertainty stemming from assumptions about dredge efficiency during the surveys, rates of growth and natural mortality between survey and season, and predicting the average recovery of meatweight from greenweight remain in these biomass estimates. A new model of scallop dredge efficiency (Bian et al. 2012) has helped to reduce this uncertainty. Managing the fisheries based on the number of recruited scallops at the start of the season as opposed to recruited biomass (the current approach) could remove the uncertainty associated with converting estimated numbers of scallops to estimated meatweight.

To better enable comparison of the results of the 2012 and 2015 surveys, data from the 2012 survey were reanalysed using the 2015 survey extent (comprising the core strata fished in SCA CS). Abundance and biomass estimates from this reanalysis are shown in Table 8. The recruited scallop population in the surveyed area of Hauraki Gulf experienced a major population decrease from 77 million in 2012 to 3 million in 2015; in the other areas surveyed in both years, recruited abundance in 2015 (12 million) was about half the size of that in 2012 (23 million).

Table 8: Estimated start-of-season abundance and biomass of scallops of 90 mm or more shell length in core areas of the Coromandel fishery in 2012 and 2015, using historical average dredge efficiency.

Year	Location	Area	Abundance					Biomass
	(grouping)	(km^2)	(millions)	CV	(t green)	CV	(t meat)	CV
2012	Barrier	4	6.4	0.23	466	0.20	57	0.24
	H. Gulf	205	77.1	0.23	6 505	0.23	794	0.26
	Colville	10	1.8	0.28	156	0.31	19	0.34
	Mercury	46	15.4	0.16	1 147	0.15	137	0.20
	Total	**265**	**100.4**	**0.18**	**8255**	**0.19**	**1 014**	**0.21**
2015	Barrier	4	1.9	0.36	136	0.37	16	0.39
	H. Gulf	205	2.6	0.29	191	0.29	23	0.32
	Colville	10	0.4	0.45	27	0.45	3	0.47
	Mercury	46	9.6	0.25	698	0.25	83	0.29
	Total	**265**	**14.5**	**0.17**	**1 065**	**0.18**	**128**	**0.20**

In the recreational SCA CS fishing areas, diver surveys of scallops were conducted annually in June–July from 2006 to 2010 (Williams et al. 2008, Williams 2009a, b, 2012). For the four small beds (total area of 4.64 km^2) surveyed each year, the projected (15 July) biomass of scallops over 100 mm shell length was estimated to be 128 t greenweight (CV of 26%) or 16 t meatweight in 2006, 82 t greenweight (CV of 13%) or 10 t meatweight (CV of 20%) in 2007, and 79 t greenweight (CV of 14%) or 10 t meatweight (CV of 21%) in 2008. Survey stratum boundaries were revised in 2009 to better reflect the extent of the scallop bed at each site, resulting in a slightly reduced total area (3.6 km^2) surveyed; the total projected biomass was estimated to be 50 t greenweight or 6 t meatweight (CVs of 13%) in 2009, and 48 t greenweight or 6 t meatweight (CVs of 13% and 16%) in 2010 (Williams 2012).

5.3 Estimation of Maximum Constant Yield (MCY)

MCY has not been estimated for Coromandel scallops because it is not thought to be a reasonable management approach for highly fluctuating stocks such as scallops.

5.4 Estimation of Target Harvest (Exploitation) Rate

Until 1997, assessments for the Coromandel fishery were based on Provisional Yield (PY, estimated as the lower bound of a 95% confidence distribution for the estimated start-of-season biomass of scallops 100 mm or more shell length). However, experiments and modelling showed this method to be sub-optimal. New estimates of the reference fishing mortality rates $F_{0.1}$, $F_{40\%}$ and F_{max} were made, taking into account experimental estimates of incidental fishing mortality. For assessments since 1998, CAY was estimated using these reference fishing mortality rates, and CAY supplanted PY as a yield estimator. Recent experimentation and modelling of juvenile mortality in relation to habitat heterogeneity suggest that even these more conservative reference fishing mortality rates may be too high. This may have resulted in overestimation of potential yield, particularly when fishing tends to focus on small proportions of the biomass.

Yield estimates are generally calculated using reference rates of fishing mortality applied to an estimate of current or reference biomass. Cryer & Parkinson (2006) reviewed reference rates of fishing mortality and summarised modelling studies by Cryer & Morrison (1997) and Cryer et al. (2004). $F_{0.1}$ is used as the target reference rate of fishing mortality for scallops. From 1998 to 2012, catch limits have been adjusted in line with estimated start-of-season recruited biomass and an estimate of CAY made using the Baranov catch equation:

$$CAY = \frac{F_{ref}}{F_{ref} + M}\left(1 - e^{-(F_{ref}+M)t}\right)B_{beg}$$

where t = 5/12 years, F_{ref} is a reference fishing mortality ($F_{0.1}$) and B_{beg} is the estimated start-of-season (15 July) recruited biomass (scallops of 90 mm or more shell length). Natural mortality is assumed to act in tandem with fishing mortality for the first five months of the fishing season, the length of the current Coromandel commercial scallop season. B_{beg} is estimated assuming historical average dredge efficiency at length, average growth (from previous tagging studies), M = 0.5 spread evenly through the year, and historical average recovery of meatweight from greenweight. Because of the uncertainty over biomass estimates, growth and mortality in a given year, and appropriate reference rates of fishing mortality, yield estimates must be treated with caution.

Modelling studies for Coromandel scallops (Cryer & Morrison 1997, Cryer et al. 2004) indicate that $F_{0.1}$ is sensitive not only to the direct incidental effects of fishing (reduced growth and increased mortality on adult scallops), but also to indirect incidental effects (such as additional juvenile mortality related to reduced habitat heterogeneity in dredged areas). By including only the direct incidental effects of fishing on scallops, Cryer et al. (2004) derived an estimate of $F_{0.1}$ = 1.034 y^{-1} (reported by Cryer et al. 2004, as 5/12 * $F_{0.1}$ = 0.431). Cryer et al. (2004) also modelled the 'feedback' effects of habitat modification by the dredge method on juvenile mortality in scallops. They developed estimates of F_{ref} that incorporated such effects, but had to make assumptions about the duration of what they called the 'critical phase' of juvenile growth during which scallops were susceptible to increased mortality. To give some guidance on the possible outcome of including 'indirect' (as well as direct) effects on yield estimates, the Cryer et al. (2004) estimate of $F_{0.1}$ = 0.658 y^{-1} (reported as 5/12 * $F_{0.1}$ = 0.274) was also applied in calculations of CAY.

For both scenarios, the estimates of CAY would have CVs at least as large as those of the estimate of start-of-season recruited biomass, are sensitive to assumptions about dredge efficiency, growth and expected recovery of meatweight from greenweight, and relate to the surveyed beds only. Further, the second approach, which includes indirect incidental effects (putative 'habitat effects'), is sensitive to the duration of any habitat-mediated increase in juvenile mortality. There is also additional uncertainty associated with using a point estimate of $F_{0.1}$ (i.e., variance associated with the point estimate of $F_{0.1}$ was not incorporated in the analysis), and the fact that the estimates of $F_{0.1}$ were generated using estimates of dredge efficiency that are different to those used to estimate current biomass; the latter may have resulted in underestimates of yield.

The last biomass survey was undertaken in 2012 and the CAY estimates calculated (t meatweight):

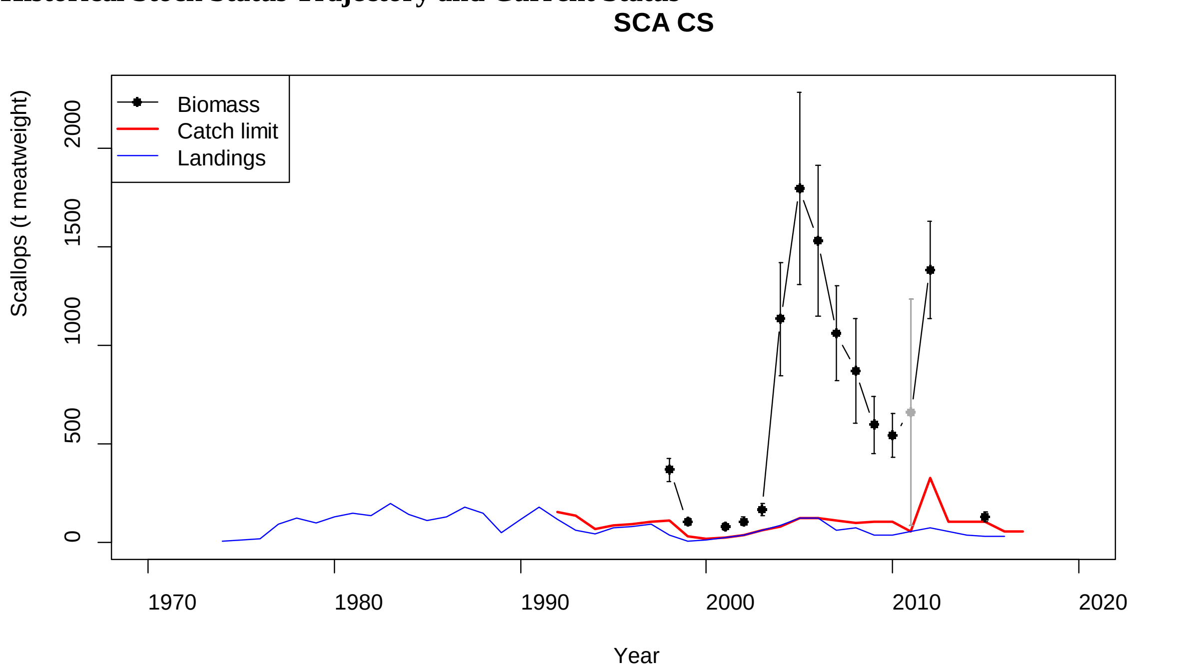
		$F_{0.1}$=0.431	$F_{0.1}$=0.274
B_{beg}	1 380 t	439 t	300 t

6. STOCK STATUS

Stock structure assumptions
The stock structure of scallops in New Zealand waters is uncertain. For the purposes of this assessment, SCA CS is assumed to be a single biological stock, although the extent to which the various beds or populations are reproductively or functionally separate is not known.

Stock Status	
Year of Most Recent Assessment	2012–13 fishing year
Assessment Runs Presented	Two approaches to estimating CAY
Reference Points	Target: Fishing mortality at or below $F_{0.1}$ ($F_{0.1}$ = 1.034 y^{-1} including direct incidental effects of fishing only, or $F_{0.1}$ = 0.658 y^{-1} including direct and indirect effects of fishing) Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: F_{MSY} as approximated by $F_{0.1}$
Status in relation to Target	Likely (> 60%) to be at or below F_{target} (in 2012–13, F_{est} = 0.145 y^{-1}) in 2012–13 Unknown for 2018–19
Status in relation to Limits	Unknown
Status in relation to Overfishing	Overfishing was Unlikely (< 40%) to be occurring in 2012–13 Unknown for 2018–19

Historical Stock Status Trajectory and Current Status



Estimated biomass (mean and CV), catch limits, and landings of recruited scallops (90 mm or larger shell length) in t meatweight for SCA CS since 1974. Research surveys were not conducted in 2000, 2011 or 2013–18. In 2011, biomass was estimated by projecting forward from the 2010 survey. Industry-based surveys were conducted in 2014 and 2015, although information from the 2014 survey was not available to be included here; biomass in the core fishery areas surveyed in 2015 was an estimated 128 t.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	The comprehensive 2012 survey coverage included a large new area of the fishery in Hauraki Gulf, and showed that it held a considerable biomass (794 t). It is unknown whether the large biomass of scallops found in 2012 was a consistent part of the population, or a product of successful recruitment in the years leading up to that survey. Including that ‘new’ area, estimated biomass in 2012 was an estimated 1014 t. The recruited scallop population in the surveyed area of Hauraki Gulf experienced a major population decrease from 794 t in 2012 to 23 t in 2015; in the other areas surveyed in both years, recruited biomass in 2015 (102 t) was about half the size of that in 2012 (213 t).

Recent Trend in Fishing Intensity or Proxy	At the fishery-wide level, estimated fishing mortality on scallops 90 mm or more was relatively low in the periods 1998–99 and 2004–12 (mean F_{est} = 0.19 y^{-1}).
Other Abundance Indices	-
Trends in Other Relevant Indicator or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	Stock projections beyond the start of the 2012 season are not available. Catch, catch rates and growth are highly variable both within and among years. Recruitment is also highly variable between years.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unlikely (< 40%) Hard Limit: Unlikely (< 40%)
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Very Unlikely (< 10%)

Assessment Methodology and Evaluation		
Assessment Type	Level 2 – Partial Quantitative Stock Assessment	
Assessment Method	Biomass surveys and CAY estimate	
Assessment Dates	Latest assessment: 2012	Next assessment: Unknown
Overall Assessment Quality Rank	1 – High Quality	
Main data inputs (rank)	Biomass survey: 2012	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	None since the 2009 assessment	
Major Sources of Uncertainty	- dredge efficiency during the survey - growth rates and natural mortality between the survey and the start of the season - predicting the average recovery of meatweight from greenweight - the extent to which dredging causes incidental mortality and affects recruitment	

Qualifying Comments
In the Coromandel fishery some scallop beds are persistent and others are ephemeral. The extent to which the various beds or populations are reproductively or functionally separate is not known.

Environmental and Ecosystem Considerations	
Observer coverage	No observer coverage
Non-target fish and invertebrate catch	The catch composition of the scallop fishery was expected to be similar to that of the non-target catch survey conducted in the Coromandel fishery in 2009. Scallops made up 26% of the catch volume. Other taxa caught were seaweeds (11%), starfish (4%), other bivalves (4%) and coralline turf (1%).
Incidental catch of seabirds	There is no known incidental catch of seabirds from *P. novaezelandiae* scallop fisheries.
Incidental catch of mammals	There is no known incidental catch of mammals from *P. novaezelandiae* scallop fisheries.

Incidental catch of other protected species	There is no known incidental catch of protected species from *P. novaezelandiae* scallop fisheries.
Benthic interactions	There have been several studies in New Zealand to assess effects of scallop dredging on benthic habitats. Generally with increasing fishing intensity there are decreases in the density and diversity of benthic communities and, especially, the density of emergent epifauna that provide structured habitat for other fauna.

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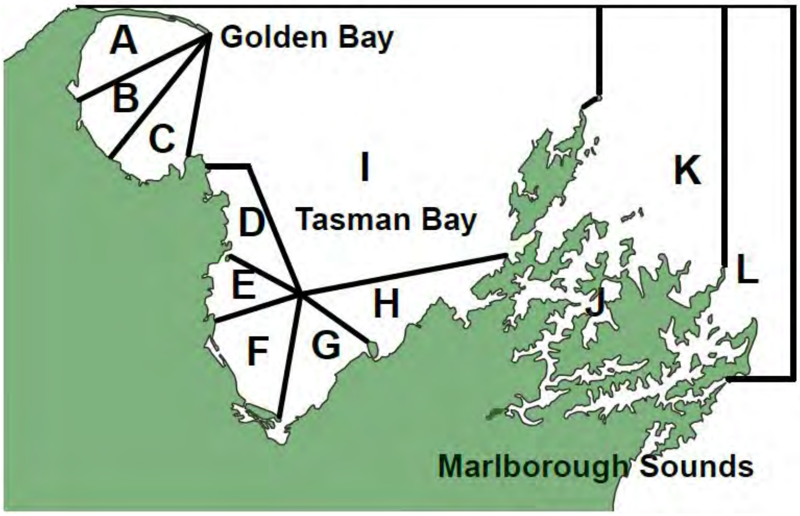
SCALLOPS Nelson/Marlborough (SCA 7)

(*Pecten novaezelandiae*)
Kuakua



1. FISHERY SUMMARY

The Nelson/Marlborough scallop fishery (SCA 7), often referred to as the ‘Southern’ or ‘Challenger’ scallop fishery, comprises 12 sectors (see A–L in the map above) spread across three regions: Golden Bay, Tasman Bay and the Marlborough Sounds. SCA 7 was introduced into a modified form of the Quota Management System (QMS) in 1992, and in 1995 an annual TACC was set at 720 t. In 2002 the TACC was increased to 747 t and a TAC set with allowances made for customary and recreational fishing. In 2014 the TACC was decreased to 400 t and an allowance of 40 t for other sources of fishing-related mortality was set within the TAC (Table 1).

Table 1: Total Allowable Commercial Catch (TACC, t) declared for SCA 7 since introduction into the QMS in 1992.

Year	TAC	Customary	Recreational	Other mortality	TACC
1995–2001	–	–	–	–	720
2002–2013	827	40	40	0	747
2014–present	520	40	40	40	400

Due to sustainability concerns, a temporary partial area closure for the taking and possession of scallops by both recreational and commercial fishers in Marlborough Sounds and part of Tasman Bay (sector 7HH) was implemented for the 2016–17 scallop season (15 July 2016 to 14 February 2017) (Ministry for Primary Industries 2016). The closure was extended for the 2017–18 scallop season to cover all areas within SCA 7 and Port Underwood (Ministry for Primary Industries 2017). The closure continued in 2018, and will remain in place until such a date that an opening regime has been developed and implemented. Fisheries New Zealand has established a multisector group (the Southern Scallop Working Group) to work on an agreed view of when the number of scallops has increased sufficiently to allow harvesting, and the rules that will be necessary to ensure that any harvest is sustainable.

1.1 Commercial fisheries

Up to 1980, the commercial fishery was managed with a combination of gear restrictions, closed areas and seasons, and a 100 mm size limit, together with limitations on the number of entrants (from 1977). Landings reached an all-time peak of 1244 t in 1975, when there were 216 licensed vessels involved in the fishery. The fishery then rapidly declined, and in 1981 and 1982 the fishery was closed. Only 48 licences were issued when it re-opened in 1983, with each vessel being allocated a defined, and equal, catch limit on an annual basis. A scallop enhancement programme was initiated in the same year. By 1989 the success of the enhancement programme enabled rotational fishing in Golden and Tasman Bays (Sectors A–I). Under the rotational fishing strategy, several sectors were opened to fishing each year, and were re-seeded following fishing down. Rotational fishing was accompanied by a reduction in the minimum legal size to 90 mm.

In 1992 when SCA 7 was introduced into the QMS an annual harvest limit of 640 t (12 t to each of the 48 licence holders, plus 64 t to Maori) was initially allocated as Individual Transferrable Quota. Provision was also made for any additional quota in excess of the 640 t to be allocated to the Crown for lease, with preference being given to existing quota holders.

Most of the management responsibilities for the fishery were transferred from government to industry in 1994 when the quota owners established the Challenger Scallop Enhancement Company Ltd. (CSEC) as the formal entity to self-govern the fishery subject to conditions agreed with the government. Key documents associated with CSEC self-governance of the fishery include a Memorandum of Understanding agreement (Ministry of Fisheries & CSEC 1998) and fisheries plans (CSEC 1998, 2005).

In October 1995, legislation was passed in which annual quotas were determined as a fixed proportion of the TACC rather than being allocated as a fixed tonnage. This provided for greater flexibility in changing the TACC. A statutory Enhancement Plan was also introduced at this time, to provide for ongoing enhancement of the fishery. The legislation was modified to enable a transition towards the enhancement programme being implemented by the CSEC rather than the Ministry of Fisheries. In 1996, because of the rotational fishing and stock enhancement management strategy being used to manage the stocks in SCA 7, the fishery was placed on the Third Schedule to the Fisheries Act 1996, and was, therefore, able to have an alternative TAC set under s14 of the Act.

A simulation modelling study of the SCA 7 scallop fishery examined the effects of catch limits, exploitation rate limits, rotational fishing and enhancement (Breen & Kendrick 1997). The results suggested that constant catch strategies are risky, but constant exploitation rate strategies are close to optimal if the maximum rate is appropriate. Rotational fishing appeared to be highly stabilising, even without enhancement. Collapses occurred only when short rotation periods were combined with high fishing intensity. Three-year rotation appeared to be safer than two-year rotation. Enhancement appeared to improve safety, catch, and biomass, and slightly reduced the population variability. The conclusions from this study underpinned the agreed rotational and enhancement management framework for the fishery. However, the theory of rotational fishing assumes that scallops, and habitats important for scallops, are distributed approximately evenly among the areas (sectors) to be fished rotationally. This is probably an invalid assumption for the SCA 7 fisheries sectors.

Over time the rotational fishing and stock enhancement management strategy changed considerably. Rotational harvesting was formally implemented in the 1989–90 fishing year. For six years from 1989–90 to 1994–95, rotational fishing was almost entirely carried out at the sector level. In the next three years from 1995–96 to 1997–98 the sector level rotation began to break down (some fishing occurred in areas that would have been closed under sector-level rotation). From 1998–99 onwards, especially in Golden Bay, sector level rotation has not occurred and parts of sectors may be fished wherever scallops are available. In addition, reseeding activity has been significantly reduced. Annual dredge surveys, which estimate biomass levels and population size structure for each sector, are conducted before each season begins. This approach enables the fishery to concentrate in areas where scallops are predominantly above the minimum legal size, and reduces disturbance in areas where most of the population is sub-legal.

CSEC submits, in consultation with MPI, a harvest plan for the Tasman/Golden Bays and the Marlborough Sounds regions of the fishery to the Minister for approval by 15 July each year. The actual commercial catch is set by CSEC within the TACC limits based on knowledge of:

- the biomass in the three regions,
- any adverse effects of fishing on the marine environment being avoided, remedied or mitigated,

- providing for an allowance for non-commercial fishing,
- a biotoxin monitoring programme being maintained, and
- the ratio of legal to non-legal sized fish that are above pre-set levels.

All commercial fishing is by dredge, with fishers using 'ring bag' dredges rather than the 'box' dredge designs used in the northern (Coromandel and Northland) fisheries. Vessels in the SCA 7 fishery tow one or two ring-bag dredges up to 2.4 m in width with heavy tickler chains (there are no teeth or tines on the leading bottom edge of the dredges in the SCA 7 fishery, unlike those of the fixed tooth bars used on dredges in the northern fisheries).

Reported landings (in meatweight; i.e., processed weight, being the adductor muscle plus attached roe) from the SCA 7 scallop fishery are shown in Figure 1 and listed in Tables 2 and 3. The fishing year applicable to this fishery is from 1 April to 31 March. Commercial fishing in recent years has usually occurred between September and November, although opening and closing dates are defined each year, and may differ between years. Historical landings and TACC changes are shown in Figure 1, Table 2 and 3.

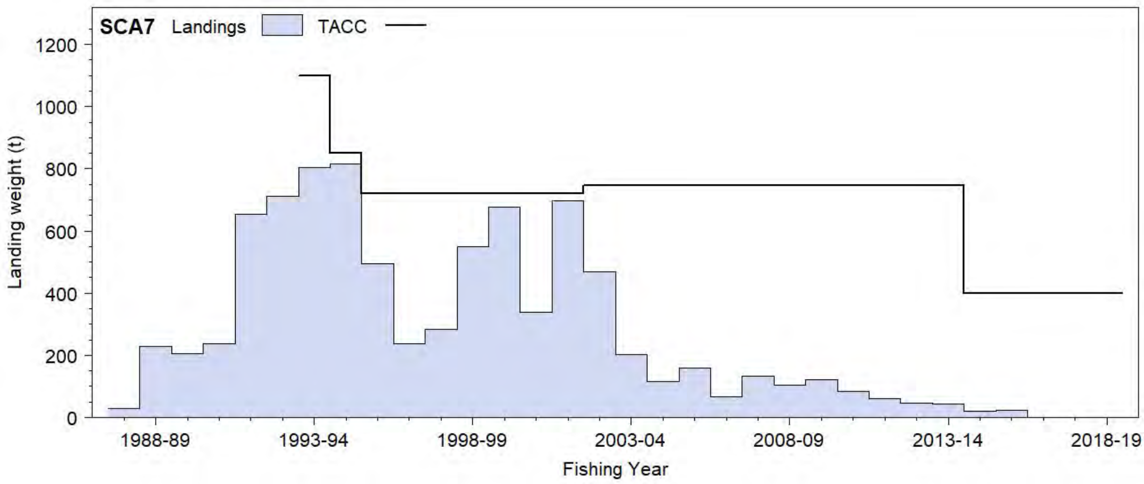


Figure 1: Historical landings and TACC (t, meatweight) for SCA 7 (Nelson/Marlborough). The fishery has been closed since 2016.

Table 2: Reported landings (t, meatweight) of scallops from SCA 7 from 1959–60 to 1982–83. The fishery was closed for the 1981–82 and 1982–83 scallop fishing years. Landings are presented by region (GB, Golden Bay; TB, Tasman Bay; MS, Marlborough Sounds) and total, except before 1977 when landings were reported by the Golden Bay and Tasman Bay combined area (Gold/Tas) (King & McKoy 1984). [Continued on next page]

Year	Gold/Tas	GB	TB	MS	Total
1959–60	1	–	–	0	1
1960–61	4	–	–	2	7
1961–62	19	–	–	0	19
1962–63	24	–	–	< 0.01	24
1963–64	105	–	–	2	107
1964–65	108	–	–	2	110
1965–66	44	–	–	< 0.5	44
1966–67	23	–	–	8	32
1967–68	16	–	–	7	23
1968–69	1	–	–	8	9
1969–70	72	–	–	6	78
1970–71	73	–	–	7	80
1971–72	206	–	–	10	215
1972–73	190	–	–	46	236
1973–74	193	–	–	127	320
1974–75	597	–	–	36	632
1975–76	1 172	–	–	73	1 244

Year	Gold/Tas	GB	TB	MS	Total
1976–77	589	–	–	79	668
1977–78	–	342	168	63	574
1978–79	–	86	4	76	166
1979–80	–	32	30	40	101
1980–81	–	0	14	27	41
1981–82	–	–	–	–	–
1982–83	–	–	–	–	–

Table 3: Catch limits and reported landings (t, meatweight) of scallops from SCA 7 since 1983–84. The fishery was closed for the 1981–82 and 1982–83 scallop fishing years, and was subsequently managed under a rotationally enhanced regime. The fishery was closed in 2016. Two catch limits are presented: TACC, Total Allowable Commercial Catch; MSCL, Marlborough Sounds catch limit (a subset of the TACC, or a subset of the Annual Allowable Catch in 1994–95). Landings data come from the following sources: FSU, Fisheries Statistics Unit; MHR, Monthly Harvest Returns (Quota Harvest Returns before October 2001); CELR, Catch Effort Landing Returns; CSEC, Challenger Scallop Enhancement Company. Landings are also presented by region (GB, Golden Bay; TB, Tasman Bay; MS, Marlborough Sounds) and best total (believed to be the most accurate record) for the SCA 7 Fishstock. – indicates no data.

	Catch limits		Landings				Landings by region and best total				
Year	TACC	MSCL	FSU	MHR	CELR	CSEC	GB	TB	MS	Best total	Source
1983–84	–	–	225	–	–	–	< 0.5	164	61	225	FSU
1984–85	–	–	367	–	–	–	45	184	138	367	FSU
1985–86	–	–	245	–	–	–	43	102	100	245	FSU
1986–87	–	–	355	–	–	–	208	30	117	355	FSU
1987–88	–	–	219	29	–	–	113	1	105	219	FSU
1988–89	–	–	222	228	–	–	127	23	72	222	FSU
1989–90	–	–	–	205	125	–	68	42	95	205	Shumway & Parsons (2004)
1990–91	–	–	–	237	228	–	154	8	66	228	CELR
1991–92	–	–	–	655	659	–	629	9	20	659	CELR
1992–93	–	–	–	712	674	–	269	247	157	674	CELR
1993–94	*1 100	–	–	805	798	–	208	461	129	798	CELR
1994–95	*850	70	–	815	825	–	415	394	16	825	CELR
1995–96	720	73	–	496	479	–	319	92	67	479	CELR
1996–97	#720	61	–	238	224	231	123	47	61	231	CSEC
1997–98	#720	58	–	284	265	299	239	2	58	299	CSEC
1998–99	#720	120	–	549	511	548	353	78	117	548	CSEC
1999–00	720	50	–	678	644	676	514	155	7	676	CSEC
2000–01	720	50	–	338	343	338	303	19	16	338	CSEC
2001–02	720	76	–	697	715	717	660	32	25	717	CSEC
2002–03	747	–	–	469	469	471	370	39	62	471	CSEC
2003–04	747	–	–	202	209	206	28	107	71	206	CSEC
2004–05	747	–	–	117	112	118	20	47	51	118	CSEC
2005–06	747	–	–	158	156	156	35	5	116	157	CSEC
2006–07	747	106	–	67	66	68	26	0	43	68	CSEC
2007–08	747	–	–	134	183	134	128	0	6	134	CSEC
2008–09	747	–	–	103	137	104	76	0	28	104	CSEC
2009–10	747	123	–	120	120	–	19	0	101	120	CELR
2010–11	747	–	–	85	85	–	10	0	74	85	CELR
2011–12	747	–	–	62	61	–	1	0	60	61	CELR
2012–13	747	53	–	48	48	–	0	0	48	48	CELR
2013–14	747	48	–	43	44	43	0.2	0	43	43	CSEC
2014–15	400	30	–	22	22	22	0	0	22	22	CSEC
2015–16	400	23	–	22	22	22	0	0.8	21	22	CSEC
2016–17	400	closure	–	0	0	–	0	0	0	0	CELR
2017–18	400	closure	–	0	0	–	0	0	0	0	CELR
2018–19	400	Closure	-	0	0	-	0	0	0	0	CELR

*Annual Allowable Catch (AAC); TACCs came into force 1 October 1995.
Initial industry controlled catch limit was 350 t in 1996–97, 310 t in 1997–98, and 450 t in 1998–99.

Scallop meatweight recovery (meatweight divided by greenweight) is variable among areas, years, and weeks within the fishing season but in general appears to be highest from scallops in parts of Golden Bay (e.g., sector A) and lowest from those in Tasman Bay (e.g., sector D). Using data on the commercial landings of recruited scallops in the period 1996–2008, the mean annual meatweight recovery was 13.8% for Golden Bay, 11.8% for Tasman Bay, and 13.2% for the Marlborough Sounds. An analysis of meatweight recovery data at the time of the survey and during the fishing season for the years 1996–2007 showed meatweight recovery measured at the time of the survey could not be used to predict meatweight recovery during the fishing season.

1.2 Recreational fisheries

CSEC consults with recreational fishers (and environmental interests) on the results of the annual biomass survey and the CSEC harvest proposals (including commercial closed areas) to seek agreement prior to submitting the Harvest Plan to the Minister. In recent years, before the fishery closure, agreement was not achieved. Estimates of annual recreational scallop harvest from SCA 7 are shown in Table 4. The harvest estimates provided by telephone-diary surveys between 1993 and 2001 are no longer considered reliable for various reasons. A Recreational Technical Working Group concluded that these harvest estimates should be used only with the following qualifications: a) they may be very inaccurate; b) the 1996 and earlier surveys contain a methodological error; and c) the 2000 and 2001 estimates are implausibly high for many important fisheries. In response to these problems and the cost and scale challenges associated with onsite methods, a National Panel Survey was conducted for the first time throughout the 2011–12 fishing year. The panel survey used face-to-face interviews of a random sample of 30 390 New Zealand households to recruit a panel of fishers and non-fishers for a full year. The panel members were contacted regularly about their fishing activities and harvest information collected in standardised phone interviews. The panel survey was repeated in 2017–18 using directly comparable methods (Wynne-Jones et al. 2019) although the fishery in SCA 7 was closed. A creel survey was conducted in 2003–04 (Cole et al. 2006). The annual recreational harvest level is likely to vary substantially through time.

Table 4: Estimates of the annual recreational harvest of scallops from SCA 7. Number, number of scallops; meat, meatweight (assuming 12.5% recovery of meatweight from greenweight). GB/TB, Golden Bay/Tasman Bay. The estimates provided by telephone diary surveys are no longer considered reliable for various reasons. The 2011–12 estimate assumes a 12.5% recovery of meat from greenweight. The fishery was closed in 2017–18.

Year	Area	Survey method	Number	CV	Meat (t)	Reference
1992–93	SCA 7	Telephone diary	1 680 000	0.15	22	Teirney et al. (1997)
1996	SCA 7	Telephone diary	1 456 000	0.21	19	Bradford (1998)
1999–00	SCA 7	Telephone diary	3 391 000	0.20	44	Boyd & Reilly (2002)
2000–01	SCA 7	Telephone diary	2 867 000	0.14	37	Boyd et al. (2004)
2003–04	GB/TB	Creel survey	860 000	0.05	9	Cole et al. (2006)
2011–12	SCA 7	Panel survey	796 164	0.23	11	Wynne-Jones et al. (2014)
2017–18	SCA 7	Panel survey	0	–		Wynne-Jones et al. (2019)

For further information on recreational fisheries refer to the introductory SCA Working Group report.

1.3 Customary fisheries

Limited quantitative information on the level of customary take is available from Fisheries New Zealand. The kilograms and numbers of scallops harvested under customary permits is given in Table 5, and is likely to be an underestimate of customary harvest.

Table 5: Fisheries New Zealand records of customary harvest of scallops (reported as greenweight (kg) or numbers) taken from the Challenger scallop fishery for years for which harvest data is available. – indicates no data.

	Weight (kg)		Numbers	
Fishing year	**Approved**	**Harvested**	**Approved**	**Harvested**
2006–07	–	–	800	800
2007–08	600	600	17 500	15 830
2008–09	–	–	6 300	5 025
2009–10	–	–	31 150	28 560

For further information on customary fisheries refer to the introductory SCA Working Group report.

1.4 Illegal catch
For information on illegal catch refer to the introductory SCA Working Group report.

1.5 Other sources of fishing mortality
Dredging has incidental effects on scallops and their habitats, but there has not been any specific research on the level of incidental mortality caused by ring-bag dredging in the SCA 7 fishery.

Incidental mortality of scallops may also result from bottom trawling, although the extent of this is unknown. Observational monitoring of *P. novaezelandiae* spat released in the first three years of enhancement (1984–86) in Golden Bay suggested that spat survival was higher in areas closed to trawling (Bradford-Grieve et al. 1994).

For further information on other sources of mortality refer to the introductory SCA Working Group report.

2. BIOLOGY

All references to 'shell length' in this report refer to the maximum linear dimension of the shell, in an anterior-posterior axis. Scallops in the outer Pelorus Sound grow to a shell length of about 60 mm in one year, and can reach 100 mm in about two to three years (Table 6). This was typical of the pattern of growth that occurred under the initial rotational fishing strategy in Tasman and Golden Bays as well. Growth slows during the winter, and was found to vary between years (it is probably influenced by water temperature, food availability and scallop density). Growth rings form on the shell during winter, but also at other times, precluding the use of ring counts as accurate indicators of age. Experience with enhanced stocks in Tasman and Golden Bays has indicated that scallops generally attain a shell length of 90 mm in just under two years although, in conditions where food is limiting, almost three years may be required to reach this size.

From studies of the ratio of live to dead scallops and the breakdown of the shell hinge in dead scallops, Bull (1976) estimated the annual natural mortality rate for two populations of adult scallops in the Marlborough Sounds (Forsyth Bay and North West Bay in Pelorus Sound) to be 23% (M = 0.26) and 39% (M = 0.49). From a tagging study conducted in Golden and Tasman Bays from 1991 to 1992, Bull & Drummond (1994) estimated the mortality of 0+ and 1+ scallops to be about 38% (M = 0.21) per year, and the mortality of 2+ scallops to be 66% (M = 0.46). These studies suggest that average natural mortality in the SCA 7 fishery is quite high (Table 6), and most previous stock assessments have assumed $M = 0.5$ y^{-1} (instantaneous rate). Incidences of large-scale die-off in localised areas have been observed (e.g., mortality associated with storms in 1998).

Table 6: Estimates of biological parameters.

		Estimates	**Source**
1. Natural mortality, M		*M*	
Pelorus Sound		0.26, 0.49	Bull (1976)
Golden & Tasman Bays		0+ & 1+, 0.21	Bull & Drummond (1994)
Golden & Tasman Bays		2+, 0.46	Bull & Drummond (1994)
2. Growth			
Age-length relationship	Age (y)	SL (mm)	
Pelorus Sound	1	60	Bull (1976)
Pelorus Sound	2	97	Bull (1976)
Pelorus Sound	3	105	Bull (1976)
Pelorus Sound	4	111	Bull (1976)
von Bertalanffy parameters	L_∞	K	
	144	0.40	Data of Bull (1976), analysed by Breen (1995)

3. STOCKS AND AREAS

Whether or not scallops in Tasman Bay and Golden Bay constituted a single genetic stock before enhancement began is unknown. Enhancement in the Marlborough Sounds has been limited, but could have contributed towards homogenising stocks. Water movements eastward through Cook Strait could have enabled a degree of genetic mixing between Tasman/Golden Bays and Marlborough Sounds before any enhancement began. It is currently assumed for management that the SCA 7 stock is made up of three individual sub-stocks (Golden Bay, Tasman Bay and Marlborough Sounds) that are separate from the Northland and Coromandel stocks and from the various west coast harbours, Stewart Island and Chatham Island areas.

For further information on stocks and areas refer to the introductory SCA Working Group report.

4. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS

In the Southern scallop stock (SCA 7), data on the non-target catch of the 1994–2013 surveys have been collected but not analysed, except for preliminary estimation of the 1998–2013 non-target catch trajectories (Williams et al. 2014).

Refer to the introductory SCA Working Group report for general information on environmental and ecosystem considerations.

5. STOCK ASSESSMENT

5.1 Estimates of fishery parameters and abundance

The status of the SCA 7 stock is assessed using data collected from fishery-independent dredge surveys. The survey data are analysed to estimate the spatial distribution, size structure, abundance, and biomass of the population of scallops within the area covered by the survey. Dredges are not 100% efficient at catching all scallops within the area of seabed swept by the dredge, making it necessary to apply dredge efficiency corrections to the raw survey data to obtain estimates of absolute abundance and biomass. Information on dredge efficiency, the proportion of the scallops in the path of the gear that are caught, has been generated from a dedicated study using paired sampling by divers and dredges (Tuck et al. 2018). Efficiency-corrected dredge survey estimates form the basis of SCA 7 science advice to fisheries management.

Surveys of scallops in the main commercial scallop beds in SCA7 have been conducted almost annually since 1994, using stratified random sampling by dredging. The surveys are usually conducted in May but the surveys in 2017 and 2018 were conducted in January in time to inform fisheries management decisions required for the 1 April sustainability round. Two-phase sampling was used in surveys until 2008, and single-phase sampling was used in the 2009–19 surveys. In 2013, 2018 and 2019, only the Marlborough Sounds sub-stock was surveyed; Golden Bay and Tasman Bay were not surveyed because of the expected low abundance of scallops in those bays. In 2015 three surveys were conducted: a pre-fishing season survey in May (Williams et al. 2015a), an in-fishing season survey of key scallop beds in October (Williams et al. 2015b) and a post-fishing season survey in November (Williams et al. 2015c). The purpose of the November 2015 survey was to survey the accessible areas of the entire SCA 7 stock and not just survey those areas utilised by the commercial fishery, as is usually the case with the pre-fishing season surveys. There was no survey in 2016.

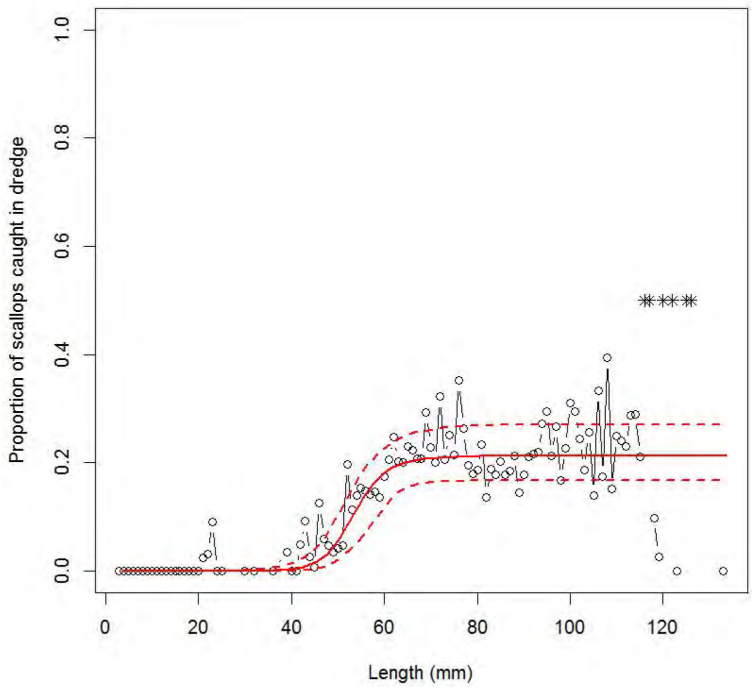


Figure 2: **SCA 7 ring-bag dredge efficiency (from Tuck et al. 2018). The plotted curve is a logistic capped selectivity ogive (L50 = 53.3mm, a95=7.3mm, amax=0.21) fitted to the proportion of scallops retained in the dredge. Solid line represents the fit to all data in the 2018 study, dashed lines represent 95% CI of selectivity at each length.**

Surveys were conducted in January in 2017 (Williams et al. 2017) and 2018 (Williams et al. 2018), to evaluate the status of the SCA 7 scallop stock (Marlborough Sounds sub-stock only in 2018) in time to inform fisheries management decisions for the 1 April sustainability round. In the January 2017 survey (Williams et al. 2017; the most recent survey to employ 'full' coverage of Golden Bay, Tasman Bay, and Marlborough Sounds), the highest catches of recruited scallops (90 mm or larger) were from tows within key strata (primarily in Marlborough Sounds, but also in Croisilles Harbour in Tasman Bay), which represent the banks and bays that support the main scallop beds; catches were very low in other strata (Figure 3). The January 2018 (Williams et al. 2018) and May 2019 (Williams et al. 2019) surveys of scallop in Marlborough Sounds found a similar pattern: most of the recruited scallop population was held in a limited number of scallop beds, mostly in the outer Sounds.

With the exception of the in-season and post-season surveys in 2015, surveys since 1998 are broadly comparable, in that they used the same fishing gear and covered similar areas. Earlier surveys covered smaller areas, although these may have included the main areas of recruited scallop densities.

Surveys up to 1995 used the 'MAF' dredge, while from 1997 the 'CSEC' dredge was used. In 1996, both dredges were used, with data from the CSEC dredge being used for the biomass analysis. Analysis of the survey data involves applying estimates of dredge efficiency to produce absolute population estimates at the time of the surveys (May–June) and at the nominal start of the fishing season (September). The analysis uses a resampling with replacement analytical procedure to better account for uncertainty in the estimates (Williams et al. 2019). The time series of scallop population estimates published in earlier versions of the Plenary report were produced by applying historical estimates of dredge efficiency derived from previous studies of dredge efficiency by Cranfield et al. (1996) and Handley et al. (2004). New research on dredge efficiency conducted in 2018 in Marlborough Sounds estimated that the average efficiency of the survey dredge was 0.21 (95% CI from 0.17 to 0.27) (Tuck et al. 2018), which is substantially lower than estimated previously (mean historical efficiency of 0.56). Williams et al. (2019) re-analysed the 1997–2019 time series of surveys by applying the new dredge efficiency parameters derived by Tuck et al. (2018) and conducting growth projections using an inverse logistic model (Tuck & Williams 2012).

From the revised SCA 7 survey series analysis conducted by Williams et al. (2019), abundance indices were generated for pre-recruits (undersize scallops 53–89 mm in length) and recruited scallops (90 mm or larger) (Figure 4). Strong patterns of recruitment are evident, illustrated by peaks in recruited numbers lagging one year after peaks in undersize scallop numbers. At the overall sub-stock scale (Golden Bay, Tasman Bay, Marlborough Sounds), recruitment (as measured by the abundance of pre-recruits) has been low (or following a declining trend in some areas) since at least 2010.

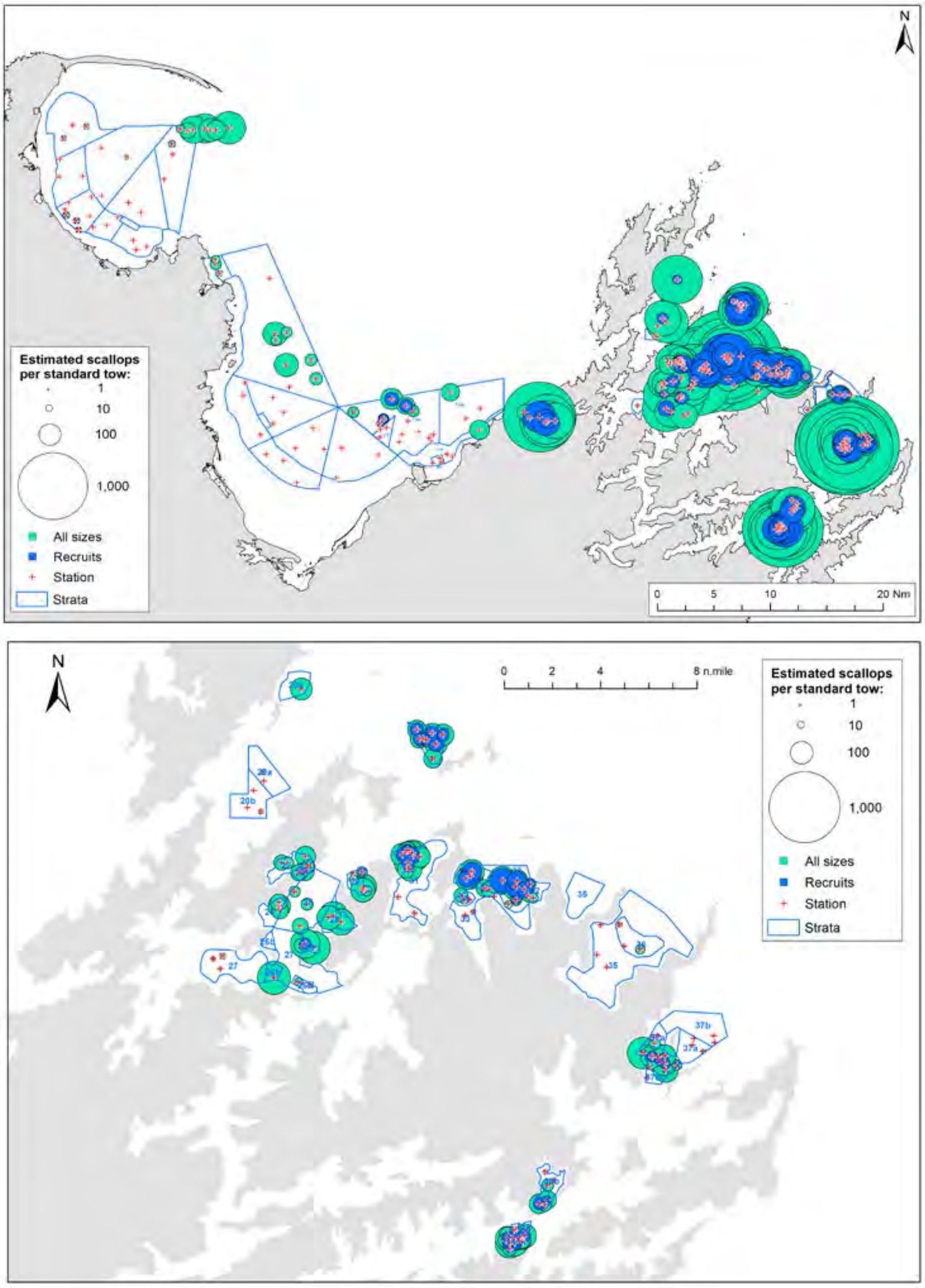


Figure 3: Time of survey catch per standard tow. Top: SCA 7 stock survey, January 2017. Bottom: Marlborough Sounds sub-stock survey, May 2019. Circle area is proportional to the number of scallops caught per standard distance towed (0.4 nautical miles). Dark blue shaded circles denote scallops of commercial recruited size (90 mm or larger), green shaded circles denote scallops of any size. Values are uncorrected for dredge efficiency. Polygons denote survey strata boundaries.

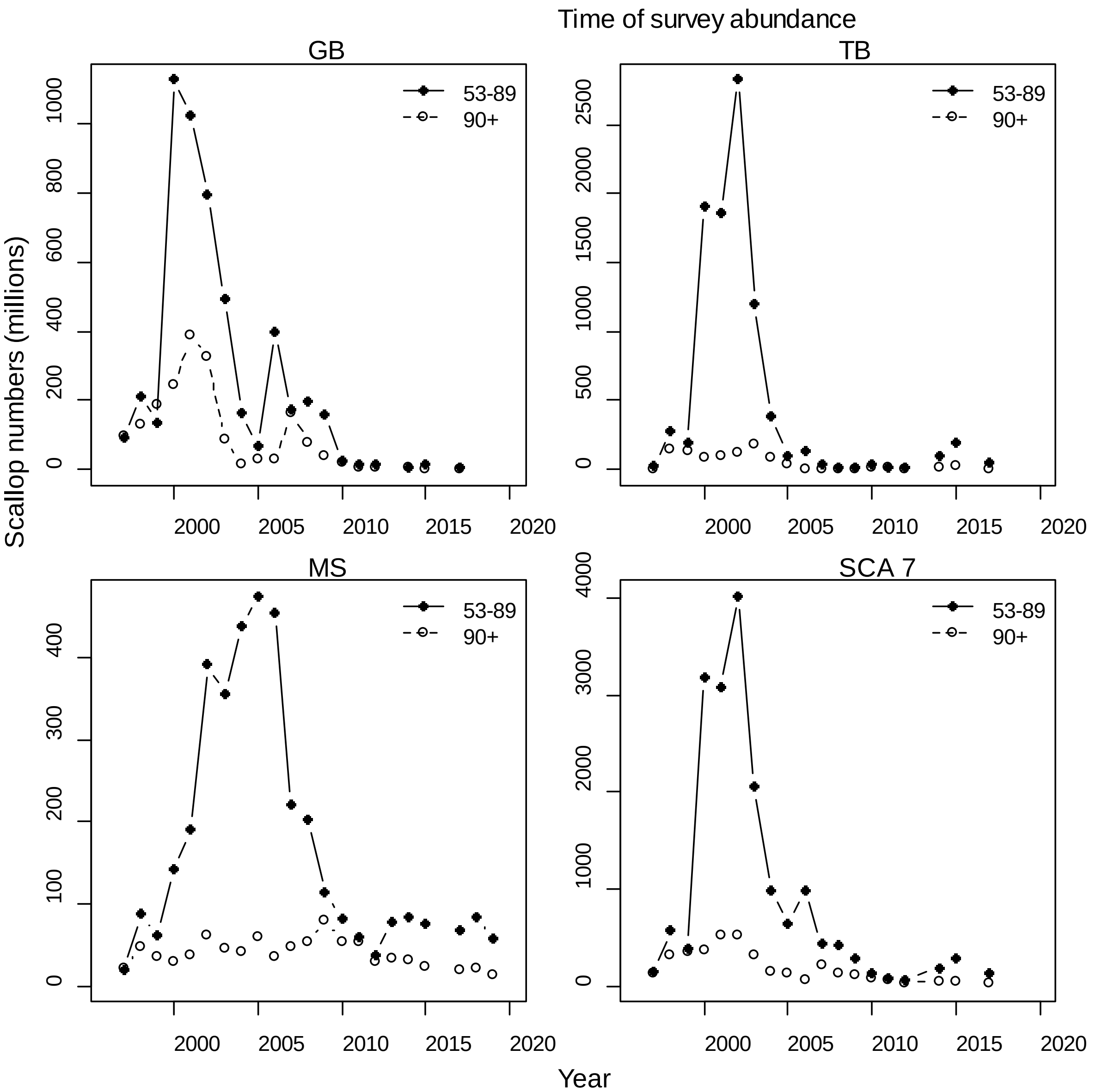


Figure 3: Time of survey abundance indices 1997 to 2019 for undersize (53– 89 mm) and recruited scallops (90 mm or larger) in Golden Bay (top left), Tasman Bay (top right), Marlborough Sounds (bottom left), and SCA 7 (all areas combined; bottom right). Golden Bay and Tasman Bay were not surveyed in 2013, 2016, 2018 or 2019. Marlborough Sounds was not surveyed in 2016. Values are median estimates of abundance (scallop numbers), corrected for dredge efficiency (Tuck et al. 2018).

5.2 Biomass estimates

Virgin biomass, B_0, and the biomass that will support the maximum sustainable yield, B_{MSY}, have not been estimated and are probably not appropriate reference points for a stock with highly variable recruitment and growth such as scallops.

Start of season (nominally 1 September) absolute recruited biomass is estimated each year from a pre-season dredge survey, which is usually conducted in May (N.B. January in 2017 and 2018). Estimates were derived by Williams et al. (2019) by re-analysing the 1997–2019 survey data, applying new dredge efficiency parameters (Tuck et al. 2018) and conducting growth projections with an inverse logistic model (Tuck & Williams 2012), using a resampling with replacement analytical procedure described to account for uncertainty in the start-of-season biomass estimates (Table 7).

Table 7: Projected median biomass (and CV) of recruited scallops (90 mm or longer shell length) at the nominal start of season (1 September) in the survey years, 1997 to present. Golden Bay and Tasman Bay were not surveyed in 2013, 2016, 2018 or 2019. No survey was conducted in 2016. Estimates were derived by Williams et al. (2019) by re-analysing the 1997–2019 survey data using a resampling with replacement analytical procedure, applying new dredge efficiency parameters (Tuck et al. 2018) and conducting growth projections with an inverse logistic model (Tuck & Williams 2012). For each year, the catch (reported on the 'Landed' section of CELRs) and exploitation rate (catch to recruited biomass ratio) are also given. Biomass and catch are in t meatweight.

				Golden Bay					Tasman Bay
Year	Biomass	CV	Catch	Catch/Biomass	Year	Biomass	CV	Catch	Catch/Biomass
1997	1253	0.17	239	0.19	1997	110	0.19	2	0.02
1998	1857	0.17	353	0.19	1998	1617	0.17	78	0.05
1999	2202	0.18	514	0.23	1999	1425	0.18	155	0.11
2000	4155	0.17	303	0.07	2000	1570	0.21	19	0.01
2001	5271	0.17	660	0.13	2001	2460	0.26	32	0.01
2002	4537	0.16	370	0.08	2002	3267	0.27	39	0.01
2003	1419	0.17	28	0.02	2003	2997	0.18	107	0.04
2004	337	0.23	20	0.06	2004	1269	0.18	47	0.04
2005	410	0.18	35	0.09	2005	477	0.17	5	0.01
2006	965	0.27	26	0.03	2006	106	0.21	0	–
2007	2214	0.18	128	0.06	2007	86	0.30	0	–
2008	1071	0.19	76	0.07	2008	29	0.38	0	–
2009	608	0.21	19	0.03	2009	39	0.32	0	–
2010	240	0.22	10	0.04	2010	128	0.65	0	–
2011	62	0.29	1	0.02	2011	121	0.65	0	–
2012	50	0.32	0.2	0.00	2012	47	0.41	0	–
2013	–	–	0	–	2013	–	–	0	–
2014	92	0.21	0	–	2014	190	0.30	0	–
2015	43	0.33	0	–	2015	498	0.34	0.8	0.00
2016	–	–	0	–	2016	–	–	0	–
2017	25	0.33	0	–	2017	178	0.35	0	–
2018	–	–	0	–	2018	–	–	0	–
2019	–	–	0	–	2019	–	–	0	–

				Marl. Sounds					SCA 7 Total
Year	Biomass	CV	Catch	Catch/Biomass	Year	Biomass	CV	Catch	Catch/Biomass
1997	252	0.16	58	0.23	1997	1620	0.15	299	0.18
1998	520	0.18	117	0.22	1998	3990	0.16	548	0.14
1999	378	0.16	7	0.02	1999	4024	0.16	676	0.17
2000	373	0.17	16	0.04	2000	6084	0.17	338	0.06
2001	449	0.17	25	0.06	2001	8219	0.18	717	0.09
2002	862	0.19	62	0.07	2002	8705	0.19	471	0.05
2003	542	0.17	71	0.13	2003	4992	0.16	206	0.04
2004	543	0.18	51	0.09	2004	2154	0.17	118	0.05
2005	712	0.18	116	0.16	2005	1606	0.16	157	0.10
2006	541	0.21	43	0.08	2006	1613	0.23	68	0.04
2007	662	0.22	6	0.01	2007	2986	0.17	134	0.04
2008	695	0.17	28	0.04	2008	1803	0.17	104	0.06
2009	920	0.20	101	0.11	2009	1571	0.17	120	0.08
2010	641	0.15	74	0.12	2010	1020	0.17	85	0.08
2011	669	0.16	60	0.09	2011	846	0.18	61	0.07
2012	361	0.17	48	0.13	2012	458	0.17	48	0.10
2013	416	0.17	43	0.10	2013	–	–	43	–
2014	376	0.17	22	0.06	2014	658	0.17	22	0.03
2015	305	0.17	21	0.07	2015	853	0.24	22	0.03
2016	–	–	0	–	2016	–	–	0	–
2017	345	0.19	0	–	2017	554	0.23	0	0.00
2018	335	0.17	0	–	2018	–	–	0	–
2019	203	0.20	0	–	2019	–	–	0	–

Biomass is held at various spatial densities (scallops per unit area), typically with smaller areas of high density aggregations commonly known as ‘beds’ distributed among larger areas of low densities or no scallops. High-density scallop beds are important both for sustainability (i.e., larval production) and for fisheries utilisation (i.e., high catch rates). It is possibly more useful for management purposes to focus on biomass trends in the higher density areas. In addition to estimates of absolute biomass, the biomass at different commercial threshold (‘critical’) densities (in the range 0–0.2 scallops m^{-2}) is also estimated each year.

Projected recruited biomass in SCA 7 in September 2017 was very sensitive to the critical density levels examined (Figure 5). In Golden Bay (excluding stratum 9b) and Tasman Bay (excluding Croisilles Harbour strata 17 and 18), there was zero recruited biomass held at potentially fishable densities (higher than 0.04 m^{-2}, or 1 scallop per 25 m^2). Of the Marlborough Sounds absolute biomass (115 t), 64% (74 t) was held in areas with a critical density of 0.04 m^{-2} or higher, and this reduced to 46% (53 t) at 0.08 m^{-2}, and 32% (37 t) at 0.12 m^{-2}. These are median point estimates, which have increasingly large uncertainty as the critical density threshold increases.

Estimates of projected recruited biomass in Marlborough Sounds are available from analysis of the January 2018 (Williams et al. 2018) and May 2019 (Williams et al. 2019) surveys, with estimated biomass gradually decreasing with increasing critical threshold density. Of the Marlborough Sounds absolute projected biomass (203 t), 84% (171 t) was held in areas with a critical density of 0.04 m^{-2} or higher; with increasing critical density, the available biomass reduced: 115 t (57%) was held in areas with a critical density of 0.2 m^{-2} or higher.

Overall, from the most recent stock survey of all three regions (Golden and Tasman Bays, and Marlborough Sounds) in 2017, the SCA 7 stock appeared to be similar to the lowest recorded level (Figure 6). The key findings in 2017 were that recruited biomasses in Golden and Tasman Bays (excluding Croisilles Harbour) were at negligible levels, similar to those observed since the large declines in the 2000s, and the declining trend in recruited biomass observed in Marlborough Sounds since 2009 appeared to have discontinued. The size structure of the January 2017 population in Marlborough Sounds provided evidence of successful spat settlement and survival in 2016.

The May 2019 survey analysis (Williams et al. 2019) provides the most recent information to assess the status of the Marlborough Sounds scallop population. The key finding is that the Marlborough Sounds recruited biomass estimate for 2019 in the overall area surveyed is the lowest on record. Virtually all the recruited biomass at potentially fishable densities is held in five scallop beds, at Guards Bay, Ship Cove, the Chetwodes, Wynens Bank, and Dieffenbach Point. Population projections predicted the Marlborough Sounds recruited biomass in September 2019 to be 203 t meat weight. The estimated abundance of small scallops (53–89 mm) in 2019 is low compared with historical estimates, especially from the early 2000s, suggesting that recruitment in the short term is likely to be relatively poor.

Before the 2016–present fishery closures, recent commercial fishing (e.g. 22 t in the 2015 season) was limited almost exclusively to a few specified areas in the Marlborough Sounds. The level of recreational harvest in most years is unknown. The commercial exploitation rate in 2015 in the Marlborough Sounds was in line with the target exploitation rate associated with an increasing biomass observed between 1999 and 2008 (see Section 5.4). A minimum reference level has not yet been established for SCA 7, and, because spatial scale is inherently important in scallop population dynamics and fisheries, a single minimum reference level for the stock would be unsuitable. It is clear, however, that the stocks in Golden and Tasman Bays are well below desirable minimum levels, and the stock in the overall Marlborough Sounds is recovering from one of the lowest recorded levels in the survey time series.

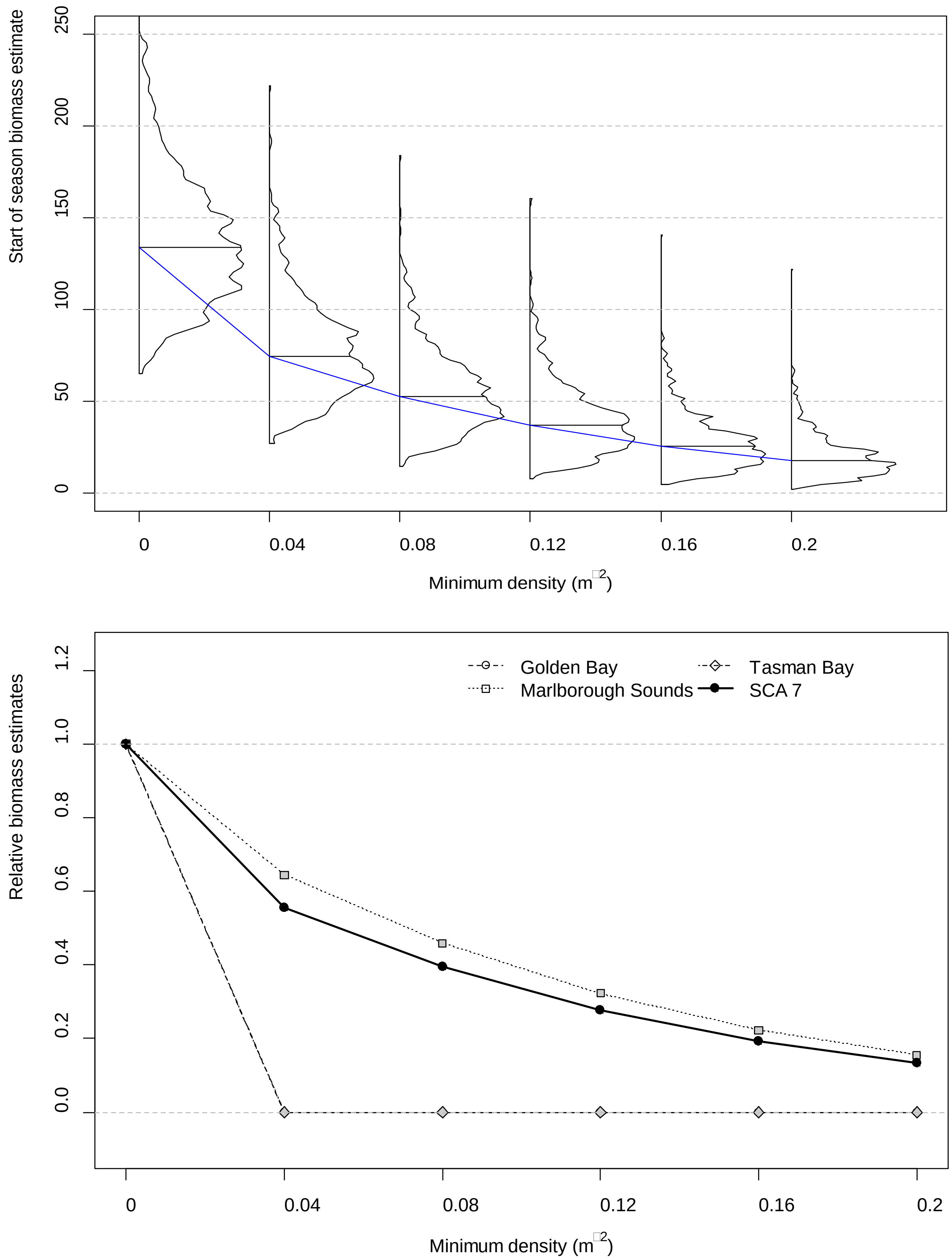


Figure 5: Effect of excluding areas of low scallop density on projected estimates of recruited biomass, SCA 7, September 2017. Estimates were produced using a Multifan projection approach. Critical density corrections were applied after correcting for historical dredge efficiency. [Top]: for each minimum ('critical') density, the distribution and median (horizontal line) of the recruited biomass in SCA 7 are shown. [Bottom]: Trend in the proportion of the total recruited biomass with increasing critical density, by sub-stock: Golden Bay (circles) symbols are obscured by Tasman Bay (diamonds) symbols; Marlborough Sounds (squares); SCA 7 (black circles joined by solid black line).

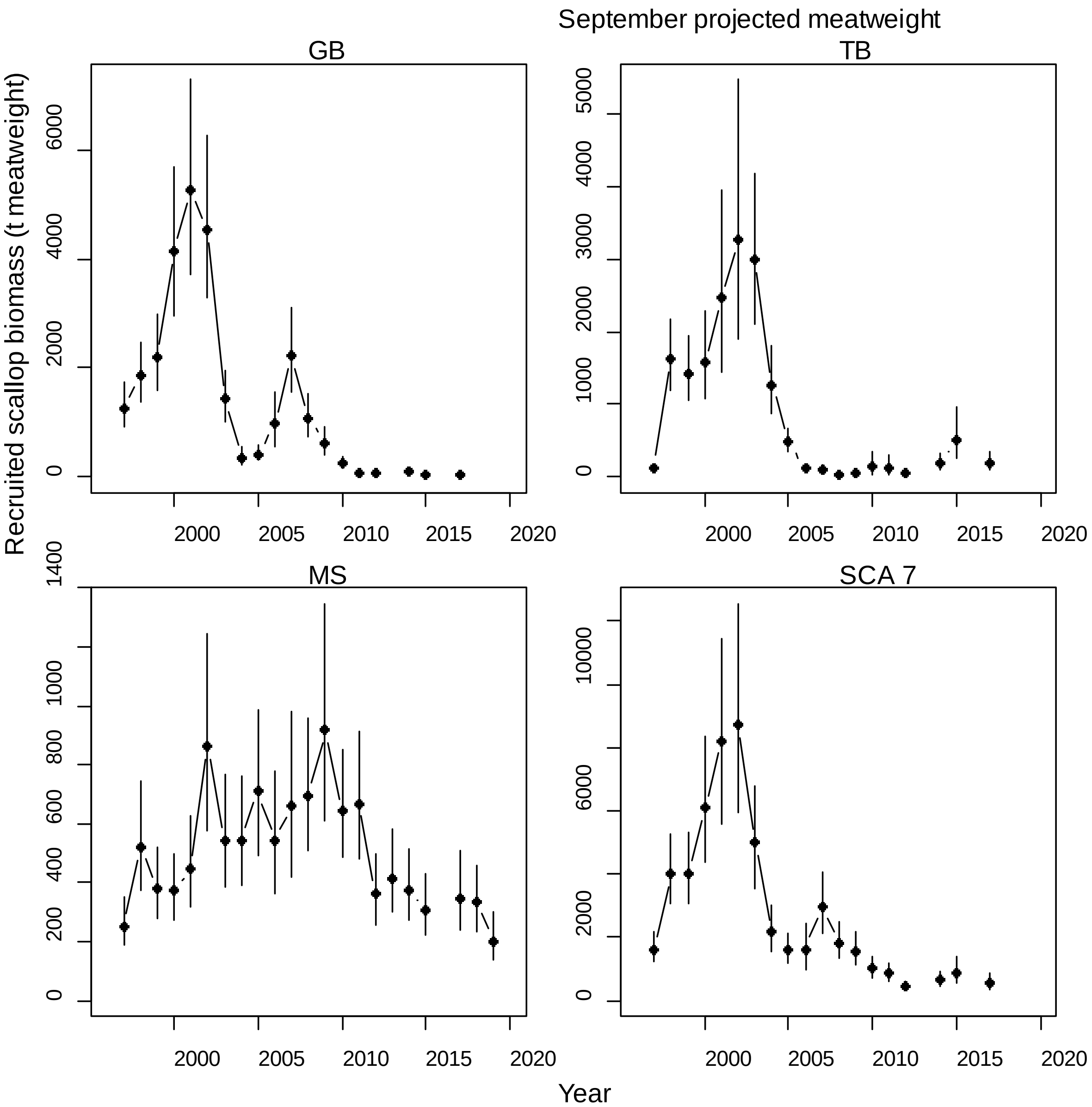


Figure 6: Trends in projected start of season (1 September, black symbols) biomass (t, meatweight) of recruited scallops (90 mm or larger) by sub-stock and for the total SCA 7 stock, 1997–2019. Values are the estimated median and 95% confidence intervals of the recruited biomass, derived using dredge efficiency estimated by Tuck et al. (2018). Golden and Tasman Bays were not surveyed in 2013, 2016, 2018 or 2019. Marlborough Sounds was not surveyed in 2016.

5.3 Estimation of Maximum Constant Yield (MCY)

MCY has not been estimated for SCA 7 scallops because it is not thought to be a reasonable management approach for highly fluctuating stocks such as scallops.

5.4 Estimation of Target Harvest (Exploitation) Rate

Historically, Current Annual Yield (CAY) has not been estimated for Golden and Tasman Bays because those areas are managed under s14 of the Fisheries Act 1996.

For the Marlborough Sounds, CAY has historically been estimated using $F_{0.1}$ as the reference fishing mortality. Estimates of $F_{0.1}$ have been high and the Plenary agreed that this has resulted in overestimation of potential yield, particularly when fishing tends to focus on a small proportion of the biomass. The agreed new approach is to calculate an empirical target harvest (exploitation) rate based on a period when the Marlborough Sounds biomass was stable or increasing (i.e., the aim is to avoid harvest rates that tend to lead to biomass decline). The previous estimate of this target was a harvest rate (catch to biomass ratio) of 0.22, which was the mean harvest rate in the period 1999–2008 calculated using biomass estimates derived by applying historical dredge efficiency parameters. However, using the revised estimates of 1999–2008 biomass (Williams et al. 2019) generated by applying the new dredge efficiency parameters (Tuck et al. 2018) suggests a target harvest rate of 7% of the absolute recruited biomass. Further research is required to inform the setting of appropriate target and biomass limit reference points.

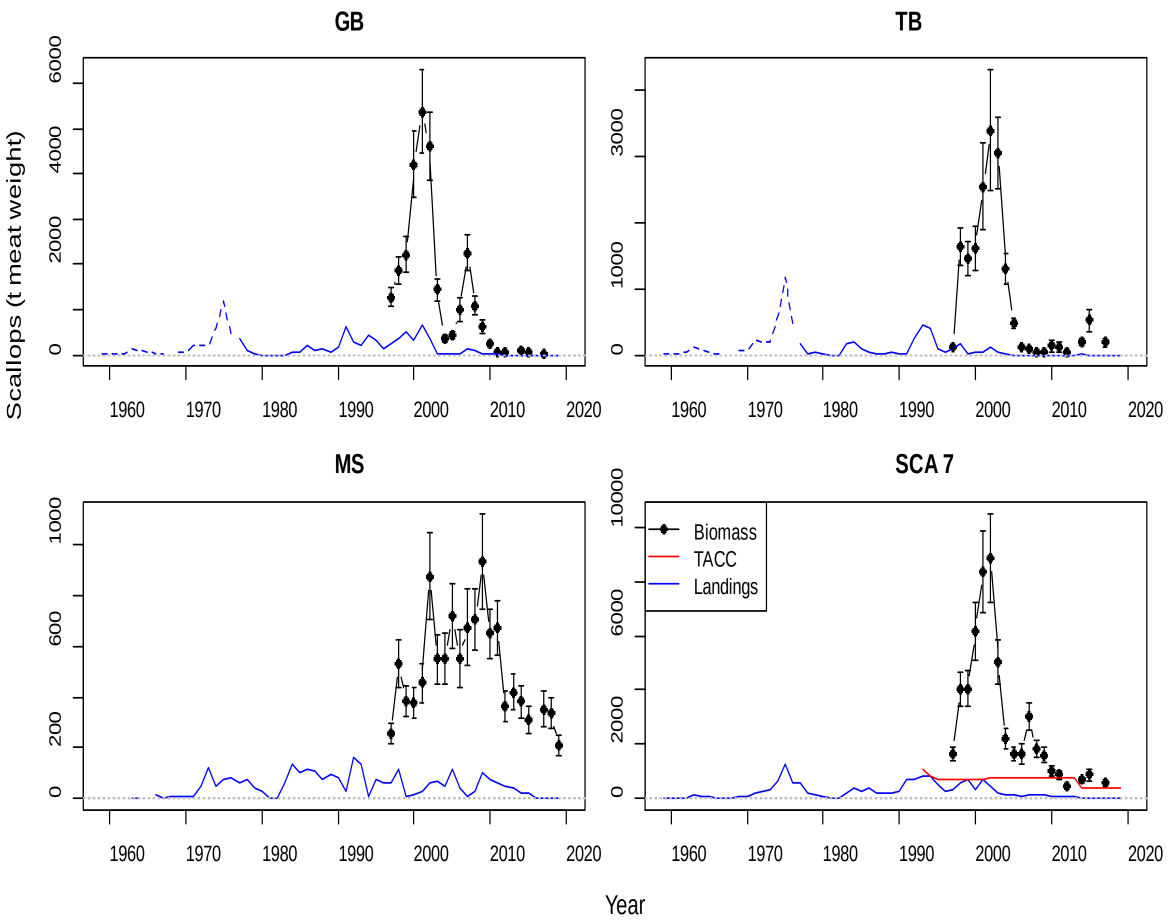
6. STATUS OF THE STOCKS

Stock structure assumptions

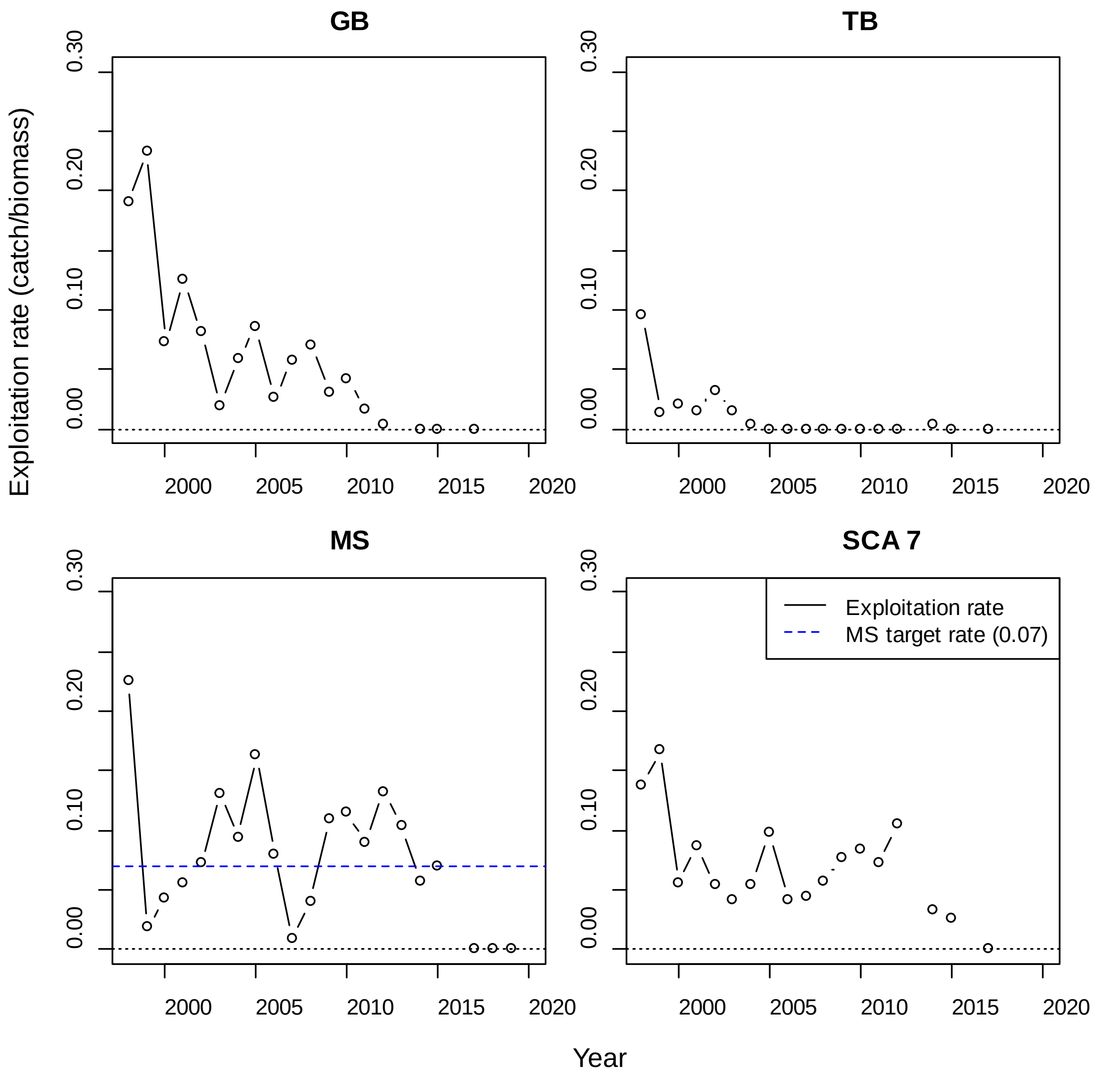
The stock structure of scallops in New Zealand waters is uncertain. For the purposes of this assessment and due to the different management regimes, Golden Bay, Tasman Bay and Marlborough Sounds are assumed to be individual and separate sub-stocks of SCA 7.

Stock Status	
Year of Most Recent Assessment	2017 (Golden and Tasman Bays) and 2019 (Marlborough Sounds
Assessment Runs Presented	Biomass estimates for Golden and Tasman Bays up to 2017; biomass estimates for Marlborough Sounds up to 2019.
Reference Points	Target: Empirical target harvest (exploitation) rate: U_{MSY} = U_{target} = 0.07 for Marlborough Sounds. No targets have been set for Golden Bay or Tasman Bay; B_{MSY} assumed Soft Limit: 20% B_0 Hard Limit: 10% B_0
Status in relation to Target	Very Likely (> 90%) to be at or below U_{target} for Marlborough Sounds. Very Unlikely (< 10%) to be at or above the biomass target for Golden Bay or Tasman Bay
Status in relation to Limits	Unknown for the soft and hard limits for Marlborough Sounds Very Likely (> 90%) to be below the soft limit for Golden Bay and Tasman Bay Likely (> 60%) to be below the hard limit for Golden Bay and Tasman Bay
Status in relation to Overfishing	For sustainability reasons, the SCA 7 fishery was partially closed during the 2016–17 fishing year and the closure was extended to the entire SCA 7 QMA plus Port Underwood from the 2017–18 fishing year. The closure will remain in place until such a time as the scallop population has recovered. Therefore, overfishing is Very Unlikely (< 10%) to have occurred in 2018–19.

Historical Stock Status Trajectory and Current Status



Estimated biomass (mean and CV), TACC, and reported landings of recruited scallops (90 mm or larger shell length) in t meatweight by sub-stock (GB, Golden Bay; TB, Tasman Bay; MS, Marlborough Sounds) and overall SCA 7 stock since 1959. Biomass estimated using historical dredge efficiency parameters. Landings before 1977 from Golden and Tasman Bays were reported as combined values from the two bays (shown as a dotted blue line). Biomass estimates from surveys before 1997 are not presented because the surveys did not cover the full extent of the SCA 7 fishery. Scale differs between plots. Note that the fishery was closed for the 1981–82 and 1982–83 scallop fishing years, and was subsequently managed under a rotationally enhanced regime. The fishery in the Marlborough Sounds and Tasman Bay sector H areas were closed for the 2016–17 scallop fishing year, and the fishery closure was extended in 2017–18 to cover the entire SCA 7 stock and adjacent Port Underwood area. The closure continues and will remain in place until such a time as the scallop population has recovered.



Harvest or exploitation rate (catch divided by biomass) trends for recruited scallops by region and for the overall SCA 7 stock (solid black lines). For the Marlborough Sounds, the target harvest rate value of 0.07 is shown as a horizontal dashed line, calculated using revised estimates of biomass derived by Williams et al. (2019); this is an empirical target based on the mean harvest rate (catch to biomass ratio) in the period 1999–2008 when the Marlborough Sounds biomass was stable or increasing (i.e., the aim is to avoid harvest rates that tend to lead to biomass decline). This target has been in place since 2014. N.B. the previous estimate of this target was a harvest rate of 0.22, calculated using biomass derived by applying historical dredge efficiency, which has since been superceded by the new dredge efficiency parameters derived by Tuck et al. (2018).

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Recruited biomass in Marlborough Sounds generally declined from 2009 to 2015, showed little change to 2018, and declined further to reach the lowest recorded level in 2019. Golden Bay and Tasman Bay were last surveyed in 2017 when biomasses remained extremely low with no indication of rebuilding.
Recent Trend in Fishing Intensity or Proxy	Marlborough Sounds harvest rate (catch to recruited biomass ratio) was high at 23% and 22% in 1997 and 1998 but dropped to 2% in 1999, followed by a general increase to reach 16% in 2005. The harvest rate subsequently decreased to 1% in 2007, followed by an increasing trend to reach 13% in 2012. In the years 2013 to 2015

	the harvest rate was in the range 6–10%. The fishery was closed in 2016. In Golden Bay, the harvest rate was high in the period 1997–99 (19–23%), followed by a decreasing trend with fluctuation from 2000, and was very low (<1%) in 2012. No fishing has occurred in Golden Bay since the 2012 fishing season. The fishery was closed in the 2017–18 fishing year. In Tasman Bay, the peak harvest rate in the time series was 11% in 1999, but otherwise has been low. No fishing occurred in Tasman Bay between 2006 and 2014, and there was minimal (exploratory) fishing in Tasman Bay in 2015 (harvest rate of <1%). Sector 7HH in Tasman Bay was closed in the 2016–17 fishing year and the entire Tasman Bay area was closed in the 2017–18 fishing year.
Other Abundance Indices	-
Trends in Other Relevant Indicator or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	Stock projections are not available. The success of natural settlement, survivorship on the seabed and the magnitude of incidental mortality are unknown.
Probability of Current Catch or TAC causing Biomass to remain below or to decline below Limits	Soft Limit: Unknown Hard Limit: Unknown
Probability of Current Catch or TAC causing Overfishing to continue or commence	For sustainability reasons, the SCA 7 fishery was partially closed during the 2016–17 fishing year and the closure was extended in 2017–18 to cover the entire SCA 7 QMA plus Port Underwood. The closure continues and will remain in place until such a time as the scallop population has recovered.

Assessment Methodology and Evaluation		
Assessment Type	Level 2 – Partial Quantitative Stock Assessment	
Assessment Method	Biomass surveys	
Assessment Dates	Latest assessment: 2019 (Marlborough Sounds) 2017 (Golden Bay, Tasman Bay and Marlborough Sounds)	Next assessment: 2020
Overall Assessment Quality Rank	1 – High Quality	
Main data inputs (rank)	Biomass survey: 2019 (Marlborough Sounds) 2017 (Golden Bay, Tasman Bay and Marlborough Sounds)	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	- Use of an empirical harvest rate (U_{target}) in preference to $F_{0.1}$	
Major Sources of Uncertainty	- dredge efficiency (efficiency and selectivity) during the survey - growth rates and natural mortality between the survey and the start of the season - predicting the average recovery of meatweight from greenweight for the time of the fishing season	

	- the spatial scale at which the assessment is conducted (currently, the target harvest rate is calculated at a broad scale using estimates of absolute biomass, but fishing occurs only in a few high-density scallop beds that support productive fishing, and are also likely to be the most important spawning beds) - the extent to which dredging causes incidental mortality and affects recruitment - appropriate limit reference points for scallops- appropriate limit reference points for scallops

Qualifying Comments
The extent to which the various beds or populations are reproductively or functionally separate is not known. In addition to direct fishing mortality, a combination of other anthropogenic (e.g., land-based influences, indirect effects of fishing) and natural (e.g., oceanographic) drivers may have affected the productivity of the SCA 7 fishery. Declines in stocks of other shellfish (oysters and mussels) have also been observed in Golden Bay and Tasman Bay.

Environmental and Ecosystem Considerations	
Observer coverage	No observer coverage
Non-target fish and invertebrate catch	Non-target catch data were routinely collected during the 1994–2013 annual surveys but not analysed, except for preliminary estimation of the 1998–2013 non-target catch trajectories. Non-target catch can include dredge oysters, green-lipped mussels, and a range of other benthic invertebrates.
Incidental catch of seabirds	There is no known incidental catch of seabirds from *P. novaezelandiae* scallop fisheries.
Incidental catch of mammals	There is no known incidental catch of mammals from *P. novaezelandiae* scallop fisheries.
Incidental catch of other protected species	There is no known incidental catch of protected species from *P. novaezelandiae* scallop fisheries.
Benthic interactions	There have been several studies in New Zealand to assess the effects of scallop dredging on benthic habitats. Generally with increasing fishing intensity there are decreases in the density and diversity of benthic communities and, especially, the density of emergent epifauna that provide structured habitat for other fauna.

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SKIPJACK TUNA (SKJ)

(Katsuwonus pelamis)
Aku

1. FISHERY SUMMARY

Management of skipjack tuna throughout the western and central Pacific Ocean (WCPO) is the responsibility of the Western and Central Pacific Fisheries Commission (WCPFC). Under this regional convention New Zealand is responsible for ensuring that the management measures applied within New Zealand fisheries waters are compatible with those adopted by the Commission.

At its annual meeting in 2014 the WCPFC approved CMM 2014-01. The aim of this CMM for skipjack is to maintain the fishing mortality rate for skipjack at a level no greater than F_{MSY}. This measure is large and detailed with numerous exemptions and provisions. Controls on fishing mortality are being attempted through seasonal Fish Aggregating Device (FAD) closures, effort limits or equivalent catch limits for purse-seine fisheries within EEZs, high seas purse-seine effort limits, as well as other methods. This measure was amended and updated in 2015 through CMM2015-06 and an interim target reference point established as 50% of the estimated recent average spawning biomass in the absence of fishing.

In 2017 WCPFC approved CMM2017-01 to provide for a robust transitional management regime ("bridging measure") that ensures the sustainability of bigeye, skipjack, and yellowfin stocks during the development of Harvest Strategies for the key stocks in the WCPO. This CMM reaffirmed the interim target reference point adopted for skipjack in 2016 as well as a number of the other suite of management measures adopted in CMM2014-01.

In 2018 CMM 2018-01 was approved that again reaffirmed the interim target reference point for skipjack and further strengthened other existing management measures.

1.1 Commercial fisheries

Skipjack was the first commercially exploited tuna in New Zealand waters, with landings beginning in the 1960s in the Taranaki Bight and quickly extending to the Bay of Plenty. The fishery in New Zealand waters has been almost exclusively a purse-seine fishery, although minor catches (less than 1%) are taken by other gear types (especially troll). The purse-seine fishery through to 2000–01 was based on a few (5–7) medium-sized vessels under 500 GRT operating on short fishing trips assisted by fixed wing aircraft, acting as spotter planes, in FMA 1, FMA 2 and occasionally FMA 9 during summer months. In addition, during the late 1970s and early 1980s a fleet of US purse seiners seasonally operated in New Zealand waters. During this period total annual catches were about 9000 t. Beginning in 2001, New Zealand companies operated four large ex-US super seiners that fish for skipjack in the EEZ, on the high seas, and in the EEZs of various Pacific Island countries in equatorial waters. This number declined to one vessel in 2017.

Domestic landings within the EEZ between 2001 and 2017 ranged between 3555 t and 13 312 t (Table 1). Catches in the New Zealand EEZ are variable and can approximate 10 000 t in good seasons. Table 1 compares New Zealand landings with total catches from the WCPO stock, while Table 2 shows the catches reported on commercial log sheets and Monthly Harvest Returns. Figure 1 shows historical landings for SKJ fisheries. Catches from within New Zealand fisheries waters are very small (0.2% for 2017–18) compared to those from the greater stock in the WCPO.

Table 1: Total New Zealand landings (t) both within and outside the New Zealand EEZ, and total landings from the western and central Pacific Ocean (t) of skipjack tuna by calendar year from 2001 to 2018.

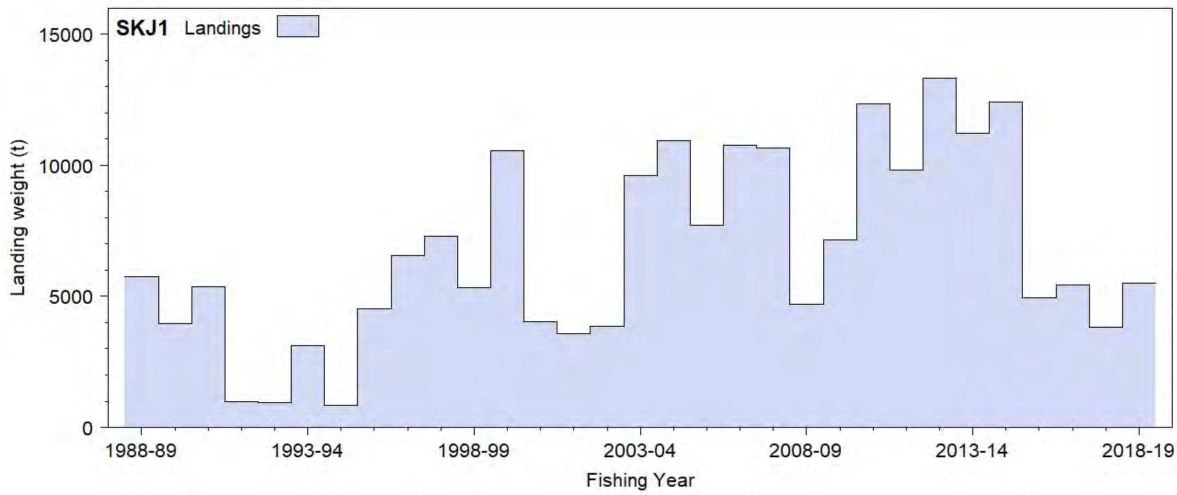
	NZ landings (t)			All WCPO landings
Year	Within NZ fisheries waters	Outside NZ fisheries waters*	Total	Total landings (t)
2001	4 261	4 069	8 330	1 106 302
2002	3 555	15 827	19 382	1 276 919
2003	3 828	14 769	18 597	1 278 420
2004	9 704	10 932	20 636	1 399 138
2005	10 819	8 335	19 154	1 395 737
2006	7 247	19 588	26 835	1 477 438
2007	11 392	22 266	33 659	1 659 557
2008	10 033	17 204	27 237	1 639 651
2009	4 685	21 991	26 676	1 777 598
2010	8 629	16 530	25 153	1 690 145
2011	10 840	9 999	20 839	1 524 599
2012	9 881	8 016	17 897	1 727 773
2013	13 312	10 207	23 520	1 771 822
2014	10 195	9 141	19 336	2 003 024
2015	12 223	6 362	18 585	1 819 798
2016	5 318	3 563	8 881	1 815 810
2017	5 120	4 307	9 427	1 623 207
2018	3 820	2 050	5 870	1 795 048

* Includes some catches taken in the EEZs of other countries under access agreements.
Source: Fisheries New Zealand Catch, Effort, Landing Returns, High Seas reporting system; OFP (2010); and Anon (2013).

Table 2: Reported commercial catches (t) within New Zealand fishing waters of skipjack by fishing year from catch effort data (mainly purse-seine fisheries), and estimated landings from LFRRs (processor records) and Monthly Harvest Returns (MHRs). [Continued next page]

Year	Total catches from catch/effort	LFRR	MHR
1988–89	0	5 769	
1989–90	6 627	3 972	
1990–91	7 408	5 371	
1991–92	1 000	988	
1992–93	1 189	946	
1993–94	3 216	3 136	
1994–95	1 113	861	

Year	Total catches from catch/effort	LFRR	MHR
1995–96	4 214	4 520	
1996–97	6 303	6 571	
1997–98	7 325	7 308	
1998–99	5 690	5 347	
1999–00	10 306	10 561	
2000–01	4 342	4 020	
2001–02	3 840	3 487	3 581
2002–03	3 664	2 826	3 868
2003–04	9 892	9 225	9 606
2004–05	10 311	8 301	10 928
2005–06	7 220	7 702	7 702
2006–07	10 115	10 761	10 762
2007–08	10 116	10 665	10 665
2008–09	4 384	4 737	4 685
2009–10		8 020	7 141
2010–11		17 764	12 326
2011–12		11 814	9 866
2012–13		14 895	13 334
2013–14		14 275	11 206
2014–15		14 491	12 411
2015–16		6 245	4959
2016–17		6 198	5438
2017–18		4 708	3821
2018–19		6 368	5519



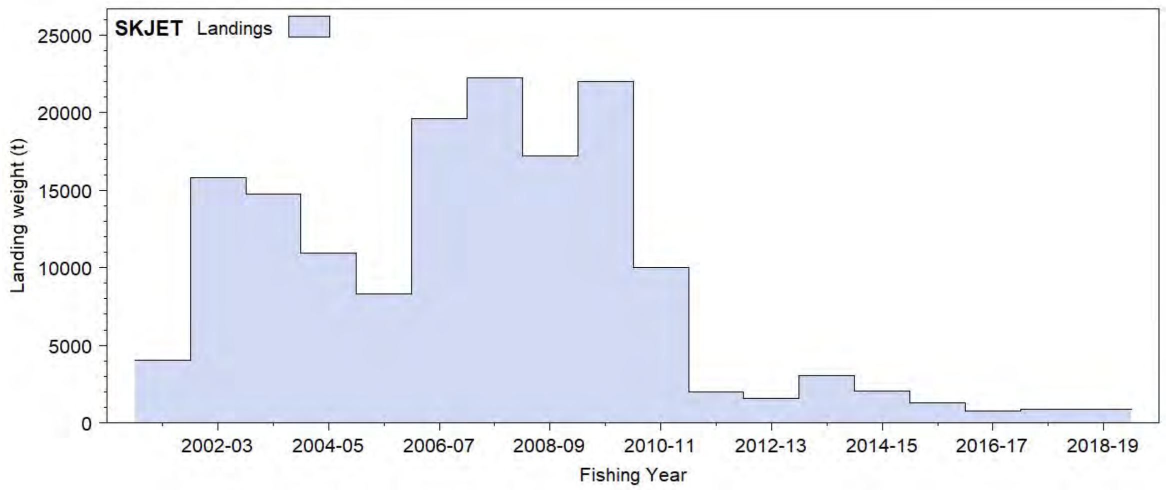


Figure 1: Skipjack purse-seine catch from 1988–89 to 2018–19 within New Zealand waters (SKJ 1), and 2001–02 to 2018–19 in the equatorial Pacific by New Zealand vessels.

In 2012–13, skipjack tuna account for the largest proportion of purse-seine target sets in New Zealand fishery waters (Figure 2). However, in 2017–18, blue mackerel made up the bulk of the catch and skipjack tuna accounted for only 19% of the landed mass of the domestic purse-seine fleet (Figure 3). The skipjack tuna catch occurs on both the east and west coasts of the North Island (Figure 4).

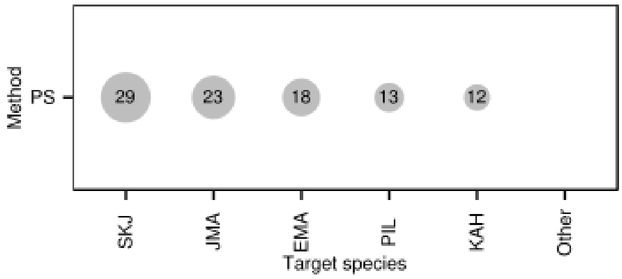


Figure 2: A summary of the proportion of target sets in the domestic purse-seine fishery for 2012–13. The area of each circle represents the percentage of the vessel days targeting each species. PS = purse seine (Bentley et al. 2013).

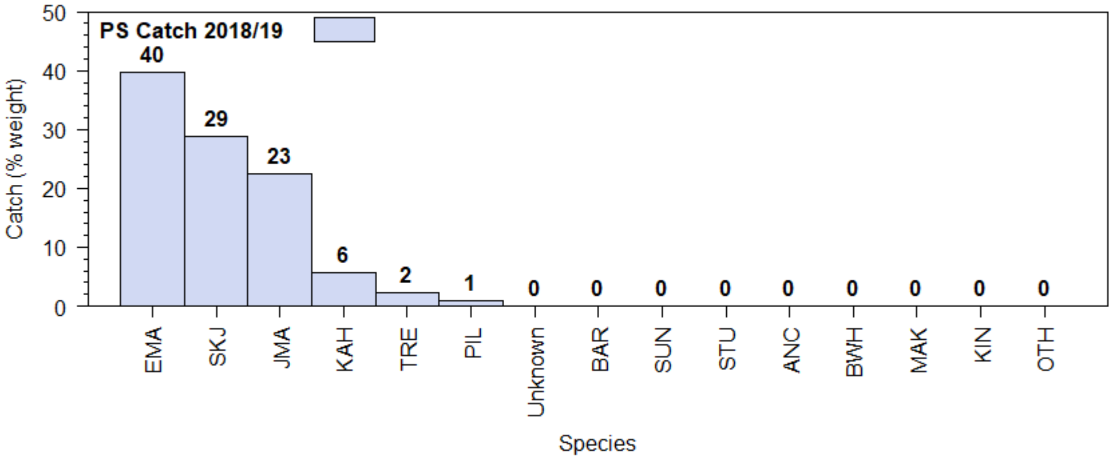


Figure 3: A summary of species composition for all domestic purse-seine estimated catch in 2018–19. The percentage by weight of each species is calculated for all domestic trips.

During 2001–09, fishing activity for skipjack tuna by New Zealand flagged vessels outside of New Zealand fishery waters was generally limited to within the 10°S to 5°N latitudinal range (Figure 5). The distribution of fishing activity was largely constrained to areas of international waters (‘high seas’) and the national waters of those countries for which the fleet has established access arrangements, most notably the EEZs of Tuvalu and Kiribati (Table 3). A limited amount of fishing has also occurred in the waters of Nauru, Solomon Islands, Tokelau, Federal States of Micronesia (FSM) and Marshall Islands although the activity in these areas has either been intermittent or maintained at a low level. Fishing access to a country’s national waters is generally negotiated collectively under the auspices of the New Zealand Far Seas Tuna Fishers Association. However, the individual members of the association may decide not to purchase a licence in a specific year (Langley 2011).

Table 3: Number of sets conducted by New Zealand flagged purse-seine vessels operating within areas of international waters (IW) and countries’ EEZ’s in the western equatorial Pacific fishery by calendar year. KI denotes Kiribati. Areas of international waters (A1–4) are defined in Figure 5 (Langley 2011). [Continued next page]

Area									Year
	2001	2002	2003	2004	2005	2006	2007	2008	2009
IW A1	0	0	50	0	0	0	0	0	0
IW A2	7	58	114	73	52	189	125	163	110
IW A3	7	15	74	37	16	39	43	19	30
IW A4	0	126	3	5	39	29	1	0	48
FSM	0	1	143	0	0	0	0	0	0
Gilbert Is (KI)	43	92	130	122	111	133	90	112	37

Line Is (KI)	0	149	0	0	3	0	27	0	0
Area									**Year**
	2001	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
Pheonix Is (KI)	12	126	31	44	144	49	62	9	164
Marshall Islands	0	0	4	6	10	0	0	0	0
Nauru	0	0	0	44	30	17	17	21	0
Solomon Islands	0	0	65	77	4	71	2	89	25
Tokelau	0	12	1	0	1	0	0	0	32
Tuvalu	94	187	29	136	81	138	141	169	211
Other	0	5	14	3	1	6	3	1	1
Total	163	771	658	547	492	671	511	583	658
% IW	9	26	37	21	22	38	33	31	29

There are four main areas of international waters within the western equatorial Pacific. Of these areas, most of the fishing by the New Zealand fleet has been within the area of international waters surrounded by the national waters of Nauru, Kiribati (Gilbert Islands), Tuvalu, Solomon Islands, Papua New Guinea and FSM (the so called 'high seas pockets', denoted A2 in Figure 5. The fleet also operates in the narrow strip of international waters between Tuvalu and the Phoenix Islands (Kiribati) (area A3) and intermittently in the eastern area of international waters between the Phoenix Islands and Line Islands (Kiribati) (area A4). Limited fishing has occurred in the international waters between Papua New Guinea and FSM (area A1). Overall, the areas of international waters account for about 30% of the annual level of fishing activity and skipjack tuna catch of the New Zealand fleet operating in the equatorial fishery (Table 3) (Langley 2011).

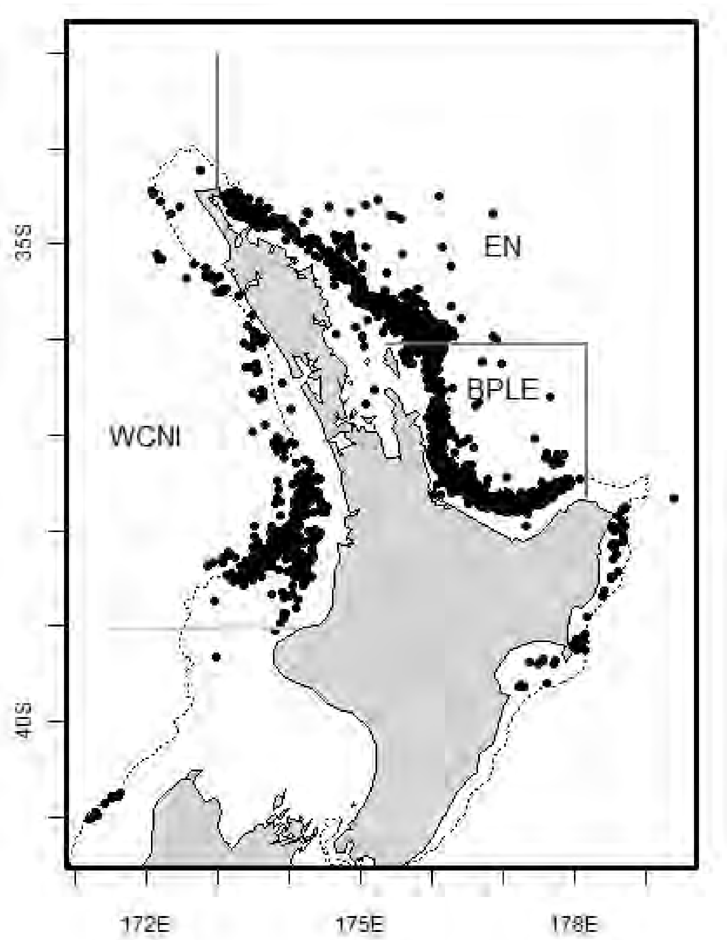


Figure 4: Location of purse-seine sets targeting skipjack tuna from 1999–2000 to 2008–09. The solid grey lines denote the boundaries of the main fishery areas (EN, east Northland; BPLE, Bay of Plenty; WCNI, west coast North Island). The dashed line represents the 200 m depth contour (Langley 2011).

Total fishing effort (number of sets) was highest in 2002 and was dominated by fishing within Kiribati waters. In the subsequent years, the fishing effort tended to fluctuate about the average level, with higher levels of effort in 2006 and 2009 and lower effort in 2005 and 2007 (Table 3) (Langley 2011).

In the initial years (2002–2005), there was considerable variability in the distribution of fishing effort among the main fishing areas. Fishing effort in Kiribati waters was high in 2002 and 2005 and fishing effort in Tuvalu waters was low in 2003 when a considerable amount of fishing occurred in the waters of FSM. During 2006–2009, the distribution of fishing effort was relatively stable with international waters and the EEZs of Tuvalu and Kiribati each accounting for about 25–35% of the annual fishing effort and 5–15% of the total effort occurring in other areas (Table 3) (Langley 2011).

Since the mid-2010's fishing effort and catch have fallen to low levels as the number of large New Zealand purse-seiners has substantially reduced.

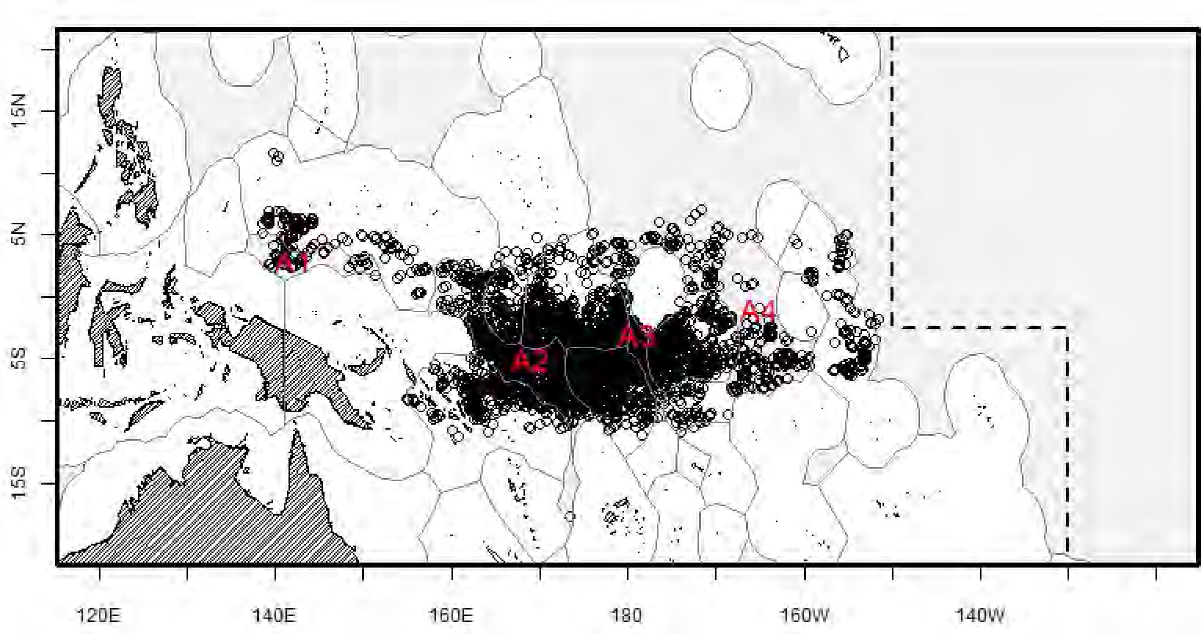


Figure 5: Distribution of purse-seine set locations for New Zealand flagged vessels operating in the equatorial region of the western Pacific Ocean from 2001 to 2009. The red labels (A1–4) denote the four areas of international waters referred to in the text.

1.2 Recreational fisheries

Skipjack by virtue of its wide distribution in coastal waters over summer is a seasonally important recreational species (the fourteenth most frequently caught finfish species by number in 2011–12). It is taken by fishers targeting it predominantly for use as bait, but it is also targeted as a food species. Skipjack are also frequently taken as bycatch when targeting other gamefish. Skipjack do not comprise part of the voluntary recreational gamefish tag-and-release programme.

Skipjack are taken almost exclusively using rod and reel (over 93% of the 2011–12 and 2017–18 harvests), and from trailer boats (over 59% of the 2011–12 and 2017–18 harvests) and launches (over 18% of the 2011–12 and 2017–18 harvests). They are caught predominantly around the upper North Island in FMAs 1 and 9 (over 80% of the 2011–12 and 2017–18 harvests). Bag frequencies ranged from 1 to 21 fish, with 81% of bags in 2011–12 being 1–4 fish.

1.2.1 Management controls

There are no specific controls in place to manage recreational harvests of skipjack.

1.2.2 Estimates of recreational harvest

No estimates of recreational harvest of skipjack were generated from the telephone-diary surveys conducted in 1994, 1996 and 2000 because so few were reported. A National Panel Survey was conducted for the first time throughout the 2011–12 fishing year. The panel survey used face-to-face interviews of a random sample of 30 390 New Zealand households to recruit a panel of fishers and non-fishers for a full year (from Wynne-Jones et al. 2014). The panel members were contacted regularly about their fishing activities and harvest information collected in standardised phone interviews. The national panel survey was repeated during the 2017–18 fishing year using very similar methods to produce directly comparable results (Wynne-Jones et al. 2019). Recreational catch estimates from the two national panel surveys are given in Table 4. Note that national panel survey estimates do not include recreational harvest taken under s111 general approvals.

Table 4: Recreational harvest estimates (in numbers of fish) for skipjack (Wynne-Jones et al. 2014, 2019).

Stock	Year	Method	Number of fish	Total weight (t)	CV
SKJ 1	2011/12	Panel survey	41 182	92.08	0.23
	2017/18	Panel survey	29 892	53.80	0.17

1.3 Customary non-commercial fisheries

There is no information on the customary take, but it is considered to be low.

1.4 Illegal catch

There is no known illegal catch of skipjack tuna.

1.5 Other sources of mortality

Skipjack tuna are occasionally caught as bycatch in the tuna longline fishery in small quantities; because of their low commercial value this bycatch is often discarded.

2. BIOLOGY

Skipjack tuna are epipelagic opportunistic predators of fish, crustaceans and cephalopods found within the upper few hundred metres of the surface. Individual tagged skipjack tuna are capable of movements of over several thousand nautical miles but also exhibit periods of residency around islands in the central and western Pacific, resulting in some degree of regional fidelity. Skipjack are typically a schooling species with juveniles and adults forming large schools at or near the surface in tropical and warm-temperate waters to at least 40ºS in New Zealand waters. Individuals found in New Zealand waters are mostly juveniles, which also occur more broadly across the Pacific Ocean, in both the northern and southern hemisphere. Adult skipjack reach a maximum size of 34.5 kg and lengths of 108 cm. The maximum reported age is 12 years old although the maximum time at liberty for a tagged skipjack of 4.5 years indicates that skipjack grow rapidly (reach 80 cm by age 4) and probably few fish live beyond 5 years old. Spawning takes place in equatorial waters across the entire Pacific Ocean throughout the year, in tropical waters spawning is almost daily. Recruitment shows a strong positive correlation with periods of El Niño.

Natural mortality is estimated to vary with age, with a maximum at age 1 and declining for older fish. A range of von Bertalanffy growth parameters has been estimated for skipjack in the western and central Pacific Ocean, depending on the area and the size of skipjack studied (Table 5). For skipjack tuna in the Pacific Ocean, the intrinsic rate of increase (k) is inversely related to asymptotic length (L_∞) by a power relationship; both parameters are also weakly correlated with sea surface temperature over the range 12º to 29ºC.

Length-frequency data were available from the Ministry’s observer programme. In most years, the sampled component of the skipjack tuna purse-seine catch from the main fishery area was dominated by fish in the 40–50 cm fork length (FL) range. Considerably larger fish were caught in the Bay of

Table 5: The range in L_∞ and k by country or area.

Country/Area	L_∞ (cm)	k
Hawaii	84.6 to 102.0	1.16 to 0.55
Indonesia	79.0 to 80.0	1.10 to 0.95
Japan	144.0	0.185
Papua New Guinea	65.0 to 74.8	0.92 to 0.52
Philippines	72.0 to 84.5	0.70 to 0.51
Taiwan	104.0	0.30 to 0.43
Vanuatu	62.0	1.10
Western Pacific	61.3	1.25
Western tropical Pacific	65.1	1.30

Plenty and east Northland fisheries in 2004–05 and in the North Taranaki Bight fishery in 2005–06 and 2006–07. The modal structure in the length composition data indicates that the fishery is principally catching fish of 1–2 years of age (Tanabe et al. 2003 estimated that skipjack tuna in the western Pacific reach 45 cm at 1 year and 65 cm at 2 years old) (Langley 2011).

3. STOCKS AND AREAS

Surface-schooling, adult skipjack tuna (over 40 cm FL) are commonly found in tropical and subtropical waters of the Pacific Ocean.

Skipjack in the western and central Pacific Ocean (WCPO) are considered a single stock for assessment purposes. A substantial amount of information on skipjack movement is available from tagging programmes. In general, skipjack movement is highly variable but is thought to be influenced by large-scale oceanographic variability. In the western Pacific, warm, poleward-flowing currents near northern Japan and southern Australia extend their distribution to 40°N and 40°S. These limits roughly correspond to the 20°C surface isotherm.

4. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS

The figures and tables in this section were updated and additional text included for the November 2019 Fishery Assessment Plenary following review of the text by the Aquatic Environment Working Group in 2016. This summary is from the perspective of the skipjack tuna fishery; a more detailed summary from an issue-by-issue perspective is available in the Aquatic Environment & Biodiversity Annual Review where the consequences are also discussed (Ministry for Primary Industries 2019).

4.1 Role in the ecosystem

Skipjack tuna (*Katsuwonus pelamis*) average 45–60 cm length in New Zealand, reaching an upper maximum of around 70 cm (Paul 2000). Skipjack are prey of larger tuna, HMS sharks and billfish.

4.2 Incidental catch in the purse-seine fishery

In the domestic skipjack purse-seine fishery observer rates are relatively high. Relative to the skipjack catch (Table 6), observed non-target catch is minor and consists mostly of teleosts. In the overall non-target catch, jack mackerel and blue mackerel are the most common teleost by weight, but small numbers of large individuals such as striped marlin and mako sharks are also caught (Table 7).

Spinetail devil rays (Mobula japanica) are the only protected fish species that have been accidentally caught by purse-seine vessels in New Zealand. Work is underway to develop safe release methods for protected species, including sharks and rays. There has been one observed incidental capture of a New Zealand fur seal in this fishery (2007-08) and three observed captures of seabirds (two in 2007-08, one in 2014-15) since 2002-03.

Table 6: Domestic purse-seine sets targeting skipjack tuna observed as a percentage of sets made for 2005–16.

Calendar year	No. sets observed	% sets observed	% SKJ catch
2005	37	4.7	4.5
2006	104	17.6	35.5
2007	77	14.8	25.2
2008	118	27.6	57.3
2009	83	10.4	33.1
2010	109	8.8	15.3
2011	125	11.9	23.8
2012	113	9.5	19.7
2013	112	9.2	19.8
2014	95	10.1	15.3
2015	102	19.6	17.5
2016	80	25.6	25.9

Table 7: Catch composition from six observed purse-seine trips targeting skipjack tuna operating within New Zealand fisheries waters in 2011 and 2013.

Common name	Scientific name	Observed catch weight (kg)	% Catch
Skipjack tuna	*Katsuwonus pelamis*	4 416 546	98.90
Jack mackerel	*Trachurus* spp.	22 057	0.49
Blue mackerel	*Scomber australasicus*	14 310	0.32
Sunfish	*Mola mola*	4 555	0.10
Spine-tailed devil ray	*Mobula japonica*	2 700	0.06
Striped marlin	*Tetrapturus audax*	1 520	0.03
Frigate tuna	*Auxis thazard*	1 010	0.02
Albacore tuna	*Thunnus alalunga*	679	0.02
Thresher shark	*Alopias vulpinus*	520	0.01
Jellyfish	Scyphozoa	309	0.01
Hammerhead shark	*Sphyrna zygaena*	245	0.01
Stingray	Dasyatididae	185	<0.01
Mako shark	*Isurus oxyrinchus*	158	<0.01
Swordfish	*Xiphias gladius*	150	<0.01
Frostfish	*Lepidopus caudatus*	102	<0.01
Flying fish	Exocoetidae	84	<0.01
Ray's bream	*Brama brama*	81	<0.01
Bronze whaler shark	*Carcharhinus brachyurus*	80	<0.01
Blue shark	*Prionace glauca*	70	<0.01
Slender tuna	*Allothunnus fallai*	50	<0.01
Snapper	*Pagrus auratus*	23	<0.01
Kahawai	*Arripis trutta*	20	<0.01
Porcupine fish	*Allomycterus jaculiferus*	15	<0.01
Tarakihi	*Nemadactylus macropterus*	15	<0.01
Electric ray	*Torpedo fairchildi*	12	<0.01
Table 7: [Continued]			
Pufferfish	*Sphoeroides pachygaster*	9	<0.01
Octopus	Octopoda	7	<0.01
Squid	Teuthoidea	7	<0.01
Kingfish	*Seriola lalandi*	6	<0.01
Rough skate	*Dipturus nasutus*	4	<0.01
Dolphinfish	*Coryphaena hippurus*	3	<0.01
Paper nautilus	*Argonauta nodosa*	2	<0.01
Pelagic ray	*Pteroplatytrygon violacea*	2	<0.01
John dory	*Zeus faber*	2	<0.01
Leatherjacket	*Parika scaber*	2	<0.01
Porae	*Nemadactylus douglasi*	2	<0.01
Rudderfish	*Centrolophus niger*	2	<0.01
Smooth skate	*Dipturus innominatus*	2	<0.01
Jack mackerel	*Trachurus murphyi*	1	<0.01
Pipefish	Syngnathidae	1	<0.01

There is a high level of bycatch of small bigeye and yellowfin tuna in the tropical skipjack purse-seine fishery when using Fish Aggregating Devices (FADs). This has increased the catch of bigeye and yellowfin and has contributed to biomass declines of these two species.

Sea turtles also get incidentally captured in purse-seine nets and FADs; the WCPFC is attempting to reduce sea turtle interactions through Conservation and Management Measures CMM2008-03 and CMM2018-04. Mortality of whale sharks and basking sharks, which act as FADs and are caught in purse-seine nets, is known to occur, but the extent of this is currently unknown.

5. STOCK ASSESSMENT

The most recent stock assessment was carried out in 2019 (Vincent et al. 2019). An additional three years of data were available since the previous assessment in 2016, and the model extends through to the end of 2018. New developments in the stock assessment included addressing the recommendations of the 2016 stock assessment report, revision and incorporation of new data sources such as maturity-at-length, creation of an additional spatial structure, exploration of model uncertainty, and improving the diagnostics of previous assessments.

Changes made in the progression from the 2016 to 2019 diagnostic models that influence perception of skipjack stock status were the:

i) update of data through the end of 2018;
ii) adoption of an eight-region model to better describe the biology of the stock;
iii) estimation of the tagging over-dispersion parameter;
iv) incorporation of Japanese tag releases that did not have release length from 1989 onward;
v) estimation of growth curves prior to the diagnostic model, which were subsequently fixed for all models in the uncertainty grid; and
vi) incorporation of newly available maturity-at-length data.

5.1 Stock status and trends

The general conclusions of this assessment are as follows:

- Total biomass and spawning potential remained relatively stable, with fluctuations, until the mid-2000s, after which it declined. Estimated recruitment shows an increasing trend from 1980 to the recent period.
- Average fishing mortality rates for juvenile and adult age-classes increase throughout the period of the assessment.
- All models in the structural uncertainty grid assessed the stock to be above the adopted LRP, and fished at rates below F_{MSY}, with 100% probability. The skipjack stock is therefore not overfished, nor subject to overfishing.
- Overall median depletion over the recent period (2015–2018; $SB_{recent}/SB_{F=0}$) was 0.44 (80 percentile range 0.34-0.53) for the 8 region model.
- Results from both regional structures indicate a stock status currently on average below the interim target reference point (TRP) for skipjack. 85% of the weighted grid estimated $SB_{recent}/SB_{F=0}$ to be less than the interim TRP (50% $SB_{F=0}$).
- Median recent fishing mortality of the grid (2014–2017; F_{recent}/F_{MSY}) was 0.45 (80 percentile range 0.34–0.60).

SC15 noted that the total provisional catch in 2018 was 1 795 048 t, a 10% increase from 2017 and a 1% decrease from 2013–2017. Purse seine catch in 2018 (1 469 520 t) was a 15% increase from 2017 and a 2% increase from the 2013–2017 average. Pole and line catch (138 534 t) was a 4% increase from 2017 and a 9% decrease from the average 2013–2017 catch. Catch by other gears (182 888 t) was a 16% decrease from 2017 and 19% decrease from the average catch in 2013–2017.

SC15 agreed to use the 8-region model to describe the stock status of skipjack tuna because SC15 considers that it better captures the biology of skipjack tuna than the existing 5-region structure. Stock status was determined over an uncertainty grid of 54 models with assumed weightings as illustrated in Table 8.

Table 8: Description of the updated structural sensitivity grid used to characterise uncertainty in the assessment.

Axis	Value	Relative weight
Steepness	0.65	0.8
	0.80	1.0
	0.95	0.8
Growth	Low	1.0
	Diagnostic	1.0
	High	1.0
Length composition Scalar	50	0.8
	100	1.0
	200	1.0
Tag mix	1	1.0
	2	1.0

The median values of recent (2015–2018) spawning biomass depletion ($SB_{recent}/SB_{F=0}$) and relative recent (2014–2017) fishing mortality (F_{recent}/F_{MSY}) over the uncertainty grid of 54 models (Table 9) were used to define stock status. The values of the upper 90th and lower 10th percentile of the empirical distributions of relative spawning biomass and relative fishing mortality from the uncertainty grid were used to characterise the probable range of stock status.

Table 9: Summary of reference points over the various models in the structural uncertainty grid. F_{mult} is the multiplier of recent (2014–2017) fishing mortality required to attain MSY, F_{recent} is the average fishing mortality of recent (2014–2017), SB_{recent} is the average spawning potential of recent years (2015–2018) and SB_{latest} is the spawning potential in 2018.

	Mean	Median	Minimum	10th %ile	90th %ile	Maximum
C_{latest}	1 755 328	1 755 693	1 749 846	1 753 471	1 757 057	1 757 083
$Y_{Frecent}$	1 877 914	1 864 040	1 679 600	1 737 702	2 043 556	2 135 200
f_{mult}	2.282	2.258	1.472	1.757	2.957	3.705
F_{MSY}	0.223	0.222	0.180	0.189	0.264	0.270
MSY	2 296 566	2 294 024	1 953 600	1 995 987	2 767 083	2 825 600
F_{recent}/F_{MSY}	0.461	0.447	0.270	0.343	0.600	0.679
$SB_{F=0}$	6 220 675	6 299 363	5 247 095	5 580 942	6 913 431	7 349 557
SB_{MSY}	1 100 947	1 064 400	631 900	723 742	1 544 060	1 688 000
$SB_{MSY}/SB_{F=0}$	0.175	0.176	0.117	0.131	0.225	0.23
$SB_{latest}/SB_{F=0}$	0.414	0.415	0.325	0.36	0.487	0.525
SB_{latest}/SB_{MSY}	2.468	2.382	1.551	1.779	3.356	3.925
$SB_{recent}/SB_{F=0}$	0.440	0.440	0.336	0.372	0.530	0.551
SB_{recent}/SB_{MSY}	2.623	2.579	1.601	1.892	3.613	4.139

The spatial structure used in the assessment model is shown in Figure 6. Time series of total annual catch (1000's t) by fishing gear for all regions is shown in Figure 7 and by region separately is shown in Figure 8. The annual average recruitment, spawning potential, and total biomass by model region for the diagnostic model are shown in Figure 9. The overall spawning potential summed across region for the diagnostic model is shown in Figure 10. The estimated annual average juvenile and adult fishing mortality for the diagnostic model is shown in Figure 11. The estimated impact of fishing (1 – $SB_{latest}/SB_{F=0}$) by region and overall regions for the diagnostic model is shown in Figure 12. The median and 80th percent quantile trajectories of fishing depletion for models in the weighted structural uncertainty grid in Table 8 is shown in Figure 13, where it can be seen that the median has been below the target since 2009. The Majuro plot shows the recent fishing mortality and spawning potential relative to the unfished spawning potential for all models in the structural uncertainty grid for (i) spawning potential in the recent time period (2015–2018) in Figure 14, and (ii) spawning potential in the latest time period (2018) in Figure 15. The Kobe plot shows the recent fishing mortality and spawning potential relative to spawning potential at MSY for all models in the structural uncertainty grid for (i) spawning potential in the recent time period (2015–2018) in Figure 16, and (ii) spawning potential in the latest time period (2018) in Figure 17.

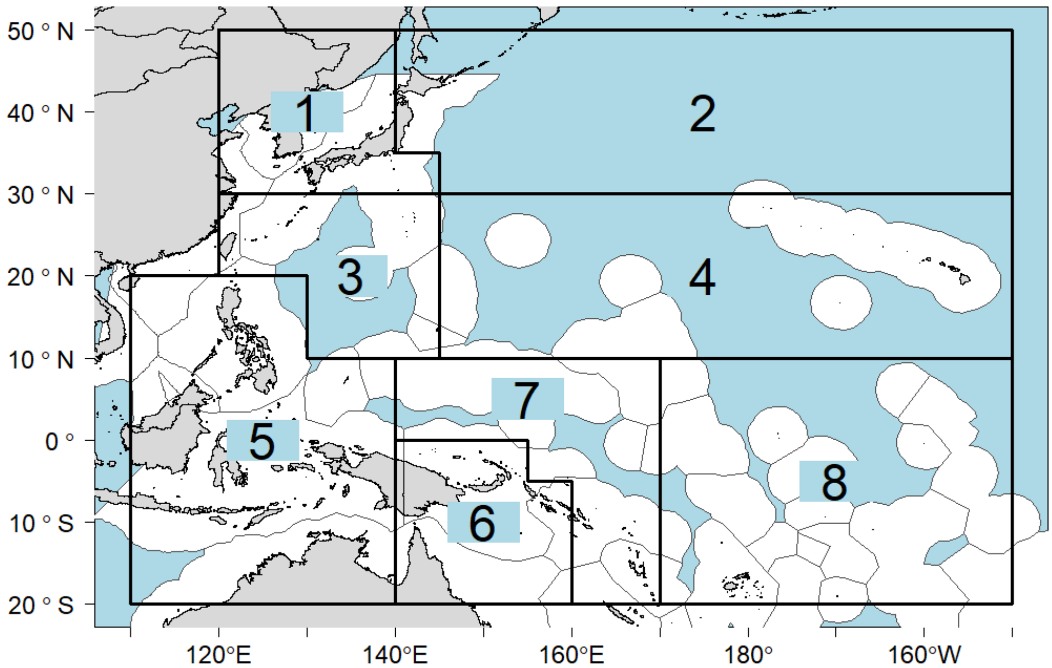


Figure 6: Eight region spatial structure used in the 2019 stock assessment model.

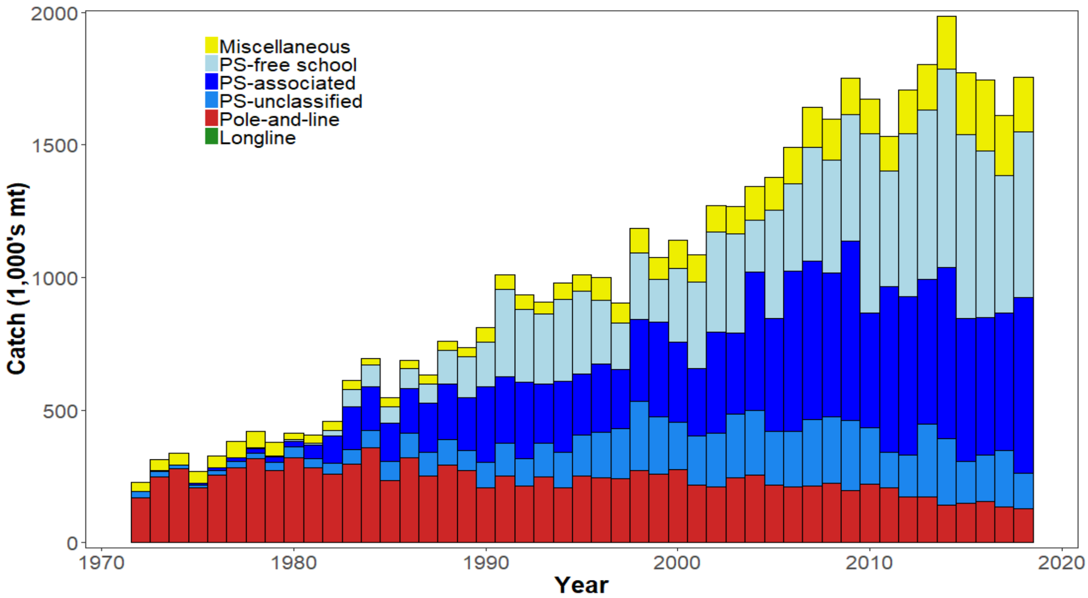


Figure 7: Time series of total annual catch (1000's mt) by fishing gear over the full assessment period.

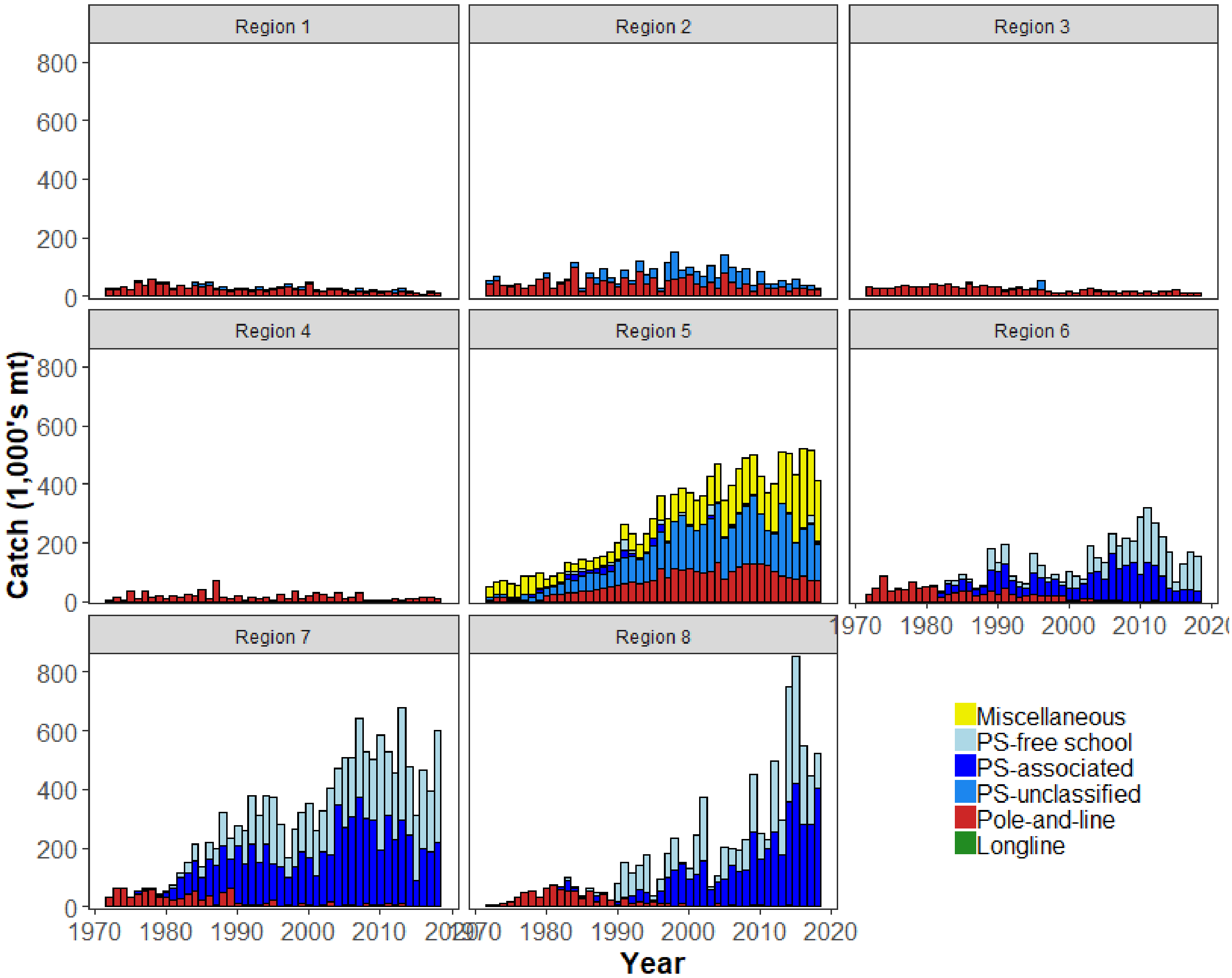


Figure 8: Time series of total annual catch (1000's mt) by fishing gear and assessment region over the full assessment period.

SC15 noted that the median level of spawning potential depletion from the uncertainty grid was $SB_{recent}/SB_{F=0}$ = 0.44 with a probable range of 0.37 to 0.53 (80% probability interval). There were no individual models where $SB_{recent}/SB_{F=0} < 0.2$, which indicated that the probability that recent spawning biomass was below the LRP was zero.

SC15 noted that the grid median F_{recent}/F_{MSY} was 0.45, with a range of 0.34 to 0.60 (80% probability interval) and that no values of F_{recent}/F_{MSY} in the grid exceed 1. Therefore, SC15 noted that there was a zero probability that the recent fishing mortality exceeds F_{MSY}.

SC15 noted that the stock was assessed to be above the adopted Limit Reference Point and fished at rates below F_{MSY} with 100% probability. Therefore, the skipjack stock is not overfished, nor subject to overfishing. At the same time, it was also noted that fishing mortality is continuously increasing for both adults and juveniles while the spawning biomass reached the historical lowest level. The skipjack interim Target Reference Point (TRP) is 50% of spawning biomass in the absence of fishing. The trajectory of the median spawning biomass depletion indicates a long-term trend, and has been under the interim TRP since 2009 (i.e., for 10 years).

SC15 noted that the largest uncertainty in the structural uncertainty grid was due to the assumed tag mixing period. In addition, SC15 acknowledges that further study is warranted to investigate the uncertainty surrounding the appropriate mixing period for the tagging data.

SC15 acknowledged that the spatial extent of the Japanese pole-and-line fishery has decreased over the time period and that the future use of this standardised CPUE index within future stock assessments is uncertain.

Therefore, SC15 acknowledged that further study of alternative indices of abundance is warranted, such as investigation of standardising the purse seine fishery and evaluation of the feasibility of conducting fishery independent surveys.

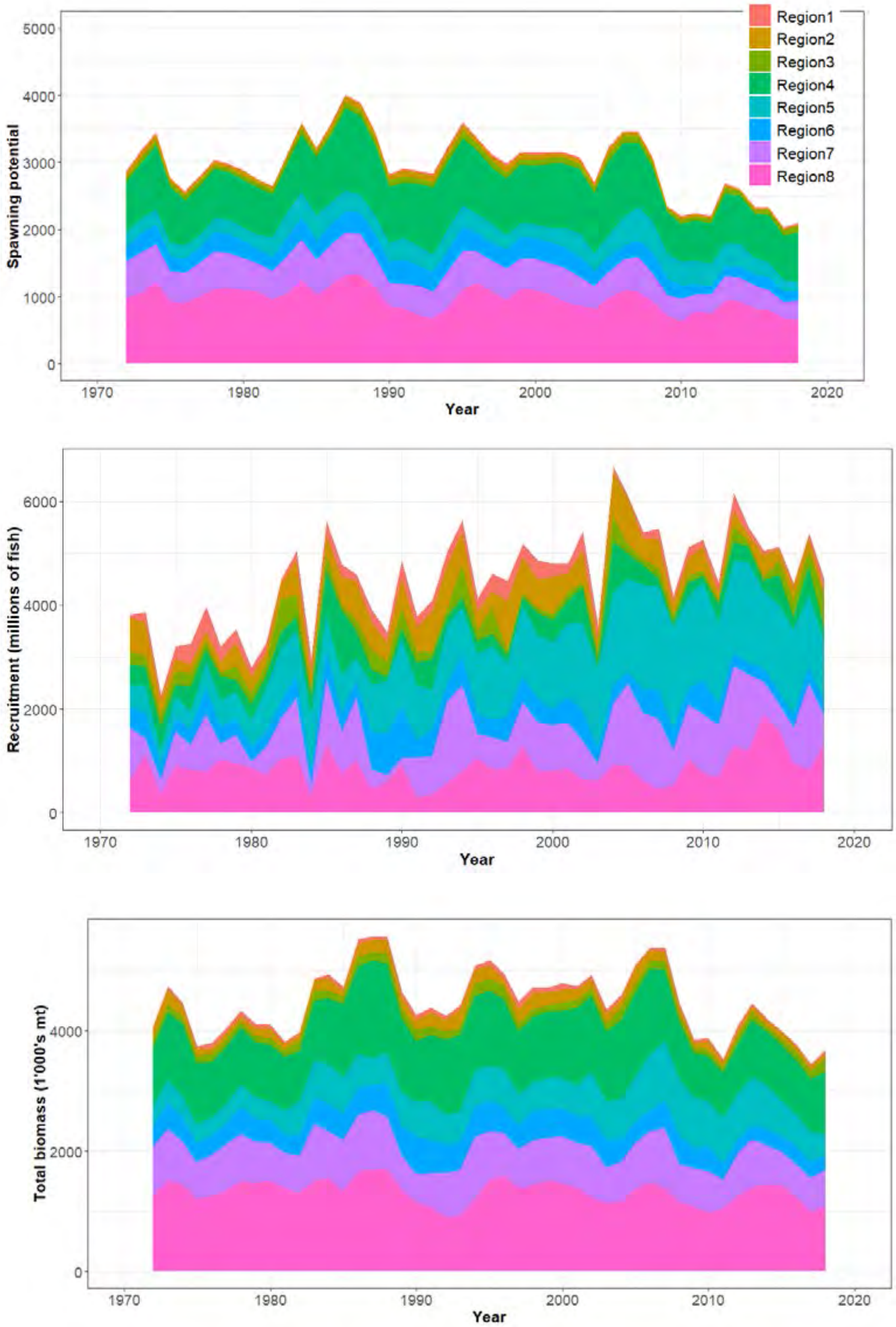


Figure 9: Estimated annual spawning potential, average recruitment and total biomass by model region for the diagnostic model, showing the relative sizes among regions for recruitment (top), spawning potential (middle) and total biomass (bottom).

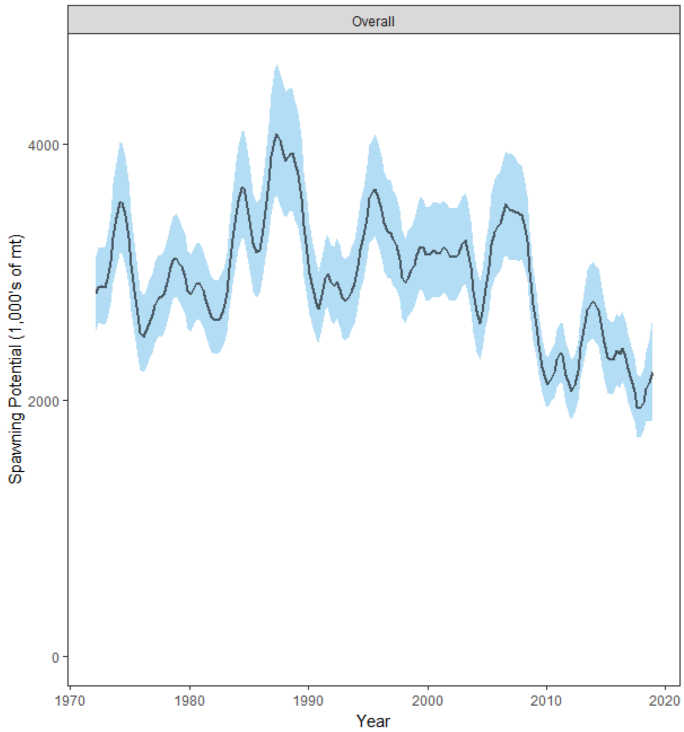


Figure 10: Estimated temporal overall spawning potential summed across regions from the diagnostic model, where the shaded region is ± 2 standard deviations (i.e., 95% CI).

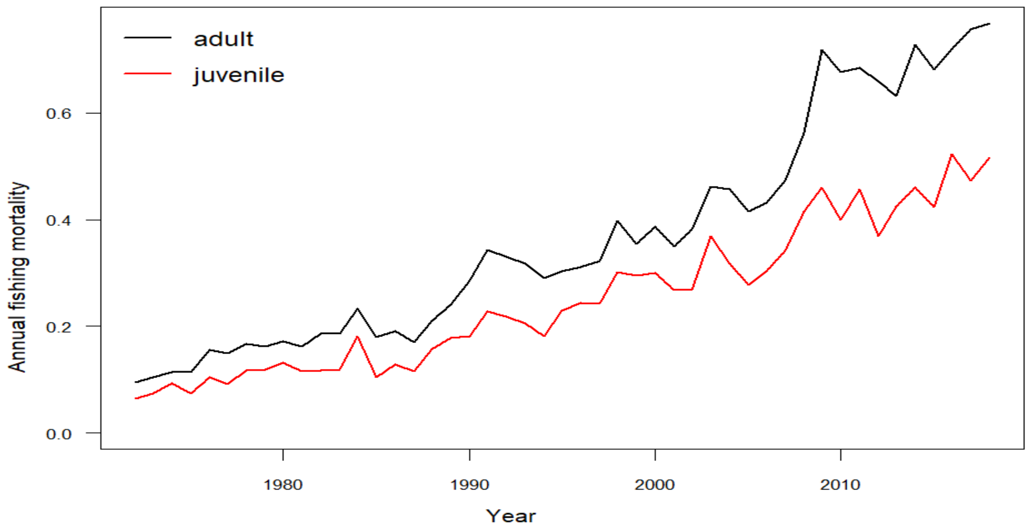


Figure 11: Estimated annual average juvenile and adult fishing mortality for the diagnostic model.

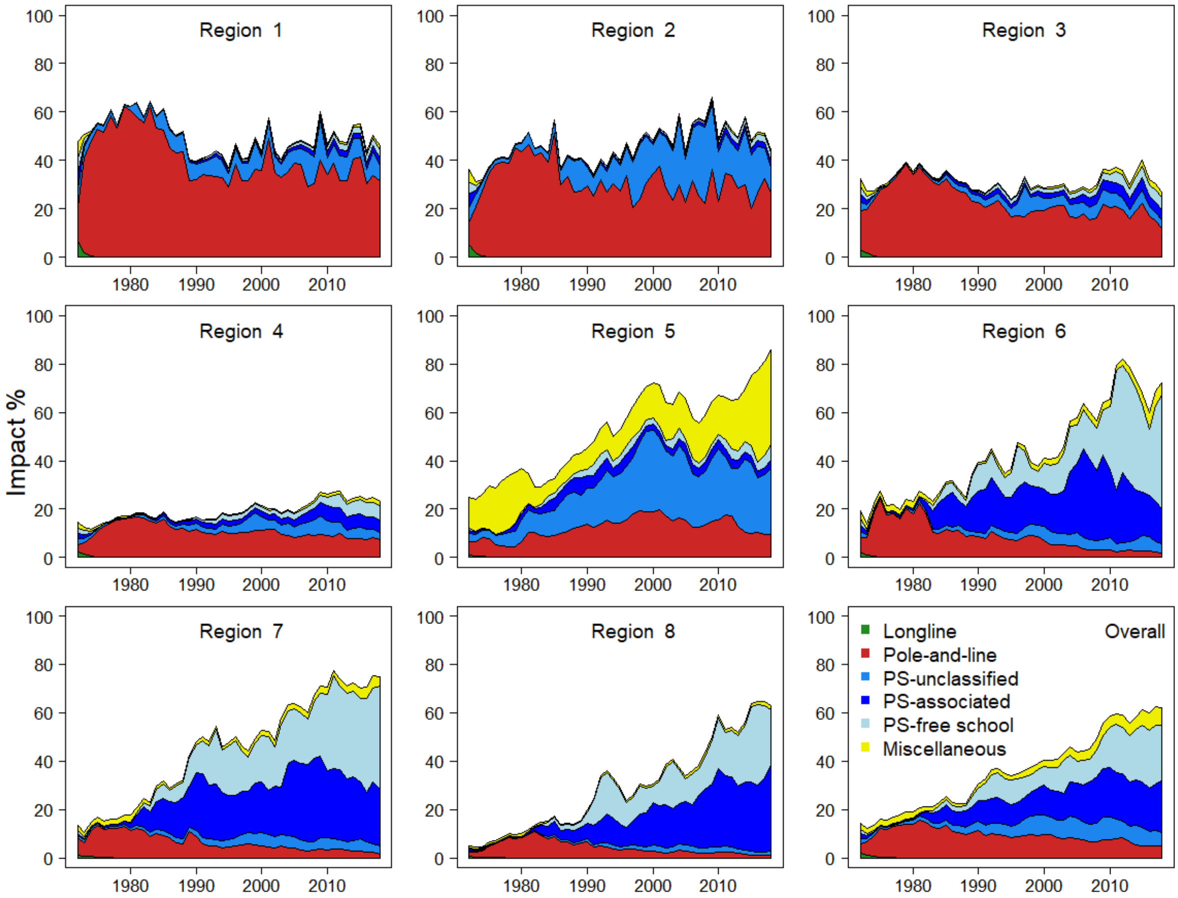


Figure 12: Estimates of reduction in spawning potential due to fishing (fishery impact = 1-$SB_{latest}/SB_{F=0}$) by region for the diagnostic model.

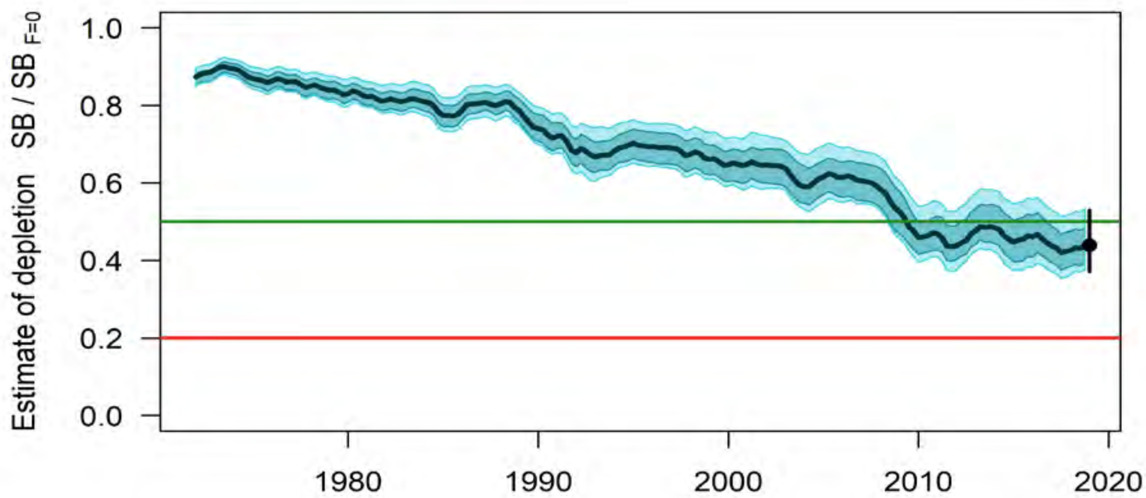


Figure 13: Plot showing the trajectories of spawning potential depletion for the model runs included in the structural uncertainty grid weighted by the values given in Table 8. Red horizontal line indicates the agreed limit reference point, the green horizontal line indicates the interim target reference point.

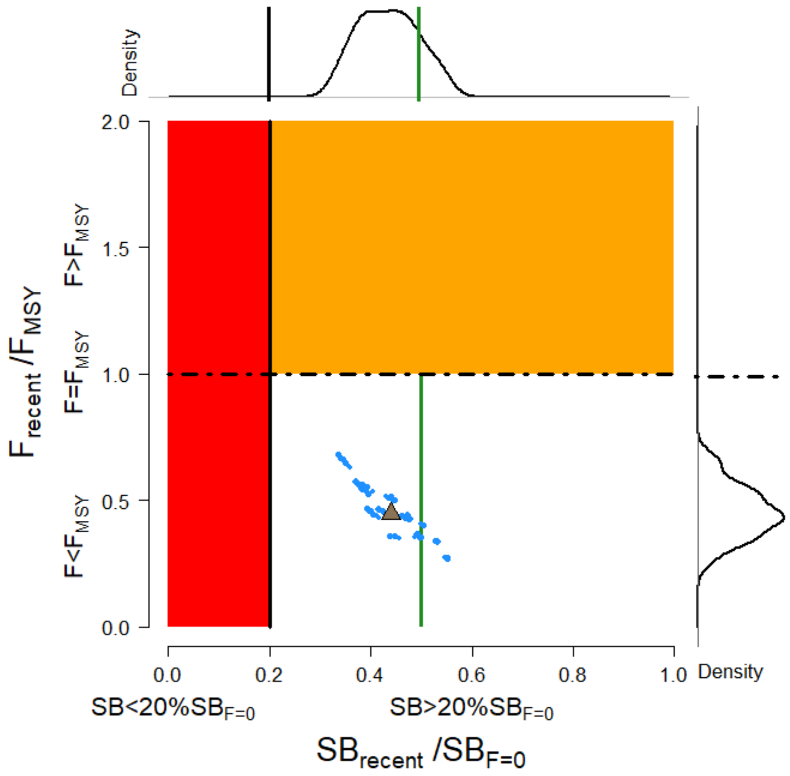


Figure 14: Majuro plot for the recent spawning potential (2015 – 2018) summarising the results for each of the models in the structural uncertainty grid with weighting. The plots represent estimates of stock status in terms of spawning potential depletion and fishing mortality, and marginal distributions of each are presented. Vertical green line denotes the interim TRP. Brown triangle indicates the median of the estimates.

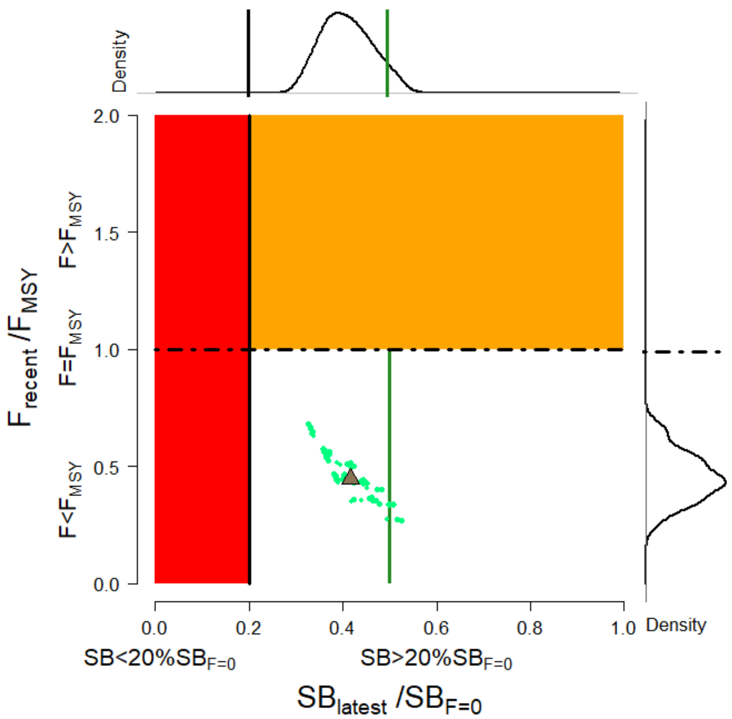


Figure 15: Majuro plot for the latest spawning potential (2018) summarising the results for each of the models in the structural uncertainty grid with weighting. The plots represent estimates of stock status in terms of spawning potential depletion and fishing mortality, and marginal distributions of each are presented. Vertical green line denotes the interim TRP. Brown triangle indicates the median of the estimates.

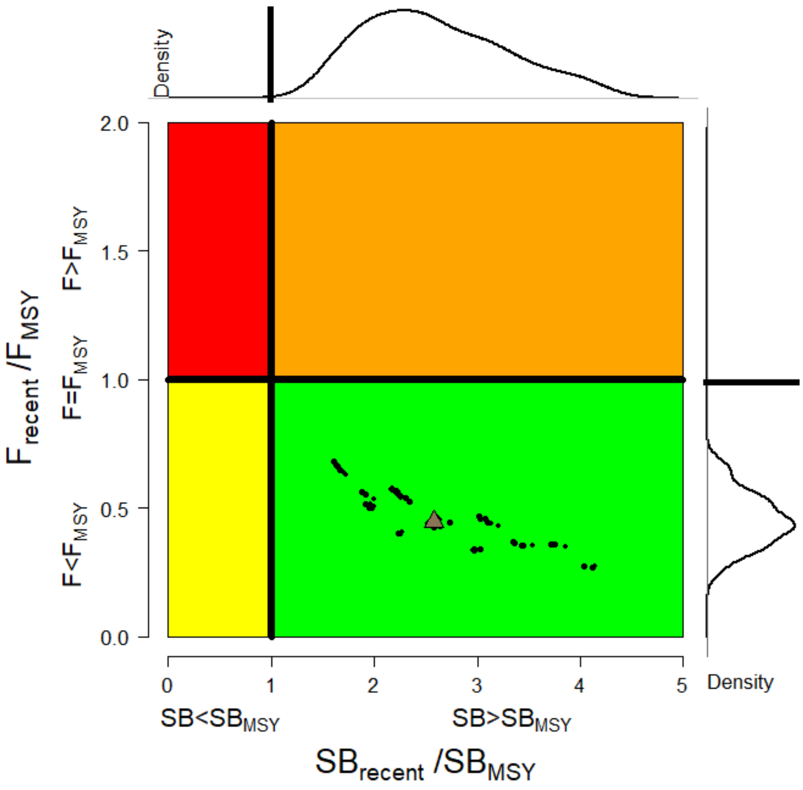


Figure 16: Kobe plot for the recent spawning potential (2015 – 2018) summarising the results for each of the models in the structural uncertainty grid. The plots represent estimates of stock status in terms of spawning potential depletion and fishing mortality and marginal distributions of each are presented. Brown triangle indicates the median of the estimates.

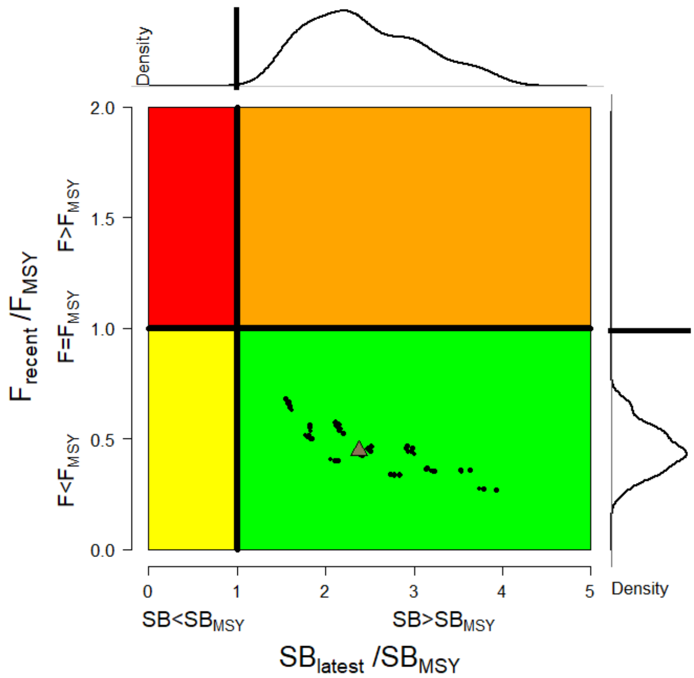


Figure 17: Kobe plot for the latest spawning potential (2018) summarising the results for each of the models in the structural uncertainty grid. The plots represent estimates of stock status in terms of spawning potential depletion and fishing mortality and marginal distributions of each are presented. Brown triangle indicates the median of the estimates.

5.2 Estimates of fishery parameters and abundance

There are no fishery-independent indices of abundance for the skipjack tuna. Unlike other pelagic tunas, the low selectivity of skipjack tuna to longline gear means that no relative abundance information is available from longline catch per unit effort data. Regional CPUE indices derived from Japanese pole-and-line log-sheet data and purse-seine associated CPUE for the Philippines and Papua New Guinea fleets are the principal indices of stock abundance incorporated in the WCPO stock assessment. However, the pole-and-line fleet has declined considerably over the last 20 years and there has been a contraction of the spatial distribution of the fishery in the equatorial region. Purse-seine catch per unit effort data are difficult to interpret. Returns from a large-scale tagging programme undertaken in the early 1990s also provides information on rates of fishing mortality, which in turn leads to improved estimates of abundance.

5.3 Yield estimates and projections

No estimates of MCY and CAY are available.

5.4 Other factors

One area of concern with fisheries for skipjack tuna relates to the potential for significant bycatch of juvenile bigeye and yellowfin tunas in the purse-seine fishery in equatorial waters. Juveniles of these species occur in mixed schools with skipjack tuna broadly through the equatorial Pacific Ocean, and are vulnerable to large-scale purse seine fishing when sets are made on floating objects (FADs). The fishery in New Zealand fisheries waters is on single species free schools.

While the skipjack resource within New Zealand waters is considered to represent a component of the wider WCPO stock, the extent of the interaction between the domestic fishery and the fisheries in the equatorial region is unclear. Catches within New Zealand waters vary inter-annually due to prevailing oceanographic conditions. A review of domestic purse-seine catch and effort data and associated aerial sightings data from the skipjack tuna fishery did not reveal any temporal trend in the availability of skipjack to the domestic fishery (Langley 2011). Recent analyses suggest that the oceanographic conditions that prevail during El Niño conditions may limit the availability of skipjack tuna to the New Zealand fishery (Langley 2019).

5.5 Research recommendations

A number of key research needs were identified in undertaking the assessment that should be investigated:

- Improved estimates of growth for skipjack are required, which could be accomplished through incorporation of tagging-based length-increment data or validation studies of otolith aging by marking with strontium-chloride.
- A thorough evaluation of alternative sources of CPUE time series such as a fishery-independent survey or a standardised purse seine fishery CPUE series.
- Further evaluation of the tagging data and associated model settings and consideration of time-varying movement functionality in MULTIFAN-CL are potential improvements for future assessments.

6. STATUS OF THE STOCKS

Stock structure assumptions

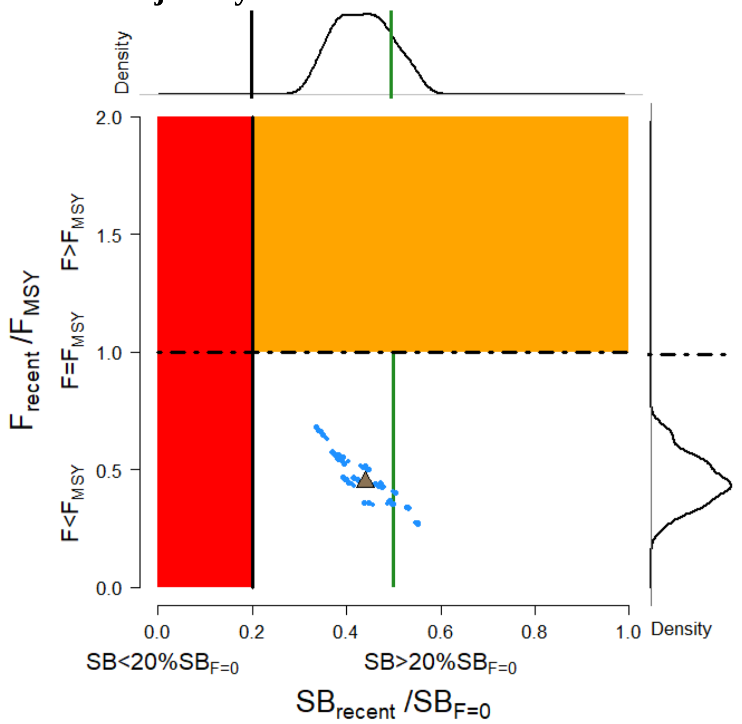
Skipjack tuna are considered to be a single stock in the western and central Pacific Ocean.

Stock Status	
Year of Most Recent Assessment	2019
Assessment Runs Presented	Diagnostic case and structural uncertainty grid

Reference Points	Agreed interim biomass-related target reference point (TRP) 50% SB_0 Limit reference point of 20% SB_0 established by WCPFC equivalent to the HSS default soft limit of 20% SB_0 Hard Limit: Not established by WCPFC; but evaluated using HSS default of 10% SB_0 Overfishing threshold: F_{MSY}
Status in relation to Target	Very Likely (> 90%) to be in the range 40–60% SB_0 and Virtually Certain (> 99%) that $F < F_{MSY}$
Status in relation to Limits	Soft Limit: Exceptionally Unlikely (< 1%) to be below Hard Limit: Exceptionally Unlikely (< 1%) to be below
Status in relation to Overfishing	Overfishing is Exceptionally Unlikely (< 1%) to be occurring

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Total biomass and spawning potential remained relatively stable, with fluctuations, until the mid-2000s, after which it declined. Recent depletion level is estimated at 0.56 (i.e., biomass is estimated to be 0.44 of the unfished level).
Recent Trend in Fishing Intensity or Proxy	F is estimated to have remained well below F_{MSY} over the history of the fishery, but the level of fishing mortality has increased since 2000.
Other Abundance Indices	-
Trends in Other Relevant Indicator or Variables	Recruitment has varied without trend during the 2000's. The estimated distribution of recruitment across regions should be interpreted with caution as MULTIFAN-CL can use a combination of movement and regional recruitment to distribute fish.

Historical Stock Status Trajectory and Current Status



Majuro plot for the recent spawning potential (2015 – 2018) summarising the results for each of the models in the structural uncertainty grid with weighting. The plots represent estimates of stock status in terms of spawning potential depletion and fishing mortality, and marginal distributions of each are presented. Vertical green line denotes the interim TRP. Brown triangle indicates the median of the estimates.

Projections and Prognosis	
Stock Projections or Prognosis	Projections not conducted
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Exceptionally Unlikely (< 1%) Hard Limit: Exceptionally Unlikely (< 1%)
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Exceptionally Unlikely (< 1%)

Assessment Methodology and Evaluation		
Assessment Type	Level 1 – Fully Quantitative Stock Assessment	
Assessment Method	The assessment uses the stock assessment model MULTIFAN-CL.	
Assessment Dates	Latest assessment: 2019	Next assessment: 2022
Overall assessment quality rank	1 – High Quality	1 – High Quality
Main data inputs	- improved purse-seine catch estimates - catch statistics of the component fisheries - standardised CPUE analyses of Japanese pole-and-line operational level catch and effort data - CPUE data for two purse-seine fisheries - size data inputs from the purse-seine fishery and New Zealand recreational fishery - revised regional structures and fisheries definitions - revision and incorporation of new data sources such as maturity-at-length - tagging data and reporting rate information	
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	- adoption of an eight-region model to better describe the biology of the stock - estimation of the tagging over-dispersion parameter - incorporation of Japanese tag releases that did not have release length from 1989 onward	
Major Sources of Uncertainty	- estimates of growth for skipjack - the current CPUE time series used as abundance indices - the current tagging data and associated model settings and consideration of time-varying movement functionality used in MULTIFAN-CL	
Qualifying Comments		
-		

Environmental and Ecosystem Considerations	
Observer coverage	Observer coverage rates are relatively high in the domestic skipjack purse-seine fishery.
Non-target fish and invertebrate catch	Relative to the skipjack catch, observed bycatch is minor and consists mostly of teleosts. Overall Jack mackerel and blue mackerel are the most common teleost accidentally caught by

	weight, but small numbers of large individuals such as striped marlin and mako sharks are also caught.
Incidental catch of seabirds	Observed incidental catch of three seabirds since 2002-03 in the domestic fishery.
Incidental catch of cetaceans	No observed incidental catch of cetaceans in the domestic fishery.
Incidental catch of pinnipeds	Observed incidental catch of one New Zealand fur seal since 2002-03 in the domestic fishery.
Incidental catch of other protected species	Spinetail devil rays (*Mobula japanica*) are the only protected fish species that have been accidentally caught by purse-seine vessels in New Zealand. Work is underway to develop safe release methods for protected species, including sharks and rays.
Benthic interactions	There are no known benthic interactions for this fishery.

7. FOR FURTHER INFORMATION

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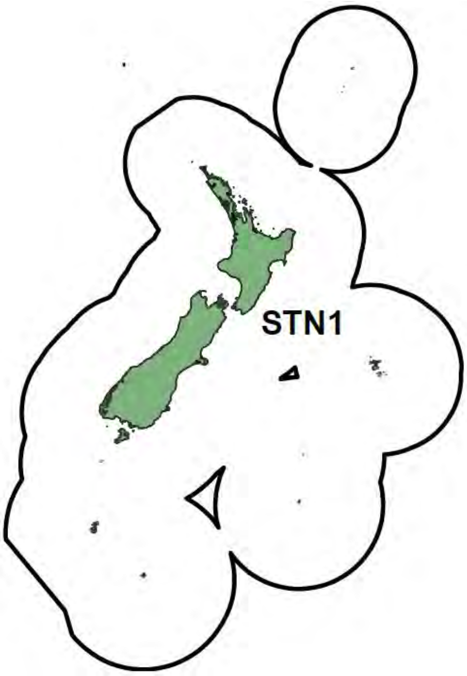
SOUTHERN BLUEFIN TUNA (STN)

(*Thunnus maccoyii)*



1. FISHERY SUMMARY

Southern bluefin tuna were introduced into the QMS on 1 October 2004 under a single QMA, STN 1, with allowances for customary and recreational fisheries and other sources of mortality within the TAC and a commercial TACC. The 2018–19 allowances and the TACC are outlined in Table 1.

Table 1: Recreational and customary non-commercial allowances, TACCs and TAC (all in t) for southern bluefin tuna for the 2018–19 fishing year.

Fishstock	Recreational allowance (t)	Customary non-commercial allowance (t)	Other mortality (t)	TACC (t)	TAC (t)
STN 1	20	2	20	1 046	1 088

Southern bluefin tuna were added to the Third Schedule of the Fisheries Act 1996 with a TAC set under s14 because a national allocation of southern bluefin tuna for New Zealand has been determined as part of an international agreement. The TAC applies to all New Zealand fisheries waters, and all waters beyond the outer boundary of the exclusive economic zone.

Southern bluefin tuna were also added to the Sixth Schedule of the Fisheries Act 1996 with the provision that:

> 'A person who is a New Zealand national fishing against New Zealand's national allocation of southern bluefin tuna may return any southern bluefin tuna to the waters from which it was taken from if –
> (a) that southern bluefin tuna is likely to survive on return; and
> (b) the return takes place as soon as practicable after the southern bluefin tuna is taken.'

Management of southern bluefin tuna throughout its range is the responsibility of the Commission for Conservation of Southern Bluefin Tuna (CCSBT), of which New Zealand is a founding member. Current members of the CCSBT also include Australia, Japan, the Republic of Korea, the Fishing Entity of Taiwan, Indonesia, the Republic of South Africa, and the European Community. The Philippines have Cooperating Non-member status. Determination of the global TAC and provision of a national allocation to New Zealand is carried out by the CCSBT.

1.1 Management procedure

In 2011, the Commission adopted a management procedure (MP) to set quotas for three-year periods based on the latest fisheries indicators from the stock. The MP is designed to rebuild the spawning stock to 20% of the unfished level by 2035 (with 70% certainty). However, the Commission decided not to fully implement the first increase indicated by the operation of the MP in 2011 as there was concern that the TAC may have to be reduced again at the end of the 3 years. Instead the Commission opted for a limited increase in the first three-year period. Quotas set for the three years allowed a 1000 t increase in 2012 to 10 449 t, and a further increase in 2013 to 10 949 t.

At the 20th meeting of CCSBT in October 2013 the TAC was confirmed at 12 449 t for 2014–15 and on the basis of the operation of the management procedure the TAC for 2015 to 2017 was recommended to be set at 14 647 t. The TAC for 2015–16 was also confirmed at this higher figure. At the 21st meeting of CCSBT in October 2014 the TAC was confirmed at 14 647 t for 2016–17. In 2016 the MP was run again and recommended a TAC of 17 647 t for 2018–20 that was confirmed by CCSBT23 in October 2016.

Table 2: Allocated catches for members for 2018–20.

Member	Effective catch limit (t)
Australia	6 165.0
Fishing Entity of Taiwan	1 240.5
Japan	6 165.0
New Zealand	1 088.0
Republic of Korea	1 240.5
Indonesia	1 002.0
European Community	11.0
South Africa	423.0

1.2 Commercial fisheries

The Japanese distant water longline fleet began fishing for southern bluefin tuna in the New Zealand region in the late 1950s and continued after the declaration of New Zealand’s EEZ in 1979 under a series of bilateral access agreements until 1995.

The domestic southern bluefin tuna fishery began with exploratory fishing by Watties in 1966 and Ferons Seafoods in 1969. Most of the catch was used for crayfish bait (reported landings began in 1972). During the 1980s the fishery developed further when substantial quantities of southern bluefin tuna were air freighted to Japan. Throughout the 1980s, small vessels hand lining and trolling for southern bluefin tuna dominated the domestic fishery. Southern bluefin tuna were landed to a dedicated freezer vessel serving as a mother ship, or, ashore for the fresh chilled market in Japan.

Longlining for southern bluefin tuna was introduced to the domestic fishery in the late 1980s under government encouragement and began in 1988 with the establishment of the New Zealand Japan Tuna Company Ltd. The Japanese charter vessels ceased fishing as of 1 May 2016 due to changes in New Zealand government legislation.

New Zealand-owned and -operated longliners, mostly smaller than 50 GRT, began fishing in 1991 for southern bluefin tuna (1 vessel). The number of domestic vessels targeting STN expanded throughout the 1990s and early 2000s prior to the introduction of STN into the QMS. Table 3 summarises southern bluefin landings in New Zealand waters since 1972. Figure 1 shows historical landings and TACC values for domestic southern bluefin tuna.

Since 1991 surface longlines have been the predominant gear used to target southern bluefin tuna in the domestic fishery with 96% of all days fished using this method and only 4% using hand line (less than 1% used trolling). This represents a major change from the 1980s when most fishing was by hand line.

In the few instances when the New Zealand allocation has been exceeded, the domestic catch limit has been reduced in the following year by an equivalent amount. Table 3 contrasts New Zealand STN catches with those from the entire stock. The low catches relative to other participants in the global fishery are due to New Zealand's limited involvement historically rather than to local availability. Table 4 indicates that, throughout most of the 1980s, catches of STN up to 2000 t were taken within the New Zealand EEZ.

Data on reported catch of southern bluefin tuna are available from the early 1950s. By 1960, catches had peaked at nearly 80 000 t, most taken on longline by Japan. From the 1960s through the mid-1970s, when Australia was expanding their domestic surface fisheries for southern bluefin tuna, total catches were in the range 40 000 to 60 000 t. From the mid-1970s through the mid-1980s catches were in the range 35 000 to 45 000 t. Catches declined from 33 325 t in 1985 to 13 869 t in 1990 with the introduction of quotas that reduced the global catch to 9 440 t in 2011 with the introduction of a Management Procedure that reduced quotas still further. Since 2011 the quota has been increased under the Management Procedure with a concomitant increase in catch, reaching 16 936 t in 2018 (see Table 4).

From 1960 to the 1990s catches by longline declined while surface-fishery catches in Australian waters increased to reach its maximum level of 21 512 t in 1982 (equal to the longline catches of Japan). During the 1980s catches by both surface and longline fisheries declined but following dramatic TAC reductions in the late 1980s, catches stabilised. The main difference between gear types is that surface fisheries target juveniles (aged 1–3 years) while longline fisheries catch older juveniles and adults (aged 4–40+ years). The surface fishery has comprised purse-seine and pole-and-line vessels supported by aerial spotter planes that search out surface schools. The Australian surface fisheries prior to 1990 were a mix of pole-and-line and purse-seine vessels, and since the mid-1990s have become almost exclusively a purse-seine fishery. Prior to 1990, surface-fishery catches supplied canneries, whereas since the mid-1990s these vessels catch juveniles for southern bluefin tuna farms where they are 'on-grown' for the Japanese fresh fish market. The fisheries of all other members (including New Zealand) are based on longline.

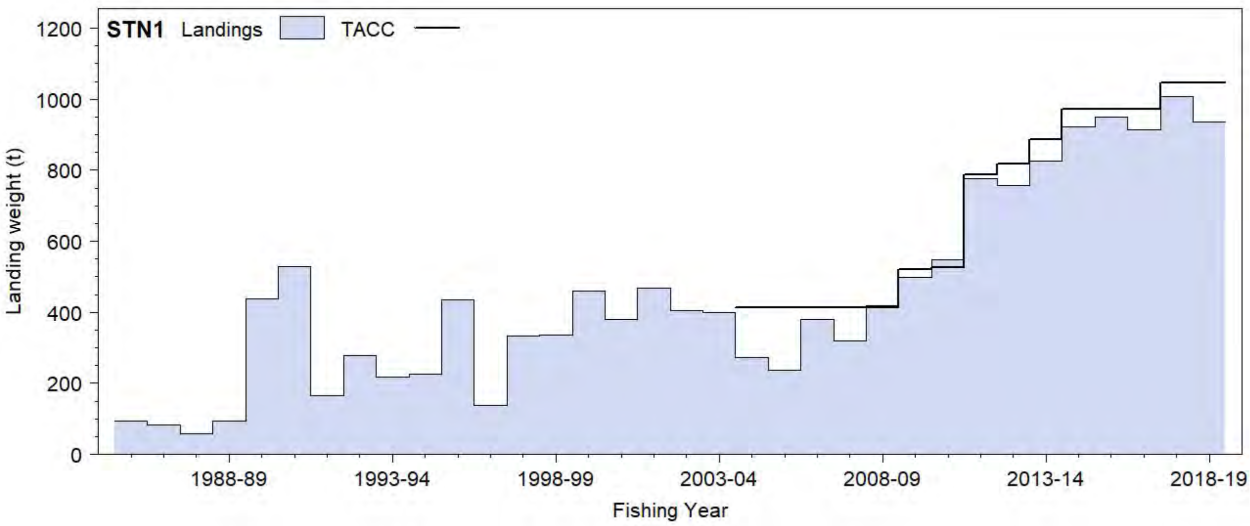


Figure 1: Commercial catch and TACC of southern bluefin tuna from 1985–86 to 2018–19 within New Zealand fishing waters (STN 1).

Table 3: Reported domestic[1] and total[2] southern bluefin tuna landings (t) from 1972 to 2018 (calendar year).

Year	NZ landings (t)	Total stock (t)	Year	NZ landings (t)	Total stock (t)
1972	1	51 925	1996	139	16 356
1973	6	41 205	1997	334	16 076
1974	4	46 777	1998	337	17 776
1975	0	32 982	1999	461	19 529
1976	0	42 509	2000	380	15 475
1977	5	42 178	2001	358	16 032
1978	10	35 908	2002	450	15 258
1979	5	38 673	2003	390	14 077
1980	130	45 054	2004	393	13 504
1981	173	45 104	2005	264	16 150
1982	305	42 788	2006	238	11 741
1983	132	42 881	2007	379	10 583
1984	93	37 090	2008	319	11 396
1985	94	33 325	2009	419	10 946
1986	82	28 319	2010	501	9 723
1987	59	25 575	2011	547	9 440
1988	94	23 145	2012	776	10 049
1989	437	17 843	2013	756	11 726
1990	529	13 870	2014	825	11 911
1991	164	13 691	2015	923	14 098
1992	279	14 217	2016	950	14 117
1993	217	14 344	2017	913	14 102
1994	277	13 154	2018	1008	16 936
1995	436	13 637			

[1] Japanese vessels operating under charter agreement, i.e., all catch against the New Zealand allocation.
[2] These figures are likely to be underestimates as they do not incorporate the findings from the Market and Farming Reviews.
Source: New Zealand data from Annual Reports on Fisheries, Fisheries New Zealand data, New Zealand Fishing Industry Board Export data and LFRR data; total stock from www.ccsbt.org.

Analysis of New Zealand catch data shows that most southern bluefin tuna are caught in FMAs 1, 2, 5 and 7. The northern FMAs (FMAs 1 and 2), which accounted for a small proportion of southern bluefin tuna before 1998 have in recent years accounted for about the same amount of southern bluefin tuna as the southern FMAs (FMAs 5 and 7). This change in spatial distribution of catches can be attributed to the increase in domestic longline effort in the northern waters. Table 5 shows the longline effort targeted at southern bluefin in New Zealand waters by the charter and domestic fleets since 1989. Some of the charter fleet effort in Region 5 was directed at other fish species than southern bluefin, but most of the effort was targeting STN.

In 2012–13, the majority of southern bluefin tuna (88%) were caught in the southern bluefin tuna fishery (Figure 2). In 2017–18, southern bluefin tuna constituted 46% of the target surface longline catch (Figure 3). Longline fishing effort is distributed along the east coast of the North Island and the south-west coast of the South Island. The west coast South Island fishery predominantly targets southern bluefin tuna, whereas the east coast of the North Island targets a range of species including bigeye, swordfish and southern bluefin tuna.

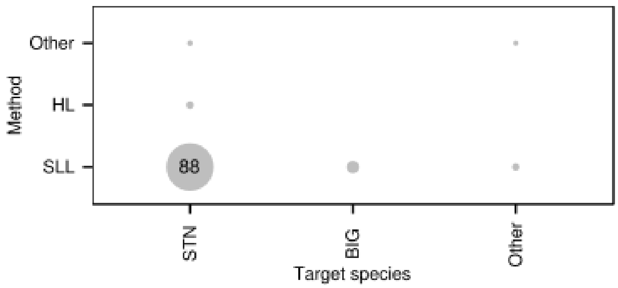


Figure 2: A summary of the proportion of landings of southern bluefin tuna taken by each target fishery and fishing method for 2012–13. The area of each circle is proportional to the percentage of landings taken using each combination of fishing method and target species. The number in the bobble is the percentage. SLL = surface longline, HL = hook and line (Bentley et al. 2013).

Table 4: Reported catches or landings (t) of southern bluefin tuna by fleet and fishing year. NZ: New Zealand domestic and charter fleet, ET: catches by New Zealand flagged vessels outside these areas, JPNFL: Japanese foreign licensed vessels, LFRR: estimated landings from Licensed Fish Receiver Returns, and MHR: Monthly Harvest Return Data.

Fishing year	JPNFL	NZ	Total	LFRR/MHR	NZ ET
1979–80	7 374.7		7 374.7		
1980–81	5 910.8		5 910.8		
1981–82	3 146.6		3 146.6		
1982–83	1 854.7		1 854.7		
1983–84	1 734.7		1 734.7		
1984–85	1 974.9		1 974.9		
1985–86	1 535.7		1 535.7		
1986–87	1 863.1		1 863.1	59.9	
1987–88	1 059.0		1 059.0	94.0	
1988–89	751.1	284.3	1 035.5	437.0	
1989–90	812.4	379.1	1 191.5	529.3	
1990–91	780.5	93.4	873.9	164.6	
1991–92	549.1	248.9	798.1	279.1	
1992–93	232.9	126.6	359.5	216.4	
1993–94	0.0	287.3	287.3	277.0	
1994–95	37.3	358.0	395.2	435.3	
1995–96		141.8	141.8	140.5	
1996–97		331.8	331.8	333.5	
1997–98		330.8	330.8	331.5	
1998–99		438.1	438.1	457.9	
1999–00		378.3	378.3	381.3	
2000–01		366.0	366.0	366.4	
2001–02		468.3	468.3	465.4	
2002–03		405.7	405.7	391.7	0.0
2003–04		399.6	399.6	394.6	0.0
2004–05		272.1	272.1	264.1	0.0
2005–06		237.7	237.7	238.0	0.1
2006–07*		379.1	379.1	379.1	-
2007–08*		318.2	318.2	318.2	-
2008–09*		417.3	417.3	417.5	-
2009–10*		499.5	499.5	499.5	-
2010–11*		547.3	547.3	547.3	-
2011–12*		775.2	775.2	775.2	-
2012–13*		758.2	758.2	758.2	-
2013–14*		824.6	824.6	824.6	-
2014–15*		923.1	923.1	923.1	-
2015–16*		949.4	949.4	949.4	-
2016–17*		913.5	913.5	913.5	-
2017–18*		1 008.1	1 008.1	1 008.1	-
2018–19*		936.3	936.3	936.9	-

* Southern bluefin tuna landings have not been separated into within zone and ET since 2006–07.

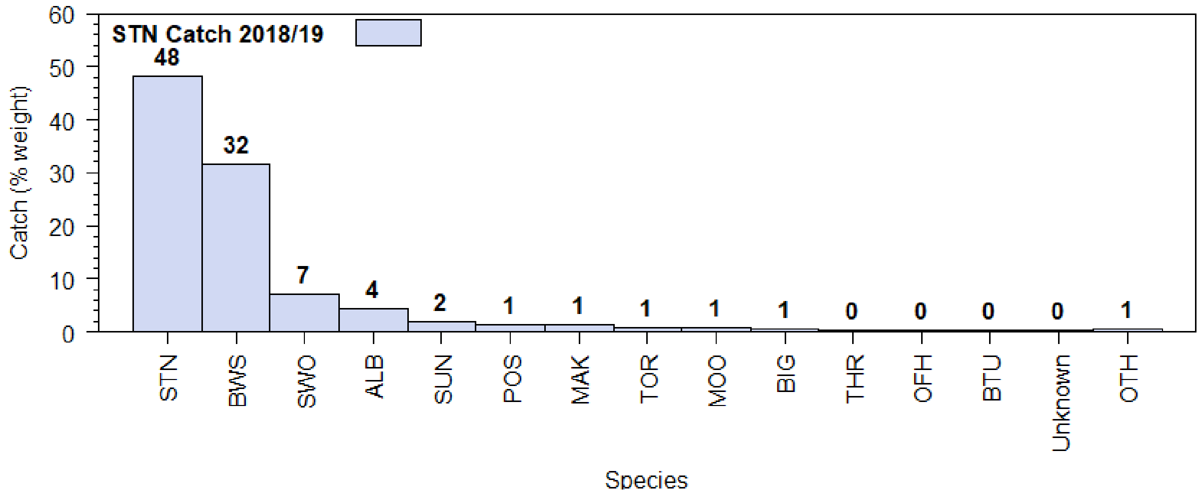


Figure 3: A summary of species composition of the reported southern bluefin tuna target surface-longline estimated catch in 2018–19. The percentage by weight of each species is calculated for all surface-longline trips targeting southern bluefin tuna.

Table 5: Effort (thousands of hooks) for the charter and domestic fleet by year and CCSBT Region. The Japanese charter vessels ceased fishing as of 1 May 2016 due to changes in New Zealand government legislation.

	Charter			Domestic[#]		
Calendar year	**Region 5**	**Region 6**	**Other***	**Region 5**	**Region 6**	**Other***
1989		1 596.0	3.5			
1990	259	1 490.6		41.7		
1991	306	1 056.5		31.5	49.2	
1992	47.6	1 386.8	3	71.7	12.1	
1993	174.1	1 125.7	101.4	644.0	108.1	7.7
1994		799.1		122.6	143.3	5.8
1995	27.1	1 198.7	13.5	221.5	760.4	26.7
1996				417.9	564.3	11.5
1997	135.2	1 098.7		736.4	8.9	17.3
1998	225	616.0		633.6	314.5	1.2
1999	57.2	955.1		1 221.4	382.9	5.5
2000	30.3	757.9		1 164.0	454.4	8.5
2001		639.4		1 027.6	751.5	1.9
2002		726.4		1 358.6	1 246.8	13.5
2003	3	866.6		1 868.7	1 569.1	4.3
2004		1 113.5		1 154.1	1 431.9	1.2
2005	137	498.9		1 133.0	153.6	2.4
2006	39.4	562.5		1 036.4	122.4	0.9
2007	271.6	1 136.1		681.2	19.0	
2008		568.3		527.8	94.0	
2009	66.8	731.0		733.9	165.4	1.3
2010		484.9		1 114.9	294.2	1.3
2011		495.9		965.0	196.5	
2012		548.4	3.4	858.1	629.8	
2013	13.2	450.8		910.8	563.0	1.2
2014		653.3		533.4	484.1	
2015		622.3		631.9	463.3	
2016				884.3	565.3	12.6
2017				867.1	589.6	7.9
2018				1027.5	505.9	3.9

* Includes erroneous position data and data without position data.
[#] Effort for sets that either targeted or caught southern bluefin tuna.

1.3 Recreational fisheries

Historically, a small summer recreational fishery has occurred out of Fiordland on the west coast of the South Island since the 1970s. A recreational fishery for Pacific bluefin tuna developed in 2005 out of Greymouth or Westport, on the west coast of the South Island, in which STN are also occasionally taken as bycatch in August and September. At present, there are two distinct recreational fisheries; the west coast of the South Island from January to July, and the east coast of the North Island in June and July, primarily in the eastern Bay of Plenty. The North Island recreational fishery emerged rapidly in 2017, when STN catches increased dramatically, and STN catches in 2018 were also high. It is likely that 2019 recreational catches from this area will also be high.

1.3.1 Estimates of recreational harvest

The recreational harvest estimate for STN in 2017–18 for all fisheries combined was 15 t and the estimated range using survey confidence intervals and the range in unaccounted catch was 13.4 to 17.0 t (Holdsworth 2019). No estimates of recreational harvest of southern bluefin tuna were generated from the telephone-diary surveys conducted in 1994, 1996 and 2000 because so few were reported. A National Panel Survey was conducted for the first time throughout the 2011–12 fishing year. The panel survey used face-to-face interviews of a random sample of 30 390 New Zealand households to recruit a panel of fishers and non-fishers for a full year (from Wynne-Jones et al. 2014). The panel members were contacted regularly about their fishing activities and harvest information collected in standardised phone interviews. The national panel survey was repeated during the 2017–18 fishing year using very similar methods to produce directly comparable results (Wynne-Jones et al. 2019). Note that national panel survey estimates do not include recreational harvest taken under s111 general approvals. The National Panel Survey results do not include estimates for southern bluefin tuna as the surveys did not capture the fishers and fishing activity for the large gamefish species well.

1.4 Customary non-commercial fisheries

An estimate of the current customary catch is not available**.** Given that Maori knew of several oceanic fish species and missionaries reported that Maori regularly fished several miles from shore, it is possible that southern bluefin tuna were part of the catch of Maori prior to European settlement. It is clear that Maori trolled lures (for kahawai) that are very similar to those still used by Tahitian fishermen for small tunas, and also used large baited hooks capable of catching large southern bluefin tuna. However, there is no Maori name for southern bluefin tuna, therefore it is uncertain if Maori caught southern bluefin tuna.

1.5 Illegal catch

There is no known illegal catch of southern bluefin tuna by New Zealand vessels in the EEZ or from the high seas.

CCSBT has operated a catch documentation scheme since 1 January 2010, with documentation and tagging requirements for all STN, coupled with market-based controls and reporting obligations. Recent actions by individual CCSBT members to improve monitoring, control and surveillance measures for southern bluefin tuna fisheries are also intended to halt the occurrence of unreported catch. The extent of unreported catch by non-cooperating non-members is not known.

1.6 Other sources of mortality

Incidental catches of southern bluefin tuna appear to be limited to occasional small catches in trawl and troll fisheries. Small catches of southern bluefin tuna have been reported as non-target catch (less than 0.5 t and 2 t, respectively), in trawl fisheries for hoki (*Macruronus novaezelandiae*) and arrow squid (*Notodarus* spp.). In addition there have been occasional anecdotal reports of southern bluefin being caught in trawl fisheries for southern blue whiting (*Micromesistius australis*) and Jack mackerel (*Trachurus* spp.) in sub-Antarctic waters.

In addition to the limited trawl bycatch there is some discarding and loss (usually as a result of shark damage) before fish are landed that occurs in the longline fishery. The overall incidental mortality rate from observed longline effort has been estimated as 0.54% of the catch. Discard rates are 0.86% on average from observer data, of which approximately 50% are discarded dead. Fish are also lost at the surface in the longline fishery during hauling, 1.47% on average from observer data, of which 95% are thought to escape alive. An allowance of 20 t has been made for other sources of mortality.

2. BIOLOGY

There is some uncertainty about the size and age when SBT mature, but available data indicate that SBT do not mature younger than 8 years (155cm fork length), and perhaps as old as 15 years.

As the growth rate has changed over the course of the fishery (see below and Table 8) the size-at-maturity depends on when the fish was alive (prior to the 1970s, during the 1970s, or in the period since 1980), as well as which maturity ogive is used. A simple linear interpolation is assumed for the 1970s. Table 6 shows the range of sizes (cm) for southern bluefin tuna aged 8 to 12 years for the two von Bertalanffy growth models used.

Table 6: Differences in southern bluefin tuna size at ages 8–12 between the 1960s and 1980s (lengths in cm).

Age	1960s	1980s
8	138.2	147.0
9	144.6	152.7
10	150.2	157.6
11	155.1	161.6
12	159.4	165.0

Radiocarbon dating of otoliths has been used to determine that southern bluefin tuna live beyond 30 years of age and that individuals reaching asymptotic length may be 20 years or older.

The sex ratio of southern bluefin caught by longline in the EEZ has been monitored since 1987. The ratio of males to females is 1.2:1.0, and is statistically significantly different than 1:1.

The parameters of length:weight relationships for southern bluefin tuna based on linear regressions of greenweight versus fork length are in Table 7.

Table 7: Parameters of length:weight relationship for southern bluefin tuna. *l*n (weight) = B_1 *l*n (length) – b_0 (weight in kg, length in cm).

	b_0	B_1
Male	-10.94	3.02
Female	-10.91	3.01
All	-10.93	3.02

The data used include all longline observer data for the period 1987 to 2000 from all vessels in the EEZ (n = 18 994).

CCSBT scientists have used two stanza von Bertalanffy growth models since 1994 (Table 8):

$$l_t = L_\infty(1 - e^{-k2(t-t0)})(1 + e^{-\beta(t-t0-\alpha)}) / (1 + e^{\beta\alpha})^{-(k2-k1)}$$, where t is age in years.

Table 8: von Bertalanffy growth parameters for southern bluefin tuna.

	L_∞	k_1	k_2	α	β	t_0
1960 von Bertalanffy	187.6	0.47	0.14	0.75	30	0.243
1980 von Bertalanffy	182	0.23	0.18	2.9	30	-0.35

While change in growth in the two periods (pre-1970 and post-1980) is significant and the impact of the change in growth on the results of population models substantial, the differences between the growth curves seem slight. The change in growth rate for juveniles and young adults has been attributed to a density dependent effect of overfishing.

No estimates of F and Z are presented because they are model dependent and because a range of models and modelling approaches are used. Prior to 1995 natural mortality rates were assumed to be constant and M = 0.2 was used. However, the results indicating that asymptotic size was reached at about 20 years and fish older than 30 years were still in the population, suggested that values of $M \geq 0.2$ were likely to be too high. Tagging results of juvenile's ages 1 to 3 years also suggests that M for these fish is high (possibly as high as M = 0.4), while M for fish of intermediate years is unknown. For these reasons M has been considered to be age-specific and represented by various M vectors. In the CCSBT stock assessments, a range of natural mortality vectors are now used.

A conversion factor of 1.15 is used for gilled and gutted southern bluefin tuna.

3. STOCKS AND AREAS

Southern bluefin tuna consist of a single stock primarily distributed between 30ºS and 45ºS, which is only known to spawn in the Indian Ocean south of Java. Adults are broadly distributed in the South Atlantic, Indian and western South Pacific Oceans, especially in temperate latitudes, while juveniles occur along the continental shelf of Western and South Australia and in high seas areas of the Indian Ocean. Southern bluefin tuna caught in the New Zealand EEZ appear to represent the easternmost extent of a stock whose centre is in the Indian Ocean.

A large-scale electronic tagging programme, involving most members of the CCSBT, has been undertaken to provide better information on stock structure. The goal has been to tag smaller fish across the range of the stock. New Zealand has participated in this programme, having deployed 19 implantable tags in small fish in 2007. Fifteen larger STN were tagged with pop-off tags as well, with 12 tags having reported data. Of note, one of the tagged fish moved to the spawning ground south of Indonesia.

Electronic tagging of juvenile STN in the Great Australian Bight showed that for a number of years tagged juveniles were not moving into the Tasman Sea. It was not known whether this was due to unfavourable environmental conditions or range contraction following the decline in the stock. However, more of these tagged juveniles have now been reported in New Zealand catches.

Two sources of information suggest that there may be 'sub-structure' within the broader STN stock, in particular the Tasman Sea. Tagging of adult STN within the Australian east coast tuna and billfish fishery suggests that STN may spend most of the years within the broader Tasman Sea region. An analysis of the length and age composition of catches from the New Zealand JV fleet showed that cohorts that were initially strong or weak did not change over time, e.g., if a particular year class was weak (or strong) when it initially recruited to the New Zealand fishery it remained so over time.

4. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS

The figures and tables in this section were updated and additional text included for the November 2019 Fishery Assessment Plenary following review of the text by the Aquatic Environment Working Group in 2016. This summary is from the perspective of the southern bluefin tuna longline fishery; a more detailed summary from an issue-by-issue perspective is available in the Aquatic Environment & Biodiversity Annual Review where the consequences are also discussed (Ministry for Primary Industries 2019).

4.1 Role in the ecosystem

Southern bluefin tuna (*Thunnus maccoyii*) are apex predators, feeding opportunistically on a mixture of fish, crustaceans and squid, and juveniles also feed on a variety of zooplankton and micronecton species (Young et al. 1997). Southern bluefin tuna are large pelagic predators, so they are likely to have a 'top down' effect on the fish, crustaceans and squid they feed on.

4.2 Incidental catch

These capture estimates relate to the southern bluefin target longline fishery only, from the New Zealand EEZ. The capture estimates presented here include all animals recovered onto the deck (alive, injured or dead) of fishing vessels but do not include any cryptic mortality (e.g., seabirds caught on a hook but not brought onboard the vessel).

4.2.1 Incidental catch of seabirds

Between 2002–03 and 2017–18, there were 8873 observed captures of birds in southern bluefin longline fisheries. Seabird capture rates since 2003 are presented in Figure 4. Observed capture rates peaked in 2015–16. Seabird captures were mostly concentrated off Fiordland and west coast South Island (see Table 9 and Figure 5). Previously Bayesian models of varying complexity dependent on data quality were used (Richard & Abraham 2014); more recently a single model structure has been developed to provide a standard basis for estimating seabird captures across a range of fisheries (Richard & Abraham 2015, Richard et al. 2017, Richard et al. 2019). Observed and estimated seabird captures in southern bluefin tuna longline fisheries are provided in Table 10.

Through the 1990s the minimum seabird mitigation requirement for surface-longline vessels was the use of a bird scaring device (tori line) but common practice was that vessels set surface longlines primarily at night. In 2007 a notice was implemented under s11 of the Fisheries Act 1996 to formalise the requirement that surface-longline vessels only set during the hours of darkness and use a tori line when setting. This notice was amended in 2008 to add the option of line weighting and tori line use if setting during the day. In 2011 the notices were combined and repromulgated under a new regulation

(Regulation 58A of the Fisheries (Commercial Fishing) Regulations 2001), which provides a more flexible regulatory environment under which to set seabird mitigation requirements. Late in 2019 work was commissioned to assess the operational functionality of an underwater bait setter during production fishing. The aim of this work was to assess the device without the use of other existing mitigation measures in the New Zealand Surface Longline fleet.

Table 9: Number of observed seabird captures in southern bluefin tuna longline fisheries, 2002–03 to 2017–18, by species and area. The risk category is an estimate of aggregate potential fatalities across trawl and longline fisheries relative to the Population Sustainability Threshold, PST (an analogue of the PBR approach) (Richard et al. 2019). The current version of the risk assessment does not include recovery factor. Other data, version 2019v1.

Species	Risk category	Fiordland	East Coast North Island	West Coast South Island	Stewart Snares Shelf	Bay of Plenty	Northland and Hauraki	Total
Southern Buller's albatross	High	330	94	35		2		461
New Zealand white-capped albatross	High	86	83	46	10	1		226
Campbell black-browed albatross	Low	4	5	17		2	3	31
Gibson's albatross	High	4	3	5			1	13
Southern royal albatross	Negligible	6	4	3				13
Antipodean albatross	Medium			5			1	6
Wandering albatrosses	N/A	2		4				6
Black-browed albatross	N/A			5				5
Salvin's albatross	High			3		1		4
Wandering albatross	N/A	1		1				2
Light-mantled sooty albatross	Negligible		1					1
Great albatrosses	N/A		1					1
Grey-headed albatross	N/A		1					1
Northern Buller's albatross	Medium			1				1
Smaller albatrosses	N/A			1				1
Total albatrosses		**433**	**192**	**126**	**10**	**6**	**5**	**772**
Grey petrel	Negligible		0	37		3	2	43
Westland petrel	High	4	24	7				35
White-chinned petrel	Negligible	21		3	1		1	26
Large seabirds	N/A	3						3
Sooty shearwater	Negligible				3			3
Cape petrels	N/A			2				2
Grey-faced petrel	N/A					1		1
Southern giant petrel	N/A			2				2
Storm petrels			1					1
Total other birds		**28**	**25**	**51**	**4**	**4**	**3**	**115**

Current results for the risk posed by commercial fishing to seabirds have been assessed via a level 2 method, supported under the NPOA-Seabirds 2013 risk assessment framework (Ministry for Primary

Industries 2013). The method used in the level 2 risk assessment arose initially from an expert workshop hosted by the Ministry of Fisheries in 2008. The overall framework is described in Sharp et al. (2011) and has been variously applied and improved in multiple iterations (Waugh et al. 2009, Richard et al. 2011, Richard & Abraham 2013, Richard et al. 2013, Richard & Abraham 2015, Richard et al. 2017, Richard et al. 2019). The method applies an 'exposure-effects' approach where exposure refers to the number of fatalities and is calculated from the overlap of seabirds with fishing effort compared with observed captures to estimate the species vulnerability (capture rates per encounter) to each fishery group. This is then compared to the population's productivity, based on population estimates and biological characteristics to yield estimates of population-level risk. The NPO-Seabirds 2013 was reviewed in 2019, with the updated version expected in 2020.

Table 10: Effort, observed and estimated seabird captures in southern bluefin tuna fisheries by fishing year within the EEZ. For each fishing year, the table gives the total number of hooks; the number of observed hooks; observer coverage (the percentage of hooks that were observed); the number of observed captures (both dead and alive); the capture rate (captures per thousand hooks); and the mean number of estimated total captures (with 95% confidence interval). Estimates are based on methods described in Abraham & Berkenbusch(2019) and are available via https://data.dragonfly.co.nz/psc. Estimates from 2002–03 to 2017–18 are based on data version 2019v1.

	Fishing effort			Observed captures		Estimated captures	
Fishing year	**All hooks**	**Observed hooks**	**% observed**	**Number**	**Rate**	**Mean**	**95% c.i.**
2002–03	3 512 911	1 133 740	32.3	43	0.04	477	369–608
2003–04	3 195 141	1 471 964	46.1	70	0.05	467	377–573
2004–05	1 665 009	734 026	44.1	36	0.05	176	138–222
2005–06	1 493 868	655 475	43.9	29	0.04	157	120–201
2006–07	1 938 111	916 660	47.3	111	0.12	225	192–266
2007–08	1 104 825	375 975	34.0	30	0.08	148	113–190
2008–09	1 484 438	840 048	56.6	48	0.06	170	136–213
2009–10	1 559 858	580 395	37.2	112	0.19	292	248–343
2010–11	1 330 265	567 204	42.6	32	0.06	189	147–239
2011–12	1 593 754	645 530	40.5	50	0.08	367	284–463
2012–13	1 516 197	491 953	32.4	23	0.05	305	232–389
2013–14	1 589 620	747 220	47.0	34	0.05	277	215–354
2014–15	1 566 919	683 250	43.6	32	0.05	258	202–328
2015–16	1 234 822	257 020	20.8	115	0.45	360	301–432
2016–17	1 246 229	263 985	21.2	42	0.16	296	233–370
2017–18	1 297 341	215 418	16.6	80	0.37	309	252–375

The 2019 iteration of the level 2 risk assessment (Richard et al. 2019) included significant modifications made to the methodology during 2016: in order to include the full uncertainty around population size the total population size was included instead of N_{min} in the PST calculation; the allometric survival rate and age at first reproduction was used for the calculation of R_{max}; a revised correction factor was applied as the previous was found to be biologically implausible; a constraint was applied on the fatalities calculated based on observed survival rates; live release survival was included; change in vulnerability over time was allowed where there was enough data; and there was a switch to assuming that the number of incidents is related to vulnerability. There were also changes made to the fisheries groups, seabird demographic data were updated and the Stewart Island shag group was split into Otago and Foveaux shags. The 2019 assessment of the risk of commercial fisheries to New Zealand seabirds, 2006–07 to 2016–17 (Richard et al. 2019) also addressed discrepancies identified in the allocation of observer effort and fishing effort and two additional years of data were included for the 2015–16 and 2016–17 fishing years. A derived risk ratio, which is an estimate of aggregate potential fatalities across trawl and longline fisheries relative to the Population Sustainability Threshold, PST (an analogue of the Potential Biological Removals, PBR, approach) (Richard et al. 2017) is used to rank species. A risk ratio above 1 indicates that PBR exceeds PST and the population is at risk of not obtaining management objectives.

The 2019 iteration of the seabird risk assessment (Richard et al. 2019) assessed the southern bluefin tuna surface-longline target fisheries' contribution to the total risk posed by New Zealand commercial fishing to seabirds (see Table 11). These target fisheries contribute 0.139 of the risk to Salvin's albatross (over 21% of the total risk to this species from commercial fishing included in the risk assessment) and 0.066 of the risk to Southern Buller's albatross (18% of the total risk assessed); both species were assessed to be at high risk from New Zealand commercial fishing. This fishery also contributed 0.038 of the total risk to Antipodean albatross (23% of the total risk assessed), which was assessed to be at medium risk from New Zealand commercial fishing (Richard et al. 2017).

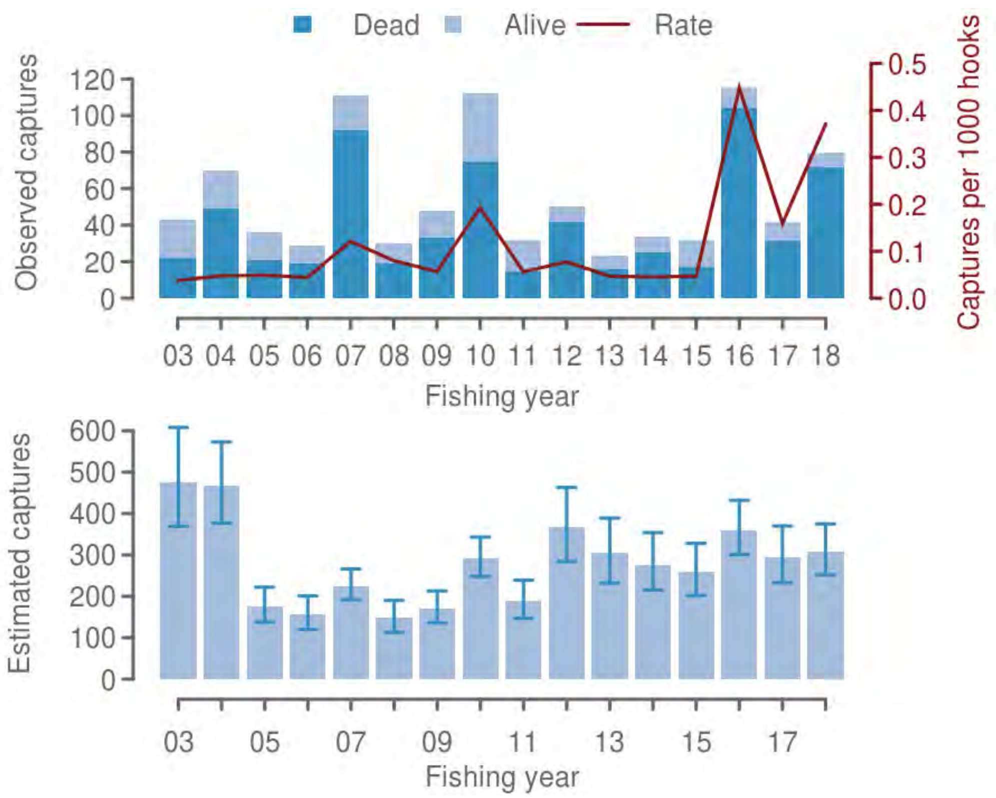


Figure 4: Observed (top) and estimated (bottom) captures of seabirds in southern bluefin tuna longline fisheries from 2002–03 to 2017–18. Data grooming and estimates are based on methods described in Abraham & Berkenbusch (2019) and are available via https://data.dragonfly.co.nz/psc. Estimates from 2002–03 to present are based on data version 2019v1.

Table 11: Risk ratio of seabirds predicted by the Level 2 risk assessment for the southern bluefin tuna target surface-longline fisheries and all fisheries included in the Level 2 risk assessment, 2006–07 to 2016–17, showing seabird species with risk category of very high or high, or a medium risk category and risk ratio of at least 1% of the total risk. The risk ratio is an estimate of aggregate potential fatalities across trawl and longline fisheries relative to the Population Sustainability Threshold, PST (an analogue of PBR approach) (from Richard et al. 2019). Other data, version 2019v1. The current version of the risk assessment does not include a recovery factor. The New Zealand threat classifications are shown (Robertson et al. 2017). [Continued on next page]

		Risk ratio			
Species name	**STN target SLL**	**Total risk from NZ commercial fishing**	**% of total risk from NZ commercial fishing**	**Risk category**	**NZ Threat Classification**
Salvin's albatross	0.139	0.654	21.2%	High	Threatened: Nationally Critical
Southern Buller's albatross	0.066	0.366	18.0%	High	At Risk: Naturally Uncommon
Flesh-footed shearwater	0.064	0.488	13.1%	High	Threatened: Nationally Vulnerable
Chatham Island albatross	0.052	0.284	18.3%	Medium	At Risk: Naturally Uncommon
Antipodean albatross	0.038	0.168	22.6%	Medium	Threatened: Nationally Critical
Campbell black-browed albatross	0.014	0.058	24.1%	Low	Threatened: Nationally Vulnerable

Gibson's albatross	0.013	0.307	4.2%	High	Threatened: Nationally Critical
Northern royal albatross	0.007	0.048	14.6%	Low	At Risk: Naturally Uncommon
Southern royal albatross	0.006	0.025	24.3%	Negligible	At Risk: Naturally Uncommon
Grey petrel	0.004	0.026	15.5%	Negligible	At Risk: Naturally Uncommon

4.2.2 Incidental catch of sea turtles

Between 2002–03 and 2017–18, there were four observed captures of sea turtles in southern bluefin longline fisheries (Tables 12 and 13, Figure 6). Observer recordings documented all sea turtles as captured and released alive. Sea turtle captures for this fishery have only been observed off the east coast of the North Island.

Table 12: Number of observed sea turtle captures in southern bluefin tuna longline fisheries, 2002–03 to 2017–18, by species and area. Data grooming methods are described in Abraham & Berkenbusch (2019) and are available via https://data.dragonfly.co.nz/psc. Data version 2019v1.

Species	Bay of Plenty	East coast North Island	Total
Leatherback turtle	1	2	3
Green turtle	0	1	1
Total	1	3	4

Table 13: Fishing effort and sea turtle captures in southern bluefin tuna longline fisheries by fishing year. For each fishing year, the table gives the total number of hooks; the number of observed hooks; observer coverage (the percentage of hooks that were observed); the number of observed captures (both dead and alive); and the capture rate (captures per thousand hooks). Data grooming methods are described in Abraham et al. (2016) and are available via https://data.dragonfly.co.nz/psc. Data version 2018v1.

Fishing year		Fishing effort		Observed captures	
	All hooks	Observed hooks	% observed	Number	Rate
2002–03	3 512 911	1 133 740	32.3	0	0.000
2003–04	3 195 141	1 471 964	46.1	0	0.000
2004–05	1 665 009	734 026	44.1	0	0.000
2005–06	1 493 868	655 475	43.9	0	0.000
2006–07	1 938 111	916 660	47.3	0	0.000
2007–08	1 104 825	375 975	34.0	0	0.000
2008–09	1 484 438	840 048	56.6	0	0.000
2009–10	1 559 858	580 395	37.2	0	0.000
2010–11	1 330 265	567 204	42.6	3	0.005
2011–12	1 593 754	645 530	40.5	0	0.000
2012–13	1 516 197	491 953	32.4	0	0.000
2013–14	1 589 620	747 220	47.0	0	0.000
2014–15	1 566 919	683 250	43.6	0	0.000
2015–16	1 234 822	257 020	20.8	1	0.004
2016–17	1 246 229	263 985	21.2	0	0.000
201718	1 297 341	215 418	16.6	0	0.000

4.2.3 Incidental catch of marine mammals

4.2.3.1 Cetaceans

Cetaceans are dispersed throughout New Zealand waters (Perrin et al. 2008). The spatial and temporal overlap of commercial fishing grounds and cetacean foraging areas has resulted in cetacean captures in fishing gear (Abraham & Thompson 2009, 2011).

Between 2002–03 and 2017–18, there were 10 observed captures of whales and dolphins in southern bluefin longline fisheries (Tables 14 and 15, Figure 7). Observed captures included three bottlenose dolphins, three beaked whales, two long-finned pilot whales, one orca and an unidentified cetacean. All captured animals recorded were documented as being caught and released alive (https://data.dragonfly.co.nz/psc, data version 2019v1), with catches occurring in the east coast of the North Island, west coast of the South Island, Fiordland and Bay of Plenty.

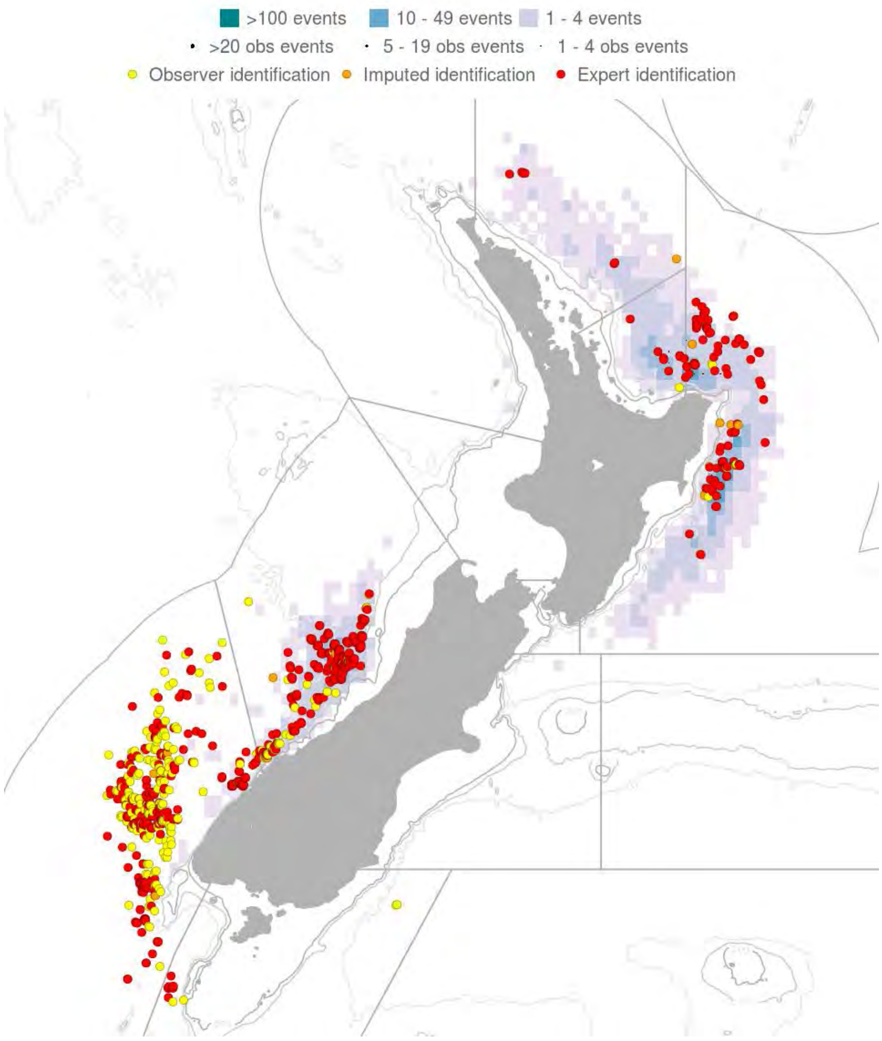


Figure 5: Distribution of fishing effort targeting southern bluefin tuna and observed seabird captures, 2002–03 to 2017–18. Fishing effort is mapped into 0.2-degree cells, with the colour of each cell being related to the amount of effort. Observed fishing events are indicated by black dots, and observed captures are indicated by red dots. Fishing is only shown if the effort could be assigned a latitude and longitude, and if there were three or more vessels fishing within a cell. Data grooming methods are described in Abraham & Berkenbusch (2019) and are available via https://data.dragonfly.co.nz/psc. Estimates from 2002–03 to 2017–18 are based on data version 2019v1.

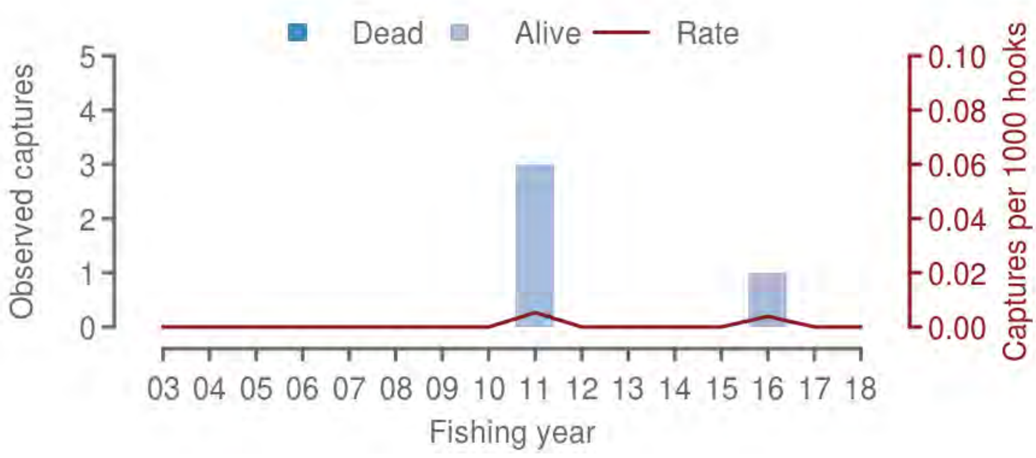


Figure 6: Observed captures of sea turtles in southern bluefin tuna longline fisheries from 2002–03 to 2017–18. Data grooming methods are described in Abraham & Berkenbusch (2019) and are available via https://data.dragonfly.co.nz/psc. Data version 2019v1.

Table 14: Number of observed cetacean captures in southern bluefin tuna longline fisheries, 2002–03 to 2017–18, by species and area. Data grooming methods are described in Abraham & Berkenbusch (2019) and are available via https://data.dragonfly.co.nz/psc. Data version 2019v1.

Species	Bay of Plenty	East coast North Island	Fiordland	West coast South Island	Total
Long-finned pilot whale	0	1	0	1	2
Beaked whales	2	1			3
Bottlenose dolphin	1	2			3
Orca	1				1
Unidentified cetacean			1		1
Total	4	4	1	1	10

Table 15: Effort and cetacean captures in southern bluefin tuna longline fisheries by fishing year. For each fishing year, the table gives the total number of hooks; the number of observed hooks; observer coverage (the percentage of hooks that were observed); the number of observed captures (both dead and alive); and the capture rate (captures per thousand hooks). For more information on the methods used to prepare the data, see Abraham & Berkenbusch (2019) and data are available via https://data.dragonfly.co.nz/psc. Data version 2019v1.

Fishing year		Fishing effort		Observed captures	
	All hooks	Observed hooks	% observed	Number	Rate
2002–03	3 512 911	1 133 740	32.3	0	0.000
2003–04	3 195 141	1 471 964	46.1	3	0.002
2004–05	1 665 009	734 026	44.1	1	0.001
2005–06	1 493 868	655 475	43.9	0	0.000
2006–07	1 938 111	916 660	47.3	0	0.000
2007–08	1 104 825	375 975	34.0	1	0.003
2008–09	1 484 438	840 048	56.6	0	0.000
2009–10	1 559 858	580 395	37.2	0	0.000
2010–11	1 330 265	567 204	42.6	0	0.000
2011–12	1 593 754	645 530	40.5	0	0.000
2012–13	1 516 197	491 953	32.4	0	0.000
2013–14	1 589 620	747 220	47.0	0	0.000
2014–15	1 566 919	683 250	43.6	1	0.001
2015–16	1 234 822	257 020	20.8	2	0.008
2016–17	1 246 229	263 985	21.2	1	0.004
2017–18	1 297 341	215 418	16.6	1	0.005

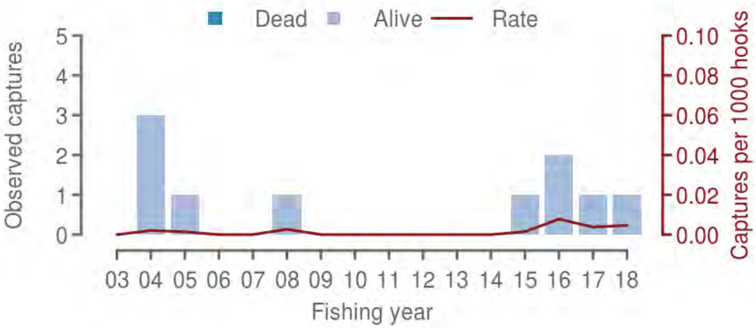


Figure 7: Observed captures of cetaceans in southern bluefin longline fisheries from 2002–03 to 2017–18. Data grooming methods are described in Abraham & Berkenbusch (2019) and are available via https://data.dragonfly.co.nz/psc. Data version 2019v1.

4.2.3.2 New Zealand fur seals

Currently, New Zealand fur seals are dispersed throughout New Zealand waters, but are more common in waters south of about 40ºS to Macquarie Island. The spatial and temporal overlap of commercial fishing grounds and New Zealand fur seal foraging areas has resulted in New Zealand fur seal captures in fishing gear (Mattlin 1987, Rowe 2009). Most fisheries with observed captures occur in waters over or close to the continental shelf, which slopes steeply to deeper waters relatively close to shore, and thus rookeries and haulouts, around much of the South Island and offshore islands. Captures on longlines occur when the fur seals attempt to feed on the bait and fish catch during hauling. Most New Zealand fur seals are released alive, typically with a hook and short snood or trace still attached.

New Zealand fur seal captures in surface-longline fisheries have been generally observed in waters south and west of Fiordland, but also in the Bay of Plenty–East Cape area. Estimated numbers range from 127 (95% c.i.: 121–133) in 1998–99 to 39 (22-62) in 2007–08 during southern bluefin tuna fishing by chartered and domestic vessels (Abraham & Berkenbusch 2019) (Tables 16 and 17). Observed captures consist primarily of fur seals that are released alive (100% of observed surface-longline captures in 2008–09; Thompson & Abraham 2010). Observed capture rates in 2013–14 and 2016–17 were higher than they were in the early 2000s (Figures 8 and 9). While fur seal captures have occurred throughout the range of this fishery, most have occurred off the south-west coast of the South Island, Fiordland (Figure 10).

Table 16: Number of observed New Zealand fur seal captures in southern bluefin tuna longline fisheries, 2002–03 to 2017–18, by species and area. Data from Abraham & Berkenbusch (2019), retrieved from http://data.dragonfly.co.nz/psc. Data version 2019v1.

	Bay of Plenty	East coast North Island	Fiordland	Northland and Hauraki	Stewart-Snares Shelf	West coast South Island	Total
New Zealand fur seal	29	58	244	4	4	65	404

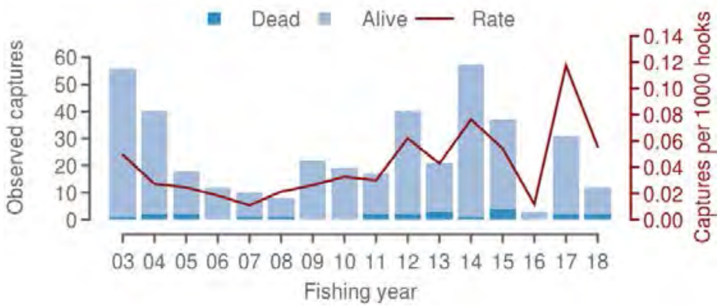


Figure 8: Observed captures of New Zealand fur seals in southern bluefin longline fisheries from 2002–03 to 2017–18. Data grooming methods are described in Abraham & Berkenbusch (2019) and are available via https://data.dragonfly.co.nz/psc. Data version 2019v1.

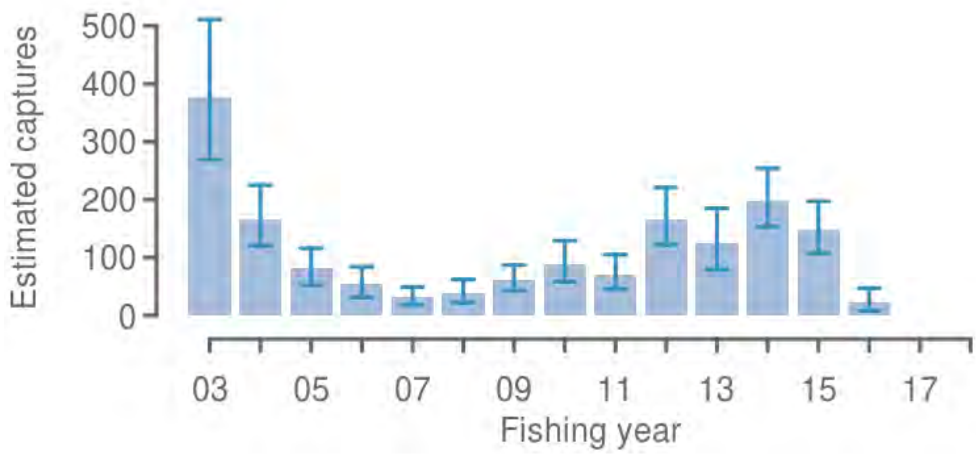


Figure 9: Estimated captures of New Zealand fur seals in southern bluefin longline fisheries from 2002–03 to 2016–17. Data grooming methods are described in Abraham & Berkenbusch (2019) and are available via https://data.dragonfly.co.nz/psc. Data version 2019v01.

Table 17: Effort and captures of New Zealand fur seals by fishing year in southern bluefin tuna longline fisheries. For each fishing year, the table gives the total number of hooks; the number of observed hooks; observer coverage (the percentage of hooks that were observed); the number of observed captures (both dead and alive); and the capture rate (captures per thousand hooks). Data from Abraham & Richard (2019), retrieved from http://data.dragonfly.co.nz/psc. Estimates from 2002–03 to 2015–16 are based on data version 2019v1.

Fishing year		Fishing effort		Observed captures		Estimated captures	
	All hooks	Observed hooks	% observed	Number	Rate	Mean	95% c.i.
2002–03	3 512 911	1 133 740	32.3	56	0.049	377	269–511
2003–04	3 195 141	1 471 964	46.1	40	0.027	166	120–225
2004–05	1 665 009	734 026	44.1	18	0.025	81	52–116
2005–06	1 493 868	655 475	43.9	12	0.018	53	31–84
2006–07	1 938 111	916 660	47.3	10	0.011	32	18–49
2007–08	1 104 825	375 975	34.0	8	0.021	39	22–62
2008–09	1 484 438	840 048	56.6	22	0.026	62	43–87
2009–10	1 559 858	580 395	37.2	19	0.033	89	58–129
2010–11	1 330 265	567 204	42.6	17	0.030	71	46–105
2011–12	1 593 754	645 530	40.5	40	0.062	167	122–221
2012–13	1 516 197	491 953	32.4	21	0.043	125	79–185
2013–14	1 589 620	747 220	47.0	57	0.076	198	153–254
2014–15	1 566 919	683 250	43.6	37	0.054	147	107–197
2015–16	1 234 822	257 020	20.8	3	0.012	23	8–47
2016–17	1 246 229	263 985	21.2	31	0.117		
2017–18	1 297 341	215 418	16.6	12	0.056		

Figure 10: Distribution of fishing effort targeting southern bluefin tuna and observed New Zealand fur seal captures, 2002–03 to 2017–18. Fishing effort is mapped into 0.2-degree cells, with the colour of each cell being related to the amount of effort. Observed fishing events are indicated by black dots, and observed captures are indicated by red dots. Fishing is only shown if the effort could be assigned a latitude and longitude, and if there were three or more vessels fishing within a cell. Data grooming methods are described in Abraham & Berkenbusch (2019) and are available via https://data.dragonfly.co.nz/psc. Data version 2019v1.

4.3 Non-target fish catch

This section summarises fish catches taken in tuna longline sets that either targeted or caught southern bluefin tuna. Numbers of fish observed, estimated numbers scaled from observer to the commercial fishing effort, and CPUE during the 2010 calendar year are shown in Table 18. The scaled estimates provided for the domestic fleet can be considered less reliable than those of the charter fleet as they are based on lower observer coverage.

Bycatch composition from the charter fleet and the domestic fleet is different. This is likely to be due to differences in waters fished, with the charter fleet mostly operating in southern waters, and the domestic vessels fishing primarily in waters north of about 40°S. Charter vessels only fished off the west coast of the South Island in 2010. Blue shark, Ray's bream, and albacore were predominant in the catches overall, with these three species making up nearly 70% of the catch. Charter vessels caught mostly blue sharks and Ray's bream. Blue sharks dominated the catches of the domestic vessels, followed by albacore.

Table 18: Numbers of fish caught reported on commercial catch effort returns (observed), estimated from observer reports and total fishing effort (scaled), and catch per unit effort (CPUE) for fish species caught on longline sets where southern bluefin tuna was either targeted or caught during the 2010 calendar year

	Charter			New Zealand domestic		
	Observed	**Scaled**	**CPUE**	**Observed**	**Scaled**	**CPUE**
Blue shark	2 024	2 501	5.226	5 062	57 834	46.406
Ray's bream	3 295	4 072	8.508	362	4 136	3.319
Albacore tuna	90	111	0.232	1 219	13 927	11.175
Dealfish	882	1 090	2.277	7	80	0.064
Big scale pomfret	349	431	0.901	3	34	0.028
Porbeagle shark	72	89	0.186	279	3 188	2.558
Deepwater dogfish	305	377	0.788	0	0	0.000
Swordfish	3	4	0.008	269	3 073	2.466
Lancetfish	3	4	0.008	337	3 850	3.089
Mako shark	11	14	0.028	211	2 411	1.934
Moonfish	76	94	0.196	143	1 634	1.311
Butterfly tuna	15	19	0.039	103	1 177	0.944
Oilfish	2	2	0.005	44	503	0.403
School shark	34	42	0.088	2	23	0.018
Sunfish	7	9	0.018	65	743	0.596
Rudderfish	39	48	0.101	18	206	0.165
Flathead pomfret	56	69	0.145	0	0	0.000
Escolar	0	0	0.000	58	663	0.532
Pelagic stingray	0	0	0.000	8	91	0.073
Thresher shark	7	9	0.018	9	103	0.083
Hoki	0	0	0.000	1	11	0.009
Pacific bluefin tuna	0	0	0.000	2	23	0.018
Skipjack tuna	0	0	0.000	1	11	0.009
Striped marlin	0	0	0.000	1	11	0.009
Yellowfin tuna	0	0	0.000	0	0	0.000

4.4 Benthic interactions

There are no known benthic interactions for this fishery.

4.5 Key environmental and ecosystem information gaps

Cryptic mortality is unknown at present but developing a better understanding of this in future may be useful for reducing uncertainty of the seabird risk assessment and could be a useful input into risk assessments for other species groups.

The survival rates of released target and bycatch species is currently unknown.

Observer coverage in the New Zealand fleet is not spatially and temporally representative of the fishing effort.

5. STOCK ASSESSMENT

Determination of the status of the southern bluefin tuna stock is undertaken by the CCSBT Scientific Committee (CCSBT-SC). The stock assessment was updated in 2017 in accordance with the three-yearly schedule of stock assessment updates agreed by the CCSBT. The report describes the reconditioning of the southern bluefin tuna operating models and current estimates of stock status, following initial work for the OMMP meeting. The assessment results are based on the agreed base case and a range of sensitivity scenarios. This is the second stock assessment since the MP was implemented in 2011. The next stock assessment is scheduled for 2020.

5.1 Estimates of fishery parameters and abundance

5.1.1 Fishery indicators

As part of the stock assessment, a range of fishery indicators that were independent of any stock assessment model were considered to provide support and/or additional information important to aspects of current stock status. Indicators considered included those relating to recent recruitment, spawning biomass, and vulnerable biomass and were based on catch-at-age data, CPUE data, and information from various surveys (e.g., aerial sightings and troll surveys).

Fishery indicators were updated in 2019 and the summary was as follows:

- Two indicators of juvenile (age 1–2) SBT abundance were provided in 2019; the trolling index (piston-line index) remained at zero, for the second year in a row, and the gene-tagging abundance estimate decreased.
- The Japanese longline CPUE indicators suggest that the current stock levels for the 4, 5, 6 & 7, and 8–11 age groups are well above the historically lowest levels observed in the late 1980s or the mid-2000s.
- The Japanese longline CPUE indices for the 5, 6 & 7, and 8–11 age classes show increasing trends in recent years, while indices for age 4 have varied around the recent past 5-year mean.
- The indices for age class 12+ have declined gradually since 2011. This decline may relate to the very low cohorts of 1999 to 2001.
- The newly developed close-kin mark recapture index of abundance increased for the latest year for which it was calculated (2014).
- The standardised CPUEs for Korea for both areas described have shown an increasing trend since the mid-2000s.
- For the Taiwanese CPUE standardisations, the CPUEs for the area east of 60 degrees east have shown an increasing trend since 2016.
- The New Zealand CPUE has been substantially higher over the past three years compared to historical levels, with all three years similar.

5.1.2 CPUE and length-frequency data in New Zealand waters

CPUE for the charter fleet for the charter fleet, which largely fished the west coast of the South Island (CCSBT Region 6), increased steadily from 2003 to 2015 when they ceased fishing in New Zealand waters. CPUE for the domestic fleet also increased steadily from 2003 to 2016 (Figure 11). Since 2007, catch rates (by number) have increased to much higher levels than in 2003–06. The length-frequency data for the charter fleet through 2015 (Figure 12) show that this increase is mainly due to the recruitment of a strong length mode that has grown through the fishery and now dominates the catch at ~155 cm.

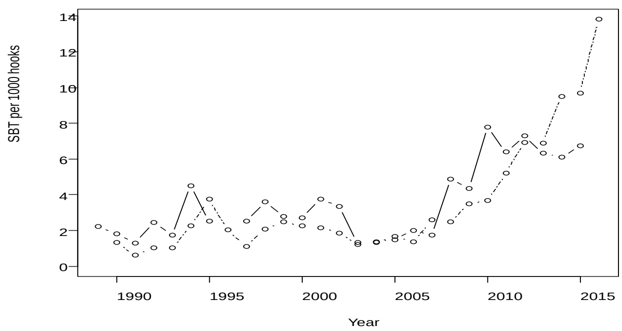


Figure 11: CPUE (number of southern bluefin tuna per 1000 hooks) by calendar year for the New Zealand charter (solid line) and domestic (dashed line) longline fleets based only on effort from sets that either targeted or caught southern bluefin tuna. Note that no charter vessels fished in 1996 nor in 2016.

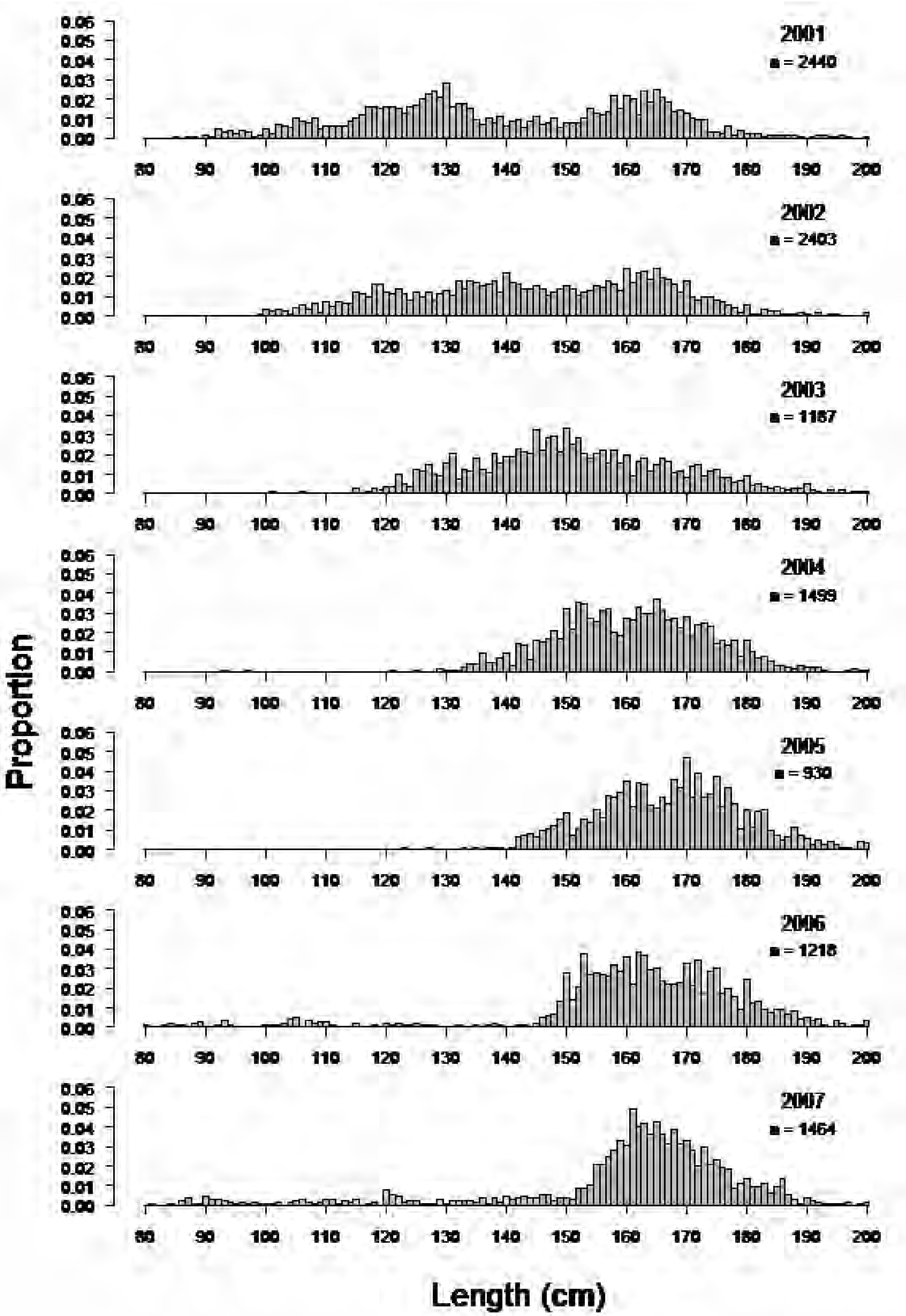


Figure 12: Proportion-at-length for the Japanese charter fleet operating in New Zealand fishery waters for 2001 to 2015. Source: CCSBT-ESC/1409/SBT Fisheries New Zealand (2014). [Continued on next page]

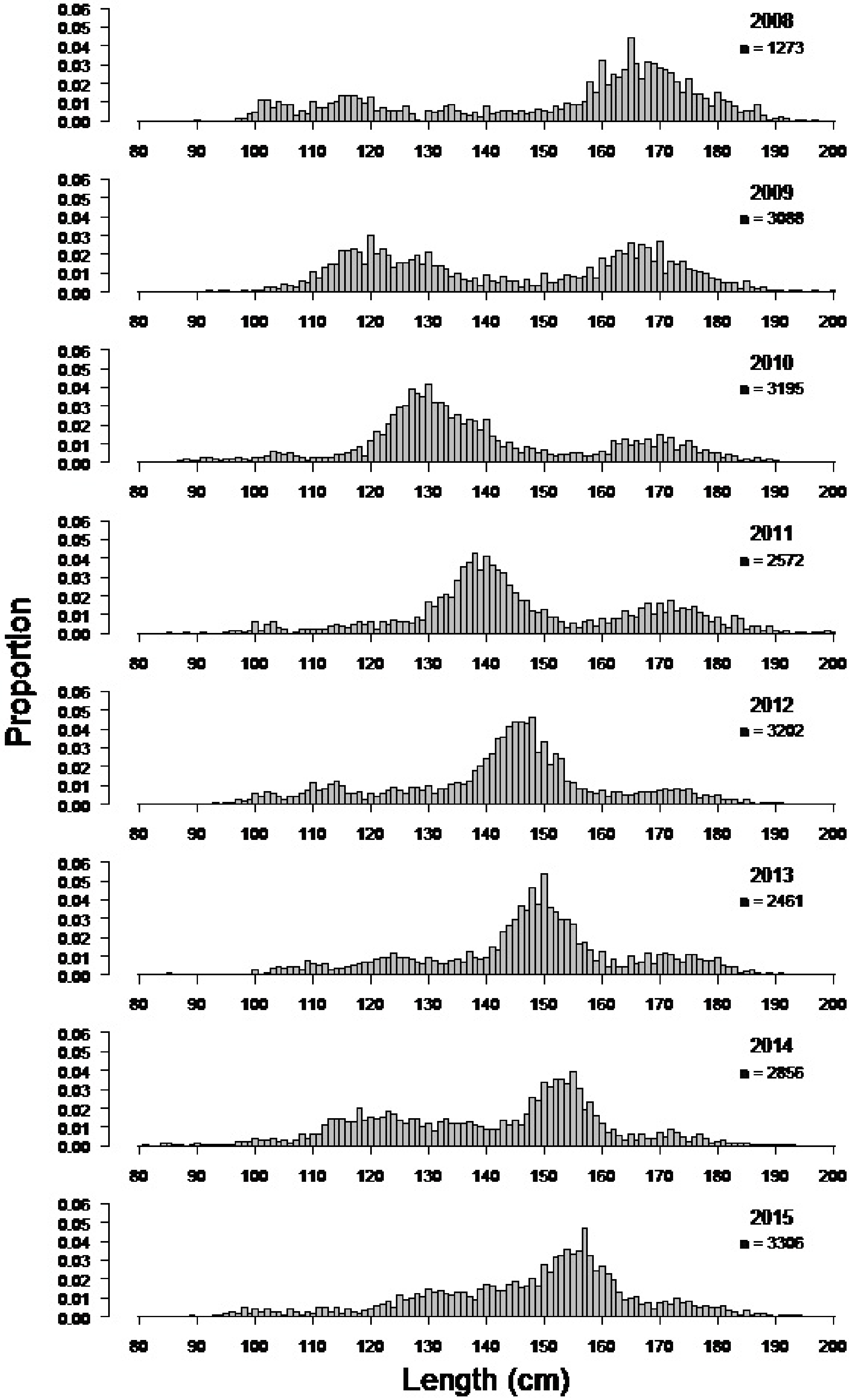


Figure 12 [Continued]: Proportion-at-length for the Japanese charter fleet operating in New Zealand fishery waters for 2001 to 2015. Source: CCSBT-ESC/1509/SBT Fisheries New Zealand (2015).

5.2 Biomass estimates

5.2.1 Spawning biomass

In 2017 the stock remains at a low level estimated to be 13% of the initial *SSB*, and below the level to produce maximum sustainable yield (MSY); however there has been some improvement since the 2014 stock assessment and fishing mortality is 50% of the level associated with MSY. *B10+* relative to initial is estimated to be 11%, which is up from the estimate of 5% in 2011.

The 2017 assessment incorporates, for the first time, the new half-sibling pair data from the close-kin mark recapture work, and additional parent-offspring-pair (POP) data that extend the existing POP data. The estimated trajectory of spawning stock biomass for the reference set over the full time series for the fishery is given in Figure 13. This shows a continuous decline from the late 1950s to the late 1970s, then a short period of stabilisation followed by a further decline from the early 1980s to mid-1990s to a very low level. The spawning stock biomass is estimated to have remained at this low level with relatively small annual variation until the early 2000s. For the more recent period, a decline in the median spawning stock biomass is evident from 2002 through 2012.

The ESC concluded that the 2017 reference set of operating models provided robust stock assessment advice. There is a recent upward trend in the adult population, which is a positive signal for rebuilding, recent recruitment is above the expected level, and current levels of fishing mortality suggest future rebuilding will be somewhat faster than initially envisaged in 2011. These positive recent trends may have implications for considering robustness tests for management procedure testing. In relation to the Bali Procedure's performance across the sensitivity analyses, in all cases the 2011 rebuilding objective was met and in some cases exceeded.

5.2.2 Assessment results

Based on the stock assessment results presented to the ESC in 2017, and the 2019 reconditioning of the SBT operating model (OM), the stock status advice was compiled from the updated reference set of operating models (Table 19). Two measures of the current spawning stock size are presented. The new method used in the operating model is presented as total reproductive output (TRO) as a new proxy for *SSB*, and is based on a revised spawning potential estimate that has been introduced into the operating model along with incorporation of the close-kin data. The biomass aged 10 years and older (*B10+*) is also presented, because this is the same measure used in previous stock assessments and therefore allows for comparisons.

Table 19: Southern bluefin tuna stock status estimates for 2016 from the 2017 stock assessment and for 2018 from the 2019 reconditioning of the SBT operating model (OMs). Uncertainty is presented in brackets as 80% confidence intervals.

Variable	2016 Status	2018 Status
SSB (TRO) depletion	0.13 (0.11–0.17)	0.17 (0.15–0.21)
B10+ depletion	0.11(0.09–0.13)	0.14 (0.12–0.17)
F relative to F_{MSY}	0.50 (0.38–0.66)	0.55 (0.41–0.74)
SSB relative to SSB_{MSY}	0.49 (0.38–0.69)	0.64 (0.47–0.91)
SSB relative to SSB_{min} in 2009		1.79 (1.63–1.93)
B10+ relative to B10+ in 2009		1.57 (1.45–1.72)

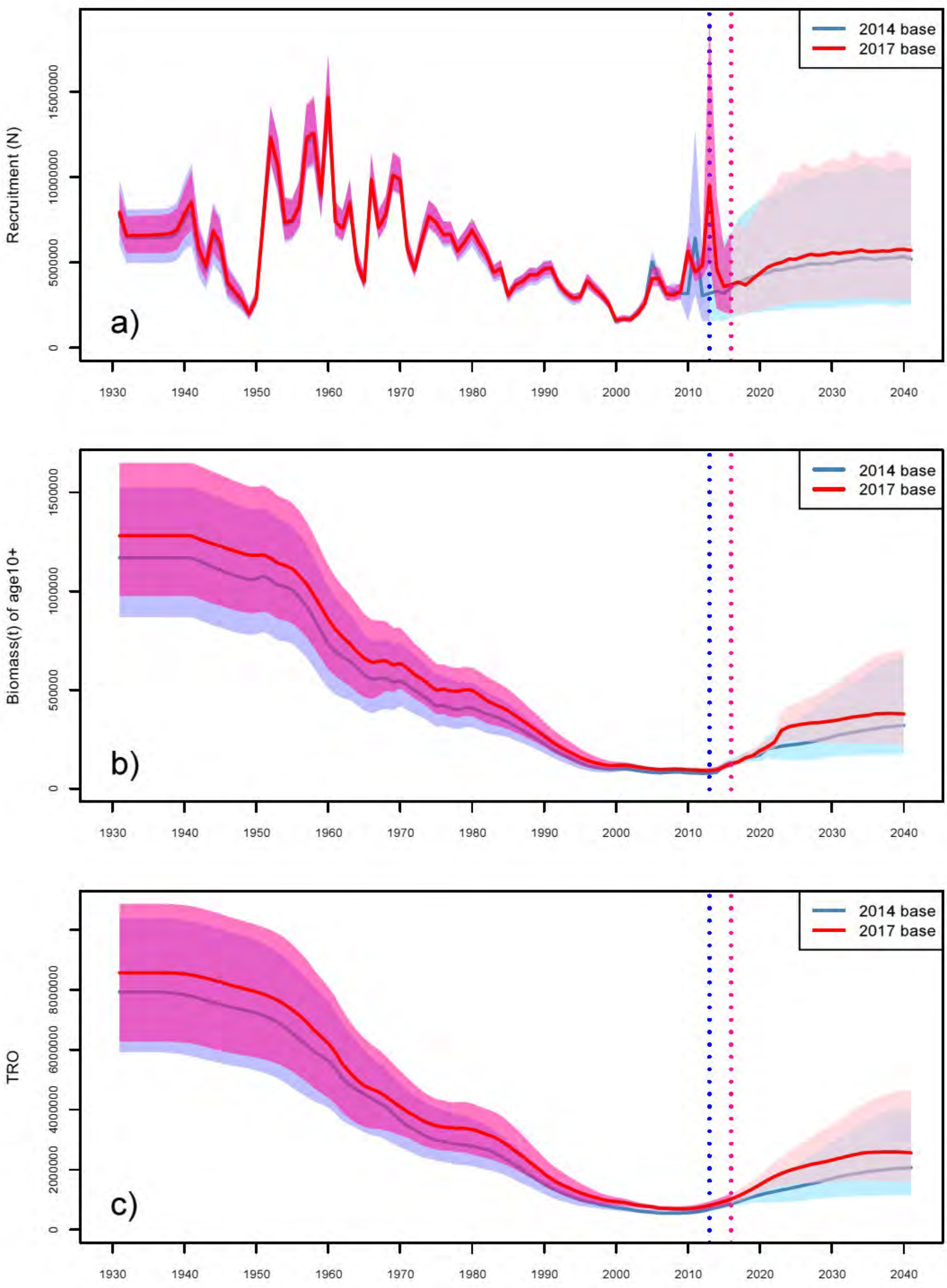


Figure 13: Historical and projected trajectories of the reference set for a) recruitment, b) biomass of age 10+ fish, and c) total reproductive output (TRO). The red line with the pink region represents the median and 90% probability intervals of the 2017 reference set (current assessment). The blue line with the light blue region represents those for the 2014 reference set (previous assessment). The dotted lines indicate the boundaries of the conditioning and projection.

In 2017 the stock was at a low state estimated to be 13% (11–17%, 80% P.I.) of the initial *SSB*, and below the level to produce maximum sustainable yield (MSY). There has been improvement since previous stock assessments, which indicated the stock was at 5% (3–8%) of original biomass in 2011 and 9% (7–12%) in 2014. The fishing mortality rate is below the level associated with MSY. The current TAC was set in 2016 following the recommendation from the management procedure adopted in 2011.

The 2019 results indicate a higher estimate for SSB depletion of 0.17 (0.15–0.21) for 2018 compared to the 2017 stock assessment estimate for 2016, which is consistent with the projections done in both 2017 and 2018. Fishing mortality relative to MSY levels had slightly increased to F/F_{MSY} = 0.55 (0.41 – 0.74) given the updated 2018 catch input. A notable difference between the 2017 stock assessment and the 2019 reconditioning of the OMs is that an additional model scenario (UAM1 – unaccounted mortality scenario) was included in the reference set of models for reconditioning the OMs, but evaluations in 2017 indicated that this did not affect SSB depletion estimates.

The ESC also decided to tabulate SSB in 2018 relative to SSB in the year 2009, where biomass was at its lowest (SSB_{min}), and B10+ in 2018 relative to *B10+* in 2009. These metrics indicate an increase in *SSB* of about +79% and an increase in B10+ of about +57% since 2009. This demonstrates the extent to which stock rebuilding has occurred.

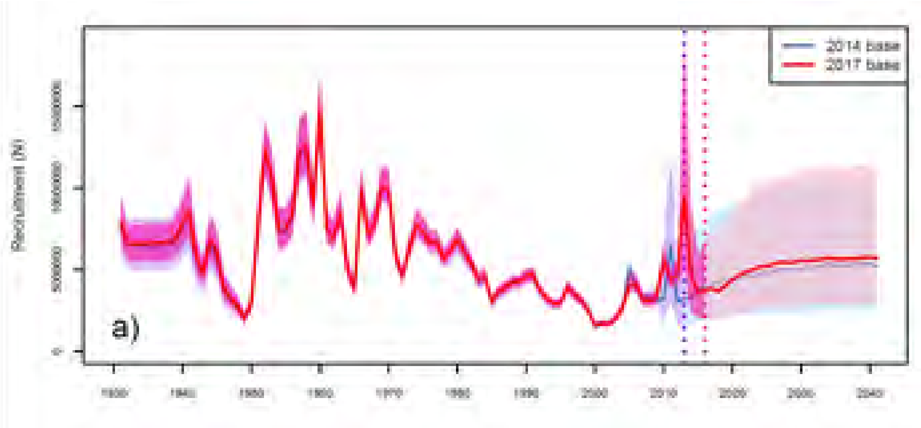
5.2.3 Stock projections

Future catch levels will be set by the CCSBT based on the output from the management procedure. The MP is designed to rebuild the spawning stock to 20% of the unfished level by 2035 (with 70% certainty). Projections for the reference set suggest that future recruitment, B10+, and total reproductive output (TRO) will increase through to the end of the projection period in 2040 and that stock rebuilding will be somewhat faster than envisaged in 2011.

6. STATUS OF THE STOCK

Stock Status	
Year of Most Recent Assessment	2017
Assessment Runs Presented	Reference set model plus a range of sensitivity scenarios
Reference Points	Target: B_{MSY} Soft Limit: Default 20% B_0 Hard Limit: Default 10% B_0 Overfishing threshold: F_{MSY}
Status in relation to Target	Well below B_{MSY}. Spawning stock biomass estimated to be about 49% B_{MSY}. Very Unlikely (< 10%) to be at or above B_{MSY}.
Status in relation to Limits	Very Likely (> 90%) to be below the Soft Limit About as Likely as Not Likely (40–60%) to be below the Hard Limit
Status in relation to Overfishing	Overfishing is Unlikely (< 40%) to be occurring

Historical Stock Status Trajectory and Current Status



Historical and projected trajectories of the reference set for recruitment, the red line with the pink region represents the median and 90% probability intervals of the 2017 reference set (current assessment). The blue line with the light blue region represents those for the 2014 reference set (previous assessment). The dotted lines indicate the boundaries of the conditioning and projections.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Increasing trajectory of SSB.
Recent Trend in Fishing Intensity or Proxy	Reduced in last 4 years. Current fishing mortality is below F_{MSY}.
Other Abundance Indices	CPUE has been increasing since 2007; juvenile abundance has improved in recent years.
Trends in Other Relevant Indicators or Variables	Recent recruitments are estimated to be well below the levels from 1950–80, but have improved since the poor recruitments of 1999–2002.

Projections and Prognosis	
Stock Projections or Prognosis	The management procedure adopted by the CCSBT in 2011 should rebuild the stock to 20% SB_0 by 2035 with a 70% probability. The MP was evaluated in 2016 and the increased CPUE and the increased index for the aerial survey resulted in a recommended TAC increase for 2018–20.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Likely (> 60%) for Soft Limit Unlikely (< 40%) for Hard Limit
Probability of Current Catch or TACC causing Overfishing to continue or commence	Unlikely (< 40%)

Assessment Methodology and Evaluation		
Assessment Type	Level 1 – Full Quantitative Stock Assessment	
Assessment Method	Reference set of reconditioned CCSBT Operating Model	
Assessment Dates	Latest assessment: 2017	Next assessment: 2020
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	CPUE, catch-at-age and length-frequency data, scientific aerial survey indices,	1 – High Quality

	close-kin (C-K) biomass estimate	
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	Biomass estimate from the close-kin (C-K) analysis incorporated into the Operating Model.	
Major Sources of Uncertainty	CPUE indices: - historical indices have an unknown bias from misreporting - fisheries management and operational changes since 2006 mean that recent CPUE series may not be comparable with earlier years - the level of assumed unaccounted mortality may have compromised OM conditioning and also the ability to achieve the rebuilding target with the agreed probability.	

Qualifying Comments
The MP was evaluated in 2016 and resulted in an increase in the TAC for 2018–20 of 3000 t to 17 647 t.

Environmental and Ecosystem Considerations	
Observer coverage	In the 2017–18 fishing year 16.6% of hooks set were observed for this fishery.
Non-target fish and invertebrate catch	In 2010 Blue shark, Ray's bream, and albacore were the predominant non-target species caught, with these three species making up nearly 70% of the catch. No invertebrates are caught in this fishery.
Incidental catch of seabirds	This fishery contributes to the total risk posed by New Zealand commercial fisheries to four high risk species; the Salvin's albatross, Southern Buller's albatross, the Flesh-footed shearwater, and the Gibson's albatross.
Incidental catch of cetaceans	Between 2002 and 2018 incidental captures of long-finned pilot whales (1), beaked whales (3), bottlenosed dolphins (3), orca (1), and unidentified cetacean (1) were observed. All of these cetaceans were released alive.
Incidental catch of pinnipeds	Between 2002 and 2018 incidental captures of 404 New Zealand fur seals were observed. Most of these were released alive.
Incidental catch of other protected species	Between 2002 and 2018 incidental captures of three Leatherback turtles and a green turtle were observed. All turtles were released alive.
Benthic interactions	There are no known benthic interactions for this fishery.

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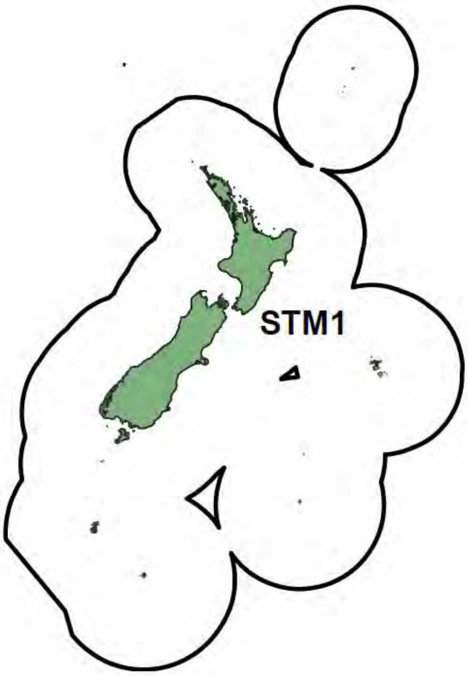
STRIPED MARLIN (STM)

(*Kajikia audax*)



1. FISHERY SUMMARY

All marlin species are currently managed outside the Quota Management System.

Management of the striped marlin and other highly migratory pelagic species throughout the western and central Pacific Ocean (WCPO) is the responsibility of the Western and Central Pacific Fisheries Commission (WCPFC). Under this regional convention, New Zealand is responsible for ensuring that the fisheries management measures applied within New Zealand fisheries waters are compatible with those of the Commission.

At its third annual meeting (2006) the WCPFC passed a Conservation and Management Measure (CMM) (this is a binding measure that all parties must abide by) relating to conservation and management of striped marlin in the south-west Pacific Ocean (www.wcpfc.int). This measure restricts the number of vessels a state can have targeting striped marlin on the high seas. However, this does not apply to those coastal states (including New Zealand) south of 15°S in the Convention Area who have already taken, and continue to take, significant steps to address concerns over the status of striped marlin in the south-western Pacific region, through the establishment of a commercial moratorium on the landing of striped marlin caught within waters under their national jurisdiction.

1.1 Commercial fisheries

Most of the commercial striped marlin catch in the south-west Pacific is caught in the tuna surface-longline fishery, which started in 1952, and in the New Zealand region in 1956. Since 1980 foreign fishing vessels had to obtain a license to fish in New Zealand's EEZ and were required to provide records of catch and effort. New Zealand domestic vessels commenced fishing with surface longlines in 1989 and the number of vessels and the fishing effort expanded rapidly during the 1990s. Also in 1989, licences were issued to charter up to five Japanese surface-longline vessels to fish on behalf of New Zealand companies. The Japanese charter vessels ceased fishing as of 1 May 2016 due to changes in New Zealand government legislation. Very few striped marlin are caught by other commercial methods, although there are occasional reports of striped marlin caught in purse-seine nets.

A three-year billfish moratorium was introduced in October 1987 in response to concerns over the decline in availability of striped marlin to recreational fishers. The moratorium prohibited access to the Auckland Fisheries Management Area (AFMA: Tirua Point to Cape Runaway) by foreign licensed and chartered tuna longline vessels between 1 October and 31 May each year. Licence restrictions required that all billfish, including broadbill swordfish, caught in the AFMA be released. In 1990, the moratorium was renewed for a further three years with some amended conditions and it was reviewed and extended in 1993 for a further year.

Regulations have prohibited domestic commercial fishing vessels from retaining billfish caught within the AFMA since 1988. In 1991 these regulations were amended to allow the retention of broadbill swordfish and prohibited the retention of marlin species (striped, blue and black marlin) by commercial fishers in New Zealand fishery waters. These regulations, and government policy changes on the access rights of foreign licensed surface-longline vessels, have replaced the billfish moratorium. A billfish memorandum of understanding (MOU) between representatives of commercial fishers and recreational interests provided a framework for discussion and agreement on billfish management measures. This MOU was reviewed annually between 1990 and 1997 and was last signed in 1996.

A review of marlin regulations and management was identified as an issue during the development of the National Fisheries Plan for Highly Migratory Species. The main focus was on the relative benefits of alternative management options for striped marlin that might either allow for some limited commercial utilisation, or further consolidate the current status of marlin as a non-commercial species.

At the review meetings in 2013 there was no agreement between sector representatives on alternative management measures for marlin. The Minister decided to retain the moratorium on commercial landings of marlin caught in New Zealand waters.

Estimates of total landings (commercial and recreational) for New Zealand are given in Table 1. Commercial catch of striped marlin reported on Catch Effort Landing Returns (CELRs) and Tuna Longline Catch and Effort Returns (TLCERs) and recreational catches from New Zealand Sport Fishing Council records are given in Table 1. Figure 1 shows historic landings and longline fishing effort for the striped marlin stocks.

Table 1: Commercial landings and discards (number of fish) of striped marlin in the New Zealand EEZ reported by fishing nation (CELRs and TLCERs), and recreational landings and number of fish tagged, by fishing year. **[Continued on next page]**

Fishing	Japan		Korea	Philippines	Australia	Domestic	NZ recreational		Total
year	Landed	Discarded	Landed	Discarded	Discarded	Discarded	Landed	Tagged	
1979–80	659						692	17	1 368
1980–81	1 663		46				792	2	2 503
1981–82	2 796		44				704	11	3 555
1982–83	973		32				702	6	1 713
1983–84	1 172		199				543	9	1 923
1984–85	548		160				262		970
1985–86	1 503		19				395	2	1 919
1986–87	1 925		26				226	2	2 179
1987–88	197		100				281	136	714
1988–89	23		30			5	647	408	1 113
1989–90	138					1	463	367	969
1990–91		1				6	532	232	771

Fishing	Japan		Korea	Philippines	Australia	Domestic	NZ Recreational		Total
Year	Landed	Discarded	Landed	Discarded	Discarded	Discarded	Landed	Tagged	
1991–92		17				1	519	242	779
1992–93						7	608	386	1 001
1993–94						59	663	929	1 651
1994–95						182	910	1 206	2 298
1995–96						456	705	1 104	2 265
1996–97						441	619	1 302	2 362
1997–98						445	543	898	1 886
1998–99						1 642	823	1 541	4 006
1999–00		2				798	398	791	1 989
2000–01						527	422	851	1 800
2001–02						225	430	771	1 426
2002–03		3		7		205	495	671	1 371
2003–04		1				423	592	1 051	2 066
2004–05						258	834	1 348	2 440
2005–06						168	630	923	1 721
2006–07					9	154	688	964	1 806
2007–08		1				208	485	806	1 499
2008–09						241	731	1 058	2 030
2009–10						195	607	858	1 660
2010–11						269	607	731	1 601
2011–12						241	635	663	1 531
2012–13		1				216	744	853	1 813
2013–14						202	620	519	1 341
2014–15						371	696	1 086	2 153
2015–16						562	900	1 530	2 992
2016–17						261	516	517	1 228
2017–18						168	544	711	1 472
2018–19						165	446	579	1 025

Total recorded commercial catch was highest in 1981–82 at 2843 fish and 198 t. Following the introduction of the billfish regulations, striped marlin caught on commercial vessels were required to be returned to the sea and few of these fish were recorded on catch/effort returns. In 1995 the Ministry of Fisheries instructed that commercially caught marlin be recorded on TLCERs. However, compliance with this requirement was inconsistent and estimated catches in the tuna longline fishery (calculated by scaling-up observed catches to the entire fleet) are considerably higher than reported catches in fishing years for which these estimates are available. However, the estimates are probably imprecise as observer coverage of the domestic fleet has been low (just below 10% for the years 2007–10) and has not adequately covered the spatial and temporal distribution of the fishery over summer.

Few striped marlin in the TLCER database were reported south of 42ºS and most striped marlin reported by commercial fishers were caught north of 38ºS. Historically, Japanese and Korean vessels caught most striped marlin between 31ºS and 35ºS with a peak at 33ºS. The New Zealand domestic fleet caught the majority of their striped marlin in the Bay of Plenty–East Cape area, between 36ºS and 37ºS.

A significant number of catch records from domestic commercial vessels provide the number of fish caught but not the estimated catch weight. The total weight of striped marlin caught per season was therefore calculated using fisher estimates from TLCER and CELR records plus the number of fish with no weights multiplied by the mean recreational striped marlin weight for that season. Reported total landings and discards (commercial and recreational) and commercial landings from outside the EEZ are shown in Table 2.

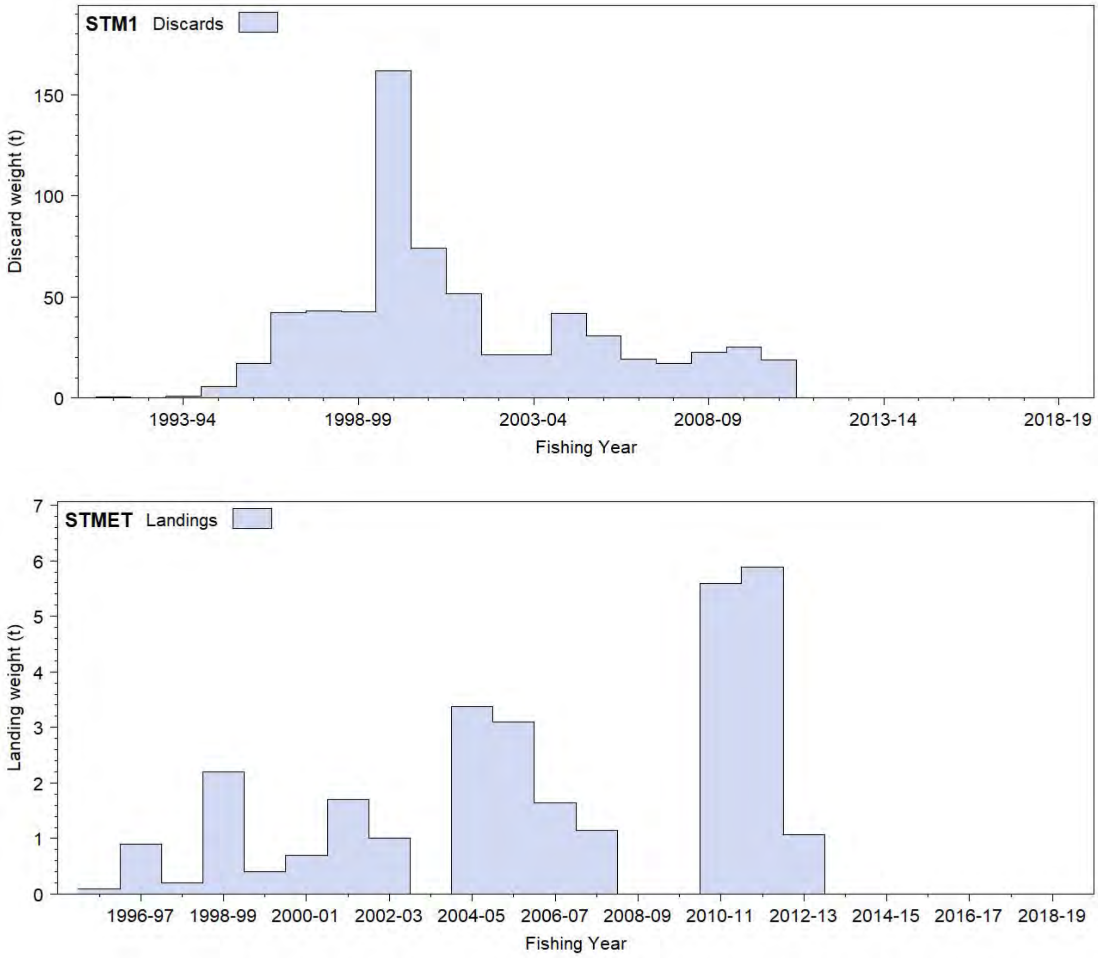


Figure 1: [Top] Striped marlin catch (commercial discards) between 1991–92 and 2018–19 within New Zealand waters (STM 1). [Bottom] Striped marlin catch between 1995–96 and 2018–19 on the high seas (STMET).

Table 2: Reported total New Zealand landings and discards (commercial and recreational, t) and commercial landings from the western and central Pacific Ocean (WCPO) (t) of striped marlin from 1991 to 2018. [Continued on next page]

	Commercial		Recreational		EEZ	NZ commercial	WCPO all
	Landed	Discarded	Landed	Tagged	Total	Outside the EEZ	gears *
1991	0.1	0.5	52	21	73		7 076
1992	0.8	0.1	57.8	21.9	81		6 878
1993	0	0.8	62.8	34.4	99		11 867
1994		5.7	66.3	81.2	153		8 013
1995		17.2	95	100	214	0.1	8 437
1996		42.3	70.6	91.6	204	0.9	6 746
1997		42.9	64.4	127.8	230	0.2	6 027
1998		42.7	56.5	80.9	182	2.2	8 501
1999		161.9	73.2	130.9	345	0.4	7 222
2000		74.1	40.9	72.1	179	0.7	5 644
2001		51.6	45.5	78.7	177	1.7	6 149
2002		21.2	45.8	76.9	144	0.9	5 962
2003		21.1	54.6	65.4	142		6 625
2004		41.7	62.7	105.6	208		6 551
2005		30.7	86.6	131.3	249	3.5	5 611
2006	0.4	19.0	60.8	85.8	166	3.2	5 336
2007	1.2	16.9	67.5	93.4	179	1.9	4 489

	Commercial		Recreational		EEZ	NZ commercial	WCPO all
	Landed	Discarded	Landed	Tagged	Total	Outside the EEZ	gears *
2008		22.6	48.6	79.7	152	1.1	5 085
2009		25.3	73.7	104.4	202		3 801
2010		18.6	63.1	79.5	163	5.6	3 897
2011		27.4	51.1	66.6	144	5.9	4 180
2012		24.0	75.9	77.6	153	1.8	4 499
2013		22.8	80.6	86.4	190	1.1	3 911
2014		19.8	66.0	51.0	137	0	3 975
2015		32.6	68.5	97.4	199		4 462
2016		14.8	92.3	137.1	244		3 509
2017		28.3	55.3	42.2	126		3 606
2018		25.0	66.7	74.1	166		3 407

Source: TLCER and CELRs; NZSFC; Holdsworth & Saul (2008); Holdsworth & Saul (2017b).* Anon (2013).

Combined landings from within New Zealand fisheries waters are relatively small compared to commercial landings from the greater stock in the south-west Pacific Ocean (8% average for 2002–06). In New Zealand, striped marlin are landed almost exclusively by the recreational sector, but there are no current estimates of recreational catch from elsewhere in the south-west Pacific.

In 2012–13, the majority of striped marlin (65%) caught in the New Zealand commercial fisheries were caught as bycatch in the bigeye tuna target surface-longline fishery (Figure 2). Striped marlin are not allowed to be retained by commercial fishers in New Zealand fishery waters but do show up in estimated catches (Figure 3). Longline fishing effort is distributed along the east coast of the North Island and the south-west coast of the South Island. The west coast South Island fishery predominantly targets southern bluefin tuna, whereas the east coast of the North Island targets a range of species including bigeye, swordfish and southern bluefin tuna.

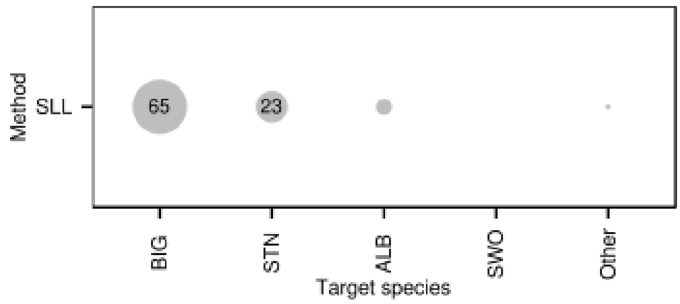


Figure 2: A summary of the proportion of striped marlin taken by each target fishery and fishing method for 2012–13. The area of each circle is proportional to the percentage of landings taken using each combination of fishing method and target species. The number in the circle is the percentage. SLL = surface longline (Bentley et al. 2013).

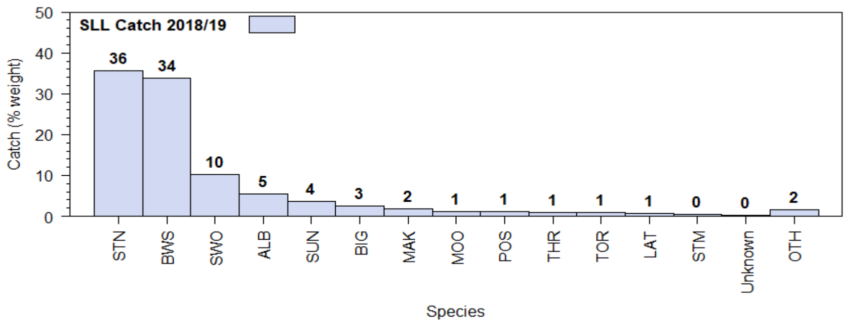


Figure 3: A summary of species composition of the surface-longline estimated catch for 2018–19. The percentage by weight of each species is calculated for all surface-longline trips.

In the longline fishery most of the striped marlin were alive when brought to the side of the vessel for all fleets during 2006–07 to 2014–15 (Table 3), and almost all have been discarded (Table 4) as required by New Zealand legislation.

Table 3: Percentage of striped marlin (including discards) that were alive or dead when arriving at the longline vessel and observed during 2006–07 to 2014–15, by fishing year, fleet and region. Small sample sizes (number observed < 20) were omitted (Griggs & Baird 2013, Griggs et al. 2018).

Year	Fleet	Area	% alive	% dead	Number
2006–07	Total		65.0	35.0	20
2007–08	Total		100.0	0.0	6
2008–09	Total		50.0	50.0	8
2009–10	Domestic	North	72.7	27.3	22
	Total		72.7	27.3	22
2010–11	Total				8
2011–12	Total				6
2012–13	Total				9
2013–14	Total				5
2014–15	Total				9

Table 4: Percentage of striped marlin that were retained, or discarded or lost, when observed on a longline vessel during 2006–07 to 2014–15, by fishing year and fleet. Small sample sizes (number observed < 20) omitted (Griggs & Baird, Griggs et al. 2018).

Year	Fleet	% retained	% discarded or lost	Number
2006–07	Total	10.0	90.0	20
2007–08	Total	0.0	100.0	6
2008–09	Total	0.0	100.0	9
2009–10	Domestic	4.3	95.7	23
	Total	4.3	95.7	23
2010–11				9
2011–12				6
2012–13				9
2013–14				5
2014–15				9

1.2 Recreational fisheries

The striped marlin fishery is an important component of the recreational fishery and tourist industry from late December to May in northern New Zealand. There are approximately 100 recreational charter boats that derive part of their income from marlin fishing and a growing number of private vessels participating in the fishery. Many of the largest fishing clubs in New Zealand target gamefish and are affiliated to the national body, the New Zealand Sport Fishing Council (NZSFC). Clubs provide facilities to weigh fish and keep catch records. The sport fishing season runs from 1 July to 30 June the following year. Almost all striped marlin are caught between January and June in the latter half of the season.

In 1988 the NZSFC proposed a voluntary minimum size of 90 kg for striped marlin in order to encourage tag and release. Fish landed under this size do not count for club or national contests or trophies but most are included in the catch records for each fishing season. In 2017–18 the 55 recreational fishing clubs affiliated to NZSFC reported landing 3383 billfish, sharks, kingfish, mahimahi and tuna, and tagged and released a further 1723 gamefish. In 2017–18, 618 striped marlin were landed and weighed by clubs (18% of landed gamefish in NZSFC records) and 785 were tagged and released (46% of tagged gamefish in NZSFC records).

There is an almost complete historical database of recreational catch for individual striped marlin caught by the Bay of Islands Swordfish Club and the Whangaroa Sport Fishing Club going back to the 1920s, when this fishery started.

1.2.1 Estimates of recreational harvest

No estimates of recreational harvest of striped marlin were generated from the telephone-diary surveys conducted in 1994, 1996 and 2000 because so few were reported. A National Panel Survey was conducted for the first time throughout the 2011–12 fishing year. The panel survey used face-to-face interviews of a random sample of 30 390 New Zealand households to recruit a panel of fishers and non-fishers for a full year (from Wynne-Jones et al. 2014). The panel members were contacted regularly about their fishing activities and harvest information collected in standardised phone interviews. The national panel survey was repeated during the 2017–18 fishing year using very similar methods to produce directly comparable results (Wynne-Jones et al. 2019). Note that national panel survey estimates do not include recreational harvest taken under s111 general approvals. The National Panel Survey results do not include estimates for striped marlin as the surveys did not capture the fishers and fishing activity for the large gamefish species well.

1.3 Customary non-commercial fisheries

Maori traditionally ate a wide variety of seafood, however, no record of specific marlin fishing methods has been found to date. An estimate of the current customary catch is not available.

1.4 Illegal catch

There is no known illegal catch of striped marlin.

1.5 Other sources of mortality

Some fish that break free from commercial or recreational fishing gear may die due to hook damage or entanglement in trailing line. A high proportion of fish that are caught are released alive by both commercial and recreational fishers. Data collected by Observer Services from the tuna longline fishery suggest that most striped marlin are alive on retrieval (72% of the observed catch). The proportion of striped marlin brought to the boat alive was similar on domestic longliners and foreign and charter vessels. However, post-release survival rates are unknown.

Recreational anglers tag and release 50% to 60% of their striped marlin catch. Most of these fish are caught on lures. Reported results from 66 pop-up satellite archival tags (PSATs) deployed on lure-caught striped marlin in New Zealand showed a high survival rate following catch and release. The PSATs are programmed to release from the fish following death. No fish died and sank to the seafloor. One fish was eaten (tag and all) by a lamnid shark about 15 hours after it was tagged and released. A small proportion of other PSATs failed to report, so the fate of these fish is unknown.

Striped marlin caught on baits in Mexico showed a 26% mortality rate within 5 days of release. Injury was a clear predictor of mortality; 100% of fish that were bleeding from the gill cavity died, 63% of fish hooked deep died, and 9% of those released in good condition died.

2. BIOLOGY

Striped marlin is one of eight species of billfish in the family Istiophoridae. They are epipelagic predators in the tropical, sub-tropical and temperate pelagic ecosystem of the Pacific and Indian Oceans. Juveniles generally stay in warmer waters, while adults move into higher latitudes and temperate water feeding grounds in summer (i.e., the first quarter of the calendar year in the southern hemisphere; the third quarter in the northern hemisphere). The latitudinal range estimated from longline data extends from 45ºN to 40ºS in the Pacific and from continental Asia to 45ºS in the Indian Ocean. Striped marlin are not uniformly distributed, having a number of areas of high abundance. Fish tagged in New Zealand have undergone extensive seasonal migrations within the south-west Pacific but not beyond.

Samples from recreationally caught striped marlin in New Zealand indicate that the most frequent prey items are saury and arrow squid, followed by Jack mackerel. However, 28 fish species and 4 cephalopod species have been identified from stomach contents indicating that they are opportunistic predators.

The highest striped marlin catch for the surface-longline method is recorded in January–February but striped marlin have been caught in New Zealand fisheries waters in every month, with lowest catches in November and December.

Striped marlin are oviparous and are known to spawn in the Coral Sea between Australia and New Caledonia. Their ovaries start to mature in this region during late September or early October. Spawning peaks in November and December and 60–70% of fish captured at this time are in spawning condition. The minimum size of mature fish in the Coral Sea is recorded at approximately 170 cm lower jaw-fork length (LJFL) and 36 kg. Striped marlin captured in New Zealand are rarely less than 200 cm (LJFL) suggesting that these fish are all mature. Female striped marlin are larger than males on average but sexual dimorphism is not as marked as that seen in blue and black marlin. The sex ratio of striped marlin sampled from the recreational fishery in Northland (n = 61) was 1:1 prior to the introduction of the voluntary minimum size restriction (90 kg). There is no clear evidence of striped marlin reproductive activity in New Zealand waters. The northern edge of the EEZ around the Kermadec Islands extends into sub-tropical waters. According to historical longline records, in some years there are moderate numbers of striped marlin in this area from October to December. Therefore, striped marlin spawning could occur in this area.

Estimated growth and validated age estimates of striped marlin were derived from fin spine and otolith age estimates from 425 striped marlin collected between 2006 and 2009. Samples came from the Australian commercial longline and recreational fisheries, longline fisheries in Pacific Island countries and 133 samples from the New Zealand recreational fishery. Ages ranged from 130 days to 8 years, in striped marlin ranging in length from 990 mm (about 4 kg) to 2871 mm (about 168 kg) LJFL (Kopf et al. 2010). Estimated ages of striped marlin from New Zealand ranged from 2 to 8 years in fish ranging in length from 2000 mm to 2871 mm LJFL. The median age of striped marlin landed in the New Zealand recreational fishery was 4.4 years for females and 3.8 years for males.

Growth for striped marlin in the south-west Pacific is broadly comparable with overseas studies. Melo-Barrera et al. (2003) identified between 2 and 11 growth bands from fish sampled in Mexico, and Skillman & Yong (1976) classified up to 12 age groups from length-frequency analysis of striped marlin in Hawaii. Recreational catch records kept by the International Game Fish Association (IGFA) list the heaviest striped marlin as 224.1 kg caught in New Zealand in 1975. Estimates of biological parameters for striped marlin in New Zealand waters are given in Table 5.

Table 5: Estimates of biological parameters.

Parameter	Estimate				Source
1. Natural mortality (M)					
STM	0.49–1.33				Boggs (1989)
STM	0.389–0.818				Hinton & Bayliff (2002)
2. Weight = a (length)^b (weight in kg, length in mm LJFL)					
	a	b			
STM	1.012×10^{-10}	3.55		South West Pacific	Kopf et al. (2010)
STM males	4.171×10^{-11}	3.67		South West Pacific	
STM females	1.902×10^{-9}	3.16		South West Pacific	
STM males	2.0×10^{-8}	2.88		New Zealand	Kopf et al. (2005)
STM females	2.0×10^{-8}	2.90			
3. Von Bertalanffy model parameter estimates					
	k	t_0	L_∞		
STM	0.44	-1.07	2 636	South West Pacific	Kopf et al. (2010)
STM	0.22	-0.04	3 010	New Zealand	Kopf et al. (2005)
STM	0.23	-1.6	2 210	Mexico	Melo-Barrera et al. (2003)
STM male	0.315–0.417	-0.521	2 774–3 144	Hawaii	Skillman & Yong (1976)
STM female	0.686–0.709	0.136	2 887–3 262	Hawaii	Skillman & Yong (1976)

3. STOCKS AND AREAS

Striped marlin are a highly migratory species, and fish caught in the New Zealand fisheries waters are part of a wider stock. The stock structure of striped marlin in the Pacific Ocean is not well understood, but resolving stock structure uncertainties is the focus of current research activities. The two most frequently considered hypotheses are: (1) a single-unit stock in the Pacific, which is supported by the continuous 'horseshoe-shaped' distribution of striped marlin; and (2) a two-stock structure, with the stocks separated roughly at the Equator, albeit with some intermixing in the eastern Pacific.

Spawning occurs in water warmer than 24ºC, in the southern hemisphere, mainly in November and December. Known spawning areas in the south-west Pacific are in the Coral Sea in the west and in French Polynesia in the east of the region. The southern hemisphere spawning season is out of phase with the north Pacific. Very warm equatorial water in the western Pacific, where striped marlin are seldom caught, may be acting as a natural barrier to stock mixing. However, in the eastern Pacific striped marlin may be found in equatorial waters and three fish tagged in the northern hemisphere were recaptured in the southern hemisphere. The results of mitochondrial DNA analysis are consistent with shallow population structuring within striped marlin in the Pacific.

The New Zealand Gamefish Tagging Programme tagged and released 27 019 striped marlin between 1 July 1975 and 30 June 2018. Of the 88 with complete release and recapture records, 31 have been made outside the EEZ spread across the region from French Polynesia (142ºW) to eastern Australia (154ºE) and from latitude 2ºS to 38ºS. There have been no reports of striped marlin tagged in the south-western Pacific being recaptured elsewhere in the Pacific Ocean.

Striped marlin are believed to have a preference for sea surface temperatures of 20–25ºC. Generally striped marlin arrive in New Zealand fisheries waters in January and February, and tag recaptures indicate that most leave the New Zealand EEZ between March and June; although they have been caught by surface longliners in the EEZ in every month. Within the EEZ most striped marlin are caught in FMAs 1 and 9.

4. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS

This summary is from the perspective of striped marlin but there is no directed fishery for this species. The incidental catch sections below reflect the New Zealand longline fishery as a whole and are not specific to this species; a more detailed summary from an issue-by-issue perspective is available in the Aquatic Environment and Biodiversity Annual Review where the consequences are also discussed (Ministry for Primary Industries 2019).

4.1 Role in the ecosystem

Striped marlin (*Kajikia audax*) are large pelagic predators, so they are likely to have a 'top down' effect on the squid, fish and crustaceans they feed on.

4.2 Non-target fish catch

Most of the commercial striped marlin catch in the south-west Pacific is caught in the tuna surface-longline fishery.

Observer records indicate that a wide range of species are landed by the longline fleets in New Zealand fishery. Blue sharks are the most commonly caught species (by number), followed by lancetfish and Porbeagle shark (Table 6).

Table 6: Total estimated catch (numbers of fish) of common bycatch species in the New Zealand longline fishery as estimated from observer data from 2015 to 2018. Also provided is the percentage of these species retained (2018 data only) and the percentage of fish that were alive when discarded, N/A (none discarded).

Species	2015	2016	2017	2018	% retained (2018)	discards % alive (2018)
Blue shark	72 480	57 210	49 924	63 618	0.0	88.7
Lancetfish	12 962	17 442	13 274	13 163	0.0	33.5
Porbeagle shark	4 058	6 566	3 101	2 594	1.0	51.1
Rays bream	17 555	7 758	2 421	1 579	99.0	26.7
Moonfish	3 060	3 036	2 022	2 698	98.0	50.0
Pelagic stingray	979	1 414	1 798	2 949	0.0	100.0
Sunfish	770	4 849	1 648	3 648	0.0	99.8
Mako shark	2 667	4 417	1 391	2 721	4.0	65.6
Rudderfish	373	237	680	253	45.0	89.4
Butterfly tuna	1 309	768	406	419	86.0	20.7
Escolar	653	669	300	594	67.0	67.9
Striped marlin	120	550	290	247	0.0	66.7
Thresher shark	177	601	260	253	0.0	76.0
Oilfish	584	281	227	602	42.0	85.4
Dealfish	842	63	72	25	0.0	31.8
School shark	88	24	59	187	84.0	100.0
Skipjack tuna	150	185	57	184	86.0	100.0
Deepwater dogfish	545	0	32	6	0.0	83.3
Big scale pomfret	59	16	17	34	100.0	n/a

4.3 Benthic interactions

There are no known benthic interactions for this fishery.

5. STOCK ASSESSMENT

With the establishment of WCPFC in 2004, the Scientific Committee of the Western and Central Pacific Fisheries Commission (WCPFC) will review stock assessments of striped marlin in the western and central Pacific Ocean stock. The stock assessment for south-western Pacific striped marlin was last updated in 2019.

The 2019 stock assessment of striped marlin is described in Ducharme-Barth et al. (2019). An additional 6 years of data were available since the previous assessment in 2012, and the model extends through the end of 2017. New developments to the stock assessment including addressing the recommendations of the 2012 stock assessment report, revision and incorporation of new data sources such as maturity-at-length, exploration of model uncertainty, and improving the diagnostics of previous assessments. Key changes made in the progression from the 2012 reference case to the 2019 diagnostic case model include:

- Updating all data through to the end of 2017.
- Using standardized CPUE for the Japanese and Chinese Taipei longline fisheries calculated using a geostatistical model.
- Updating the biological information on maturity and defining this process as a function of length and not age.

5.1 Stock status and trends

Uncertainty in the stock status and key reference points was high, though a consensus of models indicated a clear, declining trend in stock status. This decline was informed by a decline in the median weight in the New Zealand recreational fishery, as well as a decline in the CPUE index. As noted in the previous assessment, lack of knowledge on key biological processes (natural mortality and steepness) contributed to the overall level of uncertainty in the assessment. Three different, fixed levels were considered for the baseline level of average annual natural mortality (0.3, 0.4, and 0.5) and steepness (0.65, 0.8, and 0.95) in the structural uncertainty grid. Across grid runs, models assuming higher values for either of these two quantities generally estimated a more optimistic stock status. Lack of observations of small individuals did not allow these age-specific processes to be well estimated. Appropriate levels for these values are informed by meta-analyses based on life-history theory, which generally rely heavily on the growth relationship.

The general conclusions of this assessment are as follows:

- consistent with the findings of the previous Southwest Pacific striped marlin assessments, persistent declines in biomass and spawning biomass were estimated since the start of the assessment period. Recent years show a slight improvement in stock status relative to a low point at the beginning of the current decade (2010s).
- The negative trend in recruitment identified in the previous two stock assessments remains a feature of the current model. Recruitment variability (RV) appears to have reduced in the last decade as spawning stock biomass has decreased.
- Fishing mortality has gradually increased over time. The rate of increase accelerated for both the juvenile and adult components in the early 2000s before peaking at the beginning of the current decade (2010s). Fishing mortality is estimated to have declined since then.
- With respect to MSY-based reference points, 69% of runs estimate recent spawning biomass to be less than the spawning biomass that supports MSY.
- In terms of spawning biomass depletion, 50% of runs indicate that recent spawning biomass is at less than 20% of the unfished level of spawning biomass.
- With respect to fishing mortality, 56% of model runs estimate recent levels of fishing mortality to be less than the fishing mortality that would result in MSY.

The description of the updated structural sensitivity grid used to characterise uncertainty in the assessment is provided in Table 7. The spatial structure used in the assessment model is shown in Figure 4, with sub-regions used to define fisheries shown. Catch trend data is presented in Figure 5. Estimated annual average recruitment, spawning biomass, and total biomass from the diagnostic case are shown in Figure 6. Fishing mortality and depletion estimated from the diagnostic case are shown in Figures 7 and 8, respectively. The median and 80 percent quantile trajectories of the spawning biomass depletion and trajectories of fishing mortality for models in the structural uncertainty across the grid axes in Table 7 are shown in Figures 9 and 10 respectively.

Table 7: Description of the structural sensitivity grid used to characterize uncertainty in the assessment. The star denotes the level assumed in the diagnostic case.

Axis	Levels	Option
Steepness	3	0.65, 0.8* or 0.95
Growth	2	Kopf et al. 2011* or otolith age
Natural mortality	3	0.3, 0.4* or 0.5
CPUE	3	JP 2 LL*, TW 5 LL or AU 6 LL
Size frequency weighting	3	Weight/length samples divided by 10/20, 20/40* or 50/100
Recruitment penalty CV	3	0.2*, 0.5 or 2.2

The Majuro plot summarizing the results for each of the models in the structural uncertainty grid retained for management advice are represented in Figure 11. Figure 12 presents the Kobe plot summarizing the results for each of the models in the structural uncertainty grid retained for management advice.

SC15 noted that the median of recent spawning biomass depletion relative to the unfished condition was ($SB_{recent}/SB_{F=0}$) = 0.20, with a probable range of 0.09 to 0.46 (80% probable range), and there was a roughly 50 % probability (151 out of 300 models) that the recent spawning biomass depletion relative to the unfished condition was below the LRP adopted for tunas ($SB_{recent}/SB_{F=0}$ = 0.2). The median estimate (0.20) is below that estimated from the previous (2012) assessment ($SB_{2006\text{-}2009}/SB_{F=0}$ = 0.34) (see SC8-SA-WP-05), noting the differences in the use of the grid in the two assessments and different model assumptions. In the current assessment the feasible grid consisted of 300 models (186 model runs removed from 486 grid models) (Table 8).

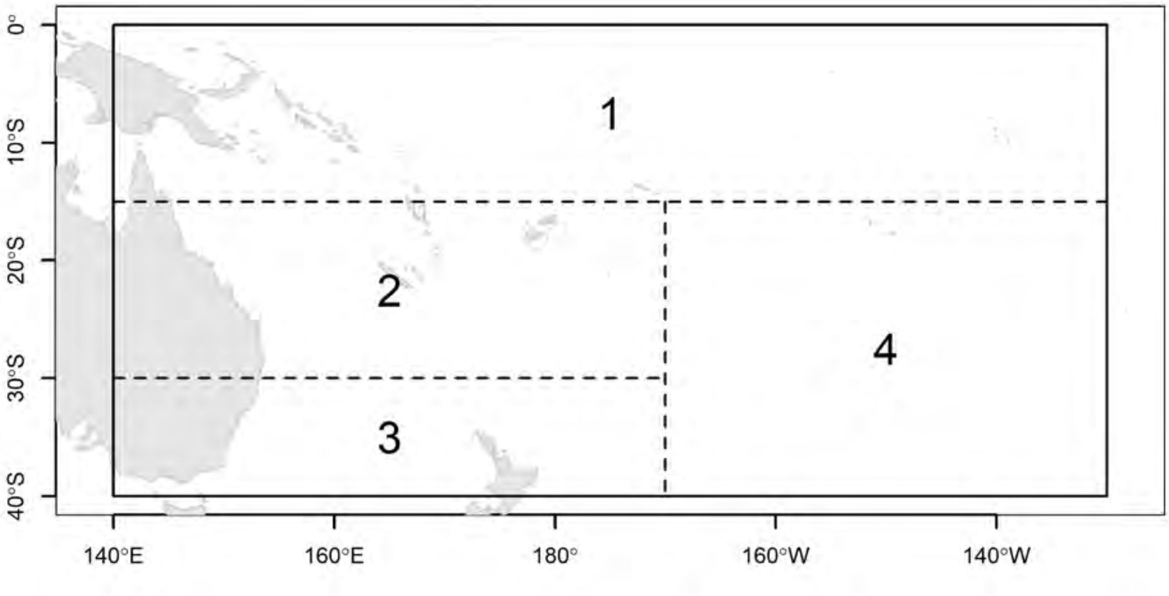


Figure 4. Single region spatial structure used in the 2019 stock assessment.

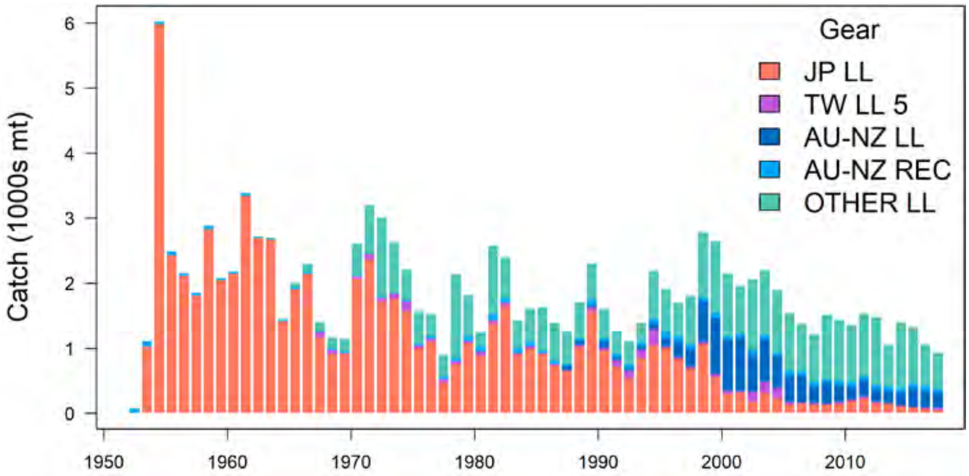


Figure 5. Time series of total annual catch (1000s mt) by fishery group over the full assessment period.

SC15 noted that the median of recent spawning biomass relative to the spawning biomass at MSY was (SB_{recent}/SB_{MSY}) = 0.74 with a probable range of 0.33 to 1.63 (80% probable range), and there was a roughly 68 % probability (206 out of 300 models) that the recent spawning biomass depletion was below the spawning biomass at MSY. The median estimate (0.74) is below that estimated from the previous (2012) assessment ($SB_{current}/SB_{MSY}$ = 0.87) (see SC8-SA-WP-05), noting the differences between the two assessments.

SC15 noted that the median of relative recent fishing mortality was (F_{recent}/F_{MSY} = 0.91) with an 80% probability interval of 0.31 to 1.89, and there was a roughly 44% probability (133 out of 300 models) that the recent fishing mortality was above F_{MSY}. The median estimate (0.91) is above that estimated from the previous assessment ($F_{current}/F_{MSY}$ = 0.81), noting the differences in the use of the grid in the two assessments.

Table 8. Summary reference points over the models in the structural uncertainty grid.

	Mean	Median	Min	10%	90%	Max
C_{latest}	1124	1130	1065	1077	1165	1197
YF_{recent}	1966	1920	235	1488	2655	3044
$fmult$	1.895	1.098	0.286	0.529	3.191	33.180
F_{MSY}	0.259	0.241	0.152	0.172	0.357	0.466
MSY	2672	2039	1742	1845	3535	23710
$F_{recent}/F_{\mathrm{MSY}}$	1.029	0.911	0.030	0.313	1.891	3.500
SB_0	16142	13195	7038	8944	22790	101400
$SB_{F=0}$	12205	10759	5450	7039	19060	44940
SB_{MSY}	3620	3032	960	1396	6109	20890
SB_{MSY}/SB_0	0.221	0.228	0.121	0.140	0.291	0.304
$SB_{MSY}/SB_{F=0}$	0.281	0.271	0.159	0.181	0.368	0.621
SB_{latest}/SB_0	0.209	0.196	0.051	0.100	0.342	0.499
$SB_{latest}/SB_{F=0}$	0.294	0.238	0.044	0.106	0.533	1.158
$SB_{latest}/SB_{\mathrm{MSY}}$	1.062	0.898	0.174	0.383	1.979	3.924
$SB_{recent}/SB_{F=0}$	0.247	0.198	0.038	0.093	0.464	0.977
$SB_{recent}/SB_{\mathrm{MSY}}$	0.895	0.737	0.152	0.334	1.635	3.312

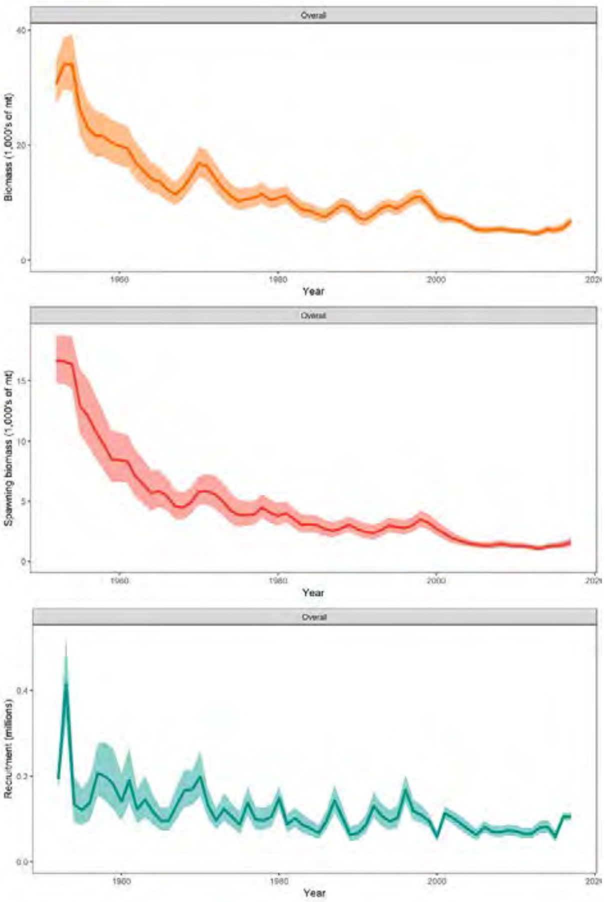


Figure 6. Estimated annual average total biomass, spawning biomass, and recruitment for the diagnostic model. Shaded region gives ± 2 standard deviations (i.e., 95% CI).

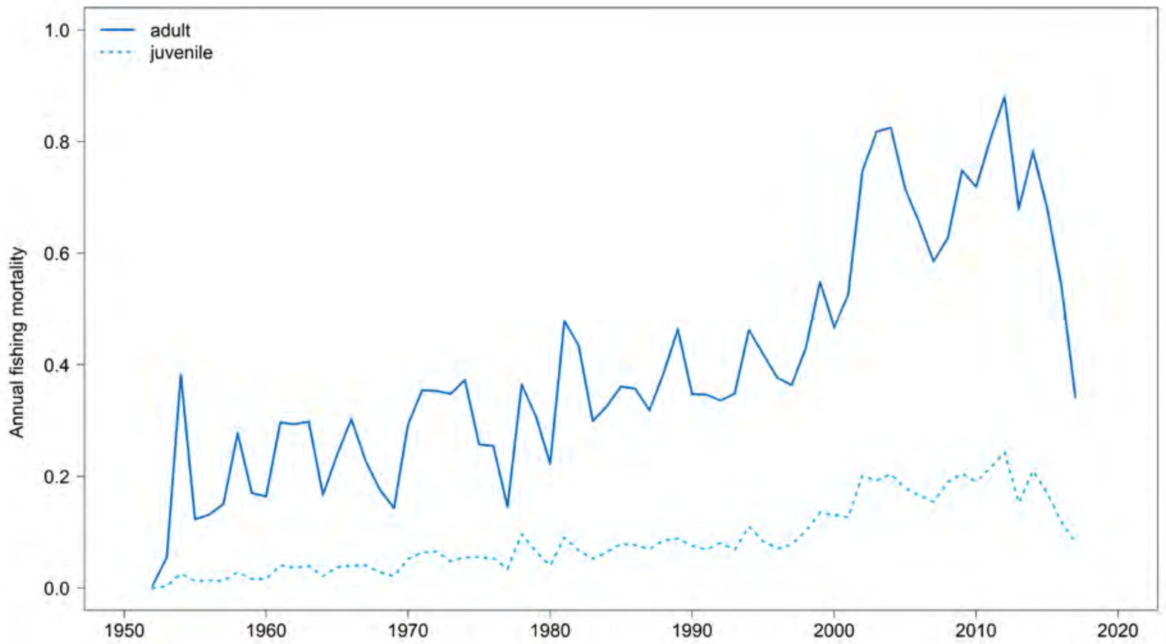


Figure 7. Estimated annual average juvenile and adult fishing mortality for the diagnostic model.

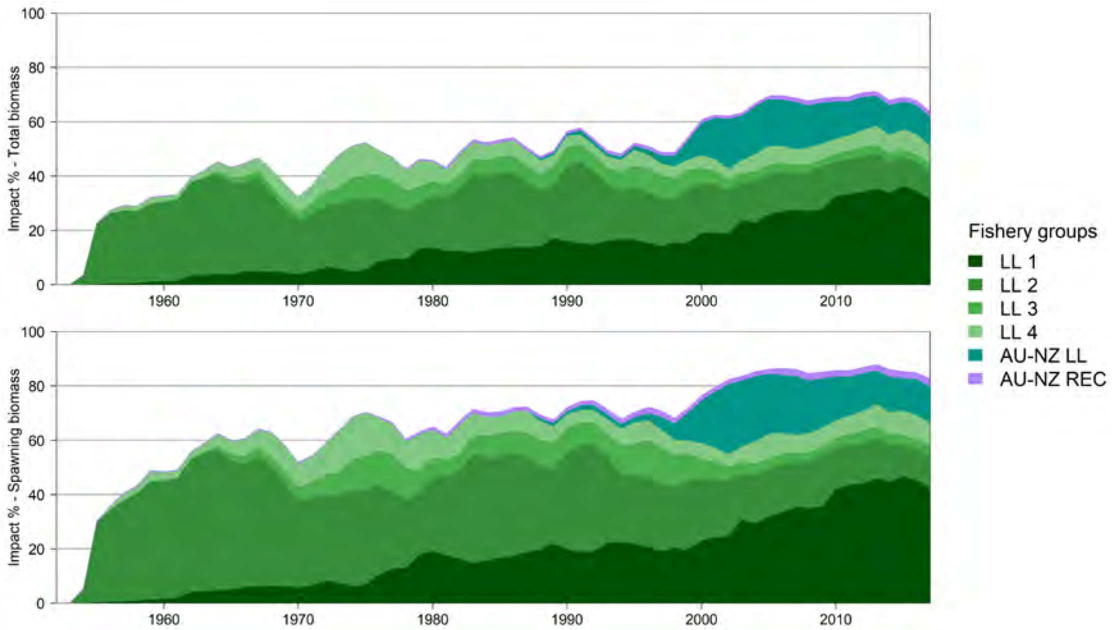


Figure 8. Estimates in reduction in spawning biomass and total biomass due to fishery impact for the diagnostic case model.

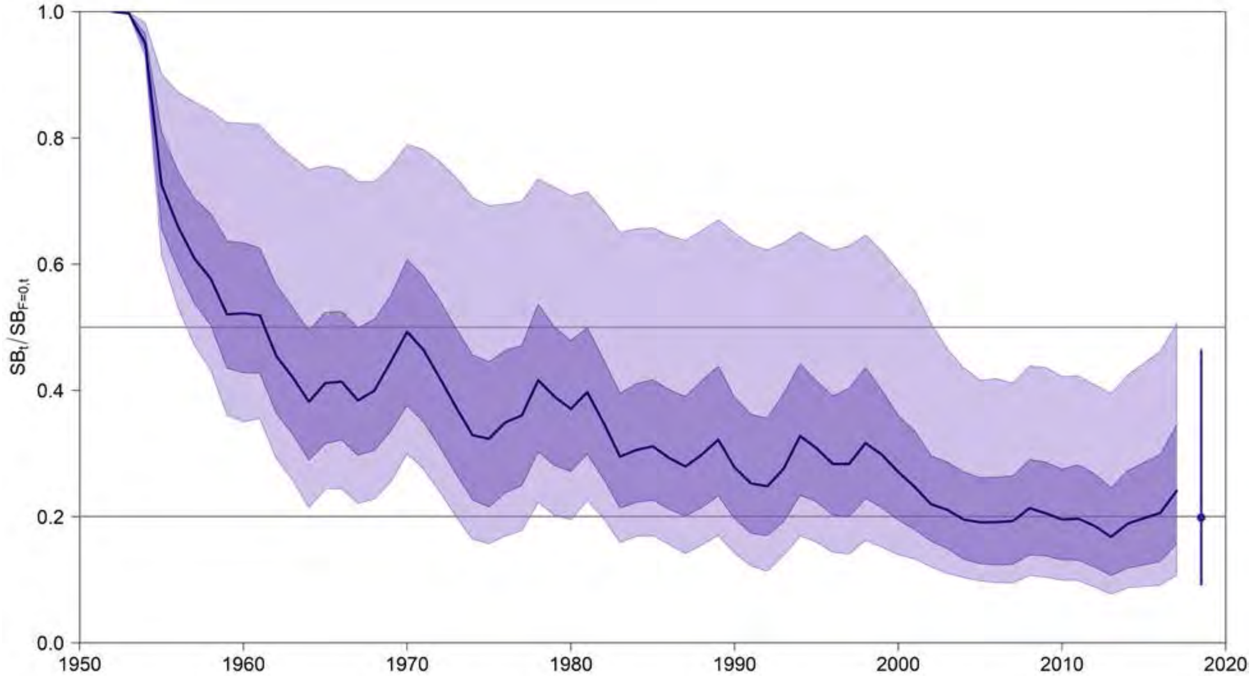


Figure 9: Plot showing the trajectories of spawning biomass depletion for the model runs included in the structural uncertainty grid described in Table 7. Gray horizontal lines indicate 50% and 20% levels of depletion. On the right of the depletion is the median point estimate of the recent level reference point with the bar indicating the 80th percentile.

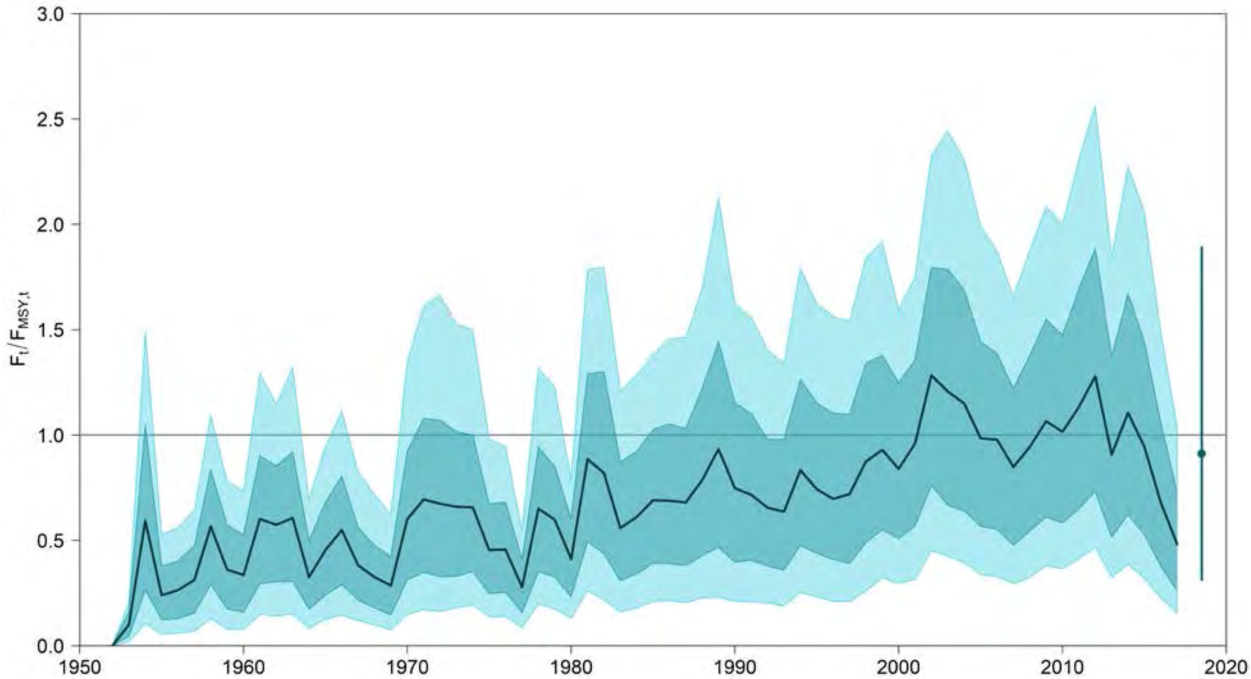


Figure 10. Plot showing the trajectories of fishing mortality for the model runs included in the structural uncertainty grid described in Table 7. Gray horizontal lines indicate F_{MSY}. On the right of the depletion is the median point estimate of the recent level reference point with the bar indicating the 80th percentile.

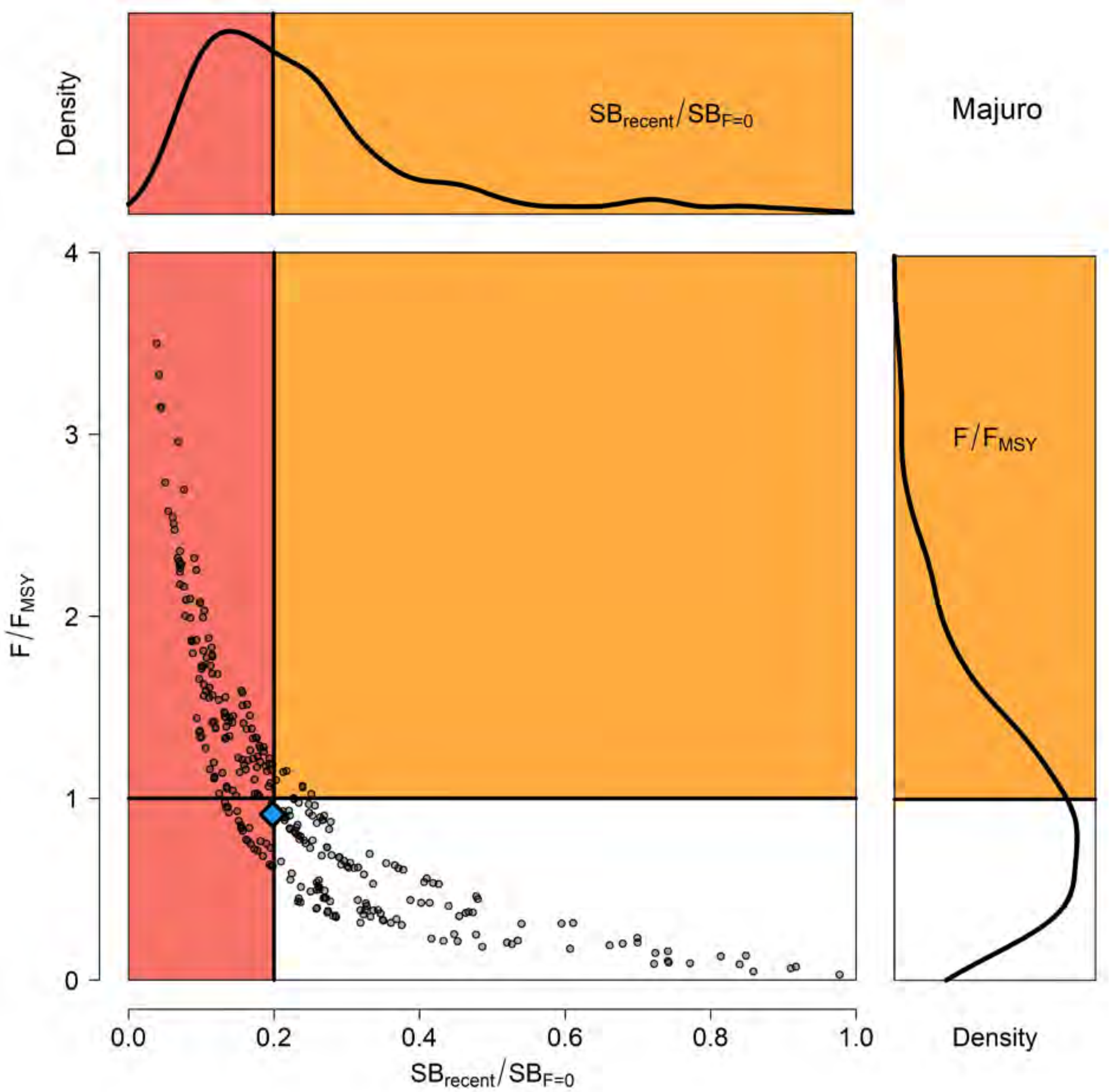


Figure 11. **Majuro plot for the recent spawning biomass (2014 – 2017) summarizing the results for each of the models in the structural uncertainty grid. The plots represent estimates of stock status in terms of spawning biomass depletion and fishing mortality, and marginal distributions of each are presented. The blue square is the median of the grid.**

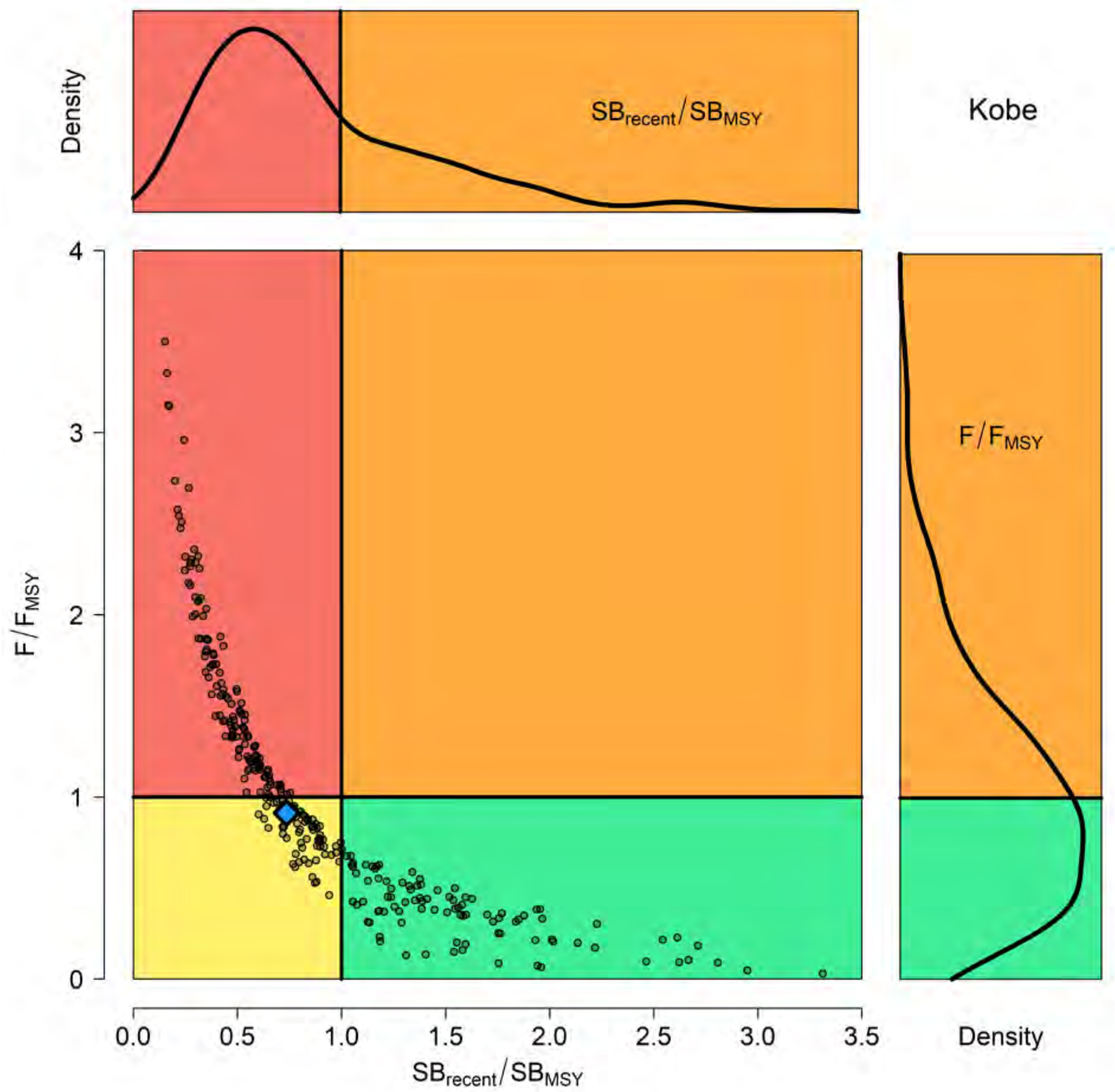


Figure 12. Kobe plot for the recent spawning biomass (2014 – 2017) summarizing the results for each of the models in the structural uncertainty grid. The plots represent estimates of stock status in terms of spawning biomass relative to the spawning biomass that produces MSY and fishing mortality, and marginal distributions of each are presented. The blue square is the median of the grid.

5.2 New Zealand recreational catch and effort

East Northland charter vessel CPUE standardisation

A general linear model (GLM) was used to standardise annual striped marlin CPUE from East Northland charter boats using the postal survey data and a matching subset of data from the Billfish Logbook Programme (Holdsworth et al. 2019). The core fleet was defined as those vessels that had fished for at least once in at least five years.

National billfish logbook CPUE standardisation

For the GLM the core fleet was defined as those vessels that had fished for at least 10 trips in each of at least 5 years (Holdsworth et al. 2019). This resulted in a core fleet size of 31 vessels which took 72% of the catch

Comparison of indices

The annual East Northland charter index showed an increasing trend in standardised CPUE following the introduction of the billfish moratorium in 1987 to the mid-1990s and then a decreasing trend back toward the long-term average (Figure 13). There have been several relatively poor years since 2013–14. A number of long term East Northland charter operators are leaving the industry and new entrants and more private vessels have been recruited to the logbook scheme. Over the time series since 1975 there has been a strong decline in the number of days fishing for marlin per season across the fleet of East Northland charter boats. The CPUE index based on daily billfish logbook data shows similar trends to the charter index over the last 11 years (Figure 13).

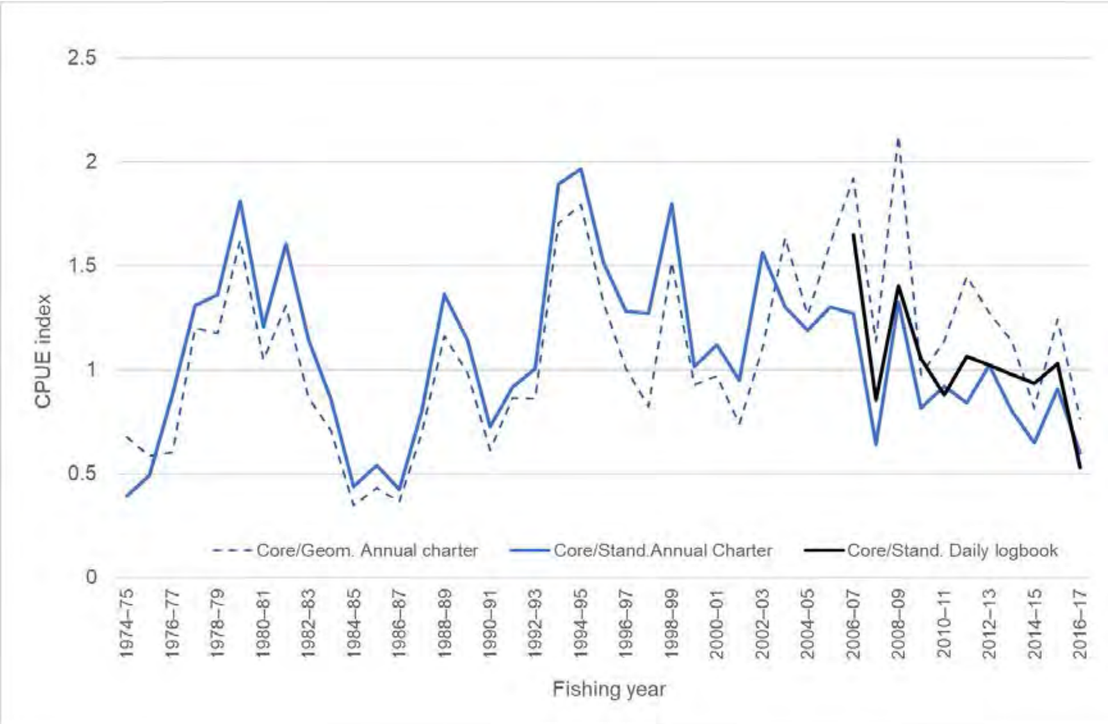


Figure 13. CPUE trends in New Zealand recreational catch and effort.

5.2 Biomass and yield estimates

No estimates of biomass or yield are available for New Zealand.

6. STATUS OF THE STOCK

The next stock assessment for south-western Pacific striped marlin is scheduled for 2023.

Stock structure assumptions

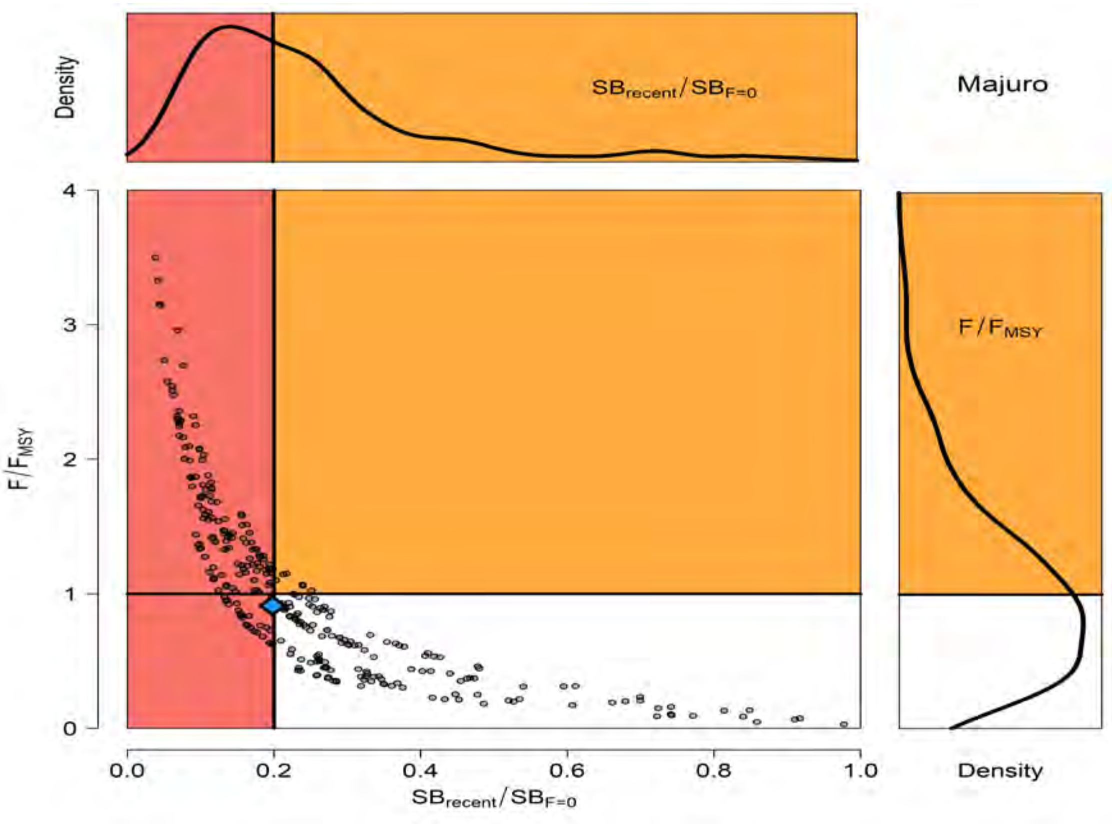
The stock structure of striped marlin in the Western and Central Pacific Ocean is not well understood. For this assessment a two-stock structure, with the stocks separated roughly at the Equator, albeit with some intermixing in the eastern Pacific, is assumed.

All biomass in this table refers to spawning biomass (SB).

Stock Status	
Year of Most Recent Assessment	2019
Assessment Runs Presented	Diagnostic case and structural uncertainty grid
Reference Points	Target: Not defined

	Soft Limit: Not established by WCPFC but evaluated using HSS default of 20% SB_0 Hard Limit: Not established by WCPFC but evaluated using HSS default of 10% SB_0 Overfishing threshold: F_{MSY}
Status in relation to Target	Unknown
Status in relation to Limits	Soft Limit: About as Likely as Not (40–60%) to be below Hard Limit: Unlikely (< 40%) to be below
Status in relation to Overfishing	Overfishing is About as Likely as Not (40–60%) to be occurring

Historical Stock Status Trajectory and Current Status



Temporal trend in annual stock status, relative to SB_{MSY} (x-axis) and F_{MSY} (y-axis) reference points for the Diagnostic case.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Stock biomass declined rapidly through the 1960s, but the stock decline was more gradual from 1970 through to about 2010, with a slight increase since.
Recent Trend in Fishing Intensity or Proxy	Overall fishing mortality showed a slow but steady increase until about 2010 followed by a sharp decline.
Other Abundance Indices	Recruitment showed a steep decline in the 1950's followed by a slow decline since
Trends in Other Relevant Indicator or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	The stock is likely to decline without management intervention
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unknown Hard Limit: Unknown
Probability of Current Catch or TACC causing Overfishing to continue or commence	About as Likely as Not (40–60%) with current catch

Assessment Methodology and Evaluation		
Assessment Type	Level 1: Fully Quantitative Stock Assessment	
Assessment Method	MULTIFAN-CL	
Assessment Dates	Latest assessment: 2019	Next assessment: 2023
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	a) Ten revised and new standardised CPUE time series (with temporal CVs) derived from: • aggregate catch-effort data for Japanese and Taiwanese longline fisheries • operational catch-effort data for the Australian longline fishery • operational catch-effort data for the Australian and New Zealand recreational fisheries b) Size composition data for the Australian recreational fishery.	1 – High Quality (all)
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	Catch estimated from the most recent years is uncertain as some catch has still not been reported. There are high levels of uncertainty regarding recruitment estimates and the resulting estimates of steepness.	

Qualifying Comments
None

Environmental and Ecosystem Considerations
Striped marlin is a non-target catch in the tuna and swordfish surface-longline fishery in the New Zealand EEZ, please refer to those species chapters for environmental and ecosystem considerations. Blue sharks are the most commonly landed non-target species (by number), followed by lancetfish and Ray’s bream in the New Zealand longline fishery.

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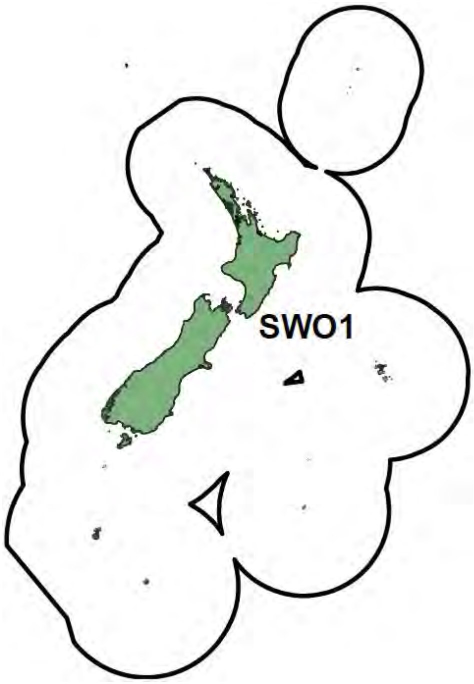
SWORDFISH (SWO)

(*Xiphias gladius*)



1. FISHERY SUMMARY

Swordfish were introduced into the QMS on 1 October 2004 under a single QMA, SWO 1, with allowances, TACC, and TAC in Table 1.

Table 1: Recreational and customary non-commercial allowances, TACC and TAC (all in t) for swordfish.

Fishstock	Recreational allowance	Customary non-commercial allowance	Other mortality	TACC	TAC
SWO 1	20	10	4	885	919

Swordfish were added to the Third Schedule of the 1996 Fisheries Act with a TAC set under s14 because swordfish is a highly migratory species and it is not possible to estimate MSY for the part of the stock that is found within New Zealand fisheries waters.

Swordfish were also added to the Sixth Schedule of the 1996 Fisheries Act with the provision that:

> 'A commercial fisher may return any swordfish to the waters from which it was taken from if –
> (a) that swordfish is likely to survive on return; and
> (b) the return takes place as soon as practicable after the swordfish is taken; and
> (c) that swordfish has a lower jaw to fork length of less than 1.25m.'

Management of swordfish throughout the western and central Pacific Ocean (WCPO) is the responsibility of the Western and Central Pacific Fisheries Commission (WCPFC). At its sixth annual meeting (2009) the WCPFC passed a Conservation and Management Measure (CMM) (this is a binding measure that all parties must abide by) relating to conservation and management of swordfish in the south-west Pacific Ocean (www.wcpfc.int/). This measure restricts the number of vessels fishing for swordfish and sets catch limits in the convention area south of 20°S.

1.1 Commercial fisheries

Annual swordfish catches throughout the Pacific have been increasing, with catches in the western and central Pacific increasing to 20 000 t in 2012 (Williams & Terawasi 2013). The swordfish catch from the south-west Pacific has averaged about 12% of the Pacific Ocean total in recent years. In New Zealand, swordfish are caught throughout the year in oceanic waters, primarily by pelagic longlines in areas where the bottom depth exceeds 1000 m.

Swordfish are either targeted or caught in the tuna longline fishery as a bycatch when targeting bigeye and to a lesser extent when targeting southern bluefin tuna. Swordfish can be caught in most FMAs and adjacent high seas areas although most catches are from waters north of 40ºS. Swordfish catch by domestic vessels increased rapidly from 1994–95 to peak at 1100 t in 2000–01. Since 2000–01, swordfish catches declined in each year coinciding with the decline in effort in the surface-longline fishery, until 2005–06 when they increased again (Table 2). This increase is attributed to the development of a target fishery, which was, in part, initiated by the arrival of several surface-longline vessels from Australia. Most of the catch is from FMAs 1, 2 and 9. Figure 1 shows historical landings and TACCs and longline effort for SWO stocks.

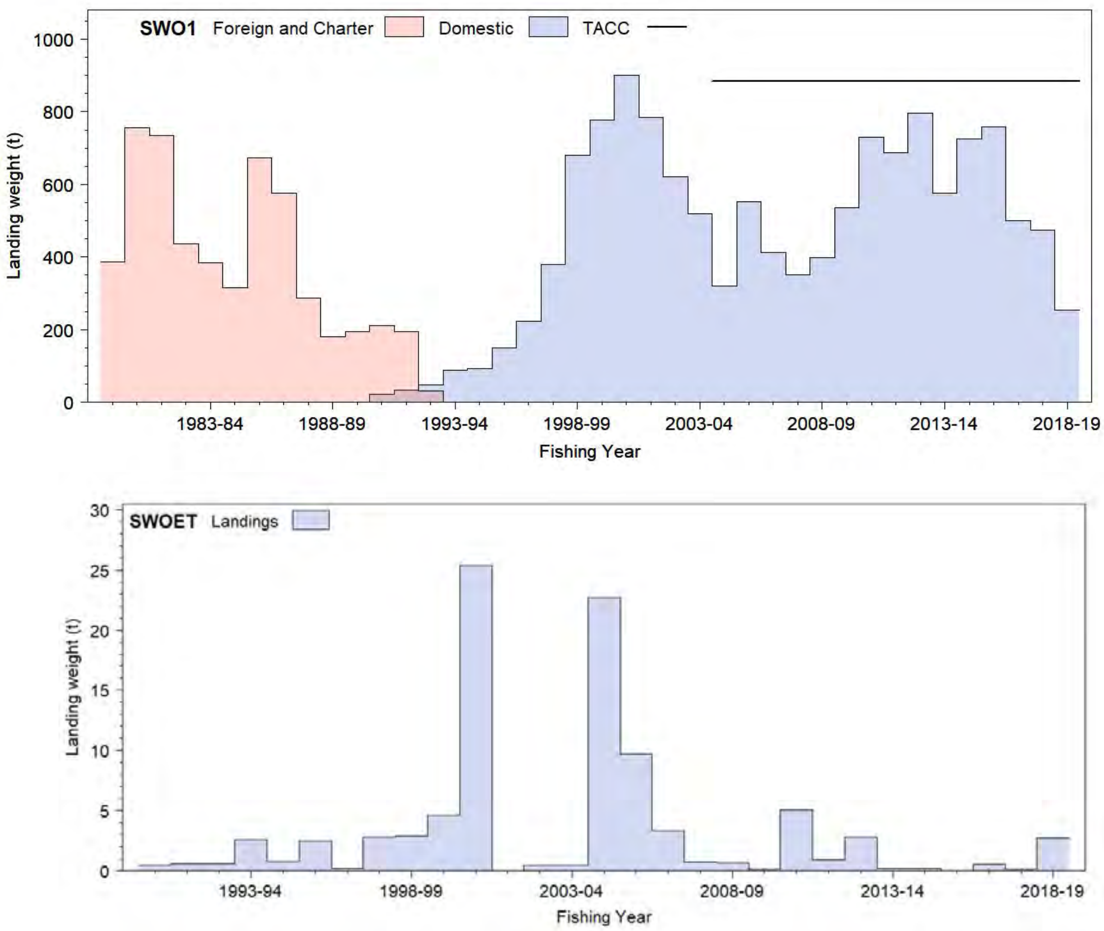


Figure 1: [Top] Swordfish catch by foreign licensed and New Zealand vessels from 1979–80 to 2018–19 in New Zealand fishery waters (SWO 1). [Bottom] Swordfish catch from 1990–91 to 2018–19 on the high seas (SWO ET).

Swordfish are processed at sea and the processed weight of the catch is converted to a greenweight using approved conversion factors. TLCER, CELR and LFRR data are provided for comparative purposes in Table 2 for the domestic fleet (New Zealand-owned and -operated vessels and chartered longline vessels).

Before the start of the domestic longline fishery in 1990–91, distant water longline fleets were granted foreign license access to fish for southern bluefin and bigeye tuna (Japan) and albacore (Korea). Swordfish catches for the Japanese fleet are given in Table 2 (Japan). The swordfish bycatch by the Japanese foreign licensed fishery averaged 388 t per year between 1979–80 and 1992–93 with a maximum catch of 761 t in 1980–81. Most of the Japanese swordfish catch (85%) was from FMAs 2 and 9. Korean catches were only small (0 to 7 t per year) and were mostly (79%) from FMAs 9 and 10.

In 2012–13, the majority of swordfish were caught in the bigeye target surface-longline fishery (62%) (Figure 2). In 2017–18, across all longline fisheries swordfish make up 15% of the catch by weight (Figure 3). Longline fishing effort is distributed along the east coast of the North Island and the south-west coast of the South Island. The west coast South Island fishery predominantly targets southern bluefin tuna, whereas the east coast of the North Island targets a range of species including bigeye, swordfish and southern bluefin tuna.

Table 2: Reported catches (t) of swordfish by fishing year (from TLCER and CELR data) for the New Zealand domestic and chartered vessel fleet 1990–91 to 2017–18 and Japanese foreign licensed fleet 1979–80 to 1992–93; annual totals from LFRR and MHR data from 2001–02 to present. [Continued on next page]

	SWO 1 (all FMAs)				
Year	**Japan**	**NZ/MHR**	**Total**	**LFRR**	**NZ ET**
1979–80	386		386		
1980–81	756.1		756.1		
1981–82	734.6		734.6		
1982–83	436.1		436.1		
1983–84	384.8		384.8		
1984–85	316.1		316.1		
1985–86	673.6		673.6		
1986–87	575.5		575.5		
1987–88	286.2		286.2		
1988–89	181.1		181.1		
1989–90	194.3		194.3		
1990–91	211.9	21.9	233.8	41	0.5
1991–92	194.5	33.5	228	32	0.6
1992–93	31.1	46.8	77.9	79	0.6
1993–94		88.2	88.2	102	2.6
1994–95		91.4	91.4	102	0.8
1995–96		148.6	148.6	187	2.5
1996–97		223.3	223.3	283	0.2
1997–98		379.7	379.7	534	2.8
1998–99		679.1	679.1	965	2.9
1999–00		778	778	976	4.6
2000–01		901.4	901.4	1 022	25.4
2001–02		945	783.9	958.8	
2002–03		673	622.0	670.1	0.5
2003–04		545	519.4	555.2	0.5
2004–05		344	320.7	344.7	22.7
2005–06		560.9	548.3	558.9	9.7
2006–07		412.7	412.7	425.8	3.3
2007–08		350.1	350.1	351.4	0.7
2008–09		398.7	398.7	393.9	0.6
2009–10		536.5	536.5	533.4	0.1
2010–11		729.6	729.6	739	5.1
2011–12		688.1	688.1	686.4	0.9
2012–13		796.8	796.8	788.4	2.8
2013–14		577.0	577.0	562.7	0.2
2014–15		726.2	730.3	716.1	0.2
2015–16		758.8	758.8	749.5	0.
2016–17		500.5	500.5		0.5
2017–18		475.0	475.0		0.1
2018–19		252.8	252.8		2.8

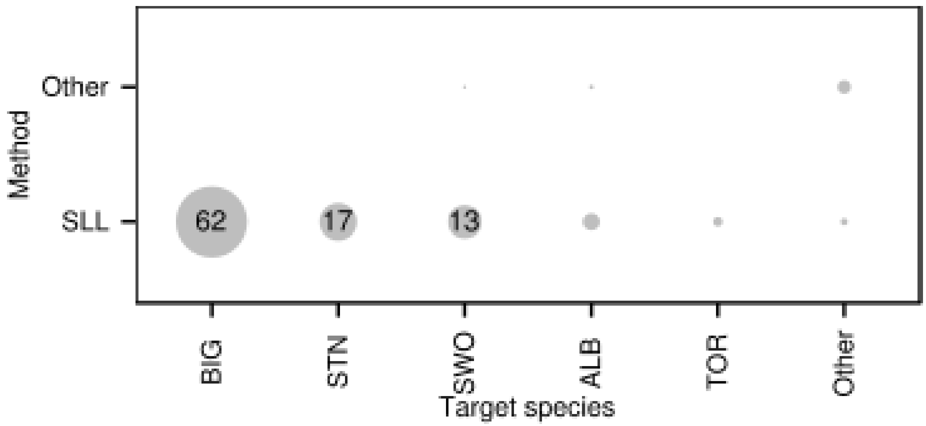


Figure 2: A summary of the proportion of landings of swordfish taken by each target fishery and fishing method for 2012–13. The area of each circle is proportional to the percentage of landings taken using each combination of fishing method and target species. The number in the circle is the percentage. SLL = surface longline (Bentley et al. 2013).

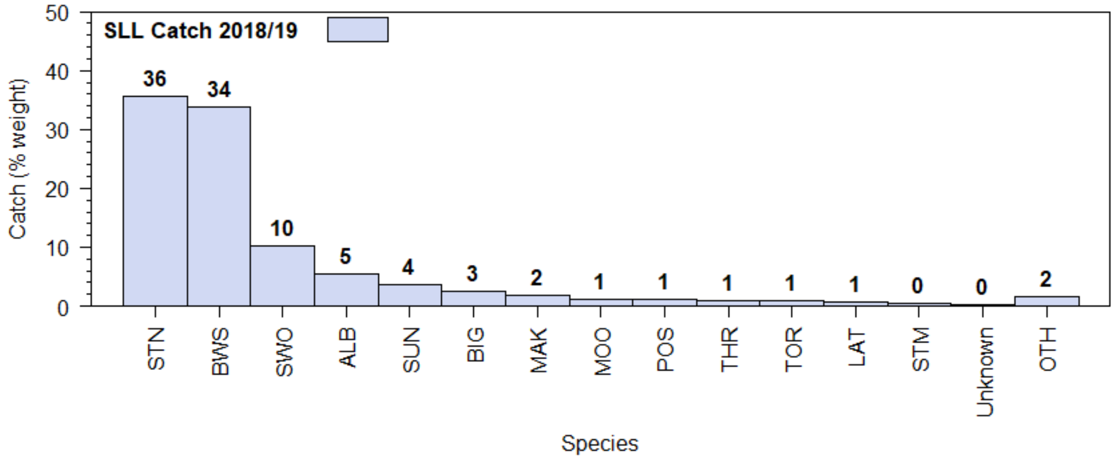


Figure 3: A summary of species composition of the surface-longline estimated catch for 2018–19. The percentage by weight of each species is calculated for all surface-longline trips.

Across all fleets in the longline fishery from 2006–-7 to 2014–15, 20–40% of the swordfish were alive when brought to the side of the vessel (Table 3). More than 90% of swordfish catches have been retained by all fleets (Table 4).

Table 3: Percentage of swordfish (including discards) that were alive or dead when arriving at the longline vessel and observed 2006–07 to 2014–15, by fishing year, fleet and region. Small sample sizes (number observed < 20) were omitted (Griggs & Baird 2013, Griggs et al. 2018). [Continued on next page]

Year	Fleet	Area	% alive	% dead	Number
2006–07	Australia	North	42.8	57.2	325
	Charter	North	58.9	41.1	90
		South	61.9	38.1	21
	Domestic	North	27.3	72.7	355
	Total		**38.2**	**61.8**	**791**
2007–08	Domestic	North	25.1	74.9	495
	Total		**25.3**	**74.7**	**498**
2008–09	Charter	North	97.0	3.0	33
	Domestic	North	26.0	74.0	416
	Total		**31.6**	**68.4**	**455**

Year	Fleet	Area	% alive	% dead	Number
2009–10	Domestic	North	23.2	76.8	448
	Total		**23.7**	**76.3**	**452**
2010–11	Domestic	North	23.1	76.9	904
	Total		**23.9**	**76.1**	**918**
2011–12	Charter	South	66.7	33.3	24
	Domestic	North	27.5	72.5	494
		South	27.8	72.2	90
	Total		**29.2**	**70.8**	**610**
2012–13	Charter	North	39.4	60.6	33
		South	63.9	36.1	36
	Domestic	North	27.4	72.6	223
	Total		**33.1**	**66.9**	**293**
2013–14	Charter	South	70.8	29.2	24
	Domestic	North	23.1	76.9	451
		South	34.5	65.5	139
		Total	**27.5**	**72.5**	**614**
2014–15	Charter	South	70.6	29.4	34
	Domestic	North	31.6	68.4	263
		South	26.0	74.0	96
		Total	**33.6**	**66.4**	**393**

Table 4: Percentage of swordfish that were retained, or discarded or lost, when observed on a longline vessel 2006–07 to 2014–15, by fishing year and fleet. Small sample sizes (number observed < 20) omitted (Griggs & Baird 2013, Griggs et al. 2018).

Year	Fleet	% retained	% discarded or lost	Number
2006–07	Australia	94.8	5.2	326
	Charter	99.1	0.9	115
	Domestic	93.2	6.8	355
	Total	**94.7**	**5.3**	**796**
2007–08	Charter	100.0	0.0	3
	Domestic	91.5	8.5	496
	Total	**91.6**	**8.4**	**499**
2008–09	Charter	100.0	0.0	43
	Domestic	97.1	2.9	418
	Total	**97.4**	**2.6**	**461**
2009–10	Charter	100.0	0.0	3
	Domestic	94.3	5.7	454
	Total	**94.3**	**5.7**	**457**
2010–11	Domestic	94.5	5.5	917
	Total	**94.6**	**5.4**	**932**
2011–12	Charter	100.0	0.0	29
	Domestic	96.8	3.2	590
	Total	**96.9**	**3.1**	**619**
2012–13	Charter	98.6	1.4	69
	Domestic	92.9	7.1	225
	Total	**94.2**	**5.8**	**294**
2013–14	Charter	96.4	3.6	28
	Domestic	95.8	4.2	590
	Total	**95.8**	**4.2**	**618**
2014–15	Charter	100.0	0.0	35
	Domestic	96.2	3.8	365
	Total	**96.5**	**3.5**	**400**

1.2 Recreational fisheries

Swordfish are targeted by recreational sport fishers with the annual recreational landed catch in fishing club records increasing since 2011 to 86 fish in 2016–17, then 72 in 2017–18. There is renewed recreational interest in swordfish using deep drifted baits during the day rather than drifting or slow trolling at night. There were 61 swordfish tagged and released by recreational fishers in 2017–18.

1.2.2 Estimates of recreational harvest

No estimates of recreational harvest of swordfish were generated from the telephone-diary surveys conducted in 1994, 1996 and 2000 because so few were reported. A National Panel Survey was conducted for the first time throughout the 2011–12 fishing year. The panel survey used face-to-face interviews of a random sample of 30 390 New Zealand households to recruit a panel of fishers and non-fishers for a full year (from Wynne-Jones et al. 2014). The panel members were contacted regularly about their fishing activities and harvest information collected in standardised phone interviews. The national panel survey was repeated during the 2017–18 fishing year using very similar methods to produce directly comparable results (Wynne-Jones et al. 2019). Note that national panel survey estimates do not include recreational harvest taken under s111 general approvals. The National Panel Survey results do not include estimates for swordfish as the surveys did not capture the fishers and fishing activity for the large gamefish species well.

1.3 Customary non-commercial fisheries

An estimate of the current customary catch is not available, but it is considered to be low.

1.4 Illegal catch

Prior to QMS introduction in 2004 it was illegal to target swordfish but analyses of CPUE data suggest targeting did occur. These catches were generally still reported (although as bycatch), so estimates of total annual catch were not affected.

1.5 Other sources of mortality

Swordfish have occasionally been observed as a bycatch in the skipjack tuna purse-seine fishery and in trawl fisheries for Jack mackerel and hoki.

2. BIOLOGY

Swordfish (*Xiphias gladius*) are an epi- and mesopelagic highly migratory species found in all tropical and temperate oceans and large seas. Based on longline catches, swordfish range from 50ºN to 45ºS in the western Pacific Ocean and from 45ºN to 35ºS in the eastern Pacific Ocean.

Growth rates have been estimated for Pacific Ocean swordfish caught off Taiwan. Estimates of growth rate indicate rapid growth, with fish reaching about 1 m in lower jaw to fork length during the first year. Growth rate slows progressively with age. Females grow significantly faster than males. Asymptotic length for males is 213 cm, while asymptotic length for females is about 300 cm. The maximum age observed in Taiwanese samples was 10 years for males and 12 years for females. The maximum size reported for a swordfish is 445 cm total length (includes the bill and furthest extension of the tail) and about 540 kg.

A number of studies of swordfish growth have been undertaken in Australia and New Zealand (Young & Drake 2004, Young et al. 2003, Young et al. 2008). The results are generally consistent within the two areas, with maximum ages of 18 and 15 years, respectively. It is likely that swordfish attain a maximum age of 20 years. Given the lack of observations of swordfish in New Zealand with ripe or running ripe gonad condition, age-at-maturity was defined on the basis of the Australian estimates of length-at-50% maturity for males and females of 101 and 221 cm, respectively. Using the growth curves estimated for New Zealand swordfish, this corresponds to ages-at-50% maturity for males and females of 1 and 10 years, respectively.

In the New Zealand EEZ swordfish size varies markedly with latitude, with larger swordfish (and hence fewer males) caught south of 40ºS. Average size of both males and females is larger in the southern region compared to the north: 228 and 158.4 cm for males, and 231.9 and 175 cm for females, respectively. Average length (lower jaw to fork length) of swordfish caught in the EEZ has been relatively stable since 1991, averaging 196.6 cm for the Japanese charter fleet and 163.9 cm for the domestic-owned and -operated fleet based on limited observer data. Overall the average size over all fleets since 1991 is 178.3 cm, however, this will be largely representative of the charter fleet. Males are substantially smaller than females with most males smaller than 189 cm (77%) and most females (51%) larger than 189 cm for all fleets. From 1987 to 2005 the average sex ratio of longline-caught swordfish in the EEZ was 1:3.15 (male:female).

A relationship between lower jaw–fork length and weight has been estimated for swordfish from observer records (n = 2 835):

$$\text{weight (kg)} = (3.8787 \times 10^{-6})\ \text{length}^{3.24}$$

Paper SC12-SA-WP-11, on determining swordfish growth and maturity relevant to the south-west Pacific stock was presented in 2016. The paper was the final report for a project cofunded by the WCPFC (Project 71). The aim of the study was to determine the degree to which differences in biological parameter estimates obtained in previous studies of swordfish in the south-west Pacific and Hawaiian regions were methodological or due to spatial variation in life history. After re-examining the sectioned anal fin spines (rays) and ovary histology from studies undertaken in Australia in the 2000s, it was found that methodological differences did exist between the previous Australian and Hawaiian studies. However, a direct comparison of age estimates from spines and otoliths found agreement up to age 7 years for females and age 4 years for males; after which otoliths tended to give much higher ages than those estimated from spines. It was noted that age estimates from otoliths were likely to be more reliable in older/larger swordfish. The otolith-based results indicate that swordfish live longer and grow slower than previously estimated. It was recommended that new growth and maturity parameters estimated from this study be included in future stock assessments for swordfish in the south-west Pacific, and that otolith-based estimates be prioritised. It was also recommend that otolith-based age estimation is investigated for other swordfish (and other billfish) stocks.

Spawning takes place in the tropical waters of the western Pacific Ocean and to a lesser extent the equatorial waters of the central Pacific Ocean. Swordfish are serial batch spawners, perhaps spawning as frequently as every few days over several months. Eggs are spawned in the upper layers of the tropical ocean and, like the protracted larval phase, are pelagic. Depending on fish size, swordfish egg production is estimated to range from 1 to 29 million eggs per year (for 68–272 kg females, respectively).

Little information on mortality rate is available, but M has been estimated elsewhere in the Pacific to be 0.22 yr^{-1}. This value is consistent with the maximum estimated ages for swordfish in Australia and New Zealand.

3. STOCKS AND AREAS

Swordfish found in the New Zealand EEZ are part of a much larger stock that spawns in the tropical central to western Pacific Ocean. They are highly migratory and their residence time in the EEZ and adjacent waters is unknown. In the Pacific Ocean, swordfish occur from 50ºN to 45ºS in the western Pacific Ocean and from 45ºN to 35ºS in the eastern Pacific Ocean. Swordfish are visual predators with a wide temperature tolerance. Extensive diel vertical migrations have been observed for swordfish in the Atlantic and Pacific Oceans from waters deeper than 600 m to the surface and across large temperature gradients (e.g., 8–27ºC) in a few hours. Swordfish are found at or near the surface at night. Within the EEZ most swordfish are caught in FMAs 1, 2, and 9 when sea surface temperatures are 17–19ºC.

Stock structure is uncertain and recent genetic studies have indicated that there may be multiple Pacific Ocean stocks. There is limited information on swordfish movement from conventional tagging studies. From a release sample of 443 swordfish tagged in the New Zealand EEZ as part of the New Zealand gamefish tagging programme, five have been recaptured. Two small fish were tagged by commercial fishers one 120 nautical miles north of New Zealand and the other 80 nautical miles north-east of East Cape. Both were recaptured after extended periods at liberty, 8 and 10 years, respectively, and had grown to sizes consistent with being sexually mature. Despite the long liberty period the recapture positions were not far (less than 130 nautical miles) from the release locations. In February 2012 a recreational angler recaptured a 130 kg swordfish he personally had tagged from the same boat and same location 8 months previously. Although the apparent net movement is limited, little can be inferred from this information in relation to swordfish stock structure or migration in, and around, New Zealand waters. In September 2013 a 170 cm tagged swordfish was recaptured by a tuna longline vessel in Tuvalu waters (Latitude 10ºS). This fish was tagged two and a half years earlier from a recreational vessel in an area north of the Three Kings Islands. A swordfish recaptured by a tuna longliner 190 nautical miles west of New Plymouth in 2016 had been tagged by a recreational fisher 4 years and 1 month earlier off east Northland.

From a release sample of 672 fish tagged in the Australian EEZ, eight recaptures have been reported. Although some fish tagged in east Australian waters have moved large distances (e.g., 893 nautical miles), none were recaptured outside of the Australian EEZ, or have crossed the Tasman Sea into the New Zealand EEZ. Nineteen pop-off satellite archival tags have been deployed on swordfish in New Zealand with the aim of tracking fish over the spring spawning period. The eight longer-term tracks (4 to 8 months) show fish moving into sub-tropical waters in spring and returning to the New Zealand EEZ or adjacent waters in summer. Data from satellite-tagged swordfish in New Zealand, Australia and the Cook Islands were used to describe the stock structure in the south-west Pacific region in the 2013 stock assessment model.

4. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS

The figures and tables in this section were updated and additional text included for the November 2019 Fishery Assessment Plenary following review of the text by the Aquatic Environment Working Group in 2016. This summary is from the perspective of the swordfish longline fishery; a more detailed summary from an issue-by-issue perspective is available in the Aquatic Environment and Biodiversity Annual Review where the consequences are also discussed (Ministry for Primary Industries 2019).

4.1 Role in the ecosystem

Swordfish (*Xiphias gladius*) are large pelagic predators, so they are likely to have a ‘top down’ effect on the squid, fish and crustaceans they feed on.

4.2 Incidental catch of seabirds, sea turtles and mammals

These capture estimates relate to the swordfish target longline fishery only, from the New Zealand EEZ. The capture estimates presented here include all animals recovered onto the deck (alive, injured or dead) of fishing vessels but do not include any cryptic mortality (e.g., seabirds caught on a hook but not brought onboard the vessel).

4.2.1 Seabird bycatch

Between 2002–03 and 2017–18, there were 99 observed captures of seabirds in swordfish longline fisheries. Seabird capture rates since 2003 are presented in Figure 4. Peaks in the observed capture rate were seen in 2006–07 and 2009–10. The seabird capture locations are predominantly within the northern area of New Zealand’s EEZ (see Table 5 and Figure 5). The high number of captures in 2007 (Figure 4) are anomalous and are the result of a new entrant vessel fishing in the EEZ with inappropriate mitigation gear, and this issue has since been resolved. Previously Bayesian models of varying complexity dependent on data quality were used (Richard & Abraham 2014); more recently a single model structure has been developed to provide a standard basis for estimating seabird captures across a range of fisheries (Abraham & Richard 2019). Observed and estimated seabird captures in swordfish longline fisheries are provided in Table 6.

Through the 1990s the minimum seabird mitigation requirement for surface-longline vessels was the use of a bird scaring device (tori line) but common practice was that vessels set surface longlines primarily at night. In 2007 a notice was implemented under s11 of the Fisheries Act 1996 to formalise the requirement that surface-longline vessels only set during the hours of darkness and use a tori line when setting. This notice was amended in 2008 to add the option of line weighting and tori line use if setting during the day. In 2011 the notices were combined and repromulgated under a new regulation (Regulation 58A of the Fisheries (Commercial Fishing) Regulations 2001), which provides a more flexible regulatory environment under which to set seabird mitigation requirements. Late in 2019 work was commissioned to assess the operational functionality of an underwater bait setter during production fishing. The aim of this work was to assess the device without the use of other existing mitigation measures in the New Zealand Surface Longline fleet.

Current results for the risk posed by commercial fishing to seabirds have been assessed via a level 2 method, supported under the NPOA-Seabirds 2013 risk assessment framework (Ministry for Primary Industries 2013). The method used in the level 2 risk assessment arose initially from an expert workshop hosted by the Ministry of Fisheries in 2008. The overall framework is described in Sharp et al. (2011) and has been variously applied and improved in multiple iterations (Waugh et al. 2009, Richard et al. 2011, Richard & Abraham 2013, Richard et al. 2013, Richard & Abraham 2015, Richard et al. 2017, Richard et al. 2019). The method applies an ‘exposure-effects’ approach where exposure refers to the number of fatalities and is calculated from the overlap of seabirds with fishing effort compared with observed captures to estimate the species vulnerability (capture rates per encounter) to each fishery group. This is then compared to the population’s productivity, based on population estimates and biological characteristics to yield estimates of population-level risk. The NPO-Seabirds 2013 was reviewed in 2019, with the updated version expected in 2020.

The 2019 iteration of the level 2 risk assessment included the significant modifications made to the methodology during 2016: in order to include the full uncertainty around population size the total population size was included instead of N_{min} in the PST calculation, the allometric survival rate and age at first reproduction was used for the calculation of R_{max}, a revised correction factor was applied as the previous was found to be biologically implausible, a constraint was applied on the fatalities calculated based on observed survival rates, live release survival was included, change in vulnerability over time was allowed where there was enough data, and there was a switch to assuming that the number of incidents is related to vulnerability. There were also changes made to the fisheries groups, seabird demographic data were updated and the Stewart Island shag group was split into Otago and Foveaux shags. The 2019 Assessment of the risk of commercial fisheries to New Zealand seabirds, 2006–07 to 2016–17 addressed discrepancies identified in the allocation of observer effort and fishing effort. In addition to this two additional years of data were included for the 2015–16 and 2016–17 fishing years. A derived risk ratio, which is an estimate of aggregate potential fatalities across trawl and longline fisheries relative to the Population Sustainability Threshold, PST (an analogue of the Potential Biological Removals, PBR, approach) (Richard et al. 2017) is used to rank species. A risk ratio above 1 indicates that PBR exceeds PST and the population is at risk of not obtaining management objectives.

The 2019 iteration of the seabird risk assessment (Richard et al. 2019) assessed the swordfish target fishery contribution to the total risk posed by New Zealand commercial fishing to seabirds (see Table 7). This target fishery contributed 0.192 of risk to the risk to Gibson’s albatross, which was assessed to be at high risk from New Zealand commercial fishing (63% of the total risk from commercial fishing included in the risk assessment). This fishery also contributed 0.090 of PST to Antipodean albatross, which was assessed to be at medium risk from New Zealand commercial fishing included in the risk assessment (Richard et al. 2019).

Table 5: Number of observed seabird captures in swordfish longline fisheries, 2002–03 to 2017–18, by taxon and area. The risk category is an estimate of aggregate potential fatalities across trawl and longline fisheries relative to the Population Sustainability Threshold, PST (an analogue of PBR approach) (Richard et al. 2019). The current version of the risk assessment does not include recovery factor. Data are available at https://data.dragonfly.co.nz/psc, and are from version 2019v1.

Taxon	Risk category	Bay of Plenty	East Coast North Island	Kermadec Islands	Northland and Hauraki	West coast North Island	West coast South Island	Total
Albatrosses	N/A			33				33
Antipodean albatross	Medium			12	3			15
Gibson's albatross	High			4	5		3	12
Antipodean and Gibson's albatrosses	N/A			5			1	5
New Zealand white-capped albatross	Medium					1	4	5
Campbell black-browed albatross	Low				2		1	3
Black-browed albatross	N/A			2				2
Wandering albatross					2			2
Southern Buller's albatross	High		1					1
Total albatrosses			**1**	**56**	**12**	**1**	**9**	**79**
Fulmars, petrels, prions and shearwaters	N/A			1				
White-chinned petrel	Low			2			5	
Black petrel	Very high	1			2	1		3
Grey-faced petrel	Negligible			1	1			
Grey petrel	Negligible			2				
Flesh-footed shearwater	High		1		1			2
Sooty shearwater	Negligible			1				
Westland petrel	High						1	
Total other seabirds		**1**	**1**	**7**	**4**	**1**	**6**	**20**

Table 6: Effort, observed and estimated seabird captures by fishing year for the swordfish fishery within the EEZ. For each fishing year, the table gives the total number of hooks; the number of observed hooks; observer coverage (the percentage of hooks that were observed); the number of observed captures (both dead and alive); the capture rate (captures per thousand hooks); and the mean number of estimated total captures (with 95% confidence interval). Estimates are based on methods described in Abraham & Richard (2019) and are available via https://data.dragonfly.co.nz/psc. Estimates from 2002–03 to 2017–18 version 2019v1.

Fishing year	Fishing effort			Observed captures		Estimated captures	
	All hooks	Observed hooks	% observed	Number	Rate	Mean	95% c.i.
2002–03	2400	0	0.0	0		1	0–6
2003–04	0	0		0			-
2004–05	132 503	11 553	8.7	2	0.17	36	19–58
2005–06	228 305	4 800	2.1	2	0.42	64	37–103
2006–07	210 175	40 174	19.1	71	1.77	133	103–175
2007–08	125 330	21 630	17.3	1	0.05	28	13–49
2008–09	41 700	3 990	9.6	0	0.00	9	2–19
2009–10	137 840	500	0.4	3	6.00	43	24–69
2010–11	177 248	18 638	10.5	0	0.00	41	22–69
2011–12	195 400	43 450	22.2	7	0.16	42	25–67
2012–13	316 390	8 250	2.6	1	0.12	87	50–137
2013–14	192 963	4 850	2.5	0	0.00	57	32–93
2014–15	447 962	17 650	3.9	6	0.34	136	86–206
2015–16	447 220	24 230	5.4	3	0.12	141	84–224
2016–17	324 040	26 340	8.1	0	0.00	95	57–149
2017–18	390 220	29 260	7.5	3	0.10	129	79–198

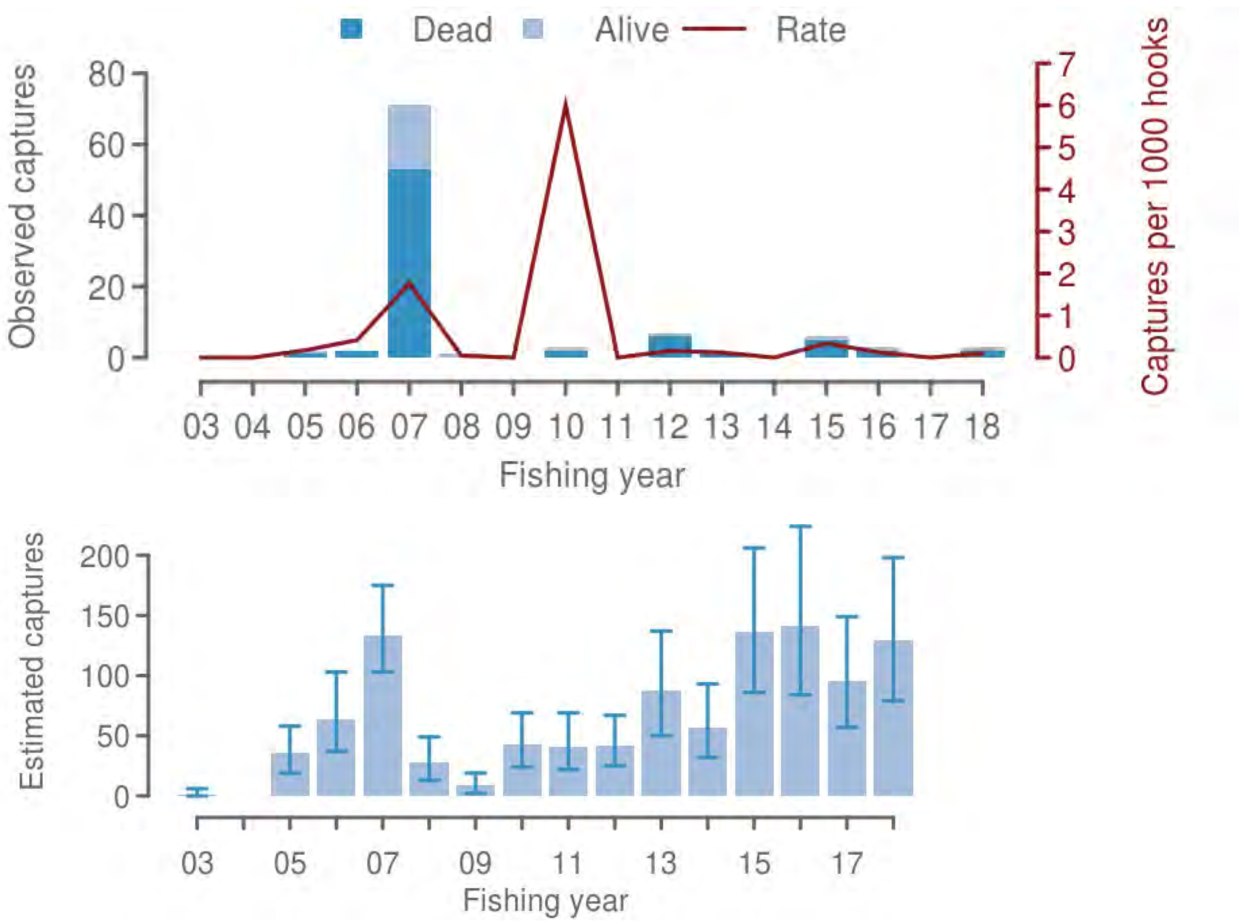


Figure 4: Observed captures and estimated captures of seabirds in swordfish longline fisheries from 2002–03 to 2017–18. Data grooming and estimates are based on methods described in Abraham & Berkenbusch (2019) and are available via https://data.dragonfly.co.nz/psc. Estimates from 2002–03 to 2017–18 are based on data version 2019v1.

Table 7: Risk ratio of seabirds predicted by the Level 2 risk assessment for the swordfish target surface-longline fisheries and all fisheries included in the Level 2 risk assessment, 2006–07 to 2016–17, with a risk posed by the SWO target SLL fishery. The risk ratio is an estimate of aggregate potential fatalities across trawl and longline fisheries relative to the Population Sustainability Threshold, PST (an analogue of PBR approach) (from Richard et al. 2019, where full details of the risk assessment approach can be found). Other data, version 2019v1. The current version of the risk assessment does not include a recovery factor. The New Zealand threat classifications are shown (Robertson et al. 2017).

	Risk ratio				
Species name	**SWO target SLL**	**Total risk from NZ commercial fishing**	**% of total risk from NZ commercial fishing**	**Risk category**	**NZ Threat Classification**
Gibson's albatross	0.192	0.307	63%	High	Threatened: Nationally Critical
Antipodean albatross	0.090	0.168	53%	Medium	Threatened: Nationally Critical
Black petrel	0.037	1.235	3%	Very high	Threatened: Nationally Vulnerable
Westland petrel	0.010	0.538	2%	High	At Risk: Naturally Uncommon
Flesh-footed shearwater	0.004	0.488	1%	High	Threatened: Nationally Vulnerable
Campbell black-browed albatross	0.002	0.058	3%	Low	Threatened: Nationally Vulnerable
Grey petrel	0.002	0.026	8%	Negligible	At Risk: Naturally Uncommon
New Zealand white-capped albatross	0.001	0.294	0%	Medium	At Risk: Declining
Northern Buller's albatross	0.001	0.263	0%	Medium	At Risk: Naturally Uncommon
White-chinned petrel	0.001	0.068	1%	Low	Not Threatened

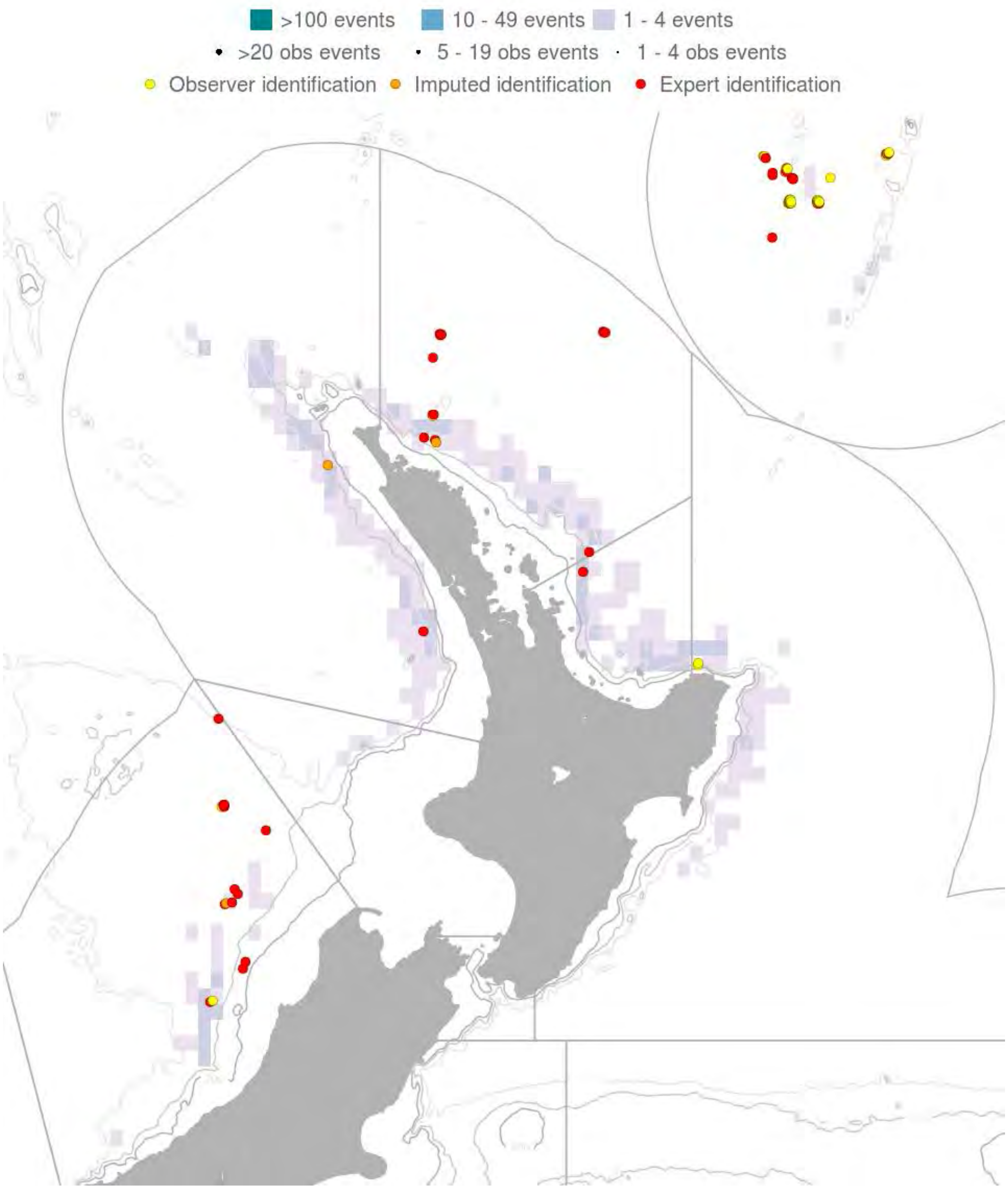


Figure 5: Distribution of fishing effort targeting swordfish and observed seabird captures, 2002–03 to 2017–18. Fishing effort is mapped into 0.2-degree cells, with the colour of each cell being related to the amount of effort. Observed fishing events are indicated by black dots, and observed captures are indicated by red dots. Fishing is only shown if the effort could be assigned a latitude and longitude, and if there were three or more vessels fishing within a cell. Data grooming methods are described in Abraham & Berkenbusch (2019) and are available via https://data.dragonfly.co.nz/psc. Estimates from 2002–03 to 2017–18 are based on data version 2019v1.

4.2.2 Sea turtle bycatch

Between 2002–03 and 2017–18, there were seven observed captures of sea turtles in swordfish longline fisheries (Table 8 and Figure 6). Observer recordings documented all sea turtles as captured and released alive. Sea turtle captures for this fishery have been observed in the Kermadec Islands, Northland and Hauraki, and West Coast South Island fishing areas (Table 8 and Figure 7). Fishing effort and sea turtle captures in swordfish longline fisheries between 2002–03 and 2017–18 are shown in Table 9.

Table 8: Number of observed sea turtle captures in swordfish longline fisheries, 2002–03 to 2017–18, by species and area. Data grooming methods are described in Abraham & Berkenbusch (2019) and are available via https://data.dragonfly.co.nz/psc. Data version 2019v1.

Species	East Coast North Island	Kermadec Islands	Northland and Hauraki	West Coast North Island	Total
Leatherback turtle	1	2	2	2	7

Table 9: Fishing effort and sea turtle captures in swordfish longline fisheries by fishing year. For each fishing year, the table gives the total number of hooks; the number of observed hooks; observer coverage (the percentage of hooks that were observed); the number of observed captures (both dead and alive); and the capture rate (captures per thousand hooks). Estimates are based on methods described in Abraham & Richard (2019) and are available via https://data.dragonfly.co.nz/psc. Estimates from 2002–03 to 2017–18 are based on data version 2019v1.

		Fishing effort		Observed captures	
Fishing year	All hooks	Observed hooks	% observed	Number	Rate
2002–03	2 400	0	0.0	0	N/A
2003–04	0	0		0	N/A
2004–05	132 503	11 553	8.7	0	0.000
2005–06	228 305	4 800	2.1	0	0.000
2006–07	210 175	40 174	19.1	1	0.025
2007–08	125 330	21 630	17.3	1	0.046
2008–09	41 700	3 990	9.6	0	0.000
2009–10	137 840	500	0.4	0	0.000
2010–11	177 248	18 638	10.5	0	0.000
2011–12	195 400	43 450	22.2	0	0.000
2012–13	316 390	8 250	2.6	0	0.000
2013–14	192 963	4 850	2.5	0	0.000
2014–15	447 962	17 650	3.9	0	0.000
2015–16	447 220	24 230	5.4	2	0.083
2016–17	324 040	26 340	8.1	2	0.076
2017–18	390 220	29 260	7.5	1	0.034

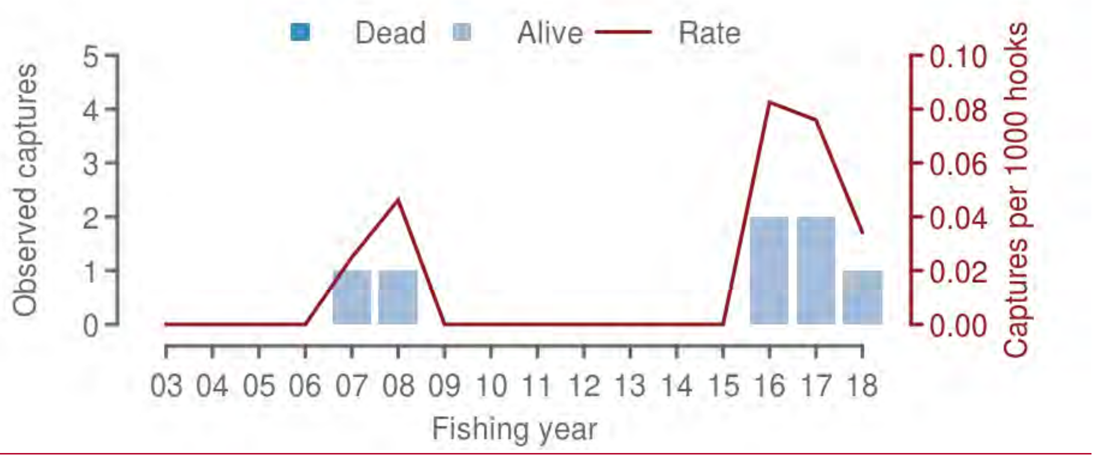


Figure 6: Observed captures of sea turtles in swordfish longline fisheries from 2002–03 to 2017–18. Data preparation methods are described in Abraham & Berkenbusch (2019) and are available via https://data.dragonfly.co.nz/psc. Estimates from 2002–03 to 2017–18 are based on data version 2019v1.

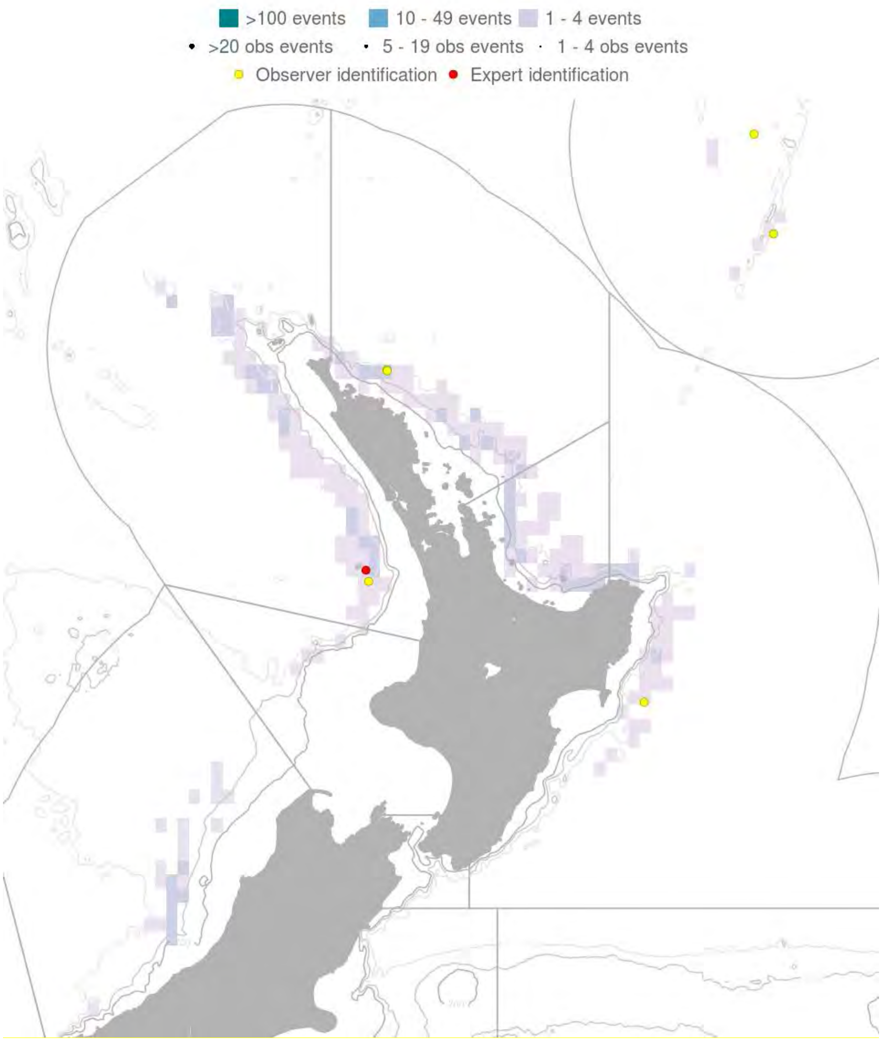


Figure 7: Distribution of fishing effort targeting swordfish and observed sea turtle captures, 2002–03 to 2017–18. Fishing effort is mapped into 0.2-degree cells, with the colour of each cell being related to the amount of effort. Observed fishing events are indicated by black dots, and observed captures are indicated by red dots. Fishing is only shown if the effort could be assigned a latitude and longitude, and if there were three or more vessels fishing within a cell. Estimates are based on methods described in Abraham & Richard (2019) are available via https://data.dragonfly.co.nz/psc. Estimates from 2002–03 to 2017–18 are based on data version 2019v1.

4.2.3 Incidental catch of marine mammals

4.2.3.1 Cetaceans

Between 2002–03 and 2017–18, there was one observed capture of a beaked whale in swordfish longline fisheries, off the West Coast of the South Island in 2016–17.

4.2.3.2 New Zealand fur seals

Currently, New Zealand fur seals are dispersed throughout New Zealand waters, but are more common in waters south of about 40ºS to Macquarie Island. The spatial and temporal overlap of commercial fishing grounds and New Zealand fur seal foraging areas has resulted in New Zealand fur seal captures in fishing gear (Mattlin 1987, Rowe 2009). Most fisheries with observed captures occur in waters over or close to the continental shelf, which slopes steeply to deeper waters relatively close to shore, and thus rookeries and haulouts, around much of the South Island and offshore islands. Captures on longlines occur when the fur seals attempt to feed on the bait and fish catch during hauling. Most New Zealand fur seals are released alive, typically with a hook and short snood or trace still attached.

Between 2002–03 and 2017–18, there were three observed captures of New Zealand fur seals in swordfish longline fisheries (Table 10 and 11, Figures 8, 9 and 10). These captures include animals that are released alive (Thompson et al. 2013).

Table 10: Number of observed New Zealand fur seal captures in swordfish longline fisheries, 2002–03 to 2017–18, by species and area. Data from Abraham & Berkenbusch (2019), retrieved from http://data.dragonfly.co.nz/psc.

	Bay of Plenty	East coast North Island	West Couth North Island	Total
New Zealand fur seal	1	1	1	3

Table 11: Effort and captures of New Zealand fur seals in swordfish longline fisheries by fishing year. For each fishing year, the table gives the total number of hooks; the number of observed hooks; observer coverage (the percentage of hooks that were observed); the number of observed captures (both dead and alive); and the capture rate (captures per thousand hooks). Estimates are based on methods described in Abraham & Richard (2019) are available via https://data.dragonfly.co.nz/psc. Estimates from 2002–03 to 2015–16 are based on data version 2019v1.

		Fishing effort		Observed captures		Estimated captures	
Fishing year	All hooks	Observed hooks	% observed	Number	Rate	Mean	95% c.i.
2002–03	2 400	0	0.0	0	NA	0	0–0
2003–04	0	0		0	NA		
2004–05	132 503	11 553	8.7	2	0.173	2	2–4
2005–06	228 305	4 800	2.1	0	0.000	0	0–2
2006–07	210 175	40 174	19.1	0	0.000	0	0–1
2007–08	125 330	21 630	17.3	0	0.000	0	0–1
2008–09	41 700	3 990	9.6	0	0.000	0	0–1
2009–10	137 840	500	0.4	0	0.000	0	0–2
2010–11	177 248	18 638	10.5	0	0.000	0	0–2
2011–12	195 400	43 450	22.2	0	0.000	1	0–3
2012–13	316 390	8 250	2.6	0	0.000	1	0–4
2013–14	192 963	4 850	2.5	0	0.000	1	0–4
2014–15	447 962	17 650	3.9	0	0.000	2	0–7
2015–16	447 220	24 230	5.4	0	0.000	0	0–2
2016–17	324 040	26 340	8.1	1	0.038		
2017–18	390 220	29 260	7.5	0	0.000		

Figure 8: Observed captures of New Zealand fur seals in swordfish longline fisheries from 2002–03 to 2017–18. Estimates are based on methods described in Abraham & Richard (2019), and are available via https://data.dragonfly.co.nz/psc. Estimates from 2002–03 to 2017–18 are based on data version 2019v1.

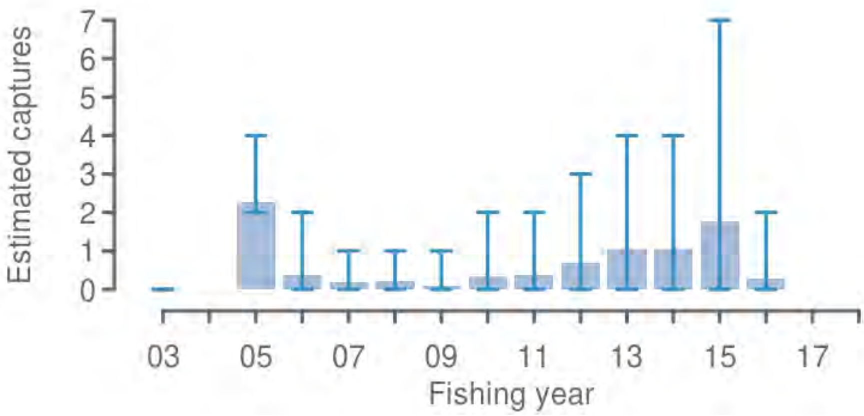


Figure 9: Estimated captures of New Zealand fur seals in swordfish longline fisheries from 2002–03 to 2015–16. Estimates are based on methods described in Abraham & Richard (2019), and are available via https://data.dragonfly.co.nz/psc. Estimates from 2002–03 to 2015–16 are based on data version 2019v1.

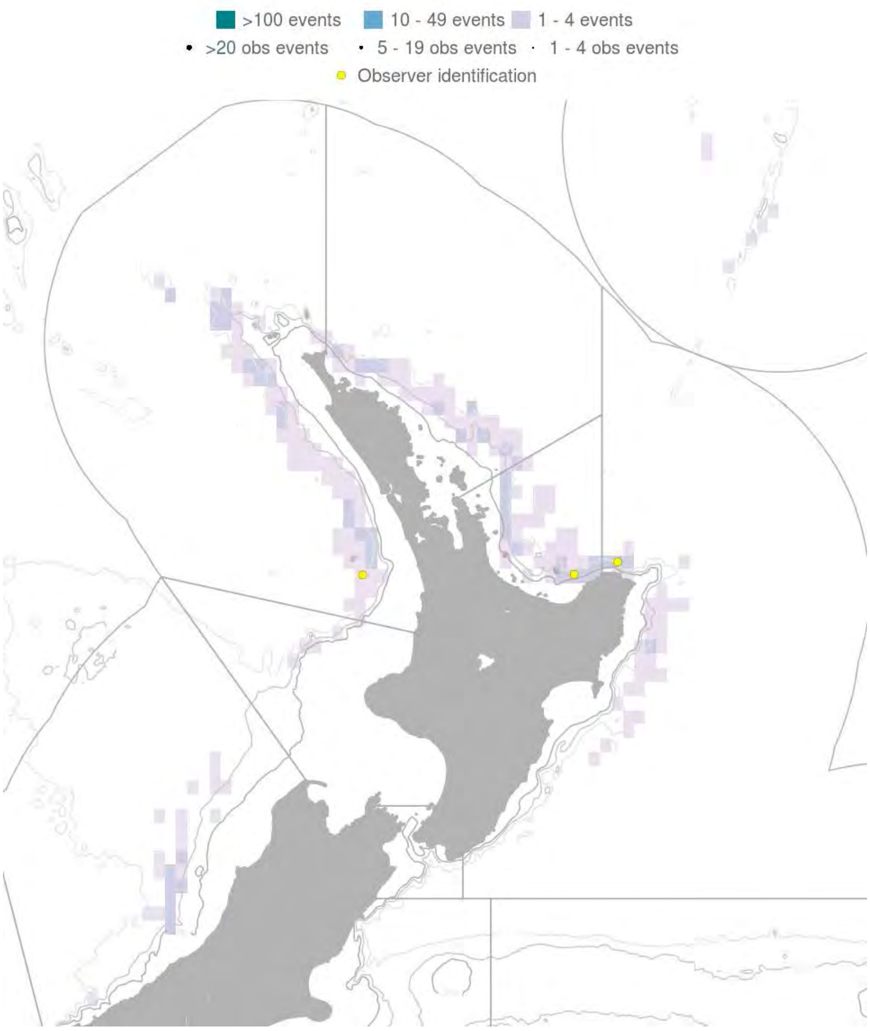


Figure 10: Distribution of fishing effort targeting swordfish and observed New Zealand fur seal captures, 2002–03 to 2017–18. Fishing effort is mapped into 0.2-degree cells, with the colour of each cell being related to the amount of effort. Observed fishing events are indicated by black dots, and observed captures are indicated by red dots. Fishing is only shown if the effort could be assigned a latitude and longitude, and if there were three or more vessels fishing within a cell. Estimates are based on methods described in Abraham & Richard (2019), and are available via https://data.dragonfly.co.nz/psc. Based on data version 2019v1.

4.3 Non-target fish catch

Observer records indicate that a wide range of species are landed by the longline fleets in New Zealand fishery waters. Blue sharks are the most commonly landed species (by number), followed by lancetfish and Ray's bream (Table 12).

Table 12: Total estimated catch (numbers of fish) of common bycatch species in the New Zealand longline fishery as estimated from observer data from 2015 to 2018. Also provided is the percentage of these species retained (2018 data only) and the percentage of fish that were alive when discarded, N/A (none discarded).

Species	2015	2016	2017	2018	% retained (2018)	discards % alive (2018)
Blue shark	72 480	57 210	49 924	63 618	0.0	88.7
Lancetfish	12 962	17 442	13 274	13 163	0.0	33.5
Porbeagle shark	4 058	6 566	3 101	2 594	1.0	51.1
Rays bream	17 555	7 758	2 421	1 579	99.0	26.7
Moonfish	3 060	3 036	2 022	2 698	98.0	50.0
Pelagic stingray	979	1 414	1 798	2 949	0.0	100.0
Sunfish	770	4 849	1 648	3 648	0.0	99.8
Mako shark	2 667	4 417	1 391	2 721	4.0	65.6
Rudderfish	373	237	680	253	45.0	89.4
Butterfly tuna	1 309	768	406	419	86.0	20.7
Escolar	653	669	300	594	67.0	67.9
Striped marlin	120	550	290	247	0.0	66.7
Thresher shark	177	601	260	253	0.0	76.0
Oilfish	584	281	227	602	42.0	85.4
Dealfish	842	63	72	25	0.0	31.8
School shark	88	24	59	187	84.0	100.0
Skipjack tuna	150	185	57	184	86.0	100.0
Deepwater dogfish	545	0	32	6	0.0	83.3
Big scale pomfret	59	16	17	34	100.0	n/a

4.4 Benthic interactions

There are no known interactions with benthic habitats in this fishery

4.5 Key environmental and ecosystem information gaps

Cryptic mortality is unknown at present but developing a better understanding of this in future may be useful for reducing uncertainty in the seabird risk assessment and could be a useful input into risk assessments for other species groups.

The survival rates of released target and bycatch species is currently unknown.

Observer coverage in the New Zealand fleet is not spatially and temporally representative of the fishing effort.

5. STOCK ASSESSMENT

With the establishment of WCPFC in 2004, stock assessments of the western and central Pacific Ocean stock of swordfish are reviewed by the WCPFC. Unlike the major tuna stocks, in the short term, development of a regional assessment for swordfish is to be undertaken by collaboration among interested members.

The paper SC13-SA-WP-13 *Stock assessment of swordfish (*Xiphias gladius*) in the southwest Pacific Ocean* presented the 2017 stock assessment of swordfish covering the southern hemisphere component of the Western and Central Pacific Fisheries Commission Convention Area (WCPFC-CA). The time period had been extended to the end of 2015, adding an additional four years of data since the previous stock assessment was conducted in 2013. A new growth curve presented at SC12 was used for this assessment, reducing the number of axes included in the uncertainty grid. The grid contained a wide range of models with some variation in estimates of stock status, trends in abundance and reference points. Biomass was estimated to have declined throughout the model period for all models in the grid, but the decline was particularly steep in the last 15 years. Those declines were found in both model regions, but were particularly notable in Region 2 (the eastern region). Fishing mortality rates for juvenile (ages 1–3), maturing (ages 4–6) and adult (ages 7+) swordfish were estimated to have increased since the 1950s. Fishing mortality rates increased notably from the mid-1990s in both model regions, on maturing aged fish in particular (seen in the diagnostic case model), to levels approximately four times that of juveniles and adults.

The stock assessment was based on a structural uncertainty grid comprising 72 models, each of which was considered to be a plausible representation of South Pacific swordfish (SWO) stock dynamics. The four structural uncertainties represented in the grid were: three stock-recruitment steepnesses, two weightings of the size data, three weightings of the diffusion rate and four natural mortalities. Each individual model consisted of a unique combination of settings from the uncertainty axes. As a result, the uncertainty grid comprised 72 related but different models, each of which made a distinct claim about the dynamics of the SWO fishery system to best explain and predict stock status. A major uncertainty related to growth and maturity noted in the previous assessment has now been resolved due to the results of new research that was presented to and endorsed by SC12 (WCPFC-SC12-2016/SA-WP-11).

1. SC13 endorsed the 2017 SWO stock assessment as the best and most up-to-date scientific information available for this species.
2. SC13 also endorsed the use of the SWO assessment model uncertainty grid to characterise stock status and management advice and implications.
3. SC13 reached consensus on the weighting of assessment models in the uncertainty grid for SWO. The consensus weighting considered all options within the four axes of uncertainty for steepness, size data, diffusion rate and natural mortality to be equally likely. The resulting uncertainty grid was used to characterise stock status, to summarise reference points as provided in the assessment document SC13-SA-WP-13, and to calculate the probability of breaching SB_{MSY} and the probability of *Frecent* being greater than F_{MSY}.

5.1 Stock status and trends

The median values of relative recent (2012–15) spawning biomass ($SBrecent/SB_{MSY}$) and relative recent fishing mortality ($Frecent/F_{MSY}$) over the uncertainty grid were used to measure the central tendency of stock status. The values of the upper 90th and lower 10th percentiles of the empirical distributions of relative spawning biomass and relative fishing mortality from the uncertainty grid were used to characterise the probable range of stock status.

Descriptions of the updated structural sensitivity grid used to characterise uncertainty in the assessment are provided in Table 13. Time trends in estimated fishing mortality and depletion are shown in Figures 11 and 12. Figures 13 and 14 show a Majuro plot summarising the results for each of the models in the structural uncertainty grid retained for management advice. Estimates of the reduction in spawning potential due to fishing by region, and over all regions are shown in Figure 15. A summary of reference points over all 72 individual models in the structural uncertainty grid is shown in Table 14.

Table 13: Descriptions of the structural sensitivity grid used to characterise uncertainty in the assessment.

Axis	Levels	Option
Steepness	3	0.65, 0.80, 0.95
Diffusion rate	3	0, 0.11, 0.25
Size frequency weighting	2	Sample size divided by 20, 40
Natural mortality vectors	4	M1, M2, M3, M4

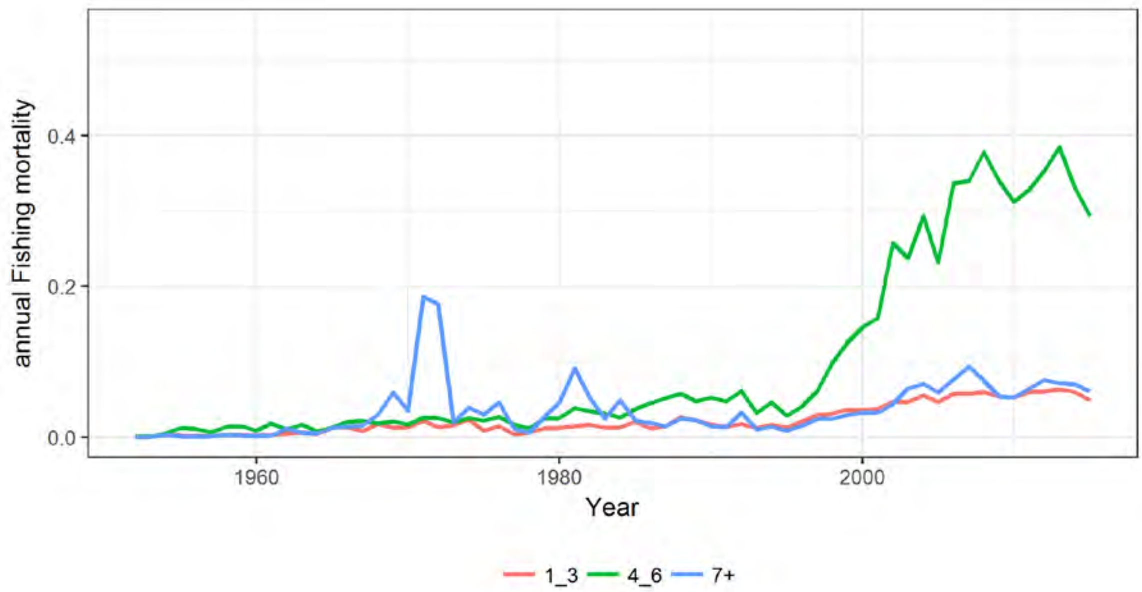


Figure 11: Estimated annual average juvenile (age classes 1–3), maturing adult (4–6) and adult (7+) fishing mortality for the diagnostic case model.

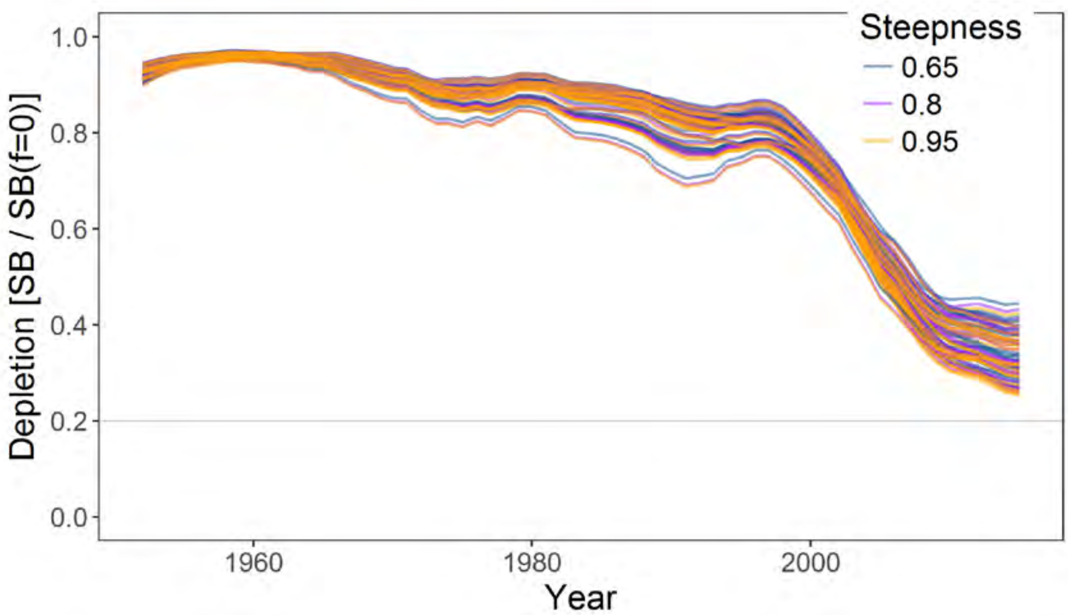


Figure 12: Plot showing the trajectories of fishing depletion (of spawning potential) for the 72 model runs retained for the structural uncertainty grid used for management advice. The colours depict the models in the grid with three levels of steepness (0.65, 0.8 and 0.95).

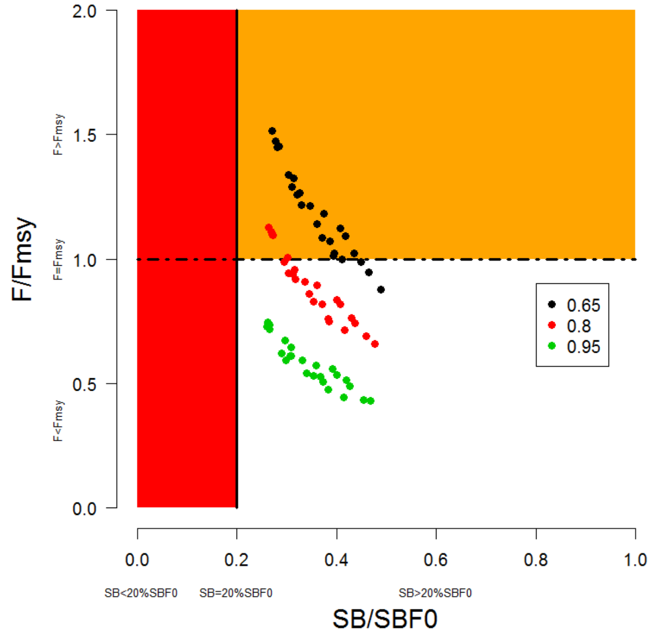


Figure 13: Majuro plot summarising the results for each of the models in the structural uncertainty grid retained for management advice. The plots represent estimates of stock status in terms of spawning potential depletion and fishing mortality. The red zone represents spawning potential levels lower than the agreed limit reference point, which is marked with the solid black line. The orange region is for fishing mortality greater than F_{MSY} (F_{MSY} is marked with the black dashed line). The points represent *SBlatest*/$SB_{F=0}$, and the colours depict the models in the grid with three levels of steepness (0.65, 0.8 and 0.95).

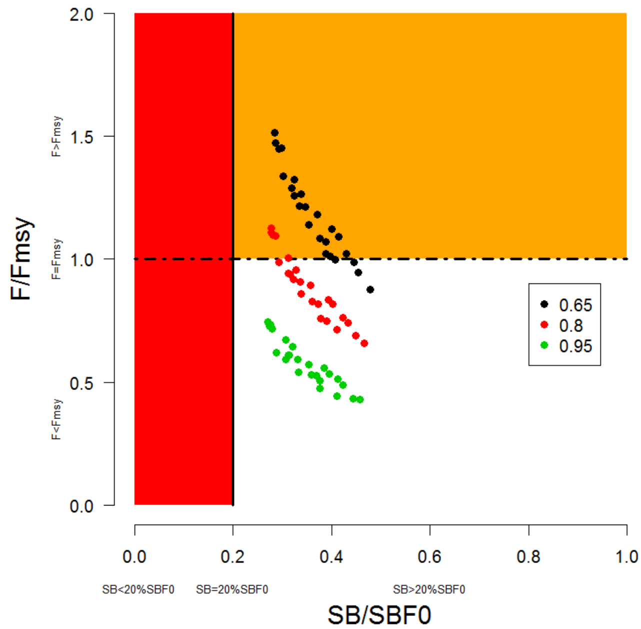


Figure 14: Majuro plot summarising the results for each of the models in the structural uncertainty grid retained for management advice. The plots represent estimates of stock status in terms of spawning potential depletion and fishing mortality. The red zone represents spawning potential levels lower than the agreed limit reference point, which is marked with the solid black line. The orange region is for fishing mortality greater than F_{MSY} (F_{MSY} is marked with the black dashed line). The points represent *SBrecent*/*SBF=0*, and the colours depict the models in the grid with three levels of steepness (0.65, 0.8 and 0.95). Note: *SBrecent* is defined as the mean of *SB* over 2012–15.

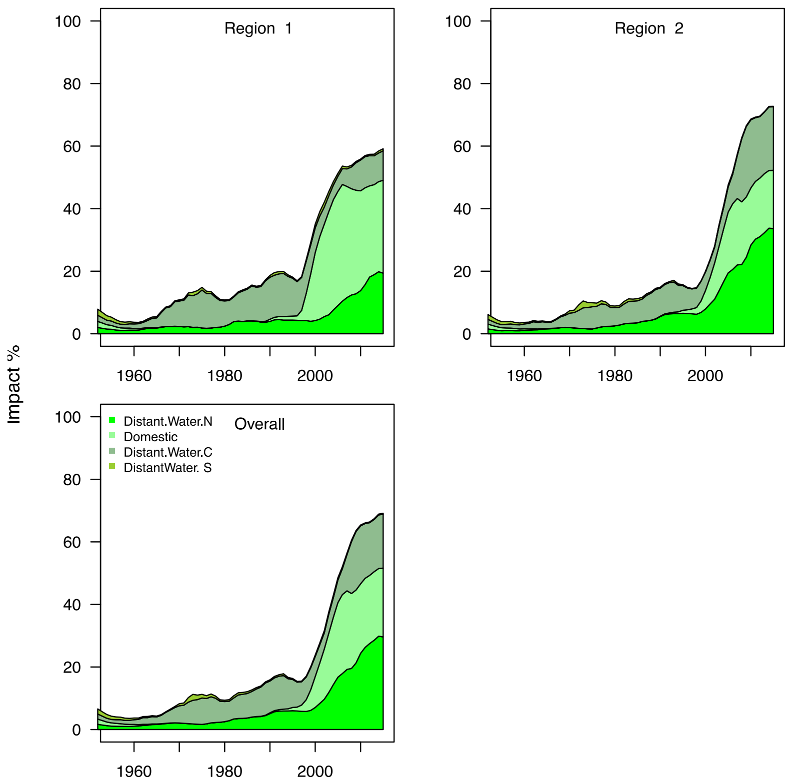


Figure 15: Estimates of reduction in spawning potential due to fishing by region, and over all regions (lower left panel), attributed to various fishery groups for the diagnostic case model. Note: Distant water C includes the EU fishery.

Table 14: Summary of reference points over the 72 models in the structural uncertainty grid for management advice. Note that *SBrecent/SBF=0* is calculated where *SBrecent* is the mean *SB* over 2012–15 instead of 2011–14 (used in the stock assessment report), at the request of the Scientific Committee.

	Mean	Median	Min	10%	90%	Max
Clatest	9 884	9 884	9 318	9 343	10 157	10 287
MSY	8 172	7 913	5 905	6 396	10 150	11 360
YFrecent	7 628	7 775	4 998	6 062	8 948	9 684
fmult	1.27	1.15	0.66	0.79	1.89	2.32
F_{MSY}	0.16	0.14	0.10	0.10	0.22	0.23
$Frecent/F_{MSY}$	0.88	0.87	0.43	0.53	1.26	1.51
SB_{MSY}	17 314	17 740	7 278	8 943	26 661	30 460
SB_0	84 173	84 075	57 070	71 199	98 039	111 000
SB_{MSY}/SB_0	0.20	0.21	0.11	0.12	0.28	0.28
$SB_{F=0}$	78 619	78 301	61 996	64 342	92 120	100 691
$SB_{MSY}/SB_{F=0}$	0.22	0.23	0.10	0.12	0.32	0.33
$SBlatest/SB_0$	0.33	0.32	0.24	0.25	0.44	0.46
$SBlatest/SBF_{=0}$	0.35	0.35	0.26	0.27	0.44	0.49
$SBlatest/SB_{MSY}$	1.85	1.61	0.85	0.99	3.14	4.05
$SBrecent/SB_{F=0}$	0.36	0.35	0.27	0.29	0.43	0.48
$SBrecent/SB_{MSY}$	1.86	1.58	0.88	1.02	3.10	3.96

SC13 noted that the central tendency of relative recent spawning biomass was the median $SBrecent/SB_{F=0}$ = 0.35 with a probable range of 0.29 to 0.43 (80% probability interval). This estimate (0.35) is below that estimated from the 2014 assessment grid ($SBcurrent/SB_{F=0}$ = 0.49, see SC9-SA-WP-05), noting the differences in grid uncertainty axes used in that assessment, due to the inclusion of two representations of growth and maturity. SC13 also noted that in the previous assessment this central tendency was not considered for the provision of management advice given the uncertainties in growth assumptions. The median estimate for $SBrecent/SB_{MSY}$ is 1.58, which is below that estimated from the 2014 assessment grid ($SBcurrent/SB_{MSY}$ = 2.07, see SC9-SA-WP-05).

SC13 noted that the central tendency of relative recent fishing mortality was the median $Frecent/F_{MSY}$ = 0.87 with an 80% probability interval of 0.53 to 1.26. While this suggested that there was likely a buffer between recent fishing mortality and F_{MSY}, it also showed that there was some probability that recent fishing mortality was above F_{MSY}.

SC13 also noted that there was a roughly 32% probability (23 out of 72 models) that the recent fishing mortality was above F_{MSY} with Pr ($Frecent/F_{MSY} > 1$) = 0.32. The median estimate (0.87) is above that estimated from the 2014 assessment grid ($Fcurrent/F_{MSY}$ = 0.74, see SC9-SA-WP-05).

The fishing mortality rate increased notably from the mid-1990s in both model regions, particularly on maturing swordfish aged 4–6.

Across all models in the uncertainty grid the spawning biomass declined steeply between the late 1990s and 2010 but since then the rate of decline has been less. Those declines were found in both model regions, but were higher in the eastern Region 2 (equator to 50°S, 165°E to 130°W).

SC13 noted that in comparison with the bigeye and yellowfin assessments, evidence for an increase in recent recruitment for south-west Pacific swordfish was not found in either the CPUE time series or estimates of recruitment. SC13 noted that the longline-only nature of the fishery, catching mainly larger, older swordfish, is not strongly informative with regards to recruitment dynamics.

5.2 Management advice and implications

Based on the uncertainty grid adopted by SC13, the south-west Pacific swordfish spawning biomass is likely above the 20% $SB_{F=0}$, biomass LRP adopted for tunas and the SB_{MSY} level (noting that the Commission has yet to adopt an LRP for South Pacific swordfish), and it is highly likely that the stock is not in an overfished condition (0% probability). Recent F is likely below F_{MSY}, and it appears that the stock is not experiencing overfishing (32% probability).

SC13 noted that there has been an increase in fishing mortality notably from the mid-1990s, and that the biomass relative to unfished levels is estimated to have declined rapidly during the period late-1990s to 2010 followed by a more gradual but continued decline after 2010, across the uncertainty grid. It was noted the fishing mortality was likely below F_{MSY}.

Consistent with its previous advice (from SC9), SC13 recommends that the Commission consider developing appropriate management measures for the area north of 20°S to the equator, which is not covered by CMM 2009-03, noting that:

- recent catches between the equator and 20°S continue to represent the largest component of the catch in Region 2 (equator to 50°S, 165°E to 130°W) and represent half the total catches from the stock, and
- catches in that area contribute substantially to fishing mortality and spawning biomass depletion levels in eastern Region 2 that are substantially higher than in the western region (Region 1).

Further, SC13 recommends that current restrictions on catches south of 20°S also be maintained.

5.3 Catch per unit effort indices (CPUE)

Catch per unit effort (CPUE) indices for swordfish (*Xiphias gladius*) in the New Zealand surface-longline fishery were updated to include fisheries data from the five years since the previous analysis, for use as relative abundance indices in a revised South Pacific-wide swordfish stock assessment model being assembled by the WCPFC (Anderson et al. 2013).

Examination of changes in the fishery data (including the use of light sticks, depth of the longline, and timing of fishing around hours of darkness and with respect to the fullness of the moon) showed that targeting of swordfish has effectively been increasing over time, particularly since 2004 when targeting became legal after the introduction of swordfish into the Quota Management System (QMS).

Generalised Additive Models (GAMs) assuming a quasi-Poisson error distribution were applied to commercial catch-effort data and remote-sensed environmental variables to produce three alternative CPUE series: all-data, based on data from 1993 to 2012 and all vessels in the fishery; core-vessel, based on a core set of vessels and the more recent fishery, 1998 to 2012; and late-series, based on the core set of vessels and the period subsequent to the introduction of swordfish into the QMS, i.e., 2005–12.

Each model showed an increase in CPUE as the fraction of the longline soak-time occurring in darkness increased. Recorded target species in the all-data model, and rate of light stick usage in the late-series model were also significant.

The indices of the updated models followed a similar temporal pattern to each other and to those of the earlier analyses for the overlapping years, indicating a decline in CPUE between 1993 and 2004, followed by a small increase to 2007. For the subsequent period, 2004–12, the revised models all showed a continuation of this increasing CPUE, reaching a level higher than that of any previous year in the series.

Although it was suspected that changes in operational procedures affecting swordfish catch rates were at least partly responsible for the recent increase in CPUE, it was not possible to determine whether these changes were sufficiently accounted for by the model variables and therefore to have confidence in the use of the year-effects as relative abundance indices.

5.4 Other factors

Other fleets also fish the stock fished in the New Zealand EEZ and the impact of current regional catches on the stock are unknown. It is often assumed that swordfish, particularly large swordfish, may have long residence times, which may make them vulnerable to overfishing. Recent Australian research suggests that swordfish CPUE has declined in areas that have been fished the longest and that vessels have maintained high catch rates by travelling further each season, suggesting that serial depletion may be occurring.

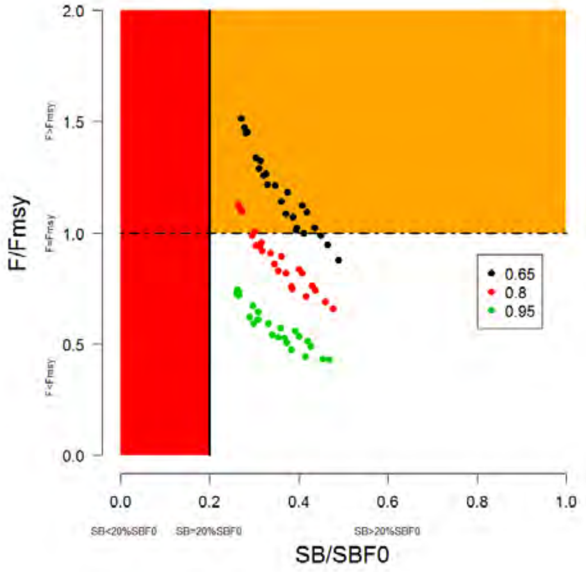
6. STATUS OF THE STOCKS

Stock structure assumptions

Swordfish taken in New Zealand are part of larger south-west and south-central Pacific stocks; the evaluation below refers to the assessment of the south-west portion of that stock.

Stock Status	
Year of Most Recent Assessment	2017
Assessment Runs Presented	Full uncertainty grid
Reference Points	Target: $B > B_{MSY}$ and $F < F_{MSY}$ Soft Limit: Not established by WCPFC but evaluated using HSS default of 20% SB_0 Hard Limit: Not established by WCPFC but evaluated using HSS default of 10% SB_0 Overfishing threshold: F_{MSY}
Status in relation to Target	Very Likely (> 90%) that B is at or above B_{MSY} and Likely (> 60%) that $F < F_{MSY}$
Status in relation to Limits	Soft Limit: Unlikely (< 40%) to be below Hard Limit: Very Unlikely (< 10%) to be below
Status in relation to Overfishing	Overfishing is Unlikely (< 40%) to be occurring

Historical Stock Status Trajectory and Current Status



Majuro plot summarising the results for each of the models in the structural uncertainty grid retained for management advice. The plots represent estimates of stock status in terms of spawning potential depletion and fishing mortality. The red zone represents spawning potential levels lower than the agreed limit reference point, which is marked with the solid black line. The orange region is for fishing mortality greater than F_{MSY} (F_{MSY} is marked with the black dashed line). The points represent *SBlatest*/$SB_{F=0}$, and the colours depict the models in the grid with three levels of steepness (0.65, 0.8 and 0.95).

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Following a period of continuous decline, the south-west Pacific swordfish biomass has recently increased.
Recent Trend in Fishing Intensity or Proxy	Fishing mortality increased substantially from 1995 to the present.
Other Abundance Indices	-
Trends in Other Relevant Indicator or Variables	Recruitment has fluctuated without trend from 1950 to the present.

Projections and Prognosis	
Stock Projections or Prognosis	Projections based on the model that used Hawaii growth predict further increases in stock size at current fishing mortality levels. However, using the Australian growth the stock is About as Likely as Not (40–60%) to decline.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unlikely (< 40%) Hard Limit: Unlikely (< 40%)
Probability of Current Catch or TACC causing Overfishing to continue or commence	About as Likely as Not (40–60%)

Assessment Methodology and Evaluation	
Assessment Type	Level 1: Full Quantitative Stock Assessment
Assessment Method	The assessment uses the stock assessment model and computer software known as MULTIFAN-CL.

Assessment Dates	Latest assessment: 2017	Next assessment: 2020
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	Commercial catch and effort data, CPUE, catch-at-age	1 – High Quality
Data not used (rank)		
Changes to Model Structure and Assumptions	Major changes from the 2013 assessment include: - an additional four years of data - new growth rate, maturity and mortality estimates.	
Major Sources of Uncertainty	Need for collection of sex-specific size data.	

Qualifying Comments
-

Environmental and Ecosystem Considerations	
Observer coverage	From 2002 to 2018, observer coverage was highly variable year to year (from 0 to 22.2%).
Non-target fish and invertebrate catch	Blue shark, lancetfish and Porbeagle shark are the most commonly non-target fish species caught by the longline fleet (by number), but are rarely retained. Other species, such as Rays bream and Moonfish are caught more rarely, but are highly retained. Fish bycatch is managed through New Zealand domestic legislation and, to a limited extent, through Conservation and Management Measure CMM2010-07. No invertebrates are caught in this fishery.
Incidental catch of seabirds	This fishery contributes to the risk posed to Gibson's albatross (a high risk species), Antipodean albatross (a medium risk species) and Black petrel (a very high risk species), among other species. Seabird bycatch mitigation measures are required in the New Zealand and Australian EEZs, and through the WCPFC Conservation and Management Measure CMM2007-04.
Incidental catch of cetaceans	Between 2002–03 and 2017–18, there was one observed capture of a beaked whale in swordfish longline fisheries, off the West Coast of the South Island in 2016–17.
Incidental catch of pinnipeds	Between 2002 and 2018, there were three observed captures of New Zealand fur seals in swordfish longline fisheries. Most of these were released alive.
Incidental catch of other protected species	Between 2002 and 2018, there were seven observed captures of sea turtles in swordfish longline fisheries in the Kermadec Islands, Northland and Hauraki, and West Coast South Island fishing areas. All sea turtles were released alive.
Benthic interactions	There are no known benthic interactions for this fishery

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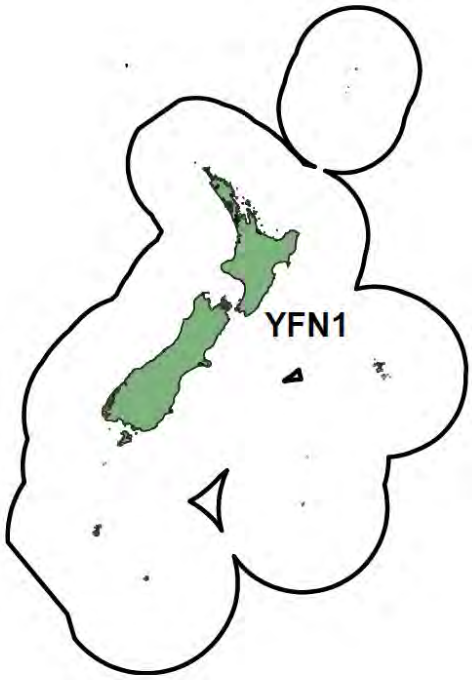
YELLOWFIN TUNA (YFN)

(Thunnus albacares)



1. FISHERY SUMMARY

Yellowfin tuna were introduced into the QMS on 1 October 2004 under a single QMA, YFN 1, with allowances, TACC, and TAC in Table 1.

Table 1: Recreational and customary non-commercial allowances, TACC and TAC (all in t) for yellowfin tuna.

Fishstock	Recreational allowance	Customary non-commercial allowance	Other mortality	TACC	TAC
YFN 1	60	30	5	263	358

Yellowfin tuna were added to the Third Schedule of the 1996 Fisheries Act with a TAC set under s14 because yellowfin tuna is a highly migratory species and it is not possible to estimate MSY for the part of the stock that is found within New Zealand fisheries waters.

Management of the yellowfin stock throughout the western and central Pacific Ocean (WCPO) is the responsibility of the Western and Central Pacific Fisheries Commission (WCPFC). Under this regional convention New Zealand is responsible for ensuring that the management measures applied within New Zealand fisheries waters are compatible with those of the Commission.

At its second annual meeting (2005) the WCPFC passed a Conservation and Management Measure (CMM) (this is a binding measure that all parties must abide by throughout the convention area including EEZs) relating to conservation and management of tunas. Key aspects of this resolution were presented in the 2006 Plenary document. A number of subsequent CMMs that impact on the catches of yellowfin have since been approved by the WCPFC.

At its annual meeting in 2014 the WCPFC approved CMM 2014-01. The aim of this CMM for yellowfin is to maintain the fishing mortality rate for yellowfin at a level no greater than F_{MSY}, although there are numerous exemptions and provisions. Controls on fishing mortality are being attempted through seasonal Fish Aggregating Device (FAD) closures, yellowfin purse-seine catch limits, high seas purse-seine effort limits, yellowfin longline catch limits, as well as other methods. This measure was amended and updated in 2017 through CMM2017-01.

In 2018 CMM 2018-01 (commonly referred to the “The tropical tuna bridging measure”) was approved that stated that pending agreement on a target reference point for yellowfin, the spawning biomass depletion ratio (SB/SBF=0) is to be maintained at or above the average SB/SBF=0 for 2012-2015.

1.1 Commercial fisheries

Most of the commercial catch of yellowfin takes place in the equatorial western Pacific Ocean (WPO) where they are taken primarily by purse seine and longline. Commercial catches by distant water Asian longliners of yellowfin tuna, in New Zealand waters, began in 1962. Catches through the 1960s averaged 283 t. Yellowfin were not a target species for these fleets, and catches remained small and seasonal. Domestic tuna longline vessels began targeting bigeye tuna in 1990–91 in northern waters of FMA 1, FMA 2 and FMA 9 (Table 2). Catches of yellowfin increased with increasing longline effort, but as yellowfin availability fluctuates dramatically between years, catches have been variable. In addition, small catches of yellowfin are made by pole-and-line fishing (about 4 t per year) and also by trolling (about 14 t per year). Figure 1 shows historic landings and longline fishing effort for YFN stocks.

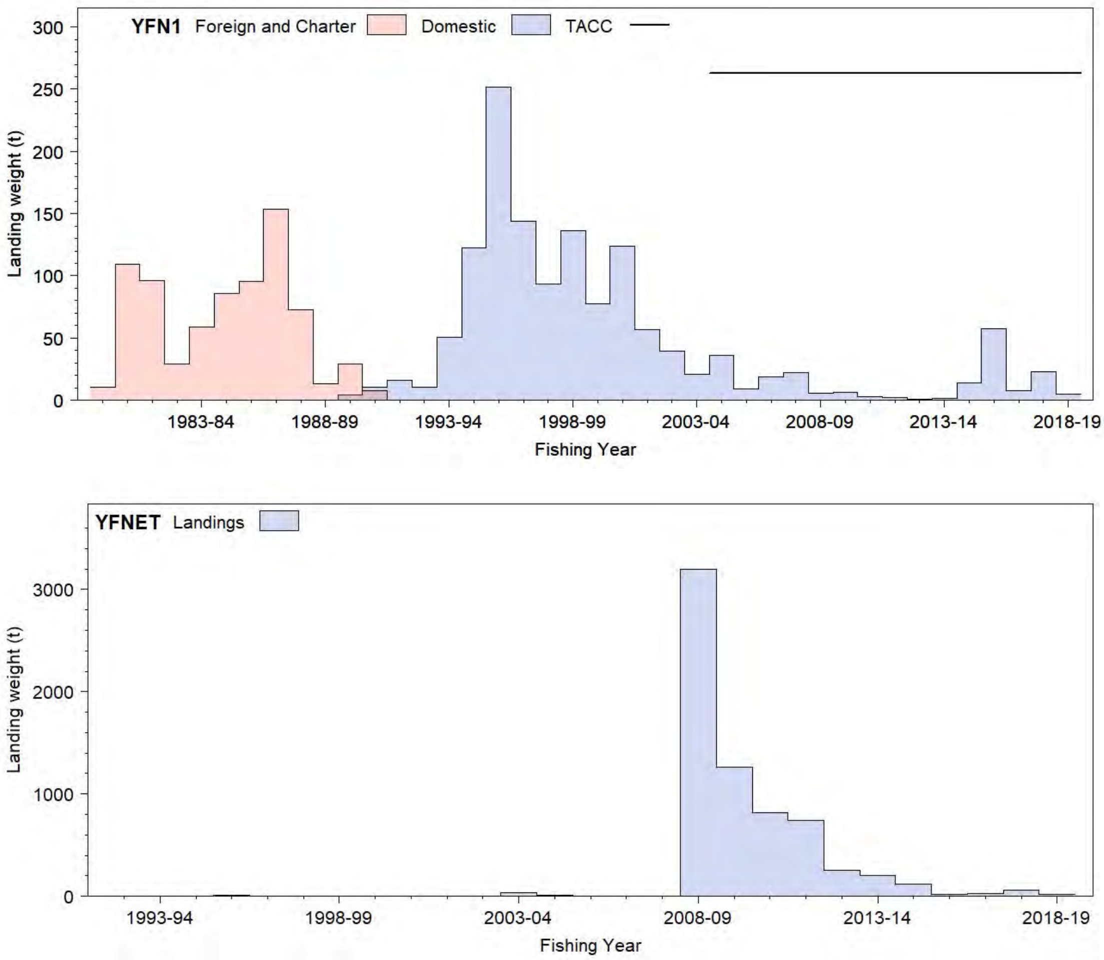


Figure 1: [Top] Yellowfin catch by foreign licensed and New Zealand vessels from 1979–80 to 2018–19 within New Zealand waters (YFN 1). [Bottom] Yellowfin catch by foreign licensed and New Zealand vessels from 1992–93 to 2018–19 on the high seas (YFN ET)

Catches from within New Zealand fisheries waters are very small (0.07% average for 2000–2011) compared to those from the greater stock in the WCPO (Table 3). In contrast to New Zealand, where yellowfin are taken almost exclusively by longline, 50% of the WCPO catches of yellowfin tuna are taken by purse seine and other surface gears (e.g., ring-nets and pole-and-line).

Table 2: Reported catches or landings (t) of yellowfin tuna by fleet and fishing year. NZ: New Zealand domestic and charter fleet, ET: catches outside these areas from New Zealand flagged longline vessels, JPNFL: Japanese foreign licensed vessels, KORFL: foreign licensed vessels from the Republic of Korea, LFRR: estimated landings from Licensed Fish Receiver Returns, and MHR: Monthly Harvest Return Data from 2001–02 onwards.

	YFN 1 (all FMAs)					
Fishing year	JPNFL	KORFL	NZ/MHR	Total	LFRR	NZ ET
1979–80	10.1			10.1		
1980–81	79.1	29.9		109		
1981–82	89.4	6.7		96.1		
1982–83	22.4	6.6		29		
1983–84	46.1	12.8		58.9		
1984–85	21.3	64.5		85.8		
1985–86	92.5	3.3		95.8		
1986–87	124.8	29		153.8		
1987–88	35.2	37.3		72.5		
1988–89	11.5	1.8		13.3	19	
1989–90	29.1		4.3	33.4	6.3	
1990–91	7.4		10.7	18.1	19.9	
1991–92	0.2		16.1	16.3	11.8	
1992–93			10.1	10.1	69.7	0.2
1993–94			50.5	50.5	114.4	1.5
1994–95			122.2	122.2	193.4	0.3
1995–96			251.6	251.6	156.7	7.4
1996–97			144.1	144.1	105.3	0.2
1997–98			93.6	93.6	174.7	2.3
1998–99			136.1	136.1	100.6	0.3
1999–00			77.8	77.8	168	2.1
2000–01			123.5	123.5	62.5	3.1
2001–02			64.5	56.7	61.9	1.9
2002–03			41.8	39.7	42.1	2.1
2003–04			57.7	21.1	21.4	36.6
2004–05			36.0	36.0	41.4	6.0
2005–06			9.2	9.2	8.8	0.1
2006–07			18.9	18.9	19.7	1.0
2007–08			22.2	22.2	22.3	0.2
2008–09			5.4	43.6	43.3	3 200
2009–10			6.2	6.2	48.2	1 264
2010–11			2.8	2.8	234.8	818
2011–12			2.2	2.2	742.6	966
2012–13			0.6	0.6	249.1	1 042
2013–14			1.4	1.4	200.8	199.4
2014–15			14.1	14.1	129.3	115.6
2015–16			57.6	57.6	73.4	16.1
2016–17			7.6	7.6	31.0	23.9
2017–18			23.1	23.1	81.7	59.4
2018–19			4.9	4.9	20.9	16.3

In 2012–13, the majority of yellowfin tuna were caught in the bigeye tuna surface-longline fishery (68%) (Figure 2). In 2017–18, across all longline fisheries blue sharks and bluefin tuna made up the bulk of the catch (31% each) and yellowfin tuna made up less than 1% of the catch (Figure 3). Longline fishing effort is distributed along the east coast of the North Island and the south-west coast of the South Island. The west coast South Island fishery predominantly targets southern bluefin tuna, whereas the east coast of the North Island targets a range of species including bigeye, swordfish and southern bluefin tuna.

Table 3: Reported total New Zealand (within EEZ) landings, catch made by New Zealand vessels outside New Zealand fishery waters (NZ ET)* and WCPO landings (t) of yellowfin tuna from 1991 to 2018.

Year	NZ landings (t)	WCPO landings (t)	Year	NZ landings (t)	NZ ET landings (t)	WCPO landings (t)
1991	6	403 152	2005	36	2 486	2005
1992	20	413 882	2006	14	2 679	2006
1993	34	351 556	2007	25	2 329	500 120
1994	53	391 108	2008	12	3 200	580 241
1995	141	381 423	2009	3	1 264	529 426
1996	198	351 762	2010	6	818	542 438
1997	143	457 984	2011	3	966	518 611
1998	127	550 299	2012	2	1 042	639 912
1999	154	479 090	2013	1	837	529 437
2000	107	523 956	2014	1	199	607 222
2001	138	527 859	2015	14	115	601 221
2002	25	482 664	2016	57	74	643 611
2003	38	540 331	2017	10	387	665 647
2004	20	578 045	2018	20	964	663 209

Source: Ministry of Fisheries Licensed Fish Receiver Returns, Solander Fisheries Ltd, Anon 2006, Williams & Terawasi 2011; WCPO landings sourced from WCPFC Yearbook 2012 (Anon 2013).
* New Zealand purse-seine vessels operating in tropical regions catch moderate levels of yellowfin tuna when fishing around Fish Aggregating Devices (FADs) and on free schools. These catches are only estimates of catch based on analysis of observer data across all fleets rather than specific data for New Zealand vessels. In addition, catches of juvenile bigeye and yellowfin tuna are often combined on catch effort returns due to difficulties in differentiating the catch.

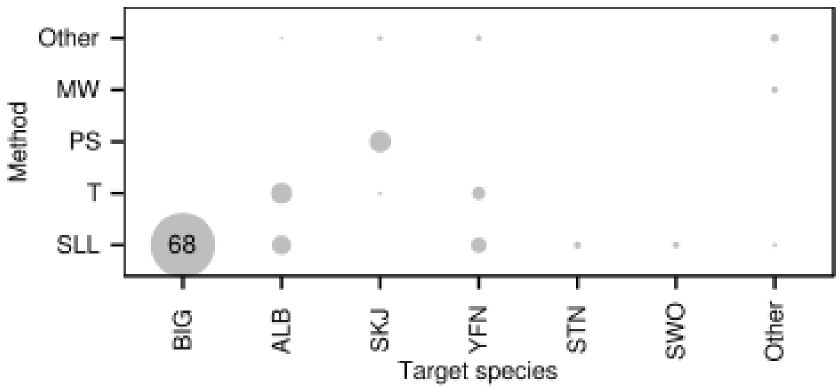


Figure 2: A summary of the proportion of landings of yellowfin tuna taken by each target fishery and fishing method for 2012–13. The area of each circle is proportional to the percentage of landings taken using each combination of fishing method and target species. The number in the circle is the percentage. SLL = surface longline, T = trawl, PS = purse seine, MW = midwater trawl (Bentley et al. 2013).

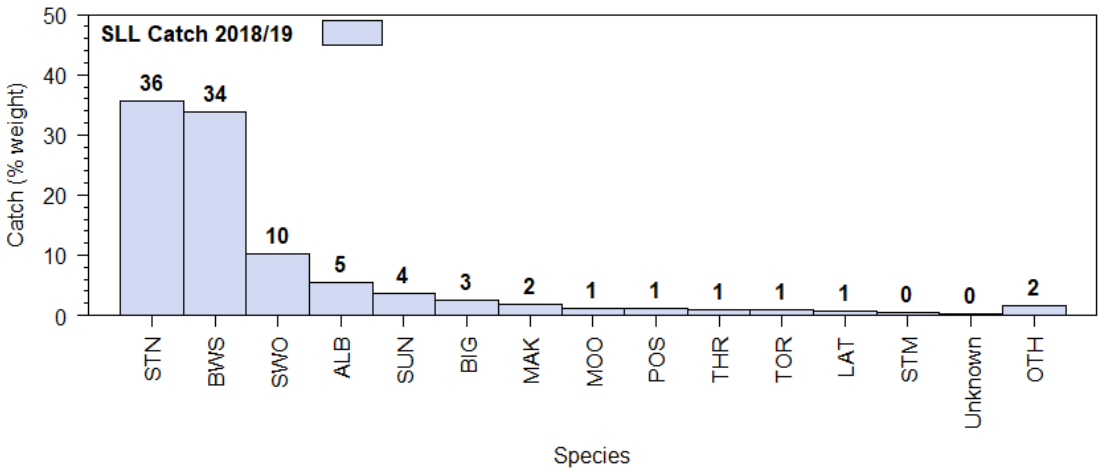


Figure 3: A summary of species composition of the surface-longline estimated catch for 2017–18. The percentage by weight of each species is calculated for all surface-longline trips.

From 2006–07 to 2014–15, across all fleets in the longline fishery more than 70% of the yellowfin tuna were alive when brought to the side of the vessel (Table 4). The domestic fleets retain between 79% and 100% of their yellowfin tuna catch (Table 5).

Table 4: Percentage of yellowfin tuna (including discards) that were alive or dead when arriving at the longline vessel and observed during 2006–07 to 2014–15, by fishing year, fleet and region. Small sample sizes (number observed < 20) were omitted (Griggs & Baird 2013, Griggs et al. 2018).

Year	Fleet	Area	% alive	% dead	Number
2006–07	Domestic	North	75.0	25.0	28
	Total		**78.3**	**21.7**	**46**
2007–08	Domestic	North	75.8	24.2	33
	Total		**75.8**	**24.2**	**33**
2008–09	**Total**		**88.9**	**11.1**	**9**
2009–10	**Total**		**88.9**	**11.1**	**9**
2010–11	**Total**				**3**
2011–12	**Total**				**3**
2012–13	**Total**				**0**
2013–14	**Total**				**2**
2014–15	**Domestic**	North	81.0	19.0	21
	Total		**81.0**	**19.0**	**21**

Table 5: Percentage yellowfin that were retained, or discarded or lost, when observed on a longline vessel during 2010–11 to 2014–15, by fishing year and fleet. Small sample sizes (number observed < 20) omitted (Griggs & Baird, Griggs et al. 2018).

Year	Fleet	% retained	% discarded or lost	Number
2006–07	Domestic	78.6	21.4	28
	Total	**80.4**	**19.6**	**46**
2007–08	Domestic	90.9	9.1	33
	Total	**90.9**	**9.1**	**33**
2008–09	**Total**	**100.0**	**0.0**	**9**
2009–10	**Total**	**100.0**	**0.0**	**9**
2010–11	**Total**			**3**
2011–12	**Total**			**3**
2012–13	**Total**			**0**
2013–14	**Total**			**2**
2014–15	Domestic	100.0	0.0	21
	Total	**100.0**	**0.0**	**21**

1.2 Recreational fisheries

Recreational fishers used to make regular catches of yellowfin tuna particularly during summer months and especially in FMA 1 and FMA 2 where the recreational fishery targeted yellowfin as far south as the Wairarapa coast. It is taken by fishers targeting it predominantly as a gamefish and is prized for food. Yellowfin comprise part of the voluntary recreational gamefish tag and release programme. While the magnitude of the recreational catch is unknown, catches weighed at sport fishing clubs dropped from over 1000 fish per year in the 1990s to an average of 30 fish per year in the period 2011–14.

1.2.1 Management controls

There are no specific controls in place to manage recreational harvests of yellowfin tuna.

1.2.2 Estimates of recreational harvest

No estimates of recreational harvest of yellowfin tuna were generated from the telephone-diary surveys conducted in 1994, 1996 and 2000 because so few were reported. A National Panel Survey was conducted for the first time throughout the 2011–12 fishing year. The panel survey used face-to-face interviews of a random sample of 30 390 New Zealand households to recruit a panel of fishers and non-fishers for a full year (from Wynne-Jones et al. 2014). The panel members were contacted regularly about their fishing activities and harvest information collected in standardised phone interviews. The national panel survey was repeated during the 2017–18 fishing year using very similar methods to produce directly comparable results (Wynne-Jones et al. 2019). Note that national panel survey estimates do not include recreational harvest taken under s111 general approvals. The National Panel Survey results do not include estimates for yellowfin tuna as the surveys did not capture the fishers and fishing activity for the large gamefish species well.

1.3 Customary non-commercial fisheries

An estimate of the current customary catch is not available.

1.4 Illegal catch

There is no known illegal catch of yellowfin tuna in the EEZ. Estimates of illegal catch are not available, but are probably insignificant.

1.5 Other sources of mortality

The estimated overall incidental mortality rate from observed longline effort is 0.22% of the catch. Discard rates are 0.92% on average from observer data of which approximately 25% are discarded dead (usually because of shark damage). Fish are also lost at the surface in the longline fishery, 0.16% on average from observer data, of which 95% are reported as escaping alive.

2. BIOLOGY

Yellowfin tuna are epipelagic opportunistic predators of fish, crustaceans and cephalopods. Yellowfin tuna are found from the surface to depths where low oxygen levels are limiting (about 250 m in the tropics but probably deeper in temperate waters). Individuals found in New Zealand waters are mostly adults that are distributed in the tropical and temperate waters of the western and central Pacific Ocean. Adults reach a maximum size of 200 kg and length of 239 cm. Maturity is reached at 60 to 80 cm (1 to 2 years old), and the size at 50% maturity is estimated to be 105 cm. The maximum reported age is 8 years. Spawning takes place at the surface at night mostly within 10º of the equator when temperatures exceed 24ºC. Spawning takes place throughout the year but the main spawning season is November to April. Yellowfin are serial spawners, spawning every few days throughout the peak of the season.

Natural mortality is assumed to vary with age. A range of von Bertalanffy growth parameters has been estimated for yellowfin in the Pacific Ocean depending on area (Table 6).

Table 6: von Bertalanffy growth parameters for yellowfin tuna by country or area.

Country/Area	L_∞ (cm)	K	t_0
Philippines	148.0	0.420	
Mexico	162.0	0.660	
Western tropical Pacific	166.0	0.250	
Japan	169.0	0.564	
Mexico	173.0	0.660	
Hawaii	190.0	0.454	
Japan	191.0	0.327	-1.02

Females predominate in the longline catch of yellowfin tuna in the New Zealand EEZ (0.75 males:females).

3. STOCKS AND AREAS

Yellowfin tuna in New Zealand waters are part of the western and central Pacific Ocean stock that is distributed throughout the north and south Pacific Ocean west of about 150ºW.

4. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS

This summary is from the perspective of yellowfin tuna but there is no directed fishery for them.

4.1 Role in the ecosystem

Yellowfin tuna (*Thunnus albacares*) are epipelagic opportunistic predators of fish, crustaceans and cephalopods generally found within the upper few hundred meters of the ocean. Yellowfin tuna are large pelagic predators, so they are likely to have a ‘top down’ effect on the fish, crustaceans and squid they feed on.

4.2 Non-target fish catch

Observer records indicate that a wide range of species are landed by the longline fleets in New Zealand fishery waters. Blue sharks are the most commonly landed species (by number), followed by lancetfish and Porbeagle shark (Table 7).

Table 7: Total estimated catch (numbers of fish) of common bycatch species in the New Zealand longline fishery as estimated from observer data from 2015 to 2018. Also provided is the percentage of these species retained (2018 data only) and the percentage of fish that were alive when discarded, N/A (none discarded).

Species	2015	2016	2017	2018	% retained (2018)	discards % alive (2018)
Blue shark	72 480	57 210	49 924	63 618	0.0	88.7
Lancetfish	12 962	17 442	13 274	13 163	0.0	33.5
Porbeagle shark	4 058	6 566	3 101	2 594	1.0	51.1
Rays bream	17 555	7 758	2 421	1 579	99.0	26.7
Moonfish	3 060	3 036	2 022	2 698	98.0	50.0
Pelagic stingray	979	1 414	1 798	2 949	0.0	100.0
Sunfish	770	4 849	1 648	3 648	0.0	99.8
Mako shark	2 667	4 417	1 391	2 721	4.0	65.6
Rudderfish	373	237	680	253	45.0	89.4
Butterfly tuna	1 309	768	406	419	86.0	20.7
Escolar	653	669	300	594	67.0	67.9
Striped marlin	120	550	290	247	0.0	66.7
Thresher shark	177	601	260	253	0.0	76.0
Oilfish	584	281	227	602	42.0	85.4
Dealfish	842	63	72	25	0.0	31.8
School shark	88	24	59	187	84.0	100.0
Skipjack tuna	150	185	57	184	86.0	100.0
Deepwater dogfish	545	0	32	6	0.0	83.3
Big scale pomfret	59	16	17	34	100.0	n/a

4.3 Benthic interactions

There are no known interactions with benthic habitats in this fishery

5. STOCK ASSESSMENT

With the establishment of WCPFC in 2004, stock assessments of the WCPO stock of yellowfin tuna are undertaken by the Oceanic Fisheries Programme (OFP) of the Secretariat of the Pacific Community (SPC) under contract to WCPFC.

No assessment is possible for yellowfin within the New Zealand EEZ as the proportion of the stock found within New Zealand fisheries waters is unknown and is likely to vary from year to year.

The yellowfin stock assessment was updated by the SPC in 2017 in SC13-SA-WP-06 (Tremblay-Boyer et al. 2017) and reviewed by the WCPFC Scientific Committee (SC13) in August 2017. The paper described the 2017 stock assessment of yellowfin tuna *Thunnus albacares* in the western and central Pacific Ocean. The model time period now extends to the end of 2015, adding a further three years of data since the last stock assessment was conducted in 2014. New developments to the stock assessment include addressing relevant recommendations of the 2014 yellowfin stock assessment report (Davies et al. 2014), investigation of an alternative regional structure, exploration of uncertainties in the assessment model, particularly in response to the inclusion of additional years of data, and improving diagnostic weaknesses of previous assessments.

The assessment was supported by additional analyses of catch-per-unit-effort data for longline fisheries (Tremblay-Boyer and Pilling 2017a, b), tagging data (McKechnie et al. 2017b), and the data summaries for fisheries definitions used in the stock assessment (McKechnie et al. 2017b).

Changes made in the progression from the 2014 reference case to 2017 diagnostic case models included:

- The 2014 reference case model.
- The 2014 reference case model with the new MFCL executable.
- A complete update of the 2014 reference case model – all inputs extended from 2012 to 2015 using identical methodology for CPUE, tagging, size frequencies etc., and the same MFCL model settings.
- The previous model with the same structure and MFCL settings but CPUE indices using the GLM approaches with the updated Pacific-wide operational LL database (McKechnie et al. 2017b).
- The previous model with the same MFCL settings but with the new regional structure and consequently all fisheries, and input data (including CPUE standardisations), reconfigured based on these new regional definitions.
- The previous model with two modifications to the recruitment estimates: the change from quarterly to annual recruitments when estimating the spawner-recruit relationship, and the fixed terminal six recruits set at the arithmetic rather than geometric mean of recruitments for the remaining period.

In addition to the diagnostic case model, the authors reported the results of one-off sensitivity models to explore the relative impacts of key data and model assumptions for the diagnostic case model on the stock assessment results and conclusions. A structural uncertainty analysis (model grid) was also undertaken for consideration in developing management advice where all possible combinations of the most important axes of uncertainty from the one-off models were included. In comparison to previous assessments, little emphasis was placed on the diagnostic case model. Instead it was recommended that management advice was formulated from the results of the structural uncertainty grid.

Across the range of model runs in this assessment, the key factor influencing estimates of stock status was the size data weighting value. Downweighting the influence of the size data by a divisor of 50 led to more pessimistic stock status estimates.

Based on the results of the model grid, the general conclusions of this assessment were as follows:

- The grid contained a wide range of models with some variation in estimates of stock status, trends in abundance and reference points. However, biomass was estimated to have declined throughout the model period for all models in the grid. Those declines were found across most tropical and temperate regions of the model.
- Subsequent to the report deadline, an extra level for the size weighting of the grid was completed with an extra level (divisor of 20; the level used in the diagnostic case model) and so the stock assessment report was modified (Rev1) to incorporate summaries that included these extra runs. The additional 24 model runs had a small effect on the summaries of the grid as, even though the extra level of the size weighting axis fell between the more extreme divisors of 10 and 50, the resulting model runs behaved similarly to that of the divisor of 10, thus making reference points more optimistic by 2–4 points.
- Across the updated model grid, the terminal depletion estimated for the majority of runs estimated stock status levels to be above 20% $SB_{F=0}$. The range of $SBlatest=SB_{F=0}$ values was 0.16 to 0.5. Only two runs (< 5%) fell below the LRP of 20% $SB_{F=0}$. The median estimate (0.39) was higher than that estimated from the 2014 assessment grid, noting the differences in grid uncertainty axes used in the two assessments.
- Corresponding estimates of $Frecent=F_{MSY}$ ranged from 0.54 to 1.13, with 2 out of the 72 runs (< 5%) indicating that $Frecent=F_{MSY} > 1$. The median estimate (0.73) was comparable to that estimated from the 2014 assessment grid.
- Fishing mortality for adult and juvenile yellowfin tuna was estimated to have increased continuously since the beginning of industrial tuna fishing (seen in the diagnostic case model). In general these had been on average higher for juveniles, but in recent years adult fishing mortality has also increased. A significant component of the increase in juvenile fishing mortality was attributable to the Philippines, Indonesian and Vietnamese surface fisheries, which had the most uncertain catch, effort and size data. The work of the WPEA project to assist in enhancing the current fishery monitoring programme and improving estimates of historical and current catch from these fisheries remained important given the contribution of these fisheries in the overall fishing impact analyses from this assessment.
- The significance of the recent increased recruitment events and the progression of these fish to the spawning potential component of the stock was encouraging, although whether this was a result of management measures for the fishery or beneficial environmental conditions was currently unclear. It was noteworthy, however, that recent favourable recruitment events had also been estimated for skipjack (McKechnie et al. 2016) and bigeye (McKechnie et al. 2017a) in the WCPO, and bigeye in the EPO (Aires-da-Silva et al. 2017), which might give weight to the favourable environmental conditions hypothesis. Whether these trends are maintained in coming years would help separate these factors and would likely provide more certainty about the future trajectories of the stock.
- It was noted that there remained a range of other model assumptions that should be investigated either internally or through directed research. Briefly, the apparent non-linear impact of the weighing on the size composition data on population estimates, and the conflict between the abundance indices and the tagging data for Region 8 were worthy of note. Also, biological studies to improve estimates of growth of yellowfin within the WCPO, for instance through direct ageing of otoliths as was done in bigeye, were considered a high priority.

SC13 endorsed the 2017 WCPO yellowfin tuna stock assessment as the most advanced and comprehensive assessment yet conducted for this species.

SC13 also endorsed the use of the assessment model uncertainty grid to characterise stock status and management advice and implications.

SC13 reached consensus on the weighting of assessment models in the uncertainty grid for yellowfin tuna. The consensus weighting considered all options within five axes of uncertainty for steepness, tagging dispersion, tag mixing, size frequency (with two levels), and regional structure to be equally likely. The resulting uncertainty grid was used to characterise stock status, to summarise reference points as provided in the assessment document SC13-SA-WP-06, and to calculate the probability of breaching the adopted spawning biomass limit reference point (0.2*$SB_{F=0}$) and the probability of *Frecent* being greater than F_{MSY}.

5.1 Stock status and trends

The median values of relative recent spawning biomass (2012–15) (*SBrecent*/$SB_{F=0}$) and relative recent fishing mortality (*Frecent*/F_{MSY}) over the uncertainty grid were used to measure the central tendency of stock status. The values of the upper 90th and lower 10th percentiles of the empirical distributions of relative spawning biomass and relative fishing mortality from the uncertainty grid were used to characterise the probable range of stock status.

Descriptions of the updated structural sensitivity grid used to characterise uncertainty in the assessment are provided in Table 8. Figure 4 shows the estimated annual average juvenile and adult fishing mortality for the diagnostic case model. Figure 5 shows the trajectories of fishing depletion for the 48 model runs retained for the structural uncertainty grid used for management advice. Majuro plots summarising the results for each of the models in the structural uncertainty grid retained for management advice are represented in Figures 6 and 7. Figure 8 provides estimates of the reduction in spawning potential due to fishing by region, and over all regions attributed to various fishery groups (gear-types) for the diagnostic case model. Table 9 provides a summary of reference points over the 48 models in the structural uncertainty grid.

Table 8: Description of the updated structural sensitivity grid used to characterise uncertainty in the assessment.

Axis	Levels	Option
Steepness	3	0.65, 0.80, 0.95
Tagging overdispersion	2	Default level (1), fixed (moderate) level
Tag mixing	2	1 or 2 quarters
Size frequency weighting	3	Sample sizes divided by 10, 20, 50
Regional structure	2	2017 regions, 2014 regions

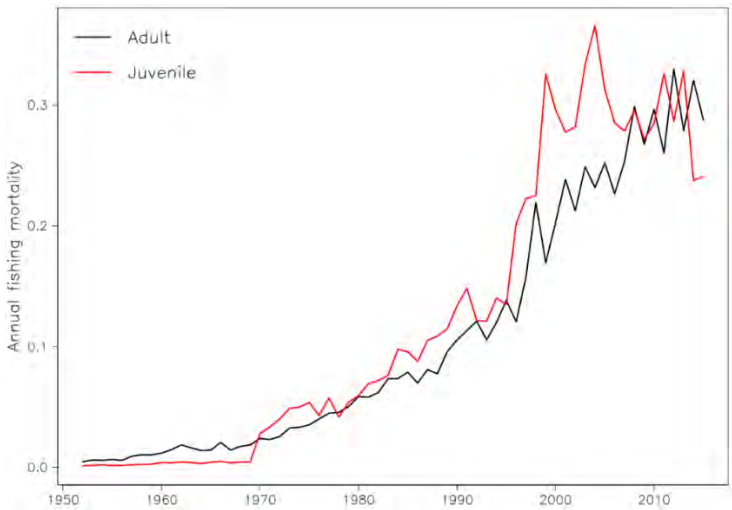


Figure 4: Estimated annual average juvenile and adult fishing mortality for the diagnostic case model.

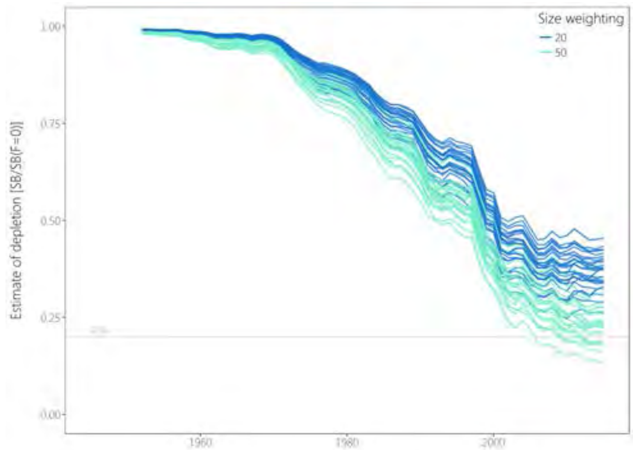


Figure 5: Plot showing the trajectories of fishing depletion (of spawning potential) for the 48 model runs retained for the structural uncertainty grid used for management advice. The colours depict the models in the grid with the size composition weighting using divisors of 20 and 50.

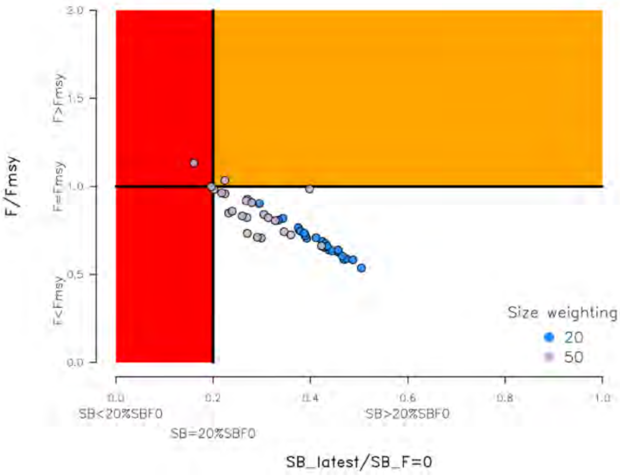


Figure 6: Majuro plot summarising the results for each of the models in the structural uncertainty grid retained for management advice. The plots represent estimates of stock status in terms of spawning potential depletion and fishing mortality. The red zone represents spawning potential levels lower than the agreed limit reference point, which is marked with the solid black line. The orange region is for fishing mortality greater than F_{MSY} (F_{MSY} is marked with the black dashed line). The points represent $SBlatest/SB_{F=0}$, and the colours depict the models in the grid with the size composition weighting using divisors of 20 and 50.

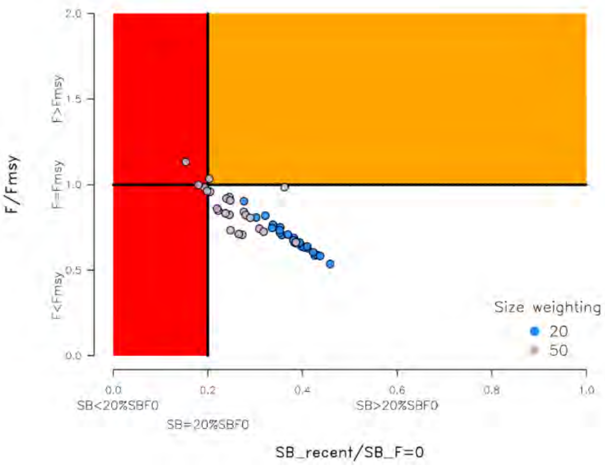


Figure 7: Majuro plot summarising the results for each of the models in the structural uncertainty grid retained for management advice. The plots represent estimates of stock status in terms of spawning potential depletion and fishing mortality. The red zone represents spawning potential levels lower than the agreed limit reference point, which is marked with the solid black line. The orange region is for fishing mortality greater than F_{MSY} (F_{MSY} is marked with the black dashed line). The points represent SB*recent*/$SB_{F=0}$, and the colours depict the models in the grid with the size composition weighting using divisors of 20 and 50.

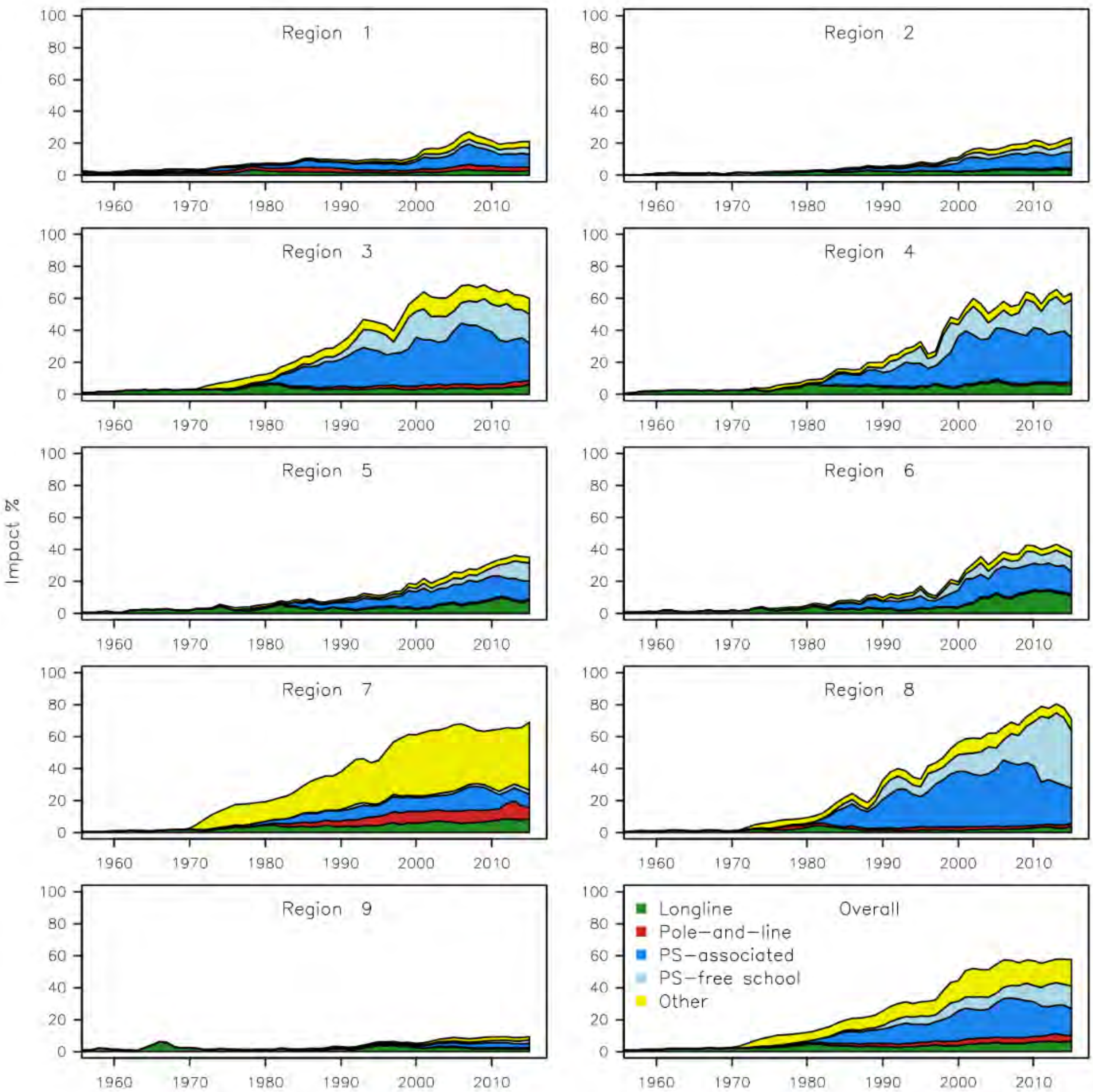


Figure 8: Estimates of reduction in spawning potential due to fishing by region, and over all regions (lower right panel), attributed to various fishery groups (gear-types) for the diagnostic case model.

SC13 noted that the central tendency of relative recent spawning biomass was the median $SBrecent/SB_{F=0}$ = 0.33 with a probable range of 0.20 to 0.41 (80% probable range), and there was a roughly 8% probability (4 out of 48 models) that the recent spawning biomass had breached the adopted LRP with Pr($SBrecent/SB_{F=0}$ < 0.2) = 0.08. The median estimate (0.33) is below that estimated from the 2014 assessment grid ($SBcurrent/SB_{F=0}$ = 0.41, see SC10-SA-WP-04), noting the differences in grid uncertainty axes used in that assessment.

SC13 noted that the central tendency of relative recent fishing mortality was the median $Frecent/F_{MSY}$ = 0.74 with an 80% probability interval of 0.62 to 0.97, and there was a roughly 4% probability (2 out of 48 models) that the recent fishing mortality was above F_{MSY} with Pr($Frecent/F_{MSY}$ > 1) = 0.04. The median estimate (0.74) is also comparable to that estimated from the 2014 assessment grid ($Fcurrent/F_{MSY}$ = 0.76, see SC10-SA-WP-04).

SC13 noted that the assessment results show that the stock has been continuously declining for about 50 years since the late 1960s.

Table 9: Summary of reference points over the 48 models in the structural uncertainty grid retained for management advice using divisors of 20 and 50 for the weighting on the size composition data. Note that *$SBrecent/SB_{F=0}$* is calculated where *SBrecent* is the mean *SB* over 2012–15 instead of 2011–14 (used in the stock assessment report), at the request of the Scientific Committee.

	Mean	Median	Min	10%	90%	Max
Clatest	611 982	612 592	606 762	607 517	614 237	614 801
MSY	670 658	670 800	539 200	601 480	735 280	795 200
YFrecent	646 075	643 400	534 400	586 120	717 880	739 600
Fmult	1.34	1.36	0.88	1.03	1.61	1.86
F_{MSY}	0.12	0.12	0.07	0.10	0.14	0.16
$Frecent/F_{MSY}$	0.77	0.74	0.54	0.62	0.97	1.13
SB_{MSY}	544 762	581 400	186 800	253 320	786 260	946 800
SB_0	2 199 750	2 290 000	1 197 000	1 366 600	2 784 500	3 256 000
SB_{MSY}/SB_0	0.24	0.24	0.15	0.18	0.28	0.34
$SB_{F=0}$	2 083 477	2 178 220	1 193 336	1 351 946	2 643 390	2 845 244
$SB_{MSY}/SB_{F=0}$	0.25	0.26	0.16	0.19	0.30	0.35
$SBlatest/SB_0$	0.33	0.34	0.18	0.23	0.42	0.45
$SBlatest/SB_{F=0}$	0.35	0.37	0.16	0.22	0.46	0.50
$SBlatest/SB_{MSY}$	1.40	1.39	0.80	1.02	1.80	1.91
$SBrecent/SB_{F=0}$	0.32	0.33	0.15	0.20	0.41	0.46
$SBrecent/SB_{MSY}$	1.40	1.41	0.81	1.05	1.71	1.93

SC13 also noted that levels of fishing mortality and depletion differ between regions, and that the fisheries impact was highest in the tropical region (Regions 3, 4, 7 and 8 in the stock assessment model), mainly due to the purse-seine fisheries in the equatorial Pacific and the ‘other’ fisheries within the western Pacific (as shown in figure 44 of SC13-SA-WP-06).

Based on the uncertainty grid adopted by SC13 the spawning biomass is highly likely above the biomass LRP and recent *F* is highly likely below F_{MSY} and therefore, while noting the level of uncertainties in the current assessment, it appears that the stock is not experiencing overfishing (96% probability) and it appears that the stock is not in an overfished condition (92% probability).

Based on the diagnostic case, both juvenile and adult fishing mortality show a steady increase since the 1970s. Adult fishing mortality has increased continuously over most of the time series, while juvenile fishing mortality has stabilised since the late 1990s at a level similar to that now estimated for adult yellowfin.

SC13 reiterated its previous advice from SC10 that WCPFC could consider measures to reduce fishing mortality from fisheries that take juveniles, with the goal to increase to maximum fisheries yields and reduce any further impacts on the spawning potential for this stock in the tropical regions.

SC13 also reiterated its previous advice from SC10 that measures should be implemented to maintain current spawning biomass levels until the Commission can agree on an appropriate target reference point (TRP).

5.2 Estimates of fishery parameters and abundance

There are no fishery-independent indices of abundance for the yellowfin tuna stock. Relative abundance information is available from standardised indices of longline catch per unit effort data. Returns from large-scale tagging programmes undertaken in the early 1990s and 2000s also provide information on rates of fishing mortality, which in turn leads to improved estimates of abundance.

5.3 Biomass estimates

These estimates apply to the WCPO portion of the stock or an area that is approximately equivalent to the waters west of 150°W. The stock assessment results and conclusions of the 2017 assessment show $SBrecent/SB_{MSY}$ is estimated at 1.41 over the period 2013–15. Spawning biomass for the WCPO is estimated to have declined to about 37% of its initial level by 2015.

5.4 Yield estimates and projections

No estimates of MCY and CAY are available.

5.5 Other yield estimates and stock assessment results

SC13 achieved consensus to accept and endorse the median of the structural uncertainty grid for providing management advice proposed in the assessment document, and that $SB_{20\%,F=0}$ be used as the LRP for stock status purposes as agreed by WCPFC. There was further discussion about whether to use *SBlatest* or *SBrecent* as the terminal spawning biomass for management purposes. The SC agreed to use *SBrecent* corresponding to 2013–15. At 0.33 $SB_{F=0}$, *SBrecent* is above the limit reference point.

SC10 also endorsed the use of the candidate biomass-related target reference point (TRP) currently under consideration for skipjack tuna, i.e., 40–60% $SB_{F=0}$. At 0.33 $SB_{F=0}$, *SBrecent* is below the target reference point.

5.6 Other factors

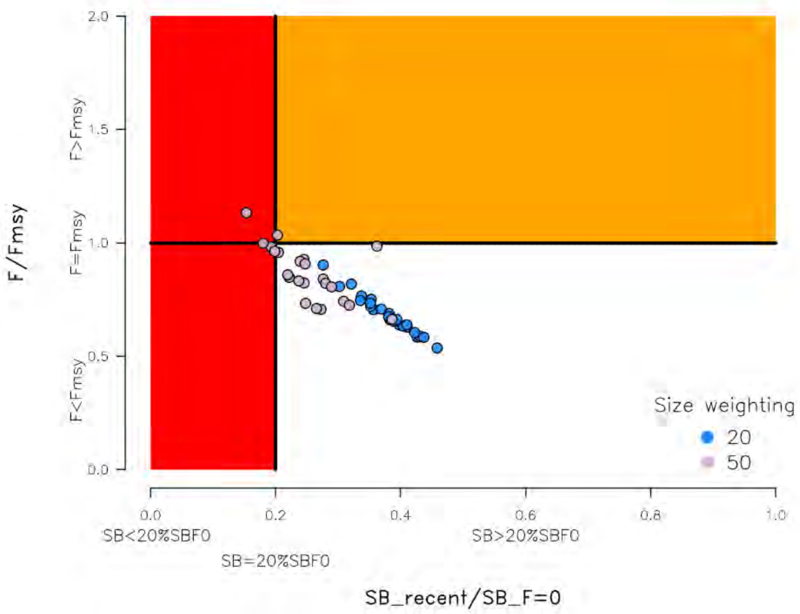
It is thought that large numbers of small yellowfin tuna are taken in surface fisheries in Indonesia and the Philippines. There are considerable uncertainties in the exact catches and these lead to uncertainties in the assessment. Programmes are in place to improve the collection of catch statistics in these fisheries.

6. STATUS OF THE STOCKS

Stock structure assumptions

The stock is considered to cover the western and central Pacific Ocean.

Stock Status	
Year of Most Recent Assessment	2017
Assessment Runs Presented	Median of the structural uncertainty grid and 80% PI
Reference Points	Candidate biomass-related target reference point (TRP) currently under consideration for key tuna species is 40–60% SB_0 Limit reference point of 20% SB_0 established by WCPFC equivalent to the HSS default of 20% SB_0 Hard Limit: Not established by WCPFC; but evaluated using HSS default of 10% SB_0 Overfishing threshold: F_{MSY}
Status in relation to Target	Recent levels of spawning biomass are About as Likely as Not (40–60%) to be at or above the lower end of the range of 40–60% SB_0 (based on both the 2013–15 average and the 2015 estimate) Likely (> 60%) that $F < F_{MSY}$
Status in relation to Limits	Soft Limit: Very Unlikely (< 10%) to be below Hard Limit: Exceptionally Unlikely (< 1%) to be below
Status in relation to Overfishing	Overfishing is Unlikely (< 40%) to be occurring

Historical Stock Status Trajectory and Current Status

Majuro plot summarising the results for each of the models in the structural uncertainty grid retained for management advice. The plots represent estimates of stock status in terms of spawning potential depletion and fishing mortality. The red zone represents spawning potential levels lower than the agreed limit reference point, which is marked with the solid black line. The orange region is for fishing mortality greater than F_{MSY} (F_{MSY} is marked with the black dashed line). The points represent $SBrecent/SB_{F=0}$, and the colours depict the models in the grid with the size composition weighting using divisors of 20 and 50.

Fishery and Stock Trends	
Recent trend in Biomass or Proxy	Biomass has been reduced steadily over time reaching a level of about 33% of unexploited biomass in 2013–15.
Recent Trend in Fishing Intensity or Proxy	Fishing mortality has increased over time but is estimated to be lower than F_{MSY} in all cases.
Other Abundance Indices	-
Trends in Other Relevant Indicator or Variables	The significance of the recent increased recruitment events and the progression of these fish to the spawning potential component of the stock was encouraging, although whether this was a result of management measures for the fishery or beneficial environmental conditions is currently unclear.

Projections and Prognosis	
Stock Projections or Prognosis	Stochastic projection results indicated that for yellowfin tuna it was Exceptionally Unlikely (< 1%) that the yellowfin stock would fall below the LRP level or that fishing mortality would increase above the F_{MSY} level by 2032.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Very Unlikely (< 10%) Hard Limit: Exceptionally Unlikely (< 1%)
Probability of Current Catch or TACC causing Overfishing to continue or commence	Exceptionally Unlikely (< 1%)

Assessment Methodology and Evaluation		
Assessment Type	Level 1: Quantitative Stock assessment	
Assessment Method	The assessment uses the stock assessment model and computer software known as MULTIFAN-CL.	
Assessment Dates	Latest assessment: 2017	Next assessment: 2020
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	This assessment includes improved purse-seine catch estimates; reviews of the catch statistics of the component fisheries; standardised CPUE analyses of operational level catch and effort data; size data inputs from the purse-seine and longline fisheries; revised regional structures and fisheries definitions; preparation of tagging data and reporting rate information.	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	Changes to the data from the 2014 assessment included: - changes to the number of spatial regions to better model the tagging and size data - a complete update of the 2014 reference case model - improved recruitment estimates - a large number of new tagging data corrected for differential post-release mortality and other tag losses.	
Major Sources of Uncertainty	The apparent non-linear impact of the weighing on the size composition data on population estimates, and the conflict between the abundance indices and the tagging data for region 8 are worthy of note. Also, biological studies to improve estimates of growth of yellowfin within the WCPO are required.	

Qualifying Comments
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Environmental and Ecosystem Considerations
Most of the yellowfin tuna catch in the New Zealand EEZ is caught in the tuna and swordfish surface-longline fishery, please refer to those species for environmental and ecosystem considerations.

7. FOR FURTHER INFORMATION

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