Chapter 10: Chondrichthyans (sharks, rays and chimaeras) - Technical Summary

Fishing threats to sharks



Non-target and incidental catches

1. THE ISSUE IN BRIEF

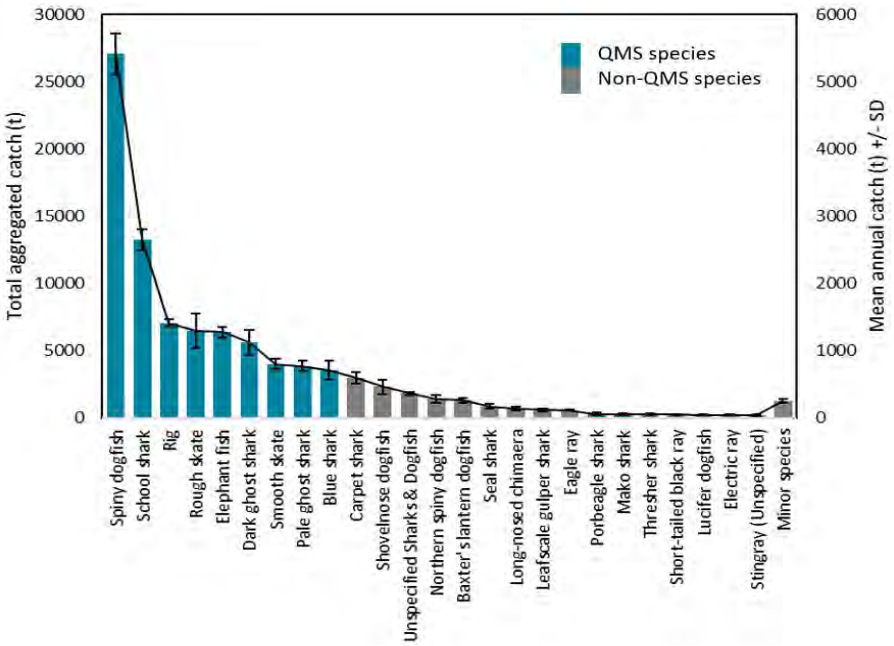
- Chondrichthyans (sharks, rays, and chimaeras) usually are long-lived, have low fecundity, and some are slow growing
- These characteristics make them potentially more vulnerable to adverse fishing effects
- 77 species of chondrichthyans have been recorded in fisheries landings, 11 of these are managed under the Quota Management System (QMS), and 7 are protected in NZ
- International conventions, national policy, and legislation govern the management of chondrichthyans in NZ

2. CHONDRICHTHYAN DIVERSITY

- There are 112 species of chondrichthyans reported in NZ waters (and 3 ray species in the Ross Sea, Antarctica), comprising of 12 chimaeras, 26 rays, and 74 sharks
- A high percentage (30%) of these chondrichthyans are only found in NZ waters (e.g. dark ghost shark)
- Chondrichthyans such as the whale shark or the manta ray are typical of warmer waters and are rare in NZ, but are occasionally seen in the northern part of NZ waters during summer (see 5.)

3. CHONDRICHTHYAN FISHERIES

- Several chondrichthyan species are of commercial interest for fisheries in NZ, and 11 species (accounting for up to 90% of total chondrichthyan catch) are managed through the QMS
- Fisheries data analyses indicate that QMS chondrichthyan stocks in NZ are either stable or increasing, with few local exceptions



- Spiny dogfish, porbeagle, blue shark, and other, non-QMS, species are often discarded. Some species can be discarded dead or alive (and are counted against the annual catch entitlement) whereas others can be released alive (and thus in most cases are not counted against the annual catch entitlement).

Reported total catches (landing, discards, and live releases) for chondrichthyan species, aggregated across 2018-19 to 2022-23 (mean indicated with a solid line and on the right vertical axis). Spiny dogfish and school shark (both in the QMS), had the highest catch tonnage.

4. RISK ASSESSMENT

• Previous and current National Plans Of Action for the Conservation and Management of Sharks use a risk-based approach to prioritise management actions
• A qualitative risk assessment was run in 2014, gathering expert knowledge on the risk to all chondrichthyans from commercial fishing in New Zealand
• The risk-assessment process was repeated in 2017 with similar methods, incorporating updated knowledge and including 50 species prioritised by the first assessment, with the goal to further select species for additional research, more quantitative future assessments, and management

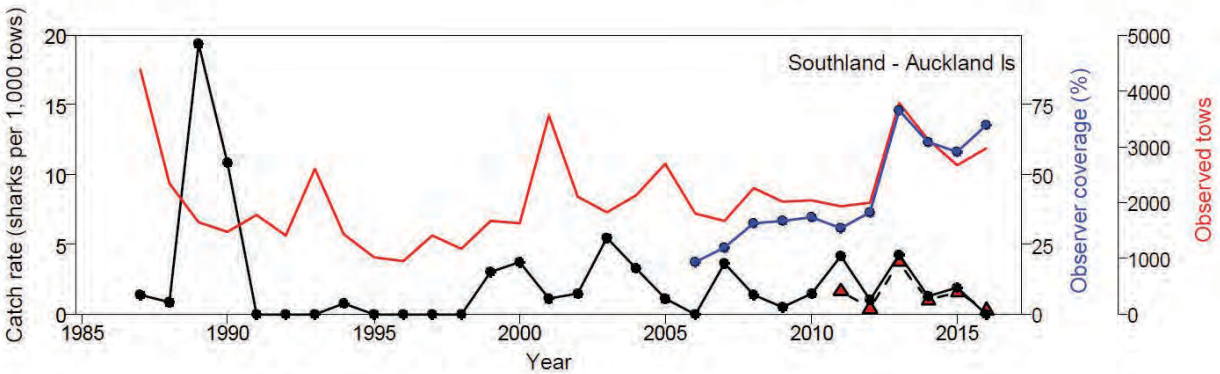
• The main outcomes of the risk assessment were:
- A general consensus that there is a low risk of unsustainable fishing impacts for most species
- Species that are caught in small quantities are data poor, and consequently there is low confidence in their risk scores
- The highest estimated risks were for some QMS and deepwater shark species, whereas protected species (i.e. basking shark, spinetail devilray and white pointer shark) had lower risk scores

5. PROTECTED SPECIES

• The Wildlife Act 1953 protects seven species of chondrichthyans:
- Basking shark (since 2007)
- White pointer shark (since 2007)
- Whale shark (since 2010)
- Deepwater nurse shark (since 2010)
- Oceanic whitetip shark (since 2013)
- Spine-tailed devil ray (since 2010)
- Manta ray (since 2010)

• It is illegal to hunt or kill these species within NZ waters, as well as trade in teeth, jaws, and fins.
However, although it is not illegal to incidentally capture or injure these species, it is mandatory to report captures and interactions

• Despite some uncertainties, analyses suggest that basking shark capture indicators are stable in recent years
• Monitoring incidental captures should be continued to ensure sustainability of fisheries



Basking shark capture rate index for the Southland-Auckland Is. area (Francis 2017). Incidental captures per unit of effort in fisheries (black lines), as well as coverage by fisheries observers (coloured lines)

6. ONGOING RESEARCH

- An updated quantitative risk assessment for selected chondrichthyan species is currently underway
- Post-release survival estimation for some pelagic and inshore sharks has recently been completed
- Identification and mapping of habitats of significance for some chondrichthyan species is currently underway

10 CHONDRICHTHYANS (SHARKS, RAYS AND CHIMAERAS)

Status of chapter	Updated in 2024.
Scope of chapter	Outlines the relevant biology of New Zealand chondrichthyans, the nature of fishing interactions, the management approach, and trends in key indicators of fishing effects. This chapter covers Quota Management System (QMS), non-QMS, and protected chondrichthyans.
Area	Primarily the New Zealand EEZ and Territorial Sea. International work relevant to chondrichthyan science in New Zealand is discussed.
Focal localities	This differs depending upon the species or fishery considered.
Key issues	Sustainability of fishing mortality with a focus on protected and non-QMS species.
Emerging issues	Potential new non-target catch mitigation technology, inadequate information on deep-sea sharks, further development of the risk assessment framework for chondrichthyans.
Fisheries New Zealand research (current)	BYC2022-02 Risk assessment for selected shark species BYC2023-03: Identification and mapping of habitats of significance for sharks
Other government research (current)	DOC CSP research: INT2021-04: Collection and curation of tissue samples from protected fishes and turtles INT2023-04 Identification of marine mammals, turtles and protected fish captured in New Zealand fisheries
University research	Biological and behavioural research for white pointer sharks (The University of Waikato) School shark research (Massey University)
Related issues/chapters	See the Non-target fish and invertebrate catch chapter. More detail is provided for QMS species in the stock assessment plenary (Fisheries New Zealand 2023, 2024).

10.1 CONTEXT

Chondrichthyes is a class of cartilaginous fishes (chondrichthyans) that is separated into two subclasses: Elasmobranchii (true sharks, skates, and rays) and Holocephali (chimaeras). In New Zealand, the Fisheries (Commercial Fishing) Regulations 2001 uses the term *sharks* to mean "a fish of the class Chondrichthyes, but excludes Batoidea". This definition therefore encompasses all true sharks as well as Order Chimaeriformes (which includes pale ghost shark, dark ghost shark and elephant fish), but excludes superorder Batoidea (rays and skates). However, in this chapter, we use the terms *chondrichthyans*, *sharks*, *rays* and *chimaeras* in their strict sense to avoid confusion. Skates are a type of ray and are grouped with rays.

In New Zealand, seven chondrichthyan species have absolute protection under the Wildlife Act (1953). The impacts of fishing on chondrichthyans are managed under the Fisheries Act (1996), with eleven species subject to the Quota Management System (QMS) and two species prohibited as target species under Schedule 4C (although they might still be taken as non-target catch). The management policy framework is contained in Fisheries Plans developed for the Deepwater, Highly Migratory, and Inshore fisheries (see Chapter 1 for fuller descriptions and web links).

New Zealand has international obligations to collaborate with other countries in the assessment and management of shared and migratory chondrichthyan stocks. New Zealand participates in a number of Regional Fisheries Management Organisations (RFMOs) that have some responsibility for chondrichthyans, including Western and Central Pacific Fisheries Commission (WCPFC; which manages tuna fisheries and the associated species), Commission for the Conservation of Southern Bluefin Tuna (CCSBT), Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR; toothfish), and the South Pacific Regional Fisheries Management Organisation (SPRFMO; multiple non-Highly Migratory Species). New Zealand is also a signatory to conventions that play a role in the management of some species, including the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and the Convention on the Conservation of Migratory Species of Wild Animals (CMS).

To address global concerns about the management of chondrichthyans[1], the Food and Agriculture Organisation of the United Nations (FAO) developed an International Plan of Action for the Conservation and Management of Sharks (IPOA)[2]. The IPOA builds upon the FAO Code of Conduct for Responsible Fisheries and was endorsed by the FAO Council in June 1999 and subsequently adopted by the November 1999 FAO Conference. The overarching objective of the IPOA is: "to ensure the conservation and management of sharks and their long-term sustainable use". To achieve this goal the IPOA suggests that each member state of FAO that regularly catches chondrichthyans, either as target or incidental catch, should develop a National Plan of Action for the Conservation and Management of Sharks (NPOA-Sharks).

New Zealand developed an NPOA-Sharks which came into effect in October 2008 (Ministry of Fisheries 2008). This was updated in 2013 (Ministry for Primary Industries 2013). Fisheries New Zealand (FNZ) and the Department of Conservation (DOC) developed an updated draft plan, NPOA-Sharks 2024, with support from a stakeholder group which included environmental and industry representatives. At the time of publication of this chapter, NPOA-Sharks 2013 remains in place. The purpose of NPOA-Sharks 2013 is:

> "*To maintain the biodiversity and the long-term viability of all New Zealand shark populations by recognising their role in marine ecosystems, ensuring that any utilisation of sharks is sustainable, and that New Zealand receives positive recognition internationally for its efforts in shark conservation and management*."

It identifies goals and five-year objectives in the following key areas:

- Biodiversity and long-term viability of shark populations
- Utilisation, waste reduction, and the elimination of shark finning
- Domestic (national) engagement and partnerships
- Non-fishing threats
- International engagement
- Research and information.

It is a comprehensive plan with the aim of improving our knowledge of chondrichthyan populations and their interactions with fisheries. Its focus is to base conservation and management actions on a science-based assessment of risks.

The NPOA-Sharks 2013 applies to all chondrichthyans that are found within New Zealand's Exclusive Economic Zone (EEZ, 12 to 200 nautical miles from the coast) and Territorial Sea (New Zealand waters within 12 nautical miles of the coast), migratory species that frequent New Zealand fisheries waters for some of their life-span, and species taken by New Zealand-flagged vessels fishing on the high seas (including the Ross Sea, Antarctica). The scope of the plan is not restricted to fishing impacts but also applies to non-fishing anthropogenic and environmental impacts on chondrichthyans. The AEBAR appendix provides a list of all 115 known New Zealand and Ross Sea chondrichthyans, including their scientific and common names, their management class and International Union for Conservation of Nature (IUCN) and DOC threat classes.

10.2 BIOLOGY

The population dynamics of chondrichthyans differ markedly from those of most bony fishes. Through their reproductive strategy, they produce a small number of well-resourced egg cases or well-developed young, rather than spawning large numbers of undeveloped eggs as do most bony fishes. Chondrichthyans either lay large yolky egg cases on the seabed or give birth to live young, but in both reproductive modes the number of young produced annually is usually in single digits or in the low tens. A few species may produce more than 100 young per litter (e.g., the blue shark, *Prionace glauca*, has up

[1] In the IPOA and in the NPOA–Sharks, the definition of 'sharks' includes all chondrichthyans, viz. sharks, rays, skates and chimaeras.
[2] FAO International Plan of Action for Conservation and Management of Sharks, https://www.fao.org/ipoa-sharks/en.

to 135 young; Last & Stevens 2009), but even in these more fecund species, large litter sizes are exceptional and the average number of young per female is much lower (30–40 in the blue shark; Last & Stevens 2009). Gestation periods and reproductive cycles last 10 months to two years in many species and may be as high as three years (e.g., school shark, *Galeorhinus galeus*; mako shark, *Isurus oxyrinchus*; Mollet et al. 2000, Walker 2005). Fecundity may increase with the size of females (e.g., rig, *Mustelus lenticulatus*, and school shark; Francis & Mace 1980, Walker 2005), so if human activities reduce the average size of females in a population (as often happens in fisheries), a greater number of mature females would be required to maintain population productivity at the same level. These characteristics mean that chondrichthyans have a much closer, potentially almost linear, relationship between population size and recruitment. Due to low fecundity, late maturity and slow growth, density-dependent compensation responses are likely to be less pronounced for chondrichthyans compared to bony fishes at low population sizes.

Many chondrichthyans are slow growing, further limiting their capacity for recovering from population declines. Many species have ages at maturity greater than 10 years and longevities in excess of 20 years, although some are faster growing and are therefore more productive (e.g., rig, Francis & Ó Maolagáin 2000). The combination of low reproductive rates and low growth rates makes chondrichthyans, especially deepwater species, particularly vulnerable to overfishing (Camhi et al. 1998, Smith et al. 1998, Dulvy et al. 2003, 2017, Kyne & Simpfendorfer 2007, Pikitch et al. 2008, Simpfendorfer & Kyne 2009).

Studies have been carried out to estimate the age, growth, length-at-maturity, and size and age composition of the three main pelagic sharks taken as non-target catch in surface longline fisheries (blue; porbeagle, *Lamna nasus*; and mako sharks) (Francis 2015, Francis 2016b, Francis & Ó Maolagáin 2016). Similar studies have also been carried out on a group of small inshore and deepwater sharks and rays (Francis et al. 2018a, 2018b). Age estimation was equivocal for some of these species (especially blue shark), and no age validation was carried out for any of the species, so our knowledge of growth and age-related parameters (maturity, longevity) remains uncertain. Nevertheless, vertebral band counts of common electric ray (*Torpedo fairchildi*), blind electric ray (*Typhlonarke aysoni*), and carpet shark (*Cephaloscyllium isabella*) indicated that these species were relatively fast growing and therefore productive, whereas band counts of dorsal fin spines in several deepwater sharks (Owston's dogfish, *Centroscymnus owstonii*; longnose velvet dogfish, *Centroselachus crepidater*; and Plunket's shark, *Scymnodon plunketi*) supported Australian studies indicating that they are slow-growing and long-lived.

Satellite tags have been deployed on blue, porbeagle, mako, and smooth hammerhead (*Sphyrna zygaena*) sharks to identify their movement patterns, migratory behaviour, habitat requirements, post-release survival and use of the water column (Francis et al. 2015b, 2023, Francis 2016a, Elliott et al. 2022). Porbeagle sharks make seasonal north-south migrations and are vertical migrators, spending daytime at depths of 200–600 m and night-time at 50–100 m. Mako sharks may remain resident in coastal waters for several months, but periodically (mainly in winter) migrate northwards to subtropical and tropical waters. Juvenile hammerheads inhabit coastal waters for their first few years of life. Satellite tagging has also been used on white pointer sharks (*Carcharodon carcharias*, also known as great white sharks) and spinetail devil rays (*Mobula japonica)* to investigate movement and post-capture survival (see e.g., Bonfil et al. 2010, Duffy et al. 2012, Francis & Jones 2017).

Biological parameters (e.g., growth, longevity, reproduction, stock identity) were reviewed for Pacific pelagic sharks, providing a readily available summary of inputs for subsequent population modelling (Clarke et al. 2015).

Anthropogenic threats other than fishing were reviewed for rig populations (Jones et al. 2015). Kaipara Harbour is the most important rig nursery area in the country, and it is significantly impacted by agricultural activities, with the southern area especially vulnerable to the effects of future urbanisation. Raglan Harbour and Kawhia Harbour may also represent significant nursery areas that are impacted mainly by agricultural activities rather than urbanisation.

Hernández et al. (2015) and Devloo-Delva et al. (2019) conducted genetic studies of South Pacific school sharks and found evidence of mixing between New Zealand and Australia (which is consistent with previous tagging results), but genetic separation of the Australasian population from the Chilean population.

To support fisheries management and conservation, a global database of chondrichthyan life history traits and abundance time series is available online (Mull et al. 2022, sharkipedia - elasmobranch traits & trends).

10.3 GLOBAL UNDERSTANDING OF FISHERIES INTERACTIONS

Overfishing presents the greatest threat to chondrichthyan species globally (Dulvy et al. 2021). There are numerous examples worldwide of chondrichthyan stocks collapsing under fishing pressure, and until the 21st Century, little attention had been focused on their management. This situation reflects the generally low importance of chondrichthyans in terms of quantity and value in commercial catches, and the consequent low research and management priority accorded to them. An important driver in the increase in global chondrichthyan fishing mortality over the last two decades was growing demand for shark and ray meat and fins, and other products such as mobulid gill plates, cartilage, skin, or liver oil (Bräutigam et al. 2015). A lack of management has led to unregulated trade and the use of umbrella terms for many threatened species, which can preclude species-level management and potentially push these species closer to extinction (Cardeñosa et al. 2022, Sharrad et al. 2023, Sherman et al. 2023). Although there is evidence of a decline in the shark fin trade since 2011 (Dent & Clarke 2015), many chondrichthyan populations are now believed to be severely depleted. There is also widespread public opposition to shark 'finning', in which only the fins are kept and the rest of the shark is discarded at sea, because of concerns about sustainability, wastage, and finning of live sharks. In New Zealand, live shark finning is an offence under the Animal Welfare Act 1999 and shark finning, as defined, was banned in October 2014. Since the ban came into effect, release rates for some species (e.g., blue, mako and porbeagle sharks) have increased (Griggs et al. 2018).

Chondrichthyans are caught in nearly all parts of the ocean, ranging from tropical to polar waters, and from estuaries and shallow coastal waters to the deepest areas fished. Chondrichthyans are caught by most fishing methods, although trawling, set netting, and longlining are the most significant ones. Reported global landings of chondrichthyans increased steadily up to almost 900 000 t in the early 2000s but have subsequently declined by ~27% to 2021 (Worm et al. 2013, Davidson et al. 2015, FAO 2023; Figure 10.1). However unreported catches are undoubtedly substantial so the true extent of chondrichthyan catches remains unclear (Bonfil 1994, Camhi et al. 1998, Clarke et al. 2006, Worm et al. 2013). Estimates of the mortality rates of chondrichthyans at the time they are hauled to a fishing vessel are available for some species (e.g., Francis et al. 1999a, Campana et al. 2009, Griggs & Baird 2013), and increasing attention is being devoted to estimating the survival of chondrichthyans released alive by fishers (Moyes et al. 2006, Campana et al. 2009, Musyl et al. 2011, Hutchinson et al. 2013, Ellis et al. 2017). The post-release mortality of mako and silky (*Carcharhinus falciformis*) sharks released from tuna longlines in New Zealand, Fiji, New Caledonia, and Marshall Islands (Clarke et al. 2017, Francis et al. 2023) and the mortality of spinetail devil rays released from purse seiners fishing for skipjack tuna in New Zealand (Francis & Jones 2017) have been investigated.

There is ample evidence that globally many chondrichthyan populations are overfished (Simpfendorfer & Kyne 2009, Dulvy et al. 2021). Management measures have been implemented by many countries, particularly for targeted species, and RFMOs are paying greater attention to the need to manage species that occur in international waters or waters that straddle national waters (e.g., Burns et al. 2023). Efforts are also focusing on reducing shark finning, particularly in fisheries catching pelagic sharks, by requiring fins to be attached to sharks at the point of landing, or to comprise no more than 5% of the landing by weight. It is not clear that this requirement has been effective in reducing catches or mortality (Clarke et al. 2012, Worm et al. 2013, 2024).

Despite the threat of overfishing, there are examples where effective management has led to the reduction of extinction risk and the sustainability of fished chondrichthyan stocks; however, many of these examples are from developed nations with well-developed fisheries management systems (Simpfendorfer & Dulvy 2017, Pacoureau et al. 2023).

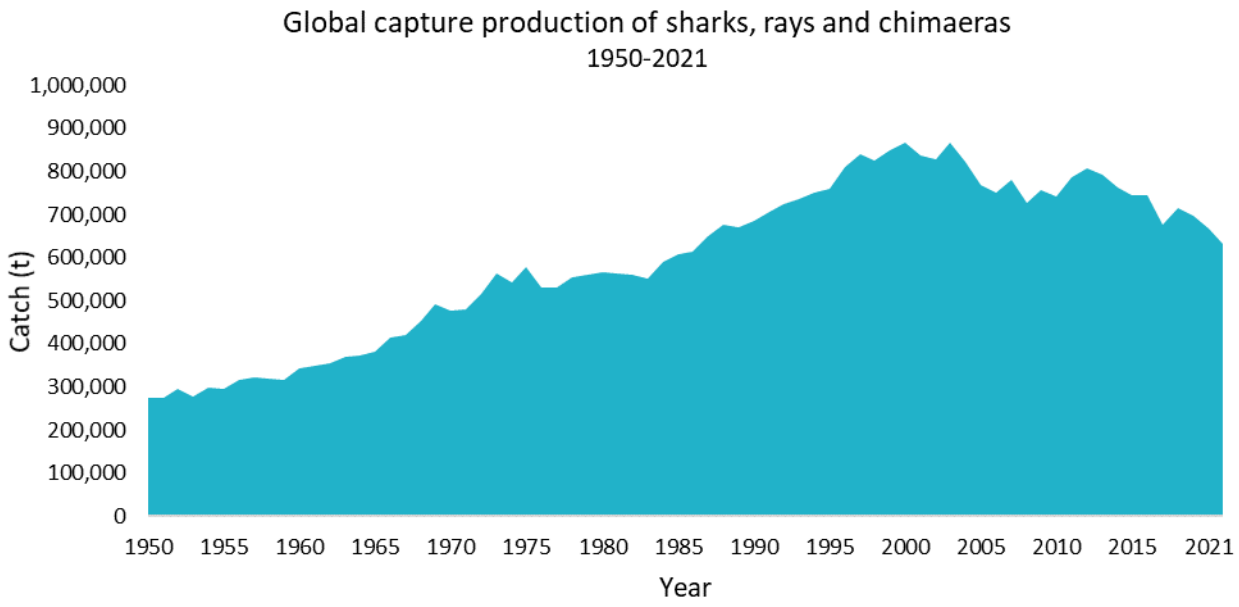


Figure 10.1: Global catches of chondrichthyans reported to FAO (1950–2021). *Source*: FAO 2023. Fishery and Aquaculture Statistics. Global capture production 1950-2021 (FishstatJ).

10.4 STATE OF KNOWLEDGE OF FISHERIES INTERACTIONS IN NEW ZEALAND

Chondrichthyans were an important resource for pre-European Māori who utilised them for food and oil and incorporated their teeth into tools and weapons. Species such as spiny dogfish (*Squalus acanthias*), northern spiny dogfish (*S. griffini*), school shark and rig were likely the most important species to pre-European Māori and were often dried for preservation before consumption at hui (meetings) and as hākari (funerary feasting). Fishing practices were varied and included the use of nooses, nets, wooden spears, wooden hooks bound with harakeke (New Zealand flax; *Phormium tenax*) and hooks fashioned from dogfish spines. Fishing seasons often commenced on natural cues; for example, upon the emergence of pōhutukawa flowers in Waitematā Harbour in mid-summer and after the full moon in January around Rangaunu Harbour. Fisheries were controlled through rāhui (prohibition) and chiefly privilege. A variety of species were utilised by Māori and a single archaeological site within Manukau Harbour was found to contain vertebrae, toothplates, tail spines and teeth of rig, school shark, bronze whaler (*Carcharhinus brachyurus*), eagle ray (*Myliobatis tenuicaudatus*), stingrays and skates (Shepherd & Campbell 2021, Campbell et al. 2022). Many chondrichthyan species are considered taonga (treasures) and hold cultural significance to Māori.

A total of 112 chondrichthyans are known from New Zealand waters (and 3 from the Ross Sea), however that number is expected to change with the continuation of taxonomic studies on deepwater species. Of these species, 12 are chimaeras, 29 are skates and rays (3 from the Ross Sea), and 74 are sharks. Many New Zealand species also occur elsewhere in the world (some have worldwide distributions), but a high percentage (30%) are considered endemic to New Zealand. New Zealand has fewer chondrichthyan species than Australia, which has more than 322 species (Last & Stevens 2009), and that partly reflects New Zealand's temperate location.

The largest threat to chondrichthyan populations is from fishing activities, although other potential impacts include dredging, sonar surveys, electromagnetic fields generated by power stations and undersea cables, loss of habitat, eutrophication and sedimentation, entrapment by aquaculture facilities, shark ecotourism, and the indirect effects of climate change (Francis & Lyon 2013, Jones et al. 2015). More than 70 of New Zealand's chondrichthyan species are caught (deliberately or incidentally) by fishers (Ministry for Primary Industries 2013). Eleven chondrichthyans are managed under the QMS (Fisheries New Zealand 2023, 2024), seven are protected (Francis & Lyon 2012), two cannot be targeted, and the remainder are non-QMS species. Due to reporting requirements, commercial landings of chondrichthyans are well known, but much less is known about recreational and customary catches.

A nationwide survey from 1 October 2011 to 30 September 2012 provided estimates of recreational chondrichthyan catches (Wynne-Jones et al. 2014) and was updated in 2017–18 (Wynne-Jones et al. 2019); the 2017–18 results are reported in Table 10.1. Most of the recreational catch is from inshore QMS species, although mako shark inhabits both inshore and offshore regions. 'Stingray' is likely to include more than one species and 'sand shark' is likely to refer mainly to rig or school shark. Mako sharks are also targeted or caught as non-target catch in the gamefish fishery, so estimates for mako are potentially underestimated because the survey was not designed to sample gamefishers. Estimates in tonnes are only available for rig and spiny dogfish, and these constituted > 4% and > 0.4%, respectively, of the reported commercial landings in the same year for those species. Information on captures of protected chondrichthyans in recreational fisheries is sparse and mostly consists of anecdotal reports to DOC. Between March 2019 and February 2020, eight juvenile white pointer sharks were reported caught in recreational fisheries, mostly from upper North Island beaches and harbours (Abraham 2021). Of these eight sharks, five were mortalities and three were released alive with unknown post-release survival. All subsequent data reported in this chapter are from the commercial fisheries.

Commercial catches of chondrichthyan species during the five-year period 2018−19 to 2022−23 are shown in Table 10.2 and Figure 10.2. Spiny dogfish produced by far the greatest catch, followed by school shark, rig, rough skate (*Zearaja nasuta*), elephantfish (*Callorhinchus milii*) and dark ghost shark (*Hydrolagus novaezealandiae*). Smooth skate (*Dipturus innominatus*), pale ghost shark (*Hydrolagus bemisi*), blue shark, carpet shark, shovelnose dogfish (*Deania calcea)* and Unspecified Sharks & Dogfish formed a second tier (between 500 and 1500 t per year on average). The remaining species had relatively low catches (less than about 400 t per year on average) and about half of the 112 species of chondrichthyans had an average catch of less than 1 tonne per year over the five-year period. In implementing the objectives of the NPOA-Sharks 2013, Fisheries New Zealand successfully worked with the fishing industry to increase the use of species-specific codes and decrease the use of generic codes (Unspecified Sharks & Dogfish (OSD) and deepwater dogfish (DWD)). OSD was once a significant category but the use of this code has declined by one-third since the late 2000s. DWD has become a minor category, declining by over 70% since the late 2000s. This indicates that fishers have become better at reporting their chondrichthyan catch to the species level.

Among QMS species, very small proportions (or none) of the catch of blue shark, mako shark and porbeagle shark were retained between 2018–19 and 2022–23 (Table 10.3). Similar low levels of retention were seen for some non-QMS species (e.g., carpet shark, northern spiny dogfish, thresher shark, short-tailed black ray, electric ray and stingray (unspecified)). Under Schedule 6 of the Fisheries Act (repealed on 1 November 2022), eight chondrichthyan species were able to be legally returned to the sea if alive, and from 2006−07 such releases were not required to be balanced against Annual Catch Entitlement (ACE) (Table 10.4). Spiny dogfish were also able to be discarded dead but were required to be balanced against a fisher's ACE whether dead or alive. The conditions of Schedule 6 releases were amended for mako, porbeagle, and blue sharks: from 1 October 2014, fishers were allowed to return these three species to the sea both alive and dead, although the life status was required to be reported. Those returned to the sea dead were counted against a fisher's ACE and the total allowable catch limit for that species. Schedule 6 returns in 2018–19 to 2022–23 were a large proportion of the catch of spiny dogfish and porbeagle, mako, and blue shark (Table 10.3). When Schedule 6 was repealed, species listed under that Schedule were automatically transferred to a new instrument issued under section 72A (2) and Schedule 1AA, Part 3, clause 7 of the Fisheries Act 1996. Under the Fisheries (Landing and Discard Exceptions) Notice which came into effect on 1 June 2024, mako, porbeagle and blue sharks and spiny dogfish may be returned alive or dead; school shark, rig, smooth skate and rough skate may be returned if they are likely to survive as determined by a fisher. Survival rates of some discarded and released chondrichthyan species in New Zealand have been investigated and are known to vary by species and fishing method (McKenzie et al. 2024, Moore & Finucci 2024).

10.4.1 QMS SPECIES

The eleven chondrichthyans managed under the QMS are listed in Table 10.4 with their Total Allowable Commercial Catches (TACCs) and landings. Landings of all species were below the TACCs.

QMS chondrichthyans are treated in detail in Fisheries New Zealand's annual Fisheries Assessment Plenary reports (Fisheries New Zealand 2023, 2024) and that material is not repeated here. Quantitative stock assessments have been attempted for only three chondrichthyan stocks (rig in SPO 3 and SPO 7, and elephantfish in ELE 3) but none were approved by the working groups and ultimately the status of these stocks and some other QMS chondrichthyan stocks is now estimated from trends in standardised CPUE analyses and trawl surveys.

Fisheries New Zealand Status of the Stocks 2023 data contains information on the status of QMS chondrichthyan stocks. Performance measures have been estimated for 16 of the 29 non-nominal stocks (non-nominal stocks are fish stocks that have a demonstrated significant commercial or non-commercial potential). Other stocks are not assessed because an appropriate quantitative analysis to ascertain stock status relative to a target or limit has not been undertaken, or because such an analysis was not definitive, generally because of insufficient or inadequate data. None of the stocks assessed were considered to be below the 'soft limit' (below this level, a fish stock is considered to be overfished and needs to be actively rebuilt, for example by reducing fishing mortality) except for one school shark stock, which was 'about as likely as not' to be below the soft limit. Three elephantfish stocks, two rig stocks and one school shark stock were considered to be 'about as likely as not' to be in an 'overfished' state. One rig stock is 'likely' to be in an 'overfished' state and one school shark stock is 'very likely' to be overfished. Corrective management actions have been implemented for both of these stocks; for the rig stock, additional set net restrictions were put in place in October 2020 and December 2022 and for the school shark stock, the Total Allowable Catch was reduced by 30% on 1 October 2021. The remainder of the stocks were considered likely to be in a favourable state.

Table 10.1: Recreational harvest estimates for New Zealand chondrichthyan species for the 2017–18 fishing year (number of trips for 2017–18 was 1.96 million cf. 2.47 million for 2011–12). Mean fish weights are only available for two species, otherwise only the counts are shown. Mgmt class = Management class, QMS is shown, all others are Non-QMS and non-protected species; CV = Coefficient of variation of the estimate to the left. Reproduced in part from Wynne-Jones et al. (2019).

Species	Mgmt class	Fishers (n)	Events (n)	Harvest (n)	CV	Mean weight (kg)	Harvest (t)	CV
Rig	QMS	153	235	35 369	0.15	1.59	56.24	0.15
School shark	QMS	42	50	6 826	0.26	–	–	–
Spiny dogfish	QMS	54	68	13 985	0.23	1.53	21.42	0.23
Stingray		22	24	2 841	0.25	–	–	–
Elephantfish	QMS	22	33	3 047	0.31	–	–	–
Sand shark		6	7	701	0.51	–	–	–
Hammerhead shark		8	10	1 158	0.46	–	–	–
Bronze whaler shark		2	2	203	0.73	–	–	–
Mako shark	QMS	3	4	1 048	0.77	–	–	–
Carpet shark		6	6	422	0.46	–	–	–

Table 10.2: Reported total catches (tonnes, including discards and live releases) for chondrichthyan reporting codes from 2018–19 to 2022–23, arranged in descending order of total catch and rounded to the nearest tonne. Only codes with more than 5 t of aggregated catch (over the 5 years) are included. The management class (Mgmt) is also shown. Source: Fisheries New Zealand catch-effort database. Note: Catches of QMS species differ from landings in Table 10.4 because they include discards and releases and are derived from a different source. Protected species are reported by number, not weight, and are not included in this table. [continued next page]

Species	Code	Mgmt	2018–19	2019–20	2020–21	2021–22	2022–23	Total	Mean
Spiny dogfish	SPD	QMS	5 635	4 904	5 646	5 527	5 369	27 080	9 027
School shark	SCH	QMS	2 732	2 626	2 836	2 405	2 654	13 254	4 418
Rig	SPO	QMS	1 383	1 411	1 335	1 493	1 445	7 068	2 356
Rough skate	RSK	QMS	1 526	1 433	1 471	1 105	936	6 471	2 157
Elephant fish	ELE	QMS	1 354	1 368	1 254	1 217	1 188	6 381	2 127
Dark ghost shark	GSH	QMS	1 424	1 047	1 173	957	1 041	5 642	1 881
Smooth skate	SSK	QMS	870	828	863	767	681	4 008	1 336

Chondrichthyans

Species	Code	Mgmt	2018–19	2019–20	2020–21	2021–22	2022–23	Total	Mean
Pale ghost shark	GSP	QMS	886	685	789	750	766	3 875	1 292
Blue shark	BWS	QMS	871	732	677	482	771	3 534	1 178
Carpet shark	CAR	Non-QMS	478	573	612	631	698	2 992	997
Shovelnose dogfish	SND	Non-QMS	527	373	521	561	335	2 316	772
Unspecified Sharks & Dogfish	OSD	Non-QMS	366	337	366	369	386	1 823	608
Northern spiny dogfish	NSD	Non-QMS	232	223	298	285	382	1 420	473
Baxter's lantern dogfish	ETB	Non-QMS	297	203	281	260	290	1 330	443
Seal shark	BSH	Non-QMS	182	220	193	152	134	881	294
Long-nosed chimaera	LCH	Non-QMS	139	120	177	142	125	702	234
Leafscale gulper shark	CSQ	Non-QMS	160	106	130	113	96	604	201
Eagle ray	EGR	Non-QMS	110	132	122	110	120	595	198
Porbeagle shark	POS	QMS	71	43	57	42	96	309	103
Mako shark	MAK	QMS	74	64	63	30	57	287	96
Thresher shark	THR	Non-QMS	55	49	66	44	66	280	93
Short-tailed black ray	BRA	Non-QMS	52	48	49	49	48	246	82
Lucifer dogfish	ETL	Non-QMS	56	38	35	48	51	229	76
Electric ray	ERA	Non-QMS	54	45	47	40	40	227	76
Stingray (Unspecified)	STR	Non-QMS	25	34	47	49	55	210	70
Longnose velvet dogfish	CYP	Non-QMS	31	25	44	65	44	210	70
Broadnose sevengill shark	SEV	Non-QMS	28	32	25	29	35	149	50
Deepwater dogfish (Unspecified)	DWD	Non-QMS	47	29	17	11	12	116	39
Whiptail ray	WRA	Non-QMS	20	18	22	25	27	112	37
Bronze whaler shark	BWH	Non-QMS	14	17	21	22	28	102	34
Hammerhead shark	HHS	Non-QMS	14	18	16	18	18	84	28
Plunket's shark	PLS	Non-QMS	20	21	10	15	7	73	24
Slender smooth-hound	SSH	Non-QMS	12	9	10	17	7	54	18
Sixgill shark	HEX	Non-QMS	8	6	14	16	5	49	16
Smooth skin dogfish	CYO	Non-QMS	2	3	15	11	18	49	16
Widenosed chimaera	RCH	Non-QMS	1	7	5	17	11	41	14
Purple chimaera	CHG	Non-QMS	3	3	17	6	13	41	14
Skate, Other	OSK	Non-QMS	6	7	6	8	8	34	11
Deepsea sharks	CEN	Non-QMS	1	5	7	3	4	20	7
Pelagic stingray	DAS	Non-QMS	0	4	9	2	2	17	6
Prickly dogfish	PDG	Non-QMS	4	4	3	2	3	17	6
Electric ray	BER	Non-QMS	2	2	2	4	4	15	5
Rays	RAY	Non-QMS	1	4	2	3	3	14	5
Portuguese dogfish	CYL	Non-QMS	1	3	2	4	1	11	4
Chimaera spp.	CHI	Non-QMS	3	1	1	4	1	10	3
Sharpnose sevengill shark	HEP	Non-QMS	1	1	2	3	3	10	3
Dawson's cat shark	DCS	Non-QMS	0	0	1	1	5	8	3
Long-tailed skate	LSK	Non-QMS	0	6	0	0	0	7	2
Deepwater spiny skate	DSK	Non-QMS	2	0	1	2	1	7	2
Longnosed deepsea skate	PSK	Non-QMS	1	1	2	2	1	7	2

Species	Code	Mgmt	2018–19	2019–20	2020–21	2021–22	2022–23	Total	Mean
Cat shark	APR	Non-QMS	1	2	1	2	1	7	2
Chimaera, purple	CHP	Non-QMS	2	2	1	1	1	6	2
Bigeye thresher	BET	Non-QMS	0	1	1	1	2	6	2
Sandbar shark	CAP	Non-QMS	0	0	0	1	4	5	2

Table 10.3: Percentages of chondrichthyan species landed, discarded and released alive from 2018–19 to 2022–23. Only the top 25 species in terms of total catch (over the 5 years) are included here and ordered by catch quantity as in Table 10.2. Protected species are not included (all are required to be discarded or released). Discards here are defined as non-QMS species that are not kept or QMS species that were authorized as a discard by an onboard observer; Released is defined here as fish below a legal size or sharks returned dead or near-dead that do not meet Schedule 6 criteria; Schedule 6 are a special type of release where specific stocks may be returned to the sea in accordance with the requirements laid out in the Fisheries Act (1996). Losses are defined as fish or fish product lost from holding containers on land or water or QMS fish that are abandoned or accidentally lost at sea for which another disposal code does not apply. Some rows do not tally to exactly 100 due to rounding.

Species Name	Code	Mgmt	Landings%	Discards%	Released%	Schedule 6%	Losses%
Spiny dogfish	SPD	QMS	28	0	0	71	0
School shark	SCH	QMS	99	1	0	0	0
Rig	SPO	QMS	99	0	0	1	0
Rough skate	RSK	QMS	89	1	0	10	0
Elephant fish	ELE	QMS	100	0	0	0	0
Dark ghost shark	GSH	QMS	94	6	0	0	0
Smooth skate	SSK	QMS	76	1	0	23	0
Pale ghost shark	GSP	QMS	98	2	0	0	0
Blue shark	BWS	QMS	0	0	16	83	1
Carpet shark	CAR	Non-QMS	1	99	0	0	0
Shovelnose dogfish	SND	Non-QMS	57	43	0	0	0
Unspecified Sharks & Dogfish	OSD	Non-QMS	41	59	0	0	0
Northern spiny dogfish	NSD	Non-QMS	5	94	0	0	0
Baxter's lantern dogfish	ETB	Non-QMS	67	33	0	0	0
Seal shark	BSH	Non-QMS	30	70	0	0	0
Long-nosed chimaera	LCH	Non-QMS	79	21	0	0	0
Leafscale gulper shark	CSQ	Non-QMS	59	41	0	0	0
Eagle ray	EGR	Non-QMS	33	67	0	0	0
Porbeagle shark	POS	QMS	1	3	57	40	0
Mako shark	MAK	QMS	5	0	43	50	2
Thresher shark	THR	Non-QMS	3	97	0	0	0
Short-tailed black ray	BRA	Non-QMS	0	99	0	0	0
Lucifer dogfish	ETL	Non-QMS	74	26	0	0	0
Electric ray	ERA	Non-QMS	8	92	0	0	0
Stingray (Unspecified)	STR	Non-QMS	0	100	0	0	0

Table 10.4: TACCs and estimated landings (tonnes) of the eleven chondrichthyans managed under the QMS for the 2022-23 fishing year. Also shown is the year of entry of each species into the QMS and year of addition to Schedule 6 of the Fisheries Act which allows release of fish into the sea. Source: Fisheries Assessment Plenaries (Fisheries New Zealand 2023, 2024). Note: Landings differ from the catches in previous tables because the latter include discards and releases. [continued next page]

Species Name	Species Code	TACC (t)	Landings (t)	Entry into QMS	Addition to Schedule 6
Spiny dogfish	SPD	12 660	5 270	2004	2004
School shark	SCH	3 213	2 650	1986	2013

Species Name	Species Code	TACC (t)	Landings (t)	Entry into QMS	Addition to Schedule 6
Rough skate	RSK	1 986	811	2003	2003
Rig	SPO	2 089	1 422	1986	2012
Dark ghost shark	GSH	3 055	1 039	1998	
Elephant fish	ELE	1 464	1 182	1986	
Pale ghost shark	GSP	1 780	766	1999	
Smooth skate	SSK	849	499	2003	2003
Blue shark	BWS	1 860	114	2004	2004
Mako shark	MAK	200	30	2004	2004
Porbeagle shark	POS	110	37	2004	2004

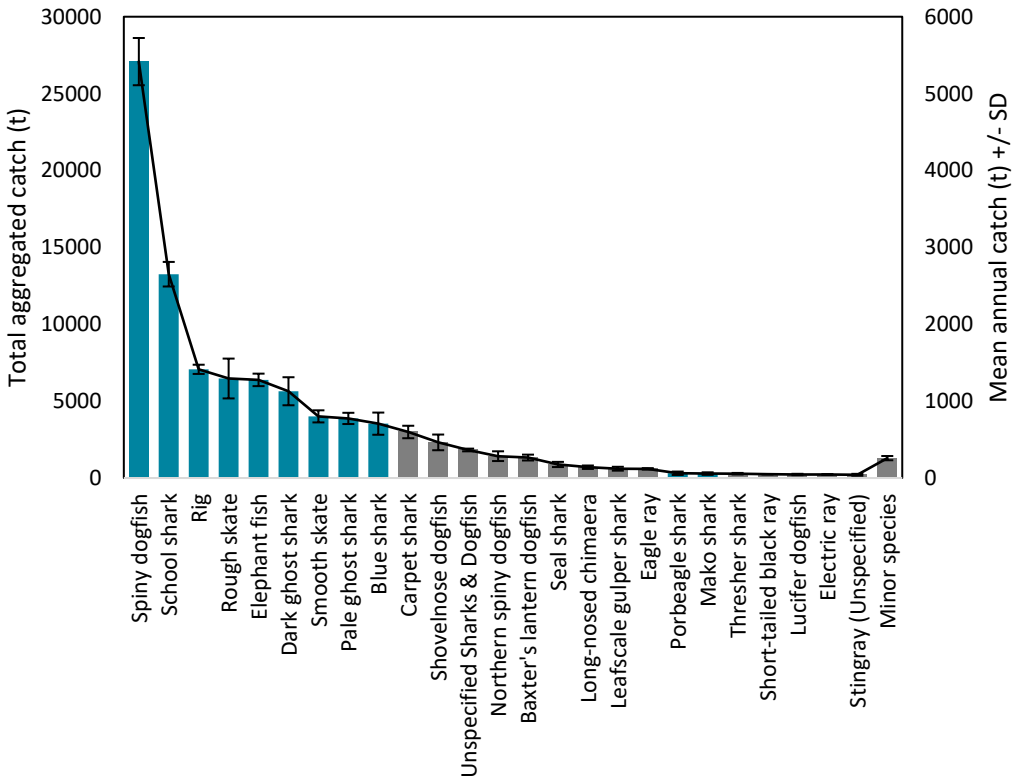


Figure 10.2: Reported total commercial catches (landings, discards, and releases) for chondrichthyan species and species groups aggregated across 2018–19 to 2022–23. The average annual catches (solid black line) ± one standard deviation are shown on the right axis. Source: Fisheries New Zealand catch-effort database. Turquoise bars indicate QMS species and grey bars non-QMS species.

10.4.2 PROTECTED SPECIES

Seven chondrichthyans are currently protected in New Zealand fisheries waters: white pointer shark was protected in 2007; spinetail devil ray, manta ray (*Mobula birostris*), whale shark (*Rhincodon typus*), deepwater nurse shark (*Odontaspis ferox*), and basking shark (*Cetorhinus maximus*) in 2010; and oceanic whitetip shark (*Carcharhinus longimanus*) in 2013.

Fishers are required to report protected species captures using a dedicated reporting form. Fisher reports of basking shark and white pointer shark captures have exceeded those reported by observers (Francis 2017a, b).

Observer coverage has been reasonably high for some larger trawl fisheries (e.g., trawl fisheries for hoki/hake/ling/silver warehou/white warehou (41.7% of tows in 2021–22), orange roughy (28.3% of tows in 2019–20), southern blue whiting (77.1% of tows in 2021–22) and squid (81.3% of tows in 2021–22)) and moderate for skipjack tuna purse seine fisheries in northern New Zealand (13.1% of sets observed in 2018–19), providing credible information on captures of basking sharks and white pointer sharks (in trawls) and of spinetail devil rays (in purse seine nets). However, observer coverage has not always been representative of the spatial and temporal distribution of these fisheries. Inshore fisheries have received only sparse observer coverage. These fisheries potentially have unobserved and unrecorded mortality of some protected species, like basking shark, white pointer shark and deepwater nurse shark, which are all occasionally present in inshore areas. Between 2023 and 2025, onboard cameras are being installed on up to 300 inshore fishing vessels, covering approximately 85% of the total inshore catch by volume. Camera coverage of these fisheries will vastly exceed that achieved through historical observer coverage.

Data from observers, along with fisher-reported data, have been used to estimate protected chondrichthyan captures. Finucci et al. (2022) characterised protected chondrichthyan capture events and these are presented in Table 10.5.

Table 10.5: Observed and reported protected chondrichthyan capture events (numbers) in the New Zealand EEZ from 2008–2021. Duplicate reported capture events (i.e., the same event reported by both an observer and fisher) are not included in the tallies. For spinetail devil ray, a total of 264 unique capture events involved 447 spinetail devil rays . * capture event occurred outside the NZ EEZ. **two reported capture events where two white pointer sharks were recorded. *** two capture events where two basking sharks were recorded. For spinetail devil ray, a total of 264 unique capture events involved 447 spinetail devil rays . 'Year' is fishing year (1 October to 30 September) and is referred to by the second year; for example, '2008' for the 1 October 2007 to 30 September 2008 fishing year. For capture events prior to 2008, see Finucci et al. 2022. Modified from Finucci et al. 2022.

Year	White pointer shark	Deepwater nurse shark	Oceanic whitetip shark	Whale shark	Basking shark	Manta ray	Spinetail devil ray
2008	1	0	1	0	9	0	19
2009	6	0	0	0	2	0	28
2010	6**	0	0	0	4	0	6
2011	4	0	1	0	11	0	23
2012	1	1*	0	0	2	0	10
2013	6	0	0	0	12	0	29
2014	11	0	0	0	8	0	3
2015	5	1	0	0	10***	0	29
2016	17	0	0	0	5	0	18
2017	10	0	0	0	8	0	20
2018	17	0	1	0	1	0	14
2019	11	1	0	0	7	0	7
2020	25**	0	0	1	11***	0	4
2021	16	2	0	0	4	1	54
Total	136	5	3	1	94	1	264

PROTECTED SPECIES GENETICS

Francis & Ritchie (2016) reviewed the available genetic information for the seven protected chondrichthyan species. They established a repository for genetic samples of protected fish species, conducted a stock-take of completed, current, and planned genetic analyses for these species internationally, and provided recommendations on the most appropriate methods for future genetic analyses to inform management of New Zealand's protected fish species in relation to fisheries bycatch. The tissue repository contains samples from white pointer shark (N=102) and basking shark (N=56), but few or no samples from the other protected species, most likely due to their relatively lower interaction rates with commercial fisheries and difficulty in obtaining tissue samples. The Department of Conservation continues to fund work to collect and curate tissue samples of protected fish from commercial fisheries.

BASKING SHARK

From 2007–08 to 2020–21, 94 basking shark capture events, involving 96 basking sharks, were reported in fisheries, mostly in bottom and midwater trawls targeting arrow squid, hake, hoki, or silver warehou (Table 10.5; Finucci et al. 2022). Of these 94 interactions, 84 were reported by fishers, and 47 fisher-reported interactions also had a matching observer record. Ten interactions reported by observers did not have a matching fisher report, possibly because some skippers may feel there is no need to report a protected species interaction when an observer was present to record the event instead. Life status information is not available prior to 2012 but since then, 39% of basking sharks were recorded alive, 34% as dead and life status was not available for the remaining 27%. It is presumed that few of the individuals returned to the sea alive are likely to survive post-release. Captured basking shark individuals are predominantly adult males; adult female captures are relatively rare.

Most basking shark capture records came from large deepwater trawlers in a variety of target fisheries with both midwater and bottom trawls. Basking sharks are also caught in set nets (Francis & Duffy 2002) but have rarely been reported by set net fishers since 2010 (Francis 2017b). The observer coverage of the set net fisheries has been traditionally low, so set net bycatch cannot be easily quantified. Basking sharks are rarely entangled in surface longlines (Francis & Duffy 2002).

Finucci et al. (2022) investigated environmental factors potentially influencing basking shark interactions in southern trawl fisheries in New Zealand. They found that interactions were predicted to be most likely when bottom trawl gear was at depths of around 600–900 m, when sea surface temperatures were around 12 °C, the mixed layer depth was shallow, and when eastwards (zonal) or northwards (meridional) currents were relatively strong.

Finucci et al. (2021a) found that areas with a high vertical flux of organic particulate matter at the seabed, indicative of higher levels of primary production, had high predicted habitat suitability index scores for basking sharks. Such areas had strong overlap with the main historic capture locations: the east coast South Island off Banks Peninsula (FMA 3), the west coast South Island between Westport and Hokitika, Puysegur (FMA 7), the shelf edge south and east of Stewart Island (FMA 5) and the Snares Islands, and around the Auckland Islands (FMA 6). Captures (and sightings) of basking sharks have also occurred around the North Island but were relatively uncommon (Francis & Duffy 2002, Francis & Sutton 2012, Francis 2017b).

In 2019, sampling protocols for basking sharks were developed and sampling kits were deployed on a number of commercial fishing vessels operating on the Stewart Island–Snares Shelf and the Auckland Islands Shelf (Finucci 2021). The information and genetic samples collected is useful for understanding more about the biology, population structure and behaviour of basking sharks in New Zealand waters. Sufficient sampling over time may help answer questions about stock structure, aggregation structure and dynamics, and could possibly be used to estimate population size.

WHITE POINTER SHARK (GREAT WHITE SHARK)

Between the 2008–09 and 2020–21 fishing years, a total of 136 white pointer shark interactions, involving 138 sharks, occurred in commercial fisheries, mostly in trawls, set nets and bottom longlines targeting a variety of fish species (Table 10.5; Finucci et al. 2022). This included 48 observed white shark interactions and 88 additional reported interactions. Recently there has been an increase in the number of white pointer shark interactions with 50% of the observed interactions (n = 24/48) from 2008 to 2021 occurring in 2020 or 2021. Nearly 20% of reported interactions (n = 17/88) occurred in the same time period. Since 2008, 75% of white pointer sharks were released alive, 23% were dead on hauling and the status of one shark was unknown. The survival of white pointer sharks after live release is unknown (Francis 2017a).

White pointer shark captures were reported from throughout mainland New Zealand and as far south as the Auckland Islands, but not from around the other outlying islands (Francis & Lyon 2012, Francis 2017a, Finucci et al. 2022). Despite their small share of effort (only 20% of the overall length of nets set), and limited geographical extent, three regions (Great Exhibition Bay, Taranaki, and Foveaux Strait) accounted for 89% of the 36 white pointer sharks reported caught by set net vessels between 2008 and 2016 (Francis 2017a).

Tagging and genetic studies have shown that New Zealand and eastern Australian white pointer sharks comprise a single stock (Duffy et al. 2012, Francis et al. 2015a). A close-kin genetics study which included New Zealand white pointer shark tissue samples estimated that the total population size of this stock was 5460 (uncertainty range 2909–12 802) including 750 adults (uncertainty range 470 to 1030) (Bruce et al. 2018, Hillary et al. 2018). The trend in abundance of adult white pointer sharks in this population was not significantly different from zero (i.e., no trend and thus a stable population where births = deaths, on average) (Bruce et al. 2018).

Vertebral samples collected from 38 white pointer sharks (20 female, 12 male, 6 unsexed) in New Zealand were used to estimate age and growth by assessing vertebral banding patterns and using microCT imaging (Finucci & Ó Maolagáin 2022). Nearly half of the samples were estimated to be 1–2 year-old sharks and only six were estimated to be older than 10 years of age. This preliminary work suggests that white pointer sharks, born at roughly 1.5 m total length (TL), are relatively fast growing initially (approximately 30 cm per year) until they reach 3 m TL, when their growth slows, possibly due to changes in diet, movement or habitat, or a reallocation of energy towards reproductive development. Understanding age and growth for white pointer sharks is useful for conservation and management, and may be useful to better understand population-level impacts on this species.

WHALE SHARK

Whale sharks are typically only seen in north-eastern North Island waters during summer and are rare (Duffy 2002), making captures exceptional events.

An individual was reportedly caught by a coastal trawler off South Canterbury in the late 1970s (as communicated to C. Duffy by a fisher, as reported by Duffy 2005). Another whale shark was captured (and released alive) in March 2020 by a purse seine vessel targeting skipjack tuna off Great Barrier Island. No captures of whale sharks have been reported by fisheries observers in New Zealand waters.

DEEPWATER NURSE SHARK (SMALLTOOTH SANDTIGER SHARK)

Deepwater nurse sharks (ODO) have been reported frequently by fishers and observers from along the edge of the continental shelf between Otago Peninsula and south of the Snares Islands (Francis & Lyon 2012). Clusters of records also exist from the Chatham Islands, and off Banks Peninsula and Farewell Spit. However, the southern limit of the known distribution of deepwater nurse sharks in New Zealand is a line from Cape Kidnappers in Hawke Bay to Cape Egmont (Roberts et al. 2015). Given that most of the records are from south of that range, and that many ODO weights were implausibly small, most records of this species are likely erroneous, probably because of reporting an incorrect species code. Since 1997, there have been 8 plausible deepwater nurse shark interactions in commercial fisheries, five of which occurred in the NZ EEZ (Finucci et al. 2022). All interactions occurred in trawl fisheries targeting different species including hoki, scampi, tarakihi and ling, amongst others. Most deepwater nurse sharks have been alive upon capture.

There are other published records of deepwater nurse sharks being caught in set nets off New Plymouth (Stewart 1997, Fergusson et al. 2008), trawl in Hawke Bay, and by the NIWA research trawl vessel *Tangaroa* on the Norfolk Ridge (Garrick 1974, Stewart 1997, Fergusson et al. 2008), confirming that the species is occasionally caught in northern waters. Duffy (2005) cited anecdotal information that deepwater nurse sharks were ‘not uncommon’ bycatch in a set net fishery operating around White Island and Volkner Rocks in the eastern Bay of Plenty but noted that this fishery had ceased. Duffy (2005) and Fergusson et al. (2008) also reported the capture of deepwater nurse sharks from the same location for display at Kelly Tarlton’s Sea Life Aquarium from the mid-1980s to the early 2000s, but all the sharks died, and the practice was discontinued.

SPINETAIL DEVIL RAY AND MANTA RAY

Spinetail devil rays (MJA) and manta rays (RMB) (Family: Mobulidae) are present during summer months, mainly in north-eastern North Island waters but also infrequently in the Taranaki Bight and north-western South Island (Duffy & Abbott 2003, Francis & Jones 2016). Historically, most mobulid rays reported caught in commercial fisheries were likely to have

been spinetail devil rays (Paulin et al. 1982). Manta ray interactions have been reported previously (with 43 interactions of 'RMB' reported on Non Fish Protected Species forms by fishers), but these interactions have been reclassified as spinetail devil rays, often with the aid of observer photographs. The first confirmed capture of a manta ray in New Zealand waters occurred in the swordfish target fishery in FMA 1 in 2021 and the manta ray was recorded as dead (Finucci et al. 2022).

Observer and commercial records were not available before 2001–02, although devil ray bycatch in purse seine catches was documented between 1975 and 1981 by Paulin et al. (1982). Between 2008 and 2021, there have been 104 observed spinetail devil ray capture events and 160 additional reported events to give a total of 264 unique events (involving 447 spinetail devil rays) (Table 10.5; Finucci et al. 2022). These capture events mostly occurred in FMA 1 (80%; n = 210/264) during summer months, while no location information was recorded for most remaining capture events. Of the observed capture events, 94% occurred in purse seine fisheries that mostly targeted skipjack tuna (92%) and blue mackerel (<1%), while the remaining 6% of capture events occurred in surface longline fisheries targeting bigeye tuna and swordfish, mainly near the 1000 m depth contour. Francis & Jones (2019) defined a hotspot region between North Cape and Great Barrier Island. In the 2020–21 fishing year, nearly all (94%; n = 15/16) observed spinetail devil ray interactions occurred in this area. Most observer records were from the edge of the continental shelf in this hotspot region.

Since 2008, just over half of the observed spinetail devil rays caught were alive (55%; n = 83/151), 36% were recorded dead and the life status of the remaining 9% was unknown (Finucci et al. 2022). Life status has improved over time; during 2008–2012, all spinetail devil rays were recorded as dead (n = 37), whereas during 2017–2021, nearly all spinetail devil rays were recorded as alive (95%, n = 54/57). In tagging experiments, four out of seven rays (57%) released from purse seine nets with satellite tags, eventually died (Francis & Jones 2017), suggesting a high post-release mortality rate. However, a more recent tagging study has shown a reduced mortality rate (Francis & Jones 2019), suggesting that mortality could be mitigated through improved release practices (Jones & Francis 2012). Some released rays have travelled north to Vanuatu and south of Fiji, indicating that they make a seasonal migration between New Zealand and the tropics.

Environmental factors potentially influencing interactions between spinetail devil rays and purse seine fisheries in northeast New Zealand have been assessed (Finucci et al. 2022). Interactions were predicted to be more likely when vessels were targeting skipjack tuna, when chlorophyll-a was low (clear waters), within the East Auckland current (mean dynamic height around 2.18 m), and when sub-surface temperatures (at 100 m depth) exceeded about 16.5 °C.

OCEANIC WHITETIP SHARK

The oceanic whitetip shark is a tropical species that enters northern New Zealand waters only in summer, and possibly only in summers that are warmer than normal (Francis et al. 1999b). Only 20 observer and three commercial fishery records (all of which had corresponding observer records) are known (Finucci et al. 2022). All records came from surface longlines set in the Kermadec Fisheries Management Area or off the north or north-eastern coast of North Island. Most (84%) of the observed sharks were alive when hauled to the vessel, and about half were processed in some way with the remainder being discarded (those captures pre-dated protection of the species in 2013). Since the last assessment by Francis & Lyon (2014), two observed oceanic whitetip interactions have occurred (in 2018 and 2021) but only the 2018 capture is considered valid (Finucci et al. 2022). The low commercial reporting rate (3 out of 20 observed sharks) and the low observer coverage of domestic surface longlines may result in higher uncertainty when estimating interactions between the surface longline fisheries and oceanic whitetips (Ministry for Primary Industries 2012, Finucci et al. 2022).

10.4.3 NON-QMS SPECIES

More than 50 species of non-QMS chondrichthyans are known to be caught by fishers in New Zealand waters, but records of non-QMS chondrichthyan catches have limited reliability (e.g., due to identification issues for some species and reporting under generic species group codes).

Inshore chondrichthyans are caught by a variety of fishing methods. Closures of some inshore waters to set netting and trawling to protect Hector's and Māui dolphin on the north-west coast of North Island and around much of South Island

may have benefitted chondrichthyan species that occur there. However, most of these species are highly vulnerable to trawl, set net, and bottom longline and have nurseries in shallow coastal waters and harbours that are still fished by set nets and longline and, to a lesser extent, trawls. Little is known about the fishery interactions of these species (but for an analysis of smooth hammerhead shark captures see Francis 2010). Similarly, there is little information on the biological productivity of most of the species, but many (all the rays and thresher shark) have very low reproductive output (a few young per year) and are therefore highly susceptible to overfishing.

Deepwater chondrichthyans are caught incidentally in deepwater trawl tows, some species in considerable quantities (Blackwell 2010). Seven species of squaloid deepwater sharks — shovelnose dogfish, Baxter's dogfish, lucifer dogfish, Owston's dogfish, longnose velvet dogfish, leafscale gulper shark, and seal shark — commonly occur over the middle and lower continental slope in depths greater than 600 m. Shovelnose dogfish has a wider depth distribution, and it also occurs on the upper and middle slope (400–600 m in depth). These seven shark species are commonly taken as non-target catch in the middle depths and deepwater fisheries for hoki, orange roughy, and oreos (Anderson & Finucci 2022, Finucci et al. 2024). They are either discarded at sea, processed for their fins (prior to the finning ban of 2014) or livers (Blackwell 2010) but an increasing number of fishmeal plants on vessels may increase their use in fish meal processing.

As well as trawls, some deepwater chondrichthyans are taken in bottom longline fisheries. The survival rate of bycaught chondrichthyans is expected to be greater in bottom longline fisheries than in trawls. The ling (*Genypterus blacodes*) longline fishery has been identified as a suitable fishery for a tagging programme to better understand the biology and ecology of deepwater chondrichthyans (Finucci 2022). Candidate species for tagging include seal shark (*Dalatias licha*), leafscale gulper shark (*Centrophorus squamosus*), shovelnose dogfish and Plunket's shark (*Scymnodon plunketi*). These species were considered at higher risk from fishing than many other chondrichthyans (Ford et al. 2018; see section 10.4.4 below).

Historical data are available from the Fisheries New Zealand Observer Programme, but a critical issue when using observer data to monitor the abundance and biology of deepwater sharks is species identification: many deepwater sharks are superficially similar and difficult to distinguish, so they have often been misidentified or aggregated under generic codes. With the recent availability of good species identification guides (McMillan et al. 2011a, 2011b, 2011c, 2019, 2024a, 2024b), observers and fishers now have the tools to better identify deepwater sharks accurately to species level. To test current observer identification accuracy, McMillan et al. (2018) compared observer identifications of six species of deepwater sharks with NIWA identifications made using images and DNA analyses of tissue samples collected from the same specimens. Of 331 observer identifications, 302 (91%) were confirmed by NIWA; most of the incorrect identifications came from a single observer. It was concluded that observer identification of deepwater sharks is generally accurate. Fisheries observer data were used in a study to validate modelled distributions of seven species of deepwater sharks derived from 1982–2018 trawl survey data (Finucci et al. 2021b). This study identified some oceanographical hotspots for these species but did not find significant trends in abundance and spatial distribution, suggestive of stable populations.

Some species that are not caught or reported in quantities sufficient to be included in Table 10.2 may also be vulnerable to overfishing. These include endemic species with limited geographic and/or depth ranges that overlap in space with the operations of deepwater trawlers, for example Dawson's catshark (Francis 2006) and some of the rarer deepwater skates and chimaeras. Their low catch weights probably reflect their rarity.

10.4.4 RISK ASSESSMENT AND THREATENED SPECIES CLASSIFICATION

One of the objectives of the NPOA-Sharks 2013 was to establish a risk-based approach to prioritising management actions. MPI hosted a workshop in 2014 that produced a qualitative (Level 1) risk assessment (RA) for all New Zealand chondrichthyan taxa (except for species with uncertain taxonomy) from commercial fishing (Ford et al. 2015). This was updated in 2017 (Ford et al. 2018).

The qualitative RA used a modified Scale Intensity Consequence Analysis approach. Before the workshops, data on catches, effort, distribution, abundance, and biological productivity were collated for all species and summarised to inform the RA.

An expert panel then scored the relative risk to each taxon from commercial fishing, based on fishing information from the previous five years, on an EEZ-wide scale. This process scored intensity and consequence of the fishery to the chondrichthyan taxa, and the rationales for the scores were documented. These intensity and consequence scores were then multiplied together to get a total risk score (Ford et al. 2018). Results were reported within the three management classes of chondrichthyans – QMS (Figure 10.3), non-QMS (Figure 10.4), and protected species (Figure 10.5).

However, out of the 50 taxa considered in detail, the panel had low confidence in the risk scores for three of 11 QMS species, 26 of 36 non-QMS taxa, and all three protected species. However, the panel considered that the available information did not indicate that commercial fishing is currently causing, or in the near future could cause, serious unsustainable impacts to any sharks, rays, or chimaera populations examined.

Of the QMS species, six attained the equal highest total risk score (dark ghost shark, elephantfish, rig, rough skate, school shark, and spiny dogfish), highlighting the need for further assessments on these species.

Plunket's shark was the highest scoring non-QMS species and basking shark and spinetail devil ray were the highest scoring protected species.

QMS SPECIES RISK

COMPONENTS OF RISK		RISK	CONFIDENCE	
Intensity	Consequence		Data	Consensus
6	3	18 - Dark ghost shark	✓✓	✓✓
6	3	18 - Elephantfish	✓✓✓	✓✓
6	3	18 - Rig	✓✓✓	✓✓
6	3	18 - Rough skate	✓✓✓	✓✓
6	3	18 - School shark	✓✓✓	✓✓
6	3	18 - Spiny dogfish	✓✓✓	✓✓
5	3.5	17.5 - Smooth skate	✓✓	✓✓
5	3	15 - Mako shark	✓✓✓	✓
5	3	15 - Pale Ghost Shark	✓✓	✓
5	3	15 - Porbeagle shark	✓✓✓	✓
4	3	12 - Blue shark	✓✓✓	✓✓

Figure 10.3: QMS species risk scores. For the COMPONENTS OF RISK higher numbers indicate greater intensity or consequence of impact. For RISK longer bars and larger numbers indicate higher risk, and for CONFIDENCE more ticks indicate higher confidence in the data, or greater consensus (two ticks in the consensus column indicate full consensus). Where species scored identical risk scores they are presented in descending order of consequences and then alphabetically. From Ford et al. (2018).

NON-QMS SPECIES RISK

COMPONENTS OF RISK		RISK	CONFIDENCE	
Intensity	Consequence		Data	Consensus
5	4.5	22.5 – Plunket's shark	✓✓	✓
5	4	20 - Baxters dogfish	✓✓	✓✓
5	4	20 - Seal shark	✓✓	✓✓
5	4	20 - Shovelnose dogfish	✓✓	✓
5	4	20 - Thresher shark	✓✓	✓✓
4	4.5	18 - Leafscale gulper shark	✓✓	✓
4.5	4	18 - Longnose velvet dogfish	✓✓	✓✓
6	3	18 - Carpet Shark	✓✓	✓✓
5	3.5	17.5 - Longtail stingray	✓	✓✓
5	3.5	17.5 - Shorttail stingray	✓	✓✓
4	4	16 - Owston's dogfish	✓✓	✓
3.5	4.5	15.75 - Dawsons catshark	✓✓	✓
4.5	3.5	15.75 - Longnose spookfish	✓	✓
5	3	15 - Electric ray	✓✓	✓
3.5	4	14 - Bronze whaler	✓✓	✓
3.5	4	14 - Prickly dogfish	✓✓	✓
4	3.5	14 - Northern spiny dogfish	✓✓	✓
3.5	3.5	12.25 - Prickly deepsea skate	✓✓	✓
3.5	3.5	12.25 - Smooth deepsea skate	✓✓	✓
3	4	12 - *Brochiraja* complex	✓	✓
3	4	12 - Brown chimaera	✓	✓✓
3	4	12 - Catsharks	✓	✓
3	4	12 - Deepwater spiny skate	✓	✓
3	4	12 - Longnose deepsea skate	✓	✓
3	4	12 - Longtail skate	✓	✓
3	4	12 - Lucifer dogfish	✓✓	✓
3	4	12 - Pacific spookfish	✓	✓✓
3	4	12 - Pelagic stingray	✓	✓
3	4	12 - Portugese dogfish	✓✓	✓
3	4	12 - Slender smooth hound	✓	✓
4	3	12 - Hammerhead shark	✓✓	✓
4	3	12 - Blind electric ray	✓✓	✓
4	3	12 - Broadnose sevengill shark	✓✓	✓
4	2.5	10 – Eagle ray	✓✓	✓
3	3	9 – Sharpnose sevengill shark	✓✓	✓
3	2	6 – Sixgill shark	✓✓	✓

Figure 10.4: Non-QMS Species Risk scores. See previous figure for detailed legend. From Ford et al. (2018).

PROTECTED SPECIES RISK

COMPONENTS OF RISK		RISK	CONFIDENCE	
Intensity	Consequence		Data	Consensus
3	4.5	13.5 – Basking shark	✓✓	✓
3	4.5	13.5 – Spinetail devil ray	✓	✓
3	4	12 – Great white shark	✓✓	✓

Figure 10.5: Protected Species Risk scores. See Figure 10.3 for detailed legend. From Ford et al. (2018).

The risk assessment was designed to help prioritise actions to conserve chondrichthyans and is most useful to prioritise future quantitative assessments. The panel made several recommendations for high-risk or protected species regarding potential research options. These included better use of existing data, data grooming, or analysis to improve inputs to assessment scores, improved taxonomy and training to underpin species identification, and collection of more biological information to increase understanding of productivity (especially the ability of a taxon to withstand and to recover from fishing impacts). The RA panel also stressed that, particularly where abundance indices are lacking, the consequence scale was more relevant to risk than the total risk score which was often dominated by the level of intensity (masking differences in potential consequence). Taxa with high consequence scores have low productivity or presumed low productivity. For such taxa, more information may improve the scores or our confidence in them, but in the interim a more precautionary approach to management was recommended by the panel (Ford et al. 2018).

Since Ford et al. (2018), progress has been made on understanding the nature of fishery interactions with protected chondrichthyans (Finucci et al. 2022) and spatial distributions (Finucci et al. 2021a, b). A trial shark and turtle risk assessment involved developing methods for estimating species spatial distributions (Mormede & Lyon 2023) and assessing fisheries risk (Edwards 2023) with the aim to move towards a more quantitative fisheries risk assessment for chondrichthyans in New Zealand.

Quantitative risk assessments have been conducted for the Southern Hemisphere porbeagle shark stock, and the Pacific Ocean bigeye thresher shark (*Alopias superciliosus*) stock. Both assessments incorporated New Zealand data and can be considered applicable to the New Zealand portion of those stocks (Fu et al. 2016, Hoyle et al. 2017). For bigeye thresher sharks, total fishing mortalities from pelagic longline fisheries in the Pacific since 2000 were generally low (less than 5%) but exceeded the maximum impact sustainable threshold in some years. For porbeagle shark, the risk assessment indicated low fishing mortality rates in the three regions comprising the assessment area (eastern Atlantic Ocean, Indian Ocean, and western Pacific Ocean), and low risk from commercial pelagic longline fisheries to porbeagle shark over the entire Southern Hemisphere.

Australian researchers (with New Zealand input) carried out an ecological risk assessment for deepwater chondrichthyans in the South Pacific Ocean (SPRFMO Convention Area) and the South Indian Ocean (Georgeson et al. 2020). Productivity-Susceptibility Analysis (PSA) and Sustainability Assessment for Fishing Effects (SAFE) methods were compared to assess the potential vulnerability of deepwater chondrichthyans to demersal trawls, midwater trawls, demersal longlines, and demersal set nets. The main outcomes highlighted probable misclassifications in the PSA relative vulnerability rankings, and the value of applying more quantitative tools, such as SAFE, when adequate data are available. *Squalus fernandezianus*, *Deania calcea*, and *Gollum attenuates* were among the species with highest risk (particularly from demersal longlines) in the South Pacific Ocean.

There have been two updated assessments of the threatened species status of New Zealand chondrichthyans. In 2016, the Department of Conservation carried out a review of their threatened species classification (Duffy et al. 2018). The conservation status of two taxa had worsened: basking shark moved to Nationally Vulnerable (from Gradual Decline) and white pointer shark was assessed as Nationally Endangered (previously assessed as Gradual Decline). Despite new evidence published between these assessments that showed a stable population for white pointer sharks (Bruce et al. 2018), new estimates revealing a previously unknown low adult population size (Hillary et al. 2018) warranted a shift to a more severe threat category. Four taxa had an improved conservation status (Galapagos shark, Kermadec smooth-hound, sixgill shark, and southern sleeper shark). In 2017, the IUCN Redlist categories of New Zealand chondrichthyans were reviewed and the status of one species, smooth skate, had improved from Near Threatened in 2003 to Least Concern (Finucci et al. 2019). The improved status of this species was due to increasing relative biomass in fisheries-independent surveys and this increase was thought to result from active management including introduction to the QMS, setting sustainable catch limits, reporting to species level and encouragement of live release under Schedule 6. The proportion of threatened chondrichthyan species in New Zealand (4%) was much lower than in Europe (32%) and the Arabian Sea (51%).

10.5 INDICATORS AND TRENDS

10.5.1 QMS SPECIES

Standardised CPUE analyses have been carried out to monitor trends in the relative abundance of some stocks of six of the 11 QMS chondrichthyans species (rig, elephantfish, blue shark, porbeagle shark, mako shark and school shark) (Table 10.6). Only one school shark stock (SCH 3S/5) was declining; all other stocks that are monitored by CPUE analyses were stable or increasing between 2018–19 and 2022–23.

For blue, porbeagle, and mako sharks, other abundance indicators have been developed in addition to standardised CPUE. They include high-CPUE (the proportion of half-degree rectangles having unstandardised CPUE greater than a specified threshold); proportion-zeroes (the proportion of half-degree rectangles having zero reported catches in a fishing year);

geometric mean index (the geometric mean of the species abundances in catches); proportion of males in the catch; and median lengths of males and females (Francis et al. 2014). A previous analysis covering the period 2005–13 suggested positive trends for all three species (Francis et al. 2014, Francis & Large 2017), but the latest analysis (Francis & Finucci 2019) suggested a declining trend in 2017–18. Since the previous indicators were published in 2014, there have been major changes in the surface longline fishery: airline restrictions on the export of shark fins in 2014, a ban on shark finning in 2014, and the addition of porbeagle shark to CITES Appendix II in 2014. As a result, most pelagic sharks are now discarded dead or released alive. Furthermore, chartered Japanese longliners ceased fishing in New Zealand waters in 2015, thus terminating an important time series of indicators. These factors combine to make interpretation of the stock status of the three species (and their trends) problematic.

Trawl survey relative abundance indices are used to monitor the populations of rig, spiny dogfish, elephantfish, rough and smooth skates, dark and pale ghost sharks and school shark (Table 10.6). For 18 out of 20 species/FMA combinations, abundance was stable or increasing between 2018–19 and 2022–23; however rig in FMA 7 and smooth skate in FMA 3 showed downward trends.

Table 10.6: Trends in abundance of QMS species monitored by standardised CPUE analysis and trawl surveys between 2018–19 and 2022–23. Time series that have not been updated within this period or where assessment results are considered unreliable have been left blank. Changes in trends through time are indicated by forward slashes. School shark management areas differ from conventional Fisheries Management Areas; more detail is available in the school shark chapter in Fisheries New Zealand (2024). *These species were assessed by Francis & Finucci (2019), but results were inconclusive. Source: Fisheries New Zealand (2023, 2024).

CPUE indices

Species	Species code	QMA1	QMA2	QMA3	QMA4	QMA5	QMA6	QMA7	QMA8
Rig	SPO	Nil	Up	Up				Up	
Elephantfish	ELE							Up	
Blue shark	BWS	Up							
Porbeagle shark*	POS								
Mako shark*	MAK								

		N/1E	2/3N	3S/5	SCH 4	7/8/1W
School shark	SCH	Up		Down	Up	

Trawl survey indices

		FMA1		FMA3	FMA4	FMA5	FMA6	FMA7	FMA8	FMA9
Rig	SPO							Down	Nil	Nil
Spiny dogfish	SPD			Down/Up	Nil			Nil		
Elephantfish	ELE									
Rough skate	RSK			Up/Down				Nil		
Smooth skate	SSK			Down				Nil		
Dark ghost shark	GSH			Nil	Nil	Nil	Nil	Nil		
Pale ghost shark	GSP	Nil/Up				Up				

		N/1E	2/3N	3S/5	SCH 4	7/8/1W
School shark	SCH			Nil	Up	Nil

Legend

	Trend up
	Stable
	Trend down

10.5.2 PROTECTED SPECIES

Of the seven protected chondrichthyan species, only the basking shark has any form of population monitoring and that is limited to assessing trends in relative abundance from incidental captures. Observer-based unstandardised CPUE analyses of trawl catches in three trawl fisheries (East Coast South Island (EC), West Coast South Island (WC), and Southland–Auckland Islands (SA)) are shown in Figure 10.6 (Francis & Sutton 2012). Inter-annual variation was large, with peak observer records occurring in 1987–92, 1997–2000, and 2003–05 depending on the region. Some years had very low or zero CPUE. Francis & Smith (2010) used Bayesian predictive hierarchical models to estimate catches and catch rates in the three trawl fisheries from observer data between 1994–95 and 2007–08. The predicted strike rates showed no overall trend since 1994–95 in any of the three areas. A total of 95 shark captures were observed from 49 165 tows over the 14-year period, an overall unstandardised capture rate of 1.9 per 1000 tows. The overall predicted capture rate was 2.5 sharks per 1000 tows, with area-specific rates of 3.9 (EC), 2.0 (WC), and 1.9 (SA) per 1000 tows. The total predicted number of captures from 1987 to 2012 was 922 individuals with a CV of 19%. Predicted captures peaked in 1997–98 and then declined steadily to low numbers. Much of the recent decline in basking shark bycatch was probably attributable to a decline in fishing effort of about 50% between 2002–03 and 2006–08 in the three areas (Francis & Smith 2010). However, unstandardised catch rates from observer data were much higher in 1988–92 than at any time since. Those high rates in earlier periods may be attributable to specific targeting by Japanese vessels prior to the species being protected (Francis & Sutton 2012). Raw observer CPUE values were updated to the 2015–16 fishing year by Francis (2017b), confirming patterns previously seen: i.e., CPUE was zero or close to zero in EC and WC fisheries and fluctuated around low levels in the SA fishery (Figure 10.6).

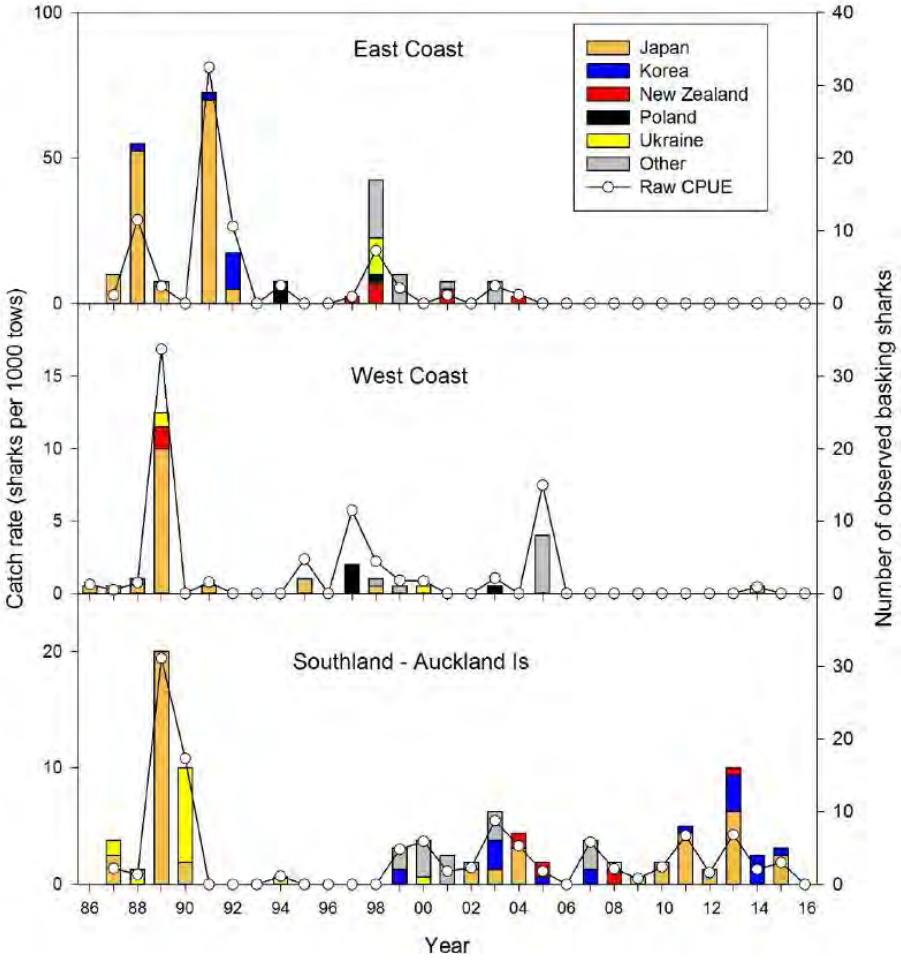


Figure 10.6: Basking shark catch rate indices (markers and lines) and number of shark observations by vessel flag (coloured bars) for three fishery areas. For raw CPUE indices, years are calendar years for West Coast and July–June years (labelled as the greater of the two years) for East Coast and Southland-Auckland Islands. Source: Francis 2017b.

The very low (often zero) CPUE in EC and WC regions since 2006, and lack of large numbers and aggregations of basking sharks observed in DOC aerial surveys for dolphins around Banks Peninsula, are cause for concern (C. Duffy, DOC, pers. comm.). There may not have been large aggregations of basking sharks in New Zealand waters since 1992. Whether such a long period without large aggregations is part of a long-term natural cycle, or evidence of a decline in population abundance, cannot yet be determined (Francis & Smith 2010).

10.5.3 NON-QMS SPECIES

Indicator analyses have been carried out for eight shark and chimaera species: carpet shark, Baxter's dogfish, seal shark, longnose velvet dogfish, Plunket's shark, leafscale gulper shark, shovelnose dogfish, and longnose spookfish (Francis et al. 2016). The indicators calculated were relative biomass, median shark length, and proportion of male sharks (all from trawl surveys); and distribution (proportion of half-degree rectangles having raw catch per unit effort greater than a specified threshold), proportion of half-degree rectangles having zero reported catches in a fishing year, species composition, concentration (a measure of whether fishing effort focuses on or avoids areas of high shark abundance), and nominal and standardised CPUE (all from commercial catch-effort or observer data). Because of data limitations, or non-applicability of the method, only a subset of the indicators could be applied to each species, and then only to a few FMAs. None of the species showed clear and consistent evidence of recent declines in abundance. However, estimated trends were often uncertain, inconsistent among indicators, based on indicators that may be unreliable (e.g., trawl survey biomass estimates for species that are not well surveyed), and based on too few indicators (only trawl survey indicators were available for five out of eight species). For a number of species, one or more indicators showed signs of decline, and ongoing monitoring was recommended (Francis et al. 2016). The relative abundance of a number of deepwater sharks are monitored in the deep strata of the Chatham Rise trawl survey and are regularly reported (e.g. Stevens et al. 2023) and used in providing aspects of management advice (figure 18 of Punt et al. 2022).

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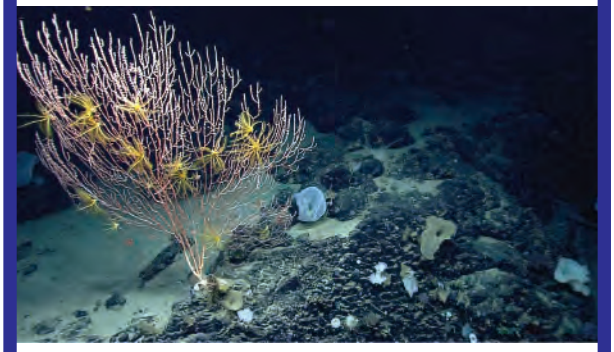
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Chapter 11: Benthic (seabed) impacts - Technical Summary

Disturbance of seabed habitats



Mapping bottom habitats and overlap with fisheries

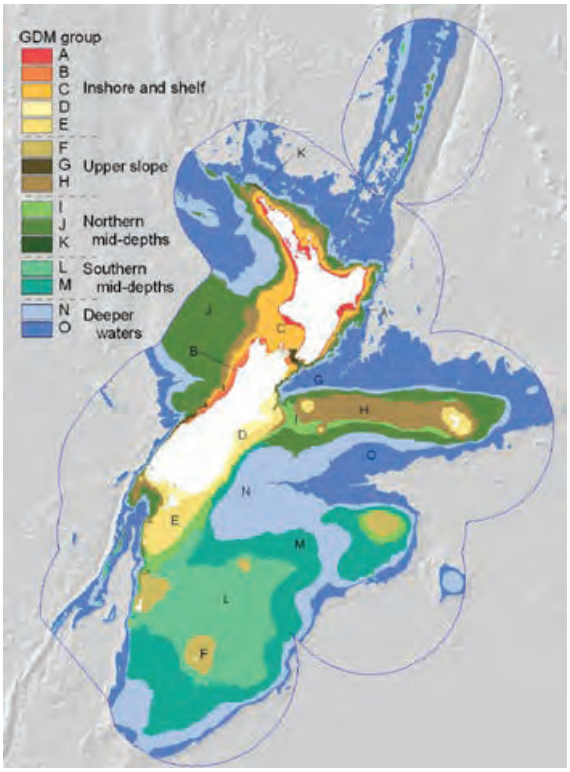
1. THE ISSUE IN BRIEF

- Biogenic habitats are important features of the seabed, because they support diverse communities
- Different types of fishing gear are dragged across the seabed to capture fish, crustaceans, or shellfish
- Contact with fishing gear can damage or kill benthic organisms, create a disturbance, and change the nature of the physical habitat
- Consequently, bottom fishing is monitored and restricted in some areas to manage (avoid, mitigate, remedy) adverse effects

2. BENTHIC IMPACTS AND RECOVERY

- Bottom fisheries can have extensive and long-lasting effects on seabed species and habitats
- Intensity of impacts depends on, among other factors, the type of fishing gear, the sensitivity of habitats or organisms to gear disturbance, and oceanographic currents
- There are challenges in estimating the effects of bottom fishing because multiple biological, environmental and anthropogenic factors need to be accounted for
- Recovery of habitats following disturbance by bottom fisheries in NZ has been studies in shallow and deep marine environments, with no recovery observed for some deep sea habitats after 14 years, and is the subject of ongoing research

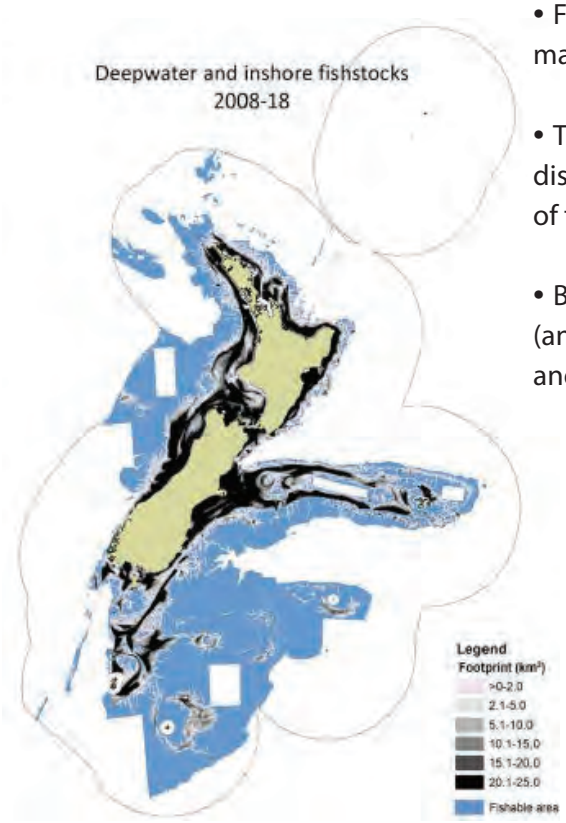
3. MAPPING BOTTOM HABITATS



- Habitats are characterised by different physical conditions and assemblages of bottom dwelling species
- Remote imaging devices, cameras, and mechanical bottom samplers are used to identify the spatial distribution of species/habitats on the seafloor
- Modelling approaches are used to predict the distributions of benthic species, communities, and habitats at large spatial scales, based on the relationships between observed distributions of species and gradients in environmental variables

The map on the left represents the model-predicted distribution of different seafloor habitats in areas shallower than 3000 m (Benthic-Optimized Marine Environment Classification, habitats classified with letters from A to O)

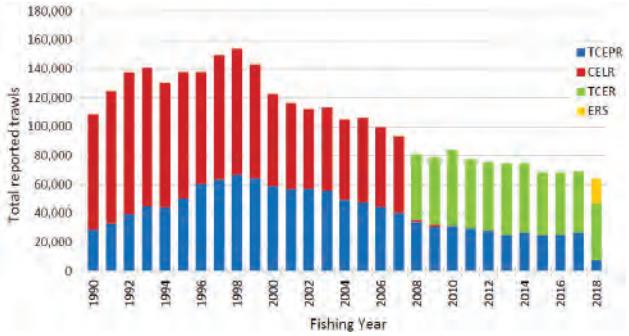
4. EXTENT AND INTENSITY OF SEABED CONTACT



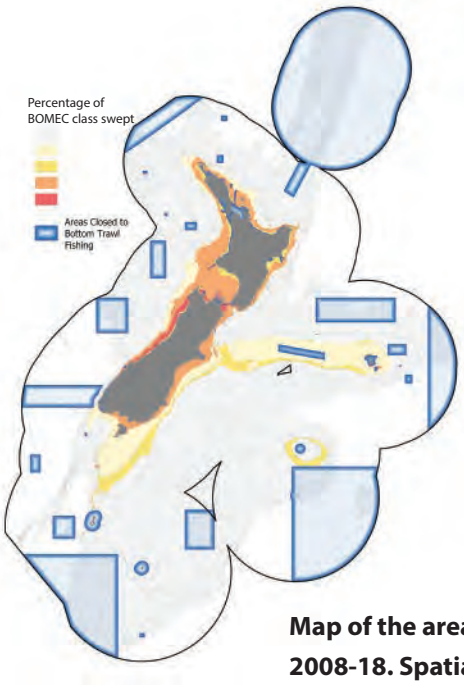
Map of NZ cumulative bottom fisheries footprint 2008-2018 (in black)

- Fisher-reported data, detailing where fishing occurs, are used to map the distribution of bottom fishing in NZ
- The extent and intensity of fisheries can be compared with the distribution of seabed habitats, and examined over different periods of time, to identify trends in fisheries overlap and impacts
- Between 2008 and 2018 bottom trawl fisheries contacted 7.2% (annual average of 2.2%) of the seabed in the NZ Territorial Sea (TS) and Exclusive Economic Zone (EEZ)

The figure below shows that the total number of trawl tows has been declining progressively since the late '90s



5. SPATIAL CONTROLS



Map of the area swept by trawl fishing gear (%) for each of the BOMEC classes in 2008-18. Spatial protection areas are represented as blue shaded zones

- Limiting fisheries interactions with sensitive habitats is one of the management options to protect them
- The 'trawlable' depth zone (<1600 m) covers about 40% of the NZ EEZ area. 15% of this area is closed to fishing within 100 m from the seabed (Benthic Protection Areas, BPAs)
- Currently 19.6% of the NZ TS and 30.2% of the NZ EEZ area is closed to bottom fishing by dfferent spatial control measures. Dedicated BPAs and sea mount closures protect 7.6% of the NZ TS and 29.8% of the NZ EEZ
- Different sensitivities of animals and seabed habitats to fishing pressure should be taken into account when managing fishing

6. ONGOING RESEARCH

- Monitoring seabed recovery after trawling closures in offshore (Graveyard) and inshore (Spirits bay) areas
- Improving predictive modeling to map seabed habitats and develop decision support tools for management
- Refining methods to estimate the extent and effects of bottom fishing, as well as recovery rates

11 BENTHIC (SEABED) IMPACTS

Status of chapter	This chapter has been partially updated for AEBAR 2021.
Scope of chapter	This chapter outlines the main effects of mobile bottom (or demersal) fishing gear on seabed habitats and communities. All trawl gears contacting the seabed and shellfish dredges are included. Danish seine and more or less static methods like bottom longline and potting are excluded in this version, as are fisheries outside the Exclusive Economic Zone (EEZ).
Area	All of the New Zealand Territorial Sea (TS) and EEZ. There will be some relevance for out-of-zone bottom trawl fisheries.
Focal localities	Areas that are fished more frequently and habitats that are more sensitive to disturbance are likely to be most affected; areas that are closed to bottom impacting methods will not be directly affected. Bottom trawling offshore is most intense on the western flanks and to the south-west of the Chatham Rise, the edge of the Stewart-Snares shelf, south-east of the Auckland Islands Shelf, and off the north-west coast of the South Island. In coastal waters shallower than 250 m, bottom trawling is most intense along the east coast of North Island, south of East Cape, and in Tasman Bay and Golden Bay. Shellfish dredges probably have the greatest effect but their footprint is much smaller than that of bottom trawl fisheries and generally in shallow waters in specific areas (e.g., Foveaux Strait).
Key issues	Habitat modification, potential loss of biodiversity, potential loss of benthic productivity, potential modification of important breeding or juvenile fish habitat leading to reduced fish recruitment.
Emerging issues	Potential for effects on habitats of particular significance to fisheries management (HPSFM). Opportunities presented by better spatial information from finer scale reporting of fishing locations (electronic reporting) and from vessel tracking data. Cumulative effects and interactions with other stressors (including existing effects, especially in the coastal zone, and climate change).
Fisheries New Zealand research (current)	BEN2019-04 *A spatially explicit benthic impact assessment for inshore and deepwater fisheries in New Zealand*; BEN2019-05 *Towards the development of a spatial decision support tool for managing the impacts of bottom fishing on in-zone, particularly vulnerable or sensitive habitats*; BEN2020-01 *Extent and intensity of seabed contact by mobile bottom fishing in the New Zealand Territorial Sea and Exclusive Economic Zone*; BEN2020-07 *Extent and intensity of trawl effort on or near underwater topographic features in New Zealand's Exclusive Economic Zone*; ZBD2020-06 *Exploring options for balancing fishing and habitat protection and recovery in the Hauraki Gulf*; ZBD2020-09 *Cumulative effects of stressors on scallops and scallop habitats in the Marlborough Sounds;* ZBD2020-11 *Review of land-based effects on coastal fisheries and kaimoana and their habitats*; BEN2021-01 *Characterisation of benthic habitats in four inshore areas and their potential as HPSFM*; BEN2021-03 *Taxonomic identification of benthic invertebrate samples*; BEN2021-05 *Habitat degradation impacts on blue cod populations*; ZBD2021-02 *Habitat degradation impacts on fishery productivity in northern harbours*.
New Zealand government research (current)	MBIE programme: Sustainable Seas COIX1515 Sustainable Seas Ko Nga Moana Whakauka.
Related chapters/issues	Biodiversity, habitats of particular significance for fisheries management (HPSFM), marine environmental monitoring, marine mining/sand extraction, land-based effects.

11.1 CONTEXT

For the purpose of this document, the term 'mobile bottom fishing methods' includes all types of trawl gear that are used in contact with the seabed as well as shellfish dredges of various designs and Danish seine nets. Relative to the information about trawls and dredges there is little information available about the distribution and effects of Danish seining, so Danish seining is not considered in detail. The benthic effects of other methods of catching fish on or

near the seabed that do not involve deliberately towing or dragging fishing gear across the seabed are thought to be considerably less than those of the mobile methods (although they are not always negligible) and these methods are not considered in this document.

Trawls and dredges are used to catch a relatively high proportion of commercial landings in New Zealand and such methods can represent the only effective and economic way of catching some species. However, the resulting disturbance to seabed habitats and communities may have consequences for biodiversity and ecosystem services, including fisheries and other secondary production. The guiding sections of the Fisheries Act 1996 for managing the effects of fishing, including benthic effects, are s.8(2)(b), which specifies that 'ensuring sustainability' (s.8(1)) includes 'avoiding, remedying, or mitigating any adverse effects of fishing on the aquatic environment' and s.9, which specifies a principle that 'biological diversity of the aquatic environment should be maintained'. Also potentially relevant is the principle in s.9 that 'habitat of particular significance for fisheries management should be protected' (see the chapter on Habitats of Particular Significance for Fisheries Management for more details).

One approach to managing the effects of mobile bottom fishing methods is through the use of spatial controls. A wide variety of such controls apply in New Zealand waters (Figure 11.1). Some of these controls were introduced specifically to manage the effects of trawling, shellfish dredging, and Danish seining in areas or habitats considered sensitive to such disturbance (e.g., the bryozoan beds off Separation Point, between Golden Bay and Tasman Bay, and the sponge-dominated fauna to the north of Spirits and Tom Bowling bays in the far north). Other closures exist for other reasons but have the effect of protecting certain areas of seabed from disturbance by mobile bottom fishing methods. These include no-take marine reserves, marine farms, pipeline and power cable exclusion zones, and areas set aside to protect marine mammals (e.g., see Figure 11.2 for areas where trawling is prohibited, Figure 11.3 for areas where gear and seasonal restrictions apply, and Figure 11.4 for areas related to marine reserves and marine farms). Marine reserves provide marine protection in a range of habitats within the Territorial Sea. Although marine reserves provide a higher level of protection by prohibiting all extractive activities, most tend to be small. New Zealand's marine reserves protect about 9.4% of New Zealand's Territorial Sea; however, most of this is in two marine reserves in the territorial seas around offshore island groups in the far north and far south of New Zealand's EEZ (Helson et al. 2010). Until 2000, most closures that had the effect of protecting areas of seabed from disturbance by trawling and dredging were in the Territorial Sea.

In the Exclusive Economic Zone, 18 seamount closures were established in 2001 to protect representative underwater topographic features from bottom trawling and dredging (Brodie & Clark 2003; see Figure 11.1). These areas included 25 features, including 12 large seamounts more than 1000 m high, covering 2% (81 000 km^2) of the EEZ. The seamount areas are closed to all types of trawling and dredging. In 2006, members of the fishing industry proposed the closure of about 31% of the EEZ to bottom trawling and dredging in Benthic Protection Areas (BPAs), including the existing seamount closures. The design criteria for the BPAs were they should be large, relatively unfished, have simple boundaries, and be broadly representative of the marine environment. After a consultation process, a substantially revised package of BPAs (including three additional areas totaling 13 887 km^2, 10 additional active hydrothermal vents, and 35 topographic features) that complemented the existing seamount closures was implemented by regulation in 2007 (Helson et al. 2010; Figure 11.1). BPAs cover about 1.1 million km^2 (31%) of New Zealand's EEZ and are closed to trawling on or close to the bottom. Midwater trawling well off the bottom is permitted in the BPAs if two observers are on board and an approved net monitoring system is used. Much of the seabed within BPAs is below trawlable depth (maximum trawlable depth is about 1600 m) and all are outside the Territorial Sea. In combination, the seamount closures and the BPAs include: 46% of underwater topographic features (a term that includes underwater hills, knolls, and seamounts); 55% of seamounts over 1000 m high; and 88% of known active hydrothermal vents.

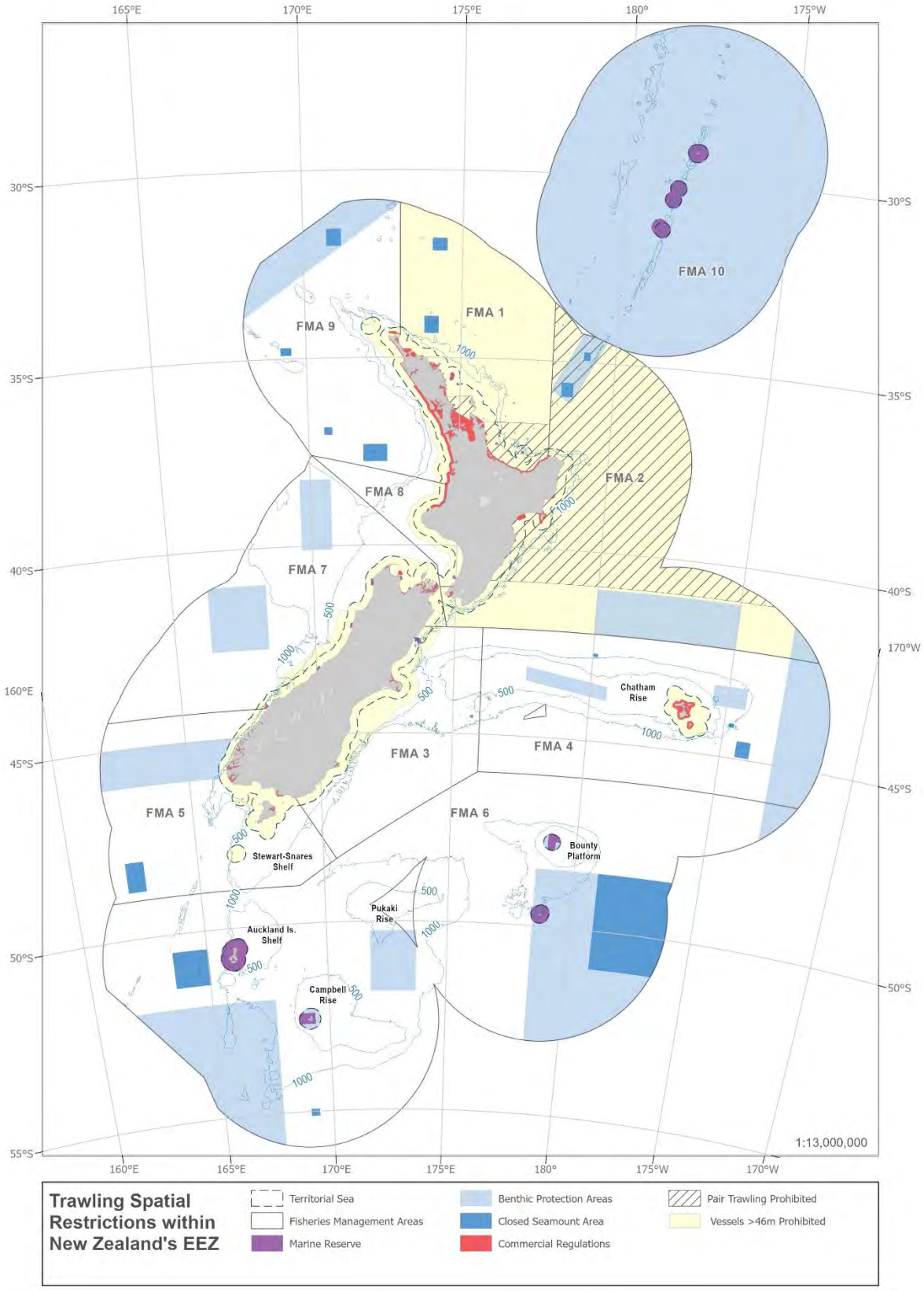


Figure 11.1: Map of the major spatial restrictions to trawling and Fisheries Management Areas (FMAs) within the outer boundary of the New Zealand EEZ. Vessels longer than 28 m may not trawl within the TS and additional restrictions are specified in the Fisheries (Auckland Kermadecs Commercial Fishing) Regulations 1986, the Fisheries (Central Area Commercial Fishing) Regulations 1986, the Fisheries (Challenger Area Commercial Fishing) Regulations 1986, the Fisheries (South East Area Commercial Fishing) Regulations 1986, and the Fisheries (Southland and Sub-Antarctic Areas Commercial Fishing) Regulations 1991. For more details of BPAs, see Helson et al. (2010). Map represents restrictions as at September 2021.

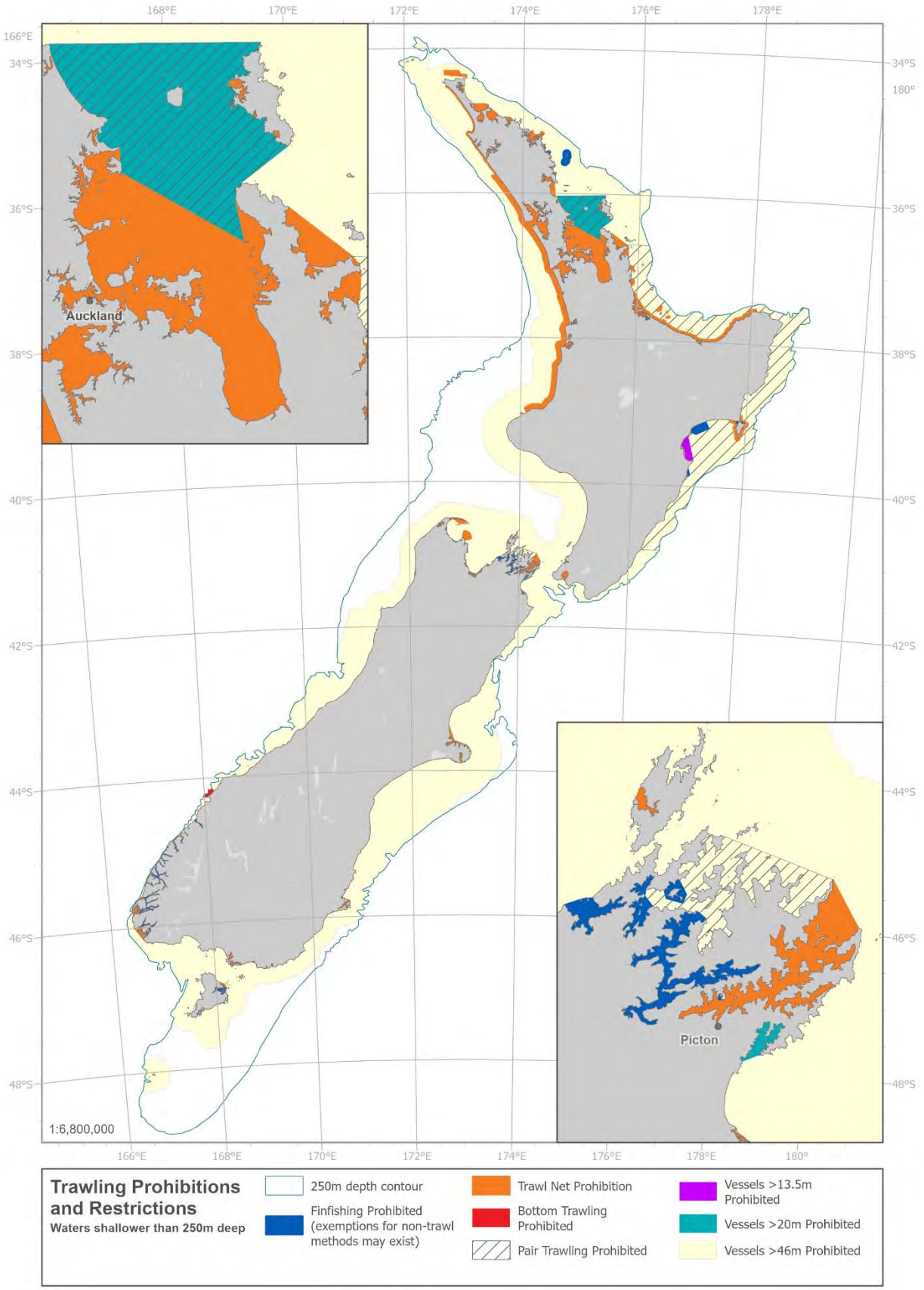


Figure 11.2: Areas showing where trawling is prohibited and other relevant restrictions apply in waters shallower than 250 m depth. Map represents prohibitions and restrictions as at September 2021.

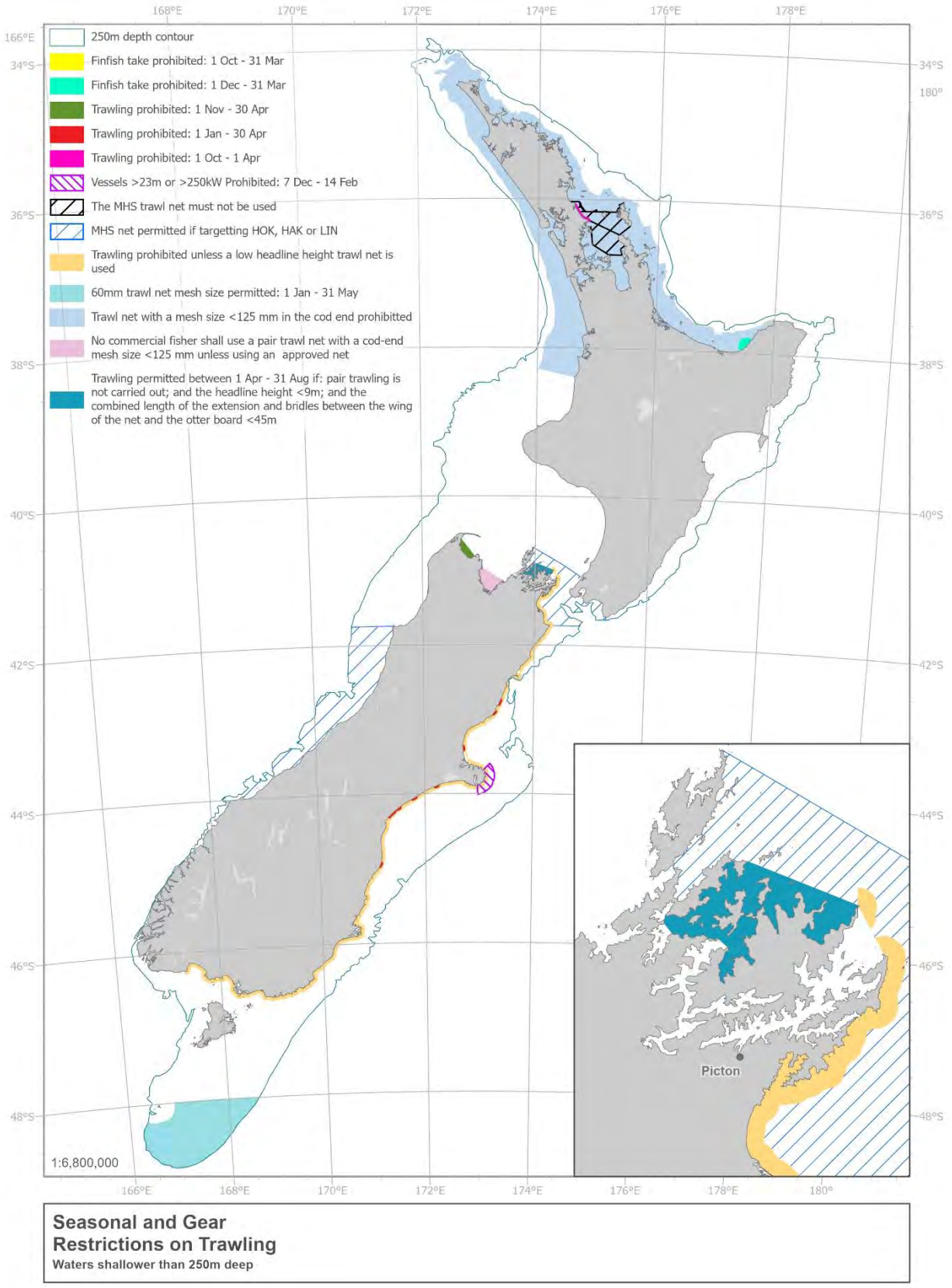


Figure 11.3: Areas where gear and seasonal restrictions apply to the use of trawl gear, in waters shallower than 250 m depth. Map represents restrictions as at September 2021.

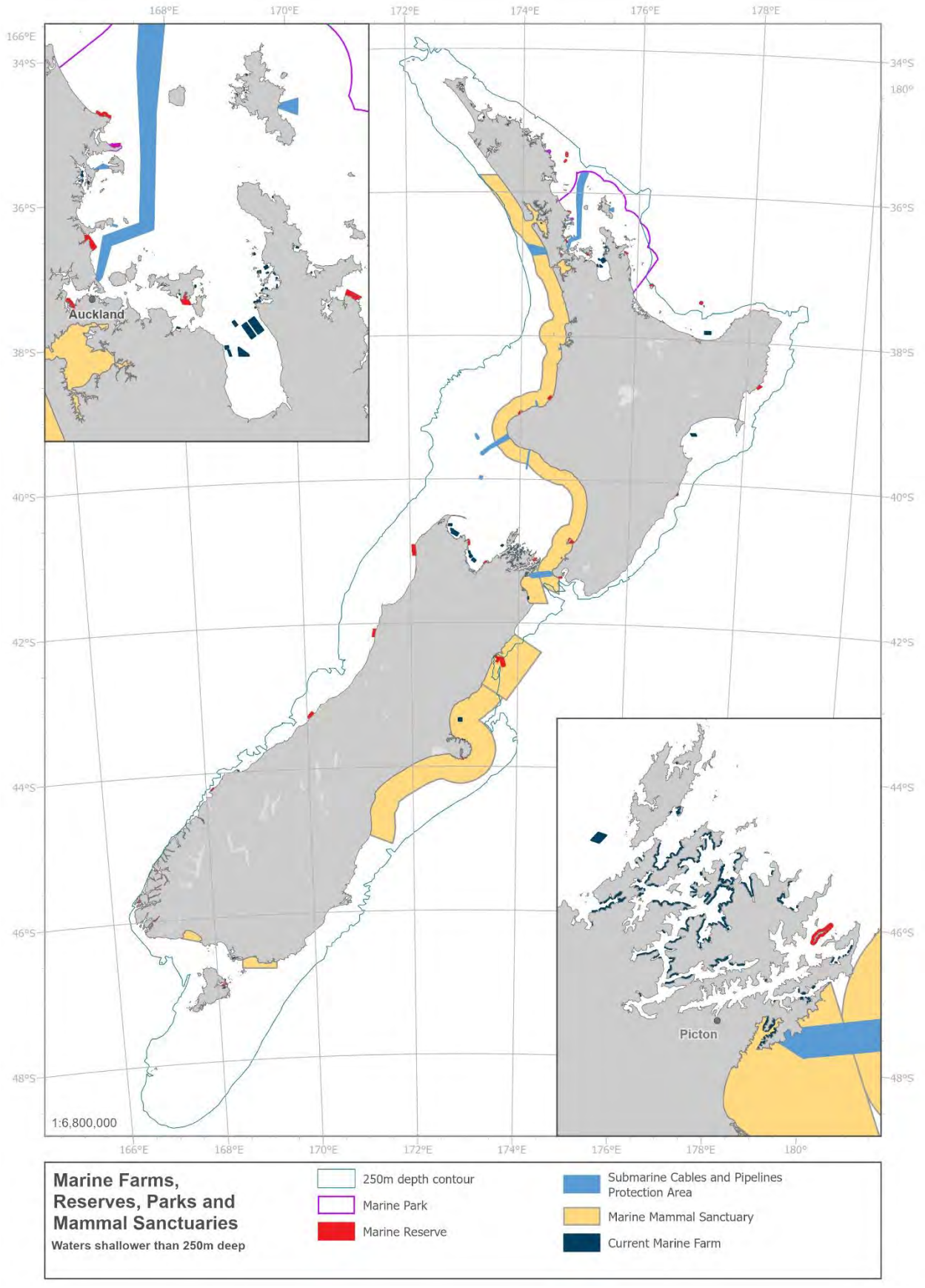


Figure 11.4: Locations of marine reserves and marine farms, marine mammal sanctuaries, marine parks, and cable and pipeline zones in waters shallower than 250 m depth. Map represents locations as at September 2021.

11.1 GLOBAL UNDERSTANDING

Concerns about the use of towed fishing gear on benthic habitats were first raised by fishermen in the fourteenth century in the UK (Lokkeborg 2005). They were worried about the capture of juvenile fish and the detrimental effects on food sources for harvestable fish. Despite this long history of concern, it is really only in the last 30 years that research efforts have focused strongly on the effects of mobile bottom fishing methods on benthic (seabed) communities, biodiversity, and production. This activity, combined with controversy around fishing effects, has spawned numerous reviews that seek to summarise or synthesise the information (Jones 1992, Dayton et al. 1995, Jennings & Kaiser 1998, Watling & Norse 1998, Lindeboom & de Groot 1998, Auster & Langton 1999, Hall 1999, ICES 2000a, 2000b, Kaiser & de Groot 2000, National Marine Fisheries Service 2002, National Research Council 2002, Dayton et al. 2002, Thrush & Dayton 2002, Lokkeborg 2005, Barnes & Thomas 2005, Clark & Koslow 2007, Clark et al. 2016).

Benthic habitats provide shelter and refuge for juvenile fish and the associated fauna can be the prey of demersal fish species. Towed fishing gears (particularly trawl doors) affect benthic habitats and organisms but the level of effect will depend on the type of trawl doors and ground gear used and the way the gear is rigged, and the physical and biological characteristics of the seabed habitats in the fishing grounds. The effects are difficult to assess because of the complexity of benthic communities and their temporal and spatial variability, and interpretation can also be complicated by environmental gradients or change. For reasons of accessibility, cost, and tractability, most research on seabed disturbance caused by human activities worldwide has been carried out in coastal systems, and our understanding of the effects of physical disturbance on the highly diverse communities of the deep sea has developed only recently.

The reviews above broadly indicate that numerical abundance of many invertebrates decline (sometimes substantially) after mining, trawling, or other major disturbance. Trawling and dredging can re-suspend sediment and can, depending on sediment and local currents, alter sediment characteristics. Physical effects include furrows and berms from trawl doors, furrows from the bobbins and rock hoppers, and sediment re-sorting, but the magnitude of these effects depends on sediment type, currents, and wave action (if any). Bottom trawling can also alter natural sediment fluxes and reduce organic carbon turnover (Pusceddu et al. 2014), the depth of the oxic layer in sediments (Churchill 1989, Warnken et al. 2003, Bradshaw et al. 2012), and the shape of the upper continental slope (Puig et al. 2012), reducing morphological complexity and benthic habitat heterogeneity. The mixing of sediments and overlying water can alter the chemical makeup of the sediment and have considerable effects in deep, stable waters (Rumohr 1998). Chemical release from the sediment can also be changed, as shown for phosphate in the North Sea (ICES 1992, noting lower fluxes were observed after trawling events).

Trawling can alter benthic communities, reduce total biomass of benthic species, and increase predation by scavengers. Sites subject to greater natural disturbance are generally thought to be less susceptible to change from bottom contact fishing (but see Schratzberger et al. 2009 who concluded that common anthropogenic disturbances differ fundamentally from natural disturbance). There has been less work on the effects of other methods of catching demersal fish or crustaceans that do not involve deliberately towing or dragging fishing gear across the seabed, but some of these methods can have non-negligible effects (e.g., Sharp et al. 2009, Williams et al. 2011).

Studies of recovery dynamics are rarer still, but a return to pre-disturbance levels after bottom-contacting fishing can take up to several years, even in some sites subject to considerable natural disturbance (see Kaiser et al. 2006 for a summary). In shallow regions with mobile sediments, the effects are generally difficult to detect and recovery can be rapid (e.g., Jennings et al. 2005). Examining epifauna, Lambert et al. (2014) estimated recovery from scallop dredging to take from less than 1 year to over 10 years, depending on functional group, with faster recovery in areas with faster tidal currents, and large-bodied species recovering faster when conspecifics were abundant locally. Hard-bottom fauna is predicted to recover most slowly and Williams et al. (2010) concluded that hard-bottom fauna on Australasian seamounts did not show signs of recovery within 5–10 years. Recovery rate is typically correlated with the spatial extent of a disturbance event (e.g., Hall 1994, Kaiser et al. 2003; see also Figure 11.5) and the effects of some ‘catastrophic’ natural disturbance events, such as large-scale marine mudslides, can be detected for hundreds of years, even for taxa thought to be robust to physical disturbance such as nematodes (Hinz et al. 2008).

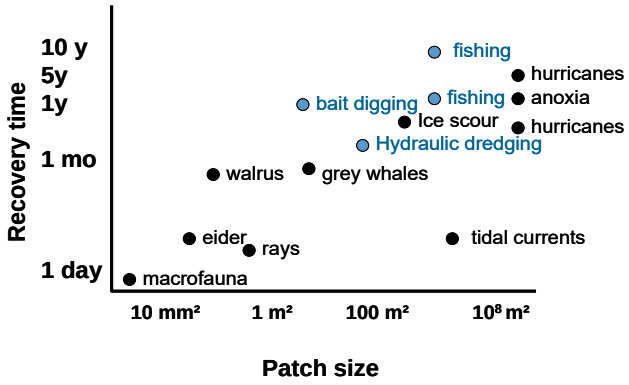


Figure 11.5: General relation between the spatial extent of disturbance events and the time taken to recover from such events in marine systems (after Kaiser et al. 2003). Blue dots signal human impacts, including fishing in habitats of different abilities to recover, and black dots signal natural disturbance.

Rice (2006) summarised the findings of five major reviews of the effects of mobile bottom-contacting fishing gears on benthic species, communities, and habitats. In this 'review of reviews' Rice (2006) summarised the findings of the multiple working groups that contributed to the reviews as follows:

Rice's (2006) conclusions about the effects on habitats of mobile bottom fishing gears were that they can:

- Damage or reduce structural biota (all reviews, strong evidence or support).
- Damage or reduce habitat complexity (all reviews, variable evidence or support).
- Reduce or remove major habitat features such as boulders (some reviews, strong evidence or support).
- Alter seafloor structure (some reviews, conflicting evidence for benefits or harm).

Other emergent conclusions on habitat effects included:

- There is a gradient of effects, with greatest effects on hard, complex bottoms and least effect on sandy bottoms (all reviews, strong support, with qualifications).
- There is a gradient of effects, with greatest effects on low energy environments and least (often negligible) effect on high-energy environments (all reviews, strong support).
- Trawls and mobile dredges are the most damaging of the gears considered (three of the reviews considered other gears; all drew this conclusion, often with qualifications).

Mobile bottom gears affect benthic species and communities in that they:

- Can change the relative abundance of species (all reviews, strong evidence or support).
- Can decrease the abundance of long-lived species with low turnover rates (all reviews, moderate to strong evidence or support).
- Can increase the abundance of short-lived species with high turnover rates (all reviews, moderate to occasionally strong evidence or support).
- Affect populations of surface-living species more often and to greater extents than populations of burrowing species (all reviews, weak to occasionally strong evidence or support).
- Have lesser effects in high-energy or frequent natural disturbance environments than in low energy environments where natural disturbances are uncommon (four reviews (the other did not address the factor), strong evidence or support).
- Affect populations of structurally fragile species more often and to greater extents than populations of 'robust' species (all reviews, variable evidence and support).
- Temporarily increase the abundance of scavengers in areas where bottom trawls have been used (three reviews, variable support or evidence, all argue for the effects being transient).
- Increase the rates of nutrient cycling or sedimentation in areas where bottom trawls have been used (two reviews, mixed views on magnitude of effects and conditions under which they occur).

Considerations in the application or adoption of mitigation measures:

- The effect of mobile fishing gears on benthic habitats and communities is not uniform. It depends on:
  - The features of the seafloor habitats, including the natural disturbance regime (all reviews, strong evidence or support);
  - The species present (all reviews, strong evidence or support, though not mentioned by National Marine Fisheries Service panel);
  - The type of gear used and methods of deployment (all reviews, moderate to strong evidence or support);
  - The history of human activities, particularly past fishing, in the area of concern (all reviews, strong evidence or support).

- Recovery time from trawl-induced disturbance can take from days to centuries, and depends on the same factors as listed above (all reviews, strong evidence or support).
- Given the above considerations, the effect of mobile bottom gears has a monotonic relationship with fishing effort, and the greatest effects are caused by the first few fishing events (all reviews, moderate to strong evidence or support).
- Application of mitigation measures requires case specific analyses and planning; there are no universally appropriate fixes (three reviews, moderate to strong evidence or support. The issue of implementing mitigation was not addressed in the FAO review. It was also stressed in the US National Academy of Sciences review and discussed in the ICES review that extensive local data are not necessary for such case-specific planning. The effects of mobile bottom gears on seafloor habitats and communities are consistent enough with well-established ecological theory, and across studies, that cautious extrapolation of information across sites is legitimate).

Rice (2006) concluded "*These overall conclusions on impacts and mitigation measures, and recommendations for management action form a coherent and consistent whole. They are relevant to the general circumstances likely to be encountered in temperate, sub-boreal, and boreal seas on coastal shelves and slopes, and probably areas … beyond the continental shelves. They allow use of all relevant information that can be made available on a case by case basis, but also guide approaches to management in areas where there is little site-specific information.*"

Since Rice's (2006) paper, Kaiser et al. (2006) published a meta-analysis of 101 separate manipulative experiments that confirms many of Rice's findings. Shellfish dredges have the greatest effect of the various mobile bottom fishing gears, biogenic habitats are the most sensitive to such disturbance (especially for attached fauna on hard substrates), and unconsolidated, coarse sediments (e.g., sands) are the least sensitive. Kaiser et al. (2006) concluded that recovery from disturbance events can take months to years, depending on the combination of fishing method and benthic habitat type. This meta-analysis of manipulative experiments was an important development, reinforcing the inferences drawn from multiple mensurative observations at much larger scale ('fisheries scale') in New Zealand (e.g., Thrush et al. 1998, Cryer et al. 2002) and overseas (e.g., Craeymeersch et al. 2000, McConnaughey et al. 2000, Bradshaw et al. 2002, Blyth et al. 2004, Tillin et al. 2006, Hiddink et al. 2006). This is a powerful combination that implies substantial generality of the findings.

The international literature is, therefore, clear that bottom (demersal) trawling and shellfish dredging are likely to have largely predictable and sometimes substantial effects on benthic community structure and function. The positive or negative consequences for ecosystem processes such as production have been addressed in several studies (e.g., Jennings et al. 2001, Reiss et al. 2009, Hiddink et al. 2011). It has been mooted that frequent disturbance should lead to the dominance of smaller species with faster life histories and that, because smaller species are more productive than larger ones, system productivity and production should increase under trawling disturbance. However, when this proposition has been tested, it has not been supported by data in real fishing situations (e.g., Hermsen et al. 2003, Reiss et al. 2009) and, where overall productivity has been assessed, it decreases with increasing trawling disturbance.

For example, Veale et al. (2000) examined spatial patterns in the scallop fishing grounds in the Irish Sea and found that total abundance, biomass, and secondary production (including that of most individual taxa examined) decreased significantly with increasing fishing effort. Echinoids, cnidarians, prosobranch molluscs, and crustaceans contributed most to the differences. Jennings et al. (2001) showed that, in the North Sea, trawling led to significant decreases in infaunal biomass and production in some areas even though production per unit biomass rose with increased trawling disturbance. The expected increase in relative production did not compensate for the loss of total production that resulted from the depletion of large-bodied species and individuals. Hermsen et al. (2003) found that mobile fishing gear disturbance had a conspicuous effect on benthic megafaunal production on Georges Bank, and cessation of such fishing led to a marked increase in benthic megafaunal production, dominated by scallops and urchins. Hiddink et al. (2006) estimated that more than half of the southern North Sea was trawled sufficiently frequently to depress benthic biomass by 10% or more, and that 27% was in a state where benthic production was depressed by 10% or more. They estimated that recovery from this situation would take 2.5–6 years or more once fishing effort had been eliminated. They further estimated that fishing reduced benthic biomass and production by 56% and 21%, respectively, compared with an unfished situation. Reiss et al. (2009) found that, although sediment composition was

the most important driver of benthic community structure in their North Sea study area, the intensity of fishing effort was also important and reductions in the secondary production of the infaunal community could be detected even within this heavily fished region.

The types of models developed by Hiddink et al. (2006, 2011; but see also Ellis & Pantus 2001 and Dichmont et al. 2008) can be used to assess the likely performance of different management approaches or levels of fishing intensity. Such management strategy evaluation (MSE) methods involve specifying management objectives, performance measures, a suite of alternative management strategies, and evaluating these alternatives using simulation (Sainsbury et al. 2000). For instance, the early study by Ellis & Pantus (2001) assessed the effect of trawling on marine benthic communities by combining an implementation of the spatial and temporal behaviour of the local fishing fleet with realistic ranges for the removal and recovery of benthic organisms. The model was used to compare the outcomes of two radically different management approaches, spatial closures and reductions in fishing effort.

From a New Zealand perspective, Mormede & Dunn (2013) developed a simple spatially explicit population model as a tool to assist ecological risk assessments, and Lundquist et al. (2010, 2013) used a more sophisticated spatially explicit landscape mosaic model with variable connectivity between patches to assess the implications of different spatial and temporal patterns of disturbance in the model landscape. They found that the scale of the disturbance regime (which could be trawling or any other physical disturbance) and the dispersal processes interact, and that the scales of these processes greatly influenced changes in the structure and diversity of the model community, and that recovery across the mosaic depended strongly on dispersal. System stability also decreased as dispersal distance decreased. Patterns of abundance of different species groups observed across gradients of fishing pressure were in general agreement with model predictions.

11.2 STATE OF KNOWLEDGE IN NEW ZEALAND

To understand the effects of mobile bottom fishing methods on benthic habitats, it is necessary to have knowledge of:

- the distribution of such habitats,
- the extent to which mobile bottom fishing methods are used in each habitat (the overlap),
- the consequences of any such disturbance (potentially in conjunction with other disturbances or stressors), and
- the nature and speed of recovery from the disturbance.

These components are discussed below.

11.2.1 DISTRIBUTION OF HABITATS

Mapping of benthic habitats at the large scales inherent in fisheries management is expensive and time-consuming so the New Zealand government commissioned an environmental classification to provide a spatial framework that subdivided the TS and EEZ into areas having similar environmental and biological character. The Marine Environment Classification (MEC) was launched in 2005 (Snelder et al. 2004, 2005, 2006) using available physical and chemical predictors, because environmental pattern was thought to be a reasonable surrogate for biological pattern. The authors suggested that the MEC provided managers with a useful spatial framework for broad-scale management, but cautioned that the full utility and limitations would become clear only as the MEC was applied to real issues. They described the MEC as a tool to organise data, analyses, and ideas, and as only one component of the information that would be employed in any analysis. The 20-class version (Figure 11.6) has been the most widely cited, although additional classification levels provide more detail that is significantly correlated with biological layers. The 2005 MEC was not optimised for any specific ecosystem component but was 'tuned' against data for demersal fish, phytoplankton, and benthic invertebrates. It performed least well as a classification of benthic invertebrates and, at the 20-class level, grouped most of the Chatham Rise and Challenger Plateau into a single class. Although separation of these two areas was evident as the MEC was driven to larger numbers of classes, their inclusion within a single class in the 20-class classification was considered counter-intuitive because their productivity and fisheries are known to be very different.

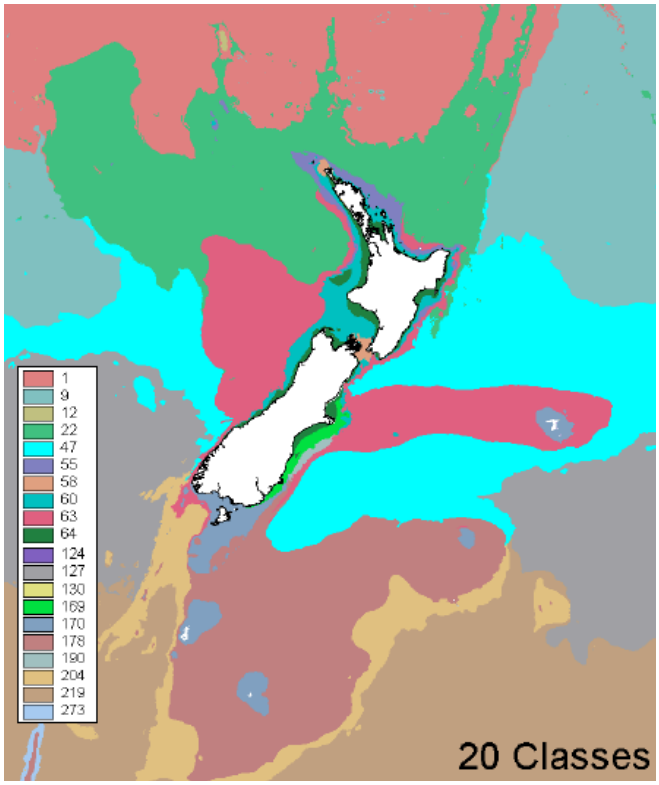


Figure 11.6: The 20-class version of the 2005 general purpose Marine Environment Classification (MEC, from Snelder et al. 2005).

This disquiet with the predictions of the original MEC for benthic habitat classes led to the development of alternatives that might perform better for benthic systems. First of these was a classification optimised for demersal fish (Leathwick et al. 2006). Several variants of this classification outperformed the original MEC for demersal fish, particularly at lower levels of classification detail and it was adopted by the Ministry for the Environment for their indicators related to bottom trawling and their 2010 Environmental Snapshot where the trawl footprint is compared with putative habitats (Ministry for the Environment 2010).

Based partly on this experience, the Ministry of Fisheries commissioned a Benthic-Optimised Marine Environment Classification, BOMEC (Leathwick et al. 2012). Many more physical, chemical, and biological data layers were available for the development and tuning of this classification than for the 2005 MEC. Especially relevant for benthic invertebrates was the inclusion of a layer for sediment grain size (notably absent from the MEC). Generalised Dissimilarity Modelling (GDM; Ferrier et al. 2002, 2007, Leathwick et al. 2011) was used to define the classification because this approach is well suited to the sparse and unevenly distributed biological data available. The BOMEC classes (15-class level version shown in Figure 11.7) were strongly driven by depth, temperature, and salinity into five major groups: inshore and shelf, upper slope, northern mid-depths, southern mid-depths, and deeper waters (generally beyond the fishing footprint, down to 3000 m, the limit of the analysis). Waters deeper than 3000 m could be considered an additional class. The 15-class BOMEC levels were used in conjunction with a broad sediment type classification and broad depth bands to identify 112 benthic habitats shallower than 250 m (Figure 11.8) (Baird et al. 2015).

Testing by Bowden et al. (2011) indicated that the BOMEC out-performed the original MEC at predicting benthic habitat classes on and around the Chatham Rise, but that none of the available classifications were very good at predicting the abundance and composition of benthic invertebrates at the fine scale of the sampling undertaken (tens of metres to kilometres). This, in conjunction with the findings of Leathwick et al. (2006), reinforces the role of environmental classifications as broad-scale predictors of general patterns at broad scale (tens to hundreds of kilometres) when more specific biological information is not available.

The Department of Conservation recently commissioned a Seafloor Community Classification (SCC, Stephenson et al. 2021). Like the previous classifications, the SCC is a numerical classification, and it provides advances on both

the MEC and BOMEC because substantially more biological and environmental data were used. Using Gradient Forest (GF) models, occurrence records for demersal fish, benthic invertebrates, macroalgae, and reef fish informed the transformation of 33 environmental variables to represent spatial patterns of taxa compositional turnover. The overall predicted spatial patterns of compositional turnover was classified into 75 groups and uncertainty estimates of compositional turnover for each of the groups were produced. The SCC groups were differentiated primarily according to oceanographic conditions such as depth and bottom temperature at broad scales. More pronounced environmental differences between groups were evident at shallower depths where variation in more localised environmental conditions such as productivity, seafloor topography, seabed disturbance, and tidal currents were important differentiating factors. An associated publication was produced providing detailed descriptions of the 75 SCC groups (Petersen et al. 2020).

Where broad-scale classification methods are not applicable, other approaches have been taken. The trawl fisheries for orange roughy, oreos, and cardinalfish take place to a large extent on seamounts or other features (Clark & O'Driscoll 2003, O'Driscoll & Clark 2005). These features are often geographically small and, in common with other localised habitats such as vents, seeps, and sponge beds, do not appear on broad-scale habitat maps (e.g., at EEZ scale) and cannot realistically be predicted by broad-scale environmental classifications. Many features have been extensively mapped in recent years (e.g., Clark et al. in review), and seamount classifications based on biologically-referenced physical and environmental 'proxies' have also been developed, in New Zealand waters by Rowden et al. (2005) and globally by Clark et al. (2010a, 2010b). Davies & Guinotte (2011) developed a method of predicting the framework-forming (i.e., physically structuring) coldwater corals that are a focus for benthic biodiversity in deepwater systems.

MPI and MBIE funded a range of projects to inform the spatial management of the South Pacific Region and support the role of New Zealand in SPRFMO. The project 'Predicting the occurrence of vulnerable marine ecosystems for planning spatial management in the South Pacific Region' is led by NIWA in collaboration with Victoria University of Wellington and the Marine Conservation Institute (USA). This has involved a major compilation of data on VME species distribution (including corals) throughout the SPRFMO area, as well as the EEZ. Modelling has been completed for the EEZ and general New Zealand region (Anderson et al. 2016a), as well as validation analyses of a wider regional model based on a survey of the Louisville Seamount Chain in 2014 (Anderson et al. 2016b). Work continues worldwide, including in New Zealand, on the development of sampling, analytical, and modelling techniques to provide cost-effective assessments of the distribution of marine habitats at a range of scales. Bowden et al. (2015) provide a desk top assessment of future options for monitoring deepwater benthic communities and conclude that photographic approaches sampling mega-epifauna are likely to be the most cost effective and relevant for detecting ecological effects at the scale of deep sea fisheries. Such sampling could be added to existing surveys but would require dedicated time. Opportunistic sampling from trawl surveys or observer data cannot be relied upon to provide representative samples of the benthic community.

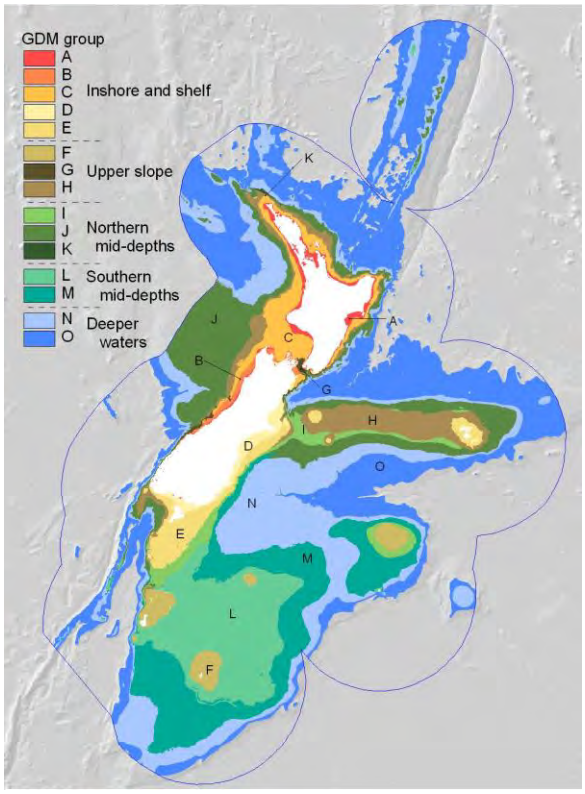


Figure 11.7: Map of the distribution of Benthic-Optimised Marine Environment Classification (BOMEC) classes defined by multivariate classification of environmental data transformed using results from GDM analyses of relationships between environment and species turnover averaged across eight taxonomic groups of benthic species. [From Leathwick et al. (2012).]

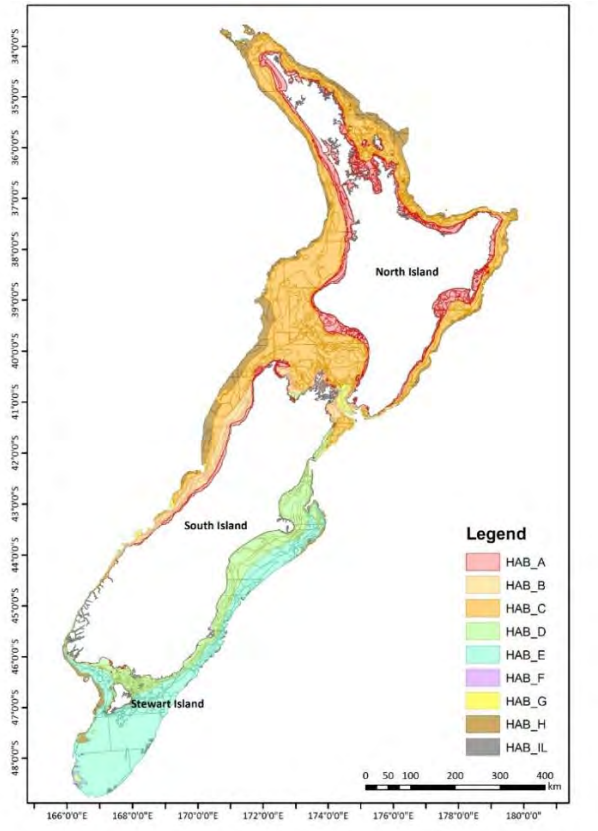


Figure 11.8: The broad habitat definitions based on the BOMEC classes, with divisions indicating areas of different sediment, depth zone, and statistical area in waters shallower than 250 m depth. [From Baird et al. (2015).]

11.2.2 DISTRIBUTION OF FISHING

Since 1989–90, mobile bottom fishing effort has been reported through one of four data collection methods each of which was introduced in different years (Table 11.2). Trawl Catch Effort and Processing Returns (TCEPRs) contain detailed spatial and other information for each trawl tow. These were introduced for vessels over 28 m that generally fished deeper waters within the New Zealand EEZ, with the first data collection year being 1 October 1989 to 30 September 1990. Since 2007–08, Trawl Catch and Effort Returns (TCERs) have been available for smaller, predominantly inshore trawlers. These include spatial and other information for each trawl tow but in less detail than on TCEPRs. Catch Effort and Landing Returns (CELRs) were used prior to 2007–08 and include only summarised information for each day's fishing, with very limited spatial resolution. This effort is not included in trawl footprint estimations due to the lack of tow-specific spatial data. Before 2007–08, the amount of overall trawl effort each year could be double that included in the trawl footprint estimation based on tow-level data reported on TCEPRs and TCERs (Baird et al. 2011).

Between 2007–08 and 2018–19, almost all trawling effort was reported on TCEPR or TCER forms. Electronic Reporting Systems (ERS) were introduced in 2018 for deepwater fishstocks and in 2019 for inshore fishstocks. This has provided similar data but at a finer resolution and, for inshore data, an endpoint for each tow. The change of data collection during the time series needs to be considered when interpreting trawl footprint estimations.

Trawl effort for all target species are included in the data shown in Figure 11.9. After the peak of over 140 000 reported trawl tows in 1996–97 and 1997–98 (Figure 11.9) when slightly over half of all tows were reported on TCEPRs, overall trawling effort declined to less than 60 000 tows per year by 2020–21, all of which are reported electronically (ERS).

Baird et al. (2002) and Baird et al. (2011) described the distribution and frequency of reported fishing by mobile bottom fishing gear (dredge, Danish seine, bottom trawl, bottom pair trawl, and midwater trawl in contact with the bottom) in New Zealand's TS and EEZ during the 1990s and up to 2004–05, respectively, for all commercial targets. This work was updated to 2011–12 by Black & Tilney (2017) for deepwater target species effort reported on TCEPRs. These reports showed that fishing was highly heterogeneous (spatially), but had considerable consistency among years; sites that were fished heavily in one year were likely to be fished heavily in other years. A similar but more detailed analysis was conducted for the Chatham Rise and subantarctic areas by Baird et al. (2006). Tows reported on TCEPRs were included in the main spatial analysis, but some additional analysis was possible using tows reported on CELRs. Until 2006–07, a substantial proportion of reported trawling effort was captured using CELRs. This was predominantly by vessels targeting inshore fish species but did also include some targeted effort for some 'deepwater' species. For instance, Cryer & Hartill (2002) estimated that, in the Bay of Plenty in the 1990s, 78%, 75%, and 39% of trawl tows targeting tarakihi, gemfish, and hoki, respectively, were reported on CELR forms.

Baird et al. (2015) analysed a combined data set of TCEPR and TCER data for the area shallower than 250 m for 2007–08 to 2011–12. Previous trawl footprint analyses (e.g., Baird et al. 2011, Black et al. 2013) underestimated trawl effort in inshore areas because tows recorded on CELR forms, which lack suitable spatial data, could not be included in the estimation of the trawl footprint.

Baird & Wood (2018) updated the three annual measures of fishing effort for deepwater fishstocks (1989–90 to 2015–16): the number of tows, the aggregate swept area (using assumed door spreads), and the coverage ('footprint') of the total trawl contact. Trawls were represented spatially as tracklines between the reported start and finish positions buffered by the assumed door spread to generate trawl polygons. The aggregate swept area for a year is the sum of the areas of the polygons and the 'footprint' is the estimated area of the seabed that is covered by the polygons overlaid. The estimated swept areas and footprint do not account for any modification that might occur alongside the trawl path as represented by the swept area polygon (e.g., by suspended sediments transported by currents away from the trawl track).

The 1989–90 to 2015–16 footprint (Baird & Wood 2018) contacted about 20% of the area shallower than 1600 m and 23% of the area that is open to bottom trawling and shallower than 1600 m.

Baird & Wood (2018) used reported tows on small topographic features that are a focus for orange roughy and cardinalfish fisheries by defining polygons for these tows as

radii around the reported start position with the area swept estimated from the reported duration and speed of the tow. These short tows do not appear to contribute substantially to broad-scale plots at the scale of the EEZ, yet can represent intense fishing effort on particular, small seamount features (e.g., O'Driscoll & Clark 2005, Rowden et al. 2005).

Baird & Mules (2019) generated a trawl footprint from the bottom-contacting trawl effort for deepwater fishstocks for 2007–08 to 2016–17, as reported on TCERs and TCEPRs . This 10 year footprint contacted about 11% of the area shallower than 1600 m and 13% of the area that is open to bottom trawling and shallower than 1600 m.

Trawl footprint estimations for inshore (2008 fishing year onwards), deepwater (1990 fishing year onwards) and all stocks combined have recently been completed up until the 2018 fishing year. (Baird & Mules 2021a) and the 2019 fishing year (Baird & Mules 2021b).

The 1990–2019 dataset used to estimate the trawl footprint includes only the effort data collected on a tow-by-tow basis. During this period, the trawl footprint was based on TCEPRs (all fishing years) and TCERs (fishing years 2008 to 2019) only; thus, for the fishing years before 2008 the data predominantly represented deepwater offshore trawling. A substantial portion of trawl effort for the period 1990–2007 (approximatley 60% of effort was reported on CELRs, see Figure 11.9) is excluded from this estimation.

The 30-year dataset is useful for assessing the annual estimated deepwater trawl footprint as well as providing an estimated footprint of all trawl tows that have been reported on a tow-by-tow basis between 1990 and 2019. A combined footprint for all bottom-contacting trawl effort (based on tow-by-tow data) between 1990 and 2019 is shown in Figures 11.10.- (Baird & Mules 2021b). The intensity of effort (measured by the number of tows per 25-km^2 cell) for the combined inshore and deepwater fishstock data for 1990 and 2019 is shown in Figure 11.11. The most intensely contacted cells were close inshore and on some shelf edges. This 30-y period combined footprint contacted 11% of the seafloor area within New Zealand Territorial Sea and EEZ and 33% of the area shallower than 1600 m (fishable depths) and open to trawling (termed the fishable area).

The most comparable period to assess trends in the annual trawl footprint for all stocks combined is for 2008–2019 where deepwater fleet trawl contact is represented mainly by TCEPR and also TCER during 2008–2017 and mainly by the ERS data in 2018 and 2019, and the inshore component is represented by the TCER in all years except for a small amount of effort in 2018 and under 50% in 2019 when ERS data collection replaced TCERs. Over this 12-year period approximately 2% of the seafloor area within New Zealand Territorial Sea and EEZ and 6–7% of the fishable area was contacted by trawl gear each fishing year. The percentage coverage of the fishable area each year is about 3% for inshore fishstocks and 3–4% for deepwater fishstocks; note there is some overlap between the inshore and deepwater footprints (Baird & Mules 2021a, 2021b). The all stocks footprint decreased over the 12 years, with the lowest value estimated for 2019. These data reflect the decreasing amount of bottom-contacting trawl effort during these years; the numbers of tows in the TCEPR, TCER, and ERS data steadily dropped from 89 236 in 2010 to 66 039 in 2019. Over the12 years, the intensity of trawling within cells was steady despite the decrease in aggregate area, implying that the contact was more concentrated.

The deepwater footprint was updated in 2020 (Baird & Mules 2021b) for all years from 1989–90 (1990) up until 2018–19 (2019). Deepwater trawl fisheries have contacted 8.6% of the EEZ+TS and 25.3% of the fishable area between 1990 and 2019. Between 1990 and 2007 annual footprint estimates ranged from 1.2% and 2.0% of the EEZ+TS and 3.4% and 5.8% of the fishable area (peaks in 2002 and 2003); whereas, between 2008 and 2019, the annual footprint contacted 1.1–1.2% and 3.2–3.7% of the fishable area (lowest values in 2019). Across the 30-year time series for deepwater data, there was a steady increase in the footprint from under 50 000 km^2 in 1990 to a sustained period of contact during 1998 to 2003 (range 72 612 to 81 005 km^2), followed by a steady decrease to 43 481 km^2 in 2019, the lowest of the full 30-year time series, with declines seen for most deepwater targets and the swept area data reflecting the drop in effort (see Figure 11.12).

An updated trawl footprint for inshore fishstocks grouped by the inshore Fishery Management Areas, was completed for the period 2007–08 (2008) to 2018–19 (2019) (Baird & Mules 2021b). Inshore trawl fisheries have contacted 3.6% of the EEZ+TS and 10.7% of the fishable area between 2008 and 2019. The annual inshore footprint has decreased, from a peak of about 47 220 km^2 in 2010 to a nadir of 38 131 km^2 in 2019 (see Figure 11.12). This contact was equivalent to 0.9–1.1% of the EEZ+TS seafloor area, and 2.7–3.4% of the fishable area, with the lowest values from 2019.

Table 11.2: Attributes, usage, and resolution of spatial reporting required on Trawl Catch Effort and Processing Returns (TCEPRs), Trawl Catch and Effort Returns (TCERs), Catch Effort and Landing Returns (CELRs), and Electronic Reporting (ERS).

	Trawl catch and effort reporting forms			
	CELR	TCEPR	TCER	ERS
Year of introduction	1988–89	1989–90	2007–08	2017–
Vessels using	Trawlers not using TCER or TCEPR Shellfish dredgers	All trawlers >28 m Other vessels as directed Other vessels optional	All trawlers 6–28 m unless exempted	All trawlers >28 m. Phased in for all other vessels (from January–December 2019)
Trawl tow reporting	Daily summary, number of tows, gear, target, fishery area	Tow by tow, start and finish locations, speed, depth, target, gear, duration	Tow by tow, start location, speed, depth, target, gear, duration	Tow by tow, start and finish locations, speed, depth, target, gear, duration, lost gear, mitigation
Spatial resolution	Statistical reporting area (optionally lat/long)	1 minute (lat/long)	1 minute (lat/long)	4 decimal places of a degree (lat/long)

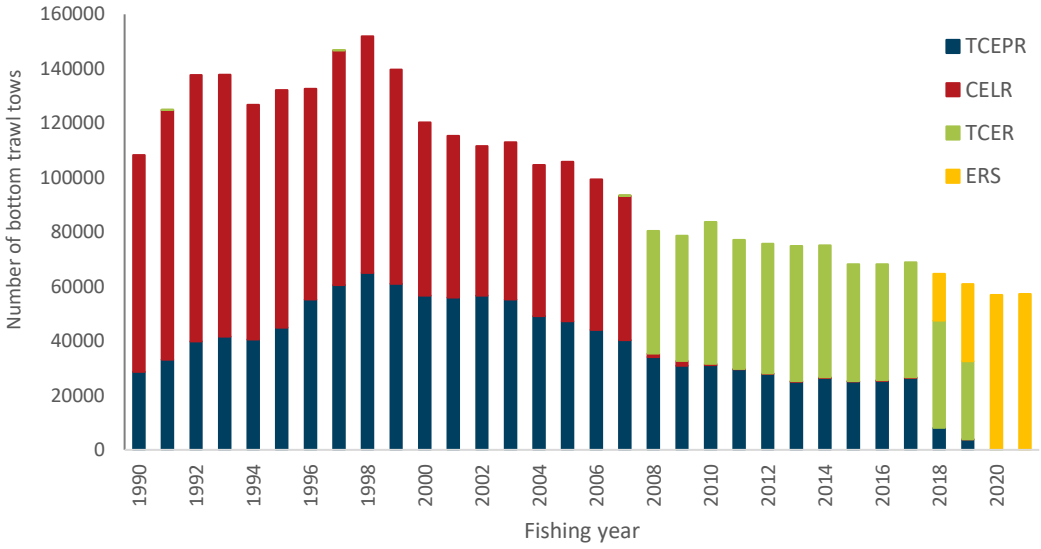


Figure 11.9: Total number of reported bottom trawl tows by fishing year and reporting form. Note: Effort reported on CELR forms is not included in the trawl footpint estimation.

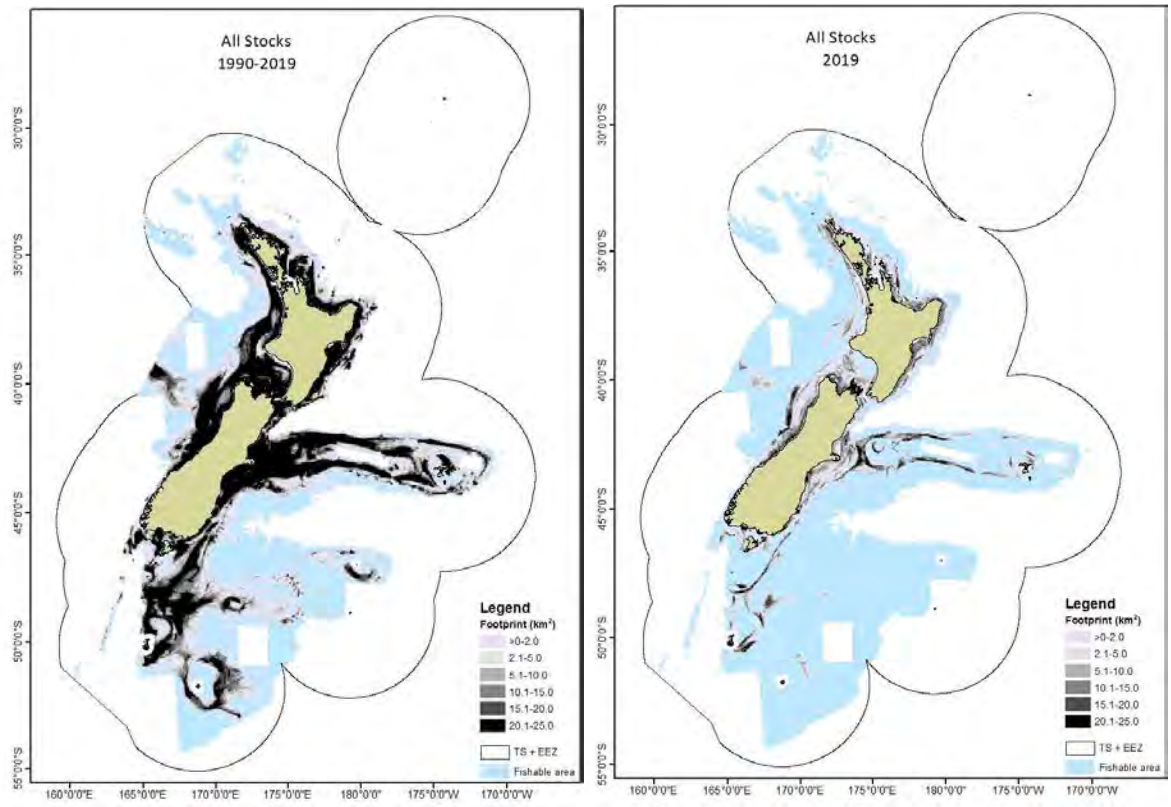


Figure 11.10: Distribution of the TCEPR and TCER all stocks footprint represented by 25-km² cells, 1990–2019 and 2019.

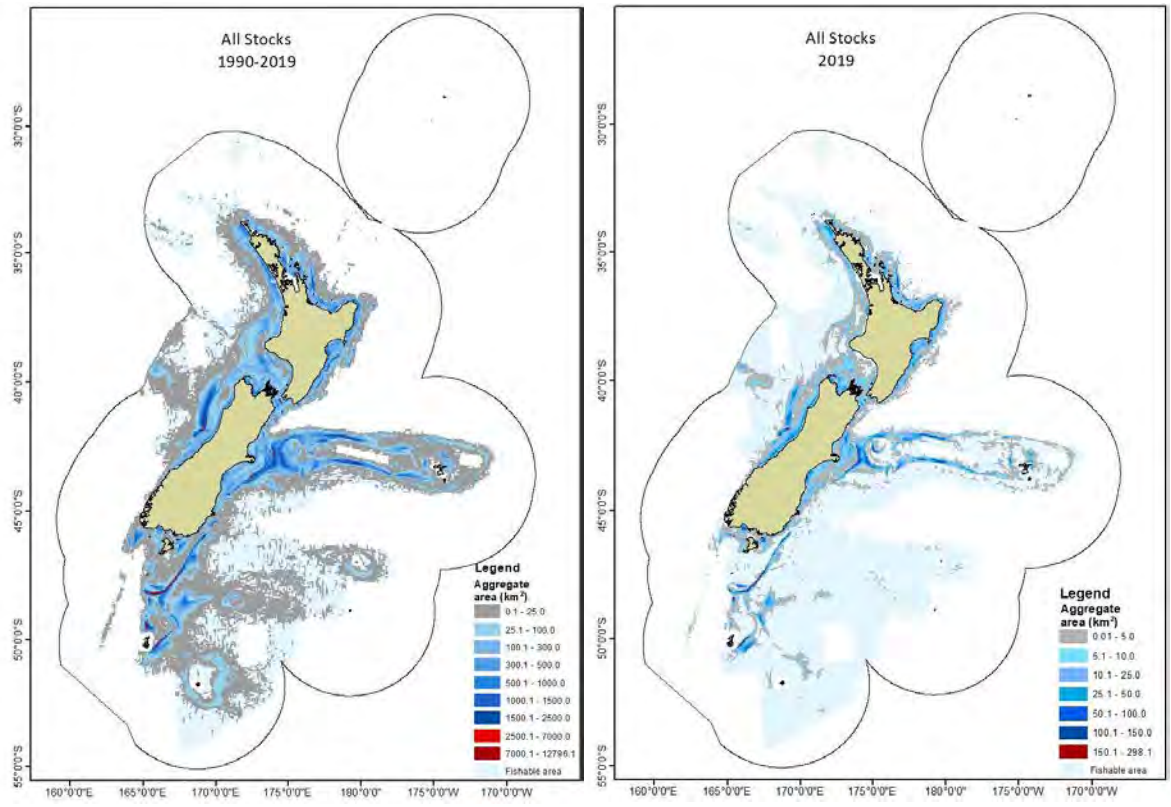


Figure 11.11: Distribution of the TCEPR and TCER all stocks aggregate area per 25-km² cell, during the combined fishing years 1990–2019 (left) and for 2019 (right).

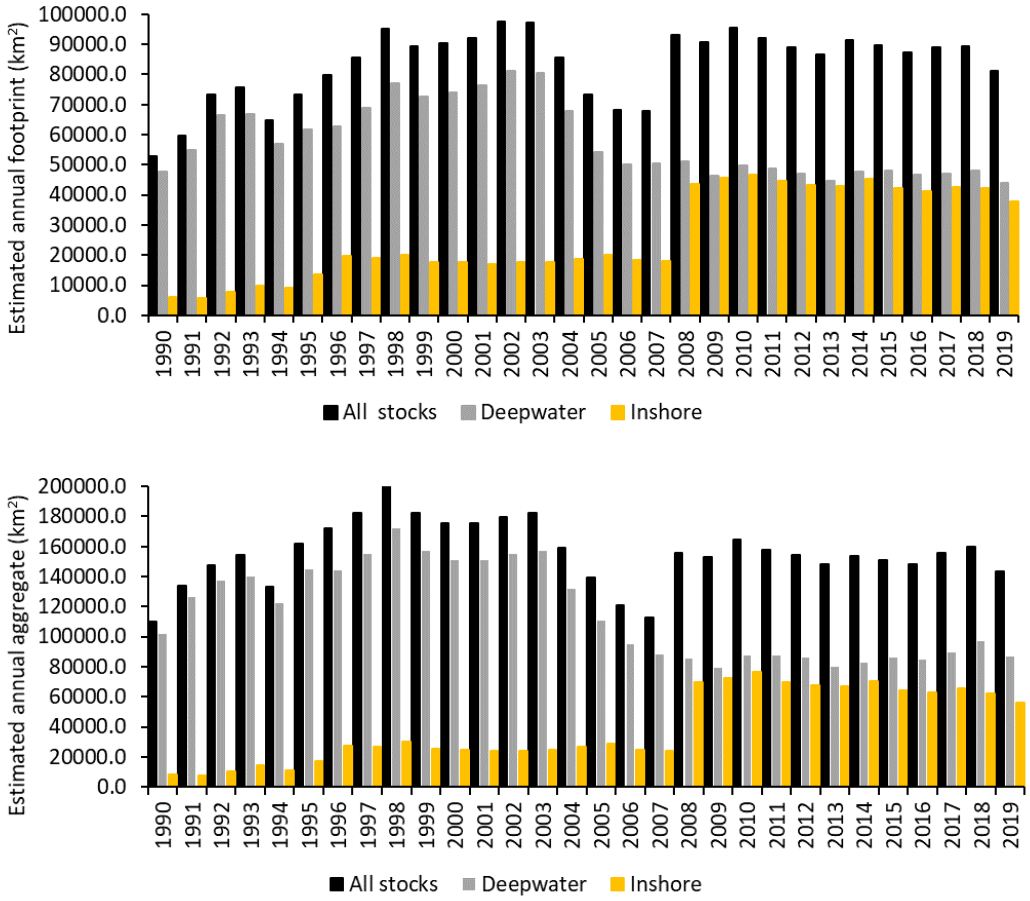


Figure 11.12: Annual estimated footprint and aggregate area for All stocks, Deepwater stocks, and Inshore stocks, 1990–2019. The data represent TCEPR (1990–2019), TCER (2008–19), and ERS (2018–2019) bottom-contacting effort. Note: TCER data collection was introduced in the 2008 fishing year and ERS data collection started in the 2018 fishing year. Effort reported on CELR forms is not included in the trawl footpint estimation. Thus, the comparable years for the all stocks footprint are for fishing years 2008 to 2019.

Dredging for shellfish (oysters and scallops) is conducted in a number of specific areas that have separate, smaller statistical reporting areas (Figure 11.13). Over the 30-year dataset, there were approximately 2 million scallop dredge tows in the four main scallop fisheries and over 1 million oyster dredge tows in the two dredge oyster fisheries. Up until 2019 data were collected on CELRs, usually at the spatial scale of a scallop or oyster fishery area and the data were summarised as the number of dredge tows. No estimates of the area swept by these dredges have been made, but the number of reported tows has declined markedly since the early 1990s with several of these fisheries being subject to multiple closures (Figure 11.14, Baird & Mules 2021b).

During the 2019 fishing year, ERS reporting was introduced in the Foveoux Strait oyster fishery (OYU 5) throughout the season. Effort was previously reported on CELR forms which collect daily effort data in the fishery-specific areas. The ERS data are collected on a 1-nm grid that overlays the fishery-specific areas (Figure 11.13), Effort data are collected at the level of a cell which effectively provides a cell-based number of tows, thereby allowing for a finer resolution for analysis than is provided by the larger fishery-specific areas. Baird & Mules (2021b) used the ERS data to develop a preliminary swept area estimation.

Our knowledge of the distribution of mobile bottom fishing effort within our TS and EEZ is, by international standards, very good; since 2007–08 we have had tow-by-tow reporting of almost all trawling with a spatial precision of about 1 n. mile. The distribution of dredge tows for shellfish has not been reported with such high precision for this period, but records kept by fishers in industry logbooks are often much more detailed than the Fisheries New Zealand statutory returns, and have sometimes been used to support spatial analyses that would not have been possible using the statutory returns (e.g., Tuck et al. 2006 for project

ZBD2005/15 on the Coromandel scallop fishery and Michael et al. 2006 for project ZBD2005/04 on the Foveaux Strait oyster fishery). The introduction of ERS in the Foveaux Strait oyster fishery in recent years has provided a means to report effort data at a finer spatial resolution and has made dredge footprint estimation possible (Baird & Mules 2021b). These studies indicate the value of records with higher spatial precision.

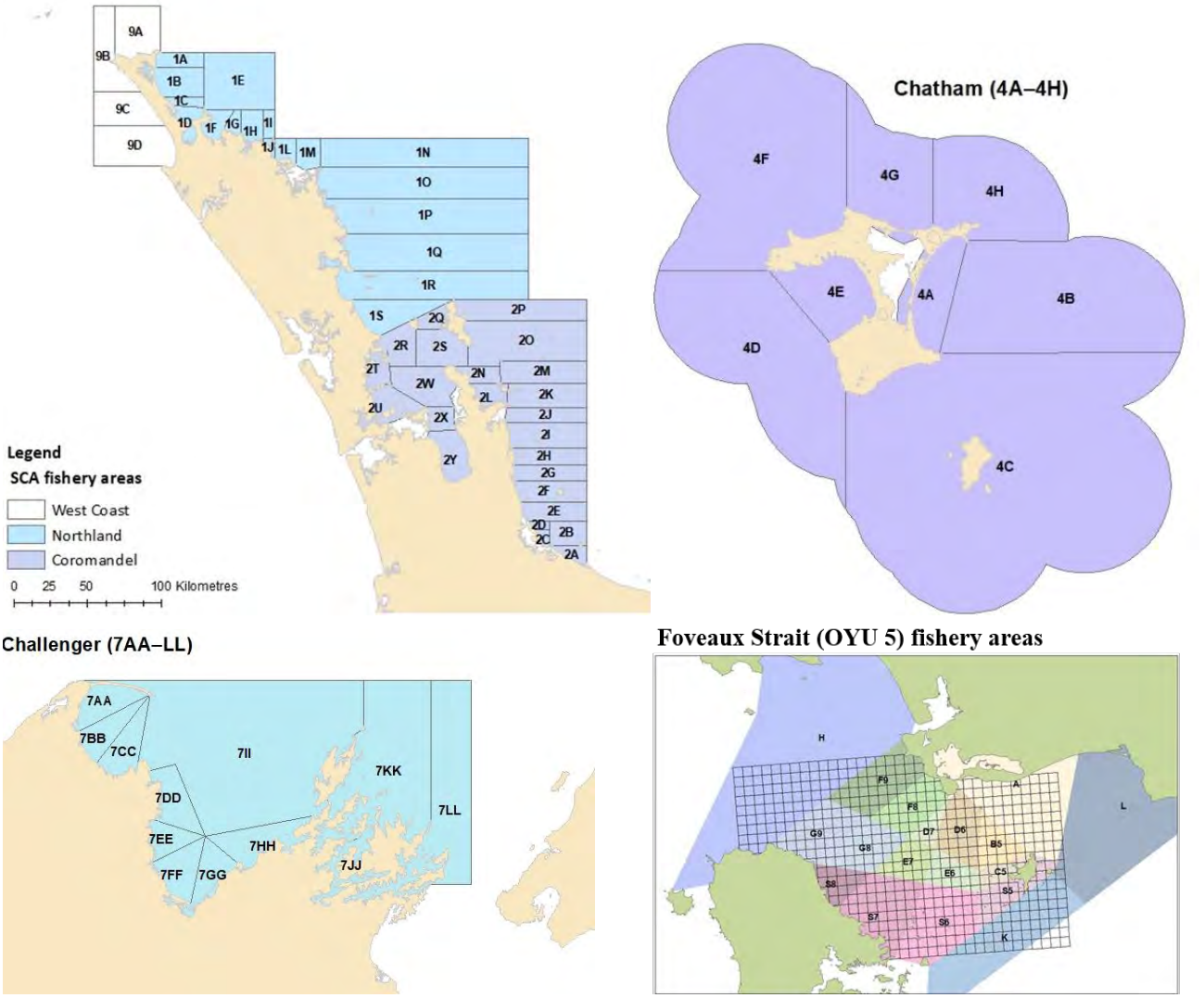


Figure 11.13: Maps taken from Baird & Mules (2021b) of statistical reporting areas for scallop and oyster fishery areas (scales differ). Note that these reporting areas are generally much smaller than the General Statistical Areas used for finfish reporting.

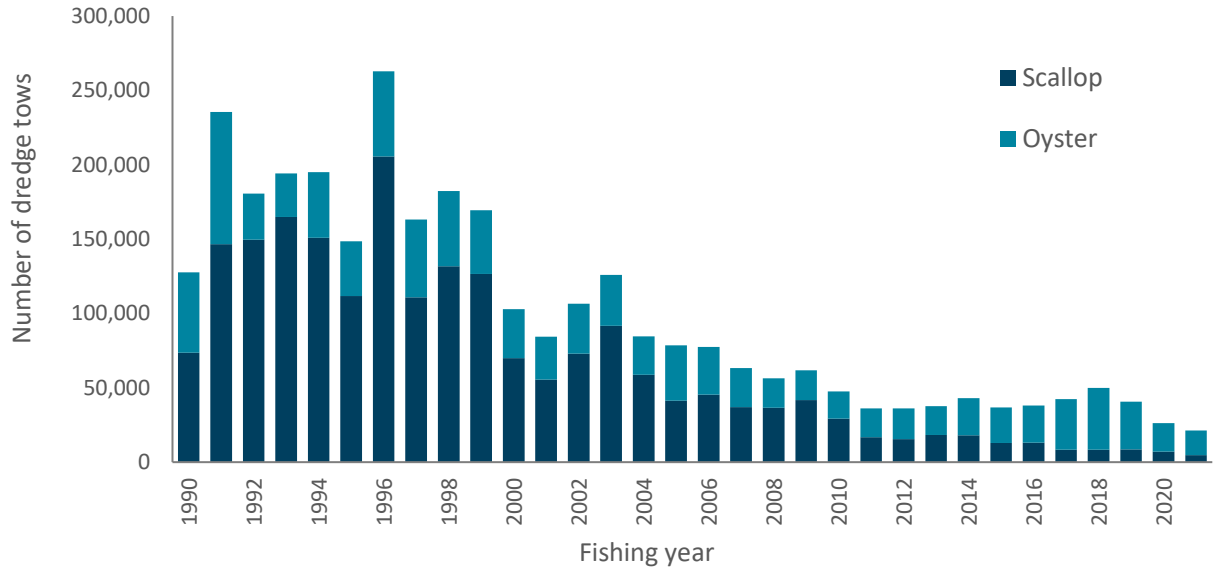


Figure 11.14: The number of dredge tows for scallop or oysters reported on Catch Effort and Landing Returns (CELR) for the 1989–90 (1990) to 2018–19 (2019) fishing years and via electronic reporting (ERS) from 2018-19 (2019) to 2020-21 (2021). [Note there was a transition to ERS during 2019]

11.2.3 OVERLAP OF FISHING AND PREDICTED HABITAT CLASSES

Tuck et al. (2014) reviewed a wide range of ecosystem indicators for deepwater fisheries and concluded that in relation to benthic impact of fishing, indices of fishing footprint and fishing intensity by habitat and gear or fishery were likely to be the most useful.

Baird & Wood (2012) provided the first assessment of the overlap of BOMEC classes and bottom trawling covering the period 1989-90 to 2004-05. Baird & Mules (2021a, 2021b) overlaid the 2007–08 to 2017–18 deepwater and inshore footprints on the 15-class BOMEC to estimate the proportion of each class that had been trawled (and reported on TCERs, TCEPRs, and ERS) in the 11 year period. They found that the size of each fishery footprint (deepwater and inshore, separately) and the proportion of each class trawled varied substantially between habitat class and fishery (Table 11.3). High percentages of the coastal BOMEC class areas are contacted by the inshore footprint; whereas, class O (the largest BOMEC class) has almost no reported fishing effort because it is mainly beyond trawlable depths. Conversely, class I is one of the smaller classes but has a larger trawl footprint (mainly deepwater) that overlaps 74% of the total class area. Two contrasting classes, together with their deepwater trawl footprints, are shown in Figure 11.15, based on analysis up to 2015–16 (Baird & Wood 2018).

Table 11.3: Estimated area of each BOMEC class (in depths of under 3000 m), the seafloor area of waters open to bottom trawling within each BOMEC class (in depths of under 1600m), the trawl footprint from TCER, TCEPR, and ERS deepwater and inshore fishstocks over the fishing years 2007–08 to 2017–18 (Baird & Mules 2021a), and the percentage overlap by the deepwater and inshore footprints. Note: previous versions have taken a longer prior time window (from 1989–90) for deepwater fisheries. Note there will be some overlap between the inshore and deepwater footprints in some inshore BOMEC classes.

BOMEC class	Total area (km²)	Area open to bottom-fishing (km²)	Deepwater footprint area (km²)	Deepwater footprint area (% of total)	Deepwater footprint area (% area open to bottom fishing)	Inshore footprint area (km²)	Inshore footprint area (% of total)	Inshore footprint area (% area open to bottom fishing)
A	27 557	19 764	493	1.8	2.5	16 109	56.6	81.5
B	12 420	11 984	3 359	27.0	28.0	10 814	89.0	90.2
C	89 710	87 914	22 419	25.0	25.5	51 256	58.1	58.3
D	27 268	25 786	1 983	7.3	7.7	20 443	74.1	79.3
E	60 990	60 211	12 656	20.8	21.0	14 037	22.7	23.3
F	38 608	30 931	3 607	9.3	11.7	0	–	–
G	6 342	6 033	2 475	39.0	41.0	4 067	69.2	67.4
H	138 550	129 323	38 856	28.0	30.0	19 218	14.0	14.9
I	52 224	51 910	26 946	51.6	51.9	676	1.3	1.3
J	311 361	277 138	32 234	10.4	11.6	4 756	1.5	1.7
K	1 290	1 290	0	–	–	36	2.8	2.8
L	198 577	175 509	23 950	12.1	13.6	6	<0.1	0.0
M	233 825	183 402	5 099	2.2	2.8	264	0.1	0.1
N	493 034	388 647	3 003	0.6	0.8	1 047	0.2	0.3
O	935 315	598 607	184	0.0	0.0	13	<0.1	0.0
Total	2 627 073	2 048 448	176 954	6.7	8.6	142 744	5.5	7.0

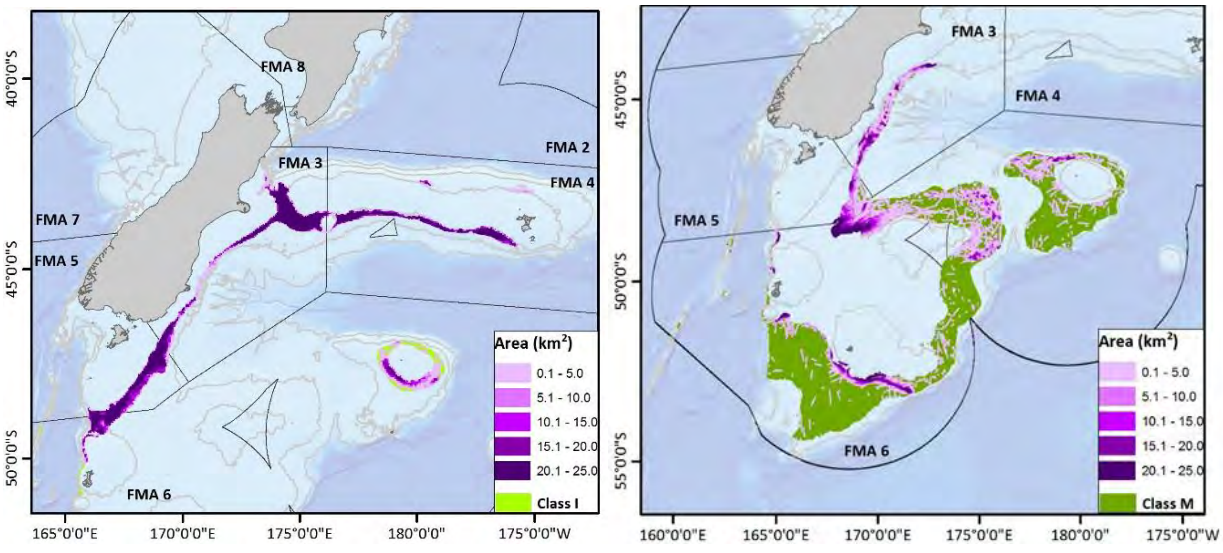


Figure 11.15: Maps created from Baird & Wood (2018) data showing BOMEC classes I (left) and M (right) overlaid with the footprint of deepwater Tier 1 and Tier 2 fishstock trawls on or near the seafloor reported on TCER and TCEPR forms between 1989-90 and 2015-16 for each 25-km² cell. Grey contour lines indicate depths of 500 m, 1000 m, and 1500 m.

11.2.4 STUDIES OF THE EFFECTS OF MOBILE BOTTOM FISHING METHODS IN NEW ZEALAND

The widespread nature of bottom trawling suggests that fishing is the main anthropogenic disturbance agent to the seabed throughout most of New Zealand's EEZ. Wind waves are certainly very widespread, but both field studies and modelling (Green et al. 1995) suggest that erosion of the seabed deeper than 50 m by waves occurs only very rarely in the New Zealand EEZ. Despite their widespread distribution at the surface, therefore, wind waves are not a dominant feature of the long-term disturbance regime throughout most of the EEZ. In some places, especially in the coastal zone and in areas close to headlands, straits, or islands, currents and tides may dominate the natural disturbance regime and a community adapted to this type of disturbance will have developed. However, over most of the EEZ between about 100 and 1000 m depths, especially in areas where there are few strong currents, fishing is probably the major broad-scale disturbance agent.

Several studies have been conducted since 1995 in New Zealand, focusing on the effects of various dredge and trawl fishing methods on a variety of different habitats in several geographical locations (Table 11.4). Despite the diversity of these studies, and their different depths, locations, and habitat types, the results are consistent with the global literature on the effects of mobile bottom fishing gear on benthic communities. Generally, there are decreases in the density and diversity of benthic communities and, especially, the density of large, structure-forming epifauna, and long-lived organisms along gradients of increasing fishing intensity. Large, emergent epifauna such as sponges and framework-forming corals that provide structured habitat for other fauna are particularly noted as being susceptible to disturbance by mobile bottom fishing methods (Cranfield et al. 1999, 2001, 2003, Cryer et al. 2000), especially on hard (non-sedimentary) seabeds (Clark & Rowden 2009, Clark et al. 2010a, 2010b, Williams et al. 2011). Even though large emergent fauna seem most susceptible, effects have also been shown in the sandy or silty sedimentary systems usually considered to be most resistant to disturbance (Thrush et al. 1995, 1998, Cryer et al. 2002). Also reflecting the international literature is a substantial variation in the extent to which individual New Zealand studies have shown clear effects. For instance, in Foveaux Strait, Cranfield et al. (1999, 2001, 2003) inferred substantial changes in the benthic system caused by over 130 years of oyster dredging, but Michael et al. (2006) did not support such conclusions in the same system. Subsequent review of these studies found much common ground but no overall consensus on the long-term effects of dredging on the benthic community of the strait.

These studies have focused predominantly on changes in patterns in biodiversity associated with trawling and/or dredging and less work has been done to assess changes in ecological process or to estimate the rate of recovery from fishing. Projects that have started on recovery rates are focused on relatively few habitats and primarily those that are known to be sensitive to physical disturbance, including by trawling or dredging (e.g., seamounts, project ENV2005/16, and areas of high current and natural biogenic structure, projects ENV9805, ENV2005/23, and BEN2009/02). Thus, the understanding of the consequences of fishing (or of ceasing to fish) for sustainability, biodiversity, ecological integrity and resilience, and fish stock productivity in the wide variety of New Zealand's benthic habitats remains incomplete. Reducing this uncertainty would allow the testing of the utility and likely long-term productivity of a variety of management strategies, and enable a move towards a regime that maximises value to the nation consistent with the MPI 'Our Strategy' document (http://www.mpi.govt.nz/about-mpi/our-strategy).

An expert-based assessment of 65 threats to 62 marine habitats from saltmarsh to the abyss (MacDiarmid et al. 2012) concluded that only 7 of the 20 most important threats to New Zealand marine habitats were directly related to human activities within the marine environment. The most important of these was bottom trawling (ranked third-equal most important), but invasive species, coastal engineering, and aquaculture were also ranked highly. However, the two top threats, five of the top six threats, and over half of the 26 top threats stemmed largely or completely from human activities external to the marine environment (the most important being ocean acidification, rising sea temperatures, and sedimentation resulting from changes in land use). The assessment suggested that the number and severity of threats to marine habitats declines with depth, particularly deeper than about 50 m. Shallow coastal habitats face up to 52 non-trivial threats whereas most deepwater habitats are threatened by fewer than five. Coastal and estuarine reef, sand, and mud habitats were considered to be the most threatened habitats whereas slope and deepwater habitats were among the least threatened.

Table 11.4: Summary of studies of the effects of bottom trawling and dredging in New Zealand waters (not updated). [Continued on next page]

Location	Approach	Key findings	References
Mercury Islands sandy sediments. Scallop dredge	Experimental	Density of common macrofauna at both sites decreased as a result of dredging at two contrasting sites; some populations were still significantly different from reference plots after three months.	Thrush et al. 1995
Hauraki Gulf various soft sediments. Bottom trawl and scallop dredge.	Observational, gradient analysis	Decreases in the density of echinoderms, longlived taxa, epifauna, especially large species, the total number of species and individuals, and the Shannon-Weiner diversity index with increasing fishing pressure (including trawl and scallop dredge). Increases in the density of deposit feeders, small opportunists, and the ratio of small to large heart urchins.	Thrush et al. 1998
Bay of Plenty continental slope. Scampi and other bottom trawls.	Observational, multiple gradient analyses	Depth and historical fishing activity (especially for scampi) at a site were the key drivers of community structure for large epifauna. The Shannon-Weiner diversity index generally decreased with increasing fishing activity and increased with depth. Many species were negatively correlated with fishing activity; fewer were positively correlated (including the target species, scampi).	Cryer et al. 1999 Cryer et al. 2002
Foveaux Strait, sedimentary and biogenic reef. Oyster dredge.	Observational, various	Interpretations of the authors differ. Cranfield et al.'s papers 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 et al. 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 *Cinctopora*.	Cranfield et al. 1999, 2001, 2003 Michael et al. 2006
Spirits Bay, sedimentary and biogenic areas. Scallop dredge.	Observational, gradient analysis	In 1999, depth was found to be the most important explanatory variable for benthic community composition but a coarse index of dredge fishing intensity was more important than substrate type for many taxonomic groups. Sponges seemed most affected by scallop dredging, and samples taken in an area once rich in sponges had few species in 1999. This area had probably been intensively dredged for scallops. Analysis of historical samples of scallop survey bycatch showed a marked decline in sponge species richness between 1996 and 1998. In 2006, significant differences were identified between areas within which fishing was or was not allowed. Species contributing to these differences included those identified as being most vulnerable to the effects of fishing. These differences could not be attributed specifically to fishing because of interactions with environmental gradients and uncertainty over the history of fishing. No significant change between 1999 and 2006 was identified. In 2010, analysis of both epifaunal and infaunal community data identified change since 2006, and significant depth, habitat, and fishing effects. The combined fishing effects accounted for 15–30% of the total variance (about half of the explained variance). Individual species responses to fishing were examined, and those identified as most sensitive to fishing in this analysis had previously been categorised as sensitive on the basis of life history characteristics within the 2006 study.	Cryer et al. 2000 Tuck et al. 2010 Tuck & Hewitt 2013
Tasman Bay and Golden Bay. Bottom	Observational, gradient analysis	A gradient analysis was adopted to investigate the importance of the different factors affecting epifaunal and infaunal communities in Tasman Bay and Golden Bay. Fishing was consistently identified as an	Tuck et al. 2017

Location	Approach	Key findings	References
trawl, scallop and oyster dredge		important factor in explaining variance in community structure, with recent trawl and scallop effort being more important than other fishing terms. Important environmental variables included maximum current speed, maximum wave height, depth, % mud, and salinity. Fishing accounted for 31–50% of the explained variance in epifaunal and infaunal community composition, species richness, and Shannon-Weiner diversity. Overall, models explained 30–54% of variance, and additional spatial patterns identified in the analysis explained a further 5–16% of variance.	
South Canterbury Bight. Bottom trawl	Observational, gradient analysis	A gradient analysis was adopted to investigate the importance of the different factors affecting epifaunal and infaunal communities in the South Canterbury Bight. Both fishing effort and environmental variables were identified as being important in explaining the patterns in the community data observed, although fishing effort accounted for only a relatively small component of the overall variance (5 – 9%). The important environmental variables for both infaunal and epifaunal community analysis, included sediment grain size and organic carbon parameters, wave height parameters, chlorophyll-*a*, and distance from earthquake epicentres (although it must be remembered that this parameter was correlated with distance north). In addition to the weak (but mostly significant) fishing effects detected in relation to species based community and univariate measures, functional trait effects were also detected, with the predicted factor ceiling response identified for long-lived, sedentary, habitat-forming species, and a significant negative effect of fishing identified on this functional trait group.	Tuck et al. 2017
Graveyard complex 'seamounts', northern Chatham Rise. Orange roughy bottom trawl.	Observational, multiple analyses	From surveys in 2001 and 2006, substrate diversity and the amount of intact coral matrix were lower on fished seamounts. Conversely, the proportions of bedrock and coral rubble were higher. No change in the megafaunal assemblage consistent with recovery over 5–10 years on seamounts where trawling had ceased. Some taxa had significantly higher abundance in later surveys. This may be because of their resistance to the direct effects of trawling, their protection in natural refuges, or because these taxa represent the earliest stages of seamount recolonisation.	Clark & Rowden 2009, Clark et al. 2010a, 2010b Williams et al. 2010

11.2.5 STUDIES OF RECOVERY OF BENTHIC HABITATS IN NEW ZEALAND

Benthic community data from surveys conducted in 2006, 2010, and 2017 were analysed to investigate the effects of fishing in the Spirits Bay area, and recovery following the closure of areas within this region (under projects BEN2014-03 and ZBD2017-05). Multivariate and univariate analyses of epifaunal and infaunal community data from the Spirits Bay area consistently identified year, habitat, and depth effects, but scallop and trawl fishing were also retained in minimum adequate models (accounting for a median level of 20% of the total variance, and up to 50% of the explained variance), with effects still detectable 7–9 years after fishing in some analyses. The effects detected were independent of similarity measure, analysis approach, or data set used, and the effects of fishing were weaker in analyses of more recent survey data, where recent fishing effort was lower. Species sensitivities, categorised on the basis of morphology and life history characteristics, were consistent with species responses to fishing terms within the modelled analysis, and most of the most sensitive species were only found in areas with no recent fishing history.

Project BEN2014-02 provided additional support to work started under FRST-funded research on underwater topographic features from 1999. This programme, and its MBIE successor ('Vulnerable Deep-Sea Communities' (CO1X0906)) developed a fishing impact recovery comparison based on repeated towed camera surveys on six of the Graveyard Knolls on the northern flank of Chatham Rise. These knolls cover conditions where trawling has ceased, where trawling is still active, or knolls which have been untrawled. Surveys were carried out in 2001, 2006, 2009, and 2015, with support from MFish, NIWA, the cross-departmental Oceans Survey 20/20 programme, and

in 2015 from MPI under BEN2014-02. Results from this time series have recently been published (Clark et al. 2019).

Univariate community metrics of biodiversity (abundance, species richness, diversity) were almost always higher for untrawled Ghoul and Gothic knolls than the other four. Multivariate community analyses of each knoll at each time-step showed a similar pattern, with the untrawled Gothic and Ghoul knolls having similar levels and patterns of community structure at one end of the ordination space, the persistently heavily trawled Graveyard seamount at the other end along with the previously heavily trawled and now closed Morgue knoll, and intermittently trawled knolls lying in-between (Figure 11.16). This ordination matches the gradient in commercial fishing effort. Community structure on Graveyard knoll was more consistent than on the other knolls, with persistently lower faunal richness, possibly due to a regular 're-setting' of the community by disturbance from trawling.

The time series of surveys indicates low resilience of benthic communities on the knolls to the effects of bottom trawling. There is no evidence that benthic communities on Morgue knoll are recovering following its closure to fishing in 2001. Intact scleractinian coral 'reef' is or was a 'climax habitat' on the Graveyard Knolls, and levels of this habitat on Morgue knoll remain much lower than those on the untrawled knolls (Figure 11.17).

Another linkage with the MBIE Vulnerable Deep-Sea Communities' project is an ongoing evaluation (under NIWA funding) of the relative vulnerability of benthic communities in several deep-sea habitats (e.g., seamounts, canyons, continental slope, hydrothermal vents, seeps) and their risk from bottom trawling. The importance of fishing effort as a factor influencing benthic invertebrate community composition has been examined for epi-megafauna from towed camera data (Bowden et al. 2016) and epibenthic sled tows (Rowden et al. 2016), and from multicorer samples for macro-infauna and meiofauna (Leduc et al. 2016, Rosli et al. 2016).

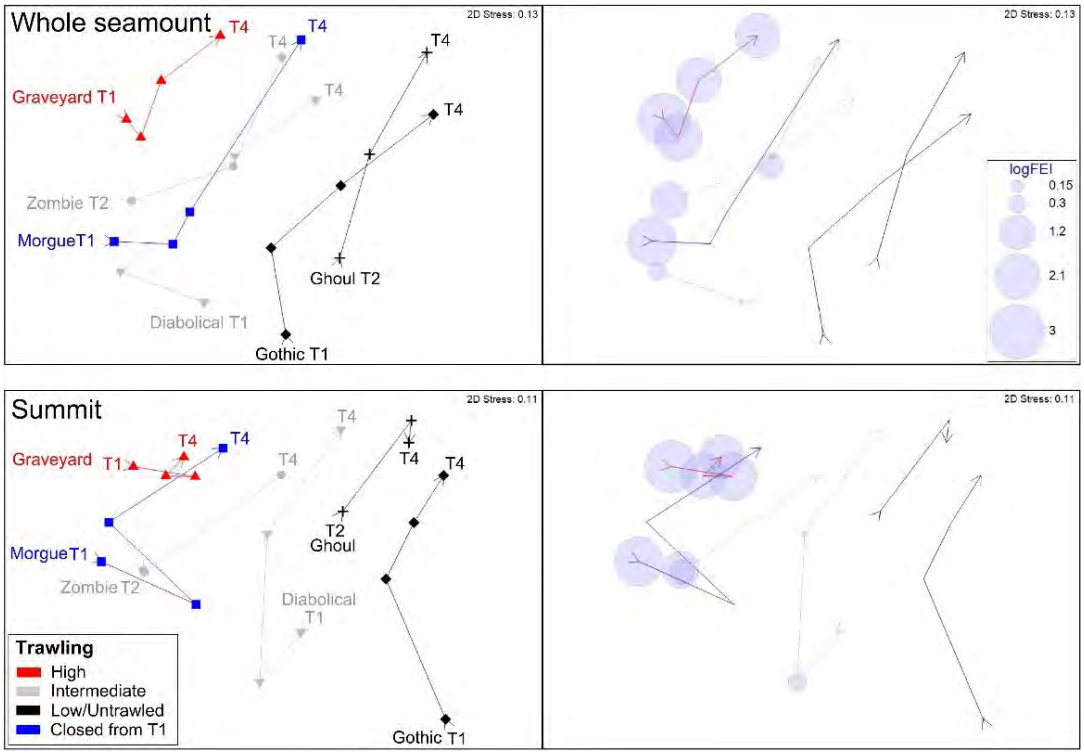


Figure 11.16: Ordinations (nMDS) illustrating benthic community similarities over time steps T1 to T4 and in relation to relative trawl history (see legend): Top panel, ordination using all images ('whole seamount'); bottom panel, only the summit sector. Right windows show trawling intensity as the Fishing Effects Index (FEI) superimposed as bubble plots for each seamount at each time step. [From Clark et al. (2019).]

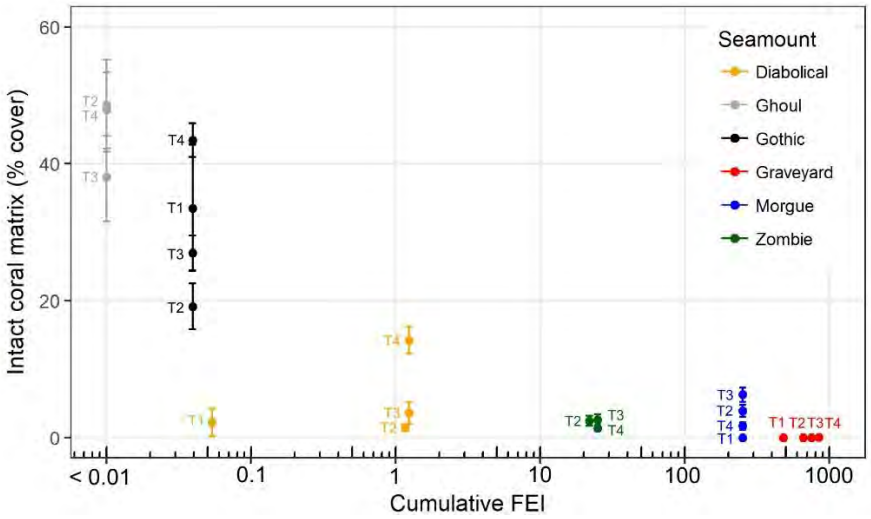


Figure 11.17: Intact coral matrix, as mean percent cover measured in individual seabed photographs, on six seamounts at each of four survey times (2001, 'T1'; 2006, 'T2'; 2009, 'T3'; and 2015, 'T4') in relation to cumulative trawling impact (Fishing Effects Index, FEI, all years up to and including the year of each survey). [From Clark et al. (2019).]

11.2.6 CURRENT RESEARCH

BEN2020-01 will provide spatial descriptions and annual monitoring of the seabed areas contacted by mobile bottom fishing gear (trawl and dredge) results for the 2007–08 to 2020–21 fishing years for all inshore fisheries and for the 1989–90 to 2020–21 fishing years for all deepwater fisheries. This will allow for the continued monitoring of trends in the extent and intensity of seabed contact by bottom fisheries in New Zealand. BEN2020-01 will also include the development of methods to estimate the spatial extent of seabed contact using Geospatial Position Reporting (GPR) data for the 2019–20 fishing year and a comparison of the estimate generated to that produced using fisher reported position data.

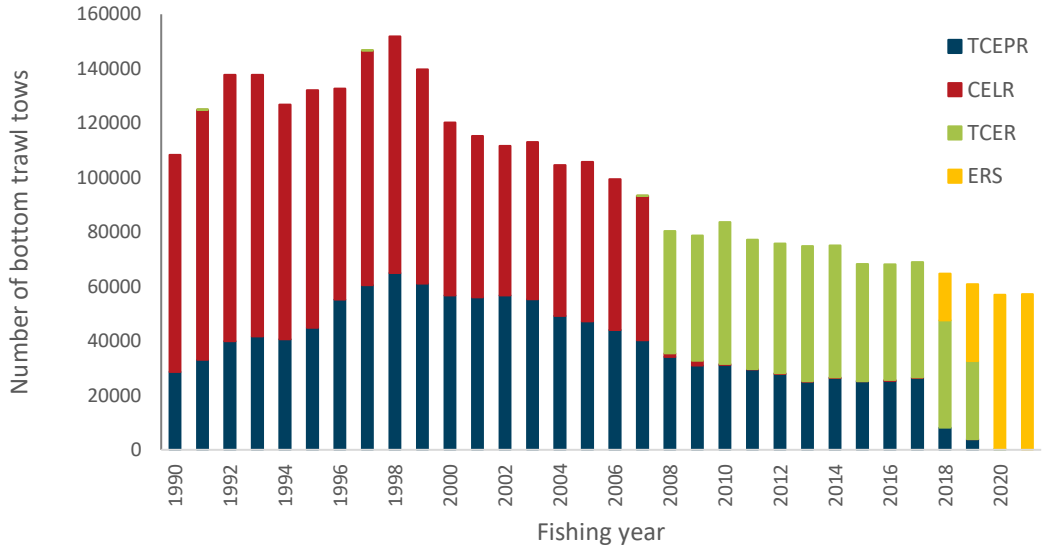
Project BEN2020-07 is nearing completion and will provide an update of all available information on UTFs in the New Zealand region and will assess the extent to which UTFs have been trawled annually by feature based fisheries within the New Zealand EEZ.

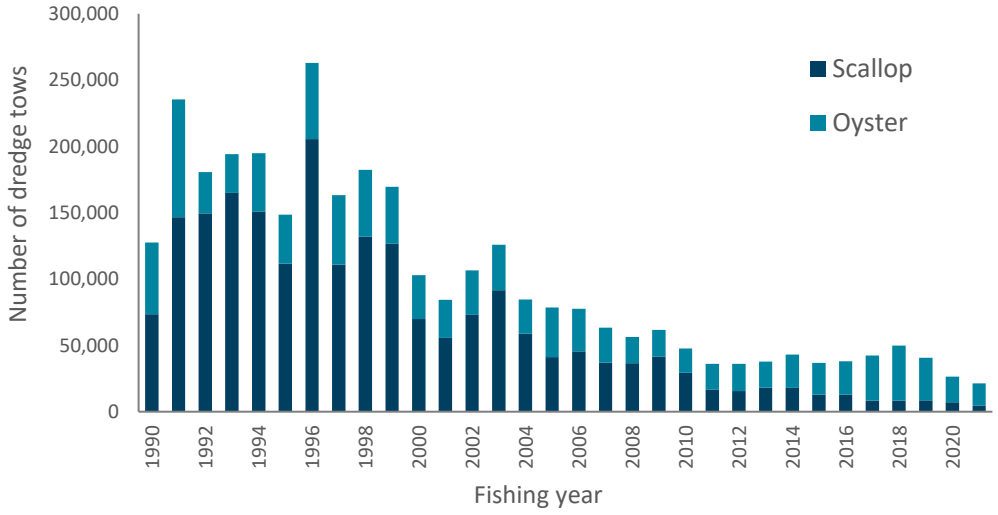
Various spatially explicit benthic impact approaches are being applied and evaluated in project BEN2019-04 to describe and quantify the likely nature and extent of impacts to benthic taxa or communities by mobile bottom fishing methods in New Zealand.

Two spatial planning projects are currently underway. Project BEN2019-05 was initiated in 2020 to develop the datasets and layers required for a spatial decision support tool to inform management of mobile bottom fishing in New Zealand's EEZ. Project ZBD2020-06 commenced in 2021 and seeks to assess spatial planning options to balance fishing activities (trawling and Danish seining) with the protection of benthic biodiversity and recovery of biogenic habitats within the Hauraki Gulf Marine Park. Both projects involved the collation and assessment of data by a research provider followed by a series of workshops with stakeholders to enable collaboration in the assessment of the spatial planning approach and outputs. The projects will rely on the use of the spatial decision support tool Zonation to test a range of scenarios.

11.3 INDICATORS AND TRENDS

Annual number of tows	2020–21 fishing year: 57 219 trawl tows 4 625 scallop dredge tows 16 642 oyster dredge tows
Trend in number of tows	Trawl and dredge effort stable or decreasing in recent years:





Overlap of trawl footprint with BOMEC habitat classes for 1989-90 to 2018–19

BOMEC class	Area (km²)	Footprint overlap (km²)		% of total footprint		Footprint overlap (%)	
		1990–2019	2019	1990–2019	2019	1990–2019	2019
A	30 661.0	17 481.6	5 236.8	3.8	6.5	57.0	17.1
B	12 786.1	11 374.4	5 297.1	2.5	6.5	89.0	41.4
C	90 256.5	74 461.7	15 782.4	16.2	19.5	82.5	17.5
D	28 085.7	21 748.7	6 934.7	4.7	8.6	77.4	24.7
E	61 258.0	34 431.6	6 316.9	7.5	7.8	56.2	10.3
F	38 775.8	6 900.9	316.7	1.5	0.4	17.8	0.8
G	6 702.3	5 173.3	1 092.4	1.1	1.3	77.2	16.3
H	138 399.1	78 072.4	12 987.0	16.9	16.0	56.4	9.4
I	52 008.3	38 811.1	9 906.8	8.4	12.2	74.6	19.0
J	312 604.9	81 921.7	10 365.4	17.8	12.8	26.2	3.3
K	1 200.2	41.5	0.4	0.0	0.0	3.5	0.0
L	198 578.4	56 638.2	5 518.0	12.3	6.8	28.5	2.8
M	233 837.4	19 138.8	719.9	4.2	0.9	8.2	0.3
N	495 154.2	13 771.8	555.4	3.0	0.7	2.8	0.1
O	1 006 911.1	614.7	19.7	0.1	0.0	0.1	0.0
Total	2 707 219.0	460 627.2	81 054.9	100.0	100.0	17.0	3.0

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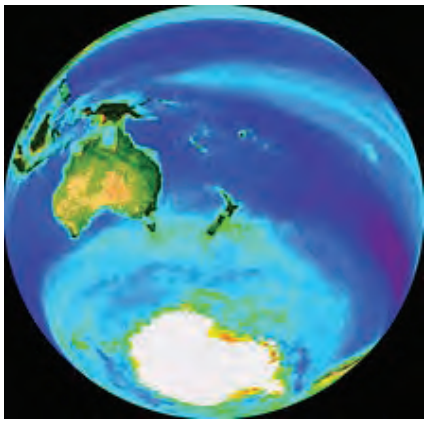
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Chapter 12: NZ Climate and Oceanic Setting - Technical Summary

Ocean variability and change



Trends, extremes, decadal cycles

1. THE ISSUE IN BRIEF

- Climate and oceanographic variability, and long-term environmental changes, are of key relevance to the carrying capacity of the marine environment
- Understanding the trends and cycles observed in the ocean allows us to understand the links between observed fisheries patterns and drivers of biological processes
- It also allows for the exploration of likely future scenarios for New Zealand fisheries as climate change and global warming continue
- The cumulative effects of climate change and other anthropogenic stressors on the ocean (productivity, structure, and function) are likely to be significant, and increasingly seen in the next 20–30 years

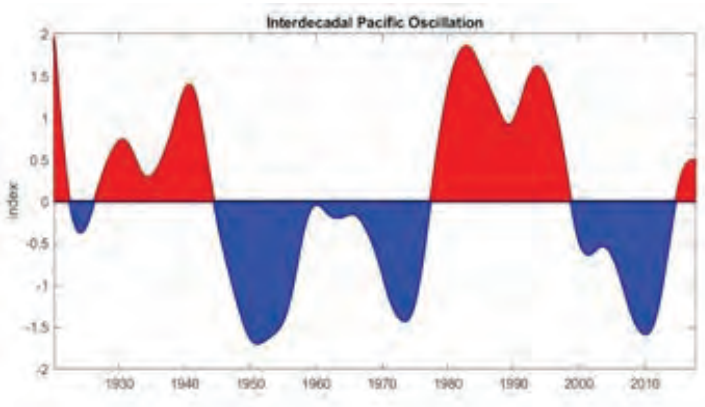
2. NEW ZEALAND'S SEAS ARE CHANGING

- The New Zealand Exclusive Economic Zone straddles ~30° of latitude and ~30° of longitude in the SW Pacific Ocean from the tropics to the Southern Ocean, with a large area, ~4 million square km, of jurisdiction
- Essentially, the direction of flow is from west to east across the Tasman Sea that has a relatively slow circulation, and then around northern and southern New Zealand to the more dynamic eastern side, bordering the Pacific Ocean
- Primary productivity is higher than most of Australasia, but lower than coastal upwelling systems around the rest of the world
- The greatest productivity is across the Chatham Rise associated with the Subtropical Front and mixing of water masses either side of the front
- Some long-term trends in the marine environment available at a national scale are incorporated in the Environmental Reporting system developed by MfE and Statistics NZ
- Like the rest of the world, our ocean is showing measurable effects of climate change and global warming. Sea temperatures are increasing, ocean acidification is increasing, storm frequencies are higher and more intense, and the knock-on effects to fish and biodiversity are evident in some areas. Extreme events such as marine heatwaves are likely to occur more often

3. INTER-DECADAL CYCLES SINCE 1900

- Positive and negative phases of the Interdecadal Pacific Oscillation index bring different ocean conditions to New Zealand waters. Under positive phases (red), La Niña conditions tend to prevail and reduced westerly flow results in less upwelling on the west coast, and warmer air and sea temperatures

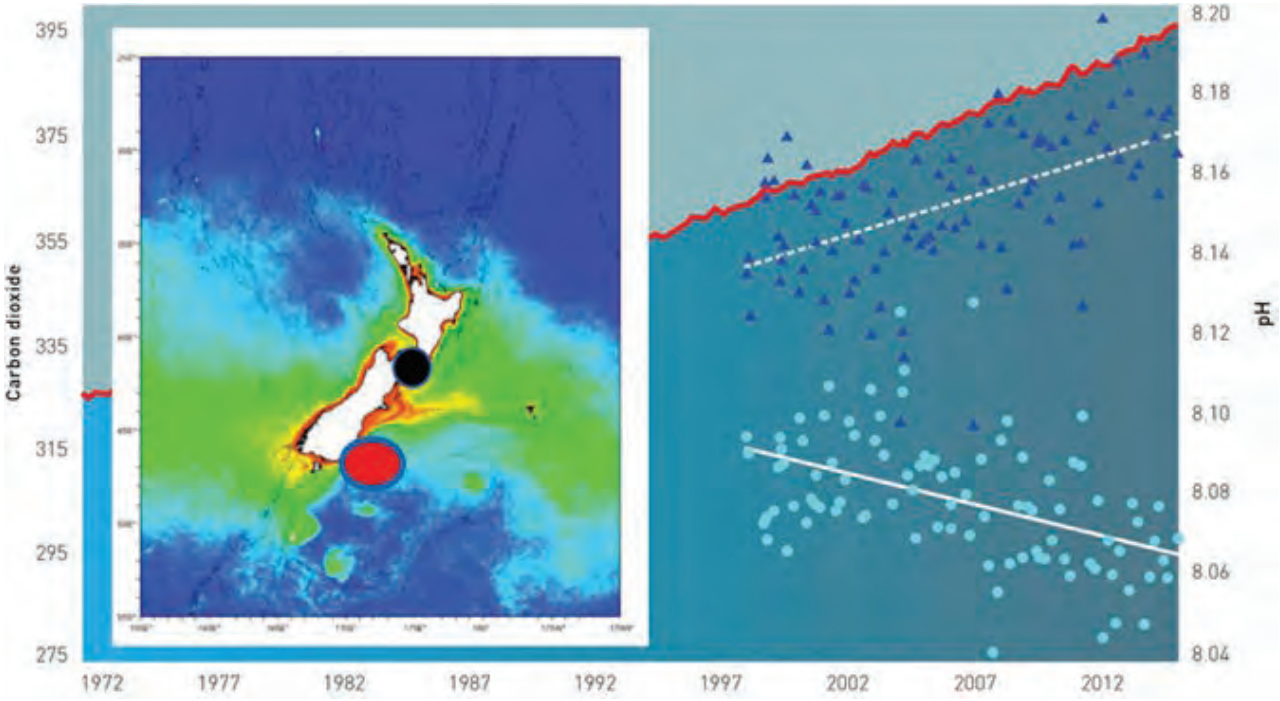
- Under negative IPO conditions (blue), El Niño conditions tend to prevail with increased westerly winds and higher upwelling. The abundance of some fish stocks reflects these cycles



4. CARBON DIOXIDE AND OCEAN ACIDIFICATION

• Levels of atmospheric CO_2, sea-surface dissolved CO_2, and pH in New Zealand offshore waters parallel similar trends reported in the northern hemisphere, i.e., increased acidification

• A large number of global studies has identified a range of direct and indirect effects of ocean acidification across a broad range of marine taxa, from bacteria to fish, and from coastal to deep sea ecosystems. Of particular concern in New Zealand are the potential effects on shellfish fisheries, aquaculture, and calcifying deep sea corals



Time series of atmospheric CO_2 (red line) at Baring Head (black dot), and surface water dissolved CO_2 (dark blue triangles and dashed trendline) and pH (light blue circles and solid trendline) near Otago (red dot)

• The highest projected regional warming occurs in the East Australian Current and in subantarctic waters to the south-east of NZ. Because of the present warming rate in the south-west Tasman Sea is similar to that measured for waters around NZ, this region may provide an analogue for future changes in NZ waters

• The depth of the surface mixed layer will decrease across much of the NZ EEZ area, except for some subantarctic water regions. The resulting increase in light exposure for plankton may be beneficial to productivity and food webs in subantarctic waters where nutrients are plentiful, but may be deleterious in warmer subtropical waters that are oligotrophic (i.e., low nutrient)

5. ONGOING RESEARCH

• Model projections for food supply to fisheries on the Chatham Rise are conflicting and need to be resolved. The Chatham Rise is identified as one of the more vulnerable areas in New Zealand, yet it may be one of the areas least affected by ocean acidification changes

• Risk assessments for fisheries under climate change scenarios are limited by short time series and limited water temperature data in particular. Methods of incorporating climate change indicators into stock assessment, and effects on species movements, are underway (see also Chapter 18)

12 NEW ZEALAND'S CLIMATE AND OCEANIC SETTING

Status of chapter	This chapter has been updated for AEBAR 2021.
Scope of chapter	This chapter provides context within which to consider interactions between the environment and the seafood sector. It provides an overview of primary productivity, oceanography, bentho-pelagic coupling, ocean acidification and oceanic climate trends in the Southwest Pacific region.
Area	New Zealand regional setting.
Focal localities	All New Zealand waters.
Key issues	• Climate and oceanographic variability and long-term changes are of relevance to resilience in fisheries and the broader marine environment. • Allows improved understanding of the links between observed patterns and drivers of biological processes. • Allows for testing of likely future climate scenarios. • New Zealand trends of increasing air and sea temperatures, as well as ocean acidification are consistent with observed global trends.
Emerging issues	• New Zealand's oceanic climate is changing. • Causal mechanisms that link the dynamics of a variable marine environment to variations in biological productivity, particularly of fisheries and biodiversity, are not well understood in New Zealand or internationally, but are the subject of multiple studies. • Cumulative effects of ocean climate change and other anthropogenic stressors on aquatic ecosystems (productivity, structure and function) are likely to be high, and seen in the next 20–30 years. • Some long-term trends in the marine environment available at a national scale are incorporated in the new Environmental Reporting system being developed by MfE and Statistics New Zealand. • There is a growing recognition that stressors will act both individually and interactively, confounding predictions of the net effects of climate change. • Improved scenario setting and the need for risk evaluation. • The first regime shift in IPO since most fisheries monitoring began occurred in 2000, which is likely to result in fewer El Niño events for a 20–30 year period, which in turn is likely to impact fish productivity. • 2018 saw a very strong marine heat wave (MHW) in the Tasman Sea. MHWs would be expected to become more frequent in a warming world. • Sub-surface temperature data in fishable depths are a major gap in our current datasets. • Understanding how physical changes propagate through ecosystems and impact on fish populations is another gap.
Fisheries New Zealand research (current)	Nil
Government and other research	NIWA Coast & Oceans Centre; NIWA Climate and Atmosphere Centre; University of Otago-NIWA shelf carbonate geochemistry & bryozoans; Munida time-series transect; Physical Oceanography research; Geomarine Services-foraminiferal record of human impact; Regional Council monitoring programmes; Ministry for the Environment-Environmental reporting "Our marine Environment 2019" https://environment.govt.nz/publications/our-marine-environment-2019/; Department of Conservation the impacts of climate change on marine protected species. Relevant global climate programmes: Argo; Southern Ocean Observing System. CARIM (Coastal Acidification Rates and Implications to Management) and MOANA project (temperature data from fishing depths below the water surface). Dragonfly science: Fast-forward fish: resilience of exploited marine populations to a changing ocean.

Related chapters/issues	This chapter provides background environmental information relevant to all chapters, but particularly to chapters on Biodiversity; Trophic and ecosystem-level effects.

12.1 CONTEXT

This chapter was updated in August 2021 and summarises information on oceanography and ocean acidification around New Zealand, and climate trends in the Southwest Pacific region. This information provides context to understand the interactions between the environment and seafood productivity in the region. Climate and oceanographic conditions play an important role in driving the productivity of our oceans and the abundance and distribution of our fish stocks and fisheries. The most recent analyses of trends in climate and oceanographic variables relevant to fisheries management in New Zealand are given by Hurst et al. (2012), Dunn et al. (2009), and Cummings et al. (2021).

New Zealand is part of a large submerged continent (Figure 12.1). The Territorial Sea (TS, extending from mean low water shoreline to 12 nautical miles), Exclusive Economic Zone (EEZ, extending from 12 nautical miles to 200 nautical miles offshore), and the extended continental shelf (ECS) combine to produce one of the largest areas of marine jurisdiction in the world, an area of almost 6 million square kilometres (Figure 12.1). New Zealand waters straddle more than 25 degrees of latitude from warm, salty subtropical waters at 30° S to cooler, fresher subantarctic waters at 56° S, and 30 degrees of longitude from 161° E in the Tasman Sea to 171° W in the western Pacific Ocean. New Zealand's coastline, with its numerous embayments, is long, with estimates ranging from 15 000 to 18 000 km, depending on the measurement method (Gordon et al. 2010).

New Zealand lies across an active subduction zone in the western Pacific plate; tectonic activity and volcanism have resulted in diverse and varied seascapes within the EEZ. The undersea topography comprises a relatively narrow band of continental shelf down to 200 m water depth, extensive continental slope areas from 200 to 1000 m, extensive abyssal plains, submarine canyons and deep-sea trenches, ridge systems and numerous seamounts, and other underwater topographic features such as hills and knolls. There are three significant submarine plateaus: Challenger Plateau, Campbell Plateau, and Chatham Rise.

The physical oceanography of the deep seas around New Zealand has recently been reviewed by Chiswell et al. (2015). Measurements from platforms including satellites, drifting and profiling floats, moorings, and oceanographic voyages have provided a wealth of new observations over the last 30 years and analyses of these observations have substantially improved our understanding of the oceanography. Chiswell et al. (2015) summarise and integrate earlier research through a series of schematics of the ocean currents around New Zealand. Their surface currents are shown in Figure 12.2.

The Tasman Sea, west of New Zealand, is isolated from the South Pacific Gyre by the New Zealand landmass. The South Pacific Western Boundary Current, the East Australian Current (EAC), flows down the east coast of Australia before separating from the Australian land mass at about 31–32° S (e.g., Ridgway & Dunn 2003). Part of the separated flow crosses the Tasman Sea as the Tasman Front (Stanton 1981, Ridgway & Dunn 2003, Sutton & Bowen 2014) which has recently been reinterpreted as an eddy field because the variability dominates the mean flow in many places (Oke et al. 2019). The remaining flow continues south in the EAC extension. The Tasman Front then feeds the western boundary currents adjacent to New Zealand — the East Auckland Current (EAUC) between North Cape and East Cape and the East Cape Current (ECC) between East Cape and the northern side of Chatham Rise. Sutton & Bowen (2014) found that the Tasman Front is a weaker connection than previously thought between the EAC and EAUC, with the Tasman Front being shallower and transporting less water than the EAC and EAUC.

At the southern limit of the Tasman Sea is the Subtropical Front which separates warm, salty subtropical water to the north from cold, fresh subantarctic water to the south. The Subtropical Front passes south of Tasmania and approaches New Zealand at the latitude of Fiordland (Stanton & Ridgway 1988, Hamilton 2006). Around 165° E, the front diverts south across Macquarie Ridge where it has two clear branches (Smith et al. 2013), which continue onto Campbell Plateau where they merge to form the Southland Front along the Otago Coast (Chiswell 1996, Sutton 2003).

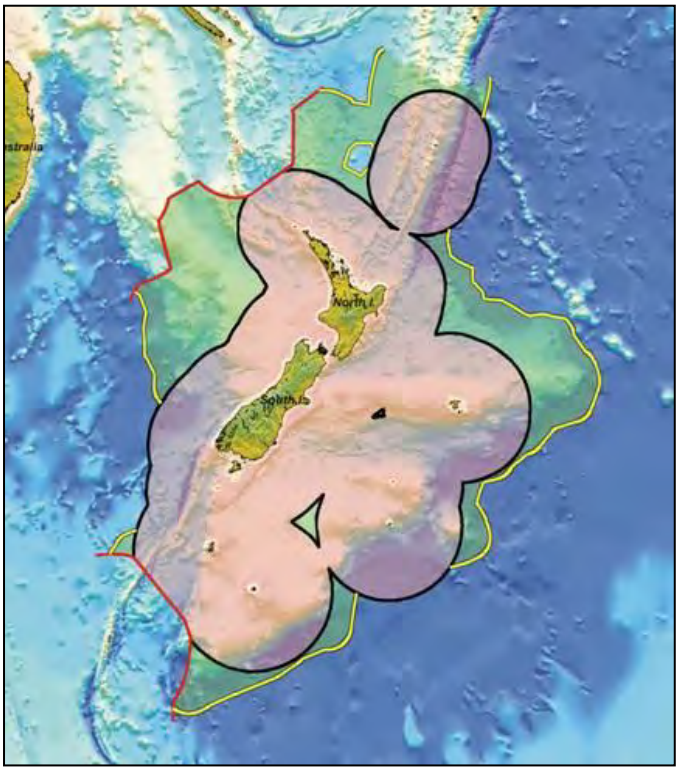


Figure 12.1: New Zealand land mass area 250 000 km²; EEZ and territorial sea area (pink) 4 200 000 km²; extended continental shelf extension area (light green) 1 700 000 km²; total area of marine jurisdiction 5 900 000 km². The black line shows the boundary of the New Zealand EEZ, the yellow line indicates the extension to New Zealand's legal continental shelf (note: to date there is no agreement on the line definition with northern neighbours), and the red line the agreed Australia/New Zealand boundary under UNCLOS Article 76. Image courtesy of GNS.

The circulation in the central Tasman Sea, east of the influence of the EAC, and between the Tasman Front and Subtropical Front is thought to be relatively slow. Ridgway & Dunn (2003) showed eastward surface flow across the interior of the Tasman Sea sourced from the southernmost limit of the EAC, with the flow separating around Challenger Plateau and, ultimately, New Zealand. Reid's (1986) analysis indicates that a small anticlockwise gyre exists in the western Tasman Sea at 1000–2500 m depth. This gyre is centred at about 35° S, 155° E on the offshore side of the EAC and west of Challenger Plateau. All indications are that the eastern Tasman region overlying Challenger Plateau has weak flows.

In contrast, the east coast of both islands and Cook Strait have strong and variable currents. Along the north-east coast of the North Island there are two semi-permanent eddies that vary in size and strength, the North Cape and East Cape Eddies (Roemmich & Sutton 1998). The inshore sides of these eddies comprise the EAUC, which flows down the east coast of the North Island to East Cape. Most of the EAUC water continues south in the ECC, with the remainder being split between the East Cape Eddy and the Pacific Ocean. There are several eddies in the East Cape Current region, with the largest known as the Wairarapa Eddy. It sits between the North Island and the northern flanks of Chatham Rise (Chiswell 2005, Chiswell et al. 2015).

Along the south-eastern coast of the South Island there is a narrow band of warm, salty subtropical water on the shelf separated from offshore cold, fresh subantarctic water by the Southland Front (the local manifestation of the Subtropical Front). This front has an associated flow of mainly subantarctic water, called the Southland Current (Sutton 2003) which flows north to the southern flank of Chatham Rise. The Southland Current then turns east, flowing along the southern flank of Chatham Rise before turning south at the Chatham Islands and then east into the Pacific Ocean contributing to the South Pacific Current (Figure 12.2, Stramma et al. 1995).

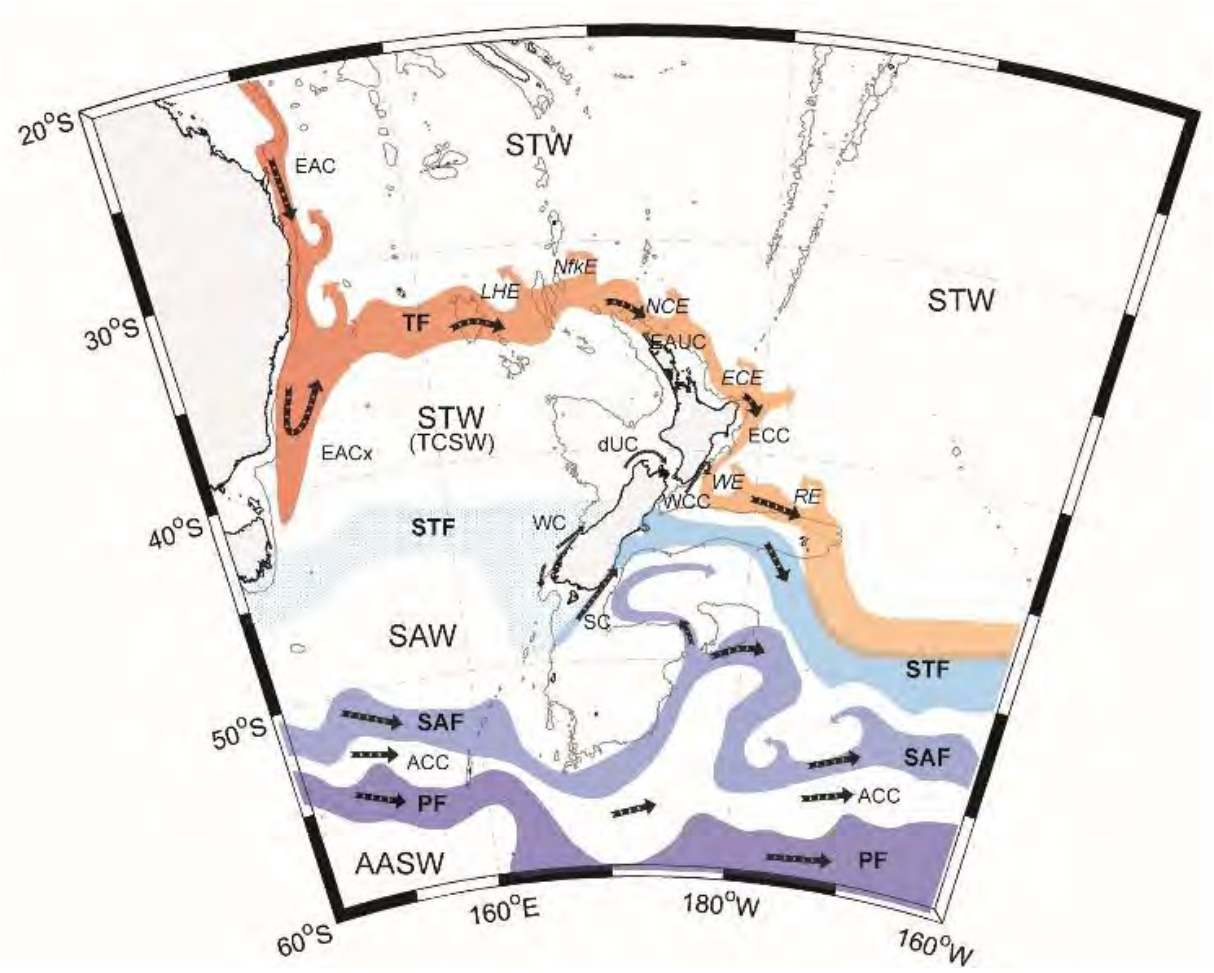


Figure 12.2: Schematic surface circulation around New Zealand based on drifter and hydrographic data. Regions of flow are shown as coloured streams. Colours reflect the temperature of the flows with red being warmest, and dark blue being coldest. The STF in the Tasman Sea is density compensated with little flow, as indicated by the shading. Water Masses are Subtropical Water (STW), Tasman Sea Central Water (TSCW), Subantarctic Water (SAW) and Antarctic Surface Water (AASW). Ocean fronts are Tasman Front (TF), Subtropical Front (STF), Subantarctic Front (SAF), and Polar Front (PF). Ocean currents are East Australia Current (EAC), East Australia Current extension (EACx), East Auckland Current (EAUC), East Cape Current (ECC), d'Urville Current (dUC), Wairarapa Coastal Current (WCC), Westland Current (WC), Southland Current (SC), and Antarctic Circumpolar Current (ACC). Eddies are Lord Howe Eddy (LHE), Norfolk Eddy (NfkE), North Cape Eddy (NCE), East Cape Eddy (ECE), Wairarapa Eddy (WE), and Rekohu Eddy (RE). Reproduced with permission from Chiswell et al. (2015).

Forcén-Vázquez (2015) showed that water from the Subtropical Front is found over a large fraction of Campbell Plateau and varies significantly from year to year. They also found that water from the Southern Ocean is mixed onto the plateau, giving it an oceanography distinct from the surrounding seas. These waters are well-mixed and are known to be iron limited (Boyd et al. 1999). It has been suggested that there are high transfer efficiencies between low and high trophic levels (Bradford-Grieve et al. 2003). Steering of currents along and around plateaus and ridges gives rise to higher ocean productivity than might be expected in the generally oligotrophic western Pacific Ocean (Figure 12.3).

The abundance and rate of growth of phytoplankton in the ocean is affected by the availability of macronutrients (such as nitrate, phosphate, silicate), micronutrients (such as iron), and light availability (which depends on cloudiness and water clarity). New Zealand phytoplankton abundance and net primary productivity levels are high compared with most of Australasia, but lower than most coastal upwelling systems around the world (Field et al. 1998; Murphy et al. 2001). Ocean colour satellites estimate phytoplankton abundance using the metric of the chlorophyll-a concentration in near-surface waters ('chl-a'). Satellite estimates of chl-a are used as a proxy for primary production by phytoplankton (i.e., the growth of phytoplankton creating organic matter). Satellite-based

estimates of primary production require local validation which is ongoing (Pinkerton et al. 2019).

Chatham Rise has the highest chl-a levels in the New Zealand region, indicative of elevated productivity associated with the Subtropical Front and mixing between the different water masses (Figure 12.3). In the Subtropical Front region, macronutrient-limited subtropical waters (Bradford-Grieve et al. 1997) mix with high nutrient, low-chlorophyll (NHLC) iron-limited subantarctic waters (Boyd et al. 1999), resulting in increased primary productivity which is apparent in ocean colour remote sensing as elevated chl-a (Figure 12.4 left panel). Seamounts, seamount chains, and ridge structures can also provide additional localised areas of mixing and increased primary productivity.

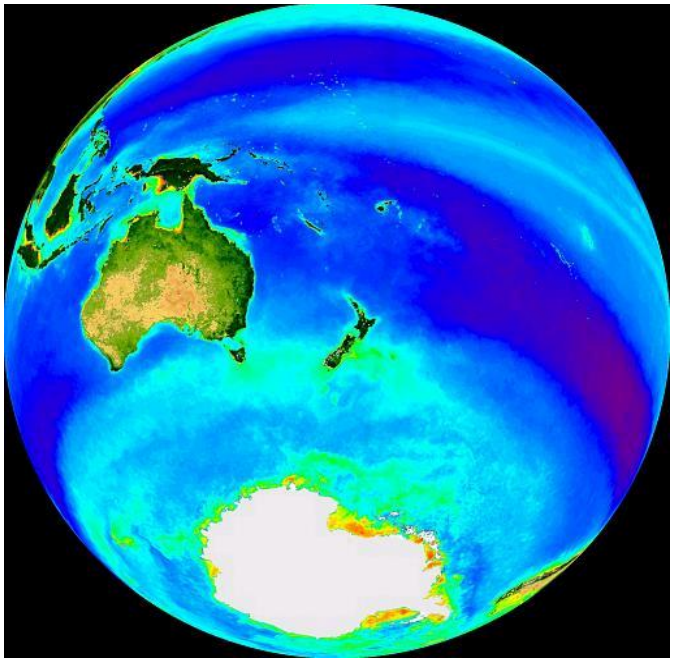


Figure 12.3: SeaWIFS image showing elevated chlorophyll a (green) near New Zealand. Image courtesy of NOAA.

Around the coast, turbulence, upwelling, resuspension of sediment, and land run-off also play key roles in determining primary productivity (Pinkerton et al. 2005, Chiswell et al. 2016). Care is needed in interpreting remotely-sensed ocean colour measurements in coastal waters because the presence of suspended sediment and dissolved coloured material can invalidate established methods for processing open-ocean satellite data. Novel approaches are now available for estimating chl-a in such 'optically-complex' coastal waters (e.g., Pinkerton et al. 2018), and so regionally-tuned coastal analyses are presented here separately from the ocean-scale analysis. Ocean and coastal processing steams will be merged in the future. Satellite observations show that chl-a in New Zealand coastal areas is elevated in areas where nutrients (especially nitrate) are brought into the coastal zone in rivers, and where upwelling of nutrient-rich deep water occurs because of wind and current patterns (Figure 12.4, right panel).

Elevated chl-a and primary production over the New Zealand shelf and slope underpin commercial shellfish and finfish fisheries from the shoreline to depths of about 1500 m. In the deeper ocean, primary productivity supports commercial deepwater fisheries (Aiken et al. 2004, Chassot et al. 2010). Primary productivity in surface waters also leads to a transfer of organic matter to the sea floor (e.g., Lutz et al. 2007) where it supports benthic ecosystems.

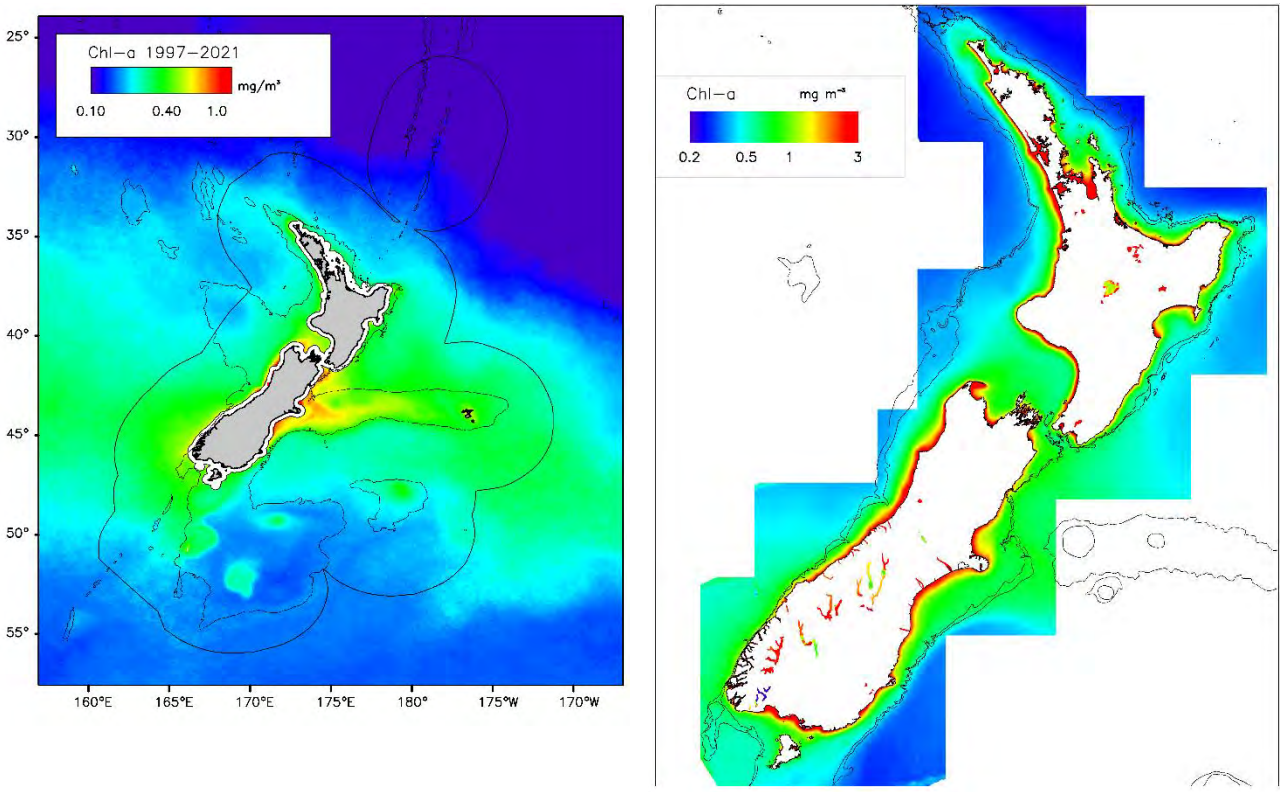


Figure 12.4: Mean annual concentration of chlorophyll-a (the ubiquitous phytoplankton pigment, chl-a) from satellite ocean colour observations [Left panel]. Ocean chl-a based on the merged dataset of SeaWiFS and MODIS-Aqua, which covers the period 1997–2021. The boundary of the New Zealand EEZ is shown and data in the territorial sea (12 n.mile from the coast) are excluded because of possible contamination by suspended sediment and river run-off. [Right panel]. Coastal chl-a based on quasi-analytic processing of MODIS-Aqua data, which covers the period 2002–2021. Images courtesy of NIWA; data used courtesy of NASA.

12.2 INDICATORS AND TRENDS

12.2.1 SEA TEMPERATURE

Sea Surface Temperature (SST), sea surface height (SSH), air temperature, and ocean temperature to 1000 m are all somewhat correlated over seasonal and interannual time scales (e.g., Sutton et al. 2005, Hurst et al. 2012, Sutton & Bowen 2019). New Zealand air temperatures have increased by about 1 °C since 1900 (Figure 12.5).

Although a linear trend has been fitted to the seven-station temperatures in Figure 12.5, the temperature changes are not uniform over time. For example, marked warming occurred through the periods 1940–60 and 1993–2000. Higher frequency variations can be related to fluctuations in the prevailing north-south airflow across New Zealand (Mullan et al. 2010). Temperatures are higher in years with stronger or more prevalent northerly winds and are lower in years with stronger or more prevalent southerly winds. This is as expected, since southerly winds transport cool air from over the Southern Ocean to New Zealand.

The unusually steep warming in the 1940–60 period is paralleled by an unusually large increase in northerly winds during this same period (Mullan et al. 2010). On a longer timeframe, there has been a trend towards less northerly (more southerly) winds since about 1960 (Mullan et al. 2010). However, New Zealand temperatures have continued to increase over this time, albeit at a reduced rate compared with earlier in the twentieth century. This is consistent with a warming of the entire Southwest Pacific (Mullan et al. 2010).

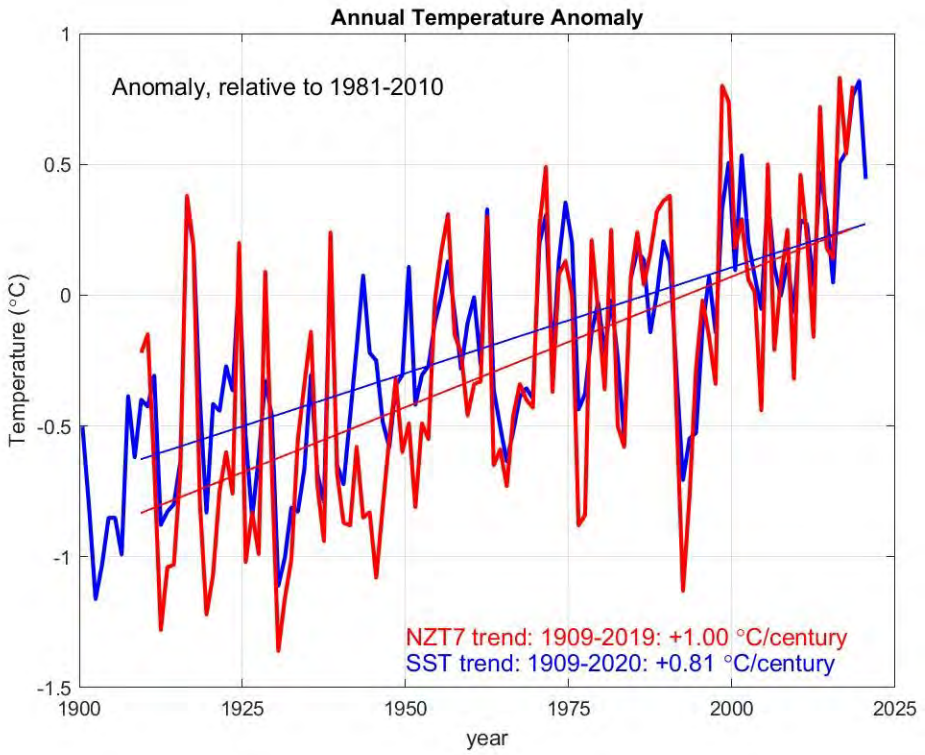


Figure 12.5: Annual time series in New Zealand. NOAA annual mean sea surface temperatures (blue line) averaged over the box outlined in black in Figure 12.6 together with NIWA's seven-station annual mean air temperature composite series (red line), expressed as anomalies relative to the 1981–2010 climatological average. Linear trends over the period 1909–2017, in °C/century, are noted under the graph. (NZT7 data from NIWA. NOAA data from ERSSTv5 (Huang et al. 2017). ERSST is Extended Reconstructed SST.)

Trends in sea surface temperature (SST) in the New Zealand region tend to be slightly smaller than trends in air temperature over land (Figure 12.5). Mullan et al. (2010) describe the pattern of warming in New Zealand as consistent with changes in sea surface temperature and prevailing winds. Their review shows enhanced rates of warming along the East Australian coast and to the east of the North Island, and much lower rates of warming south and east of the South Island (Figure 12.6).

Figure 12.7 shows SST trends since 1982 calculated from daily satellite measurements. These are at higher spatial and temporal resolution than Figure 12.6, providing more detail but span a shorter period. It is apparent that SSTs are increasing north of about 45° S and they are increasing more slowly, and decreasing in recent decades, east of Otago and south of New Zealand. This regional pattern of cooling (or only slow warming) to the south, and strong warming in the Tasman Sea and western Pacific Ocean can be related to increasing westerly winds and their effect on ocean circulation (Mullan et al. 2010, Roemmich et al. 2007, Roemmich et al. 2016). Thompson & Solomon (2002) discuss the increase in Southern Hemisphere westerlies and the relationship to global warming; Roemmich et al. (2007) and Roemmich et al. (2016) describe recent ocean circulation changes with the South Pacific subtropical gyre spinning up in response to the changing winds and Thompson et al. (2009) discuss the consequent effect on sea surface temperatures in the Tasman Sea.

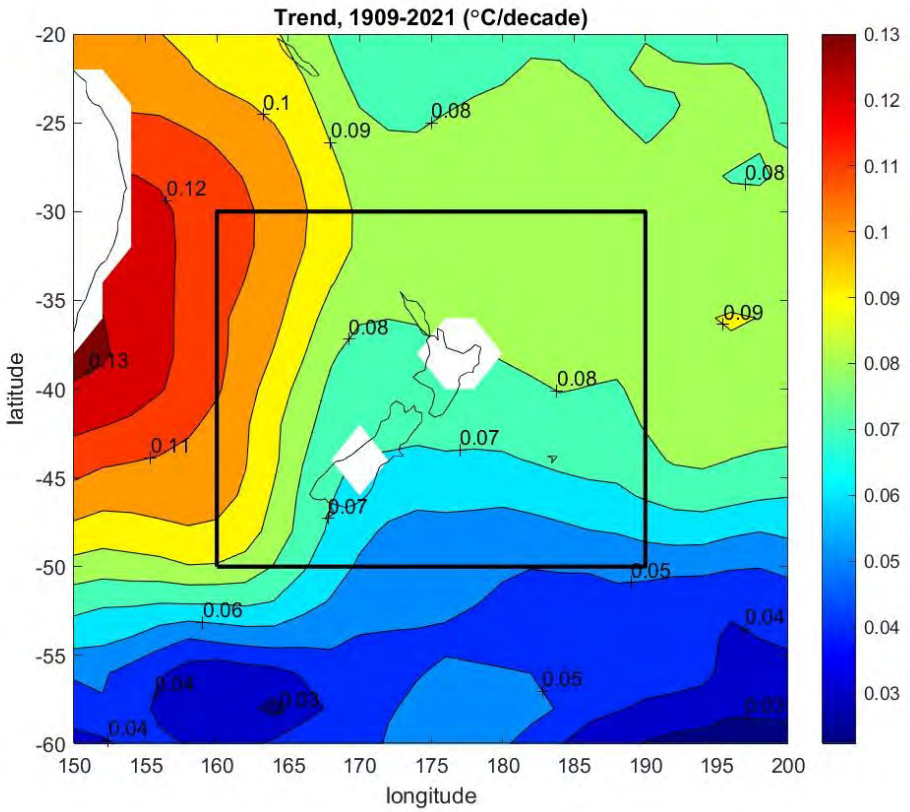


Figure 12.6: Trends in sea surface temperature, in °C/decade over the period 1909–2021, calculated from the NOAA_ERSST_v5 dataset (provided by NOAA's ESRL Physical Sciences Division, Boulder, Colorado, USA, from their web site at http://www.esrl.noaa.gov/psd). The data values are on a 2° latitude-longitude grid. The white areas are where the 2° grid points fall on land.

Comparing this updated analysis with a previous version based on measurements up until 2018 (Sutton & Bowen 2019) shows that the warming trend has generally increased. In particular, regions south of New Zealand which showed no significant trends over 1981–2018 show weak warming over 1981–2021. This acceleration is largely due to two extreme marine heatwaves that occurred in the 2017–18 and 2018–19 summers which are discussed later.

Figures 12.6 and 12.7 show some similarity but differ because trends are calculated over 1909 to 2021 in Figure 12.6 compared with 1981 to 2021 in Figure 12.7. Figure 12.6 is based on coarser resolution (2° lat/lon, monthly) ERSST that has been reconstructed from sometimes sparse ship measurements prior to the satellite era. Figure 12.7 is based on a consistent satellite dataset (AVHRR) with no changes in underlaying data or processing and 0.5° lat/lon, daily resolution.

Previous versions of this report have discussed coastal SSTs from a limited number of sites — notably the University of Auckland site at Leigh and Otago University site at Portobello. An analysis by Chiswell & Grant (2018) showed that satellite-based SSTs extracted for locations near the fixed coastal sites reproduced the variability seen in the direct coastal measurements very well. With that in mind, here we examine the SST records extracted from locations encircling the New Zealand coastline (Figure 12.8) to provide a picture of the complete coastal SST around New Zealand since 1981. This is an update of work by Sutton & Bowen (2019).

Pixels close to the coast were selected (Figure 12.8A) and annually-smoothed temperature anomaly time series from these locations are shown in Figure 12.8B with the coastline 'unwrapped' so that the y axis begins with Stewart Island before running northward up the east coast to North Cape and then southward along the west coast to complete the circuit at Stewart Island. Correlation length scales implicit in the daily OI-SST product are of the order of 100–150 km (Reynolds et al. 2007) or about half the distance between Banks Peninsula and Cook Strait, meaning that Figure 12.8B is effectively smoothed over this length scale. The OI-SST correlation time scales are much shorter than the annual

smoothing and so will not impact Figure 12.8B. Strong coherence over the entire coastline is clear in Figure 12.8B, consistent with the finding of Bowen et al. (2017) that interannual changes are correlated over large areas.

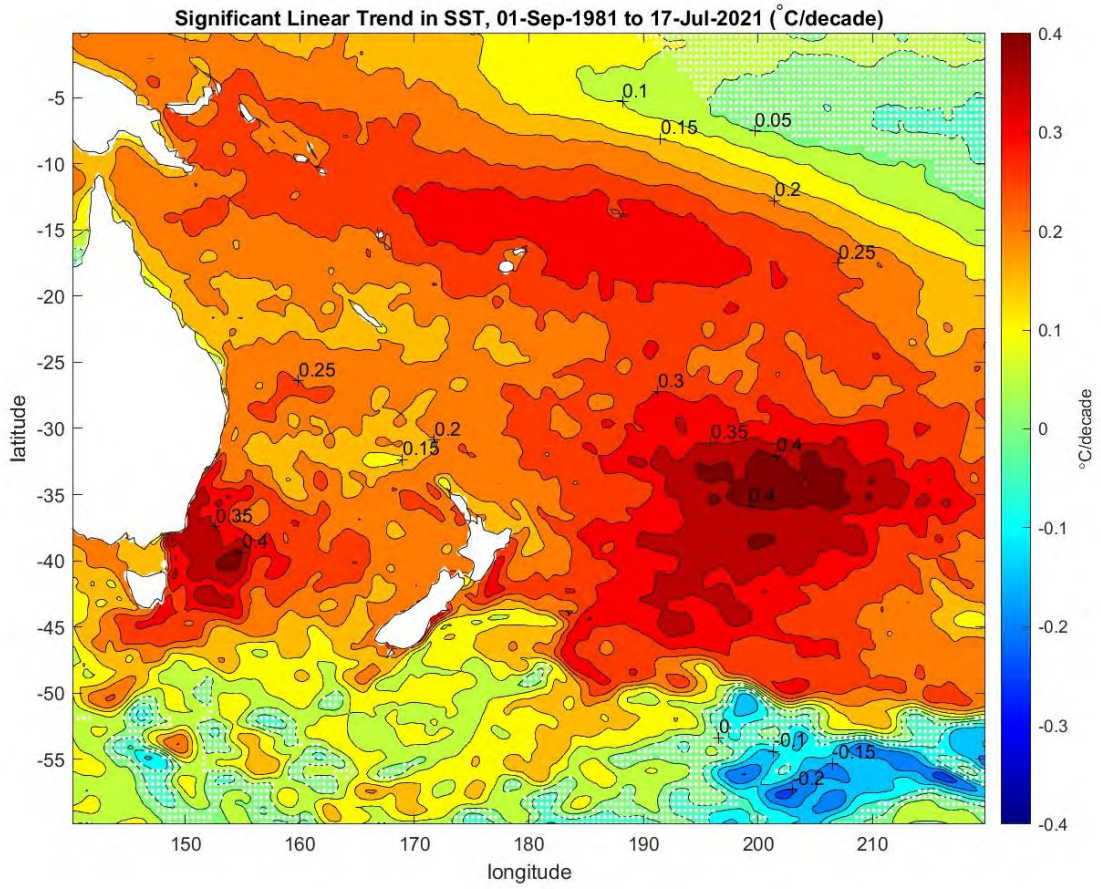
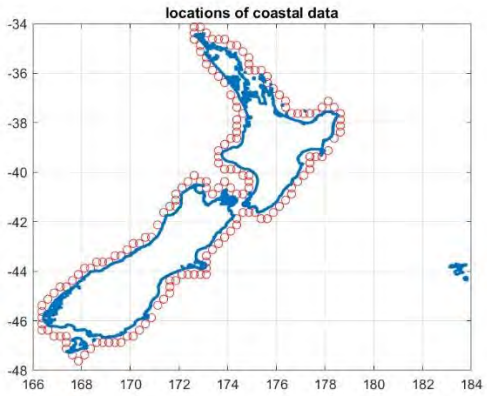


Figure 12.7: Trends in sea surface temperature, in °C/decade over the period 1982–2021. The data are from NOAA based on daily, interpolated satellite AVHRR measurements over a 0.25° grid (http://www.ncdc.noaa.gov/oisst, Reynolds et al. 2007). Areas where the trend is not statistically significant are shaded in white. Updated from Sutton & Bowen (2019).

The general pattern is that 1982–1983 is relatively cool, with a second cool period occurring in the 1990s. There was strong warming in the later 1990s (e.g., Sutton et al. 2005) with 1998 being the warmest year on record in the New Zealand air temperature seven-station record until it was surpassed in 2016 (https://www.niwa.co.nz/our-science/climate/information-and-resources/nz-temp-record/seven-station-series-temperature-data). The banding in Figure 12.8B indicates significant interannual variability. Within the large-scale pattern of variability, there are subtle changes around the coastline. The section of coast between Cook Strait and East Cape was anomalously cool at the start of the time series and shows more warm events through the 2000s, consistent with it being near the region of strongest trends. Conversely, the coast between East Cape and North Cape was not as cool in 1982–83 and does not show the warm events between 2001 and 2015, consistent with it being a local minimum in warming (Shears & Bowen 2017). The west coast varies largely in unison, which indicates that the eastern end of a repeat survey between Sydney and Wellington discussed later is representative of much of the eastern Tasman Sea. The summer of 2017–18 is anomalously warm around the entire coastline, but particularly so south of Banks Peninsula and Cape Egmont, with much of this signal resulting from the extreme marine heatwave that occurred through that summer. The weaker 2019–20 marine heatwave did not generate such a clear warm anomaly.

The ocean temperature down to 800 m between Sydney and Wellington has been sampled about four times per year since 1991 by CSIRO and Scripps Institution of Oceanography by dropping expendable bathythermographs (XBTs) from container ships (http://www-hrx.ucsd.edu/).

A)



B)

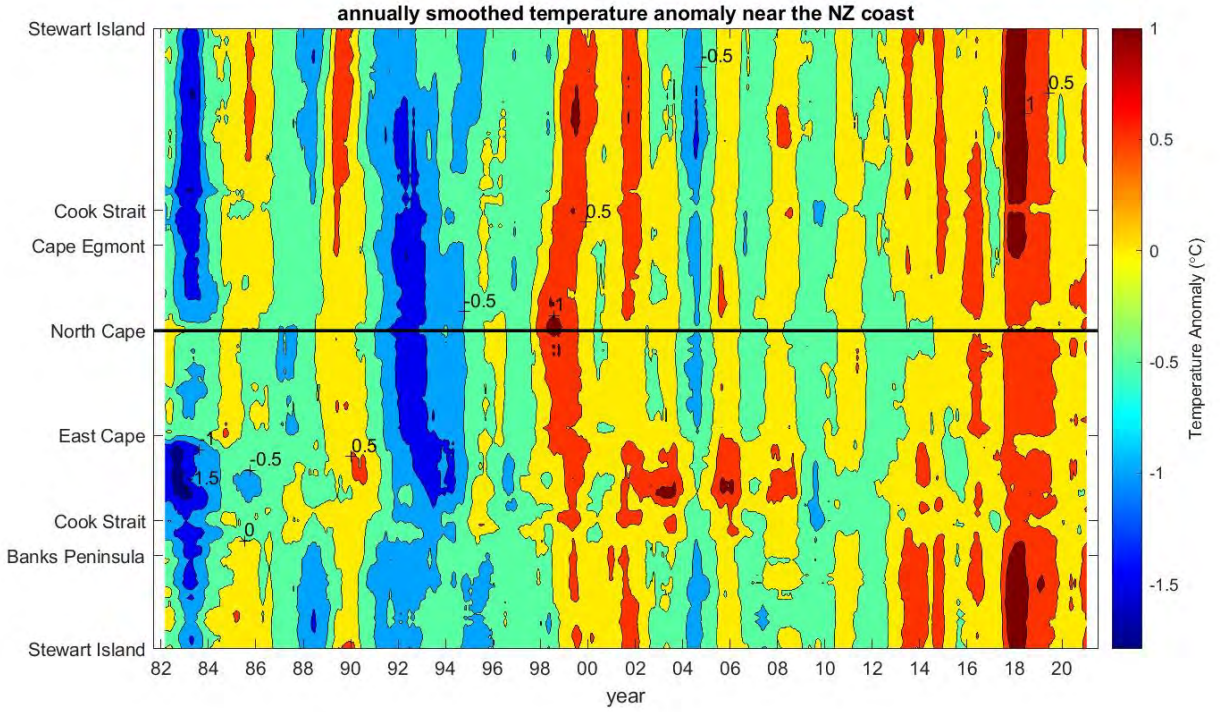


Figure 12.8: (A) The locations near the coast selected to build a near-coastal time series. (B) The time series of annually-smoothed temperature anomaly near the coast. The y axis begins at the southern-most location south of Stewart Island, then runs north along the east coast to North Cape (shown by the black line) before running south along the west coast. (Updated from Sutton & Bowen 2019.)

Analyses of the subsurface temperature field using these data include Sutton & Roemmich (2001) and Sutton et al. (2005). The temperature as a function of depth and time for the eastern portion (between 161.5° E and 172° E) of this section is shown in Figure 12.9. This eastern Tasman Sea section is close to New Zealand and has low oceanographic variability meaning that subtle inter-annual changes can be seen. The portion of the transect shown is along a fairly constant latitude and is therefore unaffected by latitudinal temperature and seasonal cycle variation. The lower panel shows the temperature averaged along the transect (with seasons removed) between the surface and 800 m and from 1991 to the most recent sampling. Unfortunately, this sampling was halted with the onset of COVID-19 so there are no newer data and a gap in the time series has been created.

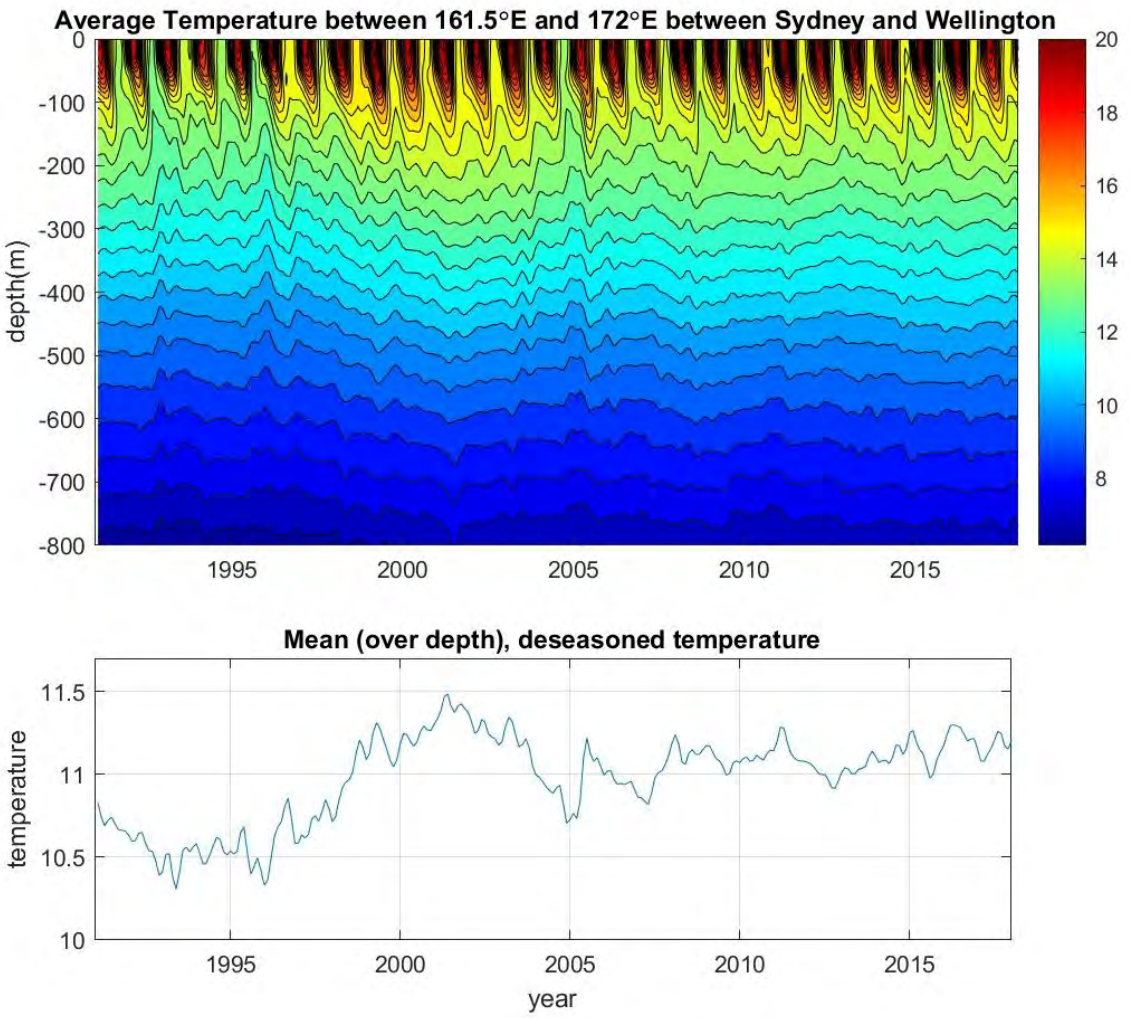


Figure 12.9: Top panel shows the eastern Tasman Sea ocean temperature along the Sydney to Wellington transect: 161.5° E to 172° E, 1991–2018. Coloured scale to the right is temperature (°C). Image updated from Sutton et al. 2005. Bottom panel shows the mean 0-800 m temperature with seasons removed.

The seasonal cycle is clearly visible in the upper 100–150 m. There is a marked warming signal that occurred through the late 1990s, apparent from the isotherms increasing in depth through that time period. This warming was significant in that it extended through the full 800 m of the measurements (effectively the full depth of the eastern Tasman Sea). It also began during an El Niño period when conditions would be expected to be relatively cool. It was thought to be linked to a large-scale warming event centred on 40° S that had hemispheric and perhaps global implications. This warming has been discussed by Sutton et al. (2005) who examined the local signals, Bowen et al. (2006) who studied the propagation of the signal into the New Zealand area, and Roemmich et al. (2007) who examined the broad-scale signal over the entire South Pacific Ocean. Roemmich et al. (2007) hypothesised that the ultimate forcing was an increase in high latitude westerly winds effectively speeding up the entire South Pacific gyre. An update of this analysis has confirmed that the gyre spin-up continued through to 2015 (Roemmich et al. 2016).

Other phenomena have led to periods of warming that are as yet not fully understood. Both stochastic environmental variability and predictable cycles of change influence the productivity and distribution of marine biota in our region.

The 2017–18 and 2018–19 summers saw very warm SSTs in the Tasman Sea (Figure 12.10), with SST anomalies reaching 4–5 °C above normal in 2017–18 and 2.5 °C above normal in 2018–19. Studies indicate that these anomalous warm

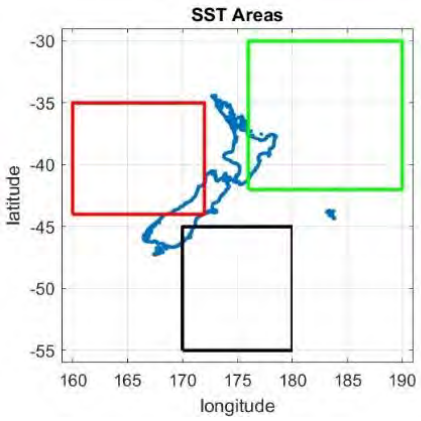
events were the result of prolonged periods of calm winds, in turn as a result of blocking atmospheric high pressure systems to the east of New Zealand (Salinger at al. 2018, Behrens et al. 2018, Salinger et al. 2020). Figure 12.10(C) shows the average vertical temperature anomaly in the upper 200 m of the eastern Tasman Sea since 2006 as measured by Argo floats. Looking at this 15-year time period, the decadal warming of ~0.3 °C as seen in the XBT analysis appears clearly. There are also upper (0–40 m) warm events, with weak events in the summers of 2007–08, 2010–11, and 2015–2016 and strong events in 2017–18 and 2018–19. The 2017–18 event stands out as the strongest. These warm events are typically associated with summers and are constrained to the upper 40 m or so of the water column — corresponding to the depth of the summer mixed layer. Cool events occur year-round and can extend to more than 100 m — corresponding to the depth of the winter mixed layer. An approximately 30 m deep layer of warm water formed in November 2017 and persisted until February 2018 before it was eroded at the surface by strong winds associated with Cyclone Fehi. The wind mixed the warm, upper water deeper into the water column as is evident in Figure 12.10(D). There was no significant change in the total heat content through this period because the anomaly was shallow, and there was also no discernible air-sea flux signature (Behrens et al. 2018). The similar, but weaker warm event in summer 2018–19 peaked at an anomaly of ~+2.5 °C. It was also mixed down into the water column by winds once the atmospheric blocking high broke down.

Longer-term occurrences of anomalously warm and cold events are shown in Figure 12.10(B). Regional average SST anomaly time series are shown for three areas (Figure 12.10(A)), along with the annually-smoothed time series and associated linear trends (updated from Sutton & Bowen 2019). Time periods where the daily anomalies are more than two standard deviations from the mean are shown in bold symbols. In all regions, the occurrences of warm and cool events are modulated by interannual variability, that is warm extreme events almost exclusively occur during warm periods and cool extreme events during cool periods, consistent with the results of Behrens et al. 2018. This modulation is clear during the early 1990s cool period in Subtropical Water (the Tasman and northeast regions), particularly so for the northeast, with the bulk of northeast cool events occurring between 1991 and 1995. Beyond this decadal modulation, there is no clear trend in the occurrence of warm or cool events in the northeast or southeast regions. There is a suggestion that the occurrence of warm events in the Tasman region is becoming more frequent, and cool events look to be becoming rarer, with only one Tasman cool event since 2008, as could be expected given the significant warming trend in the eastern Tasman Sea (Figure 12.7). The summer 2017–18 warm event stands out as being exceptional in the Tasman Sea and southeast areas.

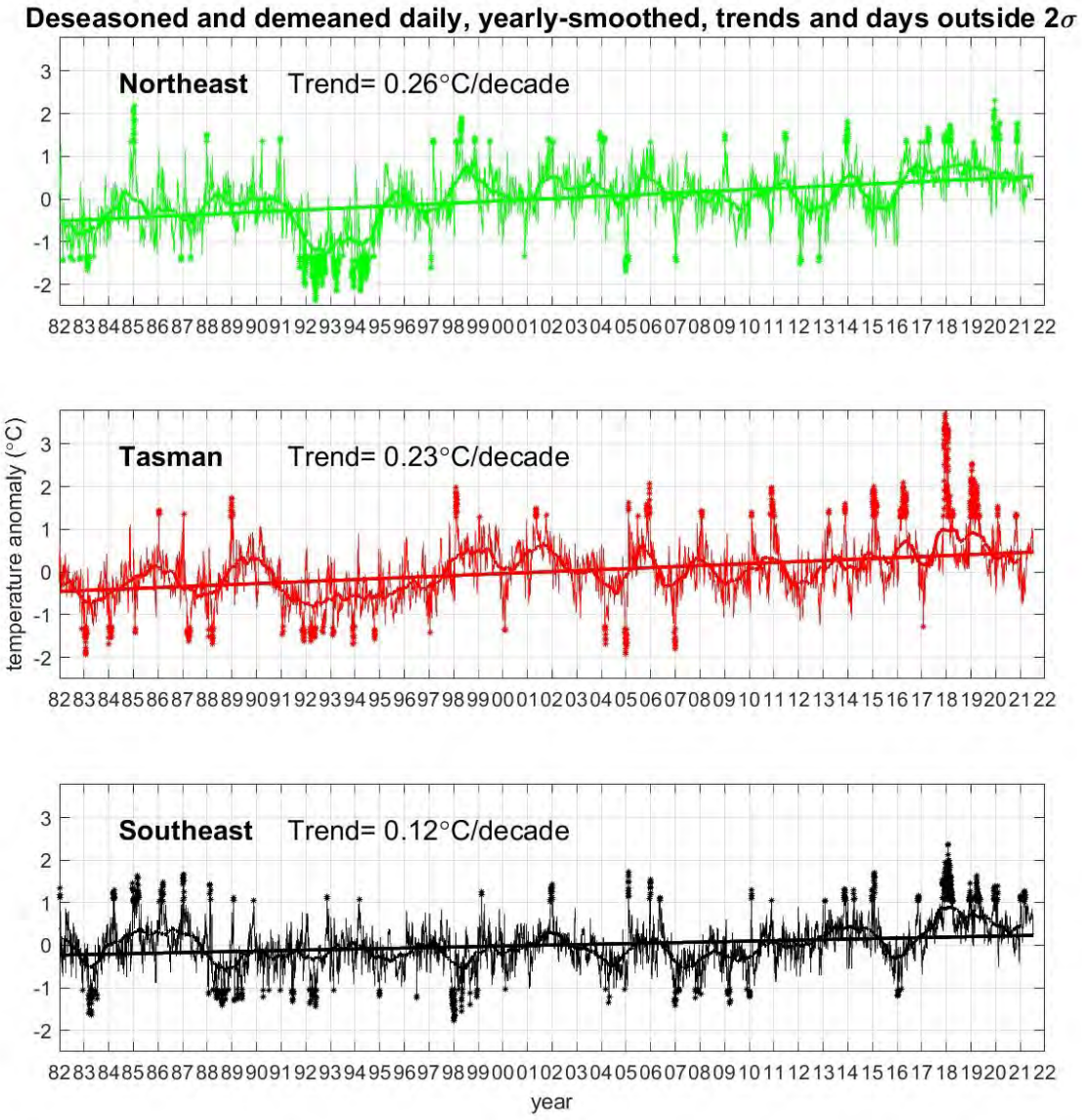
Both cool and warm events occur more often in summer (Figure 12.10). In their study offshore of the west coast, South Island, Chiswell & O'Callaghan (2021) also found this to be the case, but also concluded that warm events showed more seasonal variability. This summer bias is probably a result of the summer mixed layer being shallower and therefore requiring less energy to drive a given temperature change. In addition, the 2017–18 and 2018–19 marine heatwaves resulted from periods of light winds (Salinger at al. 2018, Behrens et al. 2018, Salinger et al. 2020), conditions that are more likely to occur during summer.

Chiswell & O'Callaghan (2021) also noted that the SST warming is not constant across seasons. Their west coast, South Island 2002–18 SST trend was positive over most of the region and resulted from increasingly warmer summers and marine heatwaves rather than year-round warming.

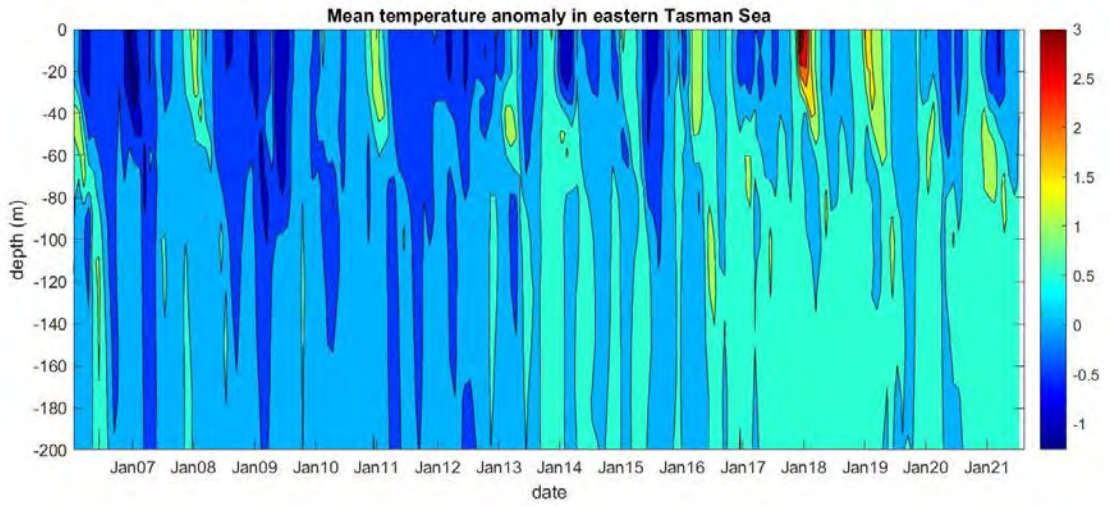
(A)


SST Areas
-30
-35
-40
-45
-50
-55
latitude
160
165
170
175
180
185
190
longitude

(B)


Deseasoned and demeaned daily, yearly-smoothed, trends and days outside 2σ
Northeast
Trend= 0.26°C/decade
Tasman
Trend= 0.23°C/decade
Southeast
Trend= 0.12°C/decade
temperature anomaly (°C)
3
2
1
0
-1
-2
82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22
year

(C)



(D)

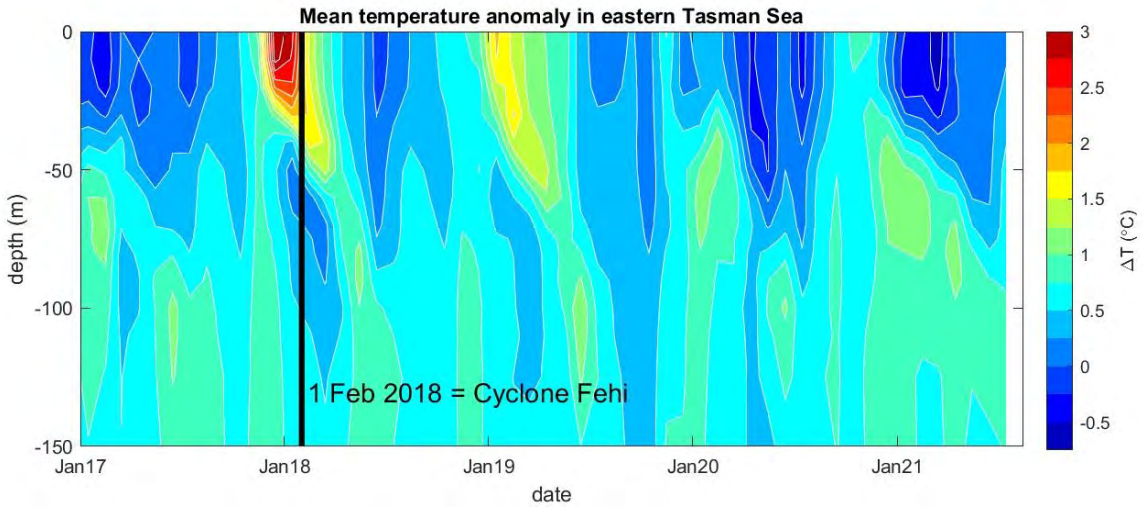


Figure 12-10: Marine heatwaves. (A) Three regions chosen to represent different regimes. (B) The mean satellite SST anomalies (with the seasonal data removed) for these regions, at daily resolution and annually-smoothed. The linear trends are also shown. Values more than two standard deviations from the mean are shown in bold symbols. (Modified from Sutton & Bowen 2019.) (C) and (D) The mean temperature anomaly in the eastern Tasman Sea as a function of depth and time from Argo data for the full Argo period (C) and since 2017 (D).

12.2.2 PRIMARY PRODUCTIVITY

Ocean primary productivity

A 23-year time series of observations of chl-a can be obtained for the ocean domain, by blending together data from overlapping satellite sensors operated by NASA (SeaWiFS and MODIS-Aqua), covering the period September 1997–August 2021. Linear trend analysis can be applied to the satellite data to estimate the long-term trends in chl-a and indicate likely changes in ocean productivity over this period (Pinkerton et al. 2019). Satellite data show that chl-a is increasing in some ocean areas around New Zealand, especially in the Subtropical Front east and west of New Zealand, and over Chatham Rise (Figure 12.11, upper). Negative trends in chl-a (indicative of decreasing ocean productivity) were found in Subtropical Water to the east of New Zealand (outside the EEZ) and around Northland and the northeast New Zealand continental slope (offshore of Hauraki Gulf, eastern Coromandel, and Bay of Plenty). Average rates of increase and decrease in chl-a in these areas was of the order of 1–2% per year which is small compared with interannual variability (~ ±20%). Most trends were not significant at the

0.95 confidence level because the time series is short and the variability in chl-a is large compared with the size of the trend.

Conventional wisdom is that upper ocean warming will result in stronger stratification and that will, in turn, impact primary productivity and chl-a. Two basic mechanisms act in opposition: 1) in nutrient-limited (oligotrophic) environments increased stratification will reduce primary productivity by reducing the availability of deep nutrients to the mixed layer; and 2) in light-limited environments, increased stratification will increase primary productivity by shoaling the depth of the phytoplankton. Chiswell & Sutton (2020) found that over the last two decades warming has reduced primary productivity in STW but has not over the STF or in SAW, consistent with this paradigm. The new analysis presented here is also consistent with this general understanding. However, the largest and most significant positive trends in chl-a anomalies over the entire 1997–2021 time series were found in the Subtropical Front both east and west of New Zealand landmass. The mechanisms leading to these observed strong increases in chl-a in the Subtropical Front are not well understood; trends in SST anomalies in these regions were not particularly high and there were no strong correlations between chl-a anomalies and SST anomalies.

Overall, the changes in ocean chl-a observed in the satellite data since 1997 show the effects of large-scale climate-environmental forcing in the New Zealand EEZ (Figure 12.11, lower panel). Negative chl-a anomalies (and likely reduced ocean primary productivity) through most of the EEZ over the period September 1997 to 2003 were followed by higher values in the middle of the time series (2004–2012), then lower values from 2012 to 2018, and finally a period of strong positive anomalies between 2018 and 2020. There was also a very large and unprecedented (in the satellite data record) EEZ-scale positive chl-a anomaly in November 2019.

Coastal primary productivity

Linear trend analysis can be carried out for the coastal data as for the ocean observations, but only for the period July 2002–June 2021 because SeaWiFS data are not suitable for this analysis. The coastal analysis shows areas with significant negative trends in coastal chl-a (likely indicative of decreasing primary productivity) along the east coast of Northland, around the Hauraki Gulf and Coromandel, Bay of Plenty, East Cape, Wairarapa coast, South Taranaki Bight, and offshore of Golden Bay and Tasman Bay (Figure 12.12, upper panel). Evidence of increasing coastal productivity over the last two decades was found in the Firth of Thames, Hawke Bay, around the Taranaki coast, and around most of the coastline of South Island. Changes in coastal primary productivity and chl-a will result from the interplay of oceanographic change at the continental shelf scale, and smaller-scale, localised effects due to the effects of land use on riverine input of nutrients and sediment. These patterns of change can hence give insights into the factors causing the changes in different areas.

The time series of change in chl-a in the territorial waters around North Island and South Island are shown in Figure 12.12, lower panels). There is evidence of a small decreasing trend in chl-a around North Island since 2002, but the magnitude of the trend is small compared with interannual variability. Around South Island, coastal chl-a has increased since late 2017, with some very large, positive anomalies in June 2020 and June 2021.

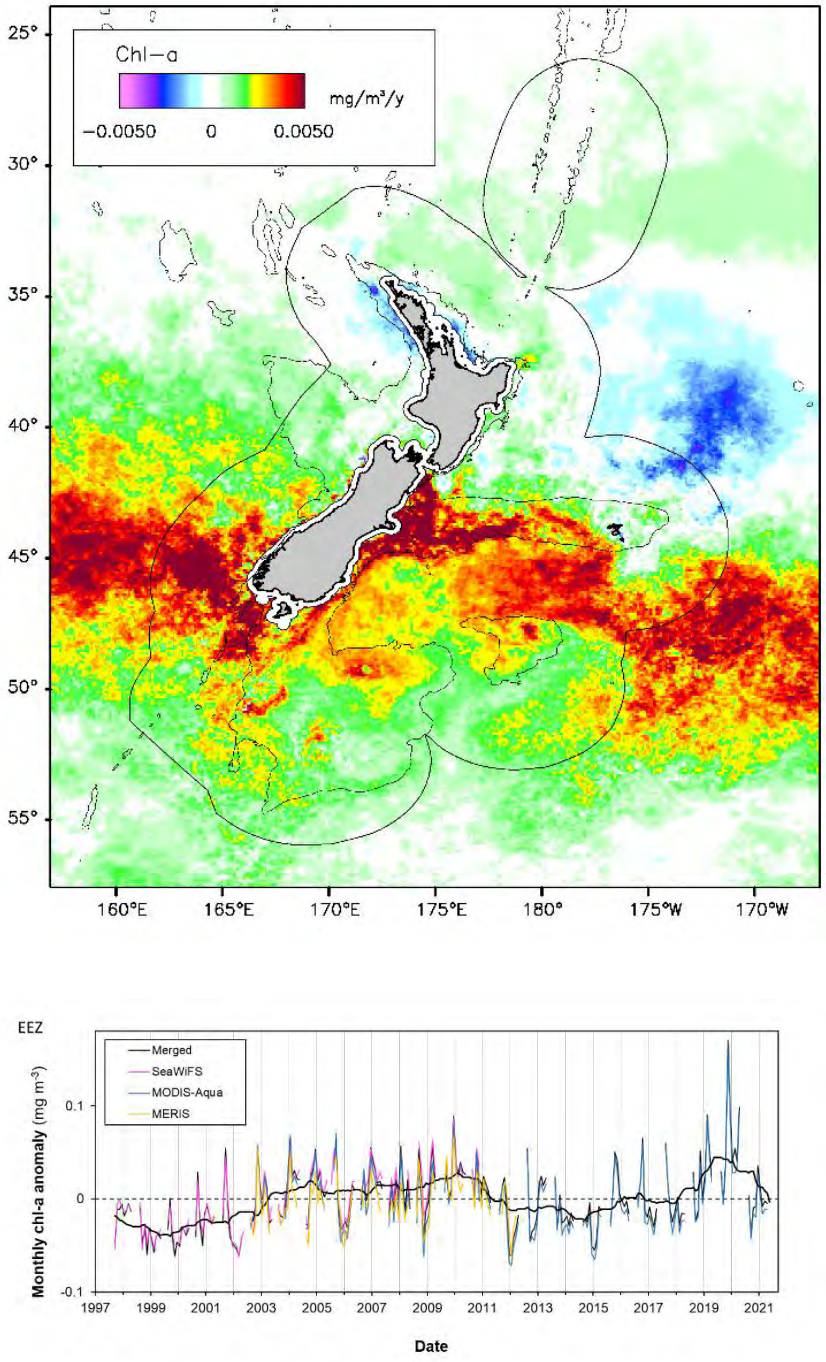


Figure 12.11: Trends (long-term change) in oceanic chlorophyll-a (the ubiquitous phytoplankton pigment) based on the merged satellite dataset of SeaWiFS and MODIS-Aqua, which covers the period 1997–2021. [Upper panel]: Spatial trends where red/orange shows increasing trends in chl-a and pink/purple shows decreasing trends. The boundary of the New Zealand EEZ is shown and data in the territorial sea (12 n.mile from the coast) are excluded because of possible contamination by suspended sediment and river run-off. [Lower panel]. Mean monthly anomalies (differences from mean monthly values) in chl-a averaged across the New Zealand Exclusive Economic Zone (EEZ). The monthly anomalies shown are the merged (SeaWiFS-MODIS-Aqua) dataset (thin black lines), SeaWiFS (pink), MODIS-Aqua (blue), and MERIS (orange). Monthly data are not shown where there was less than 80% data coverage for a given month. The thick black line is the merged dataset smoothed with a 4-year running mean, the vertical grey lines divide different years, and the dashed horizontal line shows zero anomaly. Images courtesy of NIWA; satellite data used courtesy of NASA and European Space Agency.

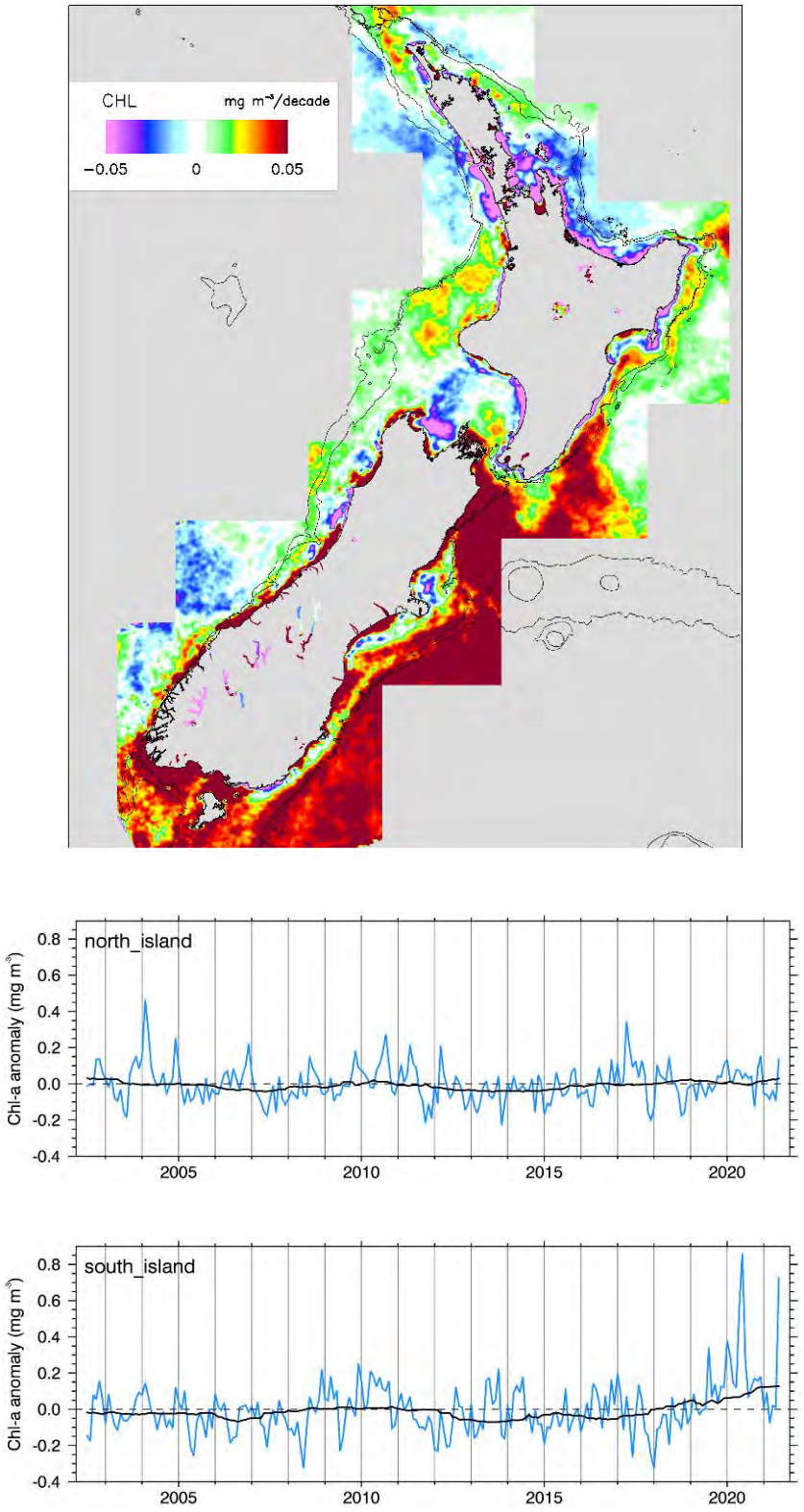


Figure 12.12: Coastal trends (long-term change) in chl-a based on the quasi-analytic processing of MODIS-Aqua data (see method of Pinkerton et al. 2018), which covers the period 2002–2021. [Top panel] Spatial trends where red/orange shows increasing trends in chl-a, and pink/purple, decreasing trends. The 250 m and 500 m depth contours are also shown. [Lower panels]: Mean monthly anomalies (differences from mean monthly values) of chl-a for the territorial waters (shore to 12 n-miles) for North Island and South Island. Thick black lines are smoothed with a 4-year running mean, and the vertical grey lines divide different years. The dashed horizontal lines show zero anomaly. Images courtesy of NIWA; satellite data used courtesy of NASA.

12.2.3 CLIMATE VARIABLES

The Interdecadal Pacific Oscillation (IPO) is a Pacific-wide reorganisation of the heat content of the upper ocean and represents large-scale, decadal temperature variability with changes in phase over 15–30-year time scales. In the past 100 years, phase changes occurred in 1926, 1943, 1978, and 1998 (Figure 12.13). The latest shift should result in New Zealand experiencing a period of reduced westerlies, with associated warmer air and sea temperatures and reduced upwelling on western coasts (Hurst et al. 2012).

The El Niño-Southern Oscillation (ENSO) cycle in the tropical Pacific has a strong influence on New Zealand. ENSO is described here by the Southern Oscillation Index (SOI), a measure of the difference in mean sea-level pressure between Tahiti and Darwin (Figure 12.14). When the SOI is strongly positive (persisting above +1), a La Niña event is taking place and New Zealand tends to experience more north-easterlies, reduced westerly winds, milder, more settled, warmer anticyclonic weather, and warmer sea temperatures (Hurst et al. 2012). When the SOI is strongly negative (persisting below -1), an El Niño event is taking place and New Zealand tends to experience increased westerly and south-westerly winds, cooler, less settled weather, and enhanced along shelf upwelling off the west coast South Island and north-east North Island (Shirtcliffe et al. 1990, Zeldis 2004, Chang & Mullan 2003, Sutton & Roemmich 2001). The SOI is available monthly from 1876 onwards (Mullan 1995).

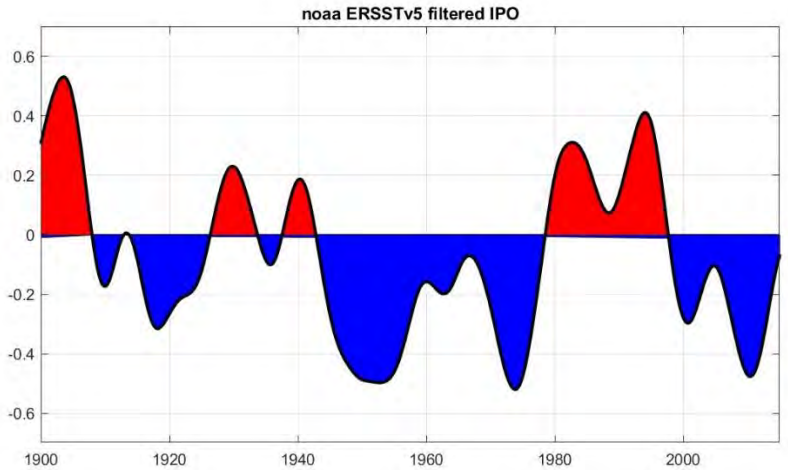


Figure 12.13: Smoothed index of the Interdecadal Pacific Oscillation (IPO) since 1900. (Filtered IPO Tripole Index of Henley et al. (2015): https://psl.noaa.gov/data/timeseries/IPOTPI/.)

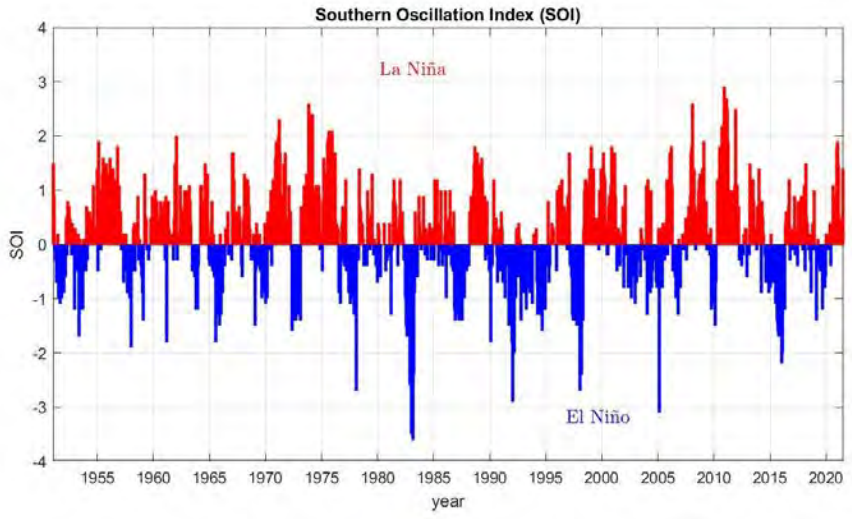


Figure 12.14: Southern Oscillation Index (SOI). Red indicates La Niña and a tendency for warmer temperatures around New Zealand, blue indicates El Niño and a tendency for cooler conditions around New Zealand. (https://www.ncdc.noaa.gov/teleconnections/enso/indicators/soi/ and https://www.cpc.ncep.noaa.gov/data/indices/soi)

12.2.4 WATER CHEMISTRY: OCEAN ACIDIFICATION

The increase in atmospheric carbon dioxide (CO_2) since the industrial revolution has been paralleled by an increase in CO_2 concentrations in the upper ocean (Sabine et al. 2004). The ocean is estimated to hold about 25% of all anthropogenic CO_2 released since 1750 (Le Quéré et al. 2018), with the anthropogenic CO_2 signal apparent to an average depth of about 1000 m and reaching depths of 3000 m in deep water formation regions (Sabine et al. 2004). The Southern Ocean is the primary route for the entry of anthropogenic CO_2, accounting for about 40% of current oceanic uptake (DeVries 2014).

Carbon dioxide absorbed by seawater reacts with the water and carbonate ions to form bicarbonate ions and releases hydrogen ions in the process (Figure 12.15). This reaction raises the acidity and lowers the pH of seawater, in addition to decreasing the amount of carbonate in the seawater. Since the beginning of the industrial era, average surface ocean pH has decreased by 0.1 units, with a further decrease of up to 0.4 units expected by the end of the century (Rhein et al. 2013). The pH scale is logarithmic, so a decrease of 0.4 in pH corresponds to a 150% increase in hydrogen ion concentration. Both the predicted pH in 2100 and the rate of change in pH are outside the range experienced by the oceans for at least half a million years.

Recent projections for the open ocean around New Zealand indicate a mean pH decline to 7.935–7.985 by 2050, depending upon the emission scenario. Under a more favourable pathway, RCP4.5, which anticipates zero emissions by mid-century, pH around New Zealand will fall to a mean of 7.95 by 2100; conversely, the worst-case scenario of continued emissions, RCP8.5, indicates that ocean pH will have fallen by about 0.33 to about 7.77 by 2100 (Law et al. 2018b). The latter projection is equivalent to an increase in hydrogen ion concentration (acidity) of 116%. The drop in pH shows little spatial variability in New Zealand waters because it is primarily driven by atmospheric CO_2.

The Munida Time Series has maintained bimonthly measurements of surface CO_2 and pH at a station in subantarctic waters off the Otago shelf for 20 years and is the longest running ocean acidification time series station in the Southern Hemisphere (Law et al. 2018a). The Munida Time Series data (available from https://marinedata.niwa.co.nz/nzoa-on-map/) show a pH decline in subantarctic surface waters since 1998, consistent with that expected from equilibrium with atmospheric CO_2 (Figure 12.16, Law et al. 2018a). Dissolved pCO_2 (partial pressure of CO_2) at the Munida station shows a statistically significant increase of 1.3 µatm yr^{-1} for 1998–2012 (Bates et al. 2014), that is consistent with long-term changes observed at other global time series sites. Surface pH in the open ocean has been determined at seven long-term time series stations, six of which are in the northern hemisphere (Bates et al. 2014, Figure 12.17). All the time series records show long-term trends of increasing pCO_2 and decreasing pH. The significant seasonal variability apparent in the subantarctic water time series is due to biological uptake of dissolved inorganic carbon and seasonal temperature changes (Brix et al. 2013).

On a global basis, the open ocean shows relatively low spatial and temporal variability in pH relative to coastal waters where pH may vary by up to 1 unit in response to precipitation events and biological activity. A New Zealand coastal ocean acidification observing network (NZOA-ON, https://marinedata.niwa.co.nz/nzoa-on/) has been operating for ten years to establish baseline conditions against which to assess future changes in pH. The network maintains pH time series for 15 coastal stations around New Zealand and includes a range of coastal morphotypes and conditions. A variety of stakeholders, including government agencies, councils, industry, and citizens, provide alkalinity and DIC samples on a fortnightly basis for analysis at a centralised facility (NIWA/University of Otago Research Centre for Oceanography). Examples of pH variability at three of the NZ-OAON sites are shown in Figure 12.16. The seasonal pH cycle is controlled by the temperature at most sites, with a maximum pH in late winter and minimum in late summer-autumn, as for Wellington Harbour in Figure 12.18. Local factors also influence pH, as at the Chatham Islands where phytoplankton blooms along the Subtropical Front result in periods of elevated pH, and in Jackson Bay (west coast, South Island) where freshwater input causes sharp pH declines. Freshwater input also supplies excess nutrients and organic matter in some regions, which enhance acidification of coastal waters. An example of this is the Firth of Thames, where seasonal surveys of surface water have shown a pH decline to 7.9 in autumn in the innermost firth (Zeldis & Swaney 2018; K. Currie, NIWA, pers. comm.), with subsequent monitoring with SeaFET sensors detecting pH events of less than 7.7 (J. Zeldis, NIWA, pers. comm.). This pH is lower than that projected

for the surface open ocean around New Zealand by the year 2100 (Law et al. 2018b), indicating that some coastal waters already experience periods of intense acidification.

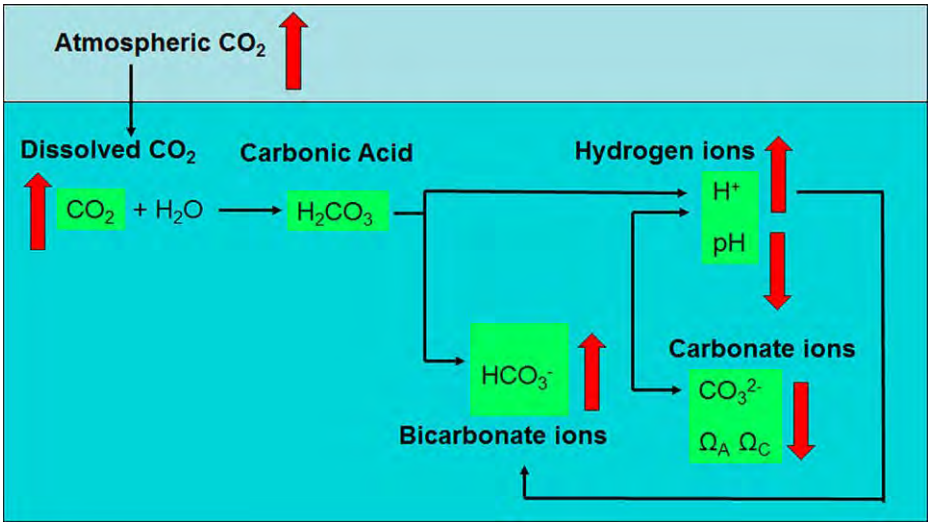


Figure 12.15: Conceptual diagram showing the reactions and chemical species of the marine carbonate system (black arrows), with the direction of the vertical red arrows indicating the net change in response to increasing atmospheric CO_2, and resulting in ocean acidification (Law et al. 2018a).

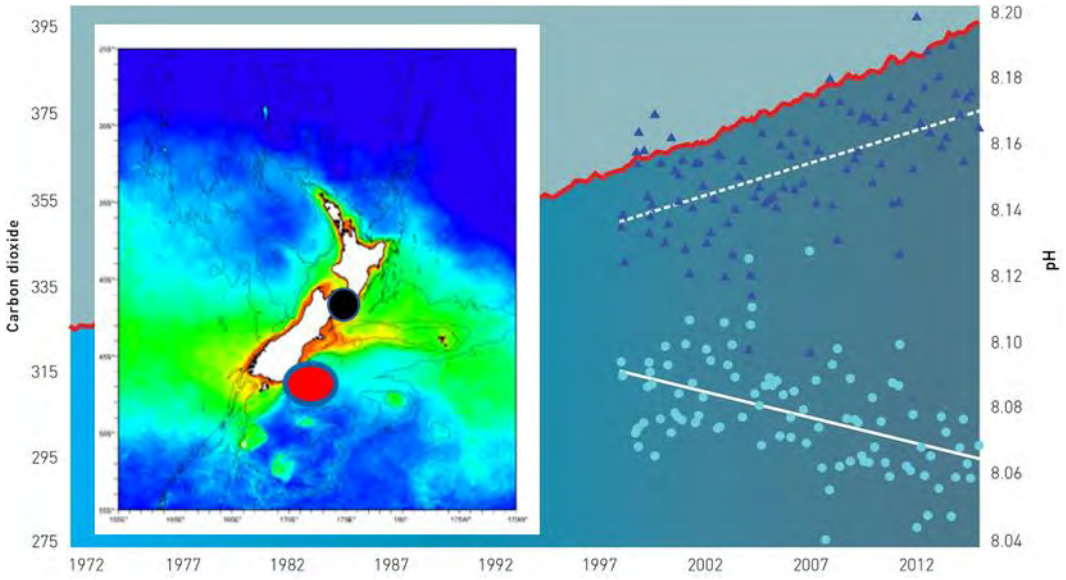


Figure 12.16: Time series of atmospheric CO_2 at Baring Head (location: black dot, Wellington; data: red line, Brailsford et al. 2012), and surface water pCO_2 (data: dark blue triangles) and pH (data: light blue circles) at the subantarctic water station (location: red dot, on the Munida transect off Dunedin) (Law et al. 2018a).

Biological implications of ocean acidification result from increasing hydrogen ion concentration (decreasing pH), decreasing carbonate availability, and increasing dissolved pCO_2. There are many international studies that have identified a range of direct and indirect effects of ocean acidification across a broad range of marine phylogenetic groups, from bacteria to whales and a number of ecosystems from coastal to deep sea. A particular concern regarding ocean acidification is that the reduction in carbonate availability may potentially impact organisms that produce shells or body structures of calcium carbonate, resulting in a weakening of shell integrity, redistribution of an organism's metabolic activity, and increased physiological stress.

Organisms likely to be affected by ocean acidification include those at the base of the food chain (protozoa, plankton), coralline algae, rhodoliths, shallow and

deepwater corals, echinoderms, molluscs (possibly including cephalopods, e.g., squids), and high-activity pelagic fish (see Feely et al. 2004 and references therein, Orr et al. 2005, Langer et al. 2006). Early life stages are particularly vulnerable in calcifying (carbonate-forming) species across many phyla (e.g., Byrne et al. 2013, Bylenga et al. 2015, Mu et al. 2015). Ocean acidification is a threat to deep-sea habitats such as seamounts, which can support structural reef-like habitat composed of stony corals (Tracey et al. 2011). A shoaling carbonate saturation horizon could push such biogenic structures to the tops of seamounts, or cause widespread die-back (e.g., Thresher et al. 2012). This has important implications for the structure and function of benthic communities. Recent research on New Zealand cold-water corals identified potential changes in physiology when maintained under lower pH for one year (Gammon et al. 2018). Changes in cold-water corals may indirectly impact commercial fisheries for deepwater species such as orange roughy (Clark 1999).

In surface and shallow waters some phytoplankton and seagrasses may benefit from an increase in dissolved pCO_2 due to increased photosynthesis. Direct effects of acidification on the physiology and development of fish have also been investigated. Adverse effects on physiology development (e.g., Franke & Clemmesen 2011) and behaviour modification (Munday et al. 2014) have been documented. Such studies highlight the potential for increasing acidification to impact larval growth and development, with implications for survival and recruitment of both forage fish and fish harvested commercially. However, recent studies showed no adverse effects of low pH on yellowtail kingfish (Munday et al. 2015), with warming having a greater impact on their behaviour (Watson et al. 2018). Parsons et al. (2020) attempted to predict the yield of Hauraki Gulf snapper under climate change based on the physiological impacts of warming and acidification. They found it was difficult to translate the physiological effects into population level impacts, summarising that the direct effects of climate change on snapper are likely to: 1) be largely determined by impacts on the larval life stage; 2) contain either positive or negative effects; and 3) incorporate an effect on larval life stages that more or less translates into a similar magnitude effect at the population level. Their most negative scenario suggested a 29% decrease in fishery yield, and the most optimistic scenario suggested a 44% increase.

An assessment of the current knowledge, and vulnerability, of different New Zealand biological groups, species, and ecosystems to ocean acidification has been published, as summarised in Table 12.1 (Law et al. 2018a). The general findings of the synthesis are that a) calcifying organisms (those with carbonate shells) are vulnerable; b) early-life history stages (eggs and larvae) are more vulnerable than later life history stages and so are a potential bottleneck to species survival; c) more research is required to determine the response of larger marine fauna (crustacea, fish, and higher trophic levels) to ocean acidification (see Table 12.1), the interaction of ocean acidification with other climate stressors and its effect on ecosystem interactions, and the potential for adaptation to ocean acidification.

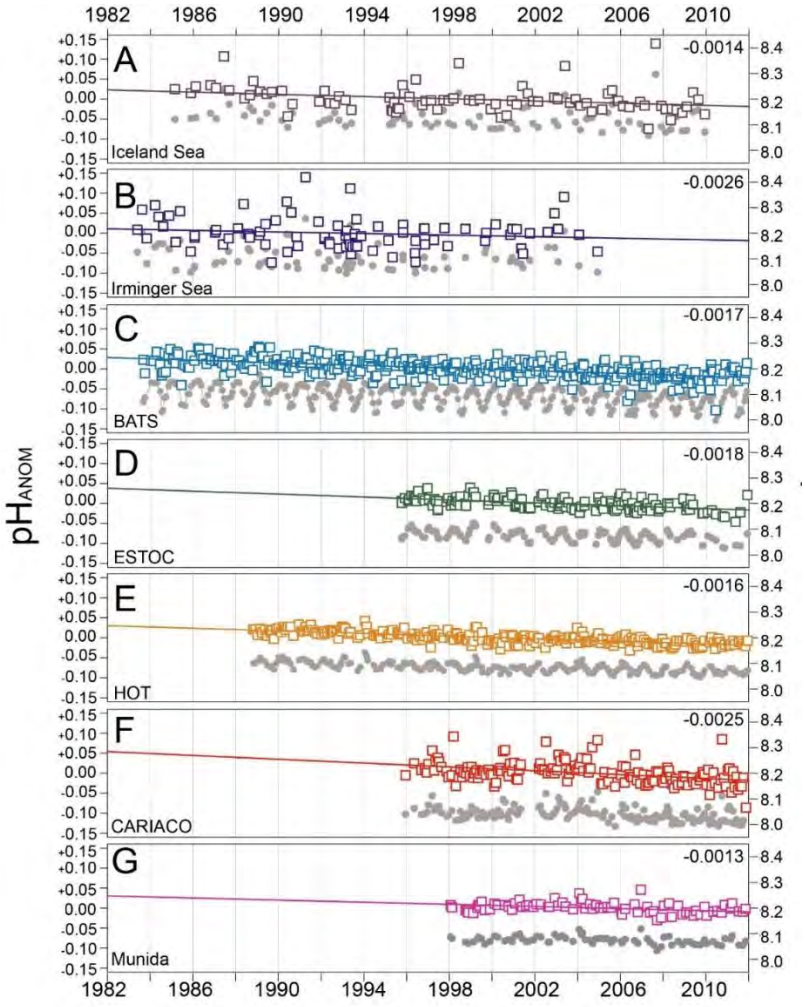


Figure 12.17: Time series of surface ocean pH (grey symbols, right hand axis) and pH anomaly (coloured symbols, left hand axis) at seven time series sites, including the Munida Time Series in New Zealand. Trends (pH change yr^{-1}) are given in the top right of each panel. (A) Iceland Sea, North Atlantic Ocean (purple); (B) Irminger Sea, North Atlantic Ocean (blue); (C) BATS, North Atlantic Ocean (cyan); (D) ESTOC, North Atlantic Ocean (green); (E) HOT, North Pacific Ocean (orange); (F) CARIACO, North Atlantic Ocean (red); and (G) MUNIDA, South Pacific (pink). Image directly sourced from Bates et al. (2014).

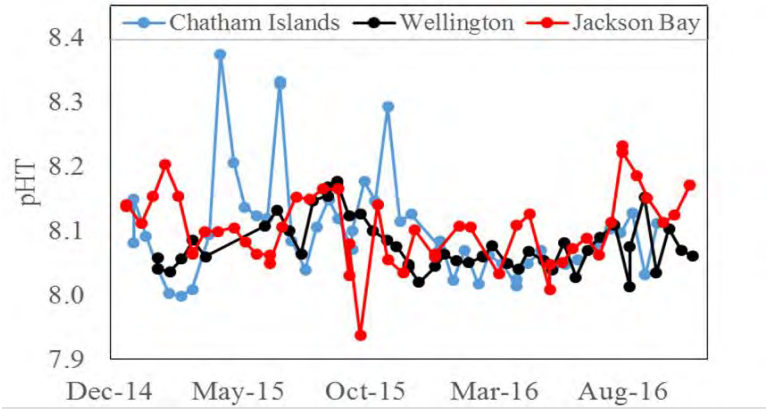


Figure 12.18: pH time series at three coastal stations: Chatham Islands (blue squares and line), Wellington (black circles and line), and Jackson Bay (red triangles and line) in the NZOA-ON (Law et al. 2018a).

Table 12.1: Qualitative assessment of a) the vulnerability, and b) the current state of knowledge of different aspects of ocean acidification research for the major biotic groups in New Zealand waters (Law et al. 2018a). Vulnerability is classified on a Low to High scale, with "?" indicating where vulnerability is currently unknown. Current knowledge is also classified on a Low to High scale and based upon the number and results of published studies (see key), with '-' indicating that no studies have been carried out. Ongoing New Zealand studies are indicated by '+', with those in the CARIM project indicated by '*' (from Law et al. 2018a).

	Heterotrophs	Primary Producers		Primary and Secondary Consumers						Tertiary Consumers	Higher Trophic
	Bacteria	Phytoplankton	Macroalgae	Bryozoa	Sponges	Cold Water Corals	Crustacea	Molluscs	Echinoderms	Fish	Cetaceans, pinnepids, seabirds
a) Vulnerability to OA in NZ waters	**Low**	**Low-Med**	**Low-Med**	**?**	**?**	**Medium**	**?**	**Med-High**	**Med-High**	**?**	**?**
b) Current knowledge in NZ waters											
Established Response to OA	Medium*+	Medium*	Med-High	-	Low	Low-Med	-	Medium*	Medium+	Low-Med*	-
Mechanistic understanding of response	Low-Med	Low-Med	Medium	-	Low	Low	-	Low-Med*	Low-Med+	Low	-
Indirect/Ecosystem interaction	Medium*+	Low-Med*	Medium*	Low	Low	Low	-	Low	Low-Med	-	-
Interaction with other stressors	Low-Med*+	Med-High*	Medium	Low	Low	Low	-	Medium	Medium+	-	-
Socio-economic/Ecosystem services	Low	Low-Med	Low-Med	Low	-	Low	-	Medium	Low-Med		-
Adaptive capacity	-	-	-	-	-	-	-	-	Low	-	-

Low single study low confidence | Low-Med 1-2 studies low-medium confidence | Medium 2-3 studies medium confidence | Med-High 4+ studies medium-high confidence

Projections for a range of climate-related variables in the surface ocean were generated by the *Climate Change: Impacts & Implications* project and published by Law et al. (2018b). The projections reflect the outputs of two Earth System Models (ESMs) identified as the 'best' models for simulating current conditions in the surface ocean around New Zealand from analysis by Rickard et al. (2016). Law et al. (2018b) provides the projected mean change for the middle and end of the 21st Century, for the RCP4.5 and 8.5 scenarios (as summarised in Table 12.2) and considers the spatial variation of change in waters around New Zealand. Results from this study include the following.

- Despite being the best models for New Zealand waters, the two ESMs provide different spatial distributions and magnitudes of change in most parameters (Figure 12.19).
- Projected Sea Surface Temperature increases of +1.6 to +2.95 °C by 2100 are comparable with the means projected for both Australian and global waters (Figure 12.19).
- Highest projected regional warming occurs in the East Australian Current and in subantarctic waters south of Chatham Rise. Because the present warming rate in the south-west Tasman Sea is similar to that projected for waters around New Zealand, this region may provide an analogue for future changes in New Zealand waters.

Table 12.2: Summary table of present-day and projected mean values (Δ = absolute change; % Δ = % change) for the middle and end of the 21st Century for all variables under RCP4.5 and 8.5 for the south west pacific region using the inner Earth System Models (R16) (from Law et al. 2018b).

		Present Day Mean	RCP4.5 Mid-Century			RCP4.5 End-Century			RCP8.5 Mid-Century			RCP8.5 End-Century		
Property	Unit		Mean	Δ	% Δ	Mean	Δ	% Δ	Mean	Δ	% Δ	Mean	Δ	% Δ
SST	°C	15.84	16.6	0.8	4.7	16.9	1.1	6.9	16.8	1	6.6	18.3	2.5	15.8
MLD	m	91	86.5	−4.5	−4.9	85.0	−6	−6.6	83.2	−7.8	−8.6	77.0	−14	−15.4
Nitrate	mmol m^{-3}	5.31	5.1	−0.2	−3	5.0	−0.28	−5.3	5.1	−0.2	−3.4	4.9	−0.4	−7.5
Phosphate	mmol m^{-3}	0.5	0.49	−0.01	−2	0.47	−0.03	−5.0	0.48	−0.02	−4.0	0.45	−0.05	−9.0
Silicate	mmol m^{-3}	3.2	3.1	−0.05	−1.5	2.7	−0.5	−15.6	3.0	−0.2	−6.3	2.55	−0.65	−20.3
Fe	mmol m^{-3}	0.13	0.16	0.03	19.2	0.17	0.05	34.62	0.14	0.01	7.7	0.16	0.04	26.9
pH		8.11	7.98	−0.12		7.95	−0.16		7.93	−0.18		7.77	−0.33	
[H+]	µmol kg^{-1}	0.008	0.010	0.003	32.1	0.011	0.003	42.2	0.012	0.004	48.3	0.017	0.009	116.3
Chl-a	mg m^{-3}	0.2	0.19	−0.005	−2.5	0.19	−0.01	−5.0	0.19	−0.01	−5.0	0.185	−0.015	−7.5
NPP	mmol $m^{-2}d^{-1}$	33.52	33.2	−0.35	−1.0	33.1	−0.4	−1.2	33.0	−0.5	−1.5	32.0	−1.5	−4.5
Exp	mg $m^{-2}d^{-1}$	50.2	49	−1.2	−1.3	47.3	−2.8	−4.5	47.5	−2.7	−4.4	43.1	−7.1	−12

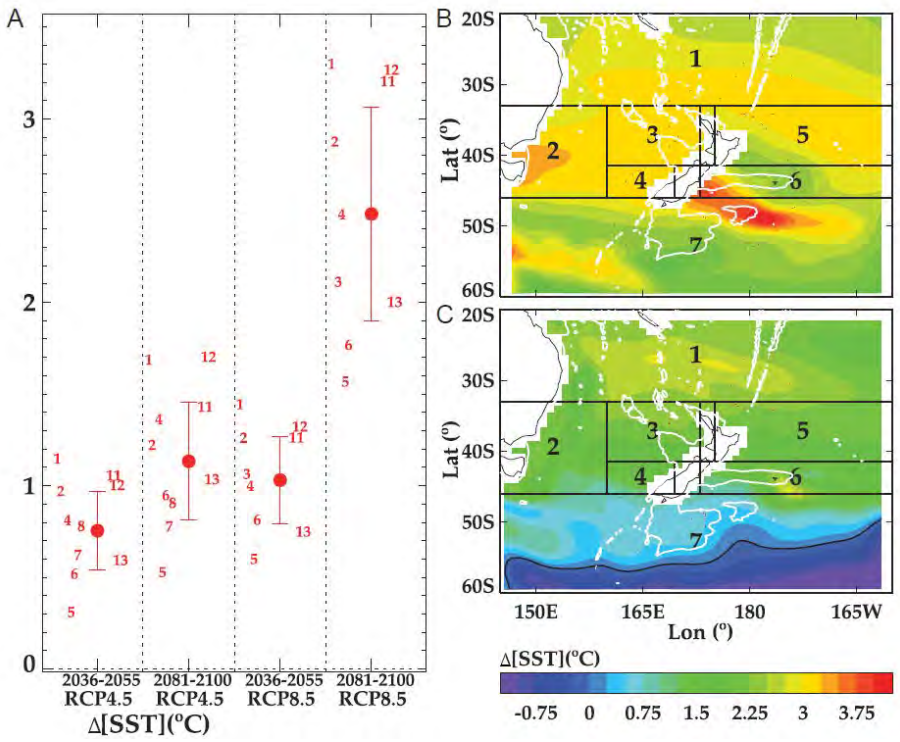


Figure 12.19: Projections of mean change in sea surface temperature (ΔSST, °C, ±1 standard deviation) for Mid and End-Century under RCP4.5 and 8.5 (delineated by vertical dashed lines) from the best ESM subset. The numbers indicate the mean for each individual ESM. The regional variation of ΔSST for the End-Century under RCP8.5 is shown for B, ESM2 and C, ESM5. The regional boxes are indicated by number, the white contours the 1000 m isobath, and the black contours indicate zero change (from Law et al. 2018b).

- The depth of the surface mixed layer will decrease across much of the New Zealand area, except for some subantarctic water regions. The resulting increase in light exposure for plankton may be beneficial to productivity and food webs in subantarctic waters where nutrients are plentiful but may be deleterious in warmer subtropical waters that are oligotrophic (i.e., low nutrient).
- Surface macronutrients (nitrate, phosphate, and silicate) will decline across the New Zealand region, although silicate may increase in subantarctic and polar waters south of New Zealand. The projected declines in nitrate and phosphate are greatest east of Chatham Rise and in subantarctic waters south of the rise. Conversely, dissolved concentrations of the micronutrient iron will increase in surface waters across much of the region.
- Surface chlorophyll-a (the pigment that provides an indicator of phytoplankton biomass) shows only minor changes across much of the region except for a band of frontal waters south-west and south-east of the South Island which shows the largest decline. The regional variations in primary productivity (see Figure 12.20) are greater, with decreases limited to warmer oligotrophic waters, and most of the region south of 40° S showing an increase in primary production.
- Projected decreases in vertical particle flux exports are 4.5% and 12% under RCP4.5 and 8.5, respectively, for the New Zealand region by 2100, which is within the range of projections for decreases in global export production under RCP8.5 of 7–18% (Bopp et al. 2013). One of the two models indicates that the decline will be greatest on Chatham Rise, suggesting a significant reduction in food supply for food webs and fisheries, whereas the second model suggests a potential increase in flux in this region.

The most vulnerable regions were identified where regional extremes occurred in three or more climate variables (see Figure 12.21). Both ESMs identified Chatham Rise as the most significant vulnerable area, with a number of parameters increasing or decreasing in this region. Polar waters south of New Zealand and subtropical waters north of 30° S were also identified as vulnerable.

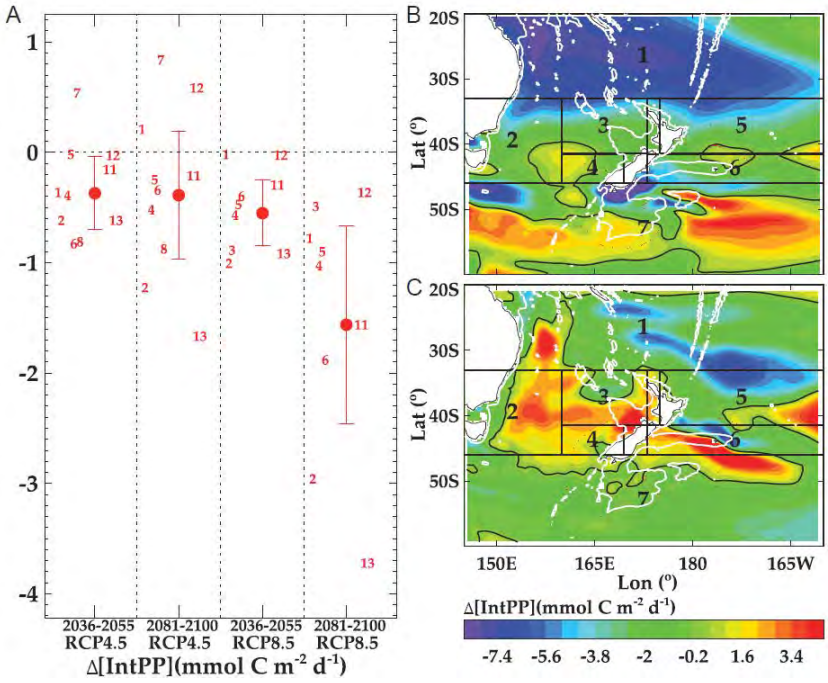


Figure 12.20: Projections of mean change in mean integrated primary production (ΔNPP, ±1 standard deviation) for Mid and End-Century under RCP4.5 and 8.5 (delineated by vertical dashed lines) from the best ESMs. Negative values indicate a decrease in rate and the horizontal dashed line indicates zero change. The numbers indicate the means for each ESM. Regional variation of the projected change in NPP for the End-Century under RCP8.5, using B, ESM2 and C, ESM5. The regional boxes are indicated by number, the white contour is the 1000 m isobath, and the black contours indicate zero change (from Law et al. 2018b).

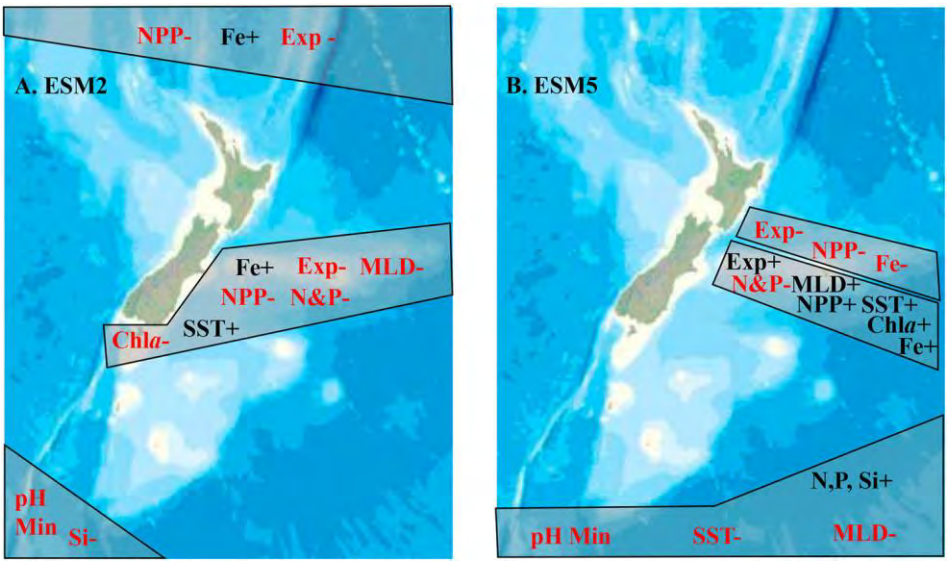


Figure 12.21: Regional extremes for climate-sensitive variables in the surface ocean around New Zealand projected for 2080–2100 using A) ESM2 and B) ESM5. The shaded areas represent potentially vulnerable regions, where two or more variables show significant change relative to the New Zealand mean. The change response is indicated by colour and sign, with a significant decrease indicated in red with a – symbol, and a significant increase in black with a + symbol. Key: SST: Sea Surface Temperature; MLD: Mixed Layer Depth; N&P: Nitrate and Phosphate; Si: Silicate; Fe: Dissolved Iron; Chl*a*: Chlorophyll-a; NPP: Integrated Primary Production; Exp: Particle flux; pH Min: lowest regional pH (from Law et al. 2018b).

12.3 OCEAN CLIMATE TRENDS AND NEW ZEALAND FISHERIES

Climate change could significantly affect New Zealand fisheries productivity, and both ocean warming and acidification may directly affect aquaculture, with indirect affects through changes in phytoplankton production also possible (Pinkerton 2017). Fishery and aquaculture industries are considering adaptation strategies, such as changing harvests and relocating farms (Pinkerton 2017). There is currently little information on how fish species and stocks around New Zealand will respond to climate change and ocean acidification. It has been postulated that distribution of habitat forming deep-sea corals may indirectly affect the future distribution of deep-sea fish that utilise these habitats (Law et al. 2018a). Cummings et al. (2021) summarised New Zealand-specific information on how changes in some of the climate variables might affect fisheries and aquaculture and noted a widespread lack of relevant data.

There have been recent quantitative projections for New Zealand fish species. Dunn et al. (2009) investigated variations in abundance and commercial catch rates of 56 New Zealand fish in relation to 20 climate indices over periods of 5–30 years; they found no consistent changes in abundance or catchability of "warmer-water" or "colder-water" species over this period. They did however find evidence of statistically-significant relationships between climate variables (e.g. SST, sea surface height, Southern Oscillation Index, and Kidson regimes (Kidson 2000)) and the productivity (i.e., biomass indices or year class strengths) of six species of New Zealand fish: macrourids *Coelorinchus aspercephalus*, *Coelorinchus bollonsi*, *Coelorinchus fasciatus*, and *Coelorhynchus oliverianus*; chimaeras *Hydrolagus novaezealandiae* and *Hydrolagus bemisi*; and ling *Genypterus blacodes*. Hurst et al. (2012) reported some general observations on recent trends in some of the key ocean climate indices that have been found to be correlated with a variety of biological processes among fish (including recruitment fluctuations, growth, distribution, productivity, and catch rates).

Recent studies have been undertaken to unravel fishing, climate change, and ocean acidification impacts (Cornwall & Eddy 2015, Christian & Holmes 2016, Morrongiello et al. 2021, Parsons et al. 2020, Neubauer et al. in prep., Dunn et al. in prep.).

A study of temperate New Zealand coastal ecosystems for the Wellington south coast suggested fishing may have a larger effect on trophic group biomasses and trophic structure than ocean acidification; the effects of ocean acidification were only large in the absence of fishing. The model results also suggested that ocean acidification may indirectly benefit certain species due to a reduction in predation (Cornwall & Eddy 2015). Under climate change scenarios, Christian & Holmes (2016) predicted that the available habitat for albacore tuna (*Thunnus alalunga*) in New Zealand waters would become much more extensive and would shift about two degrees latitude further south. A southern shift of oceanic tuna around New Zealand was also predicted by Cummings et al. (2021).

Recent tank experiments assessing the impact of elevated pCO_2 on yellowtail kingfish (*Seriola lalandi*) larvae demonstrated no effect on activity, growth, or survival but did result in reduced swimming speed and distance moved in response to startle stimuli and reduced resting metabolism at elevated pCO_2 (Laubenstein et al. 2018, Watson et al. 2018). Development of digestive organs in larval kingfish was not exacerbated by near-future ocean acidification and warming (Frommell et al. 2019). Similar experiments conducted on snapper (*Chrysophrys auratus*) suggested a range of both positive and negative effects of elevated pCO_2 on survival, distance moved from startle stimuli, aerobic scope, critical swimming speed, and hearing ability (Parsons et al. 2020). For juvenile snapper, elevated CO_2 had a greater effect on metabolic rates and swimming performance than heatwave conditions, which could reduce their overall performance and potentially have negative consequences for population recruitment (McMahon et al. 2020). A modelling assessment attempting to estimate the combined effect of elevated pCO_2 and temperature on New Zealand snapper populations was unable to determine if this effect would be positive or negative, with sensitivities suggesting both increases and decreases in fisheries yield (Parsons et al. 2020).

Morrongiello et al. (2021) showed from long-term growth chronologies of four commercially important fishes from New Zealand's coastal and shelf waters — demersal inshore species snapper and tarakihi (*Nemadactylus macropterus*) and deeper water species hoki (*Macruronus novaezelandiae*) and ling — that fishing and environmental factors can conflate to initially promote individual fish growth but then possibly heighten the

sensitivity of stocks to environmental change. Regional-scale wind and temperature affected growth of tarakihi and snapper, whereas deepwater hoki and ling growth was sensitive to the Interdecadal Pacific Oscillation (IPO).

Black et al. (2021) showed that resilience of species to stressors and mortality decreases sharply with increasing depth and that temperature alone explains up to 30% of variation in growth for populations of deep-sea fishes including for several commercial species located in the Australasian region; e.g., orange roughy (*Hoplostethus atlanticus*), alfonsino (*Beryx splendens*), hoki, and various deep-sea oreo species (Zeiformes). The meta-analysis emphasised the need to accurately model growth rates of deeper-living fish to evaluate their resiliency to escalating anthropogenic disturbance.

Brooks (2020) used ecological niche modelling (Maxent) to predict current and future hoki distribution around New Zealand. The models were trained on catch data from the Fisheries New Zealand research trawl database and remote-sensed environmental data. Under less severe climate change scenarios, by 2100 hoki habitat was predicted to be lost from the southern Sub-Antarctic. Under more severe climate change scenarios, hoki habitat was predicted to contract to the south Chatham Rise and Subtropical Convergence Zone around southern New Zealand and be lost from off the west coast South Island. The main predictors of these changes were sea surface temperature and salinity.

Dunn & Jones (2013) suggested that John dory (*Zeus faber*) may have extended their distribution further south off the west coast of the South Island from around 2000 as a result of ocean warming. Langley (2020) estimated a larger increase in abundance of the warm-water snapper off the north and west coasts of the South Island at around the same time. Brooks (2020) also identified the west coast South Island as a focal area for potential species range shifts and that predicting change around the North Island was less certain because novel conditions would occur there in the future.

General observations on recent trends in some of the key ocean climate indices that have been found to be correlated with a variety of biological processes among fish (including recruitment fluctuations, growth, distribution, productivity and catch rates) include the following.

- The Interdecadal Pacific Oscillation (IPO): available from 1871; time scale 15–30 years. The IPO has been found to have been correlated with decadal changes ('regime shifts') in north-east Pacific ecosystems (e.g., Alaska salmon catches). In the New Zealand region, there is evidence of a regime shift into the negative phase of the IPO in about 1998. During the positive phase, from the late 1970s to 1998, New Zealand experienced periods of enhanced westerlies, with associated cooler air and sea temperatures and enhanced upwelling on western coasts. Opposite patterns are expected under a negative phase. For most New Zealand fisheries, monitoring of changes in populations began in the late 1970s, so there is little information on how New Zealand fish stocks might respond to these longer-term climatic fluctuations. Some of the recent changes in fish populations since the mid-1990s, for example, low western stock hoki recruitment indices (Francis 2009) and increases in some elasmobranch abundance indices (Dunn et al. 2009) may be shorter-term fluctuations that could be related to regional warming and longer-term monitoring is necessary to establish whether they might be related to longer-term ecosystem changes. The Southern Oscillation Index: available from 1876; best represented as smoothed values over at least 3–5 months. Causal relationships of correlations of SOI with fisheries processes are poorly understood but probably related in some way to one or more of the underlying ocean climate processes such as winds or temperatures. When the index is strongly negative, an El Niño event is taking place and New Zealand tends to experience increased westerly and south-westerly winds, cooler sea surface temperatures, and enhanced upwelling in some areas. Upwelling has been found to be related to increased nutrient flux and phytoplankton growth in areas such as the west coast South Island, Pelorus Sound, and north-east coast of the North Island (Willis et al. 2007, Zeldis et al. 2008). El Niño events are likely to occur on 3–7-year time scales and are likely to be less frequent during the negative phase of the IPO which began in about 1998. This is likely to impact positively on species that show stronger

recruitment under increased temperature regimes (e.g., snapper; Francis 1993, 1994a, 1994b).

- Surface wind and pressure patterns: available from the 1940s. Variation in pressure patterns can be high over monthly and annual time scales and many of the indices are correlated with each other and with SOI and IPO indices (e.g., more zonal westerly winds, more frequent or regular cycles in southerlies in the positive IPO, 1977–2000). Correlations with biological processes in fish stocks may occur over short time scales (e.g., impact on fish catchability) as well as seasonal and annual scales (e.g., impact on recruitment success). Wind and pressure patterns have been found to be correlated with fish abundance indices for southern gemfish (*Rexea solandri*) (Renwick et al. 1998); hake, red cod (*Pseudophycis bachus*), and red gurnard (*Chelidonichthys kumu*) (Dunn et al. 2009); rock lobster (*Jasus edwardsii*) (Booth et al. 2000), and southern blue whiting (*Micromesistius australis*) (Willis et al. 2007, Hanchet & Renwick 1999). The mechanisms implied by the correlations are at best poorly understood; however, they motivate hypothesis testing into the relationship between wind and pressure patterns and fisheries.
- Temperature and sea surface height: available at least monthly over either long time scales (air temperatures from 1906) or relatively short time scales (ocean temperatures to 800 m since 1986 along two transects and more generally to 2000 m since 2006, satellite SST since 1981, SSH since 1993, and ocean temperatures to 2000 m since 2006). Ocean temperatures, SST, and SSH are all correlated with each other and smoothed air temperatures correlate well with SST in terms of inter-annual and seasonal variability; there are also some correlations of SST and SSH with surface wind and pressure patterns (Dunn et al. 2009). Sea surface temperature has been found to be correlated with relative fish abundance indices (derived from fisheries and/or trawl surveys) for elephantfish (*Callorhynchus milii*), southern gemfish, hoki, red cod, red gurnard, school shark (*Galeorhinus galeus*), snapper, stargazer (*Kathetostoma giganteum*), and tarakihi (Francis 1994a, 1994b, Renwick et al. 1998, Beentjes & Renwick 2001, Gilbert & Taylor 2001, Dunn et al. 2009). Air temperatures in New Zealand have increased since 1900 with most of the increase occurring since the mid-1940s. Increases from the late 1970s to 2000 may have been moderated by the positive phase of the IPO. Coastal SST records from 1954 at Portobello show a slight increase through the series. Satellite SST products indicate variable warming of 0–0.2 °C/decade since 1981 across almost the entire New Zealand region, with statistically insignificant changes in the Southern Ocean. Other time series (SSH, ocean temperature to 800 m) are comparatively short but show cycles of warmer and cooler periods on 1–6-year time scales. All air and ocean temperature series show the significant warming event during the late 1990s which has been followed by a relatively stable period. There have been two recent strong marine heatwaves.
- Ocean colour and upwelling: these are important time series because they potentially have a more direct link to biological processes in the ocean and are more easily incorporated into hypothesis testing. The ocean colour series starts in late 1997, so is not available for use to study changes that occurred before the late 1990s warming event. These indices also need to be analysed with respect to SST, SSH, and wind patterns at similar locations or on similar spatial scales. Preliminary series developed exhibit some important spatial differences and trends that may warrant further investigation in relation to fish abundance indices. Of note are increased chlorophyll indices off the west and south-west coasts of the South Island in spring/summer during the last 5–6 years and relatively low upwelling indices off the west coast South Island during winter in the late-1990s (Hurst et al. 2012). Chiswell & O'Callaghan (2021) found that there has been no significant decrease in the occurrence of upwelling events on the West Coast, South Island, but they did find that there has been general warming and that both warm and cold events have also showed warming.
- Currents: there are no general indices of trends or variability at present. Improvements in monitoring technology (e.g., satellite

observations of SSH; conductivity, temperature, and depth; acoustic Doppler current profile; Argo floats) have resulted in more information becoming available to study currents directly and enable the development of numerical models. Recent analyses of the currents along the eastern New Zealand margin (Fernandez et al. 2018) indicate that the currents are highly variable and that there is little coherence between water transports along the boundary. Furthermore, there are no discernible trends in the transports since the SSH measurements began in 1993. On the open ocean scale, there is considerable complexity in the New Zealand zone (e.g., frontal systems, eddy systems off the east coast). The coastal zone is further complicated by the effects of tides, winds, and freshwater (river) forcing. Nevertheless, the importance of current systems is starting to become more recognised and has been incorporated into analysis and modelling of fisheries processes and trends. Recent examples include the retention of rock lobster phyllosoma (mid-stage larvae) in eddy systems (Chiswell & Booth 2005, 2007), the apparent bounding of orange roughy nursery grounds by the presence of a cold-water front (Dunn et al. 2009), and the drift of toothfish eggs and larvae (Hanchet et al. 2008).

- Acidification: Recent model projections indicate a decrease in mean pH by about 0.33 to 7.77 by 2100. A 20-year New Zealand time series shows acidification of Sub Antarctic Water consistent with the increase in atmospheric CO_2. This timeseries is now complemented by a network of coastal stations that also highlight regional variation in pH. Some coastal waters, such as the Firth of Thames, already experience a seasonal decline in pH to 7.9, confirming that New Zealand coastal waters already experience greater acidification than open ocean waters (Law et al. 2018a). A review of the impacts of ocean acidification on New Zealand species and ecosystems (Law et al. 2018a) identifies that organisms with carbonate shells and skeletons are potentially most sensitive to a decrease in pH and that early life-history stages (eggs/larvae) may be particularly susceptible.
- Climate change was not specifically addressed as part of the report by Hurst et al. (2012), although the indices described are integral parts of monitoring the progress and impacts of climate change. As noted in the air temperature section, the slightly increasing trend in temperatures since the mid-1940s is likely to have been moderated by the positive phase of the IPO from the late 1970s to the late 1990s. With the shift to a negative phase of the IPO in 1998, it is likely that temperatures will increase more steeply. Continued monitoring of the ocean environment and response is critical. This includes not only the impacts on productivity, at all levels, but also increasing ocean acidification.

In conclusion, key ocean climate drivers in the New Zealand region for the last few decades have been:

- the significant warming event in the late 1990s;
- the shift to the negative phase of the IPO in about 1998, which is likely to result in fewer El Niño events for a 20–30-year period, i.e., fewer zonal westerly winds (already apparent compared with the 1980–2000 period) and increased temperatures — this is the first IPO change to occur since the start of most of our fisheries monitoring time series (the previous shift was in the late 1970s);
- global trends of increasing air and sea temperatures and ocean acidification; and
- recent strong marine heatwaves in summer 2017–18 and 2018–19.

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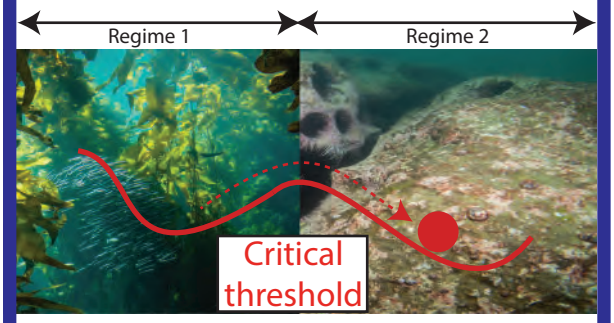
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Chapter 13: Trophic and ecosystem-level effects - Technical Summary



Baseline and regime shifts

1. THE ISSUE IN BRIEF

- Marine ecosystems are dynamic, and fluctuate naturally between different states
- Among other causes (e.g. climate change), fishing can create an imbalance by selectively removing species, which are prey and predators of other species in the food-web
- Ecosystems tend to correct any imbalance, but sometimes alterations to the food web functioning are long-lasting
- Understanding, evaluating, or predicting these changes (as well as separating natural and anthropogenic causes) is challenging, but progress has been made

2. DIFFERENT LEVELS OF EFFECTS

- Trophic and ecosystem-level effects can be ranked based on their magnitude and spatial scale
- At the local scale, effects of activities such as offal discard by fishing vessels can promote scavenging by seabirds, which can have a direct effect on the feeding behaviour of some species
- First order effects take place when the predator/prey balance is disrupted
- Second order effects influence many trophic levels, at larger scales, and are also known as trophic cascades
- Large-scale effects are called regime shifts, and can affect whole ecosystems, occasionally leading to a permanently altered ecological state

3. EXAMPLES OF FISHERIES-INDUCED CHANGES

Fishing pressure may alter fish populations

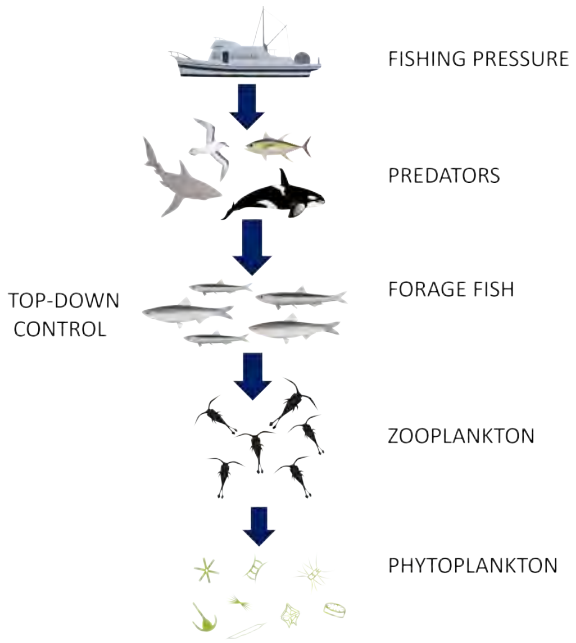
- demographic and genetic structure
- spatial distribution
- life-history traits (e.g. age at maturity)

as well as habitat structure and trophic structure of the food web, depending on fishing pressure and extent

Fishing typically affects food webs through:

- Top-down control (e.g. predator removal)
- Middle-out control (e.g. small demersal fish removal, thus altering nutrient transfer)

- Selective fishing pressures on key components of the food web are more likely to have significant effects
- Detection and scale of effects is a complex issue, and
- The use of multiple indicators can separate them from natural fluctuations



Schematic of fisheries-induced top-down effects on the ecosystem

13 TROPHIC AND ECOSYSTEM-LEVEL EFFECTS

Status of chapter	This chapter has been updated for AEBAR 2024.
Scope of chapter	This chapter outlines the global and New Zealand understanding of trophic and ecosystem-level effects of fishing, with respect to types of effects, their causes, the types of ecosystems most likely to be affected, the spatial scales of effects, and indicators of trophic and ecosystem-level effects.
Area	All areas and fisheries.
Focal localities	Whole EEZ.
Key issues	Organisms in an ecosystem are linked by trophic (feeding), habitat and other connections. Changes to one organism (by whatever means) can affect other organisms and sometimes large parts of the food web. Changes occurring across many trophic levels (ecosystem-level changes) can have implications for ecosystem resilience.
Emerging issues	• Developing an ecosystem approach to fisheries management that incorporates trophic and ecosystem-level effects into fisheries management decisions. • Understanding how fishing interacts with other stressors in marine ecosystems.
MPI research (latest)	Publications: • AEBR 324 "Fishery-induced trophic cascades and sea urchin barrens in New Zealand: A review and discussion for management" • AEBR 301 "Role of low and mid-trophic level fish in the Hauraki Gulf ecosystem" Research: • ZBD2023-03 "Summarising and updating knowledge on the distribution of kina barrens in key regions of New Zealand" • INV2023-10 "Ecosystem based management: a case study on the east coast of the South Island" • SEA2023-08 "Implications of incorporating ecosystem considerations into management targets and limits for fish stocks" • ZBD2023-05 "Importance of macroalgae to New Zealand fisheries and the effects of climate change"
NZ government research (current)	• NIWA SSIF (Strategic Science Investment Fund) – Coasts & Oceans centre: Multi-use Marine Ecosystems • Government, NIWA SSIF- Marine food webs: Marine food webs | NIWA
Related chapters	• Benthic (seabed) impacts (Chapter 11) • Climate and oceanographic context of New Zealand fisheries (Chapter 12). • Land-based effects on fisheries (Chapter 15). • Marine biodiversity (Chapter 18). • HPSFM (Chapter 14)

13.1 OVERVIEW

This chapter describes the trophic and ecosystem-level effects which may arise from fishing or in combination with other drivers of change on marine ecosystems in the New Zealand region. The region of interest for the purposes of this

chapter is the New Zealand marine exclusive economic zone (EEZ) and territorial waters, including coastal and offshore regions. The focus is on wild-caught fisheries rather than aquaculture.

Identifying the trophic and ecosystem-level effects of fishing and incorporating them into fisheries management decisions is essential to advance New Zealand's ecosystem approach to fisheries management. Summaries of the impact of fishing on trophic and ecosystem function for individual species can be found in the Environmental and Ecosystem considerations section of selected chapters of the annual Fisheries New Zealand assessment plenary (Fisheries New Zealand, 2024a). This chapter provides an overview of the potential types of trophic and ecosystem-level effects of fishing in the marine environment with descriptions of relevant examples from within New Zealand where available. While these descriptions are currently used in a qualitative manner to inform sustainability round reviews for fisheries species, Fisheries New Zealand is exploring ecosystem modelling approaches to better evaluate and incorporate the impact of different management approaches on the wider ecosystem, and to identify critical data gaps required to use these models (see Project Summary Table in the chapter introduction).

The need to consider these effects in fisheries management decisions is set out in New Zealand legislation, current New Zealand government strategic/operational policies, and international best practice. Relevant legislation, policies and best practices for managing the effects of fishing on the aquatic environment are summarized in Chapter 1 of the AEBAR (Sections 1.2 and 1.3). The requirement to incorporate trophic and ecosystem-level effects in fisheries management decisions is referenced in multiple documents including:

- The Fisheries Act 1996 *(https://www.legislation.govt.nz/act/public/1996/0088/latest/DLM394192.html)*
- MPI's Strategy 'Our Strategy': to grow the sustainable use of our natural resources *(http://www.mpi.govt.nz/about-mpi/our-strategy)*.[1]
- FAO Code of Conduct for Responsible Fisheries *(https://www.fao.org/3/v9878e/v9878e00.html)*
- Marine Stewardship Council (MSC 2010) Principle 2
- The Chief Science Advisor's report to the Prime Minister on The Future of Commercial Fishing in Aotearoa (2019) *(https://www.pmcsa.ac.nz/topics/fish/)*
- The Te Mana o Te Taiao (Aotearoa New Zealand Biodiversity Strategy 2020) *(https://www.doc.govt.nz/globalassets/documents/conservation/biodiversity/anzbs-2020.pdf)*
- The 2022 New Zealand High Court decision on the management of spiny lobster in CRA1 *(https://www.mpi.govt.nz/dmsdocument/55012-2022-High-Court-judgment-decision-for-Northland-rock-lobster)*
- The International Tribunal for the Law of the Sea (Advisory Opinion on Climate Change, 2024)

13.2 TROPHIC AND ECOSYSTEM EFFECTS

13.2.1 DEFINITION OF TROPHIC AND ECOSYSTEM-LEVEL EFFECTS

'Trophic effects' are changes to the structure and function of food webs occurring entirely or largely because of changes in the feeding of organisms within an ecosystem. 'Ecosystem-level effects' are defined as changes occurring across several trophic levels. An ecosystem is defined as a biological community of interacting organisms and their physical environment. Such effects can occur in coastal or deepwater ecosystems and can involve a wide range of biological, chemical, and physical processes. Because trophic and ecosystem-level effects occur over a range of different organisms and temporal and spatial scales, it is often difficult to be sure of the magnitude of the change or the underlying cause(s).

[1] Ministry for Primary Industries. Our Strategy. http://www.mpi.govt.nz/about-mpi/our-strategy.

This has led to much speculation and disagreement as to the mechanism or processes involved, and what management should have done to prevent ecosystem-level effects or should do to respond to the changes once they have occurred (Schiermeier 2004, Hilborn 2007, Murawski et al. 2007, Schiel 2013). Sometimes controlled experiments are conducted to see if trophic effects can be simulated, but low statistical power is a common problem (Schroeter et al. 1993). Internationally, trophic and ecosystem-level effects is an active area of research, and one in which there are generally more hypotheses than well-accepted empirical demonstrations of the effects. The following sections describe the types of trophic and ecosystem-level effects observed in the marine environment, the contributing factors and scales over which they occur, and references to relevant examples within New Zealand.

13.2.2 TYPES OF TROPHIC AND ECOSYSTEM-LEVEL EFFECTS

13.2.2.1 FIRST ORDER TROPHIC EFFECTS: PREY AVAILABILITY AND PREDATION RELEASE

Changes to the abundance, size structure and functional type[2] of a species can affect both its predators and prey through trophic interactions (Rosas-Luis et al. 2017). Increasing the abundance of a prey species may positively affect its predators (because they can expend less energy to find food) whereas reducing the abundance of a prey item may have a detrimental effect on the predators (by requiring them to hunt more intensively or by forcing a change in their diet); these are 'prey availability' or bottom-up effects (Lynam et al. 2017, Durante et al. 2022). Alternatively, changing the abundance of a predator may affect the abundance of some or all of its prey by changing their natural mortality rates (a top-down effect; Eger & Baum 2020). Decreasing the abundance of a predator (for example by fishing a predatory fish) may cause the abundance of some or all of its prey to increase (a 'predation release' effect; Casini et al. 2012). These effects act over one trophic link and are hence called 'first order' trophic effects.

For example, as part of the widespread pattern of collapses of cod (*Gadus morhua*) populations in the North Atlantic in the late 1980s and the 1990s, cod biomass off the US and Canada's East Coast dropped by a factor of five, from more than 150 000 metric tonnes (MT) to about 30 000 MT (Mayo et al. 1998, Steele et al. 1992). With some slight lag, local stocks of the cod's favoured prey, Atlantic herring (*Clupea harengus*), increased over the same period 20-fold, to nearly 2 million MT (NEFSC 1998). On the opposite side of the Atlantic, a collapse of the cod resource in the Baltic Sea was followed by an eight-fold increase in abundance of European sprat (*Sprattus sprattus*) – a major prey item for cod in that ecosystem (Köster et al. 2003b, Casini et al. 2008, 2009). In these cases, it is hypothesised that a reduction in the abundance of a piscine predator by fishing led to an increase in the prey species – a large-scale 'predation release'.

13.2.2.2 SECOND ORDER TROPHIC EFFECTS: TROPHIC CASCADES

Changes in the abundance of one species may go on to affect other species that are neither its predators nor its prey. This is a second-order trophic effect (occurring via an intermediate organism), often called a 'trophic cascade'. The awareness of trophic cascades arose originally from work in the marine intertidal zone, and lakes (Hrbácek et al. 1961, Shapiro et al. 1975, Paine 1980), but has since become the focus of considerable theoretical and empirical research in marine ecosystems, (Schiel 2013, Pershing et al. 2015, Schultz et al. 2016, Spyksma et al. 2017, Kerr & Grace 2017, Eger & Baum 2020, Williams et al. 2021, Wing et al. 2022a). While the term trophic cascade was originally termed for top-down effects of predators, it is now usually defined as the propagation of indirect effects between nonadjacent trophic levels in a food chain or food web, whatever the direction of forcing (Gruner 2013). Thus, trophic cascades may also occur when changes in the populations of primary producers force changes at higher tropic levels (Beaugrand & Reid 2003, Bakun 2010). Although initial research on trophic cascades focused on freshwater ecosystems, the potential for

[2] 'Functional type' refers to the collection of life history and ecological characteristics of an organism, including whether it is an herbivore, carnivore or omnivore, its feeding behaviour (including size of prey), location in the water column/benthos, and mobility.

fishing to cause trophic cascades in marine ecosystems is thought to be as strong or stronger than in freshwater ecosystems (ICES 2005, Borer et al. 2005). In New Zealand, a trophic cascade is thought to have occurred due to overfishing of the predators of the native sea urchin or kina (*Evechinus chloroticus*), which resulted in overgrazing and loss of kelp on shallow coastal reefs (Doheny et al. 2023, see Section 13.4.2 Case Study 2 for a full description). The evidence for this trophic cascade is based on observations from marine reserves in northeastern New Zealand, however the strength of this trophic effect and whether or not it is occurring in other parts of New Zealand remains uncertain.

A well-recognised international example of a top-down trophic cascade is between sea otters (*Enhydra lutris*), kelp grazing sea urchins, and kelp and seagrass (*Zostera marina*) in the north-east Pacific. The near extinction of sea otters due to hunting in the eighteenth and nineteenth centuries allowed urchin populations to increase, leading to overgrazing of kelp and seagrass beds (Estes & Palmisano 1974, Szpak et al. 2013, Gregr et al. 2020). Protection of sea otters and subsequent expansion or reintroduction of sea otter populations into their former range reversed this cascade (Estes & Palmisano 1974, Estes 1996, Estes & Duggins 1995). The cascading effects of sea otters on kelp extended to other coastal marine species including fish (Markel & Shurin 2015), gulls (Irons et al. 1986), bald eagles (Anthony et al. 2008) and Stellar's sea cows (Estes et al. 2016). However, the generality of the sea otter-urchin-kelp cascade has been questioned. For example, based on experimental treatments, Carter et al. (2007) and Raymond et al. (2021) found that the occurrence of this trophic cascade differs spatially due to environmental and biological variability. Kelp re-colonisation was much faster in southeast Alaska than the Aleutian Islands because sea urchins were smaller (and therefore ate less kelp) and had fewer recruitment events (population growth was slower) over the same timeframe (Estes & Duggins 1995). These observations suggest that trophic cascades are not always generalisable across spatial scales and local environmental and ecological conditions should be taken into account.

13.2.3 PERSISTANCE OF TROPHIC AND ECOSYSTEM-LEVEL EFFECTS

13.2.3.1 REGIME SHIFT

An ecosystem can change from one state to another when disturbances push it past a tipping point – this transition is called a regime-shift (Aebischer et al. 1990, Estes & Duggins 1995, Beaugrand et al. 2002, Daskalov et al. 2007, Wernberg et al. 2016, Vollset et al. 2022). Regime shifts can occur over large scales, affect many parts of the ecosystem and may be hard or slow to reverse ('hysteresis') (Figure 13.1). Ecosystem-level restructuring may also maintain the system in its new state by means of negative feedback loops (Bakun 2006, Casini et al. 2009, Möllmann et al. 2009, Lindegren et al. 2010).

Well-documented oceanographic-induced regime shifts in marine ecosystems have historically had substantial, long-lasting, and typically (but not always) negative effects on fish stocks. For example, the North Sea has historically been a hotspot for both overfishing and climate impacts (rapid warming and acidification) resulting in regime shifts. Between 1958 and 1999, the North Sea experienced two changes in hydro-climatic forcing that caused rapid, temperature-driven ecosystem shifts: a cold-biological shift (1962–1982) and a warm-biological shift (1984–1999) followed by a new dynamic warm regime after the late 1980s that favoured jellyfish in the plankton and echinoderms in the benthos (Kirby et al. 2008, 2009). Some stocks of Atlantic Cod (*Gadus morhua*), a top predator that was formerly widely distributed throughout the North Sea, experienced a collapse over the same timeframe. Atlantic Cod require cooler temperatures for successful spawning (< 10 °C), with early life stages dependent on copepods and adults feeding mainly on decapods/crustaceans (Kjesbu et al. 2023). The collapse of Atlantic cod stocks in the North Sea and central Baltic Sea is attributed to the negative effects of the regime shift on prey availability and cod reproduction (Voss & Quaas 2020) in combination with overfishing (Reid et al. 2003, Beaugrand 2004, Weijerman et al. 2005, Casini et al. 2008, Möllmann et al. 2008, Lindegren et al. 2010).

13.2.3.2 POTENTIAL FOR RECOVERY

Trophic and ecosystem-level effects of fishing may affect the ability of fish stocks to recover (rebuild) following over-exploitation. While species that mature early in life and are fished with size-selective equipment may recover more easily, many species experience little or no recovery up to 15 years following over-exploitation (Hutchings 2000). The failure of many species to recover is unexpected based on their reproductive capacity and habitat availability, and suggests that other factors are at play. Some researchers hypothesise that there are ecosystem-level impacts of over-exploitation, such as changes to community structure or habitats that inhibit fisheries from rebuilding despite management action (Steele & Schumacher 2000).

One hypothesis for how trophic effects can prevent stock recovery is the 'cultivation/depensation' mechanism (Köster & Möllmann 2000, Walters & Kitchell 2001). In this hypothesis, consider a species X whose adults consume a species Y, but whose recruits are predated by species Y. If adults of X are abundant, they can create favourable conditions for their own offspring by reducing the abundance of Y and hence reducing mortality of their pre-recruits. If the abundance of adults of X is reduced by fishing, expansion of Y may prevent re-establishment of the former species by increasing predation on the recruits of X (Folke et al. 2004). A real-world example is described in Casini et al. (2008), based on a 33-year time series in the Baltic Sea, that showed that the reduction of the cod population by fishing led to increases in abundance of sprat. Sprat, besides being preyed upon by cod, prey heavily on cod eggs and early larvae (Casini et al. 2004). Some authors have concluded that this predation, together with the likelihood that zooplanktivorous cod larvae may suffer food competition with the high sprat population, was hypothesized to be a significant factor slowing the recovery of the cod population (Jarre-Teichmann et al. 2002, Köster et al. 2003a, 2003b, Casini et al. 2009).

The prevalence of trophic or ecosystem-level effects slowing or stopping recovery after fisheries collapses has been disputed. For example, part of the same cod stock discussed above (eastern Baltic cod) showed rapid recovery after more than 20 years of low biomass and productivity. Based on increases in biomass, Cardinale & Svedäng (2008) concluded that the recovery was driven by a sudden reduction in fishing mortality rather than climate or ecosystem effects, and that single species regulation remained a suitable approach in handling natural resources. However, following the reported recovery, substantial increases in fishing quotas for cod from 2009–2014 paired with declining biological parameters resulted in a collapse of the stock to unprecedented levels (Eero et al. 2023). This case study suggests that environmental ecological conditions in the 1970's–1990's benefitted the Baltic Cod stock more than could be explained by recruitment alone and emphasizes that careful consideration of long time series that combine several indicators will provide a more comprehensive understanding of stock status and allow for more realistic target setting.

There is growing consensus among fisheries managers globally that recovery and effective management of fisheries requires a combination of traditional measures (quota allocation, catch settings) alongside strategic fishing closures, selective fishing gear and economic incentives (Worm et al. 2009). Linking these approaches depends on collaboration between fisheries managers, scientists and conservation biologists to use the best available data to manage for sustainable harvesting within ecosystem and environmental limits. In New Zealand, the Crown also must provide protection for and scope for exercise of rangatiratanga (sovereignty) in respect of traditional fisheries, as customary fishing rights are guaranteed to tangata whenua under Te Tiriti o Waitangi and protected by the Treaty of Waitangi (Fisheries Claims) Settlement Act 1992 and the 1992 Deed of Settlement. This requires the development of equitable partnerships that include collaborative and participatory management of tangata whenua (Department of Conservation 2022, Joseph et al. 2019, Hera Maxwell 2019).

13.3 CAUSES OF TROPHIC AND ECOSYSTEM-LEVEL EFFECTS

Trophic and ecosystem-level effects in marine systems can be caused by a variety of factors, often acting simultaneously. These factors are often called stressors. Stress in this context refers to physical, chemical and biological constraints on the productivity of species, their interdependencies, and on the structure and function of the ecosystem. Stressors can

act over various spatial scales (from local to ocean basin-scale) and various time scales (from days to decadal). Stressors can be natural environmental factors, or they may result from the activities of humans. Key sectoral human impacts on marine ecosystems in New Zealand include fishing and land-use impacts associated with coastal development, farming and forestry. The cumulative effects of cross-sector impacts and climate change to coastal ecosystems are recognised in parts of New Zealand such as the Marlborough Sounds (Urlich & Handley 2020). This chapter will mainly focus on the trophic effects of the fishing sector, but further information on the impacts of land-use on our fisheries is discussed further in AEBAR Chapter 15 Land-based effects on the coastal environment. Further discussion of Trophic and ecosystem-level effects can occur because of fishing, because of environmental factors entirely disconnected to fishing (especially related to climate variability/change) or by a combination of fishing and environmental variability/change acting together (Mackinson et al. 2009, Frank et al. 2007, Schiermeier 2004, Schiel 2013). Trophic and system-level effects can also result from outbreaks of disease (Behrens & Lafferty 2004, Harvell & Lamb 2020), from the arrival of non-indigenous invasive species (Mead et al. 2013, Kotta et al. 2018) and from eutrophication in estuarine ecosystems (Daskalov et al. 2007, Oguz & Gilbert 2007, Osterblom et al. 2007, Möllmann et al. 2008). Some of these causes of trophic and ecosystem-level effects are discussed further below.

13.3.1 ENVIRONMENTAL AND CROSS SECTOR-DRIVEN CHANGE

Marine ecosystems are impacted by environmental factors such as climate (Fasham et al. 2001, Schiermeier 2004, Frank et al. 2007, Mackinson et al. 2009), sedimentation (Morrison et al. 2009), invasive species (ICES 2005, D'Amen & Azzurro, 2020) and pollution. Climate forcing occurs over various timeframes, from seasonal periods, to 1–3 year oscillating but erratic periods (including marine heatwaves), to decadal aperiodic variability at 5–50 years, to centennial and longer periods, and can include sudden, large-scale shifts in environmental forcing (Overland et al. 2010). Internationally and domestically, there is increasing concern about the current and potential future impacts of climate change on fisheries (IPCC 2007a, 2007b, Valdes et al. 2009, Rice & Garcia 2011, Barange et al. 2018, Cheung & Frölicher 2020). In addition to long-term warming, climate change impacts include marine heatwaves (Cheung & Frölicher 2020), increased ocean acidification (Law et al. 2018), increased climate variability (Collins 2000), deoxygenation (Kim et al. 2023) which can affect primary production (Pinkerton et al., 2024a). Sedimentation is an important land-based environmental effect on New Zealand's fisheries, impacting both the species themselves and smothering important nursery and feeding habitats (Morrison et al. 2009). Changes to nutrient loading to the coastal zone from land run-off are also important for water quality and coastal ecosystems (Fraser et al., 2021). Excess nutrient loads can lead to increased algal blooms, reduced oxygen levels, and potentially eutrophication, which can impact marine ecosystems (Plew et al. 2020, Snelder et al. 2020). Environmental change can also make it easier for invasive species to affect New Zealand ecosystems (Hayden et al. 2009, Champion, 2018).

There are many examples internationally of trophic and ecosystem-level effects occurring from environmental change affecting marine food webs (Mackinson et al. 2009, Frank et al. 2007, Schiermeier 2004). In the eastern Pacific abrupt declines in local primary and secondary production can be caused by El Niño/Southern Oscillation (ENSO) events (Barber & Chavez 1983, Pearcy et al. 1985, Arcos et al. 2001, Hollowed et al. 2001, Arnés-Urgellés et al. 2021). During these ENSO events, the production of small pelagic fishes can be drastically reduced due to the reduction in upwelling of nutrient and plankton-rich water, on which pelagic fishes feed. (Barber & Chavez 1983, Rothschild 1994, McIlvaine 2020), As a result, predatory fish, seabirds, and pinnipeds, which are dependent on these small pelagic fish have been shown to shift their distributions, suffer reduced productivity, and have increased rates of mortality (Farchadi et al. 2019, Lehodey et al. 2020, Arnés-Urgellés et al. 2021). Historically ENSO events were periodic and ecosystem consequences were short or medium-term. However, climate change appears to contribute to more frequent, extreme and long-lasting El Nino events (Gan et al. 2023), with potentially adverse effects on ecosystem resilience.

Marine heatwaves can also effect marine food webs. For example, marine heatwave events in California between 2014 and 2016 caused sea surface temperatures (SST) to increase by approximately 2.5–7° Celsius above average (Gentemann et al. 2017, Rogers-Bennett & Catton, 2019). The extreme and extended rise in water temperature suppressed spore

production and growth of bull kelp *(Nereocystis luetkeana)*, decreasing canopy cover by approximately 90% across 350 km of coastline. Red abalone *(Haliotis rufescens)*, which feed predominantly on bull kelp, were found to be starving and suffered a 43–96% decline by 2018 (Rogers-Bennett & Catton, 2019), prompting an emergency closure of the fishery.

Specific examples of environmental-driven change resulting in trophic or ecosystem-level impacts on fisheries in New Zealand are described in Section 13.4.1 (Bottom-up forcing). An overview of climate impacts on New Zealand's fisheries are described further in AEBAR Chapter 12 and the impacts of sedimentation and other land-based effects on fisheries are discussed in AEBAR Chapter 15.

13.3.2 FISHERIES-DRIVEN CHANGE

Fishing can modify marine food webs through extraction, gear use and fisher behaviour, and may result in ecosystem level impacts. As well as reducing the overall abundance of fish, fishing usually reduces the average size of fish in harvested communities and can change the mix of species in a fish community (Dayton et al. 1995; Durante et al. 2021; Durante et al. 2022). Fishing can also have effects beyond changes to the abundance and population structure of target and bycatch species, including (a) the introduction of discarded bycatch/offal/bait into the ecosystem (Montevecchi, 2023), (b) the alteration of fish behaviour and genetic composition (Palkovacs et al. 2018; Hočevar & Kuparinen, 2021) and (c) the modification of the benthos by fishing gear (Kaiser, 2019; Hiddink et al. 2019).

Overfishing of upper trophic level species often leads to a release in predation pressure on mesopredator [3] prey species and in turn, affects lower-level species which mesopredators consume (Myers et al. 2007, Eklöf et al. 2020). Marine ecosystems can be resilient to large trophic changes, but there are limits to this resilience. Ecosystem-level changes (regime shifts) have been observed in very highly impacted (highly overfished/collapsed) systems, mainly due to trophic effects (Estes & Duggins 1995, Bakun & Weeks 2006, Daskalov et al. 2007). For example, in the Black Sea, overfishing of pelagic predatory fish, combined with the introduction of an invasive species (the comb jelly, *Mnemiopsis leidyi*) resulted in a large-scale sustained impacts on the ecosystem including reduced productivity (Daskalov et al. 2007).

Food subsidies, such as offal and discards from fishing vessels can become important sources of food for some marine species (Heath et al. 2014), influencing population dynamics, community composition and interactions, affecting and influencing ecosystem structure (Fondo et al. 2015). In New Zealand, fishery discards are thought to support the diet of seabirds such as the southern Buller's Albatross during breeding on The Snares (James & Stahl 2000) and can influence foraging patterns of Westland Petrels (Waugh et al. 2018). Discards and offal from fisheries are sometimes an important part of the diets of deepwater fish. For example, scavenged fishes accounted for up to a quarter of the diet of smooth skate (*Raja innominata*) in the Chatham Rise region (Dunn et al. 2009, Forman & Dunn 2012). Anderson & Smith (2005) estimated that between 1999 and 2003, 11 000–14 000 t per year of non-commercial species and 600–2100 t per year of hoki were discarded by the New Zealand hoki fishery, leading to the potential for a significant modification of the diet of scavenging species (Forman & Dunn 2012). Interpreting changes in diet from discards in a way that can inform fisheries management is not straightforward. For the Chatham Rise, the changes covered a period of declining hoki spawning biomass (McKenzie 2013) and occurred at the same time as evidence of climate variation, namely a shift in the prevalence of weather types (Kidson 2000) between 1992 and 2007 (Hurst et al. 2012). Disentangling these environmental and fishery drivers of changes to indicators of the demersal fish communities has not yet been attempted in New Zealand although the hypothesis that trophic or environmental factors were responsible for changes in hoki recruitment was investigated and was found not to be supported empirically (Francis et al. 2006, Bradford-Grieve & Livingston 2011). Nonetheless the indirect effects of fishing on the wider ecosystem are important to take into account in order to interpret the overall impact of fisheries on ecosystem function.

[3] A mesopredator is a predator that occupies a middle trophic level in a food web, regulating species too small for larger predators.

Durante et al. (2020) studied changes in the trophic level of fish landed off the east coast of New Zealand's South Island, from 1931 to 2015. This region is important for both commercial and recreational fishing and has been subject to the highest trawling efforts in New Zealand's EEZ since the expansion of commercial fishing (Baird et al. 2011, Macgibbon & Mules 2023). Analysis of fishery data showed that the weighted average trophic level or Marine Trophic Index (MTI) of landed fish increased gradually from 1931 as fishing intensity increased and more species were landed, peaking around the year 2000 then decreasing (Durante et al. 2020, Durante et al. 2021). The decreased MTI since 2000 illustrates smaller catches made up of lower trophic level species. These patterns are consistent with trends in the global fishing expansion since the 1950s, characterised as "fishing down the food web" (Swartz et al. 2010, Durante et al. 2020).

13.3.3 COMBINED EFFECTS OF FISHING AND ENVIRONMENTAL VARIABILITY/CHANGE

Although there have been few unequivocal empirical demonstrations of large-scale trophic and system-level effects arising solely from fishing, many studies have pointed to the potential of fishing to lead to trophic and ecosystem-level effects in concert with other factors, such as environmental variability and change (e.g., Winder & Schindler 2004, Brierley & Kingsford 2009, Kirby et al. 2009, Perry et al. 2010). These ecosystem level effects can occur even when fish stocks are not characterised as "overfished", hence the global push for ecosystem considerations to be incorporated more explicitly into fisheries management decisions. Although effective single species management is designed to take some of the effects described in this section into account, a lack of data availability on different life history stages, spatial distribution, bycatch, fish biology, ecology and fisher behaviour can inhibit effective management. Therefore, fishing is hypothesised to strengthen the relationship between environmental forcing and ecosystem variability and reduce ecosystem resilience and ecosystem integrity (as defined in Table 13.1) (e.g. Weijerman et al. 2005, Möllmann et al. 2009, Kirby & Beaugrand 2009 and Ottersen et al. 2006). For example, in Tasmania, overfishing of reef-based predators of sea urchins including spiny lobster (*Jasus edwardsii*) has reduced the resilience of kelp forests to the climate-induced expansion of populations of long-spined sea urchins (*Centrostephanus rodgersii*) and increased the risk of reefs shifting to unproductive sea urchin barrens (Ling et al. 2009). In this case, the combined effects of overfishing and climate change has reduced the resilience of these ecosystems to environmental variability and regime shift.

In northern New Zealand, fishery assessments suggest that spiny lobster stocks in the CRA 1 quota management area (QMA) from Kaipara harbour around to Te Arai Point have been managed near to their estimated maximum sustainable yield since entering the quota management system in the 1990s (Fisheries New Zealand 2023). However, in November 2022 the High Court ruled that catch settings for spiny lobster must consider the wider impact of spiny lobster fishing on the aquatic environment, (specifically pertaining to kina barrens and trophic cascades)[4]. This ruling, and subsequent decisions to further reduce the TAC for CRA1 shows that a precautionary approach that goes beyond MSY may be required for incorporating ecosystem considerations into management decision-making. Regional management approaches that take into account environmental variability within the QMA will also be important (e.g. since kina barrens are prevalent on the east coast of CRA1, but are not considered to be an issue along the west coast).

The effects of fishing that may lead to reduced ecosystem resilience and environmental impacts (Figure 13.1) include:

- Alteration of demographic structure. Size-selective removal truncates the population's age structure and lowers the buffering capacity of the population (its ability to withstand long periods of environmental conditions that are adverse for recruitment) (Hsieh et al. 2010). Fishing often selects the largest oldest fish removing females that produce the largest quantity and highest quality eggs (Calduch-Verdiell et al. 2014). This increases variability in the abundance of fished species (Hsieh et al. 2006, Hočevar & Kuparinen, 2021).

[4] The Environmental Law Initiative v Minister for Oceans and Fisheries [2022] NZHC 2969 [11 November 2022)

- **Alteration of spatial structure.** The spatial structure of marine fish populations can encompass a wide range of configurations, including patchy populations, networks, and meta-populations (Kritzer & Sale 2004). Removal or reduction of population spatial structure by fishing is likely to increase the sensitivity of the overall population to climate fluctuations at inter-annual to multi-decadal scales (e.g., Ottersen et al. 2006).
- **Alteration of life-history traits.** Size-selective fishing can decrease growth rates and age-at-maturity (Law 2000, de Roos et al. 2006, Hočevar & Kuparinen, 2021), accelerating the response of populations to climate forcing (Perry et al. 2010).
- **Alteration of habitat structure.** Changes to benthic habitat by the direct effects of fishing, particularly bottom trawling and dredging, may lead to a reduction in ecosystem resilience (Althaus et al. 2009, Lambert et al. 2014, Pusceddu et al. 2014).
- **Alteration of ecosystem trophic structure.** Fishing can decrease the stock sizes of predators, which can shift ecosystems from top-down to bottom-up control (Durante et al. 2021). Changes to trophic structure by fishing are predicted to increase ecosystem variability and reduce resilience (Jackson et al. 2001, Perry et al. 2010, Dunn et al. 2017). Ecosystems with multiple weak trophic links and generalist predators are less vulnerable to shifts caused by strongly interacting species (Shin & Cury 2001, Polunin & Pinnegar 2002, Rooney et al. 2006, McCann & Rooney 2009, Johnson et al. 2014).

13.3.4 OTHER POTENTIAL IMPACTS

In addition to environmental factors, other impacts to the marine environment that could interact with fishing to affect ecosystems include invasive species, microplastics and bioaccumulation.

13.3.4.1 INVASIVE SPECIES

Species that are novel or introduced to a new ecosystem also have the capacity to alter trophic cascades and consequently trigger a regime shift. Fishing may enhance the vulnerability of marine ecosystems to invasion by non-native species. For example, in the Mediterranean Sea the loss of native seagrass meadows by bottom-impacting fishing methods, has been hypothesised to increase colonisation success of invasive alga *Caulerpa racemosa* (Kiparissis et al. 2011). International fishing vessels, may themselves also present vectors for the introduction of non-native species that can be found in fouling on hulls, bilge water or on marine equipment. While there are many invasive marine species in New Zealand (https://marinebiosecurity.org.nz/) there are no specific examples of these species directly impacting fisheries or fisheries enabling their spread. Between 2021 and 2023, two species of exotic Caulerpa seaweed (*Caulerpa brachypus* and *Caulerpa parvifolia*) were found in several locations around the upper North Island. This seaweed forms dense mats from 2 to 35 metres depth and poses a risk to marine life central to cultural, recreational and commercial activities. Substantial effort and funds have gone into controlling and removing existing Caulerpa to reduce the potentially large ecological and cultural impacts. A monitoring programme to assess the impacts of exotic Caulerpa on the environment and taonga species was established at Aotea/Great Barrier Island in 2023 (Middleton 2023). However, the enduring impact of *Caulerpa* on New Zealand's fisheries and coastal ecosystems remains unknown.

13.3.4.2 PLASTIC POLLUTION AND BIOACCUMULATION

With approximately 8 million tonnes of plastic entering the ocean annually and affecting approximately 690 species of all sizes, from plankton to large cetaceans (Jambeck et al. 2015, Carbery et al. 2018), plastic pollutants in the marine environment can pose a serious risk to sea life. Microplastics, most often defined as particles less than 5 mm (Arthur et al. 2009), are accessible for uptake to a wide range of organisms, particularly nonselective filter feeders. Depending on size, ingested plastic can either sit in the digestive tracts of animals or can further break down into harmful chemicals and be absorbed by the organism (Carbery et al. 2018), potentially affecting population dynamics (Wu et al. 2022). While sea life may be affected both directly by plastic and by bioaccumulation of microplastics through trophic levels (Miller et al. 2020), there is little to no empirical evidence of wide-spread trophic cascade effects or regime shifts due to plastic

pollution. The Continuous Plankton Recorder (see description in 13.6.1.3) study analysed micro-and meso-sized plastics and found that the mean number of plastic pieces in near-surface seawater between New Zealand and the Ross Sea increased 11-fold between late 2009 and 2023, to an average of about 29 pieces per m^3. Almost all (>93% on average) of the plastics were microfibres. Pinkerton et al. (2024b) reports that plastic had a statistically significant and negative association with the abundance of many zooplankton groups, especially at concentrations above about 38 pieces per m^3, although cautioned that it is not known if this negative association between plastic and zooplankton is causal or merely correlative.

Table 13.1: Ecosystem resilience.

Fishing and other factors can impact **Ecosystem resilience,** the amount of disturbance that can be absorbed before an ecosystem shifts to an alternate state (Pimm 1982, Holling 1973, Cohen et al. 1990, Walker et al. 2004). It is difficult to quantitatively measure ecosystem resilience, but three qualitative measures of ecosystem resilience are:

- Does the ecosystem retain essentially the same function, structure, identity, and feedbacks after perturbation as before (Walker et al. 2004)?
- Do perturbations to one part of the ecosystem spread out and affect biota across many trophic levels or remain localised (i.e., are ecosystem-level changes likely)?
- How long does it take a food web to return to its original configuration when disturbed? Stable (resilient) food webs can absorb more disturbance without undergoing wholesale reorganisation, tend to have low tendency for ecosystem-level trophic cascades (food web perturbations remain local) and have short recovery times (Walker et al. 2004).

Trophic and ecosystem impacts to the marine environment can also impact ecological integrity (as defined in the National Policy Statement for Indigenous Biodiversity (Ministry for the Environment 2023): the extent to which an ecosystem is able to support and maintain its:

a) composition (being its natural diversity of indigenous species, habitats, and communities); and
b) structure (being its biotic and abiotic physical features); and
c) functions (being its ecological and physical processes).

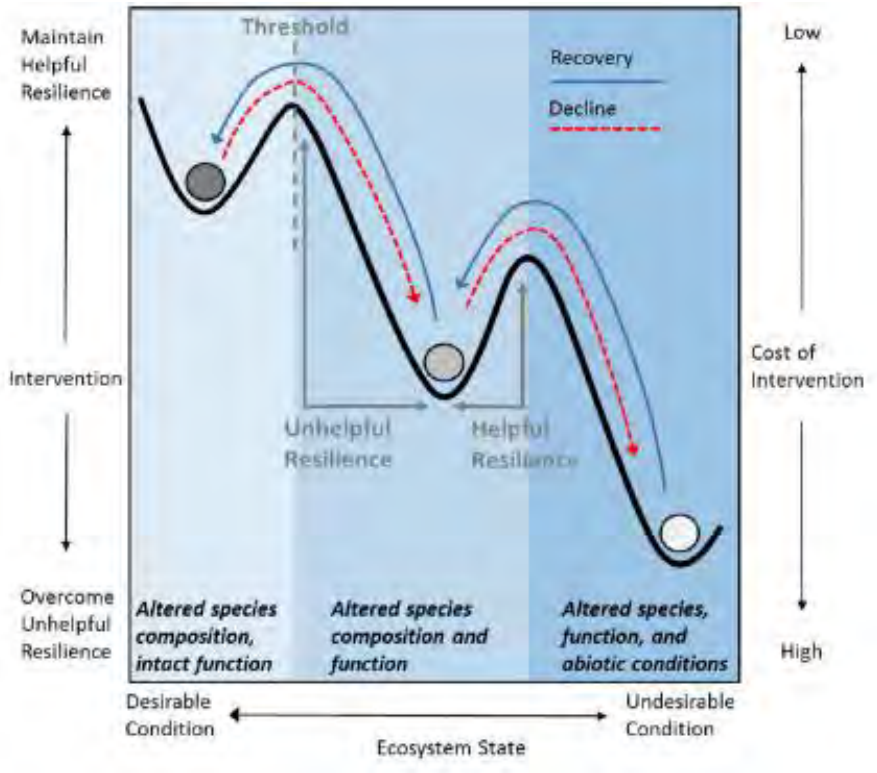


Figure 13.1: A ball and cup figure representing ecological resilience and changes in ecosystem characteristics (image from: Rasmussen & Orr 2017). Once an ecosystem is pushed past a certain threshold (due to changes in species composition and ecosystem function) it can reach a state of hysteresis, or an alternative stable state that cannot be reversed without extensive and costly intervention (Sguotti et al. 2019).

13.4 MECHANISMS DRIVING TROPHIC AND ECOSYSTEM EFFECTS IN NEW ZEALAND

The trophic and ecosystem-level effects of fishing depend on the overall type of ecosystem forcing structure. Most ecosystems will be a mixture of three types: bottom-up, top-down and middle-out forcing. These structures are described in Table 13.2 and illustrated in Figure 13.2. While these processes are often at work in the same ecosystem, and may change over time, identifying dominant patterns of ecosystem behaviour can help to predict or explain the types of change that can result from the combined effects of fisheries harvesting, climate variability/change and other human stressors (Rice 2001).

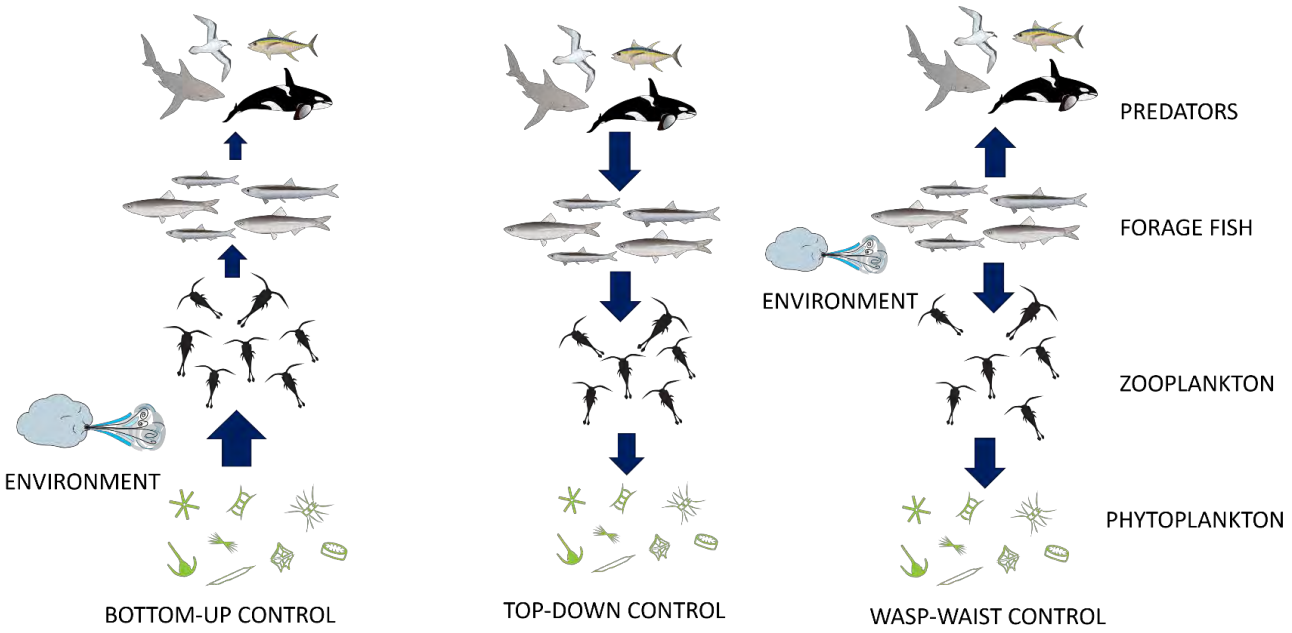


Figure 13.2: Schematic of overall types of ecosystem-forcing (adapted from Gaichas 2019). Symbols courtesy of the Integration and Application Network, ian.umces.edu/symbols/.

Table 13.3: Overall types of ecosystem-forcing.

Bottom-up ecosystem forcing	If the ecosystem-level properties (i.e., across organisms at many trophic levels) respond strongly to changes in the environment (e.g., oceanography, water column structure), the ecosystem is said to show strong bottom-up forcing. Environmental change is a strong driver of bottom-up forcing in marine ecosystems. On temperate coastal rocky reefs, macroalgae are susceptible to extreme and sustained changes in sea surface temperature (SST) such as marine heatwaves (MHW) and El Niño events (Rogers-Bennett & Catton 2019, Beas-Luna et al. 2020, Tait et al. 2021). Tait et al. (2021) found that giant kelp (*Macrocystis pyrifera*) along the south/southeastern coast of New Zealand declined in abundance and surface canopy area following the extreme marine heatwave (MHW) during 2017/2018. There was also a significant interaction between temperature and turbidity, showing that temperature-induced kelp loss was greater when water clarity was poor. The degradation of kelp communities can affect other parts of the food web, including fish. Bottom-up forcing can also alter the abundance and distribution of organisms and reduce ecosystem resilience to fishing. Poleward shifts in species' distributions are expected to be one of the principal responses to climate change as sea temperatures increase (Cabrelli et al. 2015).
Top-down ecosystem forcing	An ecosystem is said to show top-down forcing if it responds strongly to changes in the abundance of top predators (seabirds, marine mammals, high trophic level fishes, turtles). Fishing is a common top-down force affecting coastal ecosystems. Our understanding of how predators shape marine ecosystems has arisen largely from experimental studies where the effect of predation is controlled either by removing predators or introducing them to the ecosystem under study, usually in the intertidal or nearshore subtidal zone (Dunn & Hovel, 2020). In the open ocean, increases in prey populations upon the removal of their predators (e.g., by fisheries) have been taken as evidence of top-down limitation (e.g., Furness 2002, Worm & Myers 2003, Frank et al. 2005). Other evidence of top-down regulation in a marine ecosystem appears where predators are abundant at one site, but largely absent from a similar, nearby site. This can be observed in marine reserves, which provide refuge for some top predators. For example, the Fiordland marine reserves support higher abundances of two key predators, spiny lobster and blue cod (*Parapercis colias*), with more stable community structure and food webs (Wing & Jack 2014).

Middle-out forced (wasp-waisted) ecosystem	Middle out, also known as "wasp-waist" forced control of energy flow in marine ecosystems occurs when one or a very few species have a substantial influence on the flow of energy through the mid-trophic levels. The term has most frequently been applied to systems dominated by small pelagic fishes that transfer energy from the plankton to larger predators (Rice 1995, Cury et al. 2000, 2004, Bakun 2004, 2006). Ecosystems with wasp-waist control are typically highly productive coastal or upwelling systems with relatively short food chains. However, wasp-waist control can occur in open ocean ecosystems including with species such as herring (*Clupea harengus*), sprat (*Sprattus sprattus*), and anchovy (*Engraulidae spp*) in the North Atlantic (Gifford et al. 2010, Fauchald et al. 2011), krill in the Antarctic (Ainley & Pauly 2014, Atkinson et al. 2014) and copepods (*Calanus* sp.), when functioning as a 'gatekeeper' (sensu Steele 1998). When the species at the waist declines abruptly, predators often cannot compensate, at least fully, and suffer reduced growth, survivorship, and reproduction (Mehl & Sunnana 1991, Kjesbu et al. 1998, Dutil & Lambert 2000). Predators may control the wasp-waist when they are at intermediate population sizes (Bakun 2006). At other times, year-class strengths of species at the waist demonstrate strong, direct effects of environmental forcing.

13.4.1 CASE STUDY 1: BOTTOM-UP ENVIRONMENTAL FORCING ON COASTAL REEFS

Bottom-up Environmental impacts on blue cod



Figure 13.3 Blue cod (*Parapercis colias*)

Adult blue cod (*Parapercis colias,* Figure 13.3) are generalist predators that mainly forage on kelp-associated fish and crabs in coastal waters around much of New Zealand (Beentjes & Carbines 2005, Wade 2020, Kolodzey et al. 2023). The distribution of large kelps has been negatively impacted by marine heatwave events and sedimentation from land-based runoff along parts of the South Island (See bottom-up forcing in Table 13.3, Tait et al. 2021, Thomsen et al. 2019). In these same regions blue cod abundance has shown a strong negative correlation with environmental variables such as sedimentation and increasing sea surface temperature, though it is uncertain whether these variables are affecting blue cod directly or indirectly through effects on food and habitat (Brough et al. 2023). Juvenile blue cod in particular are likely to be negatively impacted by the effects of sedimentation as they are known to inhabit shallow inshore reef margins associated with turfing algae and sponges that are exposed to land-based inputs (while adults are typically associated with deep reefs) (Brough et al. 2023).

A decrease in macroalgal habitat complexity could reduce the abundance of blue cod by suppressing the availability of key prey species (Wade 2020). A New Zealand case study, using chemical tracers of diet for five fished species (blue cod (*Parapercis colias*), hapuku *(Polyprion oxgeneios*), barracouta (*Thyrsites atun*), red cod (*Pseudophycis bachus*) and ling (*Genypterus blacodes*), suggests that the historical decline of kelp forests has resulted in a less connected and more simplistic foodweb, and an increased energetic cost (reliance of fished stocks on higher trophic level foods) of fisheries productivity (Wing et al. 2022a).

Fishing and ecosystem effects are likely to have a cumulative impact on Blue Cod stocks. Kolodzey et al. (2023) compared the length frequency distributions, growth, stomach contents, and isotopic values ($\delta^{13}C$ and $\delta^{15}N$) of blue cod subpopulations at healthy biogenic reef sites and degraded sites impacted by dredging and high turbidity from suspended sediment in the Marlborough Sounds and Tasman Bay. Blue cod were significantly smaller and occupied smaller isotopic niches at the sites degraded by sediment and bottom fishing compared to healthy reef sites, which was attributed to the impacts of these factors on prey availability. Adult blue cod also have a small home range and are protogynous hermaphrodites[5], with some fish changing from female to male later in life. This life history strategy makes a population's sex ratios particularly vulnerable to fishing impacts (e.g. large males are more likely to be fished). Overfishing may then cause females to change sex, resulting in more small male fish and fewer large females. This leads to a less productive population, as observed in the Marlborough Sounds (Kolodzey & Wing 2022). Thus, while bottom-up forces affect the ecosystem structure and function required to support healthy blue cod populations, it is the combination of both bottom-up environmental factors and the top-down effects of fishing that cumulatively impact their role as an important predator in New Zealand's coastal ecosystems.

Bottom-up environmental impacts on long-spined sea urchins



Figure 13.4 *Centrostephanus rodgersii* Copyright: John Turnbull www.marineexplorer.org

In New Zealand, the population structure of the long-spined sea urchin (*Centrostephanus rodgersii,* Figure 13.4) appears to be changing under warming conditions (Doheny et al. 2023). Like kina (*Evechinus chloroticus*), the long-spined sea urchin is an echinoderm capable of contributing to trophic cascades leading to sea urchin barrens (Byrne & Andrew 2020, Davis et al. 2023). Long-spined sea urchins can create more persistent sea urchin barrens than kina because they occupy a greater depth range (Perkins et al. 2015) are more mobile and omnivorous, and potentially less vulnerable to predation (Mayer 2024, Balemi & Shears 2023). Packhorse rock lobster (*Sagmariasus verreauxi*) and spiny lobster (*Jasus edwardsii*) are the only known predators of Centrostephanus in New Zealand (Balemi & Shears 2023). While the distribution of long-spined urchins in eastern Australia has been expanding southwards as a result of increasing sea surface temperature (SST) (Byrne & Andrew 2020, Davis et al. 2023), the same extent of range expansion has not yet been observed in New Zealand populations. However, changes in the population and key biological characteristics indicate that this species has the potential to increase in range and abundance, with negative implications for the inshore ecosystems. Pecorino et al. (2013, 2014) found that further ocean warming in New Zealand could improve conditions for larval and embryonic development of long-spined sea urchins, increasing the possibility of marked range expansion. This expansion is likely to

[5] Animals that are born female and at some point later in their lifespan change sex to male

result in reduced resilience of coastal marine ecosystems to fishing effects and demand more active management to prevent catastrophic phase shifts (Ling et al. 2009).

In 2023 Australian fisheries management authorities developed the National Centro Task Force to allow for collaboration on management activities and prioritisation of environmental health in response to the spread of long-spined urchin barrens (Keane et al. 2024). The proliferation of long-spined sea urchins in Australia is largely associated with climate-driven changes in ocean currents promoting sustained ocean warming (favourable conditions for long-spined larvae) and kelp loss (Ling et al. 2008). The vulnerability of kelp beds to climate-driven phase shifts to urchin barrens is thought to be reduced by fishing of reef predators such as spiny lobsters (Ling et al. 2009). While spiny lobsters can feed on long-spined urchins, they do not appear to be effective at reducing the extent of urchin barrens in Tasmania as they prefer native species over the range-extending urchins (Smith et al. 2022) and are less effective predators on the larger urchins found in established barrens (Smith et al. 2023). The abalone industry, which was threatened by the expansion of sea urchin barrens, has invested heavily in Tasmania's response thus far by creating harvest subsidies for long-spined sea urchins, lobbying for political support and enabling the development of a commercial fishery for urchins. The Australian government is yet to allocate large-scale funds to support an ecosystem-based approach to addressing the spread of long-spined sea urchins, but steps to achieve this, including marine spatial planning approaches are outlined in the 5-year plan published in 2023 (National Centro Taskforce 2023).

13.4.2 CASE STUDY 2: TOP-DOWN FORCING AND SEA URCHIN BARRENS



Figure 13.5 Urchin barren versus healthy kelp covered reef in Northland, New Zealand. Copyright: Vince Kerr

Background on fishing-induced trophic cascades leading to sea urchin barrens

Fishing is thought to play a role in the development of sea urchin barrens in parts of New Zealand, and this relationship provides an example of top-down forcing resulting in a 'trophic cascade' (term defined in Section 13.2.2). Although multiple factors can cause kelp decline (including sedimentation and marine heatwaves), evidence from marine reserves in northeastern New Zealand suggests that fishing of apex reef predators is an important factor behind the proliferation of the grazing sea urchin/kina (*Evechinus chloroticus*), extensive kelp loss and the expansion of sea urchin barrens (Doheny et al. 2023). This relationship is based on observations of the concurrent recovery of kelp (*Ecklonia radiata*) and

predators of sea urchins (including snapper, *Chrysophrus auratus* and spiny lobsters, *Jasus edwardsii*) inside long-term marine reserves near Leigh (Babcock et al. 1999, Shears & Babcock 2002, 2003, Leleu et al. 2012), and the positive effect of protection from fishing on the abundance of kelp (*Ecklonia radiata*) and predators inside seven marine reserves from the Kermadecs to the Bay of Plenty (Edgar et al. 2017).

Extent of sea urchin barrens and interacting effects on the ecosystem

Historical photography and local knowledge indicate urchin barrens were first observed in northeastern New Zealand around the 1960s with barrens becoming quite extensive by the 1970s, and some continued expansion since then (Booth 2017). An estimated 30% (range: 7 – 49%) of shallow reef area is impacted by sea urchin barrens from Tāwharanui Peninsula in the Hauraki Gulf to Maitai Bay near the tip of the Karikari Peninsula in Northland (Kerr et al. 2024) with even higher estimates of up to 90% in parts of the Bay of Islands (Booth 2017). There is no published evidence of bottom-up forces such as ocean warming affecting kelp forest extent in these areas yet, but it is a concern for the future (Cornwall et al. 2023). The degraded state of these reefs may make them less resilient to the impacts of climate change and is likely to be already impacting ecosystem function. Urchin barrens support a lower biodiversity due to the loss of ecosystem services, including provision of complex three-dimensional habitat and organic matter, provided by kelp forests (Rogers-Bennett & Catton 2019, Udy et al. 2019) (Figure 13.5). For example, the loss of kelp forests could reduce the capacity of the ecosystem to support healthy spiny lobster populations due to their potential reliance on these habitats across multiple life stages. Studies from Tasmania suggest kelp habitat may be critical to the settlement success of spiny lobster pueruli (post-larval spiny lobster), providing important settlement cues, food and refuge (Hinojosa et al. 2015, Hinojosa et al. 2018, Shelamoff et al. 2022). The same relationship has yet to be observed for pueruli in New Zealand (Stanley et al. 2015, Hesse et al. 2016) though kelp is an important food source and sheltering habitat for older life stages of spiny lobster (MacDiarmid et al. 2013). These observed and potential relationships across the lobster life cycle suggest that prioritising kelp recovery is important from both an ecosystem and fishery perspective and that these two areas are tightly linked.

Regional and temporal variability

Where and when kina barrens occur within any region depends on abiotic factors such as turbidity, exposure and bathymetry that may affect the suitability of habitat for settlement of kina and kelp (Shears et al. 2008, Kerr et al. 2024). Short-term biotic disturbances such as disease or toxic dinoflagellate blooms can cause temporal variability in sea urchin (Shears & Ross, 2010) and kelp dynamics (Babcock & Cole 1993) but long-term trends suggest top-down control of predators is the primary mechanism controlling urchin barrens in northeastern New Zealand (Peleg et al. 2023). Experimental work in the Hauraki Gulf in 2020–21 recorded rapid kelp recovery in areas where urchin barrens were cleared by divers, suggesting that kelp re-growth is unlikely to be limited by environmental/bottom-up factors in these areas (Miller et al. 2024). In 2024 similar research led by the University of Auckland is in progress in Queen Charlotte Sound, Marlborough. Once in place, urchin barrens dominated by large urchins are persistent, and recovery of macroalgal beds requires very low urchin abundance (Miller et al. 2022).

Outside of northeastern New Zealand, and especially in central areas like the Marlborough Sounds, environmental and climatic influences, species' demographics, and catchment-derived sedimentation may be equally or potentially more important than predator abundance in structuring kelp beds (Doheny et al. 2023, Schiel 2013, Wing et al. 2022b). More research is needed to better understand the prevalence of kina barrens and contributing factors in these regions. Observations of concurrent kelp and pāua recovery inside a marine reserve in Stewart Island between 1998 and 2014 suggest that fishing of pāua may result in kina barrens since pāua may help maintain community structure by displacing sea urchins from shallow water habitats (Wing et al. 2015).

Key Predators

Key predators involved in trophic cascades leading to kina barrens and their relative importance will vary regionally depending on their distribution. Predators that consume kina include spiny lobster, packhorse lobster (*Sagmariasus verreauxi*), large sea stars and several species of fish (e.g. snapper, red moki (*Cheilodactylus spectabilis*), blue cod (*Parapercis colias*), and banded wrasse (*Notolabrus fucicola*) (Doheney et al. 2023). Evidence from marine reserves in northeastern New Zealand suggest that increased abundances of predators (including snapper and spiny lobster) were associated with the re-establishment of kelp forests in former urchin barrens. The role of spiny lobsters as keystone predators is also reflected in the results of ecosystem models in New Zealand rocky reef ecosystems, using both qualitative (Beaumont et al. 2009) and quantitative frameworks to estimate historical food web structure (Pinkerton et al. 2008, Eddy et al. 2014, Pinkerton 2012). While sea urchins are not the preferred prey of spiny lobsters, which choose soft-sediment bivalves over urchins when provided the option, and consumption is likely to vary seasonally with lobster moulting stage and/or sea urchin roe quality, large lobsters are unique in their ability to pry large urchins from rocks and consume them via the urchins' unprotected mouthparts (Flood, 2021). Urchin predation by fish such as snapper is limited by mouth gape, so only large snapper can consume large sea urchins (Marinovich et al. 2023). Thus, larger urchins may be protected from predation by most predators other than large (>130mm carapace) lobster (Andrew & MacDiarmid 1991). The presence of both spiny lobster and snapper can also influence sea urchin behaviour. For example, increased presence of these predators inside marine reserves increases cryptic behaviour (such as hiding in crevices) by sea urchins (Spyksma et al. 2017) and sea urchins consume less kelp in the presence of lobsters (Curtis & Wing 2024). Thus, snapper and rock lobster potentially mitigate trophic cascades by consuming urchins and by reducing their consumption of kelp.

Although kina were historically the primary species found in sea urchin barrens in New Zealand, warming waters are causing an increase in barrens dominated by long-spined sea urchins (as described in 13.4.1).

Management approaches to address urchin barrens

Manual removal of kina from barrens can support rapid kelp regrowth in the short-term (Miller et al. 2022, Villouta et al. 2001), but the benefits are temporary and do not promote recovery of sea urchin predators (Miller et al. 2024). Potential management solutions to address the top-down effects of fishing on the ecosystem require a suite of approaches including managing kina predators to higher abundance, spatial controls on fishing, and targeted removal of sea urchins in priority areas (Bulmer et al. 2024, Miller et al. 2022, Doheny et al. 2023, Kerr et al. 2024). However, the relative effectiveness of these measures is difficult to quantify and will require monitoring over time. The biomass of predators required to reverse, mitigate, or prevent urchin barrens is currently unknown. Sustained recovery of kelp forests in Northland has only been observed in areas closed to all fishing, not in partial closures (Shears et al. 2006), suggesting that no-take areas, and the biomass of predators they support, are an important part of the solution (Nessia et al. 2024).

13.4.3 CASE STUDY 3: MIDDLE-OUT/WASP-WAIST FOOD WEBS ON THE CHATHAM RISE

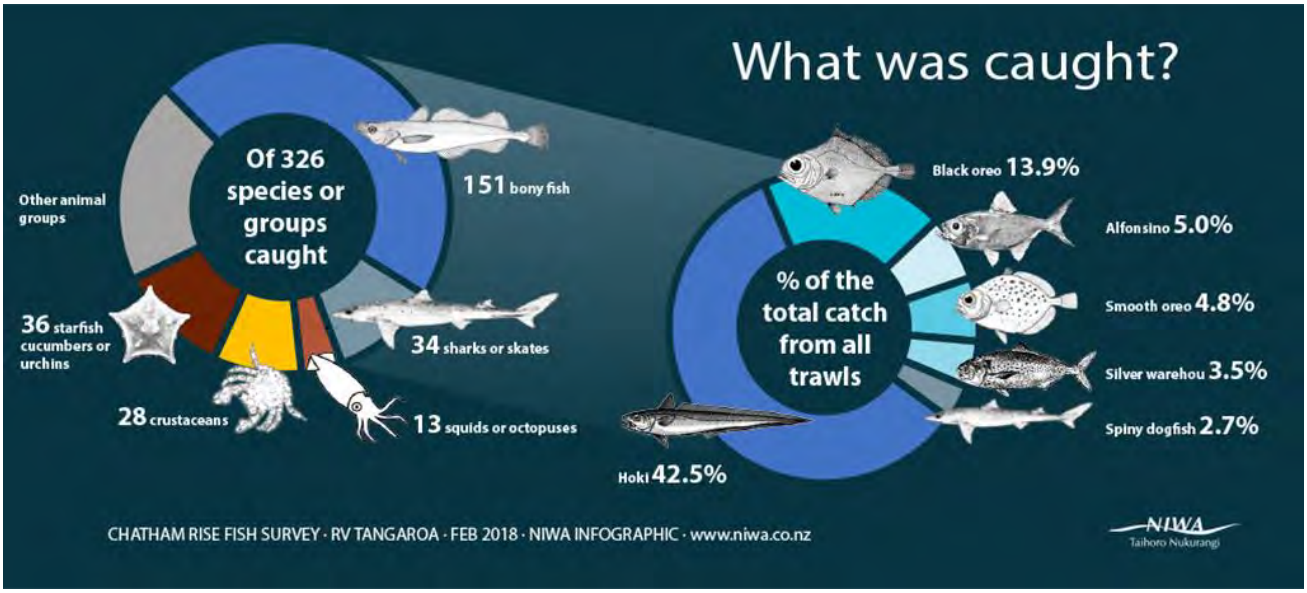


Figure 13.6 NIWA infographic illustrating the fish caught on fishery-independent Chatham Rise fish surveys (https://niwa.co.nz/news/niwa-expertise-contributes-healthy-hoki-fishery).

Research into deepwater ecosystems in the New Zealand EEZ is most advanced in the Chatham Rise region (Pinkerton 2013) which provides an example of a wasp-waist controlled ecosystem. Elevated primary production here is due to the convergence of subantarctic and subtropical water which is called the Subtropical Front (Bradford-Grieve et al. 1997, Boyd et al. 1999, Murphy et al. 2001, Sutton 2001). This front supports valuable deepwater fisheries, an unusually rich benthic ecosystem (Probert et al. 1996, McKnight & Probert 1997, Bowden 2011), and large seabird populations (Figure 13.7;Taylor 2000a, 2000b). Ecosystem modelling of the Chatham Rise food web began in 2006 (e.g. Pinkerton, 2013), the most recent version being McGregor et al. (2019), using the Atlantis ecosystem model. McGregor et al. (2019) calculated 'keystoneness'[6] (Libralato et al. 2006) and responsiveness to perturbations as measures of trophic importance in the Chatham Rise Ecosystem (CRE). The model used 53 functional groups to model biological processes across various fish, cetaceans, other mammals, seabirds, invertebrates, zoo/phytoplankton, and bacteria. These groups were modelled with biotic and abiotic variables such as depth, sea surface temperature, salinity, nutrient availability, predation effects, and fishing pressure, over a period of 1900–2015. Fish groups that ranked highest for keystoneness were; hoki (*Macruronus novaezelandiae*), orange roughy (*Hoplostethus atlanticus*), shallow benthic fish (primarily oblique banded rattail), and hake (*Merluccius merluccius*). Small to medium pelagic fish (primarily lanternfish (myctophids) and barracouta (*Thyrsites atun*) respectively) ranked next for keystoneness. These results suggest some degree of middle-out control in the system, although the number and functional diversity of these groups is higher than in other wasp-waist systems.

Other work on the Chatham Rise food web investigated change in food web structure over time using data from Chatham Rise trawl surveys between 1992 and 2007 (Tuck et al. 2009). See Figure 13.6 for a summary of key species caught in research trawl surveys. This work found evidence of increasing evenness (reducing diversity) but no evidence that species were being lost from the food web (Tuck et al. 2009). Over the sampling period, fish caught in research trawls became smaller and the mean trophic level index decreased (Pinkerton 2013), though it has subsequently increased. The proportion of piscivorous fish and of true demersal (rather than bentho-pelagic) species declined while threatened species (several species of sharks and rays) and 'low-resilience 'species, such as dogfish and rays increased relative to other species on the Chatham Rise (Tuck et al. 2009, O'Driscoll et al. 2011). This may be a result of a combination of a lack of incentive to catch these species by the fishing fleet and an increase in offal and discards that

[6] Keystoneness is defined as the impact of a species on different elements of an ecosystem resulting from a small change to the biomass of the species and its total biomass.

benefit demersal scavengers. There were also changes in the spatial distribution of fish species. MPI project ZBD2004/02 (Dunn et al. 2009, Horn & Dunn 2010) found evidence that fish (primarily myctophids such as lanternfish) were increasing in importance in the diet of hoki, but not of hake or ling.

13.5 METHODS FOR MEASURING THE SCALE AND SIGNIFICANCE OF TROPHIC AND ECOSYSTEM-LEVEL EFFECTS

13.5.1 MEASURING THE SCALE OF ECOSYSTEM EFFECTS

Delineating ecosystems is an important first step towards evaluating trophic and ecosystem-level effects of fishing. There are not usually clear spatial boundaries between different ecosystems. Instead, different parts of ecosystems vary on different spatial scales; higher trophic-level organisms usually move over a greater spatial extent than lower trophic-level organisms. For example, some seabirds and marine mammals may move large distances seasonally (outside of New Zealand's EEZ) and move between different ecosystems. In contrast, most phytoplankton, smaller zooplankton and most benthic invertebrates will live and die within a few kilometres. Some fish move long distances (for example southern bluefin tuna), but others remain in a small area all their lives (e.g., on a reef). Marine ecosystems should therefore be viewed as an interlocking matrix of the life ranges of different organisms. As such, it is difficult to unambiguously separate different ecosystems, but a number of approaches have been developed to do so. These include: (a) defining ecosystems on the basis of their physical properties, either using *a priori* thresholds (e.g., fixed depth ranges) or by multivariate clustering of physical properties (Snelder et al. 2005, Grant et al. 2006); (b) using maps of species occurrence to map biological assemblages (e.g., Leathwick et al. 2006, Stephenson et al. 2018, 2020); (c) relating community composition to environmental variables (e.g., generalised dissimilarity analysis; Leathwick et al. 2012, Stephenson et al. 2022) and using these relationships to extrapolate spatially; (d) using an image based approach to identify vulnerable marine ecosystems (Gros et al. 2023); and (e) analysing environmental DNA (eDNA) data to assess changes in the proportional abundance of taxa and to analyse the linkages between organisms (Djurhuus et al. 2020).

13.5.2 MEASURING THE SIGNIFICANCE OF ECOSYSTEM EFFECTS

The scale and significance of trophic and ecosystem-level effects depend on the particular characteristics of the ecosystem as well as on the drivers of change (Brose et al. 2005, Pascual & Dunne 2006, Brander 2010, Jennings & Brander 2010). Ecosystems are complex adaptive systems (Levin 1998, 1999); that typically have non-linear dynamics, with thresholds (also called tipping-points) and positive and negative feedback loops (Hsieh et al. 2005). The complex behaviour of ecosystems over temporal and spatial scales and the wide variety of potential stressors makes it difficult at present to forecast the response of ecosystems to change or specify tipping-points to guide management.

Several multispecies or ecosystem models have been developed that can be used to investigate the potential for trophic and ecosystem-level effects (Plagányi 2007, Plagányi et al. 2014). These include Ecopath with EcoSim (EwE; Watari et al. 2019, Craig & Link 2023), mass-balance (Pinkerton, 2010, Pinkerton 2013, Pinkerton et al., 2010, 2015a, 2023), Atlantis (Ortega-Cisneros et al. 2017, McGregor et al. 2019), OSMOSE (Grüss et al. 2015, Xing et al. 2021), Bayesian Belief Network models (Spiers et al. 2016, Trifonova et al. 2021) and a range of models of intermediate complexity (MICE; Plagányi et al. 2014). Multispecies and ecosystem models can provide useful strategic insights for fishery and resource managers (Fulton et al. 2005, Smith et al. 2011, Craig & Link 2023, Pinkerton et al. 2023). However, there are often differences in model predictions about ecosystem consequences (or lack thereof) of fishing, especially in ecosystem-scale models, so model outputs need to be used cautiously for tactical decisions (Smith et al. 2011). MICE-models (where only part of the ecosystem is modelled) are likely to provide more robust guidance for tactical decision-making (Plagányi et al. 2014). Knowledge of food web structure (Table 13.2) has also been used to evaluate responses to fishing and other changes as an alternative to dynamic ecosystem models (Ulanowicz & Puccia 1990, Libralato et al. 2006, Pinkerton &

Bradford-Grieve 2014, Pinkerton et al. 2023). Progress continues to be made to simplify methods for evaluating fishing impacts on the ecosystem and standardise approaches to advancing ecosystem-based fisheries management, including the development of ecosystem reference points (Fulton & Sainsbury 2024).

13.5.3 EXAMPLES FROM NEW ZEALAND

Several pieces of work have contributed to our understanding of the spatial distribution of marine ecosystems in New Zealand (e.g., Leathwick et al. 2006, 2012, Stephenson et al. 2018, 2020, 2022). Several approaches have been developed in New Zealand to identify or describe the estimated 62 distinct marine habitat types (Spalding et al. 2007, MacDiarmid et al. 2012) including a marine habitat classification index developed by New Zealand's Department of Conservation and MPI (Department of Conservation and Ministry of Fisheries 2011) and more recently the New Zealand Seafloor Community Classification (Stephenson et al. 2022) and the New Zealand Seafloor Bioregionalisation (Stephenson et al. 2023), characterising environmental conditions.

Despite New Zealand's small land mass, the coastline covers a wide latitudinal range with diverse geography and is exposed to widely varying environmental conditions. Thus, trophic relationships and ecosystem-level changes can vary in different parts of the country. For example, although marine heatwaves have become stronger, longer and more frequent overall in New Zealand, seasonal trends vary both within and between regions, with implications for the resilience of different ecosystems to climate change (Montie et al. 2024). These impacts can vary at quite localised scales, with kelp loss and growth stunting in pāua attributed to heat stress varying between reefs along a short stretch of coastline in the Chatham Islands (Van Nguyen et al. 2023).

Multiple ecosystem models have been developed to describe significance of fishing effects on ecosystems in New Zealand. For example, one long-term study characterised changes to the ecosystem of the Hauraki Gulf region using five balanced, quantitative models of the food web covering periods from the present day back to pre-human settlement (Pinkerton et al. 2015b). Before humans arrived in New Zealand, the models suggest that cetaceans and fur seals/sea lions were the most trophically important groups in the Hauraki Gulf ecosystem, with strong top-down ecosystem control. With the loss of seals/sea lions from the Hauraki Gulf ecosystem and the decline in cetaceans, models suggest their trophic importance was drastically reduced, potentially impacting populations of top predators such as white sharks (*Carcharodon carcharias*) and orca (*Orcinus orca*) and their prey (MacDiarmid et al. 2016). The trophic importance of other predators (spiny lobsters and sharks especially) in the models of the Hauraki Gulf ecosystem also reduced over time as a result of human harvesting suggesting a transition to a more bottom-up controlled system.

Other ecosystem models have described the historical impacts of predators on rocky reefs in the Hauraki Gulf (MacDiarmid et al. (2016), the impacts of fishing on the Chatham Rise (McGregor et al. 2019), the impacts of fishing for Antarctic toothfish (*Dissostichus mysoni*) on the ecosystem of the Ross Sea, Antarctica (Pinkerton et al. 2010, Pinkerton & Bradford-Grieve 2014), and the potential for the toothfish fishery to indirectly affect the abundance of Adelie penguins (Pinkerton et al. 2016). There are significant uncertainties in the parameters used in these models and the authors note that the results represent one of many possible solutions, and should be considered as working hypotheses. Nonetheless these models provide a valuable approach to collate the best available knowledge on large scale changes to ecosystems over time.

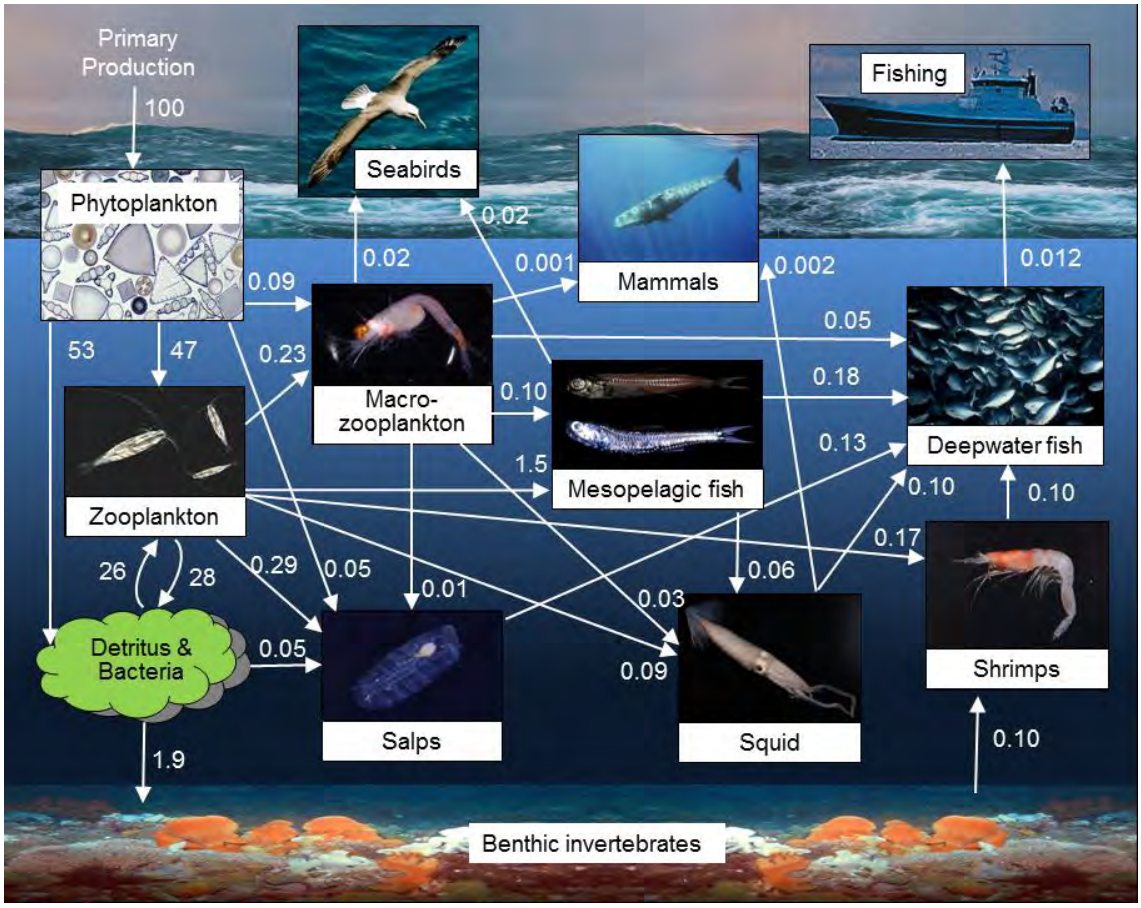


Figure 13.7: Simplified trophic model of the Chatham Rise, New Zealand (based on Pinkerton 2013). The growth of phytoplankton generates organic matter that is the fuel for the marine ecosystem. Figures show the annual flow of energy through a unit area of the food web normalised to a net primary productivity (NPP) of100, based on an equilibrium mass-balance model (similar to Ecopath).

13.6 METHODS FOR DETECTING TROPHIC AND ECOSYSTEM EFFECTS

Detecting trophic and ecosystem-level effects can be difficult as they often occur over broad temporal or spatial scales. This is particularly prevalent in the marine environment, where ecosystems and ecological thresholds can be difficult to define (Bland et al. 2018). At regional scales the easiest way to measure the effects of species on an ecosystem is to look at comparable habitats where the species is present and absent, either through experimental manipulation or natural experiments where species appear or disappear naturally over time or space.

Over broader scales ecosystem indicators can offer valuable insights. There is a consensus that a suite of indicators is needed to monitor and understand the impact of human activities on marine ecosystems (Cury & Christensen 2005 , Rice & Rochet 2005, McQuatters-Gollop et al. 2015). Given the multi-trophic nature of ecosystem-level effects and the interest in advancing approaches to ecosystem-based fisheries management (EBFM) (Rogers & Greenaway 2005, Tam et al. 2017, Thompson et al. 2019), indicators are needed that span the ecosystem, including primary producers, the microbial system, middle trophic levels, fish communities, the benthic community, and top predators. EBFM is an integrated management approach that includes consideration of both social and ecological components. A summary of some recommended indicators can be found in Appendix 1.

There has been much work in New Zealand on developing indicators of the marine environment. Fisheries New Zealand have carried out projects looking at indicators and time series, including oceanographic/climate variables (Hurst et al.

2012, Pinkerton et al. 2015a), primary production (D'Archino et al. 2019, 2021), demersal fish communities based on data from scientific trawls (Tuck et al. 2009), and a suite of indicators relevant to deepwater fisheries (Tuck et al. 2014). Other work in New Zealand on marine ecosystem indicators include reports under NIWA Core funding (Pinkerton 2010), national environmental reporting (Pinkerton 2007, Pinkerton 2014, Department of Conservation 2022) and a research project in the Hauraki Gulf funded by the Sustainable Seas National Science Challenge (https://www.sustainableseaschallenge.co.nz/our-research/ebfm-in-the-hauraki-gulf/). Existing information that can be used to detect trophic and ecosystem effects in New Zealand is summarised below.

13.6.1.1 MARINE PRIMARY PRODUCTION

Ocean colour satellite data, measuring concentrations of chlorophyll-a, has been used in New Zealand to investigate spatial and seasonal patterns in phytoplankton abundance and net primary production (NPP) (Murphy et al. 2001, Pinkerton 2007, Jiang et al. 2017, Pinkerton et al. 2019, 2024a). While there are other methods of estimating NPP from satellite data (Behrenfeld et al. 2005, Westberry et al. 2008), the concentration of chlorophyll-a (chl-a) is a more accurate and preferred metric for the purpose of monitoring change in primary production over time (Pinkerton et al. 2014, 2019, 2024a). Since 2002, mean concentrations of chlorophyll-a in the EEZ have varied spatially and temporally, with changes likely to be related to oceanographic cycles such as the Interdecadal Pacific Oscillation index and the Southern Oscillation Index, as well as to long-term climate change (evidence of surface warming since 1981). In the most recent update (Pinkerton et al., 2024a), at the ocean scale, increasing trends in chl-a were found in the Subtropical Front including a moderate increasing trend over the Chatham Rise (+1.0% of the median per decade), and a greater relative change in Subantarctic water to the south (+6.4% per decade). Conversely, a declining trend (-4.4% per decade) was identified in Subtropical waters located northeast of New Zealand. These findings generally align with previous analyses and our understanding of factors influencing primary productivity in the waters surrounding New Zealand. However, an unexpected and rapid decline in chl-a in all New Zealand ocean regions was observed since mid-2019 which has continued to late-2023. The rapid decline in chl-a in the New Zealand ocean domain may have ecological implications, including for New Zealand deepwater fisheries in the coming years.

At the New Zealand coastal scale, territorial waters have warmed over the last 40 years, and coastal scale marine heatwave events have generally become more frequent and longer-lasting (Pinkerton et al. 2024a). Since 2002, satellite observations have identified increases in chl-a around the coasts of mid-lower North Island and all South Island, particularly during winter. In contrast, coastal regions along the west coast of Northland and northeast New Zealand shelf including the Hauraki Gulf, Coromandel, and Bay of Plenty displayed decreasing trends in chl-a (productivity). Lower-than-normal chl-a was observed along the west coast of South Island during the MHW of December 2017 to March 2018 and December 2022 to January 2023 (Pinkerton et al. 2024a).

Satellite imagery data was analysed by Tait et al. (2021) to assess changes in surface canopy abundance of giant kelp *(Macrocystis pyrifera*) along the southeastern coastline of New Zealand. Sixty months of imagery was analysed for the period between December 2015 to December 2020, including the marine heatwave in 2017/2018. The approach computes vegetation indices based on measurements of near infrared electromagnetic radiation. The imagery detects vegetation not obscured by water, giving only the measurements of the floating macroalgal canopy and no indication of the full *Macrocystis* community. However, surface cover is still a key indicator of health in giant kelp populations and therefore remote sensed time series have great potential for identifying responses of kelp communities (important primary producers) to environmental stressors (Cavanaugh et al. 2011, Tait et al. 2021). Satellite imagery and aerial photography has also been used to map the spatial extent of kina barrens, which can highlight areas where kelp loss has occurred (Kerr et al. 2024, Dartnall 2022) and these methods will be applied to Fisheries New Zealand funded research project ZBD2023-03 in 2024/25.

13.6.1.2 LOWER FOOD WEB (MICROBIAL SYSTEM)

Changes to primary production are likely to translate to less food available for higher trophic levels. Virtually all wild-caught seafood in New Zealand is carnivorous, with a mean trophic index of about 4.1 (MacDiarmid et al. 2013). The trophic efficiency by which energy passes between trophic levels is often considered to be about 10% (Pauly & Christensen 1995), meaning that only about one-tenth of the energy consumed by marine organisms is used to build new body mass. This means that each tonne of wild-caught seafood in New Zealand has been supported by over a thousand tonnes of primary production that has been moved through at least two intermediate levels in the marine food web before being consumed by the target species. A change to the lower and middle parts of the New Zealand food web has the potential to affect food availability for, and potentially yield of, commercially important fish stocks. At present, there are no data available to monitor for changes in the functioning of the lower trophic levels of New Zealand's marine ecosystems or the efficiency of marine trophic transfer.

13.6.1.3 MIDDLE TROPHIC LEVELS

Middle trophic level organisms in the New Zealand ocean are diverse, from zooplankton, copepods, and krill to larger organisms such as myctophids (lanternfish) and forage fishes (e.g., anchovy, pilchards, and sprat). Although they form the basis of the diet of many commercially important New Zealand fish species (Dunn et al. 2009), the basic abundance, distribution, and ecology of key middle-trophic level groups such as myctophids and hyperbenthic arthropods (prawns and shrimps) are generally poorly known (Escobar-Flores et al. 2018). Two time series of data for middle trophic level organisms in the New Zealand ocean may be useful to investigate trophic and ecosystem-level effects: (a) New Zealand acquired a Continuous Plankton Recorder (CPR) in 2008 and this has been deployed annually since then on transits of a commercial fishing vessel to the Southern Ocean (Pinkerton et al., 2024b) in collaboration between NIWA and a commercial fishing company (Sanford Ltd), funded by MPI. The transits extend from Oamaru (approximately 45°S) to the Ross Sea; approximately 1200 km of this transect are in the subantarctic New Zealand EEZ (Robinson et al. 2021). The overall objective of the project is to understand spatial, seasonal, and long-term changes to zooplankton in New Zealand's southern EEZ and on the transit to the Ross Sea (Robinson et al. 2021). The latest analysis found a decreasing trend in phytoplankton, primary production, and total zooplankton abundance in the Ross Sea sector between 2008 and 2023, with an average rate for zooplankton of -1.9% of the mean per year (Pinkerton et al., 2024b). Trajectories of change differed between taxonomic groups of zooplankton, with some increasing. In contrast, phytoplankton, primary production and modelled environmental suitability for zooplankton generally increased in other parts of the Southern Ocean (+0.3% per year for zooplankton environmental suitability).

Other methods to estimate abundances of mid-trophic level organisms (MTLO) include multifrequency backscatter acoustic data (Escobar-Flores et al. 2022). From 2008–2014, acoustic data was analysed on 28 transects between New Zealand and the Ross Sea to identify changes in spatial and temporal patterns of MTLOs. While acoustic backscatter can be used to estimate changes in relative abundances of MTLOs over time, it is limited in its ability to estimate total biomass (Kloser et al. 2016, Pinkerton et al. 2023).The same method has been used to derive indices of abundance of mesopelagic fish and invertebrates on the Chatham Rise (McClatchie & Dunford 2003, O'Driscoll et al. 2009) and could provide valuable time series of middle trophic level species in the Hauraki Gulf and subantarctic plateau (Pinkerton et al. 2023).

13.6.1.4 DEMERSAL FISH COMMUNITIES

There are three series of scientific trawl surveys in New Zealand waters that are particularly valuable for understanding ecosystem dynamics and for monitoring for trophic and ecosystem-level effects at the level of the demersal fish community (Tuck et al. 2009): (a) a scientific trawl survey has been carried out on the Chatham Rise region approximately annually since 1992; (b) a similar survey has been carried out over the subantarctic plateau over the same period but less frequently (Bagley & O'Driscoll 2012, Tuck et al. 2009); (c) a total of 15 trawl surveys were done in the Hauraki Gulf

region between 1980 and 2000 and 2019 to present day (Parsons & Bian 2022). Each of these trawl surveys used a consistent methodology based on scientific bottom trawl gear. Tuck et al. (2009) used these scientific surveys to investigate change in a series of indicators based on the demersal fish community.

13.6.1.5 TOP PREDATORS

Top predators in New Zealand can also act as 'sentinel' species. Changes in their ecological behaviour such as distribution or diet preferences can indicate changes in trophic interactions and or environmental effects (Peters et al. 2022, Ogilvy et al. 2022). Sperm whales (*Physter macrocephalus*) and blue whales (*Balaenoptera musculus*) can act as excellent indicator species due to their long lifespan and high sensitivity to environmental shifts in their prey distribution and abundance (Hazen et al. 2019). For example, blue whale migrations are easy to observe, and their foraging patterns can offer predictions of trends in primary productivity (krill). Models based on three IPCC (Intergovernmental Panel on Climate Change) climate scenarios suggest that distributions of these species will shift southwards within the New Zealand EEZ by 2100 (Peters et al. 2022). Scenarios were based on Representative Concentration Pathways (RCP) 2.6, 4.5, and 8.5 (Pachauri et al. 2014). These pathways represent varying climate change scenarios in 2100, depending on the amount of greenhouse gases emitted in future, with 2.6 the least (~400 ppm CO_2e) and 8.5 the most (~1200 ppm CO_2e). The most severe scenario tested (RCP 8.5) generated 61% and 42% suitable habitat loss for sperm and blue whales respectively, mostly from New Zealand's northern waters.

The Māui dolphin (*Cephalorhynchus hectorii maui*) is a critically endangered cetacean that is endemic to New Zealand. Understanding its diet and foraging ecology could provide insights into its trophic relationships, habitat selection, and the health of the wider ecosystem (Derville et al. 2016). Decreases in stable isotopes $\delta^{13}C$ and $\delta^{15}N$, gathered from skin samples of Māui's dolphins between 1993 to 2021 suggests substantial changes to diet since the implementation of the Marine Mammal Sanctuary along the west coast of the North Island (Ogilvy et al. 2022). There is some concern that ENSO events are negatively impacting key dolphin prey such as juvenile red cod (Miller et al. 2013, Beentjes & Renwick 2001) and further monitoring of Māui's dolphin diet may provide a useful indication of climate change impacts to the food web.

13.7 DISCUSSION

Marine ecosystems are complex, show uneven responses to disturbance and are subject to a wide range of impacts, including fishing, climate variability and change, coastal runoff and eutrophication, habitat change, invasive species and potentially plastics. Any activities that change the composition of species in the ecosystem (in terms of size, functional group, ecosystem role, and diversity) can affect other groups in the ecosystem through trophic links and other relationships. There are thresholds that must be met before a change is observed, with more degraded systems having lower thresholds or resilience to impacts (Casini et al. 2009). A large range of trophic and ecosystem-level effects in marine systems have been documented internationally and these have generally been associated with negative impacts on fisheries (Garcia & Grainger 2005, Bakun & Weeks 2006, Valdes et al. 2009, Worm et al. 2009, Lindegren et al. 2010, Rogers-Bennet & Catton 2019). Understanding and quantifying the scale and causes of these changes remains scientifically challenging (Rice 2001, Brander 2010, Jennings & Brander 2010, Ter Hofstede et al. 2010). There remains substantial debate about the true extent and magnitude of these changes (Lindegren et al. 2016, Mumby et al. 2022) and how to allocate responsibility for these changes among different pressures, including fishing (Benoît & Swain 2008, Holt & Punt 2009, Kotta et al. 2009, Noakes & Beamish 2009, Rijnsdorp et al. 2009, Rice & Garcia 2011, Schiel 2013). Although ecosystem-level changes have rarely been ascribed solely to fisheries drivers, fishing is likely to contribute cumulatively alongside cross-sector and environmental impacts to make ecosystems less resilient to variability and change in climate/oceanographic forcing (Winder & Schindler 2004, Kirby et al. 2008, 2009). Reduced ecosystem resilience may affect the long-term sustainability of harvesting (Hughes et al. 2005), increase ecosystem variability (Salomon et al.

2010), make fisheries less predictable and harder to manage in a variable and changing climate (Badjeck et al. 2010, Brander 2010, McIlgorm et al. 2010), reduce the ability of ecosystems to recover from overfishing (Neubauer et al. 2013), and increase the likelihood or consequence of regime shifts or invasive species (Folke et al. 2004, Salomon et al. 2010).

To date, it has generally not proved possible to identify at what point fishing or other pressures may cause serious disruptions in resource productivity or ecosystem function through trophic or ecosystem-level effects. For multi-species fisheries that are managed at a stock level close to B_{MSY} in a way that does not progressively degrade benthic habitat, it is not known whether it is necessary to take trophic and ecosystem-level effects into account more explicitly to ensure long-term sustainability of fisheries (ICES 2005). Some studies (Jackson et al. 2001, Jennings et al. 2002, Branch 2009), model analyses (Walters et al. 2005, Legovic et al. 2010, Gecek & Legovic 2012, Legovic & Gecek 2012, Ghosh & Kar 2013), and expert groups (Scientific Committee on Ocean Research/Intergovernmental Oceanographic Commission working group; Cury & Christensen 2005) suggest that harvesting many species in an ecosystem at B_{MSY}[7] can lead to increased chance of fisheries collapse in the medium to long term – an effect called 'ecosystem erosion' or 'ecosystem overfishing' (Murawski 2000, Coll et al. 2008, Edgar et al. 2024).

ICES (2005) concluded that, for fisheries managed at or close to B_{MSY}, the priority was to avoid fishing practices that drastically changed benthic structure, trophic interactions, food web structures or nutrient cycling (ICES 2005). This is consistent with the widespread consensus that fisheries should be managed within an ecosystem context and by acknowledging the potentially synergistic effects of fishing and climate change (CBD 2009, Perry et al. 2010, Rice & Garcia 2011). This process of considering ecosystem level effects and interactions in fisheries management is commonly referred to as 'Ecosystem-based fisheries management' (EBFM; Townsend et al. 2019, Howell et al. 2021).

Ecosystem based fisheries management (or name variations thereof) is being increasingly implemented and used by governments around the world. Early fundamental work by the National Ocean and Atmospheric Association (NOAA) Fisheries (Marasco et al. 2007) outlined pragmatic approaches to ecosystem-based fishery management that can still be used today:

- incorporating a broader array of societal goals and uses for ecosystem products and services within a multiple use multiple stressor framework.
- recognising the significance of ocean-climate conditions.
- emphasising food web interactions (recognise that harvest of target species has profound impacts on ecosystem structure and function through trophic interactions).
- employing spatial representation (manage stocks consistent with spatial/habitat variation in productivity).
- increasing and expanding focus on characterising and maintaining viable fish habitats.
- expanding scope of research and monitoring (increased focus on understanding biological interactions/processes and measuring total fishery removals of target and non-target species).
- acknowledging and responding to higher levels of uncertainty (realistically incorporate uncertainty due to trophic and food web effects into management policy).
- reviewing and improving ecosystem modelling/research.

Building on these initial principles, NOAA Fisheries have developed an EBFM Policy and Roadmap that provides guidelines for the implementation of EBFM (National Marine Fisheries Service 2016). This document supports eight individual implementation plans to address the specific ecosystem needs and environmental conditions for regions around the United States. A full breakdown of global EBFM implementation is beyond the scope of this specific chapter. However, an EBFM approach is required to address trophic cascades and other ecosystem effects in fisheries management decisions.

[7] The biomass that allows the maximum sustainable yield to be taken.

There are differing opinions on the role of no-take reserves or marine protected areas (MPAs) in guarding against trophic and ecosystem-level effects. A full review of the value of MPAs in this regard is beyond the scope of this chapter. Some scientists believe strongly that MPAs can be effective at providing an 'ecological safety net' for trophic and ecosystem-level effects (Ballantine 2014, Edgar et al. 2014) whereas others believe MPAs are too few and too small to have any value in this regard (Kaiser 2005, Mora et al. 2006, Ovando et al. 2021, LaScala-Gruenewald et al. 2021). Viable no-take marine reserves that are large enough that most ecological processes are able to operate within them and are of sufficient size to encompass the home ranges of species or species groups that are the target of protection may have the most to contribute to our understanding of trophic and ecosystem effects by providing a 'reference ecosystem' in which populations experience low fishing pressure but a full range of other stressors (such as environmental variability/change, sedimentation, and pollution). Ecosystem changes in the reserve can then be contrasted with adjacent ecosystems exposed to the full range of fishing and other impacts (Micheli et al. 2005, Babcock et al. 2010, Hanns et al. 2022).

Specific recommendations from Marasco et al. (2007) in relation to EBFM in US fisheries are relevant to recent research initiatives in New Zealand. In 2022, the Sustainable Seas National Science Challenge (SSNSC) initiated an 'Improved decision making using an ecosystem-based management (EBM) approach" project that aims to deliver practical roadmaps for undertaking EBFM in New Zealand. The SSNSC also brought together research and provided input into regulation, policy and legislative reviews (Macpherson & Jorgensen 2024). Fisheries New Zealand commissioned further work in 2024 to advance an EBFM approach and incorporate ecosystem impacts into fisheries management decisions. These include an EBFM case study, and computer simulations to investigate the implications of incorporating ecosystem considerations into management targets and limits for fish stocks.

Addressing the issue of kina barrens has challenged New Zealand to advance the current ecosystem approach to fisheries management. A High Court decision in 2022 for the management of the CRA 1 spiny lobster stock in the Northland region confirmed that section 9 of the Fisheries Act 1996 provides an environmental bottom line requiring Fisheries New Zealand to incorporate ecosystem level issues, such as fishing-induced trophic cascades, into fisheries management decisions. Fisheries New Zealand held a National Kina Barrens workshop in Wellington in March 2023 as part of a research project on fishing-induced trophic cascades. This workshop provided a forum to share the most relevant science on the issue of trophic cascades leading to sea urchin barrens in New Zealand and developed a list of critical science and information required to support an EBFM approach (Doheny et al. 2023). Discussions with iwi and stakeholders to address the issue highlighted the need to incorporate mātauranga Māori, have harvest control rules for kina and predators and spatial planning. Outputs from this workshop are being progressed through science funding rounds and informing next steps for management.

Notwithstanding this progress, most New Zealand stocks are currently managed on a single-stock basis at close to B_{MSY} (Fisheries New Zealand 2024b) irrespective of their role in the ecosystem. Fishing close to B_{MSY} and in particular using bottom trawling (which impacts on benthic ecosystem function; Pusceddu et al. 2014) can reduce ecosystem resilience and increase ecosystem variability by trophic and ecosystem-level effects (Brock & Carpenter 2006, Carpenter & Brock 2006, van Nes & Scheffer 2007, Guttal & Jayaprakash 2008) and could increase recruitment variability. Fishing is also likely to strengthen bottom-up control of marine ecosystems (Durante et al. 2021) and make ecosystems more sensitive to the effects of climate change (Kirby et al. 2009, Perry et al. 2010). Greater sensitivity of marine ecosystems to climate variability implies a higher potential for regime shifts which may or may not be reversible (Hsieh et al. 2006). Stronger environmental (bottom-up) forcing of ecosystems suggests a greater likelihood of unexpected changes to fisheries due to extreme environmental events and that these changes may be more severe (Perry et al. 2010, Kirby & Beaugrand 2009).

Time series measurements are crucial to understanding ecosystem function and monitoring for trophic and ecosystem-level effects of fishing. There would be high value in maintaining regular fisheries-independent surveys of the demersal fish communities of key New Zealand regions (such as the Chatham Rise, Hauraki Gulf and subantarctic plateau). Information on the catches of all species by the fishing fleet is required to monitor for changes in trophically or ecologically important non-QMS species. A key knowledge gap is information to map and monitor abundances, trophic

connections, and community structure of middle trophic level species, especially mesozooplankton, mesopelagics and hyperbenthics in key fishing areas, such as the Chatham Rise, Hauraki Gulf, and the New Zealand Subantarctic Plateau.

13.8 CONCLUSIONS

1. A range of trophic and ecosystem-level effects in marine systems have been documented internationally, and these have generally been associated with negative impacts on fish stocks.

2. Trophic and ecosystem-level effects are not usually brought about by fishing alone, but fishing (especially overfishing but also at or close to B_{MSY}) in multispecies fisheries, especially using bottom impacting gear such as trawling, can make ecosystems less resilient and more sensitive to the effects of environmental variability and change.

3. The issue of kina barrens provides a valuable example of top-down forcing on ecosystems in New Zealand. Research based on observations from marine protected areas suggests fishing of sea urchin predators is causing and/or maintaining sea urchin barrens in north-east New Zealand (Doheny et al. 2023). However, the role of fishing and the extent of kina barrens appears to vary around the country depending on local physical and biological variables and the extent of different impacts on the ecosystem (Wing et al. 2022b). Further research is needed to understand the extent of kina barrens and contributing factors in other regions.

4. There is currently no evidence of a large-scale trophic or ecosystem-level effect impacting New Zealand's deepwater fisheries, but the cause of some changes in New Zealand's EEZ are not known (e.g., changes to hoki recruitment, Francis et al. 2006, Bradford-Grieve & Livingston 2011; trends in some demersal-fish indicators on the Chatham Rise and other areas, Tuck et al. 2009).

5. Time series monitoring of fish communities and middle trophic level species (meso/macro-zooplankton, mesopelagics, and hyperbenthics) are crucial for understanding and monitoring for trophic and ecosystem-level effects. However, there is a paucity of long-term monitoring information for fish communities within the New Zealand EEZ.

6. Approaches to addressing ecosystem effects on fisheries requires a combination of traditional measures (quota allocation, catch settings) alongside strategic fishing closures, selective fishing gear and economic incentives. In New Zealand, linking these approaches depends on collaboration between Māori, fisheries scientists and managers, biologists and stakeholders to use the best available data to manage coastal ecosystems sustainably. Successful implementation will require co-developing approaches that incorporate mātauranga Māori (traditional knowledge) and principals of Whanaungatanga (kinship) through equitable partnerships.

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13.10 APPENDIX 1 – METHODS FOR DETECTING TROPHIC AND ECOSYSTEM EFFECTS

MARINE PRIMARY PRODUCTION

The growth of phytoplankton in the upper layers of the ocean provides the vast majority of the energy that fuels marine ecosystems, and most fisheries, worldwide. Only in some (predominantly coastal) areas are other primary producers important: macroalgae (seaweed), seagrass, mangroves, epiphytes, autotrophic periphytes, microphytobenthos and chemosynthesisers. Light, temperature, and nutrient concentrations are major factors controlling net[8] primary production (NPP) by phytoplankton growth in the ocean (Laufkötter et al. 2015, Le Grix et al. 2022). NPP can be measured accurately from ships (typically using radioactive carbon incubations), but because of the high spatial and temporal variability of NPP, ship-based sampling is not adequate for monitoring. Instead, remotely sensed data from sensors on Earth-observing satellites are typically used to estimate NPP. There are significant differences between different methods of estimating NPP from satellite data (Campbell et al. 2002). Often, the concentration of chlorophyll-a, the ubiquitous pigment in phytoplankton, is used as a proxy for phytoplankton biomass and NPP, because this can be measured remotely with better accuracy than NPP using ocean colour satellite sensors (Roxy et al. 2016, Capuzzo et al. 2018).

LOWER FOOD WEB (MICROBIAL SYSTEM)

[8] 'Net' means after allowing for phytoplankton respiration.

Rice (2001) notes that processes that make large alterations to the allocation of production between the microbial loop, benthic detrital pathways and mesopelagic consumers may have much more impact on the dynamics of higher trophic levels than processes that alter NPP. More recently, Friedland et al. (2012) examined the relationships between NPP, fisheries yield, and parameters describing the transfer of organic matter through 52 large marine ecosystems and found that chlorophyll-a concentration, the particle-export ratio (p-ratio: the proportion of NPP exported from the surface layer of the ocean) and the ratio of mesozooplankton productivity to NPP (z-ratio) were all significantly related to fisheries yields. Stock & Dunne (2010) suggest that a warmer ocean will lead to a lower z-ratio (less mesozooplankton for a given NPP) and Friedland et al. (2012) show that lower z-ratios correspond to lower fisheries yields at basin scales.

MIDDLE TROPHIC LEVELS

Small mesopelagic[9] and hyperbenthic[10] organisms are an important part of marine ecosystems. They act as the link between the microbial/planktonic system and larger predators such as seabirds, marine mammals, and larger fish (Escobar-Flores et al. 2018, 2020). These 'middle trophic level' organisms are diverse and include hard-bodied crustaceans (such as copepods, euphausiids, amphipods, prawns and shrimps), 'jellies' (such as jellyfish and salps), cephalopods (squids and octopods), and a range of small fishes (including juveniles of larger species) living in the water column (especially myctophids or lanternfishes) or near the seabed. These species are likely to be affected both by fishing, which may reduce top-down predation control, and by climate-driven changes in lower trophic food web components (Frank et al. 2007, Richardson 2008). Middle trophic level species have a key role in ocean ecology (e.g., Banse 1995, Marine Zooplankton Colloquium 2 2001, Smetacek et al. 2004, Pinkerton 2013). Studying these middle trophic level organisms is challenging. They are typically diverse, with varied and complex life histories, can be hard to capture, and have abundances that vary over a wide range of space and time scales. Consequently, the factors that affect their dynamics are generally poorly understood. Two methods have been used for monitoring middle trophic levels. First, long time series of measurements of the zooplankton community by the Continuous Plankton Recorder (CPR) has demonstrated change in marine ecosystem (Mc Quatters-Gollop et al. 2015, Pinkerton et al. 2020, Suter et al. 2021), and been recommended as an effective way of monitoring the state of pelagic ecosystems (Beaugrand 2005). Second, multifrequency acoustics have been used to monitor abundances of mesopelagics over extended time and space scales (Trenkel & Berger 2013, Sakinan & Gücü 2017, Escobar-Flores et al. 2018, Mouget et al. 2020). However, this methodology requires more specialized knowledge and equipment than the CPR.

DEMERSAL FISH COMMUNITIES

Most of the international effort on developing ecosystem indicators have focused on those for the demersal fish community, usually based on commercial landings data or, less commonly, on catch data from fisheries surveys. Consequently, very many indicators have been proposed – a selection is discussed below.

> Marine Trophic Index: MTI is the mean trophic level of fisheries landings (Pauly & Watson 2005, Durante et al. 2020). It was recommended for use with commercial catch data by the United Nations Biodiversity Convention as a widely applicable and cost-effective indicator for monitoring reductions in biodiversity loss in marine ecosystems (CBD 2004). MTI is scored between a 1 (primary producers) to 5 (apex predators). Gradual declines in trophic levels have been observed in many finfish fisheries around the world since industrialised fishing began (Pauly et al. 1998a, Christensen et al. 2003, Christensen et al. 2014). They vary regionally around the world based on targeted species, fishing intensity, and equipment used (, Adebola & de Mutsert 2019, Durante et al. 2020). These declines are generally ascribed to fisheries targeting high trophic level species and moving on to lower trophic level species as these large species are depleted, a change called 'fishing down the food web' (Pauly et al. 1998a, Schiller et al. 2015). Essington et al. (2006) noted that 'fishing through the food web', where higher

[9] 'Mesopelagic': inhabiting the intermediate depths of the sea, between about 200 and 1000 m down.

[10] 'Hyperbenthic': ecologically associated with the seabed but living for some time in the lower water column.

trophic level fish landings are maintained but catch of lower trophic level species increases over time, may occur more often. MTI calculated from total commercial catch will vary with changes in the mix of species targeted by different fisheries over time, the relative importance of different fisheries sectors (e.g., finfish versus invertebrate fisheries), how much of the catch is reported, the quality of identification of species, and for other reasons not necessarily associated with effects of fishing (Caddy et al. 1998, Pauly et al. 1998b, Tuck et al. 2009, Branch et al. 2010, Durante et al. 2020). As such, MTI based on scientific surveys is likely to be a better indicator of change in fish communities (Branch et al. 2010, Durante et al. 2020). While the use of MTI to detect trophic shifts is widely used, modelling by Bourdaud et al. (2016) found that two new indicators, high trophic level indicator (HTI) and apex predator indicator (API) may be more suitable. The HTI is the ratio of the biomass of apex predators (TL>4) to the total biomass of consumers (TL>2) present in the ecosystem, and the API is the ratio of apex predators' biomass to the biomass of all groups whose trophic level is greater than 3.25 (Moullec et al. 2017). Trophic level cut-offs for both HTI and API were chosen to 'disentangle' the environmental effects that may disproportionately influence lower trophic organisms, from the effects of fishing.

- Species-based indicators: Many indices of diversity have been applied to fish communities (e.g., Peet 1974, Warwick & Clarke 1995, Bianchi et al. 2000, Greenstreet & Rogers 2006). These diversity indices are joint constructs of how many species are present (richness), and how similar their abundances are (evenness). Some indices give additional emphasis to the most important species in a community (dominance). Measures vary in the relative weight given to each of these factors, and on the metric used for similarity between species (e.g., by including a measure of taxonomic distinctiveness or not; Warwick & Clarke 1995). Fishing rarely causes large-scale extirpation so that measures of total species richness are likely to be less sensitive to change in trophic or ecosystem-level properties than measures of evenness. Different measures of evenness respond variously to fishing; they can increase, reduce or be unaffected by fishing depending on the initial characteristics of the ecosystem. A community initially dominated by k-selected[11] species would be expected to become more even and show increasing diversity metrics due to fishing; fishing would be expected to allow the faster growing (initially minor species) to increase at the expense of the slower growing (initially dominant) species. In contrast, diversity and evenness metrics may be expected to decrease after fishing if the ecosystem were originally dominated by r-selected[12] species.
- Functional group-based indicators: Changes to the relative abundance of different functional groups in an ecosystem can indicate trophic or ecosystem-level changes (Fulton et al. 2005, Methratta & Link 2007, Shannon et al. 2009). Functional groups can be based on various descriptors of ecological niche, such as position in the water column (e.g., pelagic, demersal, benthic), trophic guild/feeding type (e.g., piscivore, pelagic invertebrate feeder, benthic feeder, scavenger), taxonomy (e.g., elasmobranch, gadoid, macrourid), or a combination of multiple ecological and life-history traits (Methratta & Link 2007), which can be combined to suggest high or low resilience (Tuck et al. 2009). A simple and commonly used index is the proportion of piscivorous fish to all fish caught. As piscivorous fish tend to be disproportionately impacted by fishing (Caddy & Garibaldi 2000), their relative abundance in fish assemblages is a measure of ecosystem state and may reveal a trophic or system-level impact of fishing.
- Size based indicators: Marine trophic processes tend to be strongly structured by size (Badalamenti et al. 2002, Jennings et al. 2002). Fishing may lead to substantial modifications in the size structure of exploited populations because (a) high-value, generally larger species are targeted by fisheries, (b) fishing gears are size selective, often designed to catch larger fish and let smaller ones escape, (c) the cumulative effect of fishing (over the life of a cohort) leads to fewer older (larger) fish, and (d) long-lived species tend to be affected more as they have lower potential rates of increase (Eigaard et al. 2016, Tu et al. 2018). Several size-based metrics have been used to detect trophic and ecosystem-level changes (e.g., Collie et al. 2016, Lappalainen et al. 2016, Eigaard et al. 2016, Coll et al. 2008). Size-based indicators can be applied at a species or community level. Applied to a given species,

[11] Those that produce relatively low numbers of offspring, typically growing more slowly and maturing later.

[12] Those that produce high numbers of offspring, typically growing faster and maturing sooner.

possible size-based indicators include: (a) mean length at age; (b) condition (weight at length, e.g., Winters & Wheeler 1994); (c) proportion of large fish; and (d) mean length at maturity in the population. Size-based methods at the community level include: (a) mean length in the community; (b) proportion of large individuals in the community; (c) the biomass size-spectrum; and (d) the diversity size spectrum (Collie et al. 2016, Lappalainen et al. 2016).

- Spatial distributions: Fishing and climate change can alter the geographic distribution of fish species (Perry et al. 2010) and this can indicate an ecosystem-level change. The percentage area of a research survey in which most (typically 90%) of the population occurs has been used as an ecosystem indicator (e.g., Fisher & Frank 2004, Tuck et al. 2009).
- Diet-based indicators: The change of diet (or trophic position) of a species of fish may reveal that trophic or ecosystem-level changes have occurred (e.g., Smith & Lucey 2014), but trophic position may change less than the underlying ecosystem structure (Badalamenti et al. 2002). 'Niche width' measured in terms of the range of carbon and nitrogen isotope ratios occupied by a species has also been suggested as indicative of trophic changes in a marine ecosystem especially in relation to upper trophic level predators (Layman et al. 2007), but the utility of this has been questioned (Hoeinghaus & Zeug 2008).

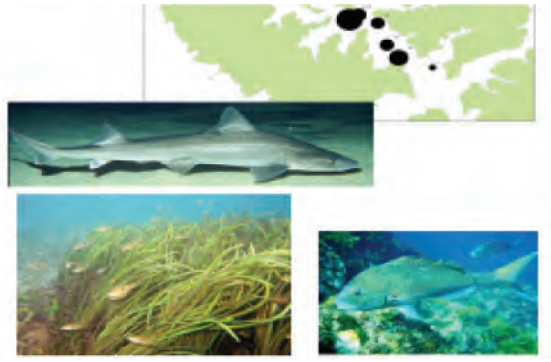
TOP PREDATORS

Top predators (upper trophic level consumers) can be used in two ways as indicators of the state of marine ecosystems. First, one Organisation of Economic Co-operation and Development (OECD) core indicator is the overall ecological threat status of species in the ecosystem, often with an emphasis placed on top predators (OECD 2003). Second, ecological aspects of selected predator species can be used to indicate changes in ecosystems. For example, top predators are widely used in monitoring the ecosystem effects of fishing krill in the Southern Ocean (Reid et al. 2005, Constable 2006), with information on the breeding of penguins, albatross, petrels, and seals collected, summarised, and considered in management annually (CEMP 2004, Agnew 1997).

Monitoring top predators as 'bellweathers' of ecosystem health is also increasingly used elsewhere (Boyd et al. 2006, Ainley 2002) as they are recognised as potentially useful downstream integrators of change in the marine ecosystem, exploit marine resources at similar spatial and temporal scales to humans, and receive high public interest. Top predators can also be indicators of ecosystem health, through the bioaccumulation of toxins and chemicals passed upwards through trophic levels. Halogenated organic compounds (HOCs) were found in five selected marine mammal species off the Southern California Bight. Cetacean species (long-beaked common dolphin, short-beaked common dolphin, and Risso's dolphin) averaged 128 HOCs, whereas pinnipeds (California sea lion and Pacific harbour seal) averaged 47 HOCs (Cossaboon et al. 2019). This demonstrates that certain chemicals, even while they're now banned, may still exist in the environment. However, given that predators respond in complex ways to many factors simultaneously, ascertaining the appropriate management response to change of a predator-based indicator is difficult (Boyd et al. 2006).

Chapter 14: Habitats of particular significance for fisheries management - Technical Summary

Loss of habitat and its connectivity



Land-based effects, benthic impacts, climate change

1. THE ISSUE IN BRIEF

- Protection of habitats of particular significance for fisheries management (HPSFM) is sanctioned in the Fisheries Act 1996
- HPFSMs have not yet been defined or applied, but some candidate habitats, such as spawning grounds and nursery areas, have been proposed
- Loss of habitat and of the connectivity between habitats have been highlighted as two of the most significant issues facing the health of marine ecosystems in New Zealand
- Like land-based impacts (see Chapter 15), HPSFM also requires an ecosystem-based approach to management

2. HABITAT SIGNIFICANCE

- HPSFMs have been proposed in areas where fish spawn and complete early life stages, but defining HPSFMs remains challenging because habitat significance is species- and life stage-specific and the elements of the habitat that are particularly important can be unclear
- Harbours and coastal areas are identified as spawning sites for several coastal fish species, but offshore areas and features such as seamounts can be relevant for deep-sea and pelagic species spawning and feeding (e.g., the Chatham rise). Overall, most areas to 1500 m of depth are significant to one species or another, but not yet quantified
- Habitat complexity plays a strong role in defining significance for fish species, and habitats built by living organisms (e.g., bryozoan beds and seagrass meadows) are particularly complex. Several existing protection measures already target some of these features
- Habitat complexity and naturalness are also relevant in freshwater, where migratory species like long-finned eels thrive in intact habitats and are negatively affected by loss of connectivity (see box 3)

3. HABITAT CONNECTIVITY LOSS

- Some animals move between different HPSFM throughout their lives
- Lack of connectivity between different HPSFM can be a potential bottleneck, can magnify the effects of habitat loss, and undermine habitat protection measures
- This is most evident in species that migrate over long distances through their life
- An example is freshwater eels that need to return to the sea to reproduce and complete their life cycle and may have their migration pathways blocked by dams



Habitat fragmentation (e.g., dams) can negatively impact species that migrate over long distances

14 HABITATS OF PARTICULAR SIGNIFICANCE FOR FISHERIES MANAGEMENT (HPSFM)

Status of chapter	This chapter has not been updated for AEBAR 2021.
Scope of chapter	This chapter highlights subject areas that might contribute to the management of HPSFM and hence provides a guide for future research.
Area	All of the New Zealand EEZ and Territorial Sea (inclusive of the freshwater and estuarine areas).
Locality hotspots	None formally defined, but already identified likely candidates include areas of biogenic habitat, e.g., Separation Point and Wairoa Hard, and areas identified with large catches and/or vulnerable populations of juveniles, e.g., Hoki Management Areas, packhorse crayfish legislated closures and toheroa beaches.
Key issues	Identifying likely HPSFM and potential threats to them.
Emerging issues	Connectivity and intra-population behaviour variability, multiple use.
MPI research (current)	HAB2007/01 *Biogenic habitats as areas of particular significance for fisheries management*; TOH2007/03 *Toheroa abundance*; ZBD2008/01 *Research on Biogenic Habitat-Forming Biota and their functional role in maintaining Biodiversity in the Inshore Region (5-150M Depths)* – this is also part-funded by Oceans Survey 2020, NIWA and MBIE; ENV2009/07 *Habitats of particular significance for fisheries management: Kaipara Harbour*; ENV2010/03 *Habitats of particular significance for inshore finfish fisheries management*; GMU2009/01 *Spatial Mixing of GMU1 using Otolith Microchemistry*.
NZ government research (current)	Ministry of Business, Innovation and Employment (MBIE) funded programmes (Coastal Conservation Management: C01X0907 *Protecting the functions of marine coastal habitats that support fish assemblages at local, regional and national scales*; C01X1229 *Predicting the occurrence of vulnerable marine ecosystems for planning spatial management in the South Pacific region*; C01X0906 *Impacts of resource use on vulnerable deep-sea communities*. NIWA Core funding in the 'Managing marine stressors' area under the 'Coasts and Oceans' centre, specifically the programme 'Managing marine resources' and the project 'Measuring mapping and conserving (C01X0505)'.
Related chapters/issues	Land-based impacts on fisheries and supporting biodiversity, bycatch composition, marine environmental monitoring.

14.1 CONTEXT

The Fisheries Act 1996, in Section 9 (Environmental principles) states that:

'All persons exercising or performing functions, duties, or powers under this Act, in relation to the utilisation of fisheries resources or ensuring sustainability, shall take into account the following environmental principles:

a. *Associated or dependent species should be maintained above a level that ensures their long-term viability:*
b. *Biological diversity of the aquatic environment should be maintained:*
c. ***Habitat of particular significance for fisheries management should be protected.'***

Work is currently ongoing on a guidance document for implementing habitats of particular significance for fisheries management (HPSFM).

This chapter will focus on examples of habitats shown to be important for fisheries and concepts likely to be important to HPSFM. Examples of potential HPSFM include: sources of larvae; larval settlement sites; habitat for juveniles; habitat that supports important prey species; migration corridors; and spawning, pupping or egg-laying grounds. Some of these habitats may be important for only part of the life cycle of an organism, or for part of a year.

The relative importance of habitats, compared with other limiting factors, is largely unknown for most stocks. For example, some stocks may be primarily habitat limited, whereas others may be limited by oceanographic

variability, food supply, predation rates (especially during juvenile phases), or a mixture of these and other factors. In the case of stocks that are habitat limited, a management goal might be to preserve or improve some aspect of the habitat for the stock.

Hundreds of legislated spatial fisheries restrictions already apply within New Zealand's Territorial Sea and Exclusive Economic Zone (www.nabis.govt.nz), but until further policy work and research is conducted we cannot be sure of what contribution they make to protecting HPSFM. Examples of these are listed below:

- Separation Point in Tasman Bay, and the Wairoa Hard in Hawke Bay, were created to protect biogenic habitat that was believed to be important as juvenile habitat for a variety of fish species (Grange et al. 2003).
- An area near North Cape is currently closed to packhorse lobster fishing to mitigate sub-legal handling disturbance in this area. This closure was established because of the small size of lobsters caught there and a tagging study that showed movement away from this area into nearby fished areas (Booth 1979).
- The largest legislated closures are the Benthic Protection Areas (BPAs) that protect about 1.2 million km^2 (about 31% of the EEZ) outside the Territorial Sea from contact of trawl and dredge gear with the bottom (Helson et al. 2010).
- Commercial fishers must not use New Zealand fishing vessels or foreign-owned New Zealand fishing vessels over 46 m in overall length for trawling in the Territorial Sea.

In addition to legislated closures, a number of non-regulatory management measures exist. For example:

- Spatial closures:
  - Trawlers greater than 28 m in length are excluded from targeting hoki in four Hoki Management Areas – Cook Strait, Canterbury Banks, Mernoo Bank, and Puysegur Bank (Deep Water Group 2008). These areas were chosen because of the larger number of juveniles caught, relative to adults in these areas.
  - Trawling and pair trawling are both closed around Kapiti Island.
- Seasonal closures:
  - A closure to trawling exists from 1 November until 30 April each year in Tasman Bay.
  - A closure to commercial potting exists for all of CRA 3 for the whole of the month of December each year.

The highly migratory fish plan addresses HPSFM in environment outcome 8.1 'Identify and where appropriate protect habitats of particular significance to highly migratory species, especially within New Zealand waters'. In the deepwater fish plan the Ministry proposes in Management Objective 2.3 'to develop policy guidelines to determine what constitutes HPSFM then apply these policy guidelines to fisheries where necessary'. Inshore fisheries management plans (freshwater, shellfish and finfish) all contain references to identifying and managing HPSFM. These plans recognise that not all impacts stem from fisheries activities, therefore managing them may include trying to influence others to better manage their impacts on HPSFM. Work is underway on a guidance document for HPSFM that will assist in implementing these outcomes and objectives.

14.2 GLOBAL UNDERSTANDING

This section focuses upon those habitats protected overseas for their value to fisheries and discusses important concepts that may help gauge the importance of any particular habitat to fisheries management. This information may guide future research into HPSFM in New Zealand and any subsequent management action.

14.2.1 HABITATS PROTECTED ELSEWHERE FOR FISHERIES MANAGEMENT

Certain habitats have been identified as important for marine species including: shallow sea grass meadows, wetlands, seaweed beds, rivers, estuaries, rhodolith beds, rocky reefs, crevices, boulders, bryozoans, submarine canyons, seamounts, coral reefs, shell beds and shallow bays or inlets (Kamenos et al. 2004, Caddy 2008, Clark 1999, Morato et al. 2010a). Discrete habitats (or parts of these) may have extremely important ecological functions, and/or be especially vulnerable to degradation. For example, seabeds with high roughness are important for many fisheries and can be easily damaged by interaction with fishing gear (Caddy 2008). Examples of these include:

1. The *Oculina* coral banks off Florida were protected in 1994 as an experimental reserve

in response to their perceived importance for reef fish populations (Rosenberg et al. 2000). Later studies confirmed that this area is the only spawning aggregation site for gag (*Mycteroperca microlepis*) and scamp (*M. phenax*) (both groper species), and other economically important reef fish in that region (Koenig et al. 2000). The size of the area within which bottom-tending gears were restricted was subsequently increased based on these findings (Rosenberg et al. 2000).

2. Lophelia cold-water coral reefs are now protected in at least Norway (Fosså et al. 2002), Sweden (Lundälv & Jonsson 2003) and the United Kingdom (European Commission 2003) due to their importance as habitat for many species of fish (Costello et al. 2005).
3. The Western Pacific Regional Fishery Management Council identified all escarpments between 40 m and 280 m as Habitat Areas of Particular Concern (HAPC) for species in the bottom-fish assemblage. The water column to a depth of 1000 m above all shallow seamounts and banks was categorised as HAPC for pelagic species. Certain north-west Hawaiian Island banks shallower than 30 m were categorised as HAPC for crustaceans, and certain Hawaiian Island banks shallower than 30 m were classified as Essential Fish Habitat (EFH) for precious corals. Fishing is closely regulated in the precious-coral EFH, and harvest is only allowed with highly selective gear types that limit impacts, such as manned and unmanned submersibles (Western Pacific Fishery Management Council 1998)

Examples of habitats protected for their freshwater fishery values also exist. For example, the US Atlantic States Interstate fishery management plan (Atlantic States Marine Fisheries Commission 2000) notes the Sargasso Sea is important for spawning, and that seaweed harvesting provides a threat of unknown magnitude to eel spawning. Habitat alteration and destruction are also listed as probably impacting on continental shelves and estuaries/rivers, respectively, but the extent to which these are important is unknown.

It is also possible that HPSFM may be defined by the functional importance of an area to the fishery. For example, large spawning aggregations can happen in midwater for set periods of time (Schumacher & Kendall 1991, Livingston 1990) these could also potentially qualify as HPSFM.

14.2.2 CONCEPTS POTENTIALLY IMPORTANT FOR HPSFM

Many nations are now moving towards formalised habitat classifications for their coastal and ocean waters, which may include fish dynamics in the classifcation, and could potentially help to define HPSFM. Such systems help provide formal definitions for management purposes, and to 'rank' habitats in terms of their relative values and vulnerability to threats. Examples include the Essential Fish Habitat (EFH) framework being advanced in North America (Benaka 1999, Diaz et al. 2004, Valavanis et al. 2008), and in terms of habitat, the developing NOAA Coastal and Marine Ecological Classification Standard for North America (CMECS) (Madden et al. 2005, Keefer et al. 2008), and the European Marine Life Information Network (MarLIN) framework, which has developed habitat classification and sensitivity definitions and rankings (Hiscock & Tyler-Walters 2006).

Habitat connectivity (the movement of species between habitats) operates across a range of spatial scales, and is a rapidly developing area in the understanding of fisheries stocks. These movements link together different habitats into 'habitat chains', which may also include 'habitat bottlenecks', where one or more spatially restricted habitats may act to constrain overall fish production (Werner et al. 1984). Human-driven degradation or loss of such bottleneck habitats may strongly reduce the overall productivity of populations, and hence ultimately reduce long-term sustainable fisheries yields. The most widely studied of these links is between juvenile nursery habitats and often spatially distant adult population areas. Most studies published have been focused on species that use estuaries as juveniles (e.g., blue grouper *Achoerodus viridis* (a large wrasse) (Gillanders & Kingsford 1986) and snapper *Pagrus auratus* (Hamer et al. 2005) in Australia; and gag (*Mycteroperca microlepis*) in the United States (Ross & Moser 1995)), which make unidirectional ontogenetic habitat shifts from estuaries and bays out to the open coast as they grow from juveniles to adults. The extent of wetland habitats in the Gulf of Mexico has also been linked to the yield of fishery species dependent on coastal bays and estuaries. Reduced fishery stock production (of shrimp and the fish menhaden) followed wetland losses and, conversely, stock gains followed increases in the area of

wetlands (Turner & Boesch 1987). Juvenile production was limited by the amount of available habitat but, equally, reproduction, larval settlement, juvenile or adult survivorship, or other demographic factors could also be limited by habitat loss or degradation, and these could have knock-on effects to stock characteristics such as productivity and its variability. Other examples include movements that may be bidirectional and regular in nature e.g., seasonal migrations of adult fish to and from spawning and/or feeding grounds, e.g., grey mullet *Mugil cephalus* off Taiwan (Chang et al. 2004).

How habitats are spatially configured to each other is also important to fish usage and associated fisheries production. For example, Nagelkerken et al. (2001) showed that the presence of mangroves in tropical systems significantly increases species richness and abundance of fish assemblages in adjacent seagrass beds. Jelbart et al. (2007) sampled Australian temperate seagrass beds close to (within 200 m) and distant from (more than 500 m from) mangroves. They found seagrass beds closer to mangroves had greater fish densities and diversities than more distant beds, especially of juveniles. Conversely, the densities of fish species in seagrass at low tide that were also found in mangroves at high tide were negatively correlated with the distance of the seagrass bed from the mangroves. This shows the important daily habitat connectivity that exists through tidal movements between mangrove and seagrass habitats. Similar dynamics may occur in more subtidal coastal systems at larger spatial and temporal scales. For example, Dorenbosch et al. (2005) showed that adult densities of coral reef fish, whose juvenile phases were found in mangrove and seagrass nursery habitats, were much reduced or absent on coral reefs located far distant from such nursery habitats, relative to those in closer proximity.

A less studied, but increasingly recognised theme is the existence of intra-population variability in movement and other behavioural traits. Different behavioural phenotypes within a given population have been shown to be very common in land birds, insects, mammals, and other groups. An example of this is a phenomenon known as 'partial migration', where part of the overall population migrates each year, often over very large distances, while another component does not move and remains resident. By definition, this partial migration also results in differential use of habitats, often over large spatial scales. Recent work on white perch (*Morone americana*) in the United States shows that this population is made up of two behavioural components: a resident natal freshwater contingent, and a dispersive brackish-water contingent (Kerr et al. 2010). The divergence appears to be a response to early life history experiences that influence individuals' growth (Kerr 2008). The proportion of the overall population that becomes dispersive for a given year class ranges from 0% in drought years to 96% in high-flow years. Modelling of how differences in growth rates and recruitment strengths of each component contributed to the overall population found that the resident component contributed to long-term population persistence (stability), whereas the dispersive component contributed to population productivity and resilience (defined as rebuilding capacity) (Kerr et al. 2010). Another species, winter flounder *Pseudopleuronectes americanus*, has also shown intra-population variability in spawning migrations; one group stays coastally resident while a second smaller group migrates into estuaries to spawn (De Celles & Cadrin 2010). The authors went on to suggest that coastal waters in the Gulf of Maine should merit consideration in the assignment of Essential Fish Habitat for this species.

Kerr & Secor (2009) and Kerr et al. (2010) argue that such phenotypic dynamics are probably very common in marine fish populations but have not yet been effectively researched and quantified. The existence of such dynamics would have important implications for fisheries management, including the possibility of spatial depletions of more resident forms and variability in the use of potential HPSFM between years. For instance, recent work on snapper in the Hauraki Gulf has shown that fish on reef habitats are more resident (i.e., have less propensity to migrate) than those of soft sediment habitats, and can experience higher fishing removals (Parsons et al. 2011).

The most effective means of protecting a HPSFM in terms of the benefit to the fishery may differ depending on the life-history characteristics of the fish. A variety of modelling, theoretical, and observational approaches have led to the conclusion that spatial protection performs best at enhancing species whose adults are relatively sedentary but whose larvae are broadcast widely (Chiappone & Sealey 2000, Murawski et al. 2000, Roberts 2000, Warner et al. 2000). The sedentary habit of adults allows the stock to accrue the maximum benefit from the protection, whereas the broadcasting of larvae helps 'seed' segments of the population outside the protection. However, the role of spatial protection in directly protecting juveniles after they have settled to seafloor habitats (via habitat protection/recovery, and/or reduced juvenile bycatch), or

their interaction with non-fisheries impacts has not yet been explicitly considered.

14.3 STATE OF KNOWLEDGE IN NEW ZEALAND

14.3.1 POTENTIAL HPSFM IN NEW ZEALAND

Important areas for spawning, pupping, and egg-laying are potential HPSFM. These areas (insofar as these are known) have been identified and described using science literature and fisheries databases and summarised within two atlases, one coastal (less than 200 m) and one deepwater (more than 200 m). Coastally, these HPSFM areas were identified for 35 important fish species by Hurst et al. (2000b). This report concluded that virtually all coastal areas were important for these functions for one species or another. The report also noted that some coastal species use deeper areas for these functions, either as juveniles, or to spawn (e.g., red cod, giant stargazer) and some coastal areas are important for juveniles of deeper spawning species (e.g., hake and ling). Some species groupings were apparent from this analysis. Elephant fish, rig, and school shark all preferred to pup or lay eggs in shallow water, and very young juveniles of these species were found in shallow coastal areas. Juvenile barracouta, jack mackerel (*Trachurus novaezelandiae*), kahawai, rig, and snapper were all relatively abundant (at least occasionally) in the inner Hauraki Gulf. Important areas for spawning, pupping, and egg-laying were identified for 32 important deepwater fish species (200 to 1500 m depth), 4 pelagic fish species, 45 invertebrate groups, and 5 seaweeds (O'Driscoll et al. 2003). This study concluded that all areas to 1500 m deep were important for either spawning or for juveniles of one or more species studied. The relative significance of areas was hard to gauge because of the variability in the data, however the Chatham Rise was identified as a 'hotspot'.

Areas of high juvenile abundances of certain species may be useful indicators of HPSFM for some species. A third atlas (Hurst et al. 2000b) details species distributions (mainly commercial) of adult and immature stages from trawl, midwater trawl and tuna longline where adequate size information was collected. No conclusions are made in this document, and generalisations across species are inherently difficult, therefore like the previous two atlases, this document is probably best examined for potential HPSFM in a species specific way.

Certain locations within New Zealand already seem likely to qualify as HPSFM under any likely definition. The Kaipara Harbour has been identified as particularly important for the SNA 8 stock. Analysis of otolith chemistry showed that, for the 2003 year class, a very high proportion of new snapper recruits to the SNA 8 stock were sourced as juveniles from the Kaipara Harbour (Morrison et al. 2008). This result is likely to be broadly applicable into the future as the Kaipara provides most of the biogenic habitat available for juvenile snapper on this coast. The Kaipara and Raglan harbours also showed large catches of juvenile rig and the Waitemata, Tamaki and Porirua harbours moderate catches (Francis et al. 2012). Recent extensive fish habitat sampling within the Kaipara harbour in 2010 as part of the MBIE Coastal Conservation Management programme showed juvenile snapper to be strongly associated with subtidal seagrass, horse mussels, sponges, and an introduced bryozoan. Negative impacts on such habitats have the potential to have far-field effects in terms of subsequent fisheries yields from coastal locations well distant from the Kaipara Harbour. Beaches that still retain substantive toheroa populations, e.g., Dargaville and Oreti beaches, may also potentially qualify as HPSFM (Beentjes 2010).

Consistent with the international literature, biogenic (living, habitat forming) habitats have been found to be particularly important juvenile habitat for some coastal fish species in New Zealand. For example: bryozoan mounds in Tasman Bay are known nursery grounds for snapper, tarakihi and John dory (Vooren 1975); northern subtidal seagrass meadows fulfil the same role for a range of fish including snapper, trevally, parore, garfish and spotties (Francis et al. 2005, Morrison et al. 2008, Schwarz et al. 2006, Vooren 1975); northern horse mussel beds for snapper and trevally (Morrison et al. 2009); and mangrove forests for grey mullet, short-finned eels, and parore (Morrisey et al. 2010). Many other types of biogenic habitats exist, and some of their locations are known (e.g., see Davidson et al. 2010 for biogenic habitats in the Marlborough Sounds), but their precise role as HPSFM remains to be quantified. Examples include open coast bryozoan fields, rhodoliths, polychaete (worm) species ranging in collective form from low swathes to large high mounds, sea pens and sea whips, sponges, hydroids, gorgonians, and many forms of algae, ranging from low benthic forms such as *Caulerpa* spp. (sea rimu) through to giant kelp (*Macrocystis pyrifera*) forests in cooler southern waters. Similarly, seamounts are well known to host reef-like formations of deep-sea stony corals (e.g., Tracey et al. 2011), as well as being major spawning or feeding areas for commercial deepwater species such as orange roughy and oreos (e.g., Clark 1999, O'Driscoll &

Clark 2005). However, the role of these benthic communities on seamounts in supporting fishstocks is uncertain, as spawning aggregations continue to form even if the coral habitat is removed by trawling (Clark & Dunn 2012). Hence the oceanography or physical characteristics of the seamount and water column may be the key drivers of spawning or early life-history stage development, rather than the biogenic habitat.

Freshwater eels are reliant upon rivers as well as coastal and oceanic environments. GIS modelling estimates that for longfin eels, about 30% of longfin habitat in the North Island and 34% in the South Island is either in a reserve or in rarely/non-fished areas, with about 49% of the national longfin stock estimate of about 12 000 t being contained in these waterways (Graynoth et al. 2008). More regional examination of the situation for eels also exists, e.g., for the Waikato Catchment (Allen 2010). Shortfin eels prefer slower-flowing coastal habitats such as lagoons, estuaries, and lower reaches of rims (Beentjes et al. 2005). In-stream cover (such as logs and debris) has been identified as important habitat, particularly in terms of influencing the survival of large juvenile eels (Graynoth et al. 2008). Short-fin eel juveniles and adults have also been found to be relatively common in estuarine mangrove forests, and their abundance positively correlated with structural complexity (seedlings, saplings, and tree densities) (Morrisey et al. 2010). In addition oceanic spawning locations are clearly important for eels, the location of these are unknown, although it has been suggested that these may be north-east of Samoa and east of Tonga for shortfins and longfins respectively (Jellyman 1994).

Many of the potential HPSFM are threatened by either fisheries or land-based effects, the reader should look to the land-based effects chapter in this document and the eel section of the Stock Assessment Plenary report for further details.

14.3.2 HABITAT CLASSIFICATION AND PREDICTIVE MODELLING

Habitat classification schemes focused upon biodiversity protection have been developed in New Zealand at both national and regional scales, these may help identify larger habitats which HPSFM may be selected from, but are unlikely to be useful in isolation for determining HPSFM. The Marine Environment Classification (MEC), the demersal fish MEC and the benthic optimised MEC (BOMEC) are national-scale classification schemes that have been developed with the goal of aiding biodiversity protection (Leathwick et al. 2004, 2006, 2012). A classification scheme also exists for New Zealand's rivers and streams based on their biodiversity values to support the Department of Conservations Waters of National Importance (WONI) project (Leathwick & Julian 2008). Regional classification schemes also exist such as ones mapping the Marine habitats of Northland, or Canterbury in order to assist in Marine Protected Area planning (Benn 2009, Kerr 2010).

Another tool that may help in terms of identifying HPSFM is the predictions of richness, occurrence and abundance of small fish in New Zealand estuaries (Francis et al. 2011). This paper contains richness predictions for 380 estuaries and occurrence predictions for 16 species. This could help minimise the need to undertake expensive field surveys to inform resource management, although environmental sampling may still be needed to drive some models.

14.3.3 CURRENT RESEARCH

Prior to 2007 research within New Zealand was not explicitly focused on identifying HPSFM. However, in line with international trends, this situation has changed in recent times, with recognition of some of the wider aspects of fisheries management.

A number of Ministry and other research projects were commissioned concerning HPSFM in the 2010–11 year. Project ENV200907, 'Habitat of particular significance to fisheries management: Kaipara Harbour', is underway and has the overall objective of identifying and mapping areas and habitats of particular significance in the Kaipara Harbour which support coastal fisheries; and identifying and assessing threats to these habitats. Included in this work is the reconstruction of environmental histories through interviews of long time local residents who have experience of the harbour, and associated collation and integration of historical data sources (e.g., catch records, photographs, diaries, maps, and fishing logs). Another output of this work will be recommendations on the best habitats and methods of monitoring to detect change to HPSFM within Kaipara Harbour.

Biogenic habitats on the continental shelf from about 5 to 150 m depths are currently being characterised and mapped through the biodiversity project ZBD2008/01, this will also provide new information on fisheries species utilisation of these habitats. Interviews with 50 retired fishers have provided valuable information on biogenic

habitat around New Zealand. A national survey to examine the present occurrences and extents of these biogenic habitats was completed in 2011 in collaboration with Oceans Survey 2020, NIWA and Ministry of Business, Innovation and Employment (MBIE) funding.

A number of other national-scale projects are also underway. A desktop review is collating information on the importance of biogenic habitats to fisheries across the entire Territorial Sea and Exclusive Economic Zone (project HAB2007/01). A project has been approved to review the literature and recommend the relative urgency of research on habitats of particular significance for inshore finfish species (project ENV2010/03).

The Ministry of Business, Innovation and Employment (MBIE) funded project Coastal Conservation Management started in 2009 and runs for six years. This programme aims to integrate and add to existing fish-habitat association work to develop a national-scale marine fish-habitat classification and predictive model framework. This project will also attempt to develop threat assessments at local, regional and national scales. MPI is maximising the synergies between its planned research and this project. As part of this synergy, work on the connectivity and stock structure of grey mullet (*Mugil cephalus*) is underway in collaboration with MPI project GMU2009/01. Otolith chemistry is being assessed for its utility in partitioning the GMU 1 stock into more biologically meaningful management units, and in quantifying the suspected existence of source and sink dynamics between the various estuaries that hold juvenile grey mullet nursery habitats.

In 2012 MBIE also funded the three-year project delivered by NIWA entitled 'Predicting the occurrence of vulnerable marine ecosystems for planning spatial management in the South Pacific region'. The development of predictive models of species occurrence under this project may also aid in identifying HPSFM. Identification of biogenic habitat has been part of the MBIE project 'Vulnerable deep-sea communities' since 2009 (and its predecessor seamount programme), which includes surveys of a range of habitats that may be important for various life-history stages of commercial fish species: seamounts, canyons, continental slope, hydrothermal vents and seeps.

14.4 INDICATORS AND TRENDS

As no HPSFM are defined this section cannot be completed.

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Chapter 15: Land-based effects on the coastal environment - Technical Summary

Degradation of coastal habitats



Sediment, contaminants, connectivity

1. THE ISSUE IN BRIEF

- The interconnections between the terrestrial and the marine environment are widely recognised
- The effects of land-based activities can be detrimental to marine coastal habitats and biological communities, and affect recreational activities and primary production (e.g. marine aquaculture, fisheries)
- Marine biodiversity that underpins fish and shellfish fisheries is impacted by land-based activities
- The influence of these activities is usually greatest near estuaries and the coastline

2. LAND-BASED EFFECTS ON COASTAL ECOSYSTEMS

- Coastal structures (e.g. harbours, outfalls) and inland structures (e.g. hydropower dams) can reduce habitat quality and connectivity for both resident and migratory aquatic life
- Contaminants in freshwater runoff are generally diluted once they reach the sea, but can have local effects
- Land-based activities (e.g. dairy farming) can lead to nutrient enrichment (i.e. eutrophication), which in turn may lead to harmful algal blooms and anoxic events in coastal waters
- Human activities (e.g. driving on beaches) can have adverse effects on shellfish, but their magnitude is unknown
- Land-based pathogens affecting marine organisms are an emerging issue for Māui dolphins (see Chapter 6)
- Different land uses can affect the erosion of soils and their subsequent transport and sedimentation in coastal areas, which is considered one of the highest threats to NZ coastal ecosystems
- The effects of sedimentation include smothering of coastal habitats, such as nursery areas for fish and shellfish
- Coastal infrastructures can change the hydrodynamics near the coastline, potentially increasing sedimentation and eutrophication



Coastal development can alter marine currents and circulation at the local scale

3. MITIGATION MEASURES

- Mitigation measures include habitat restoration of coastal, fluvial and estuary areas, improved water treatment (especially to reduce coliform bacteria), creation of fish passes for migratory species, land-use management, and the inclusion of habitat elements (e.g. holes) in coastal engineering structures
- Mitigation and monitoring of land impacts is a key responsibility of local and regional authorities through the New Zealand Coastal Policy Statement, which is managed by DOC
- Fisheries New Zealand works closely with DOC on these issues

15 LAND-BASED EFFECTS ON THE COASTAL ENVIRONMENT

Status of chapter	This chapter has not been updated for AEBAR 2021.
Scope of chapter	This chapter outlines the main known threats from land-based activities to fisheries, aquaculture and supporting biodiversity. It also describes the present status and trends in land-based impacts.
Area	All of the New Zealand freshwater, EEZ and Territorial Sea.
Focal localities	Freshwater habitats and areas closest to the coast are likely to be most impacted; this will be exacerbated in areas with low water movement. Anthropogenically increased sediment run-off is particularly high from the Waiapu and Waipaoa river catchments on the east coast of the North Island. Areas of intense urbanisation or agricultural use of catchments are also likely to be impacted by bacteria, viruses/diseases, heavy metals or nutrients, or some combination of these.
Key issues	Habitat modification, sedimentation, aquaculture, shellfish, terrestrial land-use change (particularly for urbanisation, forestry or agriculture) water quality and quantity, contamination, recreational activities, consequences of increased pollutants to seafood production, freshwater management and demand.
Emerging issues	Impacts on habitats of particular significance to fisheries management (HPSFM), linkages through rainfall patterns to climate change, shellfish bed closures, habitat remediation, domestic animal diseases in protected marine species, proposed aquaculture expansion, water abstraction impacts.
MPI research (latest)	ZBD2008/01 *Research on Biogenic Habitat-Forming Biota and their functional role in maintaining Biodiversity in the Inshore Region (5–150 m depths)* – this is also part-funded by Oceans Survey 2020, NIWA and MBIE.
NZ government research (current)	Ministry of Business, Innovation and Employment (MBIE) funded programmes: UOCX0902 *After the outfall: recovery from eutrophication in degraded New Zealand estuaries*; CO1X1005 *Management of Cumulative Effects of Stressors in Aquatic Ecosystems*. NIWA core-funded research on this topic occurs in two areas. Firstly, the 'Managing marine ecosystems' programme, specifically the projects 'Measuring mapping and conserving', 'Ecosystem-based management of coasts and estuaries', 'Coastal management' (C01X0907) and 'Marine Futures' (C01X0227) (Note that the latter two finish 30 September 2014). Secondly, in the 'Fisheries' Centre, the EAFM programme deals with ecosystem-based management approaches in conjunction with the 'Coasts and Oceans' centre. Some funding within these areas will be aligned to the Sustainable Seas Science Challenge in the near future in which the focus is on ecosystem based management of the marine environment.
Related chapters/issues	Habitats of particular significance for fisheries management (HPSFM), marine environmental monitoring.

15.1 CONTEXT

Land-based activities that may have impacts on seafood production are primarily regulated under the Resource Management Act 1991 (and subsequent amendments). Fisheries are controlled under the Fisheries Act 1996, this includes marine and freshwater resources management of aquatic life (under Part 2 of the Fisheries Act). Both the Fisheries Act 1996 and the MPI Strategy 'Our Strategy'[1] state that New Zealand's the primary sector's utilization of natural marine and freshwater fish resources needs to be sustainable.

The government's 'Fresh Start for Freshwater Programme'[2] (led by MfE and MPI) aims to create a water management

[1] Ministry for Primary Industries. Our Strategy. Retrieved from http://www.mpi.govt.nz/about-mpi/our-strategy.

[2] Ministry for the Environment. Fresh Start for Fresh Water. Retrieved from http://www.mfe.govt.nz/more/cabinet-papers-and-related-material-search/cabinet-papers/freshwater/fresh-start-fresh-water.

system that allows us to make more transparent and better targeted and informed decisions on fresh water. Businesses and water users will have more certainty so that they can plan and invest. All New Zealanders will have a greater say on the water quality they want for their lakes and rivers. The Coastal Policy Statement (2010) also has relevance to matters of fisheries interest, e.g., Policy 20(1) (paraphrased) controls the use of vehicles on beaches where (b) harm to shellfish beds may result. MPI also works with other agencies, principally DOC, MfE and regional councils and through the Natural Resource Cluster to influence these processes to ensure consideration of land-based impacts upon seafood production. The New Zealand aquaculture industry has an objective of developing into a billion dollar industry by 2025.[3] Government supports well-planned and sustainable aquaculture through its *Aquaculture Strategy and Five-year Plan*. One of the desired outcomes of actions by the New Zealand government is to enable more space to be made available for aquaculture. This outcome is likely to heighten the potential for conflict between aquaculture proponents and those creating negative land-based effects.

An MPI-funded survey of scientific experts (MacDiarmid et al. 2012) addressed the vulnerability to a number of threats of marine habitat types within the New Zealand's Territorial Sea and Exclusive Economic Zone (EEZ). Each vulnerability score was based on an assessment of five factors including the spatial scale, frequency and functional impact of the threat in the given habitat as well as the susceptibility of the habitat to the threat and the recovery time of the habitat following disturbance from that threat. The study found that the number of threats and their severity were generally considered to decrease with depth, particularly below 50 m. Reef, sand, and mud habitats in harbours and estuaries and along sheltered and exposed coasts were considered to be the most highly threatened habitats. The study also reported that over half of the 26 top threats fully, or in part, stemmed from human activities external to the marine environment itself. The top six threats in order were:

1. ocean acidification,
2. rising sea temperatures resulting from global climate change,

3rd equal. bottom trawling fishing,

3rd equal. increased sediment loadings from river inputs,

5th equal. change in currents from climate change,

5th equal. increased storminess from climate change.

The reader is guided to MacDiarmid et al. (2012) for more detail including tables of threats-by-habitat and habitats-by-threat. Climate change and ocean acidification, although they can be considered land-based effects, are covered under the chapters in this document called 'New Zealand's Climate and Oceanic Setting' and 'Biodiversity'.

Land-based effects on seafood production and biodiversity in this context are defined as resulting either from the inputs of contaminants from terrestrial sources or through engineering structures (e.g., breakwaters, causeways, bridges), that change the nature and characteristics of coastal habitats and modify hydrodynamics. The major route for entry of land-based contaminants into the marine environment is associated with freshwater flows (rivers, streams, direct runoff and ground water), although contaminants may enter the marine environment via direct inputs (e.g., landslides) or atmospheric transport processes.

Different land-use effects act over different scales; for example localised effects act on small streams and adjacent estuarine habitats, large scale effects extend to coastal embayments and shelf ecosystems. Associated risks will vary according to location and depend on the relevant ecosystem services (e.g., high value commercial fishery stocks) and their perceived sensitivities. The risk from stormwater pollutants will be more important near urban areas and the effects of nutrient enrichment will be more important near intensively farmed rural areas.

The risk from land-based impacts for seafood production is that they will limit the productivity of a stock or stocks. For example, the bryozoan beds around Separation Point in Golden Bay, were protected from fishing in 1980, partly because of their perceived role as nursery grounds for a variety of coastal fish species (Grange et al. 2003). Recent work has suggested that the main threat to these bryozoans is now sedimentation from the Motueka River, which may inhibit recovery of any damaged bryozoans (Grange et al. 2003, Morrison et al. 2009). Any declines in this bryozoan

[3] Aquaculture New Zealand. Strategy. Retrieved from http://aquaculture.org.nz/about-us/strategy.

bed and associated ecological communities could also affect the productivity of adjacent fishery stocks.

Fisheries New Zealand mainly manages in the marine environment, therefore this topic area will be dealt with first. The main freshwater fisheries management Fisheries New Zealand is involved in is the freshwater eel fishery; this will be dealt in later sections, as relevant.

15.2 GLOBAL UNDERSTANDING

15.2.1 LAND-BASED INFLUENCES

It has been acknowledged for some time now that land-based activities can have important effects on seafood production. The main threats to the quality and use of the world's oceans are (GESAMP 2001):

- alteration and destruction of habitats and ecosystems;
- effects of sewage on human health;
- widespread and increased eutrophication;
- decline of fishstocks and other renewable resources; and
- changes in sediment flows due to hydrological changes.

Coastal development is projected to impact 91% of all inhabited coasts by 2050 and will contribute to more than 80% of all marine pollution (Nellemann et al. 2008). The importance of different land-based influences differ regionally but the South Pacific Regional Environmental Programme (SPREP, which includes New Zealand) defines waste management and pollution control as one of its four strategic priorities for 2011–15 (SPREP 2010).

Influences, including land-based influences, seldom work in isolation; for example the development of farming and fishing over the last hundred years has meant that increased sediment and nutrient runoff has to some degree occurred simultaneously with increased fishing pressure. However, the impact of these influences has often been studied in isolation. In a review on coastal eutrophication, Cloern (2001) stated that *'Our view of the problem [eutrophication] is narrow because it continues to focus on one signal of change in the coastal zone, as though nutrient enrichment operates as an independent stressor; it does not reflect a broad ecosystem-scale view that considers nutrient enrichment in the context of all the other stressors that cause change in coastal ecosystems'*. These influences (in isolation or combination) can also cause indirect effects, such as decreasing species diversity that then lessens resistance to invasion by non-indigenous species or species with different life-history strategies (Balata et al. 2007, Kneitel & Perrault 2006, Piola & Johnston 2008). Studies that research a realistic mix of influences are rare, but valuable.

The most important land-based effect in New Zealand is arguably increased sediment deposition around our coasts (Morrison et al. 2009, MacDiarmid et al. 2012). This deposition has been accelerated due to increased erosion from land-use, which causes gully and channel erosion and landslides (Glade 2003). Inputs of sediments to our coastal zone, although naturally high in places due to our high rainfall and rates of tectonic uplift (Carter 1975), have been accelerated by human activities (Goff 1997). New Zealand represents only about 0.3% of the land area that drains into the oceans (Griffiths & Glasby 1985, Milliman & Syvitski 1992), yet sediment inputs make up about 1% of the estimated global detrital input to the oceans (Carter et al. 1996). Sediment deposition can be an important influence, particularly in areas of high rainfall, tectonic uplift, and forest clearances, or areas where these activities coincide. Sediments are known to erode from the land at an increased rate in response to human use, for example, estimates from a largely deforested tropical highland suggest erosion rates 10–100 times faster than pre-clearance rates (Hewawasam et al. 2003). Increased sediment either deposited on the seafloor or suspended in the water column can negatively impact invertebrates in a number of ways including: burial, scour, inhibiting settlement, decreasing filter-feeding efficiency and decreasing light penetration, generally leading to less diverse communities, with a decrease in suspension feeders (Thrush et al. 2004). These impacts can affect the structure, composition and dynamics of benthic communities (Airoldi 2003, Thrush et al. 2004). Effects of this increased sediment movement and deposition on finfish are mostly known from freshwater fish and can range from behavioural (such as decreased feeding rates) to sublethal (e.g., gill tissue disruption) and lethal as well as having effects on habitat important to fishes (Morrison et al. 2009). These effects differ by species and life-stage and are dependant upon factors that include the duration, frequency and magnitude of exposure, temperature, and other environmental variables (Servizi & Martens 1992).

Increased nutrient addition to the aquatic environment can initially increase production, but with increasing nutrients

there is an increasing likelihood of harmful algal blooms and cascades of effects damaging to most communities above the level of the plankton (Kennish 2002, Heisler et al. 2008). This excess of nutrients is termed eutrophication. Eutrophication can stimulate phytoplankton growth, which can decrease the light availability and subsequently lead to losses in benthic production from seagrass, microalgae or macroalgae and their associated animal communities. Algal blooms then die and their decay depletes oxygen and blankets the seafloor. The lack of oxygen in the bed and water column can lead to losses of finfish and benthic communities. These effects are likely to be location specific and are influenced by a number of factors including: water transparency, distribution of vascular plants and biomass of macroalgae, sediment biogeochemistry and nutrient cycling, nutrient ratios and their regulation of phytoplankton community composition, frequency of toxic/harmful algal blooms, habitat quality for metazoans, reproduction/growth/survival of pelagic and benthic invertebrates, and subtle changes such as shifts in the seasonality of ecosystems (Cloern 2001). The effects of eutrophication abound in the literature, for example, the formation of dead (or anoxic) zones is exacerbated by eutrophication, although oceanographic conditions also play a key role (Diaz & Rosenberg 2008). Dead zones have now been reported from more than 400 systems, affecting a total area of more than 245 000 km^2 (Diaz & Rosenberg 2008). This includes anoxic events from New Zealand in coastal north-eastern New Zealand and Stewart Island (Taylor et al. 1985, Morrissey 2000).

Other pollutants such as heavy metals and organic chemicals can have severe effects, but are more localised in extent than sediment or nutrient pollution (Castro and Huber 2003, Kennish 2002). Fortunately the concentration of these pollutants in most New Zealand aquatic environments is relatively low, with a few known exceptions. Examples of this include naturally elevated levels of arsenic in Northland,[4] cadmium levels in Foveaux Strait oysters (Frew et al. 1996) and levels of nickel and chromium within the Motueka river plume in Tasman Bay (Forrest et al. 2007). The high cadmium levels have caused market access issues for Foveaux Strait oysters. Some anthropogenically generated pollutants such as copper, lead, zinc and PCBs are high in localised hotspots within urban watersheds. In the Auckland region these hotspots tend to be in muddy estuarine sites and tidal creeks that receive runoff from older urban catchments (Auckland Regional Council 2010). There is a lack of knowledge on the impacts of these pollutants upon fisheries.

Climate change is likely to interact with the effect of land-based impacts as the main delivery of land-based influences is through rainfall and subsequent freshwater flows. Global climate change projections include changes in the amount and regional distribution of rainfall over New Zealand (IPCC 2007). More regional predictions include increasing frequency of heavy rainfall events over New Zealand (Whetton et al. 1996). This is likely to exacerbate the impact of some land-based influences as delivery peaks at times of high rainfall, e.g., sediment delivery (Morrison et al. 2009).

Physical alterations of the coast are generally, but not exclusively (e.g., wetland reclamation for agriculture), concentrated around urban areas and can have a number of consequences on the marine environment (Bulleri & Chapman 2010). Changes in diversity, habitat fragmentation or loss and increased invasion susceptibility have all been identified as consequences of physical alteration. The effects of physical alterations upon fisheries remain largely unquantified; however the habitat loss or alteration portion of physical alterations will be dealt with under the habitats of particular significance for fisheries management (HPSFM) section.

An area of emerging interest internationally is infectious diseases from land-based animals affecting marine populations. Perhaps the most well-known example of this is the canine distemper outbreak in Caspian seals that caused a mass mortality in the Caspian Sea in 2000 (Kennedy et al. 2000).

15.2.2 HABITAT RESTORATION

Habitat restoration or rehabilitation has been the subject of much recent research. Habitat restoration or rehabilitation rarely, if ever, replaces what was lost and is most applicable in estuarine or enclosed coastal areas as opposed to exposed coastal or open ocean habitats (Elliott et al. 2007). Connectivity of populations is a key consideration when evaluating the effectiveness of any marine restoration or rehabilitation (Lipcius et al. 2008). In the marine area, seagrass replanting methodologies are being developed to

[4] NIWA. Ocean Survey 2020. Retrieved from https://www.niwa.co.nz/coasts-and-oceans/research-projects/oceans-2020.

ensure the best survival success (Bell et al. 2008) and artificial reefs can improve fisheries catches, although whether artificial reefs boost population numbers or merely attract fish is unclear (Seaman 2007). In addition, the incorporation of habitat elements in engineering structures, e.g., artificial rockpools in seawalls, shows promise in terms of ameliorating the impacts of physical alterations (Bulleri 2006). Spatial approaches to managing land-use impacts, such as marine reserves, will be covered under the section about HPSFM.

Freshwater rehabilitation has been reviewed by Roni et al. (2008). Habitat reconnection, floodplain rehabilitation and instream habitat improvement are all suggested for improving habitat and local fish abundances. Riparian rehabilitation, sediment reduction, dam removal, and restoration of natural flood regimes have shown promise for restoring natural processes that create and maintain habitats, but there is a lack of long-term studies to gauge their success. Wild eel fisheries in America and Europe have declined over time (Allen et al. 2006, Atlantic States Marine Fisheries Commission 2000, Haro et al. 2000). Declines in wild eel fisheries have been linked to a number of factors including: barriers to migration; hydro turbine mortality; and habitat loss or alteration. Information to quantitatively assess these linkages is however often lacking (Haro et al. 2000).

15.3 STATE OF KNOWLEDGE IN NEW ZEALAND

Land-based effects will be most pronounced closest to the land, therefore freshwater, estuarine, coastal, middle depths and deepwater fisheries, will be affected in decreasing order. The scale of land-use effects will, however, differ depending upon the particular influence. The most localised are likely to be direct physical impacts; for example, the replacement of natural shorelines with seawalls; although even direct physical impacts can have larger-scale impacts, such as affecting sediment transport and hence beach erosion, or contributing to cumulative effects upon ecosystem responses. Point-source discharges are likely to have a variable scale of influence, and this influence is likely to increase where a number of point-sources discharge, particularly when this occurs into an embayed, low-current environment. An example of this is Waitemata Harbour in Auckland where there are multiple stormwater discharges (Hayward et al. 2006). The influences on the largest scale can be from diffuse-source discharges such as nutrients or sediment (Kennish 2002). For example, the influence of diffuse-source materials from the Motueka river catchment in Golden Bay on subtidal sediments and assemblages and shellfish quality can extend up to tens of kilometres offshore (Tuckey et al. 2006; Forrest et al. 2007), with even a moderate storm event extending a plume greater than 6 km offshore (Cornelisen et al. 2011). Terrestrial influences on New Zealand's marine environment can, at times, be detected by satellites from differences in ocean colour and turbidity extending many kilometres offshore from river mouths (Gibbs et al. 2006).

All coastal areas are unlikely to suffer from land-based impacts in the same way. The quantities of pollutants or structures differ spatially. Stormwater pollutants, seawalls and jetties are more likely to be concentrated around urban areas. Nutrient inputs are likely to be concentrated either around sewage outlets or associated with areas of intensive agriculture or horticulture. Sediment production has been mapped around the country and is greatest around the west coast of the South Island and the east coast of the North Island (Griffiths & Glasby 1985, Hicks & Shankar 2003, Hicks et al. 2011). Notably the catchments where improved land management may result in the biggest changes to sediment delivery to coastal environments are likely to be the Waiapu and Waipaoa river catchments on the East coast of the North Island. In addition to this, the sensitivity of receiving environments is also likely to differ; this will be covered in subsequent sections.

An MPI-funded project (IPA2007/07) reviewed the impacts of land-based influences on coastal biodiversity and fisheries (Morrison et al. 2009). This review used a number of lines of evidence to conclude that in this context, sedimentation is probably New Zealand's most important pollutant. The negative impacts of sediment include decreasing efficiency of filter-feeding shellfish (such as cockles, pipi, and scallops), reduced settlement success and survival of larval and juvenile phases (e.g., paua, kina), and reductions in the foraging abilities of finfish (e.g., juvenile snapper). Indirect effects include the modification or loss of important nursery habitats, particularly biogenic habitats (green-lipped and horse mussel beds, seagrass meadows, bryozoan and tubeworm mounds, sponge gardens, kelps/seaweeds, and a range of other structurally complex species). Inshore filter-feeding bivalves and biogenic habitats were identified as the most likely to be adversely affected by sedimentation. Eutrophication was also identified as a potential threat from experience overseas. This review identified knowledge gaps and made suggestions for more relevant research on these influences:

- identification of fisheries species/habitat associations for different life stages, including consideration of how changing habitat landscapes may change fisheries production;
- better knowledge of connectivity between habitats and ecosystems at large spatial scales;
- the role of river plumes;
- the effects of land-based influences both directly on fished species, and indirectly through impacts on nursery habitats;
- a better spatially based understanding, mapping and synthesis of the integrated impacts of land-based and marine-based influences on coastal marine ecosystems.

The locations where addressing land-based impacts is likely to result in a lowering in risk to seafood production or increased seafood production, excluding those already mentioned, are undefined.

A national-scale threat analysis has been completed for biogenic habitats, given their likely importance for fisheries management as nursery areas (Morrison et al. 2014b). The sparse data available (often anecdotal accounts), shows that strong declines in biogenic habitats have occurred, which appear largely attributable to land-based effects (e.g., sedimentation and elevated nutrient levels), and fishing impacts. Examples include the extensive loss of seagrass meadows (e.g., large areas in Whangarei, Waitemata, Manukau, Tauranga and Avon-Heathcote estuaries), green-lipped mussel beds (about 500 km^2 in the Hauraki Gulf), bryozoan beds (about 80 km^2 in Torrent Bay, about 800 km^2 in Foveaux Strait), and deepwater coral thickets on seamounts. Cumulatively, the magnitude and extent of biogenic habitat losses are likely to have been very substantial, but are unknown, and probably will never be able to be calculated. Other biogenic habitat species for which evidence points to historical losses include horse mussels, kelp forests, oyster beds, and sponges, both in assemblages where they tend to dominate, and as part of mixed biogenic habitat assemblages. A better understanding of the threats to these biogenic habitats is recommended.

The Kaipara Harbour has been identified as a system that supports important fisheries functions both for the harbour proper, and for the wider west coast North Island ecosystem (Morrison et al. 2014a). This report detailed fish-habitat associations in the harbour and concluded that increased sedimentation, and to a lesser extent the possibility of eutrophication, was probably the greatest threat to these fisheries.

The threat of sedimentation has prompted much concern and action by land managers and local communities (Morrison et al. 2014a). For example, in the Kaipara Harbour the southern subtidal seagrass meadows area is especially important as a juvenile nursery for snapper and trevally and based on its high value as a juvenile fish nursery habitat, the Auckland Council has listed this area as an Ecologically Significant Area (ESA) in its draft unitary plan. There are significant collaborative CRI/Northland Regional Council/Auckland Council sediment erosion and transport research programmes currently under way in Kaipara Harbour catchment and the harbour itself. There are also local initiatives around tree planting and the improvement of riparian and other forms of land management. The fish/fisheries habitat work described here engages and collaborates with the IKHMG and Kaipara Research Advisory Group (KRAG), and this type of collaboration/interaction between fisheries habitat research, other scientific research programmes, and management agencies is one promising way for these issues to be addressed.

Another study investigated correlations between environmental variables and flounder abundance for the Manukau and Mahurangi harbours (McKenzie et al. 2013). Consistent correlations were obtained for a variety of environmental variables for juvenile sand and yellowbelly flounder (YBF) in the Manukau, but not in Mahurangi Harbour. The influence of environmental variables on adult YBF catch in the Manukau Harbour was even more evident. These correlations suggested that decreasing oxygen and increasing ammonia and turbidity may have negatively affected yellowbelly flounder recruitment success. When these results were considered alongside the declining trends in flatfish abundance in the FLA 1 fishery, estuarine water quality may be a significant factor affecting the sustainability of the flatfish fishery.

Marine restoration studies published in New Zealand have focused on the New Zealand cockle *Austrovenus stutchburyi*. The first of these studies identified a tagging methodology to aid relocation of transplanted individuals (Stewart & Creese 2002). Subsequent studies stressed the use of adults in restoration and the importance of site selection, either from theoretical or modelling viewpoints (Lundquist et al. 2009, Marsden & Adkins 2009). Detailed restoration methodology has been investigated in

Whangarei Harbour and recommends replanting adults at densities between 222 and 832 m-2 (Cummings et al. 2007).

Multiple influences in areas relevant to seafood production in New Zealand have been addressed by three studies. A field experiment near Auckland showed greater effects on infaunal colonisation of intertidal estuarine sediments when three heavy metals (copper, lead and zinc) were in combination compared to each in isolation (Fukunaga et al. 2010). A survey approach looking at the interaction of sediment grain size, organic content and heavy metal contamination upon densities of 46 macrofaunal taxa across the Auckland region also showed a predominance of multiplicative effects (Thrush et al. 2008). However influences can work in unexpected directions; as in a study on large suspension feeding bivalves off estuary mouths where the anticipated negative impacts from sediment were not observed and these species benefitted from food resources generated from the estuaries (Savage et al. 2012).

Toheroa populations are currently closed to all but customary harvesting but have failed to recover to former population levels even though periodic (and sometimes substantial) pulses in young recruits have been detected in both Northland and Southland (Beentjes 2010, Morrison & Parkinson 2008). Current thinking suggests that a mix of influences are probably responsible for these declines including overharvesting, land-use changes leading to changes in freshwater seeps on the beaches, and vehicle traffic (Morrison et al. 2009, Williams et al. 2013). A number of discrete pieces of research have been completed in this area. A review of the wider impact of vehicles on beaches and sandy dunes has been completed, and suggested that more research was needed on the impacts of vehicle traffic on the intertidal (Stephenson 1999). A four-day study over a fishing contest on Ninety Mile Beach showed the potential of traffic to produce immediate mortalities of juvenile toheroa, but the temporal importance of this could not be gauged (Hooker & Redfearn 1998). Mortalities of toheroa from the Burt Munro Classic motorcycle race on Oreti beach have been quantified and recommendations made for how to minimise these, but again the importance of vehicle traffic for toheroa survival over longer time periods was unclear (Moller et al. 2009). Notably, similar negative impacts from driving were observed on juvenile tuatua (*Paphies donacina*) on a Pegasus Bay beach (Marsden & Taylor 2010). The impact of a range of influences upon toheroa at Ninety Mile Beach has been investigated by Williams et al. (2013). The main factors identified that potentially affect toheroa abundance were food availability, climate and weather, sand smothering/sediment instability, toxic algal blooms, predation, harvesting, vehicle impacts, and land-use change. To investigate the causal mechanisms operating, a combination of monitoring, experimental, and modelling studies may be necessary.

Rhodolith beds have been surveyed in the Bay of Islands and high diversity was reported even in areas of abundant fine sediments (Nelson et al. 2012). It is unclear if the increasing sedimentation occurring in the Te Rawhiti Reach is negatively impacting rhodoliths and whether this atypical rhodolith bed (i.e., with abundant fine sediments) is at risk if current sedimentation and mobilisation rates continue.

The protozoan *Toxoplasma gondii* has been identified as the cause of death for 7 of 28 Hector's and Māui dolphins examined since 2007 (W. Roe, Massey University, unpubl. data, 31 July 2012). Land-based runoff containing cat faeces is believed to be the means by which *Toxoplasma gondii* enters the marine environment (Hill & Dubey 2002). A Hector's dolphin has also tested positive for *Brucella abortus* (or a similar organism) a pathogen of terrestrial mammals that can cause late pregnancy abortion, and has been seen in a range of cetacean species elsewhere. This resulted in the Department of Conservation's suggested research priorities in the 'Review of the Maui's dolphin Threat Management Plan: Consultation paper', including objectives to determine the presence, pathways and possible mitigation of the threat from *Toxoplasmosis gondii* (Department of Conservation and Ministry for Primary Industries 2012). The recently established Māui dolphin Research Advisory Group[5] confirmed risk factors to Māui dolphin from *Toxoplasma gondii* as a priority area for future research.

The effects of large-scale habitat loss and modification on eels in New Zealand are clearly significant, but difficult to quantify (Beentjes et al. 2005). Significant non-fisheries mortality of New Zealand freshwater longfin and shortfin eels are caused by mechanical clearance of drainage channels, and damage by hydro-electric turbines and flood control pumping. Eels prefer habitat that offers cover and

[5] Department of Conservation. Māui Dolphin. Retrieved from http://www.doc.govt.nz/nature/native-animals/marine-mammals/dolphins/maui-dolphin.

in modified drains aquatic weed provides both daytime cover and nighttime foraging areas. Loss of weed and natural debris can thus result in significant displacement of eels to other areas. In addition, wetlands drainage has resulted in greatly reduced available habitat for eels, particularly shortfins, which prefer slower-flowing coastal habitats such as lagoons, estuaries, and lower reaches of rims. Water abstraction is one of a number of information requirements identified in Beentjes et al. (2005) to better define the effects on eel populations.

A number of Integrated Catchment Management (ICM) projects are underway in New Zealand. These take a holistic view to land management incorporating aquatic effects; this approach could help restore water quality of both fresh and coastal waters. An overview of these projects is given in a Ministry for the Environment Report on integrated catchment management (Environmental Communications Limited 2010). Many of these projects employ restoration techniques such as riparian planting, but few assessments of the effectiveness of riparian planting exist. One assessment of the effect of nine riparian zone planting schemes in the North Island on water quality, physical and ecological indicators concluded that riparian planting could improve stream quality; in particular, rapid improvements were seen in terms of visual clarity and channel stability (Parkyn et al. 2003). Nutrient and faecal contamination results were more variable. Improvement in macroinvertebrate communities did not occur in most streams and the three factors needed for these were canopy closure (which decreased stream temperature), long lengths of riparian planting and protection of headwater tributaries. A modelling study also demonstrated the long time lag needed to grow large trees, which then provide wood debris to structure channels, which achieves the best stream rehabilitation results (Davies-Colley et al. 2009). Although some of these studies extend into the marine realm (at least in terms of monitoring) it is difficult to gauge the impact of these activities upon fisheries or aquaculture, particularly on wider scales because ICM studies have been localised at small scales.

15.3.1 CURRENT RESEARCH

An MPI biodiversity project also has components that address land-based effects; the threats to biogenic habitats are addressed in project ZBD2008/01 (for more detail see the Biodiversity chapter).

A Ministry of Business, Innovation and Employment (MBIE)-funded project [6] of particular relevance is 'Nitrogen reduction and benthic recovery' (UOCX0902, University of Canterbury). This research aims to determine the trajectories and thresholds of coastal ecosystem recovery following removal of excessive nutrient loading (called 'eutrophication') and earthquake impacts. This will be achieved by monitoring the effects of diverting all of Christchurch's treated wastewater discharge from the eutrophied Avon-Heathcote (Ihutai) Estuary and the subsequent earthquake induced disturbances to this diversion.

15.4 INDICATORS AND TRENDS

A national view of the impacts of land-based influences upon seafood production does not exist; this could be facilitated by better coordination and planning of the many disparate marine monitoring programmes operating around the country. Monitoring of marine water quality and associated communities is carried out through a variety of organisations, including universities, regional councils and aquaculture or shell fisheries operations. Regional council monitoring of water quality and associated biological communities is often reported through websites such as the Auckland Regional Council environmental monitoring data, or summary reports such as the Hauraki Gulf state of the Environment 2011 report (Auckland Regional Council 2011). Water quality and associated marine communities may also be monitored for a regional council as part of a consent application or as a stipulation for a particular marine development. However the data from aquaculture and shellfisheries water quality monitoring are not generally available.

Improved coordination and planning of marine monitoring has been achieved in some countries, e.g., the United Kingdom. [7] The Marine Environmental Monitoring Programme (ZBD2010-42), is a step towards this goal, more information is available on this project in the Biodiversity chapter of this document. This project identifies remote sensing of sea surface particulate matter in nearshore waters as a possible indicator of changes in sediment inputs in the future, but this requires algorithm validation for New

[6] Ministry of Business, Innovation and Employment. Who got funded? Retrieved from http://www.msi.govt.nz/update-me/who-got-funded.

[7] CEFAS. Marine monitoring. Retrieved from http://wavenet.cefas.co.uk/Smartbuoy.

Zealand waters. Possible national-scale proxies for coastal faecal contamination may exist after collating information from sanitation area monitoring for shellfish harvesting and/or coastal bathing beaches.

High faecal coliform counts (primarily from mammal or bird faeces) can impact upon the value gained from shellfish fisheries and aquaculture. Area closures to commercial harvesting usually depend on an area's rainfall/runoff relationship and areas closer to significant farming areas or urban concentrations are likely to be closed more frequently, due to high faecal coliform counts, than areas where the catchment is unfarmed or not heavily populated. For example, Inner Pelorus sound is likely to be closed more frequently than outer Pelorus Sound (Marlborough Sounds). For coastal areas of the Marlborough Sounds, the Coromandel Peninsula and Northland closures can range from a few days to over 50% of the time in a given year (Brian Roughan, New Zealand Food Safety Authority, pers. comm.). Certain fisheries may be limited by the amount of time where water quality is sufficient to allow harvesting, e.g., the cockle fishery in COC 1A (Snake bank in Whangarei harbour) was closed for 101, 96, 167, 86, 117 and 118 days for the 2006–07, 2007–08, 2008–09, 2009–10, 2010–11 and 2011–12 fishing years, respectively, due to high faecal coliform counts from sewage spills or runoff.[8] Models also now exist that allow real-time prediction of *E. coli* pulses associated with storm events (e.g., Wilkinson et al. 2011), which may help harvesters to better cope with water quality issues.

The Ministry for the Environment (MfE) also reports on freshwater quality. River water quality indicators that have been assessed have direct relevance to the eel, and other freshwater fisheries, and this water will flow through estuaries and enter the marine environment. The National River Water Quality Network (NRWQN) has national coverage, and has been running for over 20 years and has recently reported upon the following eight variables: temperature, dissolved oxygen, visual clarity, dissolved reactive and total phosphorous, and ammoniacal, oxidised and total nitrogen (Ballantine & Davies-Colley 2009). Dissolved oxygen showed few meaningful trends and the ammoniacal nitrogen data suffered from a processing artefact. An upward, although not significant trend in temperature and an improvement of water clarity were seen at the national scale. However, a negative correlation was seen between water clarity and percent of catchment in pasture, which suggests that any expansion of pasture lands may have impacts on clarity. Strong increasing trends over time were seen in oxidised nitrogen, total nitrogen, total phosphorous and dissolved reactive phosphorous. These latter trends all signify deteriorating water quality and are mainly attributable to increased diffuse-source pollution from the expansion and intensification of pastoral agriculture.

Total nitrogen and phosphorous loads to the coast in New Zealand have been modelled and were estimated at 167 300 and 63 100 t yr-1, respectively (Elliot et al. 2005).[9] The main sources of nitrogen and phosphorous were from pastoralism (70%) and erosion (53%), respectively. Dairying contributes 37% of the nitrogen load from only 6.8% of the land. The total amount of land used for dairy farms increased by 47% (1.4 to 2.0 million ha) from 1986 to 2002. [10] These statistics provide strong circumstantial evidence that the expansion in dairying is primarily responsible for the observed declines in water quality from agricultural sources.

[8] Statistics supplied by New Zealand Food Safety Authority in Whangarei. Notably the fishery has not been operating since November 2012.

[9] This is a known underestimate because streams with catchments less than 10 km^2 were excluded from this calculation.

[10] Statistics NZ (2006) Fertiliser Use and the Environment. Retrieved from http://www3.stats.govt.nz/environment/Fertiliser_use_and_the_environment_Aug06.pdf.

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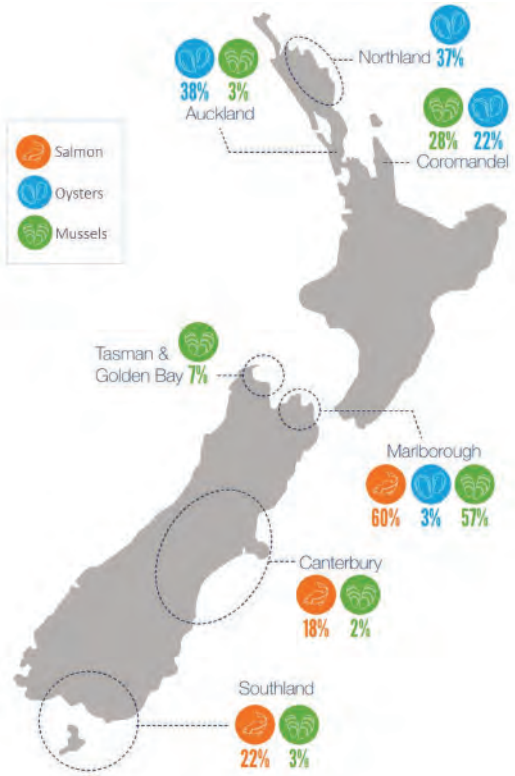
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Chapter 16: Ecological effects of marine aquaculture - Technical Summary

Aquaculture is a growing sector in NZ



Ecological effects are considered as part of any development

1. THE ISSUE IN BRIEF

- Aquaculture is the fastest growing food producing industry, supplying nearly half of the world's seafood
- NZ aquaculture industry is valued at over $600m and the NZ Government's strategy supports the potential for aquaculture to be a $3bn. industry by 2035.
- Marine aquaculture in NZ is dominated by green-lipped mussels, chinook (king) salmon, and Pacific oysters
- Aquaculture activities can have ecological effects on marine ecosystems. Some are positive, others less so. Research is ongoing to ensure aquaculture remains sustainable in New Zealand

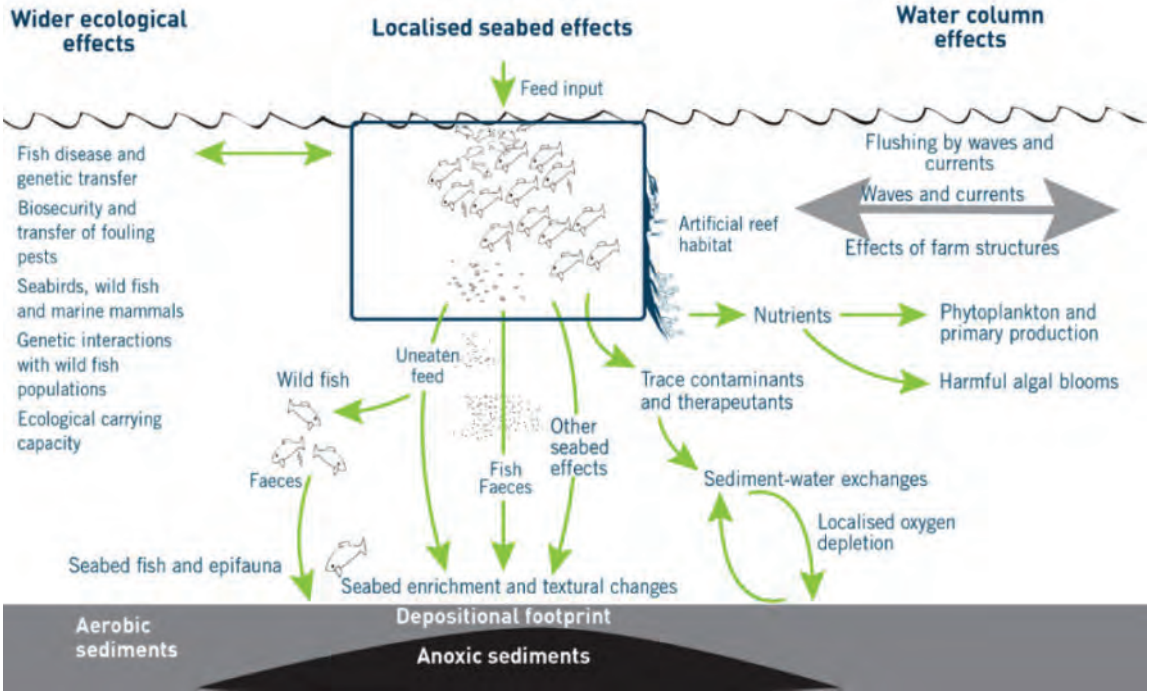
2. ECOLOGICAL EFFECTS

Different types of aquaculture (see examples A and B below) can affect marine ecosystems at different spatial scales

Potential local seabed effects include:

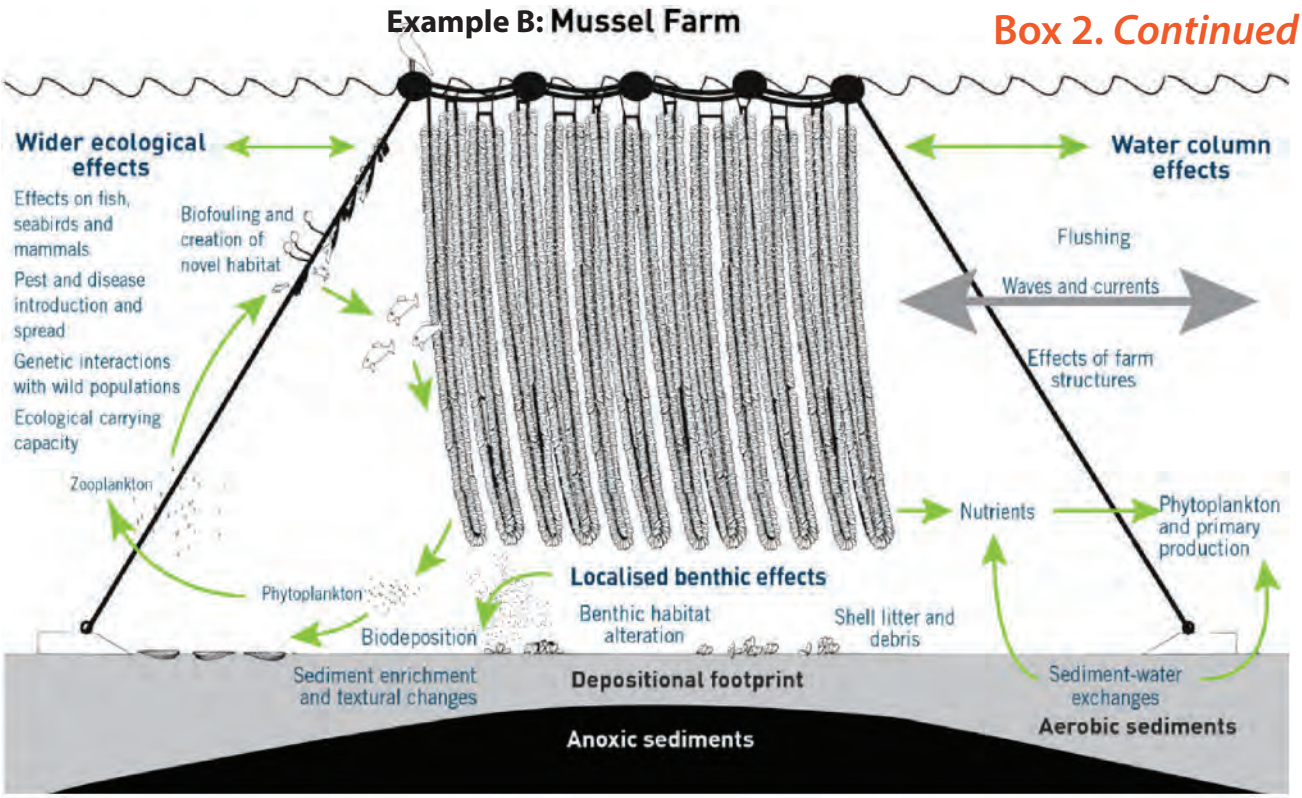
- Organic enrichment of the seabed by biodeposition beneath the farm (A+B)
- Smothering of benthic organisms and changes to the physical composition of sediments through deposition of shell litter and debris (A+B)

Example A: Finfish Farm



Schematic representation of the potential effects of marine finfish aquaculture (edited from Forrest et al. 2007)

Box 2. *Continued*



Schematic representation of the potential effects of marine shellfish aquaculture (edited from Keeley et al. 2009)

Potential local water quality effects include:

- Phytoplankton depletion and changes in planktonic community composition by cultured filter feeders (B)
- Nutrient enrichment effects from fish pellets and excretory products (A)
- Depletion of dissolved oxygen by respiration of farmed organisms (A+B)

Potential wider ecosystem effects include:

- Facilitation of the introduction, establishment, and spread of pests, parasites, and diseases (A+B)
- Disturbance, displacement, or entanglement of marine mammals and birds (A+B)
- Attraction of predators/scavengers and attraction of wild fish to aquaculture structures (A+B)
- Creation of habitats in the water column and on the seabed supporting increased biodiversity (B)
- Reduction of nutrient loads in the water column originating from other human activities (B)

3. MITIGATION OF INSHORE AQUACULTURE EFFECTS

- Aquaculture planning and consenting processes in New Zealand are managed by Regional Councils under the Resource Management Act 1991, and the potential effects of farms are considered in the consenting process
- Careful siting of farms is required to ensure adequate flushing, avoiding critical breeding and foraging areas and sensitive benthic habitats
- Consent conditions are set by Regional Councils to minimise potential ecosystem effects. In addition several voluntary measures have been developed
- Best management practices for monitoring and managing effects of salmon farming on benthic habitats and water quality have been developed for the Marlborough Sounds
- Biosecurity risk management (e.g., of diseases or parasites) is guided by industry codes of practice and an Aquaculture Biosecurity Handbook

4. KNOWLEDGE GAPS

- Cumulative effects and the carrying capacity of coastal regions where aquaculture activities take place
- Ecological effects of potential new farmed species
- Effects of open ocean aquaculture on migrating/protected species and on the offshore marine environment

16 ECOLOGICAL EFFECTS OF MARINE AQUACULTURE

Status of chapter	This chapter has been updated for AEBAR 2021.
Scope of chapter	The known ecological effects of marine aquaculture operations in New Zealand.
Area	The New Zealand EEZ and territorial sea. Presently aquaculture operations are located coastally, however, options for open ocean aquaculture are currently being explored.
Focal localities	Northland, Coromandel, Auckland, Bay of Plenty, Marlborough Sounds, Tasman Bay and Golden Bay, Canterbury, Southland.
Key issues	Uncertainty in predictions, cumulative effects, benthic effects of aquaculture in open ocean environments.
Emerging issues	Marine spatial planning, integration of monitoring datasets, effects of open ocean aquaculture, diversification of farmed species, pathogens affecting salmon, and parasites of flat oysters and pāua. The role of seaweeds in New Zealand aquaculture development.
Fisheries New Zealand research (current)	SEA2018-13 and AQU2021-01 *Validation of an eDNA multi-trophic metabarcoding enrichment stage monitoring tool.* Aquaculture research budget *Method to report environmental performance of aquaculture*.
New Zealand research (current)	Sustainable Farming Fund projects: The use of seaweed aquaculture for bioremediation (2 projects). MBIE Endeavour fund project: Greenwave regenerative ocean farming of seaweed. Phase II of the Sustainable Seas Challenge Projects: *Ecological responses to cumulative effects* and *Tools for managing cumulative effects*; *The Moana Project. Re-imagining aquaculture: inventing low-impact, offshore mobile technology that transforms finfish production.* Science for Technological Innovation National Science Challenge project: *Molecular biosensors to detect and monitor toxins from harmful algal blooms*. Strategic Science Investment Fund project: *Monitoring tools and farm management systems that quantify and minimise both the environmental effects and compliance costs of aquaculture*.
Related issues	Land-based effects, marine biodiversity, habitats of particular significance for fisheries management, climate change.

16.1 CONTEXT

Aquaculture is the world's fastest growing major food production sector and in 2018 supplied 49.4% of the supply of aquatic food globally (excluding seaweeds) (FAO 2020). The aquaculture sector in New Zealand provided over 3000 jobs in 2018 and generated over $600 million in revenue (Aquaculture New Zealand 2019). In 2018 the Oceania region (which includes New Zealand and Australia) produced only 0.25% of the world's aquaculture production (approximately 205 000 t); globally 82 million t were produced (FAO 2020).

The annual value of New Zealand aquaculture exports from 1998 to 2019 has been dominated by green-lipped mussels ($336 million in 2019), salmon ($115 million in 2019), and pacific oysters ($21 million in 2019) (Aquaculture New Zealand 2020). New Zealand has 15 000 km of coastline, making it one of the longest in the world. There are currently around 20 000 hectares of water space allocated for marine farming. Almost all the current commercial production comes from near-shore areas which account for 40% of the total allocation. The main current aquaculture locations in New Zealand are shown in Figure 16.1.

There are opportunities to grow the sector in New Zealand by improving the value of existing farming space, and by extending into land-based and open ocean aquaculture. Based on annual sales, records of growth, and development opportunities, Fisheries New Zealand predicts that New Zealand's aquaculture industry could grow to $3 billion in annual sales by 2035.

The potential benefits and opportunities offered by aquaculture are recognised by the New Zealand Government, which developed an Aquaculture Strategy in 2019 (Fisheries New Zealand 2019). One of the four key outcomes provided in the strategy is that aquaculture will lead in sustainable environmental practices. The National Environmental Standard (NES) for marine aquaculture (MA), came into effect on 1 December 2020. The NES-MA provides a nationally consistent framework for regional

councils to manage existing aquaculture activities. The NES-MA:

- increases regulatory consistency and certainty,
- ensures environmental effects are appropriately managed, and
- increases industry confidence to promote investment.

Sustainable development of aquaculture in New Zealand needs to be supported by good quality information on ecological effects to enable appropriate decision making. The aquaculture unit of MPI funded a collaborative project between NIWA and the Cawthron Institute to review the ecological effects of aquaculture (PRM2010-36). The MPI (2013) overview report and related literature reviews summarise the potential ecological effects of different types of aquaculture, discuss the magnitude and significance of those effects, consider management and mitigation options, and describe key knowledge gaps. This chapter largely summarises the findings of that larger document (MPI 2013), which should be referred to for further details, references, or clarification. In addition, MPI has supported and will continue to support work to improve environmental performance through the development of best practice standards. Recent developments in best practice guidelines to monitor and manage environmental effects of aquaculture are reported in the relevant sections below.

Increased industry interest in 'open ocean' salmon farming has resulted in four applications for open ocean sites in Marlborough and Southland. The state of knowledge of the potential effects of open ocean salmon farming in a New Zealand context has recently been reviewed (Bennett et al. 2020, Keeley 2020). The initial consent hearing from the New Zealand King Salmon Blue Endeavour open ocean salmon farm application has elicited a significant body of work and professional opinion on the potential environmental effects of offshore aquaculture. The outcome of this application is not yet known.

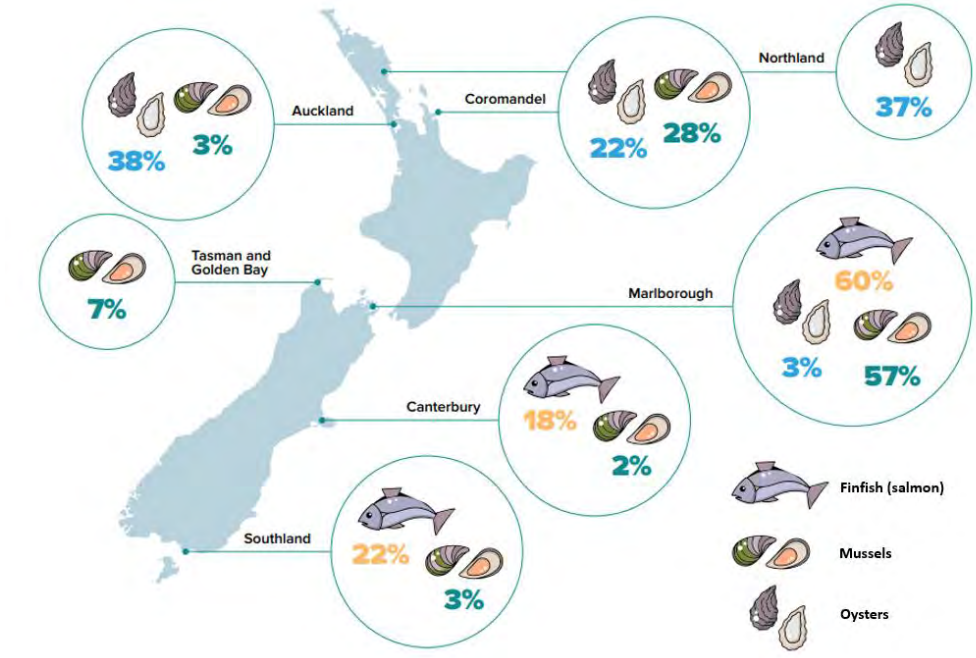


Figure 16.1: Geographic locations of main marine farming areas in New Zealand (Fisheries New Zealand 2019).

In 2012 an expert panel approach was used to trial a method for prioritising the ecological effects from aquaculture (see summary in Figures 16.2 and 16.3) (Stoklosa et al. 2012). This process brought together 17 knowledgeable participants from across a range of interested parties (central and local government, aquaculture industry, and scientists), to attempt to gain consensus on the relative importance of a range of ecological effects from aquaculture.

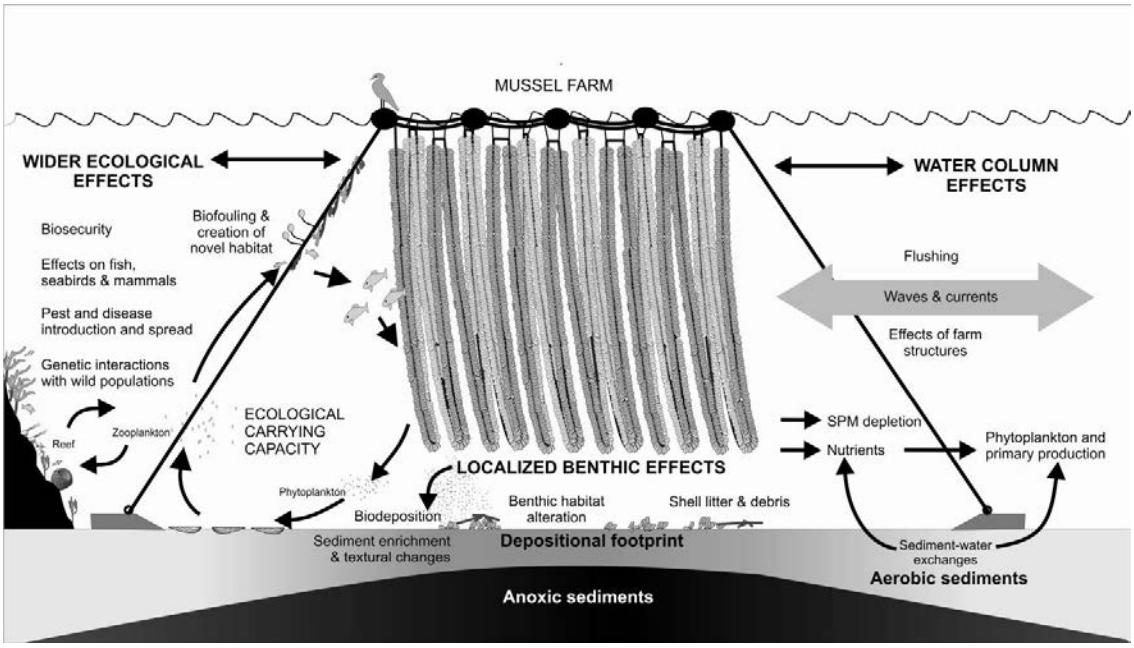


Figure 16.2: Schematic of actual and potential ecological effects from mussel farming (Keeley et al. 2019).

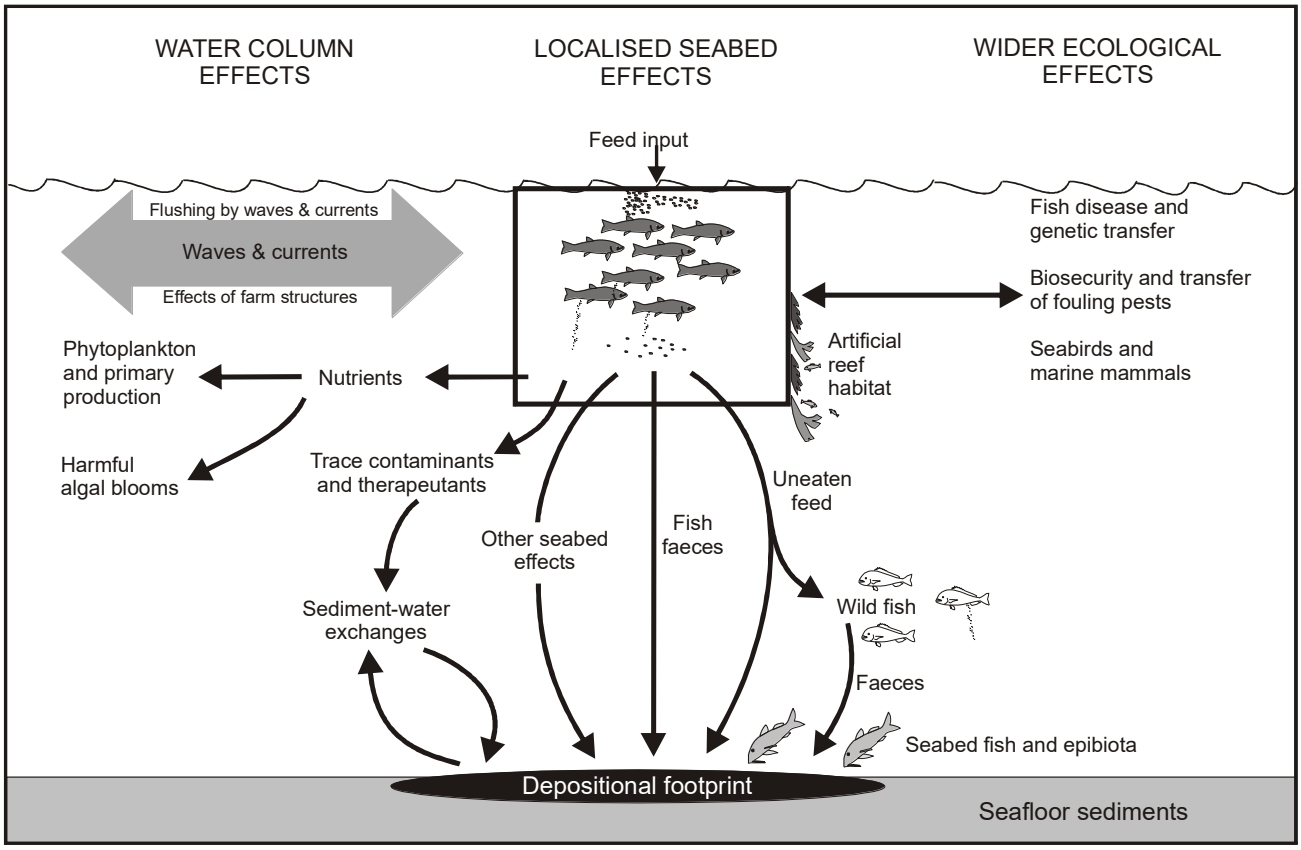


Figure 16.3: Schematic of actual and potential ecological effects from feed-added farming (from Forrest et al. 2007c).

The results of this process are only indicative, and are focused on inshore aquaculture, but for both feed-added and filter-feeding species the same three issues were identified as most important; these were (in decreasing order of importance): biosecurity threats, pelagic effects, and marine mammal interactions (

Table 16.1). Notably the score for the threat from biosecurity was more than 50% greater than the next highest score and the threat of pelagic effects was rated as

markedly higher for feed-added species than it was for filter-feeders. Other potential ecological threats considered were of lesser importance and are listed below the top three (in no particular order), along with an explanation of what was considered under each term. Interactions between threats and large-scale effects were not covered within this prioritisation exercise.

1. Biosecurity threats — how aquaculture may influence risks associated with pests and diseases.
2. Pelagic effects — aquaculture effects on the water column (excluding those explicitly dealt with by other chapters in the MPI 2013 literature review), at approximately the scale of the farm.
3. Marine mammal interactions — aquaculture effects on marine mammals.

- Benthic effects — aquaculture effects on the seafloor.
- Seabird interactions — aquaculture effects on birds.
- Effects from additives — effects of chemicals used in aquaculture upon the environment.
- Escapee effects — effects of escaped farmed species upon the environment.
- Wild fish interactions — aquaculture effects on non-farmed fish populations.
- Hydrodynamic alteration of flows — aquaculture effects on the water movement at scales greater than the farm scale.

These topic areas will be discussed further under each of their headings below (in the order above). In addition, note that stressors do not act in isolation, and any aquaculture impacts will occur within the context of (and potentially interacting with) other anthropogenic stressors and ongoing natural processes. The interacting and cumulative effects of aquaculture will be discussed in section 16.1.10 of this chapter. While the 2012 study focused on inshore aquaculture, the priority areas are also considered to be aligned with issues relating to open ocean developments.

Table 16.1: Trial prioritisation of potential classes of aquaculture effects from Stoklosa et al. (2012). Results of pair-wise comparisons using the Analytical Hierarchy Process (Saaty 1987) from the phase two workshop of the Aquaculture Ecological Guidance Project. RIW = relative importance weight. Order is decreasing in importance for the feed-added species.[1]

	Feed-added species		Filter-feeder species	
Potential ecological effects	RIW	Rank	RIW	Rank
Biosecurity threats	0.360	1	0.373	1
Pelagic effects	0.236	2	0.143	2
Marine mammal interactions	0.118	3	0.135	3
Benthic effects	0.090	4	0.088	5
Seabird interactions	0.079	5	0.092	4
Additive effects	0.042	6	0.019	9
Escapee effects	0.029	7	0.088	5
Wild fish interactions	0.026	8	0.021	8
Hydrodynamic alteration of flows	0.019	9	0.041	7

16.1.1 BIOSECURITY THREATS

Biosecurity threats posed by aquaculture activities have been reviewed by Forrest et al. (2011) for finfish and Keeley et al. (2009) for other species, and then compiled and summarised by MPI (2013). In 2016 MPI in collaboration with Aquaculture New Zealand published a technical document which provides information on the types of biosecurity risks and risk organisms and draws on national and international best practice to suggest objectives and management options for an integrated approach to on-farm biosecurity management (Georgiades et al. 2016). This section draws heavily from these sources, and the reader is referred to them for more detail.

16.1.1.1 INTRODUCTION

Aquaculture facilities (including hatcheries and open water operations) have an inherent risk of pest and disease introduction, exacerbation, or spread. Biosecurity is a set of preventive measures designed to exclude, eradicate, or

[1] Notably there was a chapter by MPI (2013) on the potential effects from genetic manipulation and polyploidy. However, genetic manipulation is controlled by the Environmental Protection Authority (EPA) and is not authorised for use in aquaculture. Polyploidy was also considered by the risk assessment workshop participants to be relatively rare in aquaculture and therefore this topic area was not considered by the prioritisation.

effectively manage the risk posed by pests and pathogens[2]. Biosecurity risk organisms include animals, plants, and micro-organisms capable of causing diseases (e.g., the ostreid herpes virus in pacific oysters) or otherwise adversely affecting New Zealand's natural, traditional, socio-cultural, or economic values (e.g., the sea squirt *Styela clava* and the Mediterranean fanworm *Sabella spallanzini*). In an aquaculture context, biosecurity also encompasses indigenous species already present in the environment that become enhanced as a result of culture operations (Forrest et al. 2011).

The primary source of entry for biosecurity risk organisms into New Zealand is through international shipping (Cranfield et al. 1998, Kospartov et al. 2010, Bell et al. 2011). Aquaculture pathways for on-farm introduction of pathogens and pests are provided by the open design of near-shore aquaculture sites and the input of seawater or freshwater into land-based systems (Peeler 2005, Johansen et al. 2011, Fitridge et al. 2012), broodstock and stock introductions, stock movements, shared infrastructure, equipment and vessels, staff, contractors or visitors, wildlife, and feed (Georgiades et al. 2016).

Aquaculture production systems may increase biosecurity risk, through acting as reservoirs or exacerbators (Okamura & Feist 2011, Peeler & Taylor 2011). Reservoirs host risk-organisms that can then spread by either natural or human-mediated mechanisms. Exacerbators create incubators/stepping stones for otherwise benign or low impact pests, pathogens, or parasites (both native and exotic species). Densely farmed populations may exacerbate the likelihood of disease outbreaks as stressed or weaker individuals that are more susceptible to infection may transmit the pathogens or parasites to healthy individuals (Handlinger et al. 2006, Robertsen 2011). Propagule pressure from pests and diseases may be exacerbated by densely farmed populations, if not managed effectively on site. In addition, farm infrastructure provides potential habitat for the settlement of biofouling organisms.

Considerable effort is placed on preventing incursions of pests, parasites, and diseases into the New Zealand environment. This is because the introduction, proliferation, and spread of risk species in New Zealand can have effects on marine and freshwater environments that are often difficult to manage, resulting in permanent and irreversible impacts (Forrest et al. 2011). The few successful efforts to eradicate aquatic invasive species (AIS) have several common elements (Locke et al. 2009b), which are unlikely to occur in combination:

- early detection and correct identification of the invader,
- pre-existing authority to take action,
- the ability to sequester the AIS to prevent dispersal, (or else the AIS had very limited dispersal capabilities),
- political and public support for management and eradication,
- acceptance of some collateral environmental damage,
- plans in place to minimise re-infestation of pests and diseases through surveillance and subsequent response actions, and
- follow-up monitoring to verify the completeness of the eradication.

The potential to develop treatment responses to marine AIS incursions was reviewed by Cahill et al. (2021). The review provides a snapshot of the current state-of-play for marine pathway treatments for AIS. Some treatment options are well understood from viewpoints of efficacy, safety, biosecurity, quality control, and compliance. However further work is required to deliver implementation ready AIS treatment protocols that can be reliably applied at scale.

Environmental factors including depth, wave climate, temperature regime, and currents influence dispersal of waste, disease agents, and pests and therefore play a significant role in determining the potential biosecurity risk for a given site.

For example, individual farms within any one Aquaculture Management Area (AMA) in Nelson Bays could function as a source of infection to other AMAs in Golden Bay (Zeldis et al. 2011b) via the transfer of viral or bacterial pathogens. Dispersion potential (within farms, between farms, or between blocks of farms), which is largely controlled by hydrodynamics, will also be influenced by temperature, because temperature can regulate metabolic growth and the proliferation of bacteria/viruses etc. that are shed as free-living single-celled organisms (Zeldis et al. 2011b).

[2] Defined here as an agent of disease, e.g., a bacterium or virus.

Temperature and salinity can also affect the biosecurity risks associated with individual species by controlling their range. For example, in the proliferation of invasive pacific oysters, the southern distribution is limited to Nelson-Marlborough, because water temperatures further south are too low for successful reproduction (Quale 1969, Askew 1972, Dinamani 1974). Salinity can vary with season, climatic variation (Scavia et al. 2002), and the catchment rainfall, with catchments that are dry in summer producing less runoff, elevating coastal salinities, which then affect the distribution of fouling species (S. Handley, NIWA, unpublished data). Farm stocks that may be susceptible to biosecurity risks are usually at greatest risk in summer. Summer is when temperatures, and hence metabolic rates of farmed animals, are highest, dissolved oxygen levels in the water are lowest (hence the risk of oxygen deprivation is highest), and the proliferation of biofouling populations is also greatest (S. Handley, NIWA, unpublished data).

Aquaculture space allocation in New Zealand has predominantly been driven by constraint mapping, allocating space in areas that do not conflict with other users and stakeholders (e.g., Handley & Jeffs 2003). This strategy increases potential biosecurity risks by encouraging development of aquaculture at environmentally less favourable sites. The use of ecosystem-based approaches to aquaculture development that incorporate tools like GIS can incorporate biosecurity risks (if known) to optimise site selection even in data poor environments (Aguilar-Manjarrez et al. 2010, Soto et al. 2008, Silva et al. 2011). In addition, models, which provide simulations of pest and pathogen spread, can be used to inform site selection. Biosecurity New Zealand have recently commissioned MetOcean Solutions Ltd to develop an application to examine coastal connectivity which could contribute to spatial planning.

16.1.1.2 SIGNIFICANCE OF EFFECTS

It is generally recognised that adverse ecological effects arising from pests, parasites, and pathogenic species associated with aquaculture can result in a range of threats including (Molnar et al. 2008):

a. disruptions to entire ecosystem processes with wider abiotic influences,
b. disruptions to wider ecosystem function, and/or keystone species or species/assemblages of high conservation value (e.g., threatened species),
c. disruptions to single species with little or no wider ecosystem impact, and
d. little or no disruption.

The infection of marine farms by pest organisms can lead to the development of significant infestations on farm structures, which may then:

1. act as a reservoir for subsequent spread to natural ecosystems and to the stock being cultured,
2. increase drag on cages and anchoring systems in high current areas, which in turn increases the chance of escapee effects if stocks are infected with pathogens or parasites (Forrest et al. 2011),
3. restrict water exchange, and thereby cause a build-up of waste, decrease in oxygen levels, and reduction in food availability (Fitridge et al. 2012)
4. harbour pathogens whose spread may be facilitated by aquaculture activities (Georgiades et al. 2016), and
5. compete for food with cultured species and thereby reduce stock growth (Georgiades et al. 2016).

Examples of significant effects from pest fouling organisms on aquaculture activities in New Zealand include documented impacts from infestation of marine farms with *Undaria* and the colonial tunicate *Didemnum vexillum* (e.g., Forrest & Taylor 2002 and L. Fletcher, Cawthron, unpublished data). As well as attached fouling organisms, aquaculture structures may also act as recruitment substrata for mobile pelagic or benthic species (e.g., jellyfish, ctenophores, sea star *Asterias amurensis*, sea cucumbers, or the crab *Carcinus maenas*; Forrest et al. 2009, 2011).

An example of the ecological effects stemming from a pathogen is the outbreak of pilchard herpes virus that was thought to have stemmed from pilchards imported for tuna aquaculture feed in South Australia. This event caused widespread mortality of pilchards, which led to starvation and the recruitment failure of little penguins, which prey on pilchards (Dann et al. 2000). The pathogens ostreid herpes virus microvariant 1 (Keeling et al. 2014) and *Bonamia ostreae* (Lane 2016) have been detected in New Zealand oysters, and disease outbreaks and management decisions have had significant impacts on New Zealand's pacific

oyster (*Magallana gigas*) and flat oyster (*Ostrea chilensis*) industries, respectively (Castinel et al. 2015, Sim-Smith et al. 2016, Ross et al. 2017). The costs of the biosecurity responses to these pathogens have been far greater than that for macro-fouling organisms.

Any attempt to assess the significance of potential effects of invasive pests, pathogens, or parasites in terms of their magnitude will be limited by the lack of robust information on the affected environments, inherent difficulties in making reliable predictions regarding the invasiveness of different species, and hence inferences regarding their direct or indirect effects (Forrest et al. 2011). The potential effects of pests and pathogens are given in Table 16.2 for finfish aquaculture in the Waikato region.

Table 16.2: Matrix illustrating the often unknown effects of pests, pathogens, and parasites associated with finfish aquaculture in the Waikato region. Examples are given of direct interactions (shaded cells) between potential biosecurity hazards and values in the Waikato region, and indirect effects (I). Direct interactions designated as: may be an important incremental risk above that already occurring (**), and probably a minor incremental risk (*). ? = direct interaction possible but significance unknown. From Forrest et al. (2011).

		Marine pests			Pathogens or parasites		
Potentially affected uses and values	**Component directly affected**	**Fouling**	**Predation**	**HABs**	**Virus**	**Monogeanean**	**Digenean**
Ecological							
Habitats and their biodiversity	Unstructured soft-sediment habitats	*	**	?			
	Structured soft-sediment habitats (physical or biogenic)	**	**	?			
	Zostera meadows	*		?			
	Saltmarsh			?			
	Rocky reef	**	**	?			
	Water column (plankton communities)			?			
Wildlife of conservation importance	Wading and seabirds	I	I	I	?+I		?
	Marine mammals	I	I	I	?+I		?
Wild fishery resources and fishing							
Finfish populations of commercial, recreational or customary importance	Conspecific finfish populations (kingfish or hapuku)			?	?	*	*
	Pelagic finfish populations (e.g. snapper, kahawai)			?	?	*	*
	Benthic finfish (e.g. flatfish) or reef-fish populations	I	I	?	?	*	*
Shellfish populations of commercial, recreational or customary importance	Infaunal soft-sediment shellfish (e.g. cockles, tuatua)	*	?	?	?		?
	Epibenthic soft-sediment shellfish (e.g. scallops)	**	?	?	?		?
	Reef-associated non-finfish species (e.g. paua, crayfish)	**	?	?	?		?
Harvesting of fish/shellfish (interference)	Pelagic finfish populations (e.g. snapper, kahawai)						
	Benthic finfish (e.g. flatfish) or reef-fish populations	*	*				
	Infaunal soft-sediment shellfish (e.g. cockles, tuatua)		*				
	Epibenthic soft-sediment shellfish (e.g. scallops)	**	*				
	Reef-associated non-finfish species (e.g. paua, crayfish)	*	*				
Harvesting of fish/shellfish (contamination)	Finfish or shellfish harvestability for human consumption			?	?	?	?

16.1.1.3 MANAGEMENT OPTIONS AND KNOWLEDGE GAPS

One of the key outcomes of the Aquaculture Strategy (Fisheries New Zealand 2019) is to ensure the industry is resilient by protecting aquaculture from biological harm and supporting it in adapting to climate change. Strengthening biosecurity management by shifting from reactive responses to planned and active management has

been identified as an objective to help achieve this outcome.

Biosecurity control of aquaculture activities currently occurs through resource consent conditions, codes of practice, and import health standards. The resource consenting process under the Resource Management Act (RMA) considers biosecurity via factors such as farm spacing, zoning,[3] staged development, and epidemiological units.

Biosecurity New Zealand in collaboration with Aquaculture New Zealand published a technical reference document containing detailed information about preventative on-farm biosecurity (Georgiades et al. 2016) and an aquaculture biosecurity handbook (MPI 2016), which provides guidance and practical and cost-effective options for biosecurity. The purpose of the reference document and handbook is to assist the industry in strengthening their on-farm biosecurity practices by providing technical information on the types of biosecurity risks, risk pathways, and risk organisms and suggesting biosecurity objectives and management options based on national and international best practice.

Biosecurity New Zealand has updated a marine pest identification guide which is available for marine farmers to use on the farm. Marine farmers must report any organism classified as 'Unwanted' or 'Notifiable' to the MPI pest and diseases hotline.

Import health standards are controlled by Biosecurity New Zealand and include requirements that must be met in the exporting country, during transit, and on arrival. For example, existing standards cover:

- import of juvenile yellowtail kingfish (*Seriola lalandi*) from Australia, and
- import of fish food and fish bait from all countries.

Possible prevention approaches that could be considered are summarised here as pathway management or on-farm management (Forrest et al. 2011).

Pathway management should focus on controls and surveillance on pathways from:

i. international source regions or pathways that are novel,
ii. pathways from domestic source regions known to be infected by recognised high-risk pests and pathogens, and
iii. pathways along which the frequency of transfers is considerably greater than that occurring as a result of other human activities.

Broadly there are two approaches to management of pathway risk (Forrest & Blakemore 2002), either a) avoid transfers on high-risk pathways, or b) treat pathways to minimise risk. Surveillance strategies for pathways can focus on entry surveillance, routine surveillance, or targeted surveillance of high-risk areas. Entry surveillance includes activities such as routine screening at airports, ports, and mail centres. MPI also commissions routine surveillance in ports and harbours around New Zealand. Targeted surveillance may be undertaken when activities such as harvest, grading, or transfer of stock from hatcheries or between sites is undertaken.

Good on-farm biosecurity management should include farm cleaning and disinfection, and surveillance (MPI 2013). Farm cleaning guidelines should deal with factors such as frequency of movement, source, and destination (i.e., locations) of movement of gear, stock, vessels, and waste and mortality disposal. Routine surveillance, undertaken on and around marine farms, is often the first point of detection of pests, pathogens, and diseases. Biosecurity measures adopted by farmers should be practical and fit for purpose, with biosecurity procedures for each farm based on their own site-specific conditions. Ideally each individual biosecurity procedure should be implemented with the understanding that it will work within a wider biosecurity plan (Georgiades et al. 2016).

New Zealand experience suggests that even when pest organisms become well established, the benefits gained from even limited management success have the potential to greatly outweigh the consequences of uncontrolled biofouling (Forrest et al. 2007a). To be effective, however, management requires buy-in from all marine aquaculture stakeholders whose activities can spread pest and pathogen organisms. Aquaculture companies can assist by:

[3] The World Organisation for Animal Health's (OIE) online aquatic animal health code (http://www.oie.int/en/international-standard-setting/aquatic-code/access-online) suggests establishing zones and using compartmentalisation (through geographical separation) to manage biosecurity and epidemiological risks.

a. developing Biosecurity Management plans, protocols, and associated Standard Operating Procedures (SOPs) for all freshwater/seawater sites and operations,
b. identifying existing and future pests and pathogens that threaten the aquaculture industry,
c. implementing surveillance of farm structures and associated vessels and infrastructure, to check for biofouling,
d. implementing regular robust cleaning and disinfection protocols of farm vessels, gear, and equipment used by farm personnel and visitors,
e. regular screening of broodstock and adult stock health,
f. managing stocking densities,
g. fallowing of sites following harvest/end of a production cycle,
h. developing coordinated and site-specific response plans for high-risk pests and pathogens before they become established,
i. developing effective contingency plans to manage effects of adverse events on the integrity of farm structures and farm operations,
j. effective training of staff in biosecurity practices and identification of diseases and signs of stress and behavioural changes in stock,
k. regular audits of biosecurity plans and incorporation of changes into ongoing training for personnel,
l. reporting unusual or higher-than-normal mortalities to Biosecurity New Zealand's Pest and Disease Hotline (0800 80 99 66),
m. managing existing pests on aquaculture structures to control biofouling and limit its impacts on stock and structures (management needs to be undertaken in a biosecure way).

For vectors of spread such as service vessels and farm equipment, preventative management options include:

i. maintenance of effective antifouling coatings for service and harvesting vessels (including dive boats),
ii. hull inspections, and hull cleaning and disinfection as necessary,
iii. cleaning and disinfection of dive equipment, and
iv. early eradication of pests from farm structures through daily checks and removal of organisms before they become well established.

However, once incursions have occurred, the use of reactive eradication treatments is necessary. There has been extensive international effort to develop reactive treatments for marine AIS, but this effort has largely not translated into implementation-ready biosecurity treatment protocols (Cahill et al. 2021). Eradication techniques that have been used in an attempt to control biofouling and pests include:

- direct treatments such as acetic acid, lime and hot water. (Carver et al. 2003, Coutts & Forrest 2005, Locke et al. 2009a, Morrisey et al. 2009),
- indirect treatments such as changing culture systems or practices (Handley & Jeffs 2003, Handley 2002, Handley & Bergquist 1997), and
- biological control agents (NRC 2010, Hidu et al. 1981, Enright et al. 1983, 1993, Cigarria et al. 1998).

Perhaps the best method for controlling the spread of disease is through the use of management practices that call for the inspection and batch testing of animals to ensure that infected animals are not moved into areas that do not currently have endemic infections (WWF 2010). Disease testing in New Zealand is currently conducted on an ad hoc basis and it is recommended that a national disease testing and surveillance system that facilitates routine disease testing of stock be established (Georgiades et al. 2016). In New Zealand, in the absence of enforced stock transfer protocols, management of stock, gear, and vessel transfers between geographic zones by voluntary codes of practice developed by industry could be used to minimise risks, e.g., the New Zealand Mussel Industry Council Ltd. code of practice for transfer of mussel seed (NZMIC 2001).

The different prospective farmed groups: feed-added (referred to as finfish), filter-feeders (referred to as shellfish), and lower trophic level species (seaweeds, e.g., *Undaria*, and sea cucumbers) and their potential impacts and management measures were covered in the literature review (MPI 2013) and are summarised in Table 16.3.

Table 16.3: Matrix of biosecurity management options and their relevance to key aquaculture groups (updated from MPI 2013). [Continued on next page]

Management Measure	Description	Finfish	Shellfish	Seaweeds	Sea Cucumbers
Import					
Import Health Standards	Import of Seedstock	y	n	n	n
Border Surveillance	Prevent import of macroscopic pests	y	y	y	y
Regulations on fouling on vessels / bilge water release.	Prevent import of macroscopic pests/fouling organisms/harmful algae	y	y	y	y
Planning and Development					
Site Selection	Meet biological requirements of stock	y	y	y	y
Zoning	Pathogen exposure from other farms, processing plants, rivers, sewage	y	y	y	y
Vessel Berthing	Segregate vessels based on local/regional movement	y	y	y	y
Targeted Surveillance	Routine monitoring of predetermined range of species	y	y	y	y
Farm Practices					
Fouling					
Management of nets and equipment	Regularly remove fouling from equipment	y	y	n	?
Antifouling	Treat equipment to prevent fouling	y	?	n	?
Transfer of equipment between sites/regions	Prevent transfer of potentially contaminated equipment between sites.	y	y	y	y
Husbandry					
Appropriate stock husbandry	Minimise stress to reduce the risk of disease becoming established	y	y	y	y
Management of feed so as not to attract birds/fish	Limit the opportunity to transfer between sites/wild stocks	y	n	n	n
Routine monitoring linked to husbandry activity	Manage stock within environmental limits.	y	y	y	y

Table 16.3 [continued from previous page]: Matrix of biosecurity management options and their relevance to key aquaculture groups (updated from MPI 2013).

Remove mortalities	Limit potential for reservoir of disease	y	n	n	n
	Reduce attraction of predators.	y	n	n	n
Use of processed feeds	Heat-treat feeds to kill pests/pathogens	y	n	n	y
Surveillance	Observe and record causes of mortality, unusual fouling, etc.	y	y	y	y
Stock Transfer					
Hatchery testing for disease	Prevent diseases stock being sent to sites	y	y	y	y
Single year class sites	Prevent disease transmission between year classes	y	n	y	y
Harvest					
Isolate waste streams from growing areas	Prevent reintroduction of pest/pathogens to harvest sites	y	y	y	y
Fallow sites	Reduce opportunities for reintroduction of pets/pathogens from intermediate hosts.	y	y	y	y
Education					
Codes of practice	Educate and alert staff to biosecurity requirements	y	y	y	y
Public information	Alert public to biosecurity risks	y	y	y	y
Eradication					
Culling	Cull diseased stock to remove pathogen/pest	y	y	y	y
Fallowing	Remove stock from an area to allow host mediated pathogen to die out	y	y	y	y
Manual removal of macroscopic organisms	Eradicate individual pest organisms early in the invasion process.	y	y	y	y
Treatment technologies	Treat the whole farm or bay to remove pests.	y	y	y	y
Pharmaceutical treatment	Treat the individual affected stocks to remove pathogens/pests.	y	n	n	n

16.1.2 PELAGIC EFFECTS

There is a large volume of international literature on the effects of shellfish and salmon farming on the pelagic environment and much of this material is referenced in three local reviews: finfish (Forrest et al. 2007a), shellfish (Keeley et al. 2009), and oysters (Forrest et al. 2007b) and summarised by MPI (2013); the reader is referred to these for more detail. Guidelines for monitoring pelagic effects have recently been developed by Fisheries New Zealand (Giles et al. 2021).

16.1.2.1 INTRODUCTION

This section deals with near-field (approximately at the scale of the farm) pelagic effects (those seen in the water column). This should be read in conjunction with the benthic effects (where wastes from the pelagic zone settle) and the cumulative effects sections (where far-field pelagic effects are seen).

The pelagic zone is the zone where:

- Filter-feeders extract phytoplankton, micro-zooplankton, and organic particulates from the water column, which can reduce food available to other consumers (Zeldis et al. 2004).
- Dissolved oxygen (DO) is extracted by respiration of farmed organisms and this can potentially lead to DO depletion when cages are heavily stocked or where they are located in shallow sites with weak flushing (La Rosa et al. 2002). Excessive DO depletion in the water column could potentially stress or kill the fish and other animals. Sediment DO depletion may result in the release of toxic by-products (e.g., hydrogen sulphide) into the water, which can also have adverse effects on fish and other organisms (Forrest et al. 2007a).
- Fish pellets and the excretory products and waste products of cultured and fouling organisms are received.

Wastes excreted can either be as a particulate 'cloud' that disperses rapidly (as for finfish) or be bound in long strands composed of digested and undigested plankton (as for filter-feeders) (Reid 2007). The difference in shellfish and finfish faeces can result in different biochemical impacts on the pelagic zone (Reid 2007). Dissolved farm waste has the potential to increase ambient DIN (Dissolved Inorganic Nitrogen), and the potential effects of this are usually experienced away from the farm (and these are discussed in the cumulative effects section 16.3.10).

16.1.2.2 SIGNIFICANCE OF EFFECTS

The significance of these key primary impacts depends on the assimilation capacity (or carrying capacity) of the environment. Local hydrodynamics, water depth, and ambient oxygen levels are the most critical criteria for determining the pelagic impacts of aquaculture (Zeldis 2008a, Zeldis et al. 2010, 2011a). In shallow areas with slow currents, effects will be more pronounced compared with a deep site with strong flow and good flushing. In the New Zealand situation where most shellfish farms are located in well-flushed areas, nutrient enrichment beyond the farm boundaries is presently difficult to detect (Zeldis 2008a). In addition, there are siting design and management factors that will greatly influence potential impacts.

- Dispersive environments (such as open ocean) will dilute inputs and generally reduce the concentration of nutrient inputs.
- Density of farms in a unit volume of water; more farms will generally have more effect.
- Stocking density: higher stocking densities will generally have more effect, and this may differ seasonally.
- Feed conversion ratio (FCR for feed-added species): FCR is a measure of the efficiency of growth relative to feed used, and the global range is 1.1 to 1.7 on average (Reid 2007). The lower the FCR the less waste will be produced.
- Cage designs and orientation to prevailing current direction. This will impact on drag on passing water masses, flushing of cages, and settlement of biofouling organisms.

For salmon farms in the Marlborough Sounds, localised and direct water quality effects are elevated nitrogen and reduced dissolved oxygen (Elvines et al. 2019b). These effects are largely periodic and are associated with periodic feed/excretion/respiration patterns (Tomasso 1994). Notably the immediate impact signal of a salmon farm decays rapidly with distance, primarily due to mixing with more distant waters, but also due to uptake by primary producers (Elvines et al. 2019b). Indeed, the signal is rarely detectable at distances greater than a few hundred metres from the pens (e.g., Knight & Beamsley 2012, Bennett et al. 2018).

Seaweed aquaculture is receiving increasing interest in New Zealand. Seaweeds tend to extract nutrients and CO_2 from seawater and are generally considered beneficial for the pelagic environment (Stenton-Dozey et al. 2020).

Sea cucumbers are benthic deposit feeders and are normally cultured at low densities. It is expected that they would have little in the way of ecological effects on the pelagic environment (Zamora et al. 2018); see MPI (2013) for further discussion.

16.1.2.3 MANAGEMENT OPTIONS AND KNOWLEDGE GAPS

Pelagic effects can be partially controlled through careful site selection. More dispersive sites provide multiple advantages in terms of environmental effects on the water column. Open ocean sites tend to have stronger currents and provide good conditions for turbulent mixing, thereby increasing the rate of dilution and dispersal of farm-derived wastes (Welch et al. 2019)

Farm design, orientation, and stocking rates should be appropriate to the site. Good farm management (e.g., compliance with The New Zealand Finfish Aquaculture Environmental Code of Practice (NZFSA 2007)) should include reducing biofouling on nets by regular cleaning and removal of biofouling waste. Monitoring, adaptive management, and the use of Integrated Multi Trophic Aquaculture (IMTA) are also potential mitigation measures (see section 16.3.10 for further discussion). Notably pelagic effects are reversible after removal of the farm.

Models are an important component in determining pelagic effects at a site. Several regional councils have commissioned biophysical modelling of the coastal environment to inform aquaculture planning and consent processes (e.g., Hadfield et al. 2014, Knight et al. 2014, and Broekhuizen et al. 2015). Modelling is an iterative process, and it is envisioned that hydrodynamic and aquaculture effects models will continue to be improved, such that over time more complex processes (e.g., cumulative effects) will be encompassed (Knight et al. 2014).

Best management practice for salmon farms in the Marlborough Sounds have recently been developed for water quality standards and monitoring protocols (Elvines et al. 2019b). The focus of the best management practice is on the broader scale nutrient enrichment effects within a region, rather than on localised effects around the farms themselves (see section 16.3.10).

16.1.3 MARINE MAMMALS

The reader is referred to Clement et al. (2021), Würsig (2021), and MPI (2013) for more detail.

16.1.3.1 INTRODUCTION

Fisheries New Zealand have recently published guidelines on best practices and technologies available to minimise and mitigate the interactions between finfish open ocean aquaculture and marine mammals (Clement et al. 2021). These guidelines draw on several overseas studies (Würsig & Gailey 2002, Kemper et al. 2003, Wright 2008) and a recent New Zealand focused review (Würsig 2021) that have characterised the possible interactions between marine mammals and aquaculture, which include the following.

- Attraction or avoidance, because marine farm structures represent a new physical, visual, or acoustic obstruction that marine mammals may choose to ignore, investigate, or avoid. Attraction might alter natural foraging and passage patterns and potentially lead to interactions, and also to incidents.

- Interactions with farm structures, defined as events when a marine mammal makes physical contact with the farm structure, which may lead to
- incidents that cause injury (e.g., rope cut, abrasion), entrapment, or entanglement (live or fatal) of a marine mammal.

The guidelines focus on mitigation of interactions through site selection, design, and operation of farm infrastructure. Because open ocean aquaculture is at an early development stage in New Zealand, carefully designed monitoring programmes will be required to assess the effectiveness of mitigation measures.

The physical location of the farm within important habitats or migration routes of New Zealand marine mammal species is the main factor that leads to potentially adverse interactions or avoidance issues. Once a farm is within the habitat or migration route of a species, the types of gear and equipment employed, as well as operational procedures around regular farm activities, influence the probability and scale of the impacts given above.

Mitigation options include:

• discourage activities that could attract marine mammals to the farm,

• minimise artificial lighting, where and when possible, to reduce attraction of prey fish and predators,

• avoid un-tensioned and/or loose ropes, lines, or nets on farms at all times,

• consider the use of predator-resistant materials in the construction of farms, and

• minimise predator exclusion nets, or design nets to minimise the likelihood of entrapment.

16.1.3.2 SIGNIFICANCE OF EFFECTS

Incidences of marine mammal entanglement with aquaculture operations are reasonably infrequent in New Zealand. This is due in part to the relatively small scale of this industry and operational procedures that minimise entanglement risk (Forrest et al. 2007c). Studies in New Zealand have so far only addressed interactions between mussel farms with Hector's (Slooten et al. 2001) and dusky dolphins (Markowitz et al. 2004, Vaughn & Würsig 2006, Duprey 2007, Pearson et al. 2007). Collectively these works suggest that, although some marine mammal species are not completely displaced from regions as a whole, they do not appear to be utilising habitats occupied by shellfish farms in the same manner as before the farms were established. Interactions between dolphins, fur seals, and salmon farms also occur. New Zealand King Salmon report all marine mammal interactions on their website.

The interactions between marine mammals and aquaculture have been considered in relation to any larger scale and offshore developments in New Zealand waters (Würsig 2021). The development of multiple farms or several types of overlapping aquaculture may lead to exclusion of some species from particular bays or regions depending on the species and its sensitivity to such activities. For depleted populations (e.g., southern right whales or Hector's and Māui dolphins), the issues of low population size and a fairly isolated population structure make these species more vulnerable to such impacts than other species.

16.1.3.3 MANAGEMENT OPTIONS AND KNOWLEDGE GAPS

Farm locations need to be carefully selected to minimise the likelihood of overlap with marine mammal migration routes and/or known habitats. In Admiralty Bay, where overlap with dusky dolphins was a concern, and distribution patterns were not well known, three years of presence monitoring was required before commencement of aquaculture development (Mulcahy & Peart 2012).

The risks associated with physical interactions can be further minimised by adopting operational and maintenance guidelines and standards for farm structures as well as any noise-generating equipment (British Columbia Shellfish Growers Association 2001, SAD 2011). Some examples include enclosing predator nets at the bottom, keeping nets taut, using mesh sizes of less than 6 cm (Kemper et al. 2003), keeping nets well maintained (e.g., repairing holes), and reducing feed waste.

In Admiralty Bay, surface lines were removed from the water over winter to minimise interactions when dolphins are more active foragers (Mulcahy & Peart 2012).

Unfortunately, detailed information on abundance, distribution, and critical habitats is available for only a handful of New Zealand's marine mammal populations. Monitoring records of the presence (and absence) of marine mammal species in the vicinity or general region of a farm site (see for example Clement & Elvines 2019), and any detailed observations of their time spent under or around the farm structure should be compiled where possible. Future research needs to focus also on those species most likely to come in contact with aquaculture. In addition, ongoing research into the types of design, maintenance features, and operational procedures that minimise entanglement risk should be supported. For example, cage technology in South Australia has developed and improved to the point where predators are excluded by the cage structures rather than predator nets (Taylor et al. 2010).

16.1.4 BENTHIC EFFECTS

This area is covered for inshore aquaculture by Forrest et al. (2007c) and summarised by MPI (2013); and for offshore aquaculture by Bennett et al. 2020 and Keeley 2020. The reader is referred to these documents for more detail. Guidelines for monitoring pelagic effects have recently

been developed by Fisheries New Zealand (Giles et al. 2021).

16.1.4.1 INTRODUCTION

The benthic effects of aquaculture can be classified as:

- Organic enrichment and smothering, which can lead to (Forrest et al. 2007c):
    - localised biodeposition leading to enrichment of the seabed and associated microbial processes, and chemical and biological changes (including to infauna and epifauna, e.g., Christensen et al. 2003, Keeley et al. 2009),
    - widespread biodeposition, in intensive filter-feeder cultivation, can potentially lead to a reduction in natural deposition rates,
    - widespread biodeposition leading to mild enrichment in naturally depositional areas which has the potential for effects on reefs, inshore habitats, and sensitive taxa,
    - smothering of benthic organisms and changes in sediment physical composition, and
    - sediment contamination (copper and zinc, covered in the additives section 16.3.6).

- Biofouling and drop-off of debris, which can lead to:
    - smothering and changes to physical composition of sediments (Keeley et al. 2009),
    - creation of habitat structure (Davidson & Brown 1999), and
    - aggregations of predators and scavengers (Inglis & Gust 2003).
- Seabed shading by structures, which can change localised productivity under the farm (Huxham et al. 2006).

The magnitude and spatial extent of seabed effects from finfish farms are a function of a number of inter-related factors, which can be broadly considered as farm attributes and physical environment attributes.

Farm attributes that can affect the mass load of organic material deposited to the seabed include the following:

- fish stocking density and settling velocities of fish faeces (Magill et al. 2006),
- the type of feed and feeding systems, the feeding efficiency of the fish stock, and the settling velocities of waste feed pellets, and
- the type of cage structure can also influence depositional effects through differences in fish holding capacity, which affects feed loadings and may affect feeding efficiencies. Furthermore, cage design and position may affect the site's hydrodynamics; any reductions in flow will reduce waste dispersal and flushing, potentially resulting in depositional effects that are more localised but also more pronounced.

The capacity of the environment to disperse and assimilate farm wastes is a function of the attributes of the site (primarily water depth, sediment type, and current speed), although assimilative capacity may also vary seasonally in relation to factors such as water temperature. Consequently, sites located in deep water (over 30 m) and exposed to strong water currents (over 15 cm s^{-1} on average) will have more widely dispersed depositional footprints with less intense enrichment than shallow, less well-flushed sites (e.g., Molina Dominguez et al. 2001, Pearson & Black 2001, Aguado-Gimenez & Garcia-Garcia 2004).

16.1.4.2 SIGNIFICANCE OF EFFECTS

The benthic effects from feed-added and filter-feeder aquaculture result from farm derived organic waste settling on the seafloor. The higher volume of waste and uneaten food involved in feed-added farming and its more particulate nature generally means that effects from feed-added aquaculture are greater than those seen from filter-feeder aquaculture, and these can be seen further away (within 1 km for feed-added species as opposed to within 100 m for filter-feeders; Forrest et al. 2007c). In extreme cases the settlement of organic waste can overwhelm the assimilative capacity of the seabed fauna and can lead to anoxia and outgassing of hydrogen sulphide and methane. At low-flow sites very little resuspension occurs and effects are largely constrained to the local environment (Forrest et al. 2007c). At high-flow sites, however, biodeposits can be resuspended, exported, and eventually deposited in a very diffuse form in neighbouring low-flow areas (e.g., in enclosed bays or inlets). If depositional inputs are sufficiently elevated, then there is potential for effects in the form of increased far-field deposition. This may result

in very mild, but potentially spatially extensive, organic enrichment.

The ecological effects of farming seaweeds are likely to be significantly less than for farming species that require artificial feed and excrete solid waste. Seaweeds are largely extractive and benthic impacts are likely to be restricted to drop-off of fouling organisms and shading. Overseas, seaweed farming has been recorded as having positive effects on benthic fauna (Visch et al. 2020).

The benthic effects of sea cucumber culture will depend on the culture technology used. Sea cucumbers caged or ranched below other aquaculture species may be expected to consume deposited organic matter from the seabed. Apart from the organic matter reduction, sea cucumbers reduce the accumulation of phytopigments, enhance bacterial activity, the mineralisation processes, and also increase nutrient dissolution into interstitial water and the water column (Stenton-Dozey et al. 2020, Keeley et al. 2009).

Fish farm and mussel farm studies in New Zealand and overseas indicate timescales for recovery of benthic habitats once farms are removed. These recovery times ranged from a few months in well-flushed areas where effects are minor, to a few years in poorly flushed areas where moderate or strong enrichment has occurred (see MPI 2013).

There is growing international recognition that, rather than be viewed solely as causing adverse environmental impacts, shellfish aquaculture may actually contribute toward the resilience of coastal ecosystems (Lindahl et al. 2005, Coen et al. 2011, Arreguín-Sánchez 2013, Saurel et al. 2014, Rose et al. 2015, Kluger et al. 2016, 2017, Bricker et al. 2018). A review of the potential ecological and ecosystem services provided by mussel farms in the Marlborough Sounds has recently been completed (Stenton-Dozey & Broekhuizen 2019). Species diversity found on mussel droppers was akin to that associated with present day benthic algae meadows, rhodolith beds, bryozoan thicket, and calcareous tube worms, whereas diversity found on mussel-culture derived reefs was akin to soft bottom non-calcareous tubeworm mounds that attract a predominance of scavengers, detritivores, and predators. The review suggested that mussel farms may to some degree compensate for the loss of biodiversity supported by biogenic reefs by providing habitats that increase the abundance of organisms that once that would have been plentiful in the Marlborough Sounds (Stenton-Dozey & Broekhuizen 2019).

16.1.4.3 MANAGEMENT OPTIONS AND KNOWLEDGE GAPS

Management measures for mitigating benthic impacts for aquaculture are similar to those for mitigating pelagic impacts (section 16.1.2.3). Site selection is important for the same reasons, to maximise the dispersive properties of the site, but should also try to avoid potentially sensitive or valuable benthic habitats (conservation areas, reefs, etc.) (see MacDiarmid et al. 2013 for examples of sensitive habitats). Depositional modelling should be used to predict benthic effects from a range of farming scenarios to inform decisions regarding optimum (sustainable) site-specific feed capacities.

Modelling techniques are continuing to evolve and increase in their ability to accurately predict the depositional footprint of finfish aquaculture (Elvines et al. 2021). Further work is required to accurately assess near-bottom flows in complex habitats that impact on particle resuspension (Smeaton & Vennell 2021).

In New Zealand we do not yet have any experience with monitoring benthic effects of finfish or mussel farming in open ocean settings, and there are relatively few examples to draw on from overseas. The characteristics of open ocean environments create new logistical challenges for monitoring. For example, farming in these new open ocean environments will likely encounter new habitats and species for which little is known about their tolerance for organic waste (Keeley 2020). The logistics of accurately monitoring benthic impacts in open ocean environments may be complicated by working at depth and in strong tidal currents.

The application of Environmental Quality Standards (EQS) that encompass a range of effects measures can be useful for assessing impacts from aquaculture. For example, best management practice guidelines (BMP) have been developed for monitoring benthic impacts from salmon farms in the Marlborough Sounds (Keeley et al. 2015a, Keeley et al. 2019). These guidelines provide consistent and clear requirements for the management and monitoring of existing farms, based around an agreed set of environmental quality standards with accompanying rationale. Details are provided about how and when to conduct the surveys, along with consequences in the event

of non-compliance. New standards will be required for open ocean aquaculture.

Staged development and Modelling-Ongrowing-Monitoring (MOM) approaches are also potentially beneficial for establishing and managing environmental effects (MPI 2013).

16.1.5 SEABIRD INTERACTIONS

The reader is referred to MPI (2013) and Gaskin et al. (2021) (and references therein) for more detail.

16.1.5.1 INTRODUCTION

In New Zealand, the negative effects (to seabirds) of both feed-added aquaculture and filter-feeder aquaculture have centred on entanglement (resulting in birds drowning) and habitat exclusion and displacement from feeding grounds. The location of the farm within the range of seabirds and the conservation status (which is a measure of the risk of extinction) of these seabird species are the main factors that may lead to issues of sustainability and conservation concern. Of particular concern are the location of farms in relation to breeding and feeding sites and the operational procedures of regular farm activities (which, for example, can affect the likelihood of entanglement).

Fisheries New Zealand have recently published guidelines on best practices and technologies available to minimise and mitigate the interactions between finfish open ocean aquaculture and seabirds (Gaskin et al. 2021).

Within these guidelines, the main effects that need to be addressed include the following.

- Attraction or avoidance, because marine farm structures represent a new physical, visual, or acoustic obstruction that seabirds may choose to ignore, investigate, or avoid. Attraction might alter natural foraging and passage patterns and potentially lead to interactions, and also to incidents.
- Interactions with farm structures, defined as events when a seabird makes physical contact with the farm structure, which may lead to
- Incidents that cause injury (e.g., rope cut, abrasion), collision, entrapment, or entanglement (live or fatal) of a seabird.

Other potential negative effects may include disturbance of breeding colonies and bird feeding, blockage of the digestive tract following ingestion of foreign objects, and the spread of pathogens or pest species.

In contrast, a potential beneficial effect includes the provision of roost sites closer to foraging areas (Lalas 2001), saving energy and enabling more efficient foraging; this is most likely to benefit shags, gulls, and terns (MPI 2013). The attraction and aggregation of small fish around marine farm structures (Grange 2002) may provide enhanced feeding opportunities for piscivorous seabirds but also may increase attraction to the farm with the associated risk of negative interactions.

16.1.5.2 SIGNIFICANCE OF EFFECTS

Siting of a farm close to a seabird breeding colony is very likely to have an immediate adverse effect that will continue as long as the duration of the farm. There are few reports of negative seabird interactions with shellfish farms (Butler 2003, Lloyd 2003); however, there are reports of seabird deaths as a result of entanglement in salmon farm nets. New Zealand King Salmon publish details of all seabird incidents (https://www.kingsalmon.co.nz/our-environment/). The potential effects of habitat exclusion by feed-added farms in New Zealand are considered to be insignificant given the small area occupied in relation to the large total area of suitable habitat available for foraging seabirds (MPI 2013).

16.1.5.3 MANAGEMENT OPTIONS AND KNOWLEDGE GAPS

At present, potential risks are identified on a farm-by-farm basis. The most obvious is the choice of site for a farm to avoid disturbance to sensitive breeding colonies of seabirds. Good operating practices (for feed-added farms) such as enclosing predator nets above and below cages, controlling litter, minimising the use of lights at night, keeping nets taut, and using mesh sizes less than 6 cm, all minimise the chances of negative seabird interactions. Given the current relatively small size of the aquaculture industry in New Zealand, the overlap of farming activities with the feeding areas of seabirds is unlikely to present significant issues. However, if larger farms are developed at open ocean sites the potential range and frequency of interactions will need to be reassessed (Gaskin et al. 2021, MPI 2013).

There are significant knowledge gaps concerning almost all seabird species in New Zealand. Detailed information on the time-specific distribution, abundance, and critical habitats is lacking. Also missing is information on key prey species of seabirds, particularly those that may be affected by aquaculture. In addition, there should be ongoing monitoring (where an issue is identified) and research into the operation, design, and maintenance of farm structures that minimise disturbance and entanglement risks. Little is known about the exclusion distance needed for different species of foraging and feeding seabirds; for example, proposed exclusion distances for king shags in the Marlborough Sounds range from 100 m to 1000 m (Davidson et al. 1995, Taylor 2000), but Lalas (2001) noted that king shags resting ashore or on emergent objects only flew off when approached to within 30 m.

Resource consent conditions may require that management plans be developed for specific species. Where knowledge gaps exist, these management plans may provide provisions which address these gaps. For example, the King Shag Management Plan, established by New Zealand King Salmon in accordance with their consent conditions, requires that aerial surveys be conducted to monitor king shag population abundance. New Zealand King Salmon must determine and take subsequent action if any population decline is a result of farm activity. King shags, classified as 'Nationally Endangered' by DOC (Robertson et al. 2021), have a small population size and restricted range and concerns have been raised regarding the effect of aquaculture activities on populations in the Marlborough Sounds (Bell 2019b). Three surveys, conducted in 2015, 2018, and 2019, have revealed fluctuations in king shag population numbers with a reduction in birds between 2015 and 2018 and a subsequent increase by 2019 (still 6% below that seen in 2015) (Bell et al. 2019).

It is difficult to interpret these fluctuations in numbers as several factors, such as annual variations in breeding success or roost sites being missed during surveys, may influence the results. Nests were counted in a boat survey in 2019 which also provided opportunity to count chicks and observe behaviours (Bell 2019a). Further research using GPS devices into the foraging behaviour of king shags is currently underway (Bell 2020, Bell 2019b); this may provide further insight into the potential effects of aquaculture activities on this species. Of eleven king shags tagged, four foraged close to mussel farms and all eleven roosted on mussel farms at times, and one of the birds was found to forage almost exclusively within mussel farms (Bell 2020).

16.1.6 EFFECTS FROM ADDITIVES

Assessments of the use and impact of chemicals used in aquaculture in New Zealand are focused on salmon farming (Forrest et al. 2007c, 2011, Wilson et al. 2009, Burridge et al. 2010, Clement et al. 2010, MPI 2013); the reader is referred to these documents for more detail.

16.1.6.1 INTRODUCTION

Additives such as antibiotics, antibacterials, and other therapeutants may be introduced intentionally at aquatic farms (MPI 2013). These therapeutants could potentially affect non-target organisms (phytoplankton, zooplankton, and sediment bacteria) and lead to an increase in resistant bacteria and/or parasites (GESAMP 1997, Forrest et al. 2007c, 2011).

Metals from fish feed (zinc) and antifouling agents used on structures (copper) may be unintentionally introduced to the marine environment at aquaculture sites (MPI 2013). The main concern with these metals is their toxicity to animals (Forrest et al. 2007c, 2010, Clement et al. 2010).

16.1.6.2 SIGNIFICANCE OF EFFECTS

Currently, no therapeutants are known to be used in the farming of bivalves and lower trophic level species and no antibiotics or pesticides have been used on salmon farms in New Zealand (Seafood Watch 2020). However, culture of native species and/or the emergence of disease may lead to the need to use therapeutants in the future.

Assessments at salmon farming sites in the Marlborough Sounds revealed locally elevated copper and zinc levels (with maxima exceeding ANZECC (2000) sediment quality guideline values; Hopkins et al. 2006). Copper antifouling paint has not been used at salmon farms in New Zealand since 2015 (Elvines et al. 2019a). Potential adverse effects from high zinc exposures range from interference with growth at low concentrations to behavioural abnormalities at high concentrations (Eisler 1993, Burridge et al. 2010); but elevated metal concentrations do not necessarily indicate adverse ecological effects because they may not be bioavailable (Sneddon & Tremblay 2011, Forrest et al. 2007c).

16.1.6.3 MANAGEMENT OPTIONS AND KNOWLEDGE GAPS

The use of therapeutants is closely controlled for all species grown for human consumption. Food safety standards regulate the acceptable concentrations of metals, chemicals, and additives in food products. New Zealand salmon farmers must also comply with the New Zealand Salmon Farmers Association's Finfish Aquaculture Environmental Code of Practice, with harvesting and processing in accordance with New Zealand food safety standards.

'Best management practice' should minimise the potential future use of therapeutants, and hence help mitigate potential effects. The most important means to reduce and manage the overall antibiotic usage would be to support development of targeted disease management strategies (biosecurity protocols) and alternative therapies, in particular vaccines.

The potential for environmental issues from therapeutant use in the future will need to be assessed on a farm-by-farm basis. The persistence of therapeutants in the environment, the induction of resistance of targeted organisms, and the effects on non-target organisms are the main knowledge gaps.

Although the use of copper antifouling has largely been phased out of New Zealand salmon farms, zinc remains as a feed additive. Careful management of feed wastage is already prioritised due to the cost of feed and need to manage environmental impacts. Studies on the bioavailability and forms of the metals will give better understanding of their toxicity; a focus is needed on sub-lethal effects on individual species and the broader effects on benthic communities.

16.1.7 ESCAPEE EFFECTS

The subject of escapee effects from aquaculture is well covered for finfish in the reviews by Forrest et al. (2007c) for New Zealand and Jensen et al. (2010) for Norway, and for shellfish by Keeley et al. (2009) and summarised by MPI (2013). The reader is referred to these sources for more detail.

16.1.7.1 INTRODUCTION

It is useful to recognise that the human-mediated transfer of numerous marine organisms to New Zealand and around the coastline is an issue with a long history that continues today. Historically, this reflects deliberate transplants of marine organisms (including salmon), and more recently the inadvertent transfer of a range of native and non-indigenous marine species (including fish), especially via vessel movements (e.g., Hayward 1997, Cranfield et al. 1998). The alteration to marine ecosystems and transfer of fish diseases via these unmanaged mechanisms is well recognised (Ruiz et al. 2000, Hilliard 2004), and hence any incremental risk from finfish culture should be considered within this broader context.

The effects of escapees from aquaculture vary considerably in relation to the following factors (Forrest et al. 2007c):

- the numbers involved in the escape episode,
- the location of the farm in relation to wild populations and its size, distribution, and health,
- whether the species is native (e.g., hāpuku, kingfish) or introduced (e.g., salmon),
- whether the brood stock is hatchery bred or wild sourced,
- the fish harvest size in relation to reproductive maturity and the ability of gametes to survive and develop in the wild, and
- the ability of escapees to survive and reproduce in the wild, as determined by their ability to feed successfully and interbreed with wild stocks.

The main effects of escapees (Forrest et al. 2007c) for feed-added species are:

- competition for resources with wild fish and related ecosystem effects from escapee fish (e.g., through predation),
- alteration of the genetic structure of wild fish populations by escapee fish and potential loss of genetic integrity in the wild populations, and
- transmission of pathogens from farmed stocks to wild fish populations.

The main factors controlling the number of fish escaping, and their subsequent effects, are the integrity of the nets used to contain the fish and the amount of difference between the wild fish and farmed fish in terms of their genetics and their pests and diseases.

16.1.7.2 SIGNIFICANCE OF EFFECTS

The likelihood of escapee effects in New Zealand is low, based on the current small size of the industry, limited overlap of wild and farmed populations (i.e., salmon; Deans et al. 2004) and the broad home range (i.e., kingfish and hāpuku), and likelihood of high genetic diversity in these native species (Paul 2002, Forrest et al. 2007c). If escapee effects are seen on wild populations they are, however, likely to be irreversible and could potentially be at a national scale.

16.1.7.3 MANAGEMENT OPTIONS AND KNOWLEDGE GAPS

Management strategies to minimise escapees are usually based upon maintaining net integrity. In Norway reporting of escapes, and estimation of numbers escaped, is mandatory and therefore provides a baseline to improve upon (Jensen et al. 2010). In New Zealand escapee events are not reported to any central authority. At this time no knowledge is available on the potential effect that escaped farmed kingfish or hāpuku could have upon the wild populations. The potential for genetic interactions between hatchery/selectively bred farmed shellfish and wild shellfish populations has not yet been investigated in New Zealand.

16.1.8 EFFECTS ON WILD FISH

The reader is referred to MPI (2013) and Taylor and Dempster (2019) (and references therein) for more detail.

16.1.8.1 INTRODUCTION

The installation of marine farming structures introduces new three-dimensional structures to the marine environment. These structures provide habitat for colonisation by fouling organisms and associated biota (Glasby 1999, Connell 2000, DeAlteris et al. 2004). These newly colonised structures and the habitat they create tend to attract wild fish species seeking foraging habitat, detrital food sources, and/or refuge from predators (e.g., DeAlteris et al. 2004). Finfish farms also provide additional feed sources to wild fish through waste feed.

The presence of farms can lead to degradation or loss of habitat beneath or within close proximity to new farm structures that may have consequences in terms of spatial overlap with critical spawning grounds and/or migration routes. Submerged artificial lighting at night is frequently used on finfish farms to control maturation and increase productivity (e.g., Porter et al. 1999). The lighting can enhance the attraction of wild fish to farm structures (Cornelisen & Quarterman 2010).

The main effects associated with the creation of artificial habitats, and attraction of wild fish species to aquaculture structures, include:

- enhanced predation on wild fish by higher trophic level predators (e.g., seals and seabirds) and predation by cultured fish on wild fish trapped within cage structures,
- consumption of waste feed by wild fish (Felsing et al. 2004, Dempster et al. 2005),
- changes in recreational fishing patterns and pressure (Taylor and Dempster 2019), which could increase fishing pressure on species attracted to structures, and
- larval fish depletion by filter-feeders (as observed by Davenport et al. 2000 and Lehane & Davenport 2002) and/or potential trophic interactions (e.g., alteration of plankton composition and food availability).

16.1.8.2 SIGNIFICANCE OF EFFECTS

In general, the effects of aquaculture on wild fish populations are likely to be small in comparison with the effects on other aspects of the marine ecosystem, such as effects on the seabed. The effects of farming hāpuku or kingfish on wild fish are expected to be generally similar to those from farming king salmon already in New Zealand. Modelling of larval egg depletion (Broekhuizen et al. 2002) and other work suggest that although shellfish aquaculture could have an impact on recruitment to fisheries, the scale of this effect will largely be governed by the extent of the culture, the behaviour and characteristics of larvae, and the flow dynamics of the regions in question (MPI 2013).

The effects of farming filter-feeders are likely to be less than those of farming feed-added species (due to the lack of waste food acting as an attractant). The extent of impacts from the farming of seaweeds and sea cucumbers is likely to have a lesser impact than feed-added or filter-feeding aquaculture. Although seaweed cultivation may offer an attractive habitat for fish aggregation (Radulovich et al. 2015) it does not provide additional food or significantly modify the benthic habitat (MPI 2013).

16.1.8.3 MANAGEMENT OPTIONS AND KNOWLEDGE GAPS

Management options identified by MPI (2013) to minimise effects on wild fish include proper site selection, which requires assessment of potential impacts of farm developments on wild fish stocks. Assessments should identify proximity and impact to critical, sensitive, or protected habitats and species, with particular reference to potential impacts on spawning grounds or juvenile habitats. Careful management of feed quality and feeding practices should minimise waste feed inputs to the surrounding environment and minimise effects on wild fish populations. The effects of finfish farms on wild fish populations in New Zealand are not well documented and knowledge gaps exist, particularly with regard to the effects of finfish farms on fish movements and various reproductive stages (e.g., larval settlement).

16.1.9 HYDRODYNAMIC EFFECTS

The reader is referred to MPI (2013), and references therein, for more detail.

16.1.9.1 INTRODUCTION

Hydrodynamic conditions are an important determinant of the suitability of a site for aquaculture, as well as the spatial size and magnitude of the environmental effects. Here, hydrodynamics refers to the physical attributes of the water including:

- currents,
- stratification, and
- waves.

Current speed is a key factor determining the exchange of water through the cage, areas over which deposition occurs, where the dissolved material is transported and how it is dispersed, and the resuspension of material. Stratification refers to the layering of water caused by differences in temperature and salinity. Stratification can play a strong role in oxygen depletion by restricting vertical transport of oxygen from the surface to deeper waters. Waves can break up stratification, play a key role in determining which species can inhabit an area, and resuspend material.

16.1.9.2 SIGNIFICANCE OF EFFECTS

Aquaculture operations can have a number of effects on hydrodynamics. The drag from cages can affect currents, causing wakes, turbulence, and flow diversion (Helsley & Kim 2005, Venayagamoorthy et al. 2011). Low-velocity areas have a higher probability of issues of deposition, oxygen depletion, and ammonium build-up. There are likely to be interactions between stratification and fish cages in the form of selective blocking, restricted underflow, generation of internal waves, and vertical mixing (Plew et al. 2006). Fish swimming may also play a role in enhancing mixing and causing upwelling within cages (Chacon-Torres et al. 1988). Wave energy is attenuated by marine farm structures, and this will result in a shadow of reduced wave activity behind the farmed areas (Chan & Lee 2001, Lader et al. 2007).

Some physical effects may affect other physical processes directly, for example attenuation of wave energy affecting surf or coastal sediment transport; it is generally more important to consider how physical effects influence ecological processes. For example, the physical effect of reduced current speeds caused by drag from aquaculture structures (Helsley & Kim 2005, Venayagamoorthy et al. 2011) may result in an increase in the flushing time of a bay (Plew 2011). This in turn may lead to increased nutrient concentrations. Reductions in wave energy near the coast may change the mix of species inhabiting an area.

16.1.9.3 MANAGEMENT OPTIONS AND KNOWLEDGE GAPS

The physical hydrodynamic effects will interact strongly with pelagic and benthic processes. Selection of suitable indicators for physical changes should ideally be based on their relative importance in determining the habitat for ecological communities in an area. However, it is this link between the physical and ecological changes that is often the least understood area of hydrodynamic impacts.

16.1.10 CUMULATIVE IMPACTS

The following section draws heavily on previous reviews of the environmental effects of finfish (Forrest et al. 2007c) and non-finfish aquaculture (Keeley et al. 2009). Complementary information on the local scale ecosystem effects of aquaculture in relation to the water column is provided in section 16.1.2: Pelagic effects. The reader is

referred to MPI (2013), and references therein, for more detail.

16.1.10.1 INTRODUCTION

The previous sections (16.1.1–16.1.9) have focused on issue-specific ecological effects of aquaculture developments on the marine environment. Our understanding of these effects is largely based on farm-scale assessments and monitoring; the potential for wider-ecosystem effects (e.g., far-field benthic enrichment, effects on fish populations, migrating mammals, etc.) is acknowledged but is far less well understood. As aquaculture develops and the number of farms in coastal waters increases, wider-ecosystem issues become more important to consider due to the cumulative environmental effects that could arise from multiple farms combined with additional anthropogenic stressors affecting, and possibly interacting with, natural marine processes (see Figure 16.4 for an example of multiple stressors interacting with natural processes).

Within the context of aquaculture development in the marine environment, cumulative effects are defined here as:

> *Ecological effects in the marine environment that result from the incremental, accumulating, and interacting effects of an aquaculture development when added to other stressors from anthropogenic activities affecting the marine environment (past, present, and future activities) and foreseeable changes in ocean conditions (i.e., in response to climate change).*

A number of examples of potential cumulative impacts of aquaculture exist, three of these will be given here to illustrate the definition above:

- Drop-off of mussels, shells, and biofouling organisms to the seabed beneath mussel farms can lead to the creation of reef-like habitat and alter the composition and abundance of benthic organisms beneath farms (see section 16.1.4). Where this occurs in high densities such as the ribbon-like developments in the Marlborough Sounds, this could lead to additive (cumulative) effects on the wider ecosystem due to alteration of a larger proportion of the benthos.
- The presence of farm structures, where aquaculture involves numerous farms situated along the coast, could also have cumulative effects on near-shore currents and waves, which in turn could affect important processes (e.g., larval transport, nutrient exchange) along the shoreline (see section 16.1.9).
- As aquaculture development intensifies, there is likely to be an increase in man-made structures and boat traffic, increasing the risk of invasion and establishment of pests. Cumulative degradation of the marine environment from multiple stressors compromises habitat quality and could enhance biosecurity risks by increasing productivity and proliferation of pest species such as invasive macroalage (e.g., *Undaria*) and invertebrates (e.g., the bivalve *Theora lubrica* and tunicate *Styela clava*) that thrive on the benthos under conditions of high organic enrichment (section 16.1.1 provides comprehensive information on methods to minimise biosecurity risk that are applicable to wider, regional scales).

Because of limited resources and uncertainty in understanding all the potentially complex interactions between aquaculture, other stressors, and the environment, it is necessary to focus on those aspects of aquaculture most likely to contribute to cumulative environmental change. Hence, increasing emphasis has been placed on assessing the contribution of aquaculture to cumulative changes in nutrient conditions and primary production and, in turn, the knock-on effects on the wider ecosystem (see Hargrave et al. 2005, Volkman et al. 2009, and chapters therein). All forms of aquaculture addressed in this report contribute to these nutrient effects, whether through nutrient emissions to the water column and seabed, or the net extraction of plankton (filter-feeding bivalves) and nutrients (nutrient uptake by macroalgae) from the water column. The following sections focus on the potential far-field nutrient implications of aquaculture.

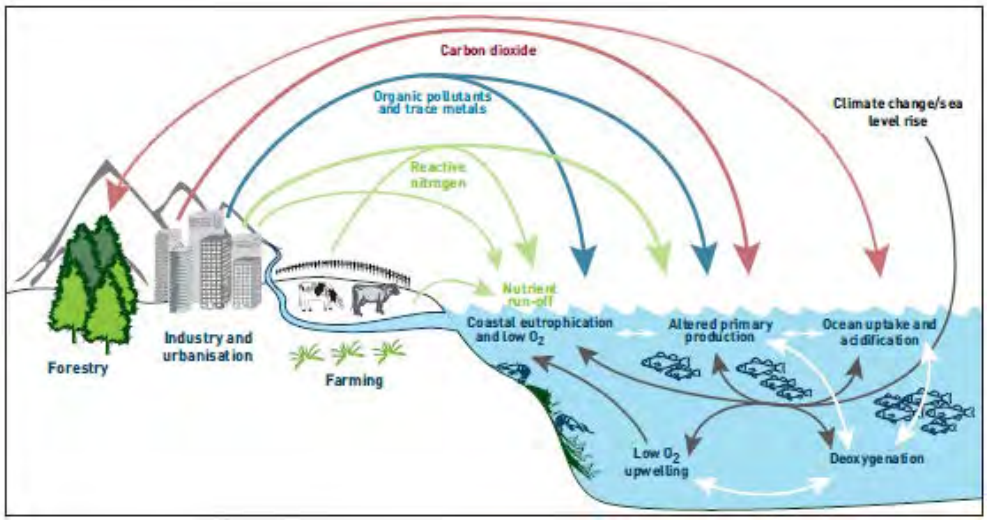


Figure 16.4: Conceptual diagram of anthropogenic influence in marine ecosystems.

16.1.10.2 SIGNIFICANCE OF EFFECTS

A particular concern with the potential expansion of fish farms is the potential risk of eutrophication (SEPA 2000, Hargrave et al. 2005, Díaz et al. 2012). Eutrophication is the process where excessive nutrient inputs to a water body result in accelerated primary production (phytoplankton and macroalgae growth) and flow-on effects to the wider environment such as reduced water clarity, physical smothering of biota, or extreme reductions in dissolved oxygen because of microbial decay (Degobbis 1989, Cloern 2001, Paerl 2006). On a global scale, runoff from land-based agriculture has been identified as the primary driver of intense eutrophication of coastal environments; however, feed-added forms of aquaculture have been singled out as an important emerging contributor to nutrient enrichment (Díaz et al. 2012).

Nutrients of varying particulate and dissolved organic and inorganic forms are added to the environment as a result of feed-added aquaculture. Particulate organic nitrogen (PON) and phosphorus (POP) are primarily deposited onto the seabed as fish faeces but also as waste feed pellets and particles. Farmed fish also excrete dissolved inorganic nutrients such as ammonium. Smaller particles of feed in the water column (through the addition of feed and/or via resuspension) can be consumed by other organisms such as zooplankton and shellfish, which, through subsequent excretion, in turn contribute to the dissolved nutrient pool. The dissolved inorganic nutrients from feed-added aquaculture combined with other sources of nutrient inputs can fuel the growth of phytoplankton (Wu et al. 1994) and at high concentrations can cause harmful phytoplankton blooms (Sorokin et al. 1996). In New Zealand's temperate waters, nitrogen may be the nutrient that limits phytoplankton growth under certain conditions, e.g., when concentrations are generally low, and light is plentiful (MacKenzie 2004, Howarth & Marino 2006). However, nutrients from finfish farms are only one source of nutrients in the marine environment, and, like other sources, their inputs vary over time, e.g., salmon farms in the Marlborough Sounds increase feed levels by about 50% during summer months, which is also the period of greatest light availability for primary production. Internationally there have been experiences of blooms of species that produce biotoxins, some of which can be directly toxic to fish and others which can accumulate in shellfish and affect consumers. As far as is known to date, salmon farming in New Zealand has not given rise to any harmful phytoplankton blooms and such effects are unlikely in the near future unless considerable new development occurs (Forrest et al. 2007c).

The risk of exceeding the assimilative capacity and accelerating eutrophication will be dictated by the physical characteristics of a region, such as retention time, water depth, and ambient nutrient concentrations, combined with the intensity and types of existing and planned aquaculture and upstream land-based developments. There is compelling evidence that bivalve aquaculture can affect nutrient cycling and the quantity and quality of food (plankton) across a range of spatial scales from local to system wide (Prins et al. 1998, Cerco & Noel 2007, Coen et al. 2007). In turn, the quantity and quality of food available to other consumers could be affected (Prins et al. 1998, Dupuy et al. 2000, Pietros & Rice 2003, Leguerrier et al. 2004), with consequences for local populations of higher trophic level organisms such as fish.

In some regions where numerous farms with high-density cultures occur, there is the potential risk of exceeding the region's capacity to sustain high shellfish production and the wider ecosystem itself. An example is Pelorus Sound, where questions around the concept of carrying capacity arose following observed decreases of about 25% in green-lipped mussel yields between 1999 and 2002 (Zeldis et al. 2008). These reductions were attributed to climatic forcing conditions and inter-annual variability in phytoplankton biomass over multi-year time scales (Zeldis et al. 2008). This suggests that this region is close to sustainable production limits during years of naturally low primary production.

16.1.10.3 MANAGEMENT OPTIONS AND KNOWLEDGE GAPS

Internationally there is a limited understanding of the cumulative effects of multiple stressors on marine ecosystems in the long term. A critical requirement for understanding these effects is to have good information about existing environmental conditions, and continued monitoring to provide long time series datasets from which to validate models and to quantify and forecast changes occurring in the wider environment. Monitoring programmes, the use of models and existing data, and suggested management approaches for future aquaculture development, which contribute to cumulative effects management in New Zealand, are discussed below.

16.1.10.3.1 MONITORING PROGRAMMES

Management of cumulative effects in the marine environment can be conducted using a two-tiered approach that not only considers the contribution of effects from individual developments, but also an overall regional assessment of wider environmental change in response to the many stressors impacting on the marine environment (e.g., Dubé 2003). Critical to regional assessments of cumulative effects in the marine environment is accessibility and coordination of datasets, including those derived from consent monitoring at individual farms, and long-term State of the Environment monitoring programmes by regional councils. Standardisation of monitoring requirements for aquaculture is an important step to ensure the usefulness of consent monitoring datasets within broader-scale assessments. The requirements for assessment and management of cumulative effects fall beyond the scope of a single consent applicant or industry and are best dealt with through regional councils (e.g., Dubé 2003, Hargrave et al. 2005, Zeldis 2008a, 2008b) or central government departments (Morrisey et al. 2009, Zeldis et al. 2011a, 2011b).

Much work has been completed in New Zealand to guide the implementation of regional scale monitoring programmes. These include the following.

- The use of the Limits of Acceptable Change adaptive framework to develop a management framework for the 3000 ha Wilson Bay Aquaculture Management Area, in the eastern Firth of Thames. This involved agreement by stakeholders, both to levels of acceptable change in indicators and to management responses if monitoring showed that these changes have been exceeded (Zeldis et al. 2006).
- The production of a series of reports for the Waikato Regional Council to guide the implementation of a regional programme to monitor water quality and benthic habitats. Three reports were produced: the first provides the rationale and key elements of a regional monitoring framework that integrates monitoring associated with consented activities and wider State of the Environment monitoring (Forrest & Cornelisen 2015); the second describes the ecological effects of aquaculture in the Waikato coastal management area and identifies priority issues (Forrest et al. 2015); and the third recommends methodologies and standards for monitoring the seabed, water column, and the wider environment in relation to the potential effects of aquaculture (Keeley et al. 2015b)
- The development of water quality standards and a framework to monitor and manage potential water column nutrient enrichment from salmon farms in the Marlborough Sounds. These best management practice guidelines were developed by a multi-stakeholder working group (Elvines et al. 2019b). The guidelines were informed by international examples of best practice and customised to the biophysical conditions of the Marlborough Sounds; however, much of the monitoring and management framework may be broadly applicable to other finfish farms or feed-added aquaculture, and/or existing salmon farms in low-flow locations. The aim of the monitoring protocol is to provide early detection, or warning signs, of a deterioration in water quality from

nutrient enrichment at a regional scale. A tiered monitoring approach is recommended. This consists of routine regional scale monitoring (Tier 1), which encompasses the State of the Environment monitoring by regional councils, against the water quality standards. Tier 2 monitoring is triggered when the water quality standards are exceeded, to determine whether salmon farm inputs are likely to be the primary cause. Tier 3 monitoring can be initiated on a farm-by-farm basis if more intensive monitoring is required. Tiers 2 and 3 monitoring protocols are not explicitly defined in the guidelines, because these would be performed and designed on a farm-by-farm basis (Elvines et al. 2019b).

- The development of benthic environmental quality standards and a framework to monitor and manage potential benthic habitat impacts from salmon farms in the Marlborough Sounds. These best management practice guidelines were developed by a multi-stakeholder working group (Keeley et al. 2015a, Keeley et al. 2019). The recommended monitoring protocol seeks to provide consistent and clear requirements for the benthic monitoring and management of existing farms, based around an agreed set of environmental quality standards with accompanying rationale. The monitoring protocol focuses on farm-scale monitoring of effects in the immediate vicinity of the farm and near-field and far-field effects. An option is provided to include cumulative effects monitoring sites stationed in areas that are potentially predisposed to organic accumulation or are otherwise of concern, e.g., a nearby depression or an area close to habitats of ecological significance.

A project, commissioned by MPI, to provide recommendations for a national marine environmental monitoring programme for New Zealand (Hewitt et al. 2014) identified several variables that could, with small extensions in data collection, together with the development of analytical and reporting techniques, be reported at a national level. These variables cover various aspects of physics, chemistry, and biology, and research has demonstrated both strong links to other components of the ecosystem and strong responses to anthropogenic stressors (Hewitt et al. 2014).

16.1.10.3.2 MODELLING AND DATA USE

Modelling has an important role to play in understanding, prediction, and management of cumulative effects. New Zealand has access to extensive modelling capability; yet in most analyses the uncertainty in model accuracy remains high due to insufficient field data for their calibration and validation. For example, underlying hydrodynamic models require sufficient time series data on currents and water column stratification, and more advanced biogeochemical models require validated estimates of inputs (e.g., surface water, groundwater, marine parameters) and losses (denitrification, burial rates) of nutrients specific to New Zealand's coastal waters.

Spatial modelling tools offer a way to estimate the extent to which the cumulative effects of aquaculture may be approaching ecological carrying capacity on 'bay-wide' and 'regional' scales. However, knowledge gaps are still evident in these models; particularly in the biological aspects (e.g., feeding behaviour and growth of the shellfish), which are still areas of active research. Some generalisations have been proposed for carrying capacity, but these are not always in agreement. Using 'sustainability performance indicators', Gibbs (2007) suggests that the retention (flushing) time for a water body should not exceed 5% of the clearance time of farmed mussels to minimise cumulative effects on the wider ecosystem. The proposed bivalve aquaculture standards suggest that if the clearance time for the farmed bivalves divided by the retention time of the water body is less than 1, and the area occupied by the farms is less than 10% of the total area of the water body, then ecological impacts are likely to be acceptable (Bivalve Aquaculture Dialogue 2010).

ECOPATH modelling (Christensen et al. 2000) was applied to assess the potential of Tasman Bay for mussel aquaculture development. This indicated that significant ecosystem energy flow changes occurred at mussel biomass levels less than 20% of a mussel-dominated ecosystem, thus implying that ecological carrying capacity limits may be much lower than production carrying capacity limits (Jiang & Gibbs 2005). Typically, modelling is therefore used to determine the ecological carrying capacity of each system.

For analyses of cumulative effects related to eutrophication, there is currently a very limited scientific understanding of the transport, fate, and ecological consequences of nutrient loading from different sources

and, in turn, how they cumulatively affect marine ecosystems (Olsen et al. 2008). A review commissioned by MPI highlighted a range of approaches used internationally to understand and manage the effects of nitrogen loading from aquaculture on the marine environment (Hartstein & Oldman 2015). The review found commonalities between approaches used in several countries in that they all (1) set some environmental trigger/s at which point a review of production, management, or some other intervention occurs, (2) provide an understanding of the dynamics of the system (through modelling and/or monitoring), and (3) quantify the impacts of the existing and/or proposed aquaculture production in the context of the natural variability of the system.

The trigger level approach adopted overseas (and being developed in New Zealand) is recommended as the standard for assessing how a system is responding to the establishment or expansion of aquaculture areas and should become an integral part of adaptive management plans. The process of establishing such triggers necessitates development of a thorough understanding of the marine system being considered through a combination of modelling and monitoring. With such tools in place, the relative roles of natural variability and the impacts of potential aquaculture development scenarios can be assessed.

A precautionary approach necessitates establishment of conservative thresholds or limits to minimise risks and the extent of cumulative effects. Nutrient mass-balance models can provide guidance on nutrient loading rates in a region under various scenarios and on gauging proximity to conservative critical nutrient loading rates (Olsen et al. 2008). The mass-balance approach has facilitated the development of system-wide nutrient budgets and estimates of carrying capacity for feed-added aquaculture in Golden Bay and Tasman Bay (Zeldis 2008b, Zeldis et al. 2011a, 2011b) and the Firth of Thames (Zeldis 2008a, Zeldis et al. 2010).

Projects currently underway which may help to address some of the knowledge gaps include the following.

- Phase II of the Sustainable Seas Challenge. Phase II includes two projects under the theme 'Degradation and recovery'. One of the projects will investigate ecological responses to cumulative effects and the other will explore tools to manage cumulative effects. Multiple stakeholders are helping to co-develop these projects, including Fisheries New Zealand. Phase II of the Challenge commenced in 2019 and results are expected in 2024.
- The Moana project by MetOcean Solutions. This project is currently underway and supported by Fisheries New Zealand. The project aims to deliver an open-access archive of oceanography data for New Zealand; accurate historical wave, wind, and current data at high spatial and temporal resolutions; an accurate description of current flows around New Zealand; and data access tools and products. These long-term data sets will help to inform the assessment of potential effects of aquaculture and feed into ecological and depositional models.

16.1.10.3.3 MANAGING FUTURE DEVELOPMENTS

Managing cumulative effects to achieve sustainability ultimately requires regional approaches to manage developments and activities in a holistic, ecosystem-based management (EBM) framework which utilises spatial planning (Crain et al. 2008). In the absence of over-arching EBM programmes and a robust scientific base for adaptive management in response to cumulative effects, a precautionary approach is warranted in future developments of feed-added aquaculture. Development should be conducted in a staged manner based on conservative limits of expansion taking into account the level of uncertainty associated with potential ecological effects. Important tools and components of a precautionary approach include the following.

1. The use of models and existing data to gauge limits to development[4] within the context of a region's assimilation capacity (i.e., ecological carrying capacity).
2. Establishment of wider-ecosystem, long-term monitoring programmes that include establishment of baseline conditions of a region and adoption of limits of acceptable change.
3. Mitigation of effects through continual improvement of on-farm practices, potentially

[4] Areas may not be suitable for any development of aquaculture.

including improved feed technologies and the use of Integrated Multitrophic Aquaculture (IMTA, Figure 16.5). IMTA combines farming of different species to potentially ameliorate environmental effects.

4. Targeted monitoring and research to validate and improve accuracy of predictive models (see, for example, Elvines et al. 2021) and to understand the role of feed-added aquaculture in driving cumulative effects.

An overseas example of the precautionary approach is the M-O-M system (Modelling–Ongrowing fish farms–Monitoring), which has been used in Norway to provide information for adaptive management of salmon farming (Ervik et al. 1997, Hansen et al. 2001).

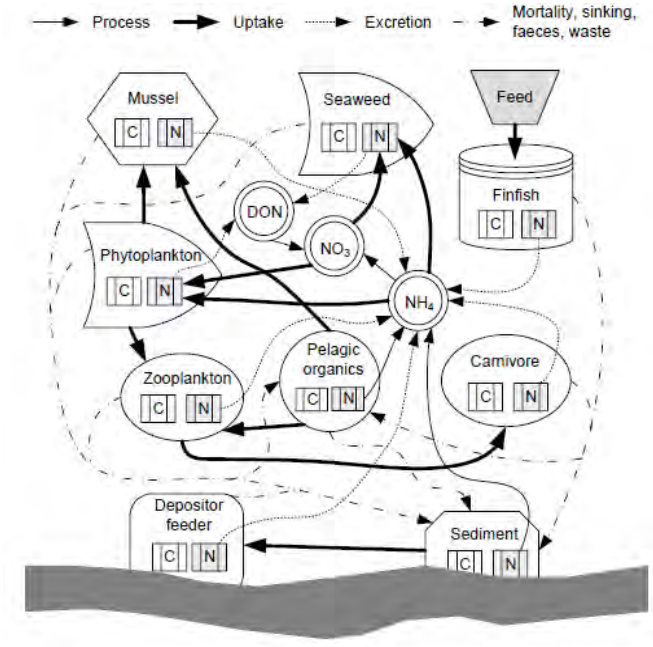


Figure 16.5: Conceptual diagram of IMTA model in terms of carbon (C) and nitrogen (N) biomass (from J Ren. NIWA pers. comm.).

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Chapter 17: Antarctic Science - Technical Summary

1. THE ISSUE IN BRIEF

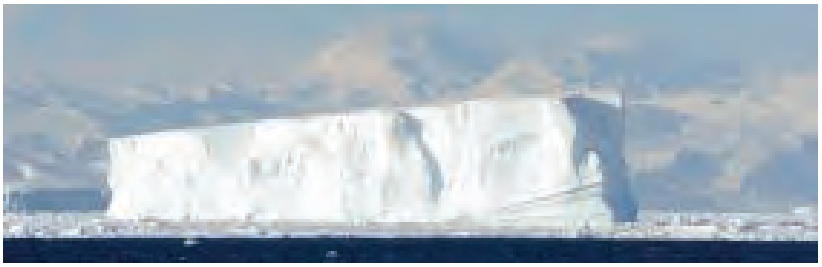
- The Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR) was established in 1982. It was the first international agreement to explicitly focus on conservation and require that fisheries management considers the effects of fishing on dependent and associated species.
- Under the Antarctic Treaty system, Antarctica is designated as a natural reserve, devoted to peace and science, and New Zealand is committed to preserving and protecting Antarctica and the Southern Ocean for present and future generations. New Zealand's interest in CCAMLR is the health and conservation of the Southern Ocean, with a main focus on the Ross Sea ecosystem where there is a bottom longline fishery for toothfish involving vessels from multiple countries, including New Zealand.
- Now the Ross Sea toothfish fishery is managed to meet very precautionary decision rules, among the most precautionary management of any fisheries globally. New Zealand leads the stock assessment research for this fishery. The current status of the stock is healthy and well above target level.
- The world's largest Marine Protected Area (MPA) was established in the Ross Sea in 2017. New Zealand, along with other countries, contributes to the research and monitoring of the MPA
- New Zealand also undertakes regular compliance monitoring of activities within the MPA, and also in the Ross Sea fishery to confirm all fishing vessels are complying with the rules in force

2. IMPACTS OF TOOTHFISH FISHING ON THE ROSS SEA ENVIRONMENT



- Fish bycatch: The main bycatch species in the Ross Sea region are macrourids or grenadiers, icefish, skates, eel cods, and deepsea (morid) cods. There are several approaches in place to mitigate fish bycatch, including catch limits. A skate tagging research programme is also underway to assess the abundance of skates and to understand the survivability of returned live skates
- Seabird mortality: Following the introduction of some of the strictest management requirements anywhere in the world, seabird bycatch rates in Southern Ocean fisheries are now negligible. In the Ross Sea toothfish fishery, only 2 seabird mortalities have occurred since 2007
- Mammal mortality: There have been no reported mortalities of marine mammals in the toothfish longline fisheries in the Ross Sea or Amundsen Sea regions
- Benthic communities: The impacts of bottom longlining on benthic communities are not well understood and are recognised as in need of attention. Several benthic focussed research programmes are underway to verify and quantify the impacts of fishing gear on the benthos, including the use of deep-sea cameras to photograph and map the seabed where fishing takes place
- Effects on top predators: Predators can potentially be affected by changes in the abundance of their prey due to fishery removals. Weddell seals, killer whales, and sperm whales are known to feed on toothfish. Adélie penguins feed on silverfish, which are prey for toothfish. Limited information is known on these effects, but given the health of the toothfish stock these effects are considered to be negligible
- General environment: The broader impacts of fishing on the marine environment such as marine pollution, lost fishing gear, and biosecurity, are strictly managed by rules that align with global best practices

3. ROSS SEA REGION MARINE PROTECTED AREA



• CCAMLR members unanimously supported the establishment of the Ross Sea region Marine Protected Area, which came into force in 2017. New Zealand and USA were the co-proponents that designed it and developed its objectives

• The MPA has multiple objectives including providing a reference area to better understand the ecosystem effects of climate change and fishing, and to preserve a representative portion of the Ross Sea environment (including benthic and pelagic marine environments), and to protect core foraging areas for land-based predators

• A Scientific Research and Monitoring Plan has been developed. New Zealand along with other nations, including Italy, South Korea, and the USA are actively conducting research to feed into the first scientific review of the MPA in 2022



The MPA consists of:

- A 'no take' General Protection Zone (a fully protected area where no commercial fishing is permitted) split into three separate areas
- A Krill Research Zone which allows for controlled research fishing for krill, in accordance with the objectives of the MPA
- A Special Research Zone which allows for limited research fishing for krill and toothfish

17 ANTARCTIC SCIENCE

Status of chapter	This chapter was updated for AEBAR 2021.
Scope of chapter	This chapter outlines the following for the Ross Sea sector of the Southern Ocean (Ross Sea and Amundsen Sea): the ecosystem structure, the toothfish fishery, the nature of ecosystem-fishing interactions, the management approach, trends in key indicators of fishing effects, and major sources of uncertainty and research priorities.
Area	Ross Sea region; Amundsen Sea region (CCAMLR areas 88.1 and 88.2).
Focal localities	Areas with significant fisheries interactions include the Ross Sea shelf and slope, Amundsen Sea seamounts and shelf, and areas of the Pacific-Antarctic Ridge.
Key issues	Fisheries in the region are managed by CCAMLR according to the principles of conservation given in Article 2 of the Convention for the Conservation of Antarctic Marine Living Resources. Effects of fishing are considered in the following categories: (1) bycatch species, (2) prey of target species, (3) predators of target species, (4) ecosystem at the system-level, and (5) benthic habitat.
Emerging issues	Role of Marine Protected Areas in the Ross Sea region.
Fisheries New Zealand research (current)	ANT2019-01.
New Zealand government research (current)	MBIE: C01X1226 *Ross Sea Climate and Ecosystem*. MBIE: END18301 *Ross Sea Region Research and Monitoring Programme*. NIWA Core Funding, Coasts & Oceans Programme 4: 'Structure and function of marine ecosystems' Antarctica New Zealand: Antarctic SIF
Related chapters/issues	Benthic (seabed) impacts; Trophic and ecosystem-level effects; Biodiversity. Fisheries Plenary Report May 2021 Chapter on Toothfish (Fisheries New Zealand 2021).

17.1 CONTEXT

17.1.1 THIS CHAPTER

This chapter discusses the ecosystem effects of fishing for toothfish (principally Antarctic toothfish) in the Ross Sea region (150° E to 150° W) and the Amundsen Sea region (150° W to 105° W) (Figure 17.1). There is currently no krill fishing in the Ross Sea and Amundsen Sea regions.

The focus is on the ecosystem effects of fishing rather than the management of the toothfish stock itself. The stock assessment for Antarctic toothfish in the Ross Sea region is updated every two years (most recently in 2021, Grüss et al. 2021c) and a summary is available as part of the May Plenary Report (Fisheries New Zealand 2021). Research towards a stock assessment for Antarctic toothfish in the Amundsen Sea region was last completed in 2016 (Mormede et al. 2016) and an assessment is planned for 2022.

Section 17.1 presents a brief history of Southern Ocean fisheries, the present management framework for toothfish, and overviews of the life history, fishery, and management of toothfish fisheries in the Ross Sea and Amundsen Sea regions, including the Ross Sea region Marine Protected Area (RSrMPA).

Section 17.2 gives a characterisation of the Ross Sea ecosystem; no characterisation is yet available for the Amundsen Sea ecosystem.

Section 17.3 presents information on the major ecosystem effects of fishing in five categories:

- Effects of fishing on bycatch species,
- Effects of fishing on prey species,
- Effects of fishing on predator species,
- Trophic and system-level effects,
- Effects of fishing on habitats.

Section 17.4 summarises information on indicators and trends for the ecosystem effects of fishing in the Ross Sea and Amundsen Sea regions in the same five categories.

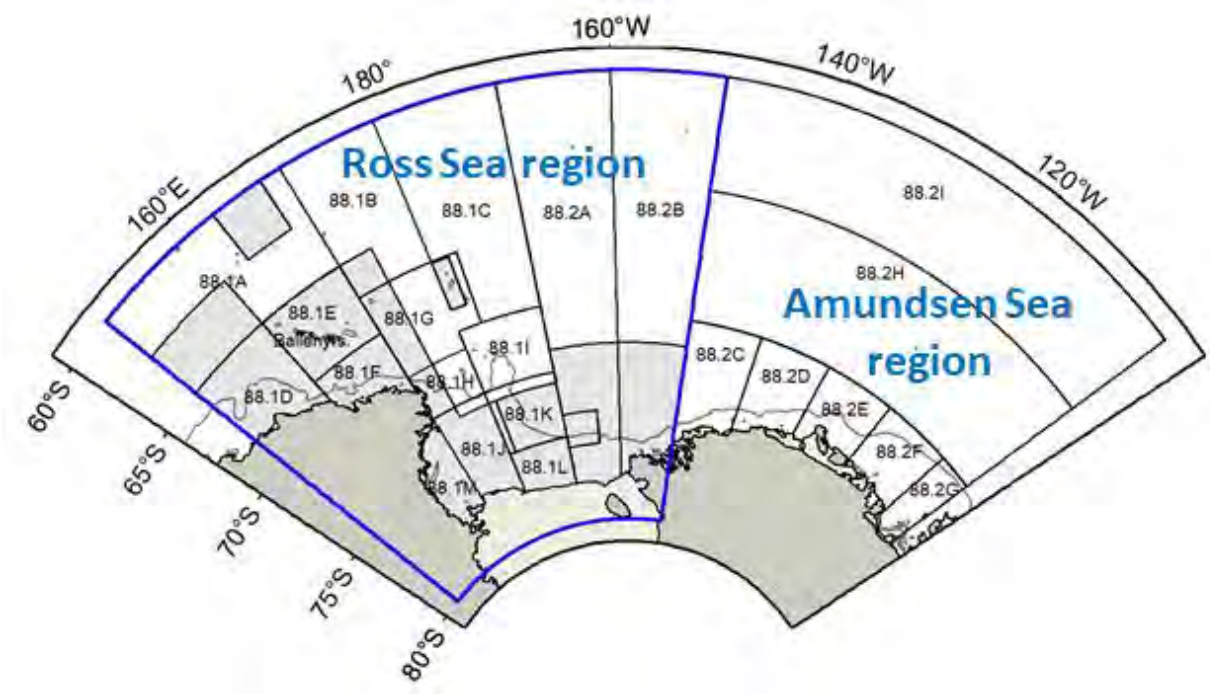


Figure 17.1: The Ross Sea and Amundsen Sea regions, which span CCAMLR (Commission for the Conservation of Antarctic Marine Living Resources) Subareas 88.1 and 88.2. CCAMLR small scale research units (SSRUs) and the depth contour at 1000 m are shown. The Ross Sea region is made up of 88.1 and 88.2A, B. The Amundsen Sea region includes SSRUs 88.2C–I. The Ross Sea *slope* region (with depths of approximately 1000–3000 m) is mainly contained in SSRUs 88.1H, 88.1I and 88.1K. Areas that are shallower than about 1000 m are called *shelf* regions (comprising 88.1J, 88.1L, 88.1M for the Ross Sea shelf). Shaded regions indicate the Ross Sea region MPA boundaries and include the Special Research Zone, Krill Research Zone, and General Protected Zones (i), (ii), and (iii).

17.1.2 SOUTHERN OCEAN FISHERIES

A brief history of fisheries in the Southern Ocean[1] is given by CCAMLR (Commission for the Conservation of Antarctic Marine Living Resources)[2] and this section summarises that text. Seal harvesting in the Southern Ocean began in 1790. By 1825, some populations of fur seal were hunted close to extinction, and sealers began hunting elephant seals and some species of penguins for their oil. Sealing continued on a small scale into the 20th century, but there has been no commercial sealing in Antarctica since the 1950s.

Whaling in the Southern Ocean area began in 1904 and multiple species of whales found in the region were extensively exploited (see section 17.2.3 for more details about whaling in the Ross Sea region). A moratorium on commercial whaling was introduced in 1987. Whale sanctuaries were established in the Indian Ocean in 1979 and Southern Ocean in 1994. Management of whales is today the responsibility of the International Whaling Commission (IWC). There are indications that some species of whale are recovering, but the low abundance of some of the largest species has made total numbers difficult to estimate.

Large-scale fishing for finfish in the Southern Ocean began in the late 1960s. Overall trends in fishery catches have varied widely, reflecting intense fishing during the 1960s and 1970s prior to the establishment of CCAMLR. Such fishing led to the overexploitation of some finfish species in the mid-1970s and 1980s. This overfishing, along with interest in large-scale exploitation of Antarctic krill, raised concerns about the sustainability of Southern Oceans fisheries.

In the 1980s and 1990s, fishing in the Southern Ocean focused on krill (*Euphausia superba*), Patagonian toothfish (*Dissostichus eleginoides*), mackerel icefish (*Champsocephalus gunnari*) and, to a limited extent, squid

[1] The Southern Ocean extends from the coast of the Antarctic continent northwards to the Antarctic Polar Front and represents approximately 15% of the world's ocean area.

[2] CCAMLR, History: The Southern Ocean. Retrieved from https://www.ccamlr.org/en/organisation/history.

and crab. Since the 1990s there has been growing interest in fisheries targeting Antarctic toothfish (*Dissostichus mawsoni*) adjacent to the Antarctic continent.

At the Eighth Antarctic Treaty Consultative Meeting in 1975, the Parties adopted the recommendation that noted the need to promote protection, scientific study, and rational use of Antarctic marine living resources. This led to a Conference on the Conservation of Antarctic Marine Living Resources (CAMLR), which resulted in the CAMLR Convention.

New Zealand was a founding member of the CAMLR Convention which entered into force in 1982. The area of jurisdiction of the CAMLR Convention is approximately south of the circumpolar Antarctic Polar Front (Antarctic Convergence) in the Southern Ocean (Figure 17.2). The position of the Antarctic Polar Front varies seasonally and geographically, but is generally located near 50° S in the Atlantic and Indian sectors of the Southern Ocean and 60° S in the Pacific sector.

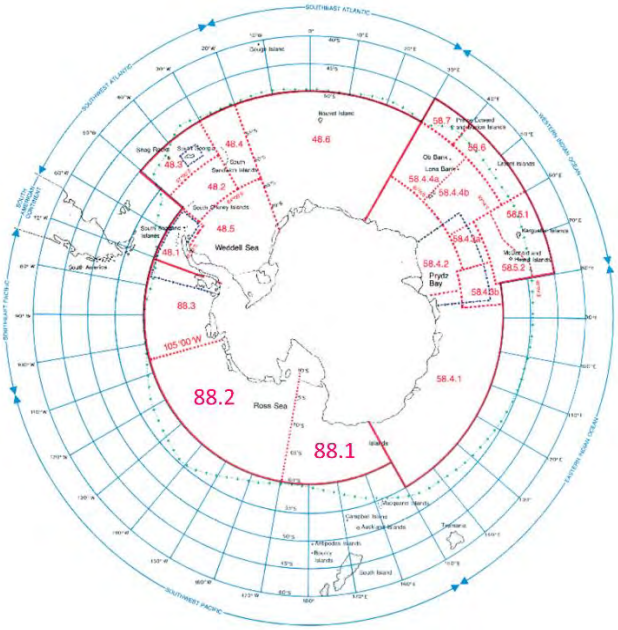


Figure 17.2: Boundary (solid pink line) of area managed according to the Convention for the Conservation of Antarctic Marine Living Resources. Dashed pink lines delineate CCAMLR statistical subareas.

17.1.3 CCAMLR'S MANAGEMENT

The aim of the CAMLR Convention is to conserve the marine life of the Southern Ocean while allowing rational use of marine resources, including commercial fishing (CAMLR Convention 1980). The CAMLR Convention was the first international fishing agreement to explicitly require that management considers the effects of fishing on dependent and associated species as well as on the target species. The principles of conservation are given in Article II of the CAMLR Convention and allow fishing in the CCAMLR Area subject to:

(a) maintenance of the size of harvested population at levels which ensure stable recruitment;
(b) maintenance of ecological relationships between harvested, dependent, and related populations;
(c) prevention or minimisation of the risk of changes in the marine ecosystem that are not reversible in 20–30 years.

The regulatory framework for CCAMLR-managed fisheries recognises five types of fisheries: (1) new fishery; (2) exploratory fishery; (3) established fishery; (4) lapsed fishery; and (5) closed fishery.

Both the Ross Sea region and Amundsen Sea region toothfish fisheries are managed as 'exploratory fisheries' by CCAMLR. Exploratory fisheries are not allowed to expand faster than the acquisition of information necessary for managing the fishery within CCAMLR's management objectives. In addition, notification and permission are required each year prior to fishing (Conservation Measure CM 21-02). Finally, a fishery remains an exploratory fishery until sufficient information is available on appropriate catch and effort levels and the potential impacts on dependent and related species.

Decisions in CCAMLR are made by consensus among member states. At present members of the Commission include 25 States[3] and the European Union (acting as a single member). A further 10 countries[4] have acceded to the Convention. CCAMLR's Secretariat facilitates the implementation of the CAMLR Convention. Measures to manage Southern Ocean fisheries are implemented by means of a series of Conservation Measures (CMs), which

[3] Argentina, Australia, Belgium, Brazil, Chile, China, European Union, France, Germany, India, Italy, Japan, Republic of Korea, Namibia, Netherlands, New Zealand, Norway, Poland, Russian Federation, South Africa, Spain, Sweden, Ukraine, United Kingdom, United States of America, Uruguay.

[4] Bulgaria, Canada, Cook Islands, Finland, Greece, Mauritius, Islamic Republic of Pakistan, Republic of Panama, Peru, Vanuatu.

are published annually[5] following decisions by the CCAMLR members at the annual Commission meetings in October. Scientific information, analyses, and discussion to inform management are brought together annually by the CCAMLR Scientific Committee, which in turn is informed by several working groups, including: (1) Working Group on Ecosystem Monitoring and Management (WG-EMM); (2) Working Group on Fish Stock Assessment (WG-FSA); (3) Working Group on Statistics, Assessments and Modelling (WG-SAM); (4) Working Group on Incidental Mortality Associated with Fishing (WG-IMAF); (5) Subgroup on Acoustics, Survey and Analysis Methods (SG-ASAM).

The Scientific Committee on Antarctic Research (SCAR) has also advised CCAMLR in respect of key scientific areas for research. Work to develop greater collaboration between CCAMLR and IWC has been underway since 2013, especially with regard to managing the trophic impact of fishing for krill on baleen whales and other krill predators. Of particular relevance is the IWC-Southern Ocean Research Partnership (SORP).[6]

17.1.4 ANTARCTIC AND PATAGONIAN TOOTHFISH

Antarctic toothfish (*Dissostichus mawsoni*, Norman 1937) is endemic to the Southern Ocean, with a circumpolar distribution. The species is found in higher latitudes south of the Antarctic Convergence (Gon & Heemstra 1990). Patagonian toothfish (*Dissostichus eleginoides*, Smitt 1898), often marketed as '*Chilean sea bass*', shares many similarities with Antarctic toothfish but has a more northern distribution being rarely found in latitudes south of the Antarctic Convergence at about 65° S (Figure 17.3). A species profile, covering aspects of the biology, fisheries, and stock assessment of both toothfish species was completed by Hanchet (2010) and Hanchet et al. (2015a).

For Antarctic toothfish in the Ross Sea region, spawning dynamics and early life history is described by Hanchet et al. (2008), Hanchet et al. (2015a), Ghigliotti et al. (2018), Parker et al. (2019), and Behrens et al. (in press).

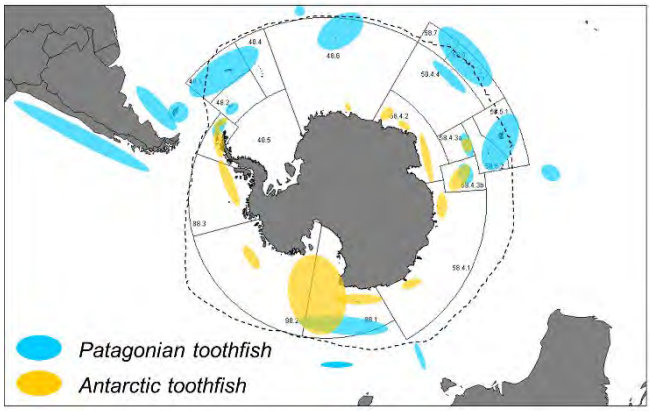


Figure 17.3: Distributions of Antarctic and Patagonian toothfish in the Southern Ocean. Approximate location of Antarctic Convergence shown by the dotted line.[7]

The toothfish stocks in the Amundsen Sea region are managed separately by CCAMLR from those in the Ross Sea region. Parker et al. (2014) reviewed the information from genetic studies, otolith microchemistry, stable isotopes, tagging, size and age structure, growth dynamics, and egg and larval dispersal simulations. The study concluded that it is likely that juveniles (less than 80 cm total length) from the two stocks mix in the shelf region, but that there is very limited mixing of adults between the Ross Sea and Amundsen Sea regions. Dispersal modelling indicated eggs (and then juveniles) can be transported from spawning areas in the Ross Sea into the Amundsen Sea (Behrens et al. in press). The Amundsen Sea stock probably includes juveniles and adults along the continental margin of the Amundsen and Bellingshausen seas, and a spawning region in the seamount complex of SSRU 88.2H (Amundsen Sea). Further information is needed to improve knowledge of the toothfish stock structure in the Amundsen Sea region (Delegations of New Zealand, Norway and the United Kingdom 2014).

For Antarctic toothfish in the Ross Sea and Amundsen Sea regions, spawning is thought to take place to the north of the Antarctic continental slope, during winter (Hanchet et al. 2008). The first winter longline survey of Antarctic toothfish conducted during June and July 2016 in the northern Ross Sea region confirmed toothfish spawning in this region (Stevens et al. 2016). A second survey in the same area in 2019, conducted in September and October, found eggs at the eyed-embryo stage in surface waters and

[5] CCAMLR Publications. Retrieved from https://www.ccamlr.org/en/publications/publications.

[6] International Whaling Commission. The Southern Ocean Research Partnership (IWC-SORP). Retrieved from https://iwc.int/sorp.

[7] NIWA. Antarctic Toothfish Fishery in the Ross Sea. Retrieved from https://www.niwa.co.nz/fisheries/research-projects/the-ross-sea-trophic-model/toothfish-fishery.

confirmed spawning had been completed by mid-August (Parker & DiBlasi 2020).

More information on the life history and stock structure can be found in the Fisheries Assessment Plenary (Fisheries New Zealand 2021).

The stock structure of Patagonian toothfish in the Ross Sea and Amundsen Sea regions is less well known. Patagonian toothfish in the Ross Sea region are believed to come from a stock which is widely distributed beyond Macquarie and Campbell Plateau and into the high seas.

17.1.5 ROSS SEA REGION TOOTHFISH FISHERY

A characterisation of the fishery in the Ross Sea region is given by Grüss et al. (2021a). Fishing for toothfish began in the Ross Sea region in 1997. The Ross Sea region is the major fishing area for Antarctic toothfish in the Southern Ocean (Hanchet et al. 2008). Most of the catch in the Ross Sea region (over 99%) is Antarctic toothfish (an average of 2860 t y^{-1} since 2005). Catches of Patagonian toothfish, taken mainly from the north-west of the Ross Sea region, have averaged only about 0.1% of the total reported toothfish catch over the period 2010–2021.

The toothfish fishery in the Ross Sea region saw a steady expansion of effort (number of sets) from 1998 to 2001, and an almost three-fold increase in 2004, which led to the increases in catches shown in Figure 17.4. Since 2005, effort has been more stable. All fishing for toothfish in the Ross Sea and Amundsen Sea regions uses baited longlines. In earlier years, most vessels fished with the autoline system, but these have been joined by vessels fishing with Spanish lines and, more recently, trotlines.

The average Illegal, Unreported, and Unregulated (IUU) catch of toothfish in Subarea 88.1 was estimated to be 92 t in 2002, 240 t in 2004, 28 t in 2005 and 272t in 2008. Following the recognition of methodological issues regarding the estimation of IUU catch levels since 2011, evidence of IUU presence or activity has continued to be recorded, but no corresponding estimates of the IUU catch for *Dissostichus* spp. have been provided. One IUU-listed fishing vessel was observed in Subarea 88.1 during 2006 and 2010 and unmarked fishing gear, potentially from an IUU vessel, was reported in 2016 (CCAMLR 2021a).

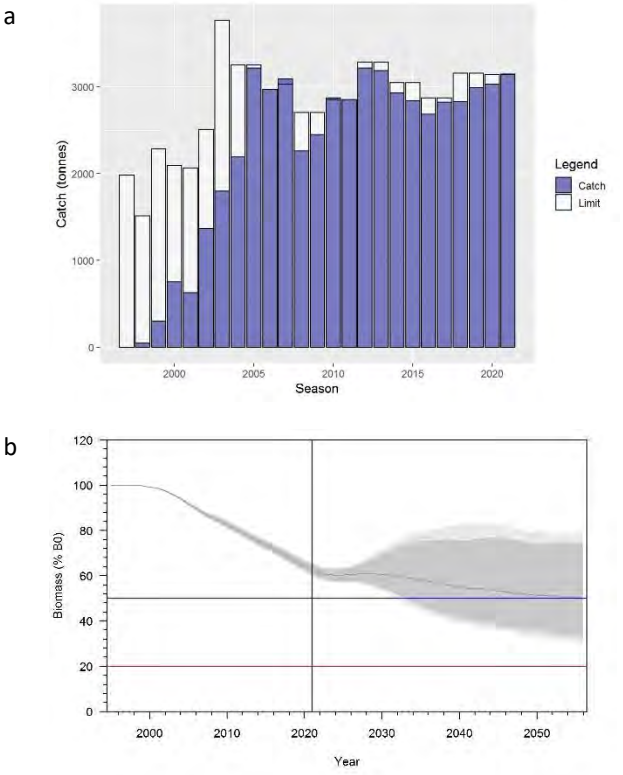


Figure 17.4: [a] Catch and catch limit, [b] assessed spawning stock biomass (with 5th–95th percentiles in grey) for Antarctic toothfish in the Ross Sea region (CCAMLR subareas 88.1 and 88.2A, B). Antarctic fishing years are labelled as the later year of the season (e.g., the 1997–98 fishing season is labelled '1998'). [CCAMLR 2021a; Grüss et al. 2021a, Grüss et al. 2021c].

Annual research surveys of sub-adult (70–110 cm) toothfish have been carried out in the southern Ross Sea since 2011 to provide an estimate of any changes in recruitment (e.g., Devine et al. 2021).

Spatial information on fishing in the 88.1/88.2 is often described using CCAMLR Small-Scale Research Units (SSRUs; Figure 17.1). Although most SSRUs have been fished over time, the proportion of effort in each SSRU has varied considerably each year and with different ice conditions. Two of the three slope SSRUs (88.1H and 88.1I) have been the most consistently fished SSRUs (Figure 17.5). In years with ice conditions favourable to fishing the fishery also extends into 88.1K.

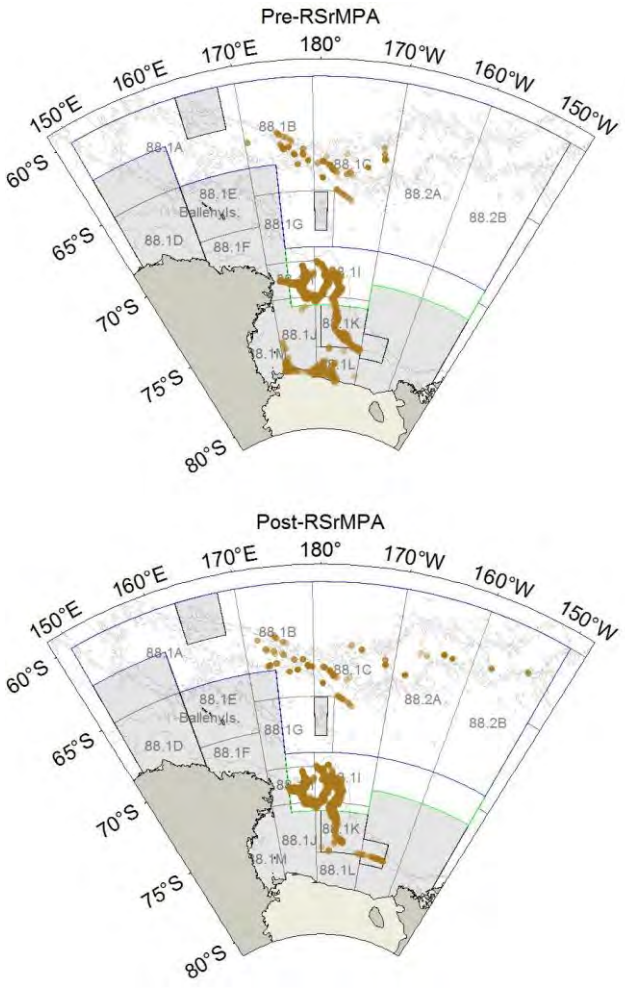


Figure 17.5: Spatial distribution of total toothfish catch (t) in the Ross Sea region before implementation of the Ross Sea region Marine Protected Area (2014–2017) and after (2018–2021).

The length of the fishing season in the Ross Sea fishery has changed over time. In the first few years the fishery was mainly carried out from January to March, and between 2001 and 2003 extended into April and May. Since 2006, fishing starts on 1st December (ice permitting) and is usually finished by early February (Grüss et al. 2021a).

The Ross Sea region toothfish fishery was first certified by the Marine Stewardship Council (MSC) in November 2010 and was recertified in 2015 and 2021. The MSC Fisheries Standard is designed to assess whether a fishery is well managed and sustainable. There are three core principles that every fishery must meet:

1) sustainable fish stock,
2) minimising environmental impact,
3) effective management.

17.1.6 AMUNDSEN SEA REGION FISHERY

The Amundsen Sea toothfish fishery is designated as an exploratory fishery by CCAMLR and a characterisation of the fishery in this region is given by Grüss et al (2021b). The toothfish fishery in the Amundsen Sea region has been operating since 2003, with an annual catch of 106–753 t since 2006 (Grüss et al. 2021b).

The main fishery in this area operated in the northern SSRU until 2013 and then decreased effort following reductions in the catch limit (Grüss et al. 2021b). The total catch distribution for 1997–2021 is shown in Figure 17.6. Within the northern waters, fishing has concentrated mainly on one seamount (the furthest north); effort and catch spreads to other seamounts depending on ice access, number of vessels present, and remaining catch limit at the time. Parker (2014) showed high local exploitation rates and indications of localised depletion on some individual seamounts in the north. Currently, data quality is impacted by the low spatial overlap between locations of released tagged fish and fishing effort in the subsequent year and reductions in fishing effort in the area, exacerbated by lower catch limits (Grüss et al. 2021b).

Only seven Patagonian toothfish have been caught in the Amundsen Sea region since 2004.

More data are required before a robust stock assessment for the Amundsen Sea region can be developed (Mormede et al. 2016, Parker et al. 2021).

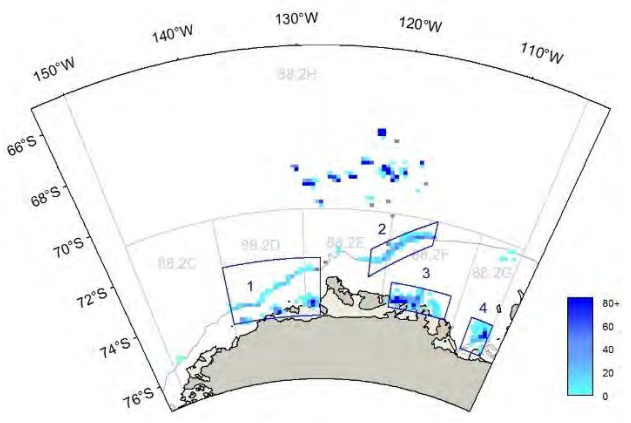


Figure 17.6: Spatial distribution of total toothfish catch (t) in the Amundsen Sea region from 1997 to 2021.

17.2 ROSS SEA ECOSYSTEM

17.2.1 OVERVIEW

Although annual primary productivity is still low on a global scale, seasonally, the shelf waters of the Ross Sea are amongst the most biologically productive areas of the Southern Ocean (Arrigo & van Dijken 2004). Irradiance, iron, and macronutrients (nitrate, silicate) variously limit algal growth through the year (Smith et al. 2003). The high latitude position of the Ross Sea means that primary production is highly seasonal, driven by the annual light/dark cycle and the freezing and thawing of the sea surface. Insolation sets the dominant limit on primary production from autumn to spring; in summer, macronutrients are not depleted and iron appears to limit primary production (e.g., Sedwick et al. 2000, Arrigo et al. 2003). Organisms have various strategies for survival through the winter, including storage of lipids or other high-energy products, winter quiescence, vertical migration, adoption of a wide range of feeding styles, and adaptation of breeding cycles, including migrating in and out of the region (some whales, seals, birds) (Battaglia et al. 1997).

Sea ice plays a key structural role in influencing the ecology of the Ross Sea (Thomas & Dieckmann 2002, Arrigo & Thomas 2004). The mean monthly sea ice cover in the Ross Sea varies from 5% ice-free in winter to 70% ice-free in January (Arrigo & van Dijken 2004), with ice reaching a maximum thickness around November of about 2 m. The Ross Sea polynya[8] is the major structural oceanographic feature of the Ross Sea (Jacobs & Comiso 1989). The dynamics of phytoplankton in the open water of the Ross Sea polynya are very different to those in the marginal ice zone around the polynya. Although ice extent in the Ross Sea region is increasing (Comiso 2003), sea ice in the Ross Sea itself has been decreasing and getting thinner as the Ross Sea polynya has become larger and more persistent (Parkinson 2002).

The upper surface of the ice provides a habitat for a number of seabirds and mammals (Ackley et al. 2003). At the same time, the ice itself, especially the underpart, which is in contact with the water, constitutes a unique habitat for microalgae and bacteria. This provides a food source for associated microfauna and meiofauna and the cryopelagic fauna of the surface water layer immediately below the ice (Garrison 1991, Brierley & Thomas 2002, Arrigo & Thomas 2004). Present estimates suggest that the contribution of epontic[9] algae to total primary production in the Ross Sea is a few percent (Arrigo et al. 1997, Pinkerton et al. 2010a).

The flow of energy from primary production in the water column and sea ice in the Ross Sea consumers is channelled mainly through the copepods. However, the trophic connection between primary producers and copepods is usually not direct. Heterotrophic flagellates and larger heterotrophic microplankton (including dinoflagellates, tintinnids, other ciliates, and eggs and developmental stages of metazoans) graze primary production and often form a large part of the diet of many copepods (Umani et al. 1998, Caron et al. 2000).

Two species of krill are found in the Ross Sea: *Euphausia crystallorophias* and *E. superba*. *E. crystallorophias* is only found over the shelf and *E. superba* is found primarily along the continental slope. Although they form an important link between the water column, sea ice, and larger predators, they are believed to be less productive and have slower turnover rates than the large epipelagic copepods (*Calanoides acutus*, *Calanus propinquus*, *Rhincalanus gigas*, and *Metridia gerlachei*) (Voronina 1998, Tarling et al. 2004). Neither species of krill seems to be as abundant in the Ross Sea as *E. superba* is in the Scotia Sea, where a commercial krill fishery operates and specialist krill predators dominate the ecosystem.

In addition to krill, Antarctic silverfish (*Pleuragramma antarctica*) are a major link between mesozooplankton (mainly copepods) and the larger predators. *Pleuragramma antarctica* are found in the diet of all large animals (seabirds, seals, toothed and baleen whales, toothfish, many other species of fish, and squid) (DeWitt 1970, Laws 1984, Eastman 1985, Vacchi et al. 2017). Throughout their life history the distribution of Antarctic silverfish is thought to include the whole Ross Sea shelf and slope (Hubold 1985), and their juveniles dominate the Ross Sea ichthyoplankton.

More than 100 species and 18 families of fishes have been recorded from the Ross Sea shelf and slope (Chernova & Eastman 2001, Eastman & Hubold 1999, Stewart & Roberts 2001, Bradford-Grieve & Fenwick 2001). Little is known of the abundance of many of these fish species.

The fish fauna of the Ross Sea region can be divided into: (1) a coastal (shelf) fauna, (2) a continental slope fauna, and

[8] Polynya is a stretch of open water surrounded by ice.

[9] Epontic refers to organisms closely associated with sea ice.

(3) a northern, deeper, oceanic fauna. The shelf fish fauna is dominated (over 90% of biomass) by the four notothenioid families (Nototheniidae, Artedidraconidae, Bathydraconidae, and Channichthyidae), which are endemic to high-latitude Antarctic waters (La Mesa et al. 2004). The benthic shelf fish fauna is species-rich, but the number of species decreases with depth, particularly past the shelf break. Many species have a circum-Antarctic distribution. The Ross Sea slope fish fauna is dominated (in terms of biomass) by the macrourids *Macrourus whitsoni* and *M. caml*, skates (especially *Bathyraja eatonii*), icefish (*Chionobathyscus dewitti*), and eel cods (*Muraenolepis* sp.). To the north of the Ross Sea shelf, the fish fauna is dominated by the small pelagic lanternfishes (myctophidae), especially *Electrona antarctica*, *E. carlsbergii*, *Gymnoscopelus braueri*, and *G. nicholsi*; Antarctic silverfish are not found north of the Ross Sea slope.

Cephalopods (squid and octopods) are likely to be important components of the Ross Sea ecosystem because they appear in the diets of many predators (Rodhouse 2013), but their abundance and trophic roles are poorly known (Okutani 1995, Thompson et al. 2012).

Avian abundance in the Ross Sea region is dominated by penguins. About 38% of the world population of Adélie penguins (*Pygoscelis adeliae*) reside in the Ross Sea, breeding at 35 rookeries (Figure 17.7) with a total of about 1 million breeding pairs (Young 1981, Kooyman & Mullins 1990, Lyver et al. 2014). There are more than 40 000 pairs of emperor penguins (*Aptenodytes forsteri*) breeding between Cape Roget and Cape Crozier, and at Cape Colbeck (Young 1981, Harper et al. 1984, Kooyman & Mullins 1990, Wienecke 2011). There are a significant number of non-breeders and juvenile birds in addition to these breeders.

Seals are the most common marine mammals in the Ross Sea region, with more than 200 000 crabeater seals (*Lobodon carcinophaga*) alone (Ainley 1985). Weddell seals (*Leptonychotes weddellii*) are likely to be the second-most common seal in the Ross Sea, with estimates for the larger Ross Sea region of 32 000 individuals (Stirling 1969, Ainley 1985, Stewart et al. 2003), or about 45% of the entire Pacific sector population. There is debate over the degree to which Weddell seals are migratory. Some individuals may remain in residence year-round in the fast ice at latitudes as high as 78° S in McMurdo Sound. Others, particularly newly weaned and sub-adult animals, might disperse north and east from the continent in the Ross Sea and may spend the winter in the pack ice north of the Ross Sea (Goetz 2015). Smaller numbers of Ross seal (*Ommatophoca rossii*) and leopard seal (*Hydrurga leptonyx*) breed in the region, but abundances are not well known (Ainley 1985, Pinkerton et al. 2010a). Southern elephant seals (*Mirounga leonina*) are also present in the Ross Sea region but the nearest breeding colony is on Macquarie Island.

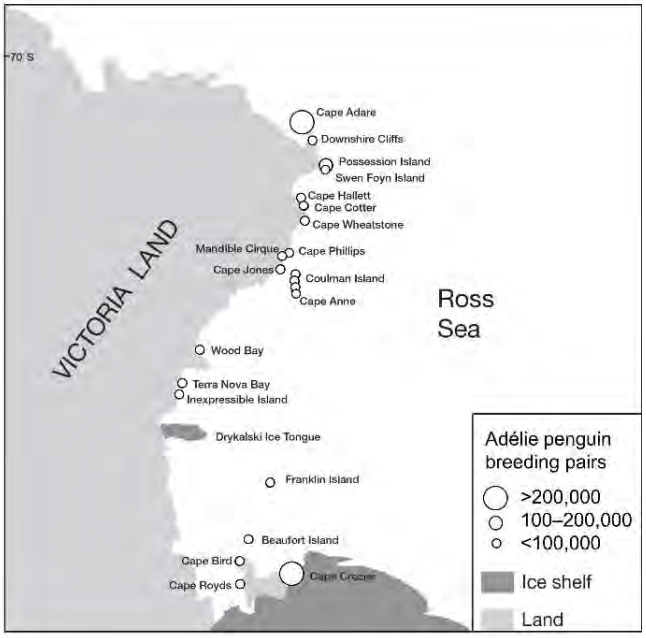


Figure 17.7: The number of breeding pairs of Adélie penguins in the Ross Sea from aerial census methods between 2001 and 2013 (Lyver, unpublished data).

The movements of minke and other baleen whales are poorly understood. In the summer, baleen whales present include minke whale (*Balaenoptera bonaerensis*), fin whale (*Balaenoptera physalus*), humpback whale (*Megaptera novaeangliae*), sei whale (*Balaenoptera borealis*), and blue whale (*Balaenoptera musculus*). They tend to congregate in a feeding zone associated with the pack ice north of the Ross Sea slope where krill are abundant. Over the Ross Sea shelf, humpback and sei whales are largely absent (Ainley 1985, Pinkerton et al. 2010b), although minke whales are relatively common in summer. Antarctic minke whales penetrate deep into coastal sea ice and, together killer whales and beaked whales, have the southernmost distribution of all cetaceans in the Ross Sea region.

Toothed whales present in the Ross Sea region include sperm whale (*Physeter macrocephalus*), killer whale (*Orcinus orca*), southern bottlenose whale (*Hyperoodon planifrons*), and Arnoux's beaked whale (*Berardius arnuxii*). Information on the seasonal abundance of toothed whales in the Ross Sea is rather limited, coming primarily from

infrequent surveys of their distribution and numbers (e.g., Ainley 1985). There are at least three different types of killer whale in the Ross Sea region (Pitman et al. 2001, Pitman & Ensor 2003, Pitman 2003, Eisert et al. 2015). Both Type B (penguin and seal-eating) and Type C (fish-eating) killer whales occur in the McMurdo Sound region (extreme south-west of the Ross Sea), but Type C are by far the more common form. Both Type B and Type C killer whales appear to undergo seasonal northward migration and have been sighted in New Zealand waters (Visser 1999, Eisert et al. 2015).

The Ross Sea benthic fauna has high diversity in some taxa, but lacks crabs and lobsters and has low diversity of some major groups such as gastropods, bivalves, polychaetes, and amphipods. There is a dominance of sessile animals, and benthic communities may be multi-storeyed (i.e., occurring in different layers in some areas). Gigantism is found amongst sponges, pycnogonids, amphipods, isopods, and polychaetes.

A review of the biodiversity of the Ross Sea was provided by Bradford-Grieve & Fenwick (2001). However, in contrast, relatively little is known about the biodiversity, structure, or dynamics of the ecosystem of the Amundsen Sea region.

17.2.2 TROPHIC MODELLING

Species in an ecosystem are connected in many ways, but one of the main types of connection is trophic, i.e., the feeding of one organism on another within the food web (McCann et al. 1998, Pace et al. 1999, Frank et al. 2005). Research on the structure of the food web of the Ross Sea has culminated in complex qualitative descriptions (e.g., Smith et al. 2007, Smith et al. 2012) and a quantitative mass-balance model (Pinkerton et al. 2010a, 2016).

The Ross Sea trophic model describes food web structure in a typical year during the period 1990–2000 when fishing has not reduced the toothfish population (Mormede et al. 2015). Biomass and flows were modelled in terms of organic carbon density (gC m^{-2}) as a proxy for energy flow (Figure 17.8). The Ross Sea trophic model covers an area of 637 000 km^2, which includes the Ross Sea shelf and slope and includes 41 trophic groups. The modelling framework for the trophic model is a mass-balance similar to that of Ecopath (Christensen & Walters 2004, Christensen et al. 2008), but non-trophic transfers (including the release of material from sea ice to the water column and vertical detrital flux) were included. Detailed information on the estimation of the parameters is available online from the NIWA website.[10] Revisions and updates to the model are detailed by Pinkerton et al. (2016).

[10] NIWA. Ross Sea Ecosystem and Trophic Model. Retrieved from https://www.niwa.co.nz/fisheries/research-projects/the-ross-sea-trophic-model/ross-sea-ecosystem-and-trophic-model.

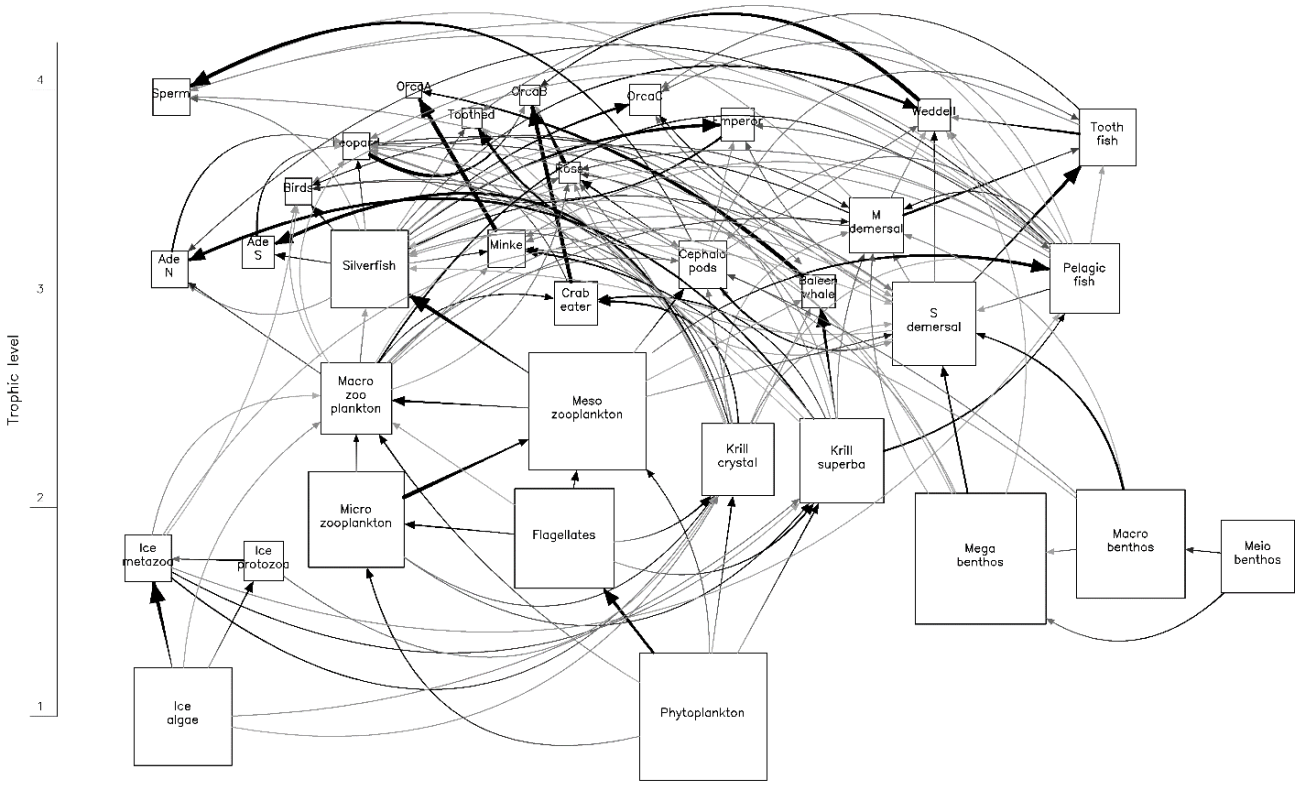


Figure 17.8: Ross Sea trophic model flow diagram, with arrows showing the direction of organic carbon flow. Bacterial and detrital groups omitted for clarity. Bigger boxes indicate more biomass. Boxes are positioned vertically according to trophic level. Thicker/darker lines show higher flows in or out of the group in proportion to total flows in or out of the group. Sperm = sperm whale; Orca-A = Type A killer whale; Orca-B = Type B killer whale; Orca-C = Type C killer whale; Toothed = other toothed whales; Minke = minke whale; Crabeater = crabeater seal; Weddell = Weddell seal; Leopard = leopard seal; Ross= Ross seal; Ade N = Adélie penguins from northern Ross Sea breeding colonies (north of and including Wood Bay); Ade S = Adélie penguins from southern Ross Sea breeding colonies; Birds = flying birds; M demersal = medium-sized (40–100 cm total length) demersal fish ; S demersal = small demersal fish (<40 cm total length). [Pinkerton et al. 2010a, 2016].

17.2.3 HISTORICAL HUMAN EFFECTS ON THE ROSS SEA ECOSYSTEM

The Ross Sea has been identified as the one of the ocean regions least affected by human activity (Halpern et al. 2008). Major industrial sealing did not affect the Ross Sea, although an estimated 2000 Weddell seals were killed in southern McMurdo Sound to supply dog food to early polar expeditions and permanent stations (Scott Base and McMurdo Station) (Stirling 1971, Ainley 2009).

Blue, fin, and sei whales were taken from the continental slope of the Ross Sea in the 1920s–70s but little whaling was carried out over the Ross Sea shelf itself (Ainley 2009). The removal of an estimated 9330 blue whales from the Ross Sea region (Ainley 2009) may have represented most of the local population of this species. Subsequent industrial whaling for minke whales during the 1970s–80s was largely confined to waters north, east, and west of the Ross Sea (Ainley 2009), and the minke whale population seems to have recovered after whaling ceased in the 1980s (Branch 2006). Catches of southern right whales (*Eubalaena australis*) and sperm whales in the Ross Sea region were also low and confined to waters north of the Ross Sea slope (Whitehead 2000, Ainley 2009). In the early 1980s whalers from the former Soviet Union killed more than 900 killer whales belonging to multiple types in one season (Pitman 2003), which represents a significant perturbation to a population estimated at about 3000 animals (Ainley 2009).

Before the advent of the toothfish fishery in 1997 there was no commercial fishing for finfish in the Ross Sea region.

17.3 ECOSYSTEM EFFECTS OF FISHING IN THE ANTARCTIC

17.3.1 INTRODUCTION

CCAMLR's approach to management recognises that species in an ecosystem are linked (Constable et al. 2000, Kock 2000). Target species are often important components of the ecosystem. Changing their abundance may substantially impact related and dependent species, and affect whole-system dynamics and resilience (Murawski 2000, ICES 2005). To develop management in the Ross Sea and Amundsen Sea regions consistent with CCAMLR's principles of conservation has required the management scope to extend beyond single-stock reference points (Hanchet et al. 2014).

Research and management of the ecosystem effects of fishing are more advanced in the Ross Sea region than in the Amundsen Sea region. The toothfish fishery in the Ross Sea has been operating for longer than in the Amundsen Sea, and the development of a stable stock assessment model in the former (since 2004) has allowed more focus on ecosystem effects of fishing there.

17.3.2 EFFECTS ON BYCATCH SPECIES

Seabird mortality

There are two potential impacts of the fishery on seabirds in the Ross Sea region: (1) direct mortality of flying birds from interaction with fishing gear; (2) indirect impacts on seabirds due to trophic effects (e.g., changes in availability of prey for seabirds – see Section 17.3.5). Extensive measures to mitigate the direct effects of fishing on seabirds in the Ross Sea have been in place since the initiation of the fishery (Reid et al. 2010; CMs 24-02, 25-02). These include the use of streamer lines, the use of weights or weighted lines to enable faster line sink rates, and no discharge of offal south of 60° S. Since the beginning of the fishery in 1997, only two seabirds have been reported as caught by fishing vessels.

Mammal mortality

There has also been no reported bycatch of marine mammals on longlines in the toothfish fisheries of the Ross Sea or Amundsen Sea regions.

Fish bycatch

A detailed characterisation of the bycatch in the toothfish fishery in the Ross Sea region was carried out by Stevenson et al. (2012). Moore & Parker (2021) provided an update on recent catches and data availability for the Ross Sea toothfish fishery. An updated characterisation of the main bycatch species in the fishery is planned for 2022. Fishery bycatch in the Amundsen Sea region has not yet been characterised in detail. The main bycatch species in the Ross Sea region are macrourids or grenadiers (*Macrourus whitsoni* and *M. caml*), icefish (mainly *Chionobathyscus dewitti*), skates (mainly *Amblyraja georgiana*), eel cods (*Muraenolepis* spp.) and deepsea (morid) cods (mainly *Antimora rostrata*). A small bycatch of rock cods and ice cods is also taken.

Spatial distributions of fish bycatch are shown in Figure 17.9.

The highest catches for macrourids, skates, eel cods, and icefish occur on the Ross Sea continental slope, near Iselin Bank. Since the implementation of the Ross Sea region Marine Protected Area, catches have become more concentrated in this area (Figure 17.9) (Moore & Parker 2021). Deepsea (morid) cods have a more northern range and relatively higher catches occur over seamounts in the Pacific-Antarctic Ridge. Rock cods and ice cods tend to occur at shallower depths, especially over the Ross Sea shelf and around the Balleny Islands.

Except for skates and rays, the main bycatch species in the toothfish fishery are also the main prey items for toothfish (Fenaughty et al. 2003, Stevens et al. 2014). One of the reasons is the paucity of other large teleost or squid prey in the Ross Sea region (Bradford-Grieve & Fenwick 2001, Smith et al. 2012). For macrourids and icefish, it is likely that the predation release effect (see Section 17.3.3; Soulé et al. 1988, Prugh et al. 2009) may be stronger than the direct effect of fishing mortality on these species.

Macrourids

The main bycatch species in the Ross Sea are macrourids, which form around 5% of the total catch by weight and about 30% of the total catch by number per year, with recent catches at around 120 t y^{-1} (Moore & Parker 2021). Macrourid bycatch in the Ross Sea region was considered to be almost exclusively *M. whitsoni* (Regan 1913) until samples collected on the IPY-CAML voyage in 2008 led to the identification of a new species, *M. caml* (Smith et al.

2011, McMillan et al. 2012). The relative proportion of *M. caml* to *M. whitsoni* in the catch has not been assessed, but observers have been gathering information on this since 2013. Preliminary results suggest *M. caml* and *M. whitsoni* are sympatric by depth (both appearing to be abundant between depths of 900 and 1900 m) (Pinkerton et al. 2013).

There are several approaches in place to mitigate macrourid bycatch, including Subarea and amalgamated SSRU limits on the amount of bycatch (CM 41-09, 41-10), introduced in 2002. Macrourid catch limits were initially based on analogy to fisheries in other areas of the Southern Ocean, but more recently limits have been based on the results of the IPY-CAML trawl survey of the Ross Sea slope. Bycatch limits for macrourids were exceeded in a number of SSRUs during the early period of the fishery but since 2007 the total macrourid catch has always been less than half of the macrourid catch limit. To help prevent localised depletion of macrourids, 'move-on' rules were introduced in the 2001/02 season (CM 33-03). These rules require a vessel to move to another location at least 5 n. miles distant if the bycatch of any one species is equal to or greater than 1 t in any one set. An additional measure in CM 33-03 makes vessels responsible for managing their individual macrourid bycatch by requiring a vessel to cease fishing in an SSRU for the remainder of the season if its macrourid catch exceeds 16% of its catch of *Dissostichus* spp.

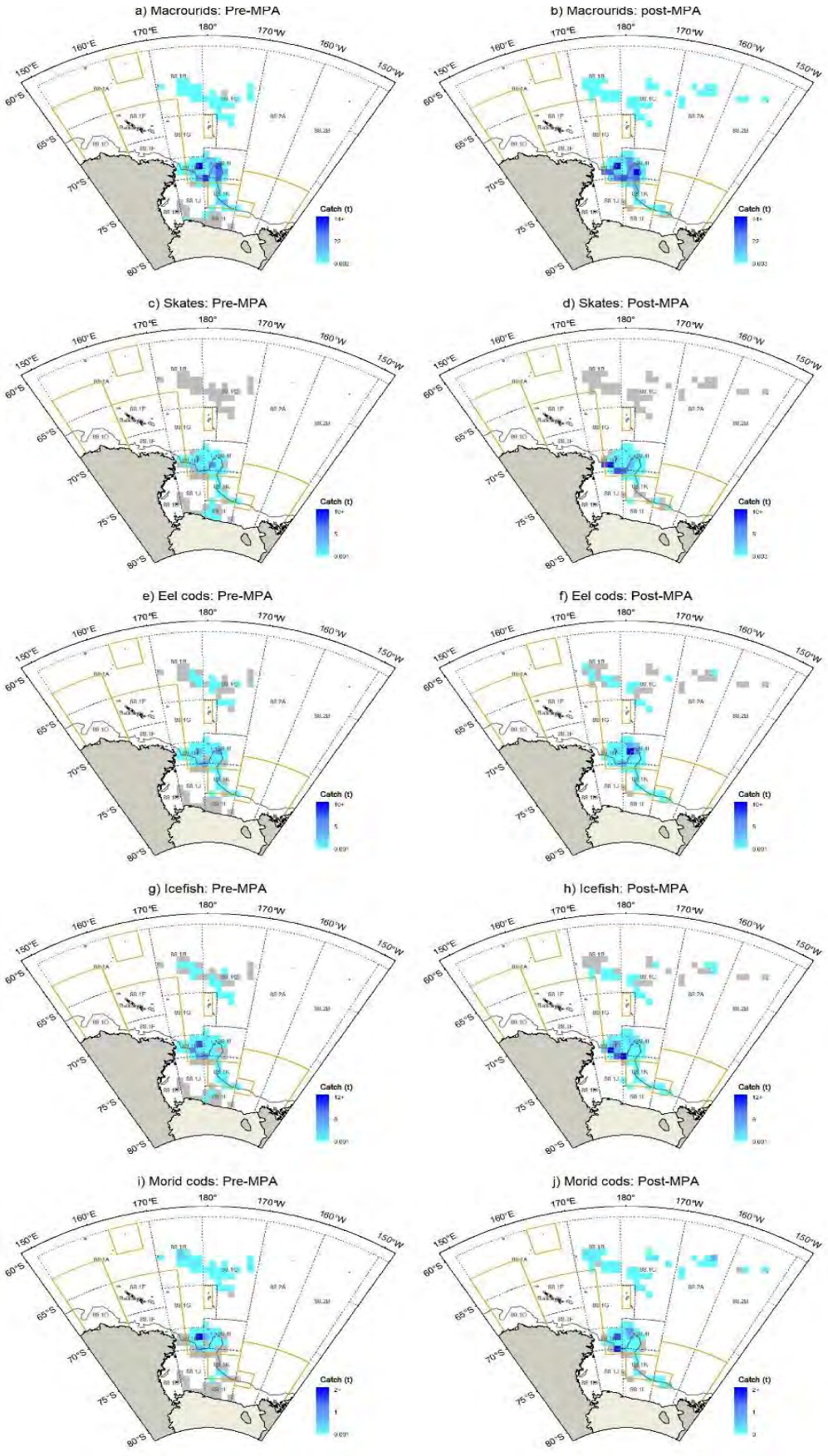


Figure 17.9: Densities of retained catches of macrourids (a, b), skates (c, d), eel cods (e, f), icefish (g, h), and morid cods (i, j) by weight before (2014–2017; left column) and after (2018–2021; right column) implementation of the Ross Sea region Marine Protected Area. From Moore & Parker (2021).

Managing the effects of fishing on macrourids has been applied to all species of macrourid combined. Although the two species of macrourid seem to occur in the same places and at the same depths, their longevities and ages at maturity differ; females of *M. whitsoni* only become sexually mature at 79% of L_{inf} (maximum length) as opposed to about 50%L_{inf} as is common for most macrourids including *M. caml* (Pinkerton et al. 2013). This may make *M. whitsoni* more vulnerable than *M. caml* to the effects of fishing (Reynolds et al. 2005). Although there remains the potential for fishing to affect the two species of macrourid differently in the Ross Sea region, perhaps necessitating species-specific management, information is not yet available to develop this.

Skates and rays (rajids)

Skates and rays (rajids) are the second highest group of bycatch species. Since the start of the fishery, skates have comprised less than 1% of the catch brought onboard (by weight) because most are cut off alive at the surface (Moore & Parker 2021). The main skate caught is the Antarctic starry skate (*Amblyraja georgiana*).

Rajids are required to be brought onboard or alongside the hauler to be checked for tags from historical tagging and for their condition to be assessed. All rajids which are caught alive and with 'a high probability for survival' are released alive at the surface; any 'dead or injured skates' are retained onboard (CM 33-03). The retained catch of rajids is very low (1 t y^{-1}) and has never exceeded the bycatch limit for rajids (Large et al. 2015).

In the Ross Sea region, the highest catch rates of the Antarctic starry skate are in 850–1350 m, whereas Eaton's skates (*Bathyraja eatonii*) are generally caught in 750–850 m. Catch rates are much lower than those of starry skates (Mormede & Dunn 2010). There have been some measurements of skate survival rates in longline fisheries in the Southern Ocean (Endicott & Agnew 2004), but little data on survival of skates caught shallower than 1200 m. Skate survivorship experiments in South Georgia (Subarea 48.3) show that some skates (n=95 fish) survive the capture event, at least for 12 hrs following capture, and that survival rates are higher at shallower depths (Endicott & Agnew 2004). There is also a move-on rule in place to help prevent localised depletion of rajids (CM 33-03). Potential methods for monitoring skates in the Ross Sea region were reviewed by O'Driscoll et al. (2005), who concluded that a tag-recapture experiment was likely to be most successful for monitoring skates.

A preliminary stock assessment based on skate tag-recapture data and ancillary fishery data was completed by Dunn et al. (2007). They identified several problems with the data currently being collected and made the following recommendations: improve species identification, improve detection of tagged skates, increase number of skates measured and sexed, validate the estimates of age and growth, revise skate tagging protocols, and undertake additional survivorship experiments. Following the CCAMLR 'Year of the Skate' in 2008–09, an updated characterisation of skate catches was carried out by Mormede & Dunn (2010). They noted that, up to and including the 2010 season, a total of 14 000 skates had been tagged and released and a total of 179 skates had been recaptured. The return rates for tagged skates in CCAMLR fisheries is typically lower than from tagging programmes elsewhere in the world and the reasons for this are unclear (McCully et al. 2013).

A 2-year programme was implemented in the 2019/20 and 2020/21 fishing seasons in the Ross Sea region to tag and release skates for population size estimation and to validate the thorn ageing method for Antarctic starry skate. During this programme a total of 8 506 skates were tagged and released in the Ross Sea region, with a further 484 individual skates voluntarily tagged in the Amundsen Sea region. Preliminary findings suggest skates do not move great distances, although results are limited by both the small number of recaptures (n=44 from the programme) and limited time at liberty of tagged individuals (Moore et al. 2021).

The medium-term research plan (Delegations of New Zealand, Norway and the United Kingdom 2014; Section 17.3.9) has identified that further analysis is needed to understand the effect of fishing on rajids in the Ross Sea region.

Icefish

Icefish are caught in low numbers with bottom longline and trawl gears throughout the Southern Ocean (CCAMLR 2014). In the Ross Sea region, the bycatch of icefish in the toothfish fishery is typically less than 10 t y^{-1}, with a peak of about 25 t reported in 2020 (Moore & Parker 2021). Since 2014, a total of 8 species codes have been used for icefish caught in the Ross Sea fishery (Moore & Parker 2021). Although a large amount of catch is reported as

'unspecified icefish', the most common species in the catch is *C. dewitti* (Sutton et al. 2008, Moore & Parker 2021).

In the Ross Sea region, *C. dewitti* becomes sexually mature aged about four years and the oldest fish aged was 12 years old from a sample size of 296 fish (Sutton et al. 2008). Icefish are a major prey of toothfish, comprising 20–25% by weight of the prey of sub-adult and adult toothfish on the Ross Sea slope. Icefish are less common over the northern seamounts in the Ross Sea region where they comprise less than 5% by weight of the diet of toothfish.

Eel cods

Muraenolepididae (eel cods) occur over the continental shelf and slope of cold temperate and Antarctic southern hemisphere (Nelson 2006). They are caught in low numbers with bottom longline and trawl gears throughout the Ross Sea region (Parker et al. 2012). On northern Iselin Bank where the median catch rate in the Ross Sea region is highest, catches are less than 0.01 kg per hook. Overall catches in Subarea 88.1 have been stable throughout the fishery at typically less than 10 t y^{-1}, with a peak catch of about 20 t in 2007 when 19 sets reported greater than 100 kg of *Muraenolepis* spp. (Parker et al. 2012, Moore & Parker 2021).

Morphological identification of eel cod species continues to be difficult and previous identifications of *Muraenolepis microps* from the Ross Sea region are now considered incorrect (Parker et al. 2012). Thirteen *Muraenolepis* specimens captured in the Ross Sea region during the 2008 IPY/CAML voyage were identified, based on morphology, as *M. evseenkoi* (identification by Te Papa Tongarewa Museum of New Zealand).

Genetic methods appear to be more effective than morphology at identifying eel cod species and are increasingly used (Fitzcharles 2014, Fitzcharles et al. 2021). Genetic identification of more than a hundred specimens indicates that eel cods on the Ross Sea slope are exclusively *M. evseenkoi* (Fitzcharles 2014). Eel cods caught over the Pacific-Antarctic fracture zone in the north of the Ross Sea region were identified genetically as predominantly *M. evseenkoi* with a single specimen of *M. microcephalus* (Fitzcharles 2014).

The biological studies published on species in the genus *Muraenolepis* suggest a relatively fast growing, semelparous[11] life history with a maximum age of 11 years (Parker et al. 2012). In the Ross Sea, eel cods selected by longline gear are almost exclusively female, and a localised area of high catch rates occurs on Iselin Bank on Ross Sea slope. Eel cods comprise a total of about 11% by weight of prey of sub-adult toothfish and about 14% by weight of prey of adult toothfish on the Ross Sea slope (Stevens et al. 2014).

Fishing is likely to affect eel cods in the Ross Sea region by a combination of predation release (fewer toothfish consuming eels cods) and fishing mortality (increased overall mortality), which act in opposition. The overall effects of fishing on this bycatch species depend on factors such as the distribution pattern and total biomass of eel cods, as well as their productivity. Further directed sampling to determine species composition, life-history attributes, reproductive strategy, sex-specific distribution, and any trends in biomass is needed from the Ross Sea area and throughout the CCAMLR Convention Area (Parker et al. 2012).

Deepsea (morid) cods

Catches of deepsea (morid) cods are dominated by *Antimora rostrata*. This species has a wide spatial distribution, north to the New Zealand EEZ where it is called 'violet cod' or 'blue antimora'. The stock structure of this species is unknown. The species forms less than 2% of the diet of toothfish on the Ross Sea slope, but about 20% by weight of diet over the northern (seamount) region of the Ross Sea (Stevens et al. 2014).

Rock cods and ice cods

Rock cods and ice cods (Nototheniidae) comprised less than 0.01% of the total retained catch between 1998 and 2020 (Moore & Parker 2021).

The highest catch rates for rock cods occur in a narrow depth band of 400–600 m (Stevenson et al. 2012).

Four different codes have been used to record rock cod and ice cod catches in the Ross Sea region and it is likely that different species dominate this group in different SSRUs. In SSRUs 88.1E and 88.1G, the highest mean catch rates are likely to mainly comprise the striped rock cod

[11] 'Semelparous' means the adults breed once in their life then die.

(*Lepidonotothen kempi*); this species was the most abundant species caught in research trawls and observed on videos during the BioRoss and IPY-CAML biodiversity surveys (Clark et al. 2010). Catches on the Ross Sea shelf are likely to mainly comprise the deepwater notothen (*Trematomus loenbergii*); this species was the most commonly caught species in the sub-adult toothfish survey over the southern Ross Sea shelf (Hanchet et al. 2012).

17.3.3 EFFECTS ON PREY SPECIES

Fishing can reduce predation on prey species by removing parts of the predator population (i.e., the target species for fishing operations). This can lead to mesopredator (or predation) release (Soulé et al. 1988, Prugh et al. 2009).

Empirical meta-analysis suggests that predation release tends to be weaker in pelagic marine and terrestrial systems than in benthic marine and freshwater systems (Shurin et al. 2002). Predation release tends to be stronger where the predator is large and mobile, has high metabolic rate, where prey species are long-lived, functional predator diversity is low, and predator intraguild predation is weak or absent (Borer et al. 2005, Heithaus et al. 2008).

Many of these factors are present in the Ross Sea. On the Ross Sea continental slope, where the majority of the regional Antarctic toothfish population feeds (Hanchet et al. 2008), toothfish are likely to be by far the major predators of macrourids, icefish, and eel-cods (Pinkerton et al. 2010a, Stevens et al. 2014, Pinkerton & Bradford-Grieve 2014). There are no other piscine predators of the size of Antarctic toothfish over the Ross Sea shelf and slope (Smith et al. 2012). Some prey species of toothfish have relatively high longevities and low productivity rates. Macrourids tend to be long-lived (Bergstad 1995, Kelly et al. 1997) and, in the Ross Sea region, otolith ageing found maximum recorded ages of 27 years for *M. whitsoni* (n=227) and 62 years for *M. caml* (n=319) (Pinkerton et al. 2013). In contrast, *C. dewitti* and *M. evseenkoi* are faster-growing and shorter-lived species, with maximum recorded ages of around 11 years (Sutton et al. 2008, Parker et al. 2012). One mitigating factor against strong top-down changes to prey species is the relatively low consumption rate of toothfish, which is likely to be only one to two times its body mass per year because of its large size and the cold water (Pinkerton et al. 2010a).

Models of specific cases of predation release in marine systems are few (Prugh et al. 2009) partly because reliable information on marine predators is often scarce (Heupel et al. 2014). A number of approaches have been used to investigate ecological interactions in marine systems including full-ecosystem models (Plagányi 2007, Rose et al. 2010) and mixed-trophic impact analysis (Ulanowicz & Puccia 1990).

Mixed trophic impact analysis was applied to the Ross Sea trophic model (Pinkerton et al. 2010a, Pinkerton & Bradford-Grieve 2014) and suggested a strong trophic connection between toothfish and medium-sized demersal fish (mainly macrourids and icefish). In the Ross Sea trophic model, toothfish consumed 64% of the annual production of medium-sized demersal fish. This led to the strongest, top-down impact in the whole multiple-step analysis of Pinkerton & Bradford-Grieve (2014) who concluded that at least some piscine prey of toothfish will experience a relatively strong predation-release effect as the abundance of toothfish is reduced by fishing.

Such 'whole system' approaches tend not to consider interactions over small spatial scales or affecting only parts of populations, and their ability to reliably represent the dynamics of whole ecosystems remains limited (Beckage et al. 2011, Planque 2015). Modelling predation release within a key subset of the whole marine system may be more robust and hence more useful for fisheries management (Plagányi 2007, Plagányi et al. 2014).

To explore the potential effects of the toothfish fishery on these medium-sized demersal fish, a minimum realistic model (MRM) of Antarctic toothfish, macrourids, and icefish was developed (Mormede et al. 2014d). This was spatially explicit and dynamic, and based on a model of predator-prey interactions for the Ross Sea Region. The MRM included age-based population dynamics of toothfish, macrourids, and icefish, and included natural mortality, predation mortality, and fishing mortality on all three species. The MRM suggested that the predation release caused by the fishery effect on toothfish abundance was greater than the direct fishing mortality on both prey species and that icefish were expected to show a larger increase in biomass through time than macrourids (Mormede et al. 2014d). This may affect the proportions of macrourids and icefish in the diet of toothfish over time (Mormede et al. 2014d).

17.3.4 EFFECTS ON PREDATOR SPECIES

Three species are known to prey on toothfish in the Ross Sea region: Weddell seals, Type C killer whales, and sperm whales. Other species discussed below may also consume toothfish. In assessing the potential consequences of fishing to its predators of toothfish, two factors are important:

1. To what extent is the predator population *ecologically dependent* on toothfish as a prey item? This includes aspects such as the proportion of toothfish in the predator's diet and whether alternative prey items are available (and at what additional ecological cost to the predator). Also relevant is whether toothfish is especially important as prey at a particular time of year, in a particular area, or to a particular part of the predator population.

2. To what extent will the fishery reduce the availability of toothfish to the predators at ecologically relevant scales – i.e., taking into account temporal, spatial, and population factors?

Weddell seal

There remains uncertainty over the degree to which Weddell seals are ecologically dependent on toothfish as prey (Pinkerton et al. 2008, Eisert et al. 2013). Nutritional analysis of Ross Sea prey suggests that toothfish may represent a unique high-energy food resource for Weddell seals that may not be replaceable by other prey, in particular during periods of high energy demand such as late-stage lactation and the post-breeding recovery of body weight and condition for adult females (Eisert et al. 2013).

Changes to toothfish availability near Weddell seal breeding colonies in the period between pupping and weaning could affect survival of Weddell seal pups and lactating mothers, and fertility rates in the following season, and hence have a compounding impact on Weddell seal populations in these areas (e.g., Pinkerton et al. 2008, Eisert et al. 2013).

Eisert et al. (2013) recommended that the assumed dominance of Antarctic silverfish in Weddell seal diets should be re-examined given the known biases of methods used to derive diet estimates; although large (over 30 g) silverfish occurring at high densities are likely to be a valuable nutritional resource to Weddell seals, smaller size classes of silverfish are unlikely to be adequate to meet the estimated energy requirements of adult Weddell seals.

Killer whale

Killer whales are considered to constitute a single species throughout the world (Rice 1998) but there are at least four different forms (or 'ecotypes') of killer whale in the Antarctic (Pitman & Ensor 2003). The Ross Sea (or 'Type C') killer whale ecotype is believed to feed almost entirely on fish. There is strong circumstantial evidence that toothfish are an important prey item for Type C killer whales in the Ross Sea region (Torres et al. 2013, Eisert et al. 2013, 2014).

The evidence includes:

(1) Killer whale population ecology includes high consumption rates, low abundances, low production rates, often specialised diets, and unknown potential for foraging innovation.

(2) Type C killer whales near McMurdo Sound have been commonly observed carrying toothfish in their mouths (Eisert et al. 2013, 2014).

(3) Comparison of the relative nutrient density of toothfish with silverfish and other prey shows that toothfish represent a high-energy food resource of much higher quality than other potential prey in the Ross Sea region (Eisert et al. 2014). While equivalent energy-dense non-fish prey is available in the Ross Sea (e.g., penguins or seals), observations in northern hemisphere killer whale populations suggest that switching from fish to endotherm (warm blooded) prey is unlikely (Barrett-Lennard et al. 1996, Barrett-Lennard 2011).

(4) An important recent finding is the high incidence of suckling calves observed in Type C killer whale groups in McMurdo Sound (Eisert et al. 2014). Caring for young (less than six months old) calves greatly increases the energy requirement of lactating females, not only for milk production, but also because mothers assist their calves through drafting, which increases their own locomotory costs. Revised estimates of energy requirements indicate that lactating female killer whales of the fish-eating ecotype require toothfish to meet their elevated demand.

(5) Densities of other alternative potential prey (Antarctic silverfish, cryopelagic fish) seem too low to justify killer whales coming to the Ross Sea for feeding and the development of a fish-eating ecotype (Eisert et al. 2014).

However, other information on the potential feeding by killer whales on toothfish was inconclusive:

(1) It is not known to what extent toothfish forage pelagically or how deep type C killer whales can dive. Type C killer whales in the Ross Sea can routinely dive to 200–400 m, with a maximum of over 700 m (Torres et al. 2013, Eisert et al. 2015). This is deep enough to reach demersal prey over much of the Ross Sea shelf, but foraging times would be short at these depths.

(2) Stable isotope analysis of tissue from killer whales and toothfish was inconclusive, due to the unknown rate of skin turnover and the stable isotope gradient across the killer whale known range (Krahn et al. 2008, Graham & Bury 2019).

The balance of evidence suggests that toothfish are likely to form a significant part of the diet of Type C killer whales in McMurdo Sound in summer, but it is not possible to say whether toothfish are an important prey item to Type C killer whales in other locations on the Ross Sea shelf (e.g., Terra Nova Bay, Bay of Whales, Sulzberger Bay) or at the scale of the whole Ross Sea shelf and slope (Torres et al. 2013, Eisert et al. 2014).

Evidence derived from limited satellite tagging and photo-identification shows that Type C killer whales undergo long-distance travel from the southern Ross Sea to New Zealand waters and into subtropical regions (Figure 17.10; Eisert et al. 2015).

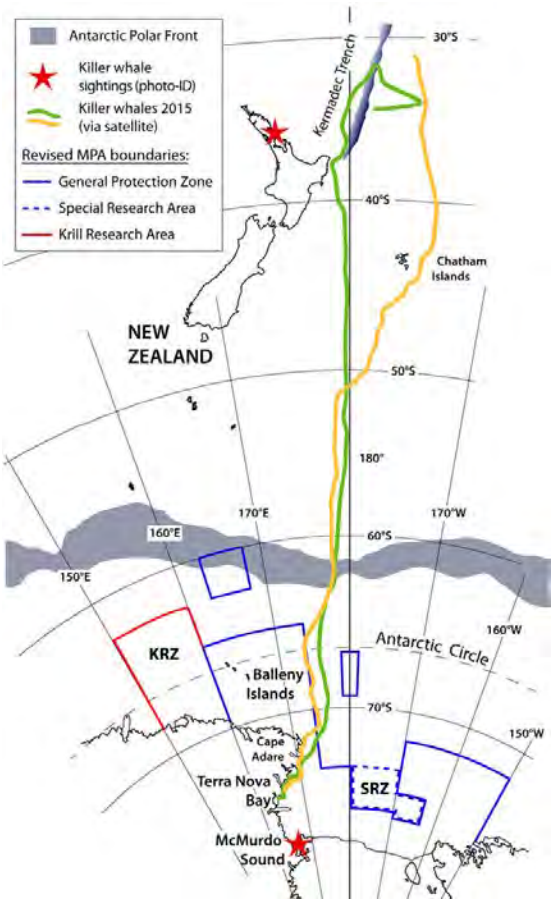


Figure 17.10: Satellite tracking of Type C killer whales showing ecological connectivity for this species between the Ross Sea and New Zealand (Eisert et al. 2015).

Analysis of photo-ID data indicates that Type C killer whales from the Terra Nova Bay area of the Ross Sea show a high degree of seasonal site fidelity. Individual whales returned over different years to areas of ecological significance, including New Zealand waters north and east of East Cape, the Kermadec Trench region, and the Ross Sea (Eisert et al. 2015).

Sperm whale

Sperm whales are migratory and are distributed from the tropics to the pack ice edges in both hemispheres. The subtropical convergence at about 40° S marks the southern limit of females and young males; only the larger males penetrate further south (Lockyer & Brown 1981, Knox 2007). Sperm whales are the largest toothed whale and sexually dimorphic (males reach 16 m and 45 t, females 11 m and 15 t; Whitehead 2018).

Present and historical occurrence of sperm whales along the Ross Sea continental slope remains unclear. Kasamatsu & Joyce (1995) reported a southernmost sighting of a

sperm whale at 74° S on the Ross Sea slope and summarised data collected in sighting surveys between 1976–77 and 1987–88 during mid-December to mid-February. The IWC data from the 1990s showed sperm whale sightings in the area defined by 70–78° S, 150–180° E (along the Ross Sea shelf edge). However, sperm whales have rarely been sighted on the Ross Sea slope from fishing vessels (Fenaughty, pers. comm.). We are not aware of any systematic surveys of sperm whales in the Ross Sea or Amundsen Sea regions in the last 30 years.

Sperm whales are deep divers. They typically stay submerged for about 45 min (up to two hours) and commonly dive to about 600 m, but may be able to reach depths of >2000 m (Clarke 1976, Watkins et al. 1993, Perrin et al. 2002, Whitehead 2018). Sperm whales in the Southern Ocean and Pacific subantarctic waters are reported as feeding primarily on squid and secondarily on fish (Clarke 1980, Knox 2007, Evans & Hindell 2004). Knox (2007) gives the ratio of squid to fish in their diet as 9:1.

Yukhov (1971, 1972) and Abe & Iwami (1989) described Antarctic toothfish as prey items but proportions are not known. Yukhov (1971, 1972) examined large numbers of stomachs from 12–18 m long (i.e., subadult and adult) sperm whales from the Pacific Ocean sector of the Antarctic from 1965 to 1969 and found that the main prey were cephalopods but that Antarctic toothfish (97–160 cm total length) were also frequently found in the sperm whale stomachs. Although some records were associated with seamounts and ridges, many occurred over deep water (more than 4000 m) suggesting that the sperm whales were feeding pelagically (Yukhov 1972).

Other potential predators of toothfish

Other possible predators of toothfish in the Ross Sea region include southern elephant seals, Arnoux's beaked whales, and colossal squid.

Southern elephant seals (*Mirounga leonina*) enter the Ross Sea only in the summer from breeding and feeding grounds further to the north. They are likely to be mainly feeding on small pelagic fish, squid, and crustaceans (Walters et al. 2014). However, their deep diving capability (about 1500 m) and occurrence around the Ross Sea slope, as well as photographic evidence from the Antarctic Peninsula region (Eisert and Smellie, pers. comm.) suggests that elephant seals may consume Antarctic toothfish.

Very little is known about the predation of Arnoux's beaked whales (*Berardius arnuxii*) on toothfish but this is unlikely to be significant. These whales are known to occur in the Ross Sea to 77° S (Eisert, pers. comm.), are capable of diving to depths where toothfish occur on the Ross Sea slope, and are predominantly small fish and squid eaters (Walker et al. 2002, Ohizumi et al. 2003).

Beak-shaped bite marks on toothfish caught on longlines suggest some depredation on toothfish by colossal squid (*Mesonychoteuthis hamiltoni*). However, stable isotope analysis of tissue of this species of squid suggests that it is unlikely to feed on toothfish.

Effects of fishing on availability of toothfish as prey

There are four ways in which the fishery could alter the availability of toothfish for predators in the Ross Sea region:

(1) *Smaller stock size*. Fishing leads to fewer fish available as prey.

(2) *Local depletion by fishing within a season*. Fishing may locally reduce toothfish abundance (catch rates typically decline when an area is fished). If fishing occurs in an area where predators forage, the availability of toothfish to predators may be reduced for some time. In 2008, CCAMLR set a zero allowable catch for SSRU 88.1M (along the Victoria Land coast), which had the effect of moving fishing effort away from the known foraging grounds of Weddell seals and Type C killer whales in the south-west Ross Sea.

(3) *Reduced recruitment*. The number of sub-adult toothfish available in the southwest Ross Sea could decline if there was reduced toothfish recruitment. The stock assessment suggests that toothfish spawning biomass in 2021 was about 62.7% B_0 (Grüss et al. 2021c). At this level, recruitment of toothfish is not estimated to be reduced. Based on the stock-recruit relationship with steepness assumed at 0.75 in the stock assessment (Mormede et al. 2014a), recruitment is predicted to be reduced to about 92% of unfished recruitment when the spawning stock biomass reaches 50% of its unfished status.

(4) *Density-dependent* or *stock-contraction effects*. As has been seen in some other species elsewhere (Swain & Sinclair 1993, Hutchings 1996, Atkinson et al. 1997, Fisher & Frank 2004), fishing may change movement patterns and distribution of toothfish throughout the Ross Sea region. Changes in the distribution of toothfish that affect

abundance at the edges of the toothfish range may be important to their predators.

17.3.5 TROPHIC AND SYSTEM-LEVEL EFFECTS

Changes in the abundance of one species may impact other species that are neither its predators nor its prey. These are called 'second order' trophic effect, or ecosystem-level effects and can include trophic cascades and regime shifts. Well-documented, oceanographic-induced regime shifts in marine ecosystems have historically had substantial, long-lasting, and typically (but not always) negative effects on fisheries. A review of trophic and ecosystem level effects of fishing is given in Chapter 13: Trophic and ecosystem-level effects.

Trophic effects arising from fishing are more likely to be important if the target species has a key role or is of high trophic importance in the ecosystem (Fletcher et al. 2002, Fletcher 2005). An estimate of trophic importance, using mixed trophic impact analysis (Ulanowicz & Puccia 1990) was applied to the Ross Sea (Pinkerton & Bradford-Grieve 2014) based on the Ross Sea trophic model (Section 17.2.2). This concluded that Antarctic toothfish has moderate trophic importance in the Ross Sea food web as a whole. The analysis did not support the hypothesis that changes to toothfish abundances due to fishing will cascade through the Ross Sea regional ecosystem by simple trophic effects. Pinkerton & Bradford-Grieve (2014) did not rule out cascading effects on the Ross Sea ecosystem due to changes in the abundance of toothfish, but noted that for such changes to occur, a mechanism other than simple trophic interactions would need to be involved. Instead, Pinkerton & Bradford-Grieve (2014) found that trophic importance was highest in the middle-trophic level organisms of the Ross Sea food web. Antarctic silverfish, krill, small demersal and pelagic fishes, cephalopods, and mesozooplankton were identified as having key roles in maintaining ecosystem resilience.

17.3.6 EFFECTS ON HABITATS

Vulnerable Marine Ecosystems (VMEs) constitute areas that may be vulnerable to impacts from fishing activities. Taxa considered to comprise VMEs vary geographically. Essentially, VMEs are ecosystems with organisms that create biogenic structures, are fragile relative to the fishing gears in question, are rare or endemic, or have life-history traits that imply slow recovery from disturbance (Rogers et al. 2008, FAO 2008).

In 2007 CCAMLR adopted Conservation Measure (CM) 22-06 requiring Member countries to assess and manage adverse effects of bottom fishing on VMEs in the Convention Area. The *New Zealand Antarctic Bottom Fishing Impact Assessment Workshop* in 2007 identified 14 groups of taxa indicative of habitats or communities where VME organisms occur (Parker et al. 2008). A CCAMLR guide to VME taxa was produced in 2009.[12]

All fishing for toothfish in the Ross Sea and Amundsen Sea regions is by longline, which are laid on or close to the seabed and held down by weights and grapples (Fenaughty 2008). Structure-forming benthic invertebrates can be damaged by the longlines, especially during their hauling (recovery from depth) when the longlines may move laterally. Benthic invertebrates that have been brought to the surface attached to lines in the Ross Sea region include anemones (Actiniaria), stony corals (Scleractinia), gorgonians (Gorgonacea), sponges (Porifera), and ascidians (Ascidiacea) (Parker & Bowden 2009).

The potential for the longlines to significantly affect a particular group of structure-forming benthic habitat in the Ross Sea is related to the spatial scale of the area of contact between fishing gear and the seafloor as a proportion of the total area in which the habitat is present. An impact assessment method developed by Sharp et al. (2009) showed that regardless of the distribution of VME taxa (for which actual spatial distributions are unknown) the cumulative impact on VME organisms of all historical longline fishing effort in the Ross Sea region has been very low. At a very fine scale (i.e., spatial cells measuring 0.05° latitude by 0.167° longitude) fewer than 5% of cells within fishable depths have been fished. Average impacts within fished cells are less than 0.1% total mortality of vulnerable taxa; estimated impact in the single most heavily impacted cell is less than 5% (Sharp 2010). These low impacts reflect both the spatially restricted area within which the fishery operates and the very narrow spatial footprint of individual longlines.

A spatially explicit production model was developed and used to simulate likely population level effects (including

[12] CCAMLR. VME Taxa Classification Guide 2009. Retrieved from https://www.ccamlr.org/en/system/files/VME-guide.pdf.

recovery) arising from benthic impacts from longline fishing effort in the Ross Sea region (Dunn et al. 2010). Simulations included different productivity assumptions, impact, and spatial scale, with and without management by areal closures. The results of the simulations suggested that management action of areal closures in the Ross Sea region would improve the outcome for VMEs, but that the improvement was very small, given the already low level of impact.

Research has not found significant correlation between the occurrence of VMEs and toothfish abundance within areas fished for toothfish in the Ross Sea region (Parker & Mormede 2009, Parker et al. 2010, Parker & Smith 2010). Dunn et al. (2010) recommended further work on simulating effects of fishing on VMEs, including investigating how changes in the distribution of future fishing may result in alternative impacts or how different assumptions of the underlying distributions of benthic organisms may influence the results.

17.3.7 SYNERGISTIC EFFECTS OF FISHING AND CLIMATE CHANGE

There is increasing understanding of the potential impacts of climate change on fisheries (Valdes et al. 2009, Rice & Garcia 2011, IPCC 2014). Fishing can also act synergistically with climate variation/change and lead to ecosystem-level change (e.g., Winder & Schindler 2004, Brierley & Kingsford 2009, Kirby et al. 2009, Perry et al. 2010; see also Chapter 13).

If change to the level of toothfish recruitment in the Ross Sea or Amundsen Sea regions did occur (for example due to effects of fishing and climate change), would the current monitoring and management framework be able to detect this, and after how long?

Changes in age structure caused by changes in recruitment strength would most likely be detected from the fisheries catch data, but would not be apparent until the relevant cohort was of sufficient age to be fully selected by the fishery. Even then, the signal may be confounded with changing effort patterns. Without specific monitoring of sub-adult toothfish in the Ross Sea any substantial change in recruitment would not likely be detected until some years after it occurs.

This delay in detecting any effect of the fishery on recruitment was one reason for the start of the sub-adult survey for Antarctic toothfish over the southern Ross Sea shelf in 2012 (Hanchet et al. 2012). There have been six surveys to date (Hanchet et al. 2012, Parker et al. 2013b, Mormede et al. 2014c, Hanchet et al. 2015b, Dunn et al. 2016, Large et al. 2017). These surveys use a consistent, stratified design for sampling sub-adult toothfish to better estimate recruitment variability and provide an early-warning of changes in toothfish recruitment. It is likely that this survey, if continued on the same basis as at present, would detect changes to recruitment about five years after it occurred. In contrast, in the absence of a fishery-independent survey, the relevant cohort would not be available to the commercial fishery for approximately 10 years, and it is possible that any recruitment signal in the fishery-dependent data would be confounded by the effects of variable or uncontrolled commercial fishery selectivity. The survey hence reduces risk of changes in recruitment of toothfish in the Ross Sea region being detected too late for management to respond.

17.3.8 REVERSIBILITY OF ECOSYSTEM EFFECTS OF FISHING

Principle (b) of Article II of the CAMLR Convention requires the "maintenance of ecological relationships" in the ecosystem. Principle (c) of Article II of the CAMLR Convention states also that changes due to fishing should be "reversible over two or three decades".

It has been suggested that trophic interactions can affect the ability of fish populations (and by extension, related or dependent species in the ecosystem) to regain their former characteristics following exploitation (Hutchings 2000, Steele & Schumacher 2000). Predictions as to the reversibility of ecosystem effects of fishing would be limited by three key factors. First, there is presently no information with which to estimate density-dependent effects of changes to toothfish (Abrams 2014). Second, the reversibility of different types of ecosystem effects of fishing will vary, so any theoretical investigations of reversibility will need to be carried out for each effect of fishing separately. Third, it is not known whether trophic and ecosystem-level effects or genetic or behavioural factors may come into play should fishing for toothfish cease. At present, there is very limited scientific ability to predict the dynamics of ecosystems (Planque 2015).

Keith & Hutchings (2012) concluded that "emergent and demographic Allee [density-dependent] effects, coupled with altered interspecific interactions, render questionable the presumption that the recovery of heavily depleted

populations can be reliably forecasted by population dynamical behaviour during the decline." However, in this context, 'heavily depleted' means depleted to much lower levels than the CCAMLR target of 50% B_0 so issues of reversibility are likely to be relevant only in the case of *significant overdepletion* of toothfish or arising from *substantial ecosystem effects* in other parts of the system. The focus in CCAMLR and in the Ross Sea and Amundsen Sea regions has hence been on preventing significant overdepletion of target species and on developing indicators for changes in dependent or related species (e.g., CEMP 2004, Delegations of New Zealand, Norway and the United Kingdom 2014). At present, evidence does not suggest that significant overdepletion of target species or substantial ecosystem effects are occurring in the Ross Sea and Amundsen Sea regions.

17.3.9 RESEARCH PRIORITIES

The medium-term (5–10 year) research priorities for the Antarctic toothfish fishery in the Ross Sea and Amundsen Sea regions were updated in 2014 (Delegations of New Zealand, Norway and the United Kingdom 2014). The first two sections of the medium-term research plan (MTRP, Table 17.1) prioritised research to assess, monitor and maintain the reproductive potential of the toothfish population. The third section dealt with issues related to the ecosystem effects of fishing, including reversibility of any effects of fishing.

Table 17.1: Medium-term research plan (MTRP) priorities with regard to the ecosystem effects of the fishery for toothfish in the Ross Sea and Amundsen Sea regions (Delegations of New Zealand, Norway and the United Kingdom 2014). The other two parts of the MTR plan are not shown. These are to (1) reduce uncertainty in toothfish model parameters; and (2) reduce management uncertainty.

Section	Key research priorities	
Maintenance of ecosystem structure and function	(i)	To determine the temporal and spatial extent of the overlap in the distribution of toothfish and its key predators (in particular killer whales and Weddell seals).
	(ii)	To investigate the abundance, foraging ecology, habitat use, functional importance and resilience of key toothfish predators (in particular killer whales and Weddell seals).
	(iii)	To develop methods of monitoring changes in relative abundance of key prey/bycatch species (in particular macrourids and icefish) on the Ross Sea slope and hence assess the potential impact of the toothfish fishery on these species.
	(iv)	To monitor diet of toothfish in key areas, especially on the Ross Sea slope.
	(v)	To simulate the effect of the fishery on populations of toothfish, its predators, and its prey (using Minimum Realistic Models or similar).
	(vi)	To develop quantitative and testable hypotheses as to the 'second-order' effects (such as trophic cascades, regime shift) and ensure data collection is adequate to monitor for any risks deemed reasonable.
	(vii)	To assess the impact of the toothfish fishery on Patagonian toothfish.
	(viii)	To estimate survivorship of released skates.
	(ix)	To develop semi-quantitative and spatially explicit risk assessments for macrourids and Antarctic skates (*A. georgiana*), especially in the slope fishery of the Ross Sea.
	(x)	To develop methods to assess whether the potential impacts of the toothfish fishery on the ecosystem are likely to be reversible in two to three decades.

The research priorities for the ecosystem effects of fishing were:

1. Further analysis is needed to understand the effect of fishing on rajids in the Ross Sea region.

2. To improve our understanding of the effect of fish on the prey assemblage of toothfish, especially in the most heavily-fished area of the Ross Sea slope, further information on the two species of macrourid separately is needed. In particular, information is needed on the relative abundances of *M. whitsoni*, *M. caml*, the relative catch of the two species across the Ross Sea and Amundsen Sea regions and the relative amount of the two species consumed by toothfish. Some of this research is underway. For example, the RV *Tangaroa* voyages to the Ross Sea in February 2015 and in January-February in 2019 included depth-stratified demersal trawl surveys of the Iselin Bank (SSRU 88.1I) and the results are being analysed. New Zealand observers have been identifying some of the macrourid bycatch in the Ross Sea region to species level since 2012 (i.e., separating *M. caml* from *M. whitsoni*), and macrourid prey found in the stomachs of toothfish during diet analysis will be identified to species level.

3. The minimum realistic model of interactions between toothfish and key prey species (especially macrourids and icefish) should be further developed. This modelling

enables the potential impacts of the fishery on key prey species to be evaluated to generate hypotheses of future change and to design monitoring tools for ecosystem effects.

4. Ongoing monitoring of toothfish diet is recommended, as is the monitoring of the icefish and macrourid populations (especially in SSRUs 88.1H and 88.1K) through the development of age frequencies (length measurements and ageing) (Pinkerton & Bradford-Grieve 2014, Mormede et al. 2014d).

5. Our ability to determine to what extent Weddell seal, Type C killer whale, and sperm whale populations in the Ross Sea and Amundsen Sea regions are ecologically dependent on toothfish requires further information on their diet and improved information on their seasonal and spatial abundances.

17.3.10 MARINE PROTECTED AREAS

The CAMLR Convention provides the overarching basis for marine resource conservation in the Southern Ocean. It includes a role for marine protected areas (MPAs). The CCAMLR position on MPAs is given online.[13] A decision was made at the World Summit on Sustainable Development (WSSD) in 2002 in Johannesburg, South Africa, to achieve a representative network of MPAs by 2012. CCAMLR responded to the WSSD target by aiming to establish a representative network of MPAs in the CAMLR Convention Area by 2012.

Globally, spatial fishing closures have been proposed as one way that fisheries management can manage, avoid, or mitigate the risk of ecosystem effects of fishing.[14] Although there are different types, in general, an MPA is a kind of spatial fisheries management that provides protection for all or part of the natural resources it contains. MPAs do not necessarily exclude fishing, research, or other human activities. MPAs in which no fishing is allowed are often referred to as 'no-take areas'. Other uses may still be permitted.

The Ross Sea region MPA was approved by CCAMLR at its Commission meeting in October 2016. Conservation Measure 91-05 (2016) (CM 91-05)[15] details the specificities of the MPA. The boundaries of the MPA can be found in the CM (Figure 17.11). It has an area of 1.55 million km^2. It came into force in December 2017 and the period of designation is 35 years. The full chronology and scientific basis for the design and designation of the Ross Sea region MPA by CCAMLR is summarised in Delegations of New Zealand and the United States of America (2014).

The MPA limits activities inside its boundaries to meet conservation, habitat protection, ecosystem monitoring, and fisheries management objectives (Table 17.2). The MPA is divided into three zones:

- the General Protection Zone, which corresponds to 72% of the MPA, is a 'no-take' zone, which prohibits commercial fishing;
- the Special Research Zone (SRZ), which permits some commercial fishing as a part of scientific research;
- the Krill Research Zone (KRZ), which permits some harvesting of krill as a part of scientific research.

A management plan has been agreed and provides further details about the features or areas within the MPA associated with the specific objectives, as well as the management measures and administrative arrangements for achieving them (Annex 91-05/B of CM 91-05).

A Scientific Research and Monitoring Plan was developed for the October 2017 CCAMLR Commission meeting (Dunn et al. 2017). Priority elements for the plan can be found in Annex 91-05/C of Conservation Measure 91-05.

The Conservation Measure defining the Ross Sea is due for review at least every 10 years to evaluate whether the specific objectives of the MPA are still relevant or being achieved and to evaluate the delivery of the research and monitoring plan.

There are no proposals to establish MPAs in the Amundsen Sea region.

[13] CCAMLR. Marine Protected Areas. Retrieved from https://www.ccamlr.org/en/science/marine-protected-areas-mpas.

[14] Scientific Consensus Statement on Marine Reserves and Marine Protected Areas, https://www.nceas.ucsb.edu/Consensus.

[15] CCAMLR. Conservation Measure 91-05 (2016). Retrieved from https://www.ccamlr.org/en/measure-91-05-2016.

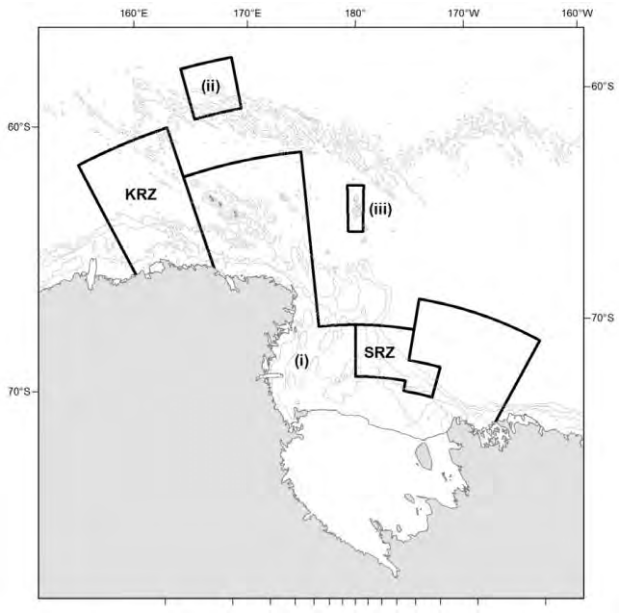


Figure 17.11: Map of the Marine Protected Area in the Ross Sea region. The black lines indicate the boundaries of the General Protection Zone (composed of areas (i), (ii), and (iii)), the Special Research Zone (SRZ), and the Krill Research Zone (KRZ). Depth contours are at 500 m, 1500 m, and 2500 m.

Table 17.2: Objectives of the Marine Protected Area in the Ross Sea region.

1	To conserve ecological structure and function throughout the Ross Sea Region at all levels of biological organisation, by protecting habitats that are important to native mammals, birds, fishes, and invertebrates.
2	To provide a reference area in which fishing is limited, to better gauge the ecosystem effects of climate change and fishing, and to provide other opportunities for better understanding the Antarctic marine ecosystem.
3	To promote research and other scientific activities (including monitoring) focused on marine living resources.
4	To protect a representative portion of benthic and pelagic marine environments.
5	To protect large-scale ecosystem processes responsible for the productivity and functional integrity of the ecosystem.
6	To protect core distributions of trophically dominant pelagic prey species.
7	To protect core foraging areas for land-based predators or those that may experience direct trophic competition from fisheries.
8	To protect coastal locations of particular ecological importance.
9	To protect areas of importance in the lifecycle of Antarctic toothfish.
10	To protect known rare or vulnerable benthic habitats.
11	To promote research and scientific understanding of krill, including in the Krill Research Zone in the north-western Ross Sea region.

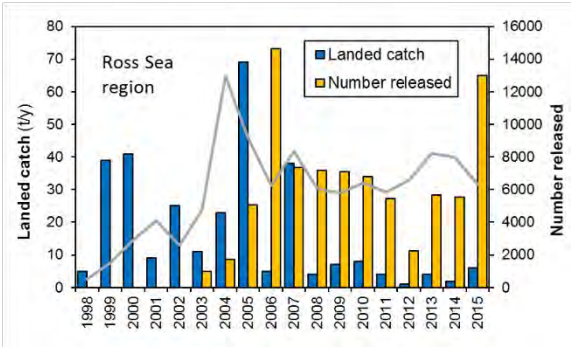
17.4 INDICATORS AND TRENDS

17.4.1 EFFECTS ON BYCATCH SPECIES

Rajids (skates and rays) are the bycatch group deemed at most risk from a direct effect of fishing in the Ross Sea region (Delegations of New Zealand, Norway and the United Kingdom 2014). No information or indicators as to the ecological effects of fishing on rajids in the Ross Sea and Amundsen Sea regions are available. Before the 2008 fishing season skates were cut off in the water with the hook attached. Starting in the 2008 fishing season, skates that were not already tagged (i.e., recaptured tagged fish) and which were deemed to be in reasonable condition were required to be cut from longlines (CM 33-03). This led to a fall in the number of rajids landed onboard and an increase in numbers released (Figure 17.12).

Macrourid bycatch in the Ross Sea and Amundsen Sea regions increased to a maximum in 2005 and 2006, respectively, as the fisheries expanded and then decreased (Figure 17.13).

a



b

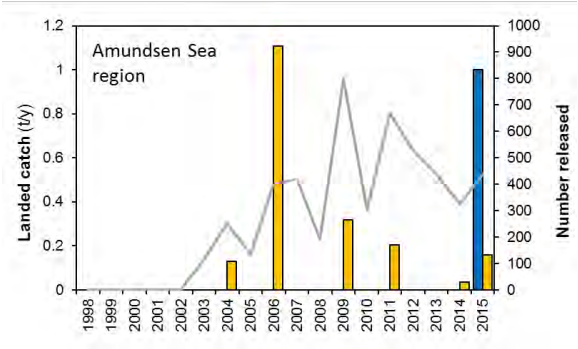


Figure 17.12: Catch of rajids (skates and rays). [a] Ross Sea region; [b] Amundsen Sea region. Weight of landed rajids (blue) and numbers cut off alive (orange). The relative effort (number of sets) is shown as the grey line.

Predation release of macrourids and icefish is expected to be larger than fishing mortality and may lead to increased abundance over time (Pinkerton & Bradford-Grieve 2014, Mormede et al. 2014d). Analysis of the rates of bycatch for macrourids (*M. whitsoni* and *M. caml*), icefish (principally *Chionobathyscus dewitti*), eel cods (*Muraenolepis* spp.), and deepsea cods (*Antimora rostrata*) has been carried out (Moore & Parker 2021), using standardisation to control for area and vessel reporting.

It is likely that changes to CCAMLR management rules aimed at reducing bycatch of macrourids together with more targeted fishing practices have led to decreases in the catch of macrourids in the Ross Sea slope region. These changes in fishing locations and practices are also likely to have affected catch rates for bycatch species so that changes in catch rates in Figure 17.14 probably do not reflect changes in population sizes.

Alternative methods to look for changes in the population abundance of macrourids over time are being explored, including acoustics (O'Driscoll et al. 2012, Ladroit et al. 2014). Also, 'catch-curve' analysis to explore changes in the total mortality rate of macrourids is being investigated.

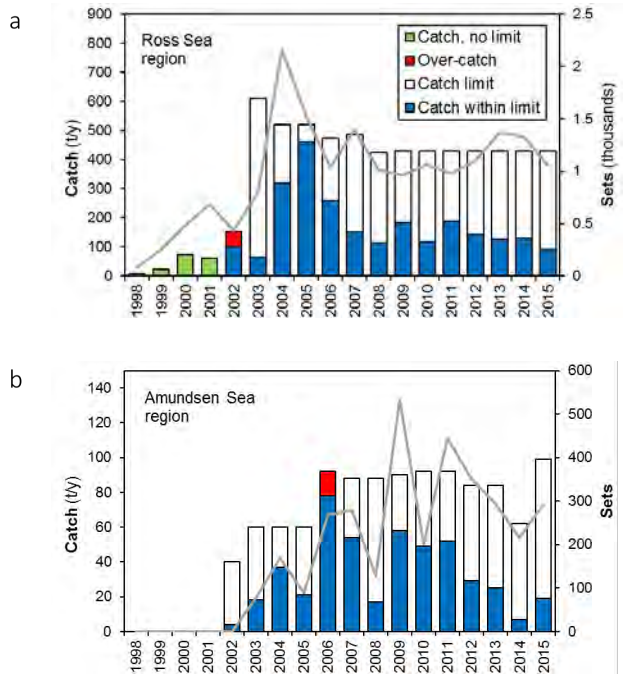


Figure 17.13: Macrourid bycatch (bars) and total fishing effort in terms of number of sets (grey line). [a] Ross Sea region; [b] Amundsen Sea region. White bars shows where the catch limit exceeds the catch, and red bars indicate that catch exceeded the catch limit in that year.

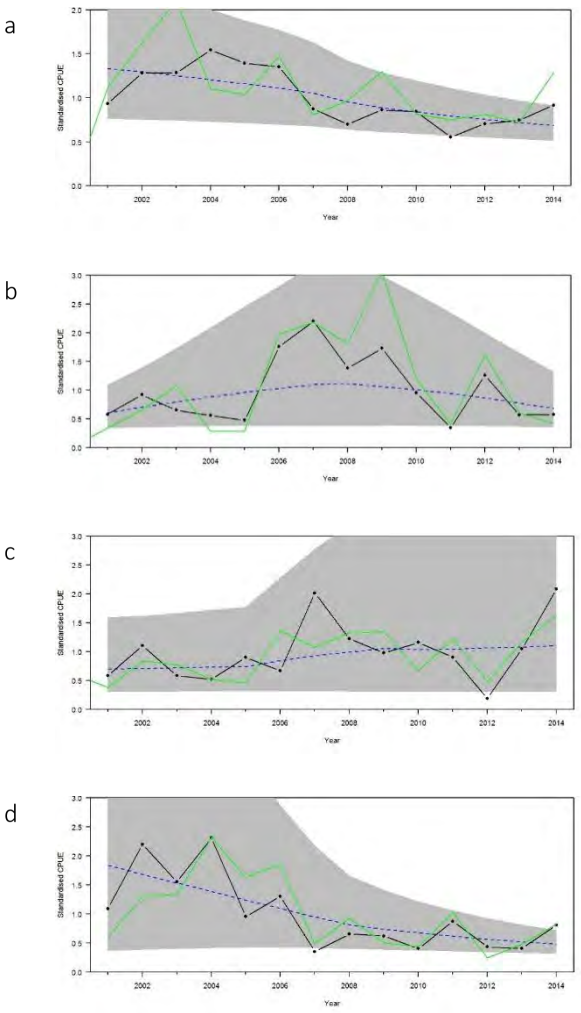


Figure 17.14: Raw (green), standardised (black), trends (blue) and 95% confidence intervals (grey) for catch-per-unit-effort (CPUE) in groups of bycatch species on the Ross Sea continental slope (small-scale research units (SSRUs) 88.1 H and I). [a] Macrourids; [b] icefish; [c] eel cods; [d] deepsea cod.

17.4.2 EFFECTS ON PREY SPECIES

Both mixed trophic impact analysis and the minimum realistic model of trophic interactions between toothfish, macrourids, and icefish in the Ross Sea region suggest that the toothfish fishery is likely to cause predation release in prey species, especially on the Ross Sea slope (Pinkerton & Bradford-Grieve 2014, Mormede et al. 2014d). The differential strength of the predation release on macrourids and icefish would be likely to lead to a change in the diet of toothfish over time in favour of more icefish being consumed (Mormede et al. 2014d).

Stevens et al. (2014) found no significant temporal change in the diet of toothfish between 2003 and 2010 based on examination of stomach contents of toothfish on the Ross

Sea slope. Pinkerton et al. (2014) found a small but significant reduction in the trophic level of toothfish between 2006 and 2014 in a direction consistent with more icefish and fewer macrourids being consumed.

Monitoring for changes in the diet of toothfish, with a focus on the Ross Sea slope, is a research priority (Delegations of New Zealand, Norway and the United Kingdom 2014) and is continuing through periodic collection of toothfish stomachs and analysis of toothfish tissue samples by stable isotope analysis to test for changes in trophic level over time.

17.4.3 EFFECTS ON PREDATOR SPECIES

At present, no indicators are available to monitor changes to the ecological state of known predators of toothfish (Type C killer whales, Weddell seals, and sperm whales) in the Ross Sea or Amundsen Sea regions, and this is a recognised priority for future research (Delegations of New Zealand, Norway and the United Kingdom 2014). The fact that Type C killer whales, and potentially sperm whales, move between the Ross Sea and the EEZ, gives New Zealand a key role in the management of risks to these species.

Information is available on the extent to which fishing is likely to have reduced the availability of toothfish to predators of toothfish. Two factors are important when considering indicators for changes to the availability of toothfish as relevant to toothfish predators.

First, different predators forage over different spatial scales so that spatial patterns in changes to toothfish abundance over time are important. For example, the foraging ranges of lactating Weddell seals are constrained by the seals having to return to fast-ice colonies to feed the pups. Foraging range of Type C killer whales in the Ross Sea is not known, but it appears that the McMurdo Sound is important (Eisert et al. 2015). Sperm whales are unlikely to venture south of the Ross Sea slope.

Second, the size of toothfish consumed by predators is important because different size classes of toothfish will be affected differentially over time by fishing. Weddell seals consume toothfish of total length (TL) 60–110 cm (median TL about 80 cm; Kim et al. 2011, Ainley & Siniff 2009). Although information on the size of toothfish taken by killer whales is scarce, Type C killer whales appear to take larger toothfish than Weddell seals. In the McMurdo Sound region at least, a Type C killer whale was observed with an approximately 150 cm TL toothfish (Eisert et al. 2015). This size of toothfish coincides with the modal size classes (130–159 cm TL) of toothfish caught in McMurdo Sound by scientists (Ainley et al. 2013). For sperm whales, because of their ability to access the entire water column, it is likely that all sizes of toothfish present in the Ross Sea slope region are available as prey.

Simulations of changes to the abundance of toothfish by geographic area were generated by the spatial population model of Mormede et al. (2014b). This model estimates the distribution of age classes of toothfish in the Ross Sea region.

Over the Ross Sea continental shelf (where Weddell seals and Type C killer whales overlap in distribution with toothfish), the spatial population model suggests that the biomass of sexually mature toothfish (greater than about 110–130 cm TL; Parker & Marriott 2012) was about 74% B_0 in 2013 and will decrease to about 57% B_0 in 2048 (Pinkerton et al. 2016). In SSRUs 88.1H and 88.1I on the Ross Sea slope (where sperm whales may occur and feed on toothfish) the spatial model suggests that total toothfish biomass (all lengths) in 2013 was 77% of that before fishing, and that this will decrease to 60% of the pre-exploitation biomass by 2048.

Changes in the length-frequency distribution of toothfish taken over the Ross Sea shelf by the fishery, in the SRZ and the south of 70° S, between 1998 and 2021 are summarised by Grüss et al. (2021a) and shown in Figure 17.15.

For the southern part of the Ross Sea shelf, the sub-adult survey catches a lower proportion of toothfish over 150 cm TL than the commercial fishery over the whole shelf (Figure 17.16; Devine et al. 2021) but again, changes to the proportion of large toothfish in the sub-adult survey over this period are not obvious. Furthermore, the standardised catch rates from a research longline survey of pre-recruit toothfish (70–110 cm TL) in the southern Ross Sea in 2012 were similar to those made by the same vessel fishing in the area earlier in the fishery, between 1999 and 2003 (Hanchet et al. 2012).

In the vicinity of McMurdo Sound, scientific droplining (through ice holes) had suggested large decreases in toothfish abundance since the 1970s (Ainley et al. 2013), but Parker et al. (2015) obtained catch rates of toothfish similar to those prior to the advent of the toothfish fishery (Figure 17.17). Results from Parker et al. (2015) suggest that either large old fish have returned to McMurdo Sound following a temporary environmentally driven absence, or

that they remained locally present but were not detected in the areas sampled.

17.4.4 TROPHIC AND SYSTEM-LEVEL EFFECTS

The Ross Sea is home to about a third of the world population of Adélie penguins. Between 2001 and 2013 the number of breeding pairs of Adélie penguins at colonies in the southwestern Ross Sea more than doubled (Figures 17.18a,b) from about 235 000 to more than half a million (Lyver et al. 2014).

It is not known what has caused this increase but it is likely that changing ice patterns (Stammerjohn et al. 2008) play a primary role. Some researchers (Ainley et al. 2013, Lyver et al. 2014) previously suggested that reduced toothfish abundance in association with the Antarctic toothfish fishery had reduced predation on Antarctic silverfish and that the observed magnitude of the population response led to increases in the abundance of this species, which is known to be an important prey for Adélie penguins, especially during chick rearing. Other small fish are also taken by Adélie penguins. However, a predation release model of this effect acting via silverfish was not consistent with the magnitude of any plausible fishery-associated predation release. The mass of silverfish released from predation due to the effects of fishing was estimated to be equivalent to less than 2% of the biomass of silverfish estimated to be consumed annually by Adélie penguins (Pinkerton et al. 2016). Even if toothfish consumed only silverfish, the predicted predation release effect would still not be sufficient to explain the observed increase in the number of Adélie penguins in the southern Ross Sea (Pinkerton et al. 2016, Figure 17.18c).

The reasons for the increase in Adélie penguin numbers in the Ross Sea region are still not known. The fact that similar colony growth rates were seen for several Adélie penguin colonies in the south-west Ross Sea suggests that large-scale factors were responsible (Whitehead et al. 2015). The paucity of census data for the northern Ross Sea metapopulation makes it difficult to discern trends there (Lyver et al. 2014).

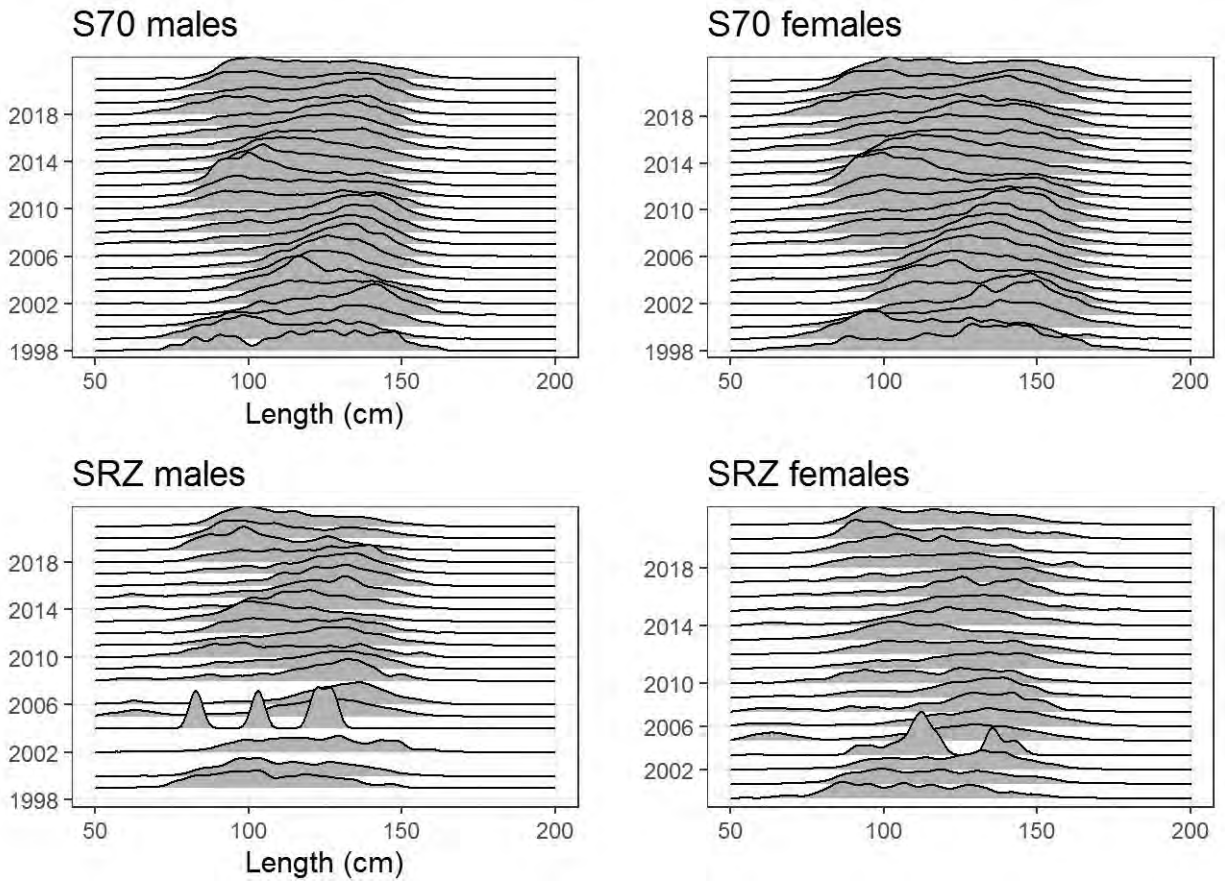


Figure 17.15: Estimated proportion of fish at length by sex for all vessels in the shelf region (south of 70° S and the SRZ) of the Ross Sea, for the years 1998–2021 (Grüss et al. 2021a).

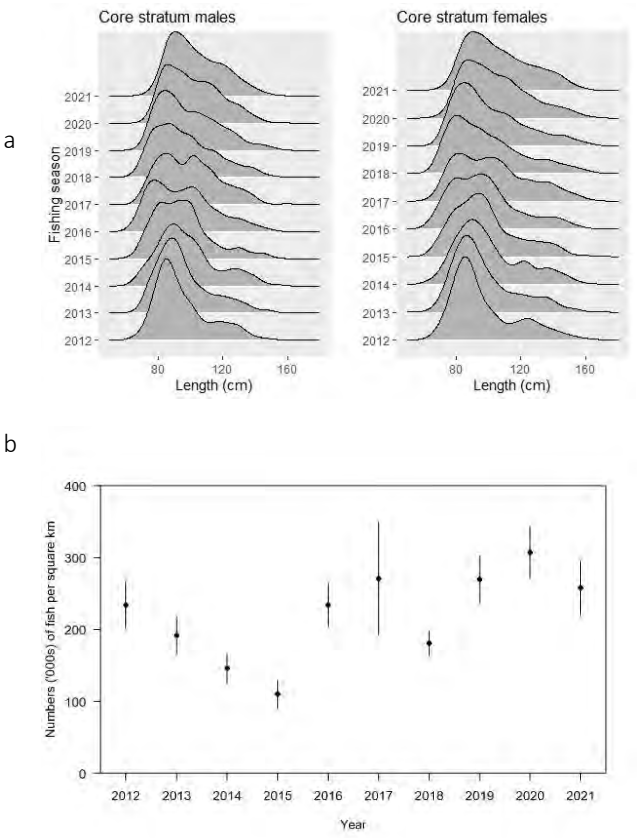


Figure 17.16: [a] Toothfish length frequency distributions in the Ross Sea shelf core strata (A–C) for the 2012–21 sub-adult surveys (Devine et al. 2021). [b] Estimated abundance index (numbers) for Antarctic toothfish in the core strata of the Ross Sea shelf survey 2012–2021. Error bars indicate the 95% confidence intervals (Devine et al. 2021).

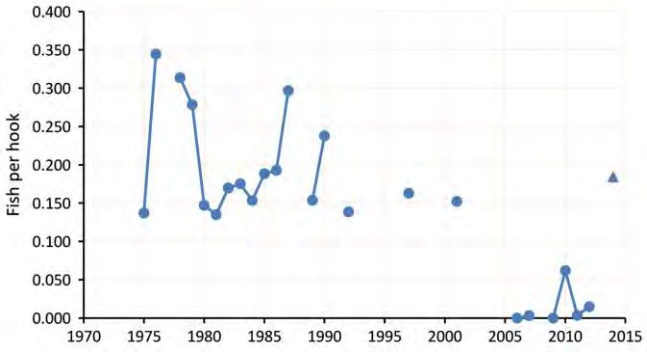


Figure 17.17: Catch rates (fish per hook) for toothfish sampled in McMurdo Sound, Antarctica, 1975–2014. Circles indicate pre-2013 data recalculated from Ainley et al. (2013) and triangle indicates the 2014 value from Parker et al. (2015). [Parker et al. (2015), figure 3].

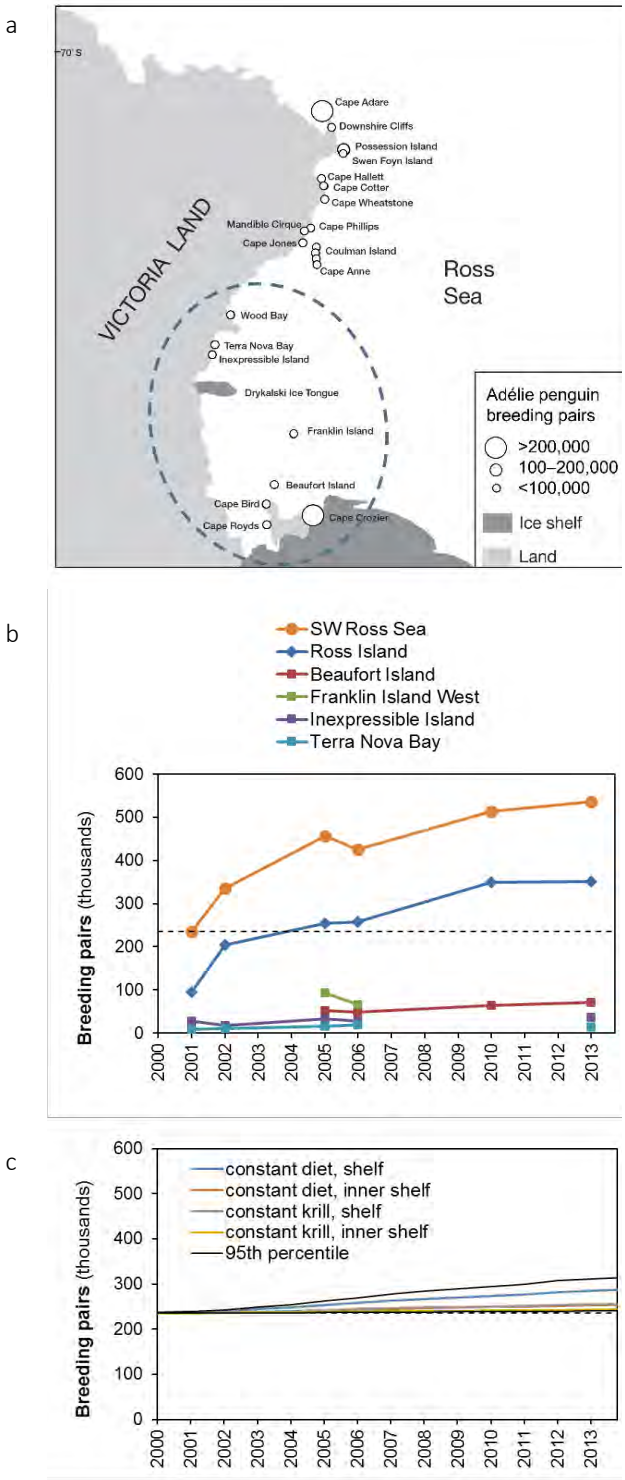


Figure 17.18: [a] Location and sizes of breeding colonies of Adélie penguins in the Ross Sea region. Those forming the 'southwest (SW) metapopulation' are enclosed in the dashed ellipse and forage over the Ross Sea shelf between chick hatching and fledging. [b] Changes to the total number of Adélie penguins breeding in the SW colonies (orange line) driven largely by increases in numbers breeding on Ross Island (blue line, capes Crozier, Bird, and Royds). [c] Greatest modelled effect of number of Adélie penguins that could be supported from additional silverfish released from predation by the toothfish fishery. [Pinkerton et al. 2016].

17.4.5 EFFECTS ON HABITATS

There are no indicators available to assess effects on the benthic habitat of fishing for toothfish in the Ross Sea or Amundsen Sea regions.

The status of selected habitat-forming benthic invertebrates likely to be physically impacted by fishing (vulnerable marine ecosystems, VMEs) was simulated (Dunn et al. 2010) under various scenarios of future fishing and assuming no correlation between distributions of VMEs and fishing. Predicted changes to the status of selected VMEs were small at the scale of the Ross Sea region, even with no specific management of VME impacts (Figure 17.19).

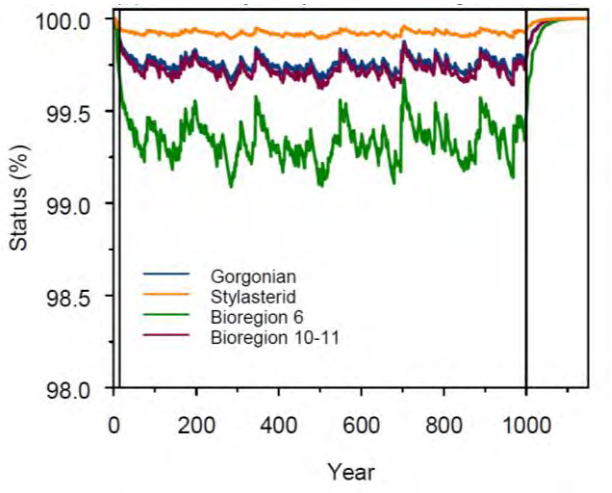


Figure 17.19: Simulated changes in the status of selected vulnerable marine ecosystems (VMEs) over time. Here, a status of 100% indicates that the habitat has the same extent and biomass as before fishing began and 0% indicates habitat removal at the scale of the Ross Sea region. Results are based on the medium-scale benthic habitat model of Dunn et al. (2010). The runs are for VMEs characterised as Gorgonian, Stylasterid, or for all VMEs in three indicative areas of the Ross Sea that have been identified as having different benthic biological conditions (benthic bioregions; Sharp et al. 2010). The benthic model assumes historical fishing pattern intensity up to 1000 years.

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Chapter 18: Biodiversity - Technical Summary

Declining marine biodiversity



Habitat loss, debris, climate change

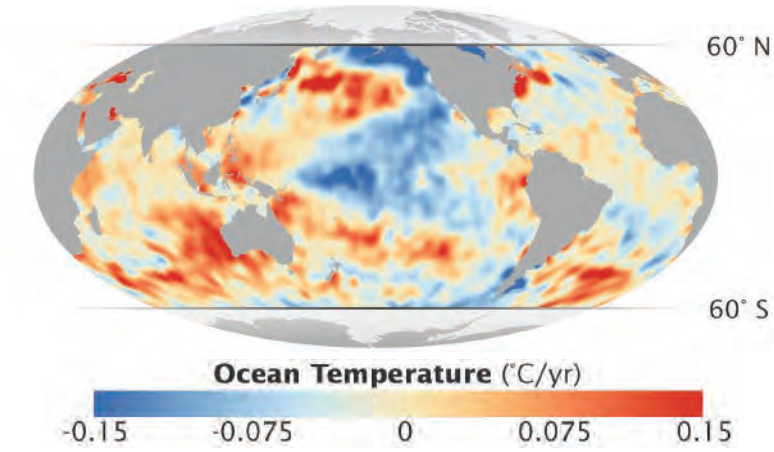
1. THE ISSUE IN BRIEF

- Ecosystems, biodiversity, and the productivity of the marine environment are under threat worldwide from the cumulative effects of human pressures on the ocean
- The contribution of biodiversity to a healthy functioning marine ecosystem is not easily quantified and the rate of decline is confounded by poorly documented biodiversity
- Since the launch of NZ's Biodiversity Strategy 2000, Fisheries New Zealand has run a Marine Biodiversity Research Programme with 67 projects to date, addressing biodiversity knowledge gaps
- Cumulative effects and the effects of climate change on biodiversity have yet to be quantified

2. NEW ZEALAND'S MARINE BIODIVERSITY

- NZ marine biodiversity is rich with ~ 18,000 known species and a further 13,000 species yet to be described
- NZ marine biodiversity forms 8% of global marine biodiversity, and approximately 40% of species identified so far are endemic
- The number of species discovered continues to climb annually (Lundquist et al. 2014). Our state of knowledge about marine biodiversity is assessed as being sixth across 18 nations (Costello et al. 2010)
- Identification guides are available for a wide range of biota

3. THREATS TO BIODIVERSITY AND RELATED WORKSTREAMS



2003–2012 sea surface temperature trend from NASA

- Direct threats to biodiversity and marine ecosystems from human activities in NZ include biosecurity risks, commercial fishing, marine debris pollution (including plastics), noise pollution, nutrient and sediment run-off, recreational fishing, and seabed mining
- Climate change and ocean acidification pose an external threat to biodiversity (see also Chapter 12). Some useful indicators of change have been identified, but tracking ecosystem-wide health is more elusive

- There are six biodiversity workstreams at Fisheries New Zealand

1. Development of ecological measures for more integrated fisheries management
2. Tools and methods for improved assessment of biodiversity health
3. Monitoring and assessing the effects of environmental change on fisheries and biological productivity
4. Sustainable development of the blue-green economy
5. Evaluate and safeguard natural capital for future generations
6. Progressing integrated management approaches to meet international obligations

4. BIODIVERSITY RESEARCH PROGRESS AND UPTAKE



• Strategic uptake of biodiversity research
The Marine Biodiversity Research Programme enables Fisheries New Zealand and MPI to meet longer term commitments to New Zealand's international and national obligations regarding the distribution and identification of species, the environmental footprint of fishing, spatial management, and cumulative effects of environmental change

• Several biodiversity projects have resulted in management and policy uptake
Examples include land-sea interactions; spatial marine protection; national environmental monitoring reporting and environmental risk assessment; innovative modelling approaches; Vulnerable Marine Ecosystem move-on rules in the South Pacific Regional Fisheries Management Organisation; Marine Environmental Classification; eco-certification; substrate-disturbance modelling and sedimentation; bioindicators

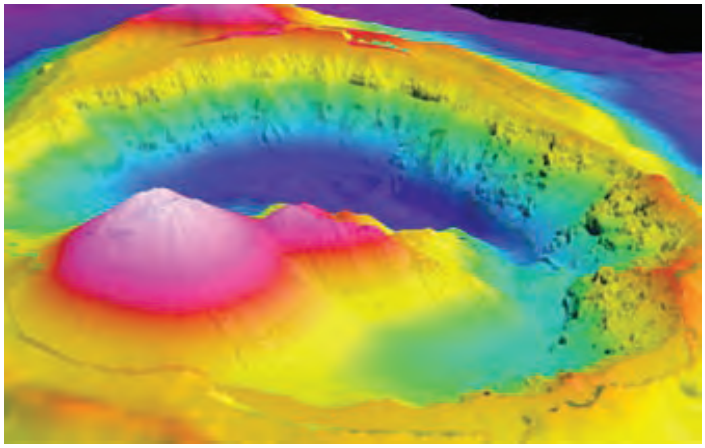
***Architeuthis longimanus* - Transactions and proceedings of the New Zealand Institute (1887)**

5. SEABED MAPPING

• Methods to quantify biota across large tracts of seabed have gradually improved through the development of new technology

• However, seabed mapping to identify habitats and biodiversity hotspots is a long-term goal that is far from complete in NZ waters

• More integrated fisheries management approaches require greater understanding of biodiversity and habitat distribution



6. ONGOING RESEARCH

• Public awareness of biodiversity and environmental effects of resource use has increased. Current research directions in this programme are being driven by Fisheries New Zealand and MPI goals to improve environmental sustainability, and cross-government goals to better manage biodiversity outcomes through the refresh of the NZ Biodiversity Strategy
• Climate change is measurably affecting NZ waters. Current research focuses on identifying climate change risks to the marine environment and the seafood sector, biodiversity, deepwater corals, biogenic habitats, fish, shellfish, plankton, primary productivity, and regime shifts
• Improving monitoring methods to measure change and assess future scenarios has become important. Methods of incorporating climate change indicators into stock assessment, and methods to assess species movements, are underway
• The requirement to integrate land-based activities and downstream effects with the marine environment, and the need to better include Treaty Partners in research planning and decision making, have also been recognised

18 BIODIVERSITY

Status of chapter	This chapter has been updated for AEBAR 2021.
Scope of chapter	This chapter outlines the current status and trends in Fisheries New Zealand marine biodiversity research, links between biodiversity and ecosystem function, and innovative methods and indicators for evaluating marine biodiversity and ecosystem health in New Zealand. An overview of research within the Fisheries New Zealand Marine Biodiversity Programme for 2000–20 is described within the context of international and national policy obligations, whole-of-government research initiatives and aligned international and national research programmes.
Area	New Zealand Territorial Sea, Exclusive Economic Zone, and Extended Continental Shelf; South-west Pacific Region associated with South Pacific Regional Fisheries Management Organisation (SPRFMO); Southern Ocean and Ross Sea region
Focal issues	• The chapter outlines new workstreams that respond to New Zealand's new biodiversity strategy 'Te Mana o te Taiao' and Fisheries New Zealand strategic priorities in the environment. The new workstreams are summarised below and aim to develop robust methods that estimate biodiversity patterns and trends, to develop and use as suitable indicators for national and international reporting, and to meet domestic and international obligations within constraints of limited data. • Map and document the identity, abundance, and distribution patterns of New Zealand's marine biodiversity in this extremely large area of responsibility (about 5.8 million km^2) which is far from complete. • Improve understanding of links between biodiversity and ecosystem function in near-shore and offshore marine ecosystems, and effects of cumulative stressors on ecosystem health. • Develop new approaches and indicators to evaluate efficacy of current spatial measures and management actions to protect marine biodiversity. • Increase recognition of connections between land-based stressors (e.g., sediment and nutrients) and the health of near-shore biodiversity and ecosystems (see Chapter 15). • Evaluate the risks of climate change to marine biodiversity and marine ecosystems. Identifying areas of high biodiversity remains a challenge, particularly for environmental impact evaluation or assessing response to climate change scenarios.
Emerging issues	• Use of environmental data to inform stock assessment of fish stocks and a move towards Ecosystem Based Fisheries Management as signalled in Fisheries Management Plans. • Assessment of marine debris and pollution, particularly in the coastal zone. • Urgent need for ecosystem approaches to marine resource management, to allow development of the blue economy within environmental constraints and facilitate integration of socioeconomic factors into fisheries management. • Trophic dynamics and fishing. Trophic modelling studies from parts of New Zealand suggest tight coupling among components of the food web. • Exploration of new technologies for measuring marine biodiversity (e.g., eDNA). • Working more closely with DOC and MfE on marine biodiversity initiatives to meet the directions signalled under the new Oceans and Fisheries portfolio and the Future of Fisheries report released by the Office of the Prime Minister Chief Science Advisor, and the Marine Protected Areas Science Advisory Group (MSAG).

Fisheries New Zealand Research (current)	Current research includes: ZBD2020-11 *Review of land-based effects on coastal fisheries and kaimoana and their habitats;* ZBD2020-09 *Cumulative effects of stressors on scallops and scallop habitats in the Marlborough Sounds;* ZBD2020-08 *Role of low and mid trophic fish in the Hauraki Gulf;* ZBD2020-07 *Recovery of Seamount Communities;* ZBD2020-06 *Recovery of biogenic habitats;* ZBD2019-11 *Development of Electronic Automated Reporting System (EARS) to improve seabird bycatch monitoring* (see Seabirds Chapter); ZBD2019-01 *Quantifying benthic habitats Part 2*; ZBD2019-04 *Plastics and marine debris across the ocean floor in New Zealand waters*; ZBD2018-01 *5 year continuous plankton survey (Phase 3)*; ZBD2018-02 *Climate change, fish distribution meta-analysis*; ZBD2018-03 *Climate variability, trends, and fish population parameters*; ZBD2018-05 *Ecosystem function and regime shifts in the Subantarctic*; ZBD2016-11 *Quantifying benthic biodiversity across natural gradients*; ZBD2016-07 *Multiple Stressors on Coastal Ecosystems in situ;* ZBD2016-04 *Organic Carbon Recycling in Deepwater*; ZBD2014-09 *Climate change risks and opportunities;* ZBD2014-03 *Sublethal effects of environmental change on fish populations.*
External research	The Biodiversity Programme has synergies with the Aquatic Environment Working Group (AEWG), Fisheries New Zealand 'Fisheries Change Programme', the Natural Resource Sector, Aotearoa Circle, biodiversity research (DOC), the Marine Protected Areas Science Advisory Group (MSAG) established by the Ministry for the Environment in 2016 has commissioned relevant biodiversity work that links to this Biodiversity Programme, environmental reporting (MfE), the new Fisheries and Oceans ministerial portfolio and Te Mana o te Taiao - Aotearoa New Zealand Biodiversity Strategy 2020. Awareness and understanding of climate change has been a key topic in recent years. Research programmes and database initiatives at research institutes and universities, e.g., NIWA Strategic Science Investment Funding – Oceans, Coasts and Estuaries, and Fisheries, World Register of Marine Species (WoRMS), OBIS, New Zealand Organisms Register, MBIE National Science Challenge 'Sustainable Seas', MBIE-funded projects CARIM (Coastal Acidification: Rates, Impact and Management) and the recent Moana Project are all important in ensuring that synergies across government are optimised.
Related chapters/issues	Cumulative effects, land-based effects, protected areas, benthic impacts, ecosystem approaches to fisheries and marine resource management, ocean context.

18.1 INTRODUCTION

This chapter summarises the development and progress of the twenty-year Fisheries New Zealand Biodiversity Research Programme 2000–2020 and reviews the work commissioned by Fisheries New Zealand in the context of national and global concerns about the maintenance of biodiversity initially under the New Zealand Biodiversity Strategy (NZBS, Anon 2000) and now the new Biodiversity Strategy 'Te Mana O Te Taiao' (Aotearoa New Zealand Biodiversity Strategy 2020).

The recognition of increasing societal expectation to use fisheries management measures that will achieve biodiversity conservation was signalled in the policy document Fisheries 2030 (Ministry of Fisheries 2009) in its long-term commitment to ecosystem-based fisheries management and to ensuring that *"biodiversity and the function of ecological systems, including trophic linkages, are conserved"*. Although New Zealand's environmental performance with regard to fishing is perceived to be relatively high on an international scale, Fisheries New Zealand is not complacent about the ongoing requirement to monitor and provide evidence that measures to achieve biodiversity conservation needs are being met. This includes the need to better understand and mitigate the effects of fishing in the areas impacted by fishing, and to evaluate the effectiveness of management approaches in non-fished areas such as marine reserves and Benthic Protection Areas (BPAs). Assessing the effects of fishing on the aquatic environment and risks to biodiversity and the aquatic environment are supported through the Ministry for Primary Industries Strategic Intentions 2021-25

https://www.mpi.govt.nz/dmsdocument/48589-Strategic-Intentions-2021-2025 and Fisheries New Zealand's National Fisheries Plans (deepwater, highly migratory species, inshore finfish, inshore shellfish, and freshwater fisheries) as well as the Aquatic Environment Medium Term Research plan (draft).

Fisheries New Zealand is also one of several government agencies with a strong interest and a statutory management mandate in the Ross Sea region of Antarctica through the Antarctic Marine Living Resources Act 1981. Fisheries New Zealand's Antarctic science contributes strongly to New Zealand's whole-of-government involvement in contributions to the Commission for the Convention on Antarctic Marine Living Resources (CCAMLR) and the Antarctic Treaty.

There are a range of societal values beyond commercial, customary, and recreational take from the sea that are recognised as part of 'strengthening our society' in New Zealand. These include aesthetic and cultural values as well as other economic values such as tourism and other forms of marine recreation (Le Heron et al. 2016). To link socioeconomic values of biodiversity to science supporting fisheries management will require a multi-disciplinary approach that is only just beginning in New Zealand (Lundquist et al. 2016).

18.1.1 NEW ZEALAND BIODIVERSITY STRATEGY REFRESH 2020

In June 2000, the 'New Zealand Biodiversity Strategy – Our Chance to Turn the Tide' (NZBS) was launched as part of New Zealand's commitment to the international Convention on Biological Diversity 1993 (Anon 2000). To meet long-term goals of the NZBS (i.e., to halt the decline of biodiversity in New Zealand and protect and enhance the environment), a comprehensive plan with stated objectives and actions was developed to address biodiversity issues in terrestrial, freshwater, and marine systems. This document has been succeeded by a new Aotearoa Biodiversity Strategy 2020, 'Te Mana o te Taiao' (TMOTT) available at https://www.doc.govt.nz/globalassets/documents/conservation/biodiversity/anzbs-2020.pdf.

In the marine environment, biodiversity decline is characterised primarily in relation to megafaunal taxa (marine mammals, seabirds, see Chapters 4–8) and other protected species such as sharks, which may experience changes in threat status and risk of extinction. Biodiversity is also influenced by environmental degradation due to habitats being diminished or removed, and by the disruption of ecosystem structure, function, and the disruption of ecological processes (e.g., biological cycling of water, nutrients, and energy), species invasion, and hybridisations that affect the diversity of marine species and their life history strategies. Measuring the decline of marine biodiversity is complicated by the 'shifting baseline syndrome', a common obstacle to useful biodiversity assessment and monitoring (Soga & Gaston 2018). Furthermore, the size range of organisms sampled is often limited to macroscopic or larger. Changes (declines) in the diversity of smaller-sized organisms below the sampling threshold that may be critical to marine ecosystem health and well-being are therefore likely to be missed (Azam & Malfatti 2007).

The task of implementing TMOTT is led by the Department of Conservation (DOC), with significant input from the Ministry for Environment (MfE), and Fisheries New Zealand.

Te Mana o te Taiao - Aotearoa New Zealand Biodiversity Strategy 2020 comes at a time when perspectives on biodiversity are changing the way in which it is assessed, managed, and valued. Various knowledge systems are being drawn upon to take a more informed and holistic approach to biodiversity (e.g., Māori knowledge and scientific disciplines, e.g., Home - Te Ahu o Rehua). It is more widely recognised that human well-being relies on healthy, functioning ecosystems and this is changing the way biodiversity is valued and cared for (e.g., Short 2015, Díaz et al. 2018). These themes are strongly reflected in Te Mana o te Taiao which states that "*people are a part of nature… we can only thrive when nature thrives*". The strategy places much emphasis on collaboration between Treaty partners and promotes objectives and goals that unify New Zealanders in stewardship of our unique biodiversity and indigenous species. This new strategy will likely be updated in the future to be aligned with the Convention on Biological Diversity 'Post-2020 Global Biodiversity Framework' which is currently in its first draft stage. The objectives of TMOTT are provided in Table 18.1.

Table 18.1: The objectives of TMOTT set out what the strategy aims to achieve by 2050. Objectives of particular relevance to Fisheries New Zealand are in bold (2-5, 9-13).

1. Governance, legislation and funding systems are in place and enable delivery of the strategy outcomes
2. Treaty partners, whānau, hapū, iwi and Māori organisations are rangatira and kaitiaki
3. Biodiversity protection is at the heart of economic activity
4. Improved systems for knowledge, science, data and innovation inform our work
5. Mātauranga Māori is an integral part of biodiversity research and management
6. Aotearoa New Zealand is making a meaningful contribution to biodiversity globally
7. All New Zealanders have the skills, knowledge and capability to be effective
8. Resourcing and support are enabling connected, active guardians of nature
9. Collaboration, co-design and partnership are delivering better outcomes
10: Ecosystems and species are protected, restored, resilient and connected from mountain tops to ocean depths
11. Management ensures that Biological threats and pressures are reduced through management
12. Natural resources are managed sustainably
13. Biodiversity provides nature-based solutions to climate change and is resilient to its effects

18.2 THE FISHERIES NEW ZEALAND BIODIVERSITY RESEARCH PROGRAMME

The Ministry of Fisheries responded to the NZBS in 2000 with the establishment of the Marine Biodiversity Research Programme (MBRP) to address aspects of biodiversity in NZBS Theme 3 that would complement research under the Aquatic Environment Programme. The focus of the MBRP was initially to map and describe marine biodiversity throughout New Zealand and in the Ross Sea, particularly to conduct benthic habitat surveys and describe the taxonomy of new species. DOC and Ministry of Fisheries/MPI research on protected species and marine spatial protection was largely dealt with outside the MBRP.

In more recent years, the MBRP focus has incorporated the effects of climate change on marine biodiversity.

The core purpose of the Marine Biodiversity Research Programme is *"To ensure that biodiversity, marine habitat diversity, and ecosystem services that underpin the sustainability of wild caught fisheries productivity and ecosystem resilience are understood and maintained."*

The Biodiversity Research Programme is guided by a multi-stakeholder biodiversity research advisory group (BRAG), chaired by Fisheries New Zealand. The research commissioned at different phases of the Programme have evolved and the workstreams refreshed in 2017 have been further modified here to reflect the new TMOTT. An overview of the revised Biodiversity Programme Workstreams (2021) is given in Table 18.2

Table 18.2: Revised Biodiversity Programme Workstreams to reflect TMOTT. Note that Workstream 1 is completely new, and that the international Workstream 6 from the previous version has been removed.

New Workstreams to match TMOTT	Purpose	Related Objectives and 2025 Goals from Te Mana o te Taiao - Aotearoa New Zealand Biodiversity Strategy 2020
Workstream 1 Iwi and community-based biodiversity projects (New workstream)	Engage with local communities, whānau, hapū, iwi, and Māori organisations to promote collaborative research efforts that connect biodiversity to local knowledge and decision-making. This workstream includes projects related to indigenous/taonga species and aims to improve understanding through multiple scientific disciplines and knowledge systems including mātauranga Māori and citizen science. Iwi Fisheries Forums will provide a platform to support this workstream.	• Objective 2 o Goal 2.2 o Goal 2.3 • Objective 5 o Goal 5.3 • Objective 9 o Goal 9.1
Workstream 2 Baseline knowledge for EBFM (incorporates former Workstream 1)	Identify key biodiversity and ecosystem components related to fisheries activity that will inform mitigation and spatial planning in New Zealand to meet development goals for Ecosystem-Based Fisheries Management (EBFM). This workstream aims to improve understanding about the key drivers of biodiversity distribution and abundance. The outputs will be used to inform and develop performance measures and environmental standards or guidelines for decision-makers.	• Objective 10 o Goal 10.1.1 o Goal 10.4.1 o Goal 10.5.1 • Objective 13 o Goal 13.1.1 o Goal 13.2.1
Workstream 3 Tools and methods for biodiversity and ecosystem assessment (incorporates former Workstream 2)	Work synergistically across government to produce tools such as ID guides, ecological maps or atlases of seabed habitats, ecosystem and biodiversity indicators and report cards. Genetic tools and emerging technology (e.g., electronic monitoring, cameras on boats) are included in this workstream.	• Objective 4 o Goal 4.1 o Goal 4.5
Workstream 4 Functional threats to biodiversity (incorporates former Workstream 3)	Investigate the effects of multiple stressors (e.g., sedimentation, cumulative effects) and environmental change (e.g., climate change, regime shifts, trophic effects) on ecosystems, their functions, and fisheries. This includes working with local and national government, Crown Research Institutes, and universities to gain a national and regional record of long-term changes through the development of robust indicators, metrics, and monitoring programmes.	• Objective 10 o Goal 10.2.1 • Objective 12 o Goal 12.7.1 • Objective 13 o Goal 13.3.1
Workstream 5 Sustainability for future generations (Former Workstreams 4 and 5)	Ensure the socio-ecological and sustainable use of natural resources. This includes understanding the effectiveness of protected/closed areas, preserving cultural practices as they relate to fisheries and biodiversity, maintaining a social licence to operate, and identifying creative solutions that allow for sustainable development of the marine economy with biodiversity at its core.	• Objective 3 o Goal 3.1 o Goal 3.2 o Goal 3.3 • Objective 10 o Goal 10.4.1 o Goal 10.5.1 o Goal 10.6.1 o Goal 10.8.1 • Objective 12 o Goal 12.1.1 o Goal 12.5.1

18.3 MARINE BIODIVERSITY TRENDS IN NEW ZEALAND

18.3.1 NEW ZEALAND'S MARINE BIODIVERSITY

New Zealand's ocean territory is vast, covering approximately 5.8 million km^2 including the Territorial Sea (TS) and the recent continental shelf extension. It is very large relative to the area of land and includes approximately 15 000–18 000 kilometres of coastline extending from the subtropical north to the cool sub-Antarctic waters in the south. New Zealand also has a rich marine biodiversity that is globally significant with up to 38% of all marine species (46% for Animalia) estimated as endemic (Gordon et al. 2010, Lundquist et al. 2014) and comprises up to 8% of global marine biodiversity. These estimates do not include undiscovered species, which are likely to increase the proportion of endemics.

The most recent summary of knowledge about marine biodiversity in New Zealand is provided by Gordon (2009, 2010, 2012) and Gordon et al. (2010), which estimates a tally of 17 987 living species in the EEZ, including 4320 known undescribed species in collections. Since 2010, further updates using all records available within OBIS, NIWA, and Te Papa Tongarewa collections have assessed the spatial distribution of biodiversity records and suggested metrics for reporting on the status of marine biodiversity (Lundquist et al. 2014). Species diversity for the most intensively studied animal phyla (Cnidaria, Mollusca, Brachiopoda, Bryozoa, Kinorhyncha, Echinodermata, Chordata) is more or less equivalent to that in the ERMS (European Register of Marine Species) region, an area 5.5 times larger than the New Zealand EEZ (Gordon et al. 2010), suggesting that the New Zealand region biodiversity is proportionately richer than the ERMS region. In the Southern Hemisphere though, New Zealand has approximately 50% lower species richness than Australia (in terms of species by area), noting that Australia's EEZ also includes substantial tropical and subtropical regions.

The approximately 18 000 known marine species and associated ecosystems around New Zealand deliver a wide range of environmental goods and services that sustain considerable fishing, aquaculture, and tourism industries, as well as drive major biogeochemical and ecological processes. An estimate of undiscovered marine biodiversity suggests another 13 000 species, with several factors suggesting that this estimate of total marine species is conservative. Such factors include the difficulty of sampling such a large region with depths exceeding 10 000 m, the geomorphological and hydrological complexity created by tectonic and seismic activity, limited water column sampling and limited benthic sampling (especially below 1500 m), and rates of new species descriptions, currently about 50 per year. Inflating estimates of undiscovered marine biodiversity is the potentially very large numbers of parasitic and commensal protists (especially microsporidia) and parasitic animals such as myxozoans and nematodes, as well as free-living nematodes. Expectations of massive oceanic microbial diversity (e.g., Sogin et al. 2006) have yet to eventuate; an expert assessment recently determined that between one-third and two-thirds of marine eukaryotic species may be undescribed and previous estimates of there being more than one million such species appear highly unlikely (Appeltans et al. 2012). A recent review of New Zealand's marine biogenic habitat revealed the lack of knowledge on biodiversity associated with such habitats and indicated the potential to increase marine biodiversity records in the New Zealand region (Anderson et al. 2019).

18.3.2 MECHANISMS FOR INCREASING MARINE BIODIVERSITY RECORDS

Scientific research has provided information about the predicted distribution and abundance of marine biodiversity in some areas of New Zealand's coasts and oceans. Advances in the marine protection of the Ross Sea Region have been made and available information has been used to assess habitat types at greatest risk from disturbance, particularly fishing (Clark & Rowden 2009, Clark & Tittensor 2010, Hewitt et al. 2011a, 2011b, Floerl & Hewitt 2012). Many ecosystems within New Zealand waters remain poorly sampled however, and the efficacy of current spatial protection measures for biodiversity in New Zealand is unknown. Further, the proportion of different marine habitat types that should be or can be protected to maintain a healthy aquatic environment is also unknown (Lundquist et al. 2015).

A number of initiatives have been supported by Fisheries New Zealand and its predecessors to meet the goals of the former NZBS. Commitments included the creation of NABIS (the National Aquatic Biodiversity Information System; http://www.nabis.govt.nz), for making data on marine biodiversity more accessible. DOC surveys and monitors aspects of marine biodiversity, particularly in marine reserves and in relation to protected and threatened

marine species. Periodic marine 'BioBlitzes' around New Zealand yield surprising numbers of new species, even in well-studied areas, have the advantage of engaging children, parents, and teachers in discovery, and involve research scientists who then describe the new taxa (e.g., Harper et al. 2009). More of these citizen science projects can be found under the MBIE funded Curious Minds programme (https://www.curiousminds.nz). The museums of Auckland, Canterbury, Otago, and the Museum of New Zealand (Te Papa Tongarewa) also conduct biodiversity sampling expeditions and national collections of specimens have been set up within museums and at NIWA (https://niwa.co.nz/our-services/online-services/nic).

Marine biodiversity research in New Zealand is largely supported through public good funding and is conducted in both universities and CRIs. Both have contributed to New Zealand's high profile for marine biodiversity on the international scientific network through participation in global initiatives such as the Census of Marine Life (CoML) (http://www.coml.org), as well as to local programmes that have improved understanding of the role of biodiversity in the marine ecosystem.

In 2010, New Zealand contributed to the CoML, an unprecedented global collaboration among researchers from more than 80 nations to assess and explain the diversity, distribution, and abundance of life in the oceans. NIWA scientists were part of the team that led CenSeam (http://www.coml.org/global-census-marine-life-seamounts-censeam), the seamount component of CoML, and New Zealand scientists played significant roles in a number of other CoML programmes. The New Zealand International Polar Year-Census of Antarctic Marine Life (IPY-CAML) voyage to the Ross Sea in 2008 was also a major contribution to CoML (O'Driscoll 2009).

The CoML-facilitated activities led to better assessments of global marine biodiversity, resulting in an increase in the total number of known marine species by about 20 000, from 230 000 in 2000 to about 250 000 in 2010. The digital archive (the Ocean Biodiversity Information System OBIS; http://www.iobis.org) has now grown to almost 80 million distribution records, and the Census helped to create the first comprehensive list of the known marine species and facilitated an initiative which resulted in a web-based database of over 80 000 species, the Encyclopaedia of Life (http:/www.eol.org).

A summary of the overall state of knowledge about marine biodiversity by Costello et al. (2010) places New Zealand 6th out of 18 national regions based on the collective knowledge assembled by CoML National and Regional Implementation Committees (NRIC) and comparison of the Spearman rank correlation coefficients between known diversity (total species richness, alien species, and endemics) and available resources, such as numbers of taxonomic guides and experts.

18.3.3 THREATS TO BIODIVERSITY

Understanding of New Zealand's coastal marine environment and its land-sea interactions has progressed since the launch of the NZBS, although knowledge about the state of the marine environment and marine biodiversity at a national scale remains limited (Lundquist et al. 2014). Recent knowledge about New Zealand's and the Ross Sea's marine biodiversity suggests that it may generally be in better shape than that of many other countries (Costello et al. 2010, Gordon et al. 2010). New Zealand was placed 12th out of 18 regions in terms of overall threat levels to biodiversity, overfishing, and alien species invasion (first place being the most threatened). Habitat loss and ocean acidification were identified as the biggest threats to marine biodiversity and marine habitats in New Zealand (Costello et al. 2010, MacDiarmid et al. 2012).

Key marine environment and biodiversity related stressors are outlined in Environment Aotearoa 2015 (Ministry for the Environment & Statistics New Zealand 2015). New Zealand's marine biodiversity is affected by many uses of the marine environment, including fishing, aquaculture, shipping, petroleum and mineral extraction, renewable energy, tourism, and recreation (Royal Society of New Zealand 2012). Impacts from changing land use, including agriculture, urban run-off, and coastal development can also affect marine biodiversity through processes such as sedimentation and eutrophication (Morrison et al. 2009, Larned et al. 2018). The most conspicuous impacts in the marine environment include habitat degradation and reductions in mussels, cockle and scallop beds, seagrass meadows, bryozoan and tubeworm mounds, sponge gardens, kelp forests, and biogenic habitats provided by these organisms (Larned et al. 2018). There are ongoing concerns about the decline of some key species (Ministry for the Environment 2016), localised impacts on habitats and conditions (Thrush & Dayton 2002, Cryer et al. 2002, Clark et al. 2010a, 2010b, Gordon et al. 2010), and

emerging threats to the marine environment (MacDiarmid et al. 2012).

The past 750 years of human activity has impacted on marine environments. For example, depletion of fur seals and sea lions occurred from the earliest days of human settlement, not just with European arrival (Smith 2005, 2011). There was also a pulse of sedimentation coinciding with the initial clearance of 40% of New Zealand forests within 200 years of Polynesian settlement (McWethy et al. 2010). Impacts have occurred in remote areas, as well as near population centres, and to sea depths in excess of 1000 m (Carroll et al. 2014, MacDiarmid et al. 2014, 2016a, 2016b, 2018, Maxwell & MacDiarmid 2016, Pinkerton et al. 2015, Fisheries New Zealand 2018).

Although New Zealand has reasonable archaeological, historical, and contemporary data on the decline in abundance of some individual marine species, current trends in the status of New Zealand's marine biodiversity are difficult to determine for several reasons. These include a lack of both pre-disturbance baseline and recent information, and a lack of a nationally coordinated approach to assessing and monitoring marine biodiversity (Lundquist et al. 2014). A multidisciplinary study 'Taking Stock' that examined records from two locations in New Zealand's coastal marine shelf system provided significant insight into marine biodiversity changes over a 1000 year period since early human settlement (MacDiarmid et al. 2016a). Evidence from local ecological knowledge, archaeological digs, museum archives, fisheries records, natural history records, and other sources, shows that top predators, particularly marine mammals and some species of shellfish and fish have taken a major hit in abundance and distribution since human settlement, but that intermediate components of the food chain remain largely intact.

Threat status and susceptibility of biodiversity to capture by fishing activity is discussed in other chapters for marine mammals, seabirds, and other protected species (see Chapters 4–8). Progress has been made on evaluating threats and risks to the marine environment and components within it (e.g., Currey et al. 2012, MacDiarmid et al. 2011, 2012, 2014, Ministry for Primary Industries 2013; Ministry for Primary Industries & Department of Conservation 2013, Larned et al. 2018) and some of these have been followed up with a Spatially Explicit Risk Assessment (Richard et al. 2017, 2020). Marine mammals, seabirds, and reptiles are regularly assessed using the New Zealand Threat Classification System (NZTCS). However, most fish and invertebrates have not been assessed (reviewed by Lundquist et al. 2014). For example, only a small fraction (less than 5%) of New Zealand's marine invertebrate fauna have been evaluated for their threat status and many taxa remain 'data deficient' or unlisted (Freeman et al. 2010, 2013). These are important assessments about the state of knowledge and can help to focus where attention is needed across our marine biota.

MacDiarmid et al. (2012) undertook an expert assessment of the impact of 65 potentially hazardous human activities on 62 identifiable marine habitats in New Zealand's Territorial Sea and 200 nautical mile Exclusive Economic Zone (EEZ). Experts concluded that many of the biggest threats stemmed from human activities outside the marine environment itself. The two biggest threats identified by participants were ocean acidification and ocean warming. Seven other threats deriving from global climate change all ranked in the top 20 threats indicating the importance of global climate change to New Zealand's marine ecosystems.

Climate change can have an adverse impact on the spatial patterns of marine biodiversity and ecosystem function through changes in species distributions, species mix, and habitat availability, particularly at critical stages of species life histories (Lundquist et al. 2011, Poloczanska et al. 2013, Poloczanska et al. 2016). Understanding the dynamics of climate change and predicting the impacts on food webs and fisheries productivity has improved and is a substantial research topic in many parts of the world (e.g., Brown et al. 2010, Blasiak et al. 2017, Phillips & Perez-Ramirez 2017), including New Zealand (e.g., CARIM; http://www.carim.nz). Recently, in New Zealand, Cummings et al. (2021) examined the likely effects of climate change on the New Zealand seafood sector, and this is described further in section 18.4.7.

Understanding the resilience of biodiversity and its rate of change in response to the cumulative effects of multiple stressors across large spatial scales (e.g., ocean acidification, temperature increase, and oxygen depletion) remains an ongoing topic of investigation. A study of global patterns of climate change impacts predicted dramatic species turnovers of over 60% of present biodiversity by 2050. This was based on model projections of changes in the distributional ranges of a sample of 1066 exploited marine fish and invertebrates using a newly developed dynamic bioclimate envelope model (Cheung et al. 2009).

The study showed that climate change and other stressors may lead to numerous local extinctions in the sub-polar regions, the tropics, and semi-enclosed seas, as well as ecological disturbances that potentially disrupt ecosystem services.

The loss of marine biodiversity and loss of functionality associated with climate change and ocean acidification are of increasing concern worldwide (e.g., Guinotte et al. 2006, Ramirez-Llodra et al. 2011), as well as in New Zealand (e.g., Royal Society of New Zealand 2012). In late June 2011, two science-based reports heightened concerns about the critical state of the world's oceans in response to climate change. One focused on the potential impacts of ocean acidification on fisheries and higher trophic level ecology and took a modelling approach to scaling from physiology to ecology (Le Quesne & Pinnegar 2012), and the other assessed the critical state of the world's oceans in relation to climate change and other stressors (Rogers & Laffoley 2011). Implications of global climate change have been further summarised by the Intergovernmental Panel on Climate Change (IPCC 2018).

Global-scale threats associated with the potential effects of ocean acidification on microbial diversity and their roles in biogeochemical processes have yet to be quantified but could have EEZ-wide implications (Bostock et al. 2012). The growing arrival of non-indigenous (sometimes invasive) marine species is also a threat to local biodiversity (e.g., Cheung et al. 2009, Coutts & Dodgshun 2007, Cranfield et al. 2003, Gould & Ahyong 2008, Russell et al. 2008, Williams et al. 2008).

Last year, United Nations officials reported that the world's nations largely failed to achieve the Aichi targets of the previous global agreement on biodiversity, made in 2010 https://news.un.org/en/story/2020/09/1072292.

18.3.4 NATIONAL BIODIVERSITY LEGISLATION, REGULATIONS, AND POLICIES

A broad range of legislation, regulations, and policies are in place to manage and regulate uses of the marine environment, to protect marine biodiversity, to improve management of the coastal and marine environment and to meet worldwide consumer demands for improved sustainability. The development and implementation of fisheries management is one of the goals for Te Mana o te Taiao and for the Ocean Fisheries Workplan under the Oceans and Fisheries Ministerial Portfolio. It is also a recommendation from the 'The future of commercial fishing in Aotearoa New Zealand' prepared by the Prime Minister's Chief Science Advisor https://www.pmcsa.ac.nz/topics/fish/

Managing fisheries in a more holistic way through Ecosystem Based Fisheries Management (EBFM) has been signalled by Fisheries New Zealand through National Fisheries Plans as a priority to make progress on over the next 3 –5 years.

However, there is currently no integrated national oceans policy, and ocean management is fragmented across agencies and statutes (Lundquist et al. 2016; Davies et al. 2018a). Initiatives and research funded through the Sustainable Seas National Science Challenge are developing a framework for cumulative effects management across land and sea resource management sectors, industries, and communities — an internal component of an Ecosystems Based Management (EBM) approach. A further Sustainable Seas project has examined whether current legislation, policy, and institutional practice are sufficient to enact EBM, and what additional approaches could be acted on to further enhance EBM.

Marine spatial planning and marine reserves have allowed for stakeholder driven processes to inform marine management and allocation of space for marine protection (Davies et al. 2018b) and other uses of the marine environment (e.g., aquaculture). The Hauraki Gulf Forum initiated the Sea Change – Tai Timu Tai Pari Hauraki Gulf Marine Spatial Plan in 2013, taking a holistic and integrated approach to marine management and restoring the marine productivity in the area (http://www.seachange.org.nz), with a recent announcement from government to support implementation of the plan (November 2018). MPI commissioned a small knowledge review to help inform possible restoration efforts for the Hauraki Gulf (Morrison 2021).

A Marine Protected Areas Science Advisory Group (MSAG) was established by MfE in 2016. The MSAG comprises marine science staff from DOC, Fisheries New Zealand, and MfE. The role of the MSAG is to discuss, commission, undertake, and review science — to build the scientific foundation to enable the implementation of a representative network of marine protected areas and advise on emerging issues relating to marine protected areas and spatial management.

Recent work undertaken by the MSAG includes: the development of a New Zealand Seafloor Community Classification; guidance for the use of decision-support tools for identifying optimal areas for biodiversity conservation; collation of data for mapping key ecological areas in the New Zealand marine environment; principles for MPA network design in New Zealand and a review of the scientific basis; and application of quantitative targets for marine protection.

Reports associated with work are available through the DOC Marine Protected Areas Research Programme webpage: https://www.doc.govt.nz/our-work/mpas-research-programme/

18.3.5 INTERNATIONAL BIODIVERSITY OBLIGATIONS

As mentioned above, it has been widely recognised that the Convention on Biological Diversity's (CBD) 2020 Global Biodiversity Framework (including the Aichi targets) did not progress sufficiently and the threats to biodiversity and the extinction of species have continued throughout the period.

The UN Environment Management Group identifies five main direct drivers of biodiversity loss and degradation: changes in the use of land and sea; over-exploitation of biodiversity; climate change; pollution; and invasive alien species.

Today, with a decade left to achieve the Sustainable Development Goals (SDGs), the 2020 SDGs Report (https://unstats.un.org/sdgs/report/2021/) paints a daunting picture, one worsened by the COVID-19 pandemic addition. Most of the SDGs related to biodiversity and environmental sustainability will not be achieved under current trajectories, posing a risk to the overall achievement of the 2030 Agenda. https://unemg.org/wp-content/uploads/2021/04/EMG-Biodiversity-WEB.pdf

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) was established in 2012 and provides a mechanism to assess the state of the planet's biodiversity, its ecosystems, and the essential services they provide to society (http://www.ipbes.net). This international platform is similar in function to the Intergovernmental Panel on Climate Change (IPCC) in terms of bringing together international expertise and will review information on the provisioning of biodiversity for ecosystem services, stimulate science and innovation on this research topic, and interact with national and international management agencies to integrate IPBES results into policy and management.

The 2019 IPBES Global Assessment Report on Biodiversity and Ecosystem Services (IPBES 2019) states that around 25 per cent of species in assessed animal and plant groups are threatened, suggesting that some one million species already face extinction, and also warns that current biodiversity loss is increasingly putting human security and well-being at risk. This also echoes similar calls from the IPCC in its special report on Global Warming of 1.5 °C (IPCC 2018), the European Environment Agency's (EEA) Sustainability transitions: policy and practice, the CBD's fifth Global Biodiversity Outlook (GBO-5), UNEP's Global Environment Outlook (GEO-6), and FAO's report on The State of the World's Biodiversity for Food and Agriculture (FAO 2019). The full text of the First Global Integrated Marine Assessment, conducted by some of the world's foremost experts on ocean issues for policymakers, was released online in 2016 and stresses the need to act immediately to halt the degradation of the world's oceans and marine biodiversity (https://www.unep.org/resources/report/first-global-integrated-marine-assessment-world-ocean-assessment-i).

To address both the biodiversity crisis and the climate crisis, there is growing scientific research suggesting that half of the planet must be kept in a natural state. Some papers have suggested that the number should be even higher, and some have suggested slightly lower. Despite this, experts agree that a scientifically credible and necessary interim goal is to achieve a minimum of 30% protection by 2030 (https://www.hacfornatureandpeople.org/why-30x30) and one study has assessed where protection would be most effective to achieve this goal (Zhao et al. 2020).

The Convention on Biological Diversity is developing new targets for the decade to 2030 which will replace the Aichi targets set for 2011–2020 and will also lead towards the longer 2050 goal: living in harmony with nature. These targets may inform any future updates to Te Mana o te Taiao, New Zealand's new Biodiversity Strategy which informs the workstreams of Fisheries New Zealand's Biodiversity Research Programme.

Most of New Zealand's commercial fisheries are wild-caught and continuation of their productivity is dependent on the retention of a healthy functioning marine ecosystem. The 'licence to operate' is mandated by the Fisheries Act 1996 and requires strict compliance with sustainable and environmentally responsible use of fish stocks. Compliance is also required with other legislation such as the Marine Mammals Protection Act 1978 and a range of international obligations such as the United Nations Convention on the Law of the Sea (UNCLOS). Under the Quota Management System, considerable monitoring of fishing activity and the environmental footprint of commercial operators is required.

18.3.6 CURRENT CHALLENGES AND AGENDAS

The economy of the sea is a significant part of the overall economy in New Zealand and has potential for growth, particularly in aquaculture, oil and gas, and minerals (Ministry of Business, Innovation and Employment 2017). It is important that the aquatic environment and biodiversity are not adversely affected by new or increasing activities, be they in the seafood sector or other natural resource industries (Fisheries Act 1996, Exclusive Economic Zone and Continental Shelf (Environment Effects) Act 2012).

The large-scale threats to the marine environment and biodiversity include climate change and ocean acidification, increasing exploitation of resources (living or non-living), and the cumulative effect of multiple uses of the marine environment (e.g., renewable energy, commercial fisheries, recreational fisheries, aquaculture, and hydrocarbon and mineral extraction) (Kingsford et al. 2009, Lundquist et al. 2011). These threats are increasingly being recognised in policy and government circles (e.g., Office of the Prime Minister's Science Advisory Committee 2013; Statistics New Zealand 2013; Royal Society of New Zealand 2012; Capson & Guinotte 2014).

Despite this recognition, progress on tackling marine-related climate change effects and investment in long-term monitoring of the marine environment and ready access to data remains slow (although see Table 18.3 for a number of data-collecting initiatives that are contributing to long-term historical datasets, noting that these are primarily of environmental drivers rather than measures of biodiversity itself). Long-term monitoring and environmental reporting has been recognised as a major gap by the government and in September 2015 the Environmental Reporting Act (2015) was passed into law. The new framework for environmental reporting divides the environment into five environmental domains. Under each domain three main types of information are reported on: pressures, states, and impacts. 'Our marine environment 2016' was the first report released under the new legislation (Ministry for the Environment 2016). In 2015, a number of challenges were identified in relation to taxonomy and the maintenance of biological collections and databases in New Zealand (Nelson et al. 2015). Recommendations from this report focused on increasing support for the discovery, documentation, and accessibility of biodiversity information. This was followed by the decadal plan for taxonomy and biosystematics in Australia and New Zealand 2018–2028 (https://www.royalsociety.org.nz/assets/Uploads/Discovering-Biodiversity-decadal-plan.pdf) which echoed the recommendations of the New Zealand report. Increasing the capacity and capability of taxonomy in New Zealand would make significant progress towards the successful delivery of TMOTT.

18.3.7 GLOBAL MONITORING AND INDICATORS FOR MARINE BIODIVERSITY

There are numerous schemes within and between nations to monitor the marine environment, including physical, chemical, and biological components (Table 18.3). A challenge for Fisheries New Zealand, other government agencies, and for New Zealand is how to assimilate any or all of the above monitoring approaches and international datasets to assess the nature and extent of biodiversity change, and to assess the effectiveness of management measures to protect or enhance biodiversity or halt its decline.

Table 18.3: Examples of international marine global monitoring datasets.

Name	Description	Website
Global Ocean Observing System (GOOS)	Permanent global system for observations, modelling, and analysis of marine and ocean variables.	http://www.goosocean.org/
Deep Ocean Observing Strategy (DOOS)	This is the deep-sea component of GOOS.	https://deepoceanobserving.org/
Global Climate Observing System (GCOS)	United Nations-ratified programme which regularly assesses the status of global climate observations and produces guidance for its improvement.	https://gcos.wmo.int/
Southern Ocean Observing System (SOOS)	International initiative of the Scientific Committee on Antarctic Research (SCAR) and the Scientific Committee on Oceanic Research (SCOR), officially launched in 2011 and hosted by the Institute for Marine and Antarctic Studies (IMAS) at the University of Tasmania, Australia.	http://www.scar.org/soos
ARGO	International deepwater monitoring system of free-floating buoys that are part of the integrated global observation strategy. New Zealand makes a significant contribution to ARGO floats in the Pacific Ocean.	http://www.argo.net/ https://www.niwa.co.nz/coasts-and-oceans/research-projects/argo-floats
Continuous Plankton Recorder (CPR) Surveys	CPR surveys collect data about the spatio-temporal patterns of zooplankton and then use the sensitivity of plankton to environmental change as an early warning indicator of ocean health. CPR originated in the North Atlantic and the North Sea in 1931. New Zealand BRAG-funded projects contribute to the SCAR Southern Ocean CPR data collection established in 1991 by the Australian Antarctic Division to map the Southern Ocean.	https://www.cprsurvey.org/
Australia's Integrated Marine Observing System (IMOS)	IMOS, established in 2007, is designed to be a fully integrated national array of observation equipment to monitor the open oceans and coastal marine environment around Australasia, covering physical, chemical, and biological variables. All IMOS data are freely and openly available.	http://imos.org.au
Oceans 2025	This 5-year programme, now completed, was an initiative of the Natural Environment Research Council (NERC) funded Marine Research Centres to address environmental issues that require sustained long-term observations.	https://imber.info/science/endorsed-projects/completed-endorsed-prodjects/strategic-marine-research-programme-of-the-uk-natural-environment-research-council-oceans-2025/
Global Ocean Acidification Observing Network (GOA-ON)	An existing global ocean carbon observatory network of repeat hydrographic surveys, time-series stations, floats and glider observations, and volunteer observing ships, with participation from scientists from over 30 countries.	http://www.goa-on.org/
NZ Ocean Acidification monitoring Network (NZOA-ON)	Initiated in 2014 by NIWA and the University of Otago, this programme now has 11 sampling sites around New Zealand and is part of the Ocean Acidification Alliance.	https://www.niwa.co.nz/coasts-and-oceans/research-projects/new-zealand-ocean-acidification-observing-network-nzoa-on https://www.oaalliance.org/current-members

18.4 OVERALL PROGRESS IN FISHERIES NEW ZEALAND MARINE BIODIVERSITY RESEARCH

18.4.1 HISTORICAL BIODIVERSITY RESEARCH

To date, 95 research projects have been commissioned. Early studies focused primarily on reviews, identification guides, habitat and community characterisations, and revised taxonomy for certain groups of organisms. Later studies have included large collaborative ship-based surveys that have contributed to improved seabed classification in New Zealand waters and the exploration of new habitats in the region and in Antarctic waters.

Progress in the BRAG research programme has increased in conceptual complexity from simply cataloguing biodiversity to an increasingly complex understanding of environmental drivers and the functionality of biodiversity, and ultimately towards the development of standards and the protection of biodiversity. A full list of projects can be obtained from Appendix 19.6 at the back of the full document.

Greatest progress has been made in the shallower inshore parts of the marine environment, not least because of cost and ease of access. However, by leveraging from existing offshore projects, significant progress has also been made to depths of 1500 m. In recent years, biodiversity research based in Antarctica has lagged behind EEZ-based research, simply because of the difficulty in securing additional funding to access and work in such a remote marine environment.

Over time, the complexity and scale of studies has increased, with projects on the functional ecology of marine ecosystems ranging from localised experimental manipulation to broad-scale observations across hundreds of square kilometres. Such studies have also prompted the development of improved measures of biodiversity and indicators. One study reviewed genetic variation in the New Zealand marine environment and conducted field observations on several species to examine genetic variation across latitudinal gradients. Another study on changes in shelf ecosystems over the past 1000 years has yielded insights into the effects of long-term climate change, land-use effects, and fishing, on marine ecosystems; and some studies have begun to address the effects of ocean acidification on marine biodiversity.

18.4.2 ALIGNED MARINE BIODIVERSITY RESEARCH

In New Zealand, a number of marine research projects commissioned by MPI have contributed to the state of knowledge and management of marine biodiversity. The 'Marine Futures' programme (2012–14) investigated decision-making frameworks for ocean management and developed new tools for enabling participation of all stakeholders (public, iwi, industry, government), to facilitate economic growth, improve marine stewardship and ensure that cumulative stresses placed on the environment do not degrade the ecosystem beyond its ecological adaptive capacity (MBIE project code C01X1227). The 'Ross Sea Climate & Ecosystem' Programme (concluded in 2016) modelled likely future changes in the physical environment of the region and potential consequences of these changes on the ecosystem in terms of functional links between the environment and the marine food web (MBIE project code C01X1226). 'Management of offshore mining' (concluded in 2016) developed a clear framework that will guide appropriate and robust environmental impact assessments and the development of integrated environmental management plans for the marine mining sector, other resource users, and resource management agencies (MBIE project code C01X1228). 'Resilience of benthic communities to the effects of sedimentation' (2016-2021) assessed the impacts on and recovery of benthic communities to physical disturbance and sedimentation that could result from future deep-sea mining and bottom-contact fishing (MBIE project code C01X1614). 'Juvenile fish habitat bottlenecks' is currently assessing the restrictions on juvenile fish resulting from degraded biogenic habitats and seeks to promote actions that remove these restrictions with the ultimate aim of seeing more juvenile fish enter the adult populations (MBIE project code C01X1618).

The MBIE-funded Climate Change Impacts and Implications project had a coastal and an ocean case study and released a synthesis report upon its conclusion in 2016 (Law et al. 2016). The MBIE-funded CARIM project 'Coastal Acidification: Rate, Impacts & Management' that Fisheries New Zealand has contributed to was completed in 2020 (http://www.carim.nz/).

One of the largest marine research developments in recent times was the launch of the MBIE-funded National Science Challenge 'Sustainable Seas'. Sustainable Seas aims to enhance the utilisation of New Zealand's marine resources

within environmental and biological constraints (https://sustainableseaschallenge.co.nz/). Achieving this aim will require a new way of managing the many uses of our marine resources that combines the aspirations and experience of Māori, communities, and industry with the evidence of scientific research to transform New Zealand into a world leader in sustainable marine ecosystem-based management.

Phase 2 of the challenge was launched in 2020 and this incorporates closer links between science, policy, and Treaty Partners and includes case studies for EBFM as well as end-users, particularly with regard to fisheries. Current projects are investigating cumulative effects on biodiversity and ecosystem functioning, developing ecosystem indicators in the Hauraki Gulf for EBFM, assessing shellfish habitat and potential restoration in the Marlborough Sounds, and mapping marine environmental stressors in Hawke's Bay.

International partnerships are also being leveraged to support BRAG research priorities (Table 18.4), and other research relevant or specifically linked to BRAG research workstreams are listed in Table 18.5.

Table 18.4: Current New Zealand/International partnerships.

BAYESIANMETAFLATS – Spatial organisation of species distributions: hierarchical and scale-dependent patterns and processes in coastal seascapes (completed)	https://cordis.europa.eu/result/rcn/185059_en.html
Chess – Biogeography of Deep-Water Chemosynthetic Ecosystems	http://www.coml.org/projects/biography-deep-water-chemosynthetic-ecosystems-chess.html
INDEEP – International Network for Scientific Investigation of Deepsea Ecosystems (Now incorporated into Deep Ocean Stewardship Initiative)	http://www.indeep-project.org/ https://www.dosi-project.org/
PHARMASEA – Increasing Value and Flow in the Marine Biodiscovery Pipeline	http://www.pharma-sea.eu/
UN OCEAN DECADE (2021-2030)	https://tetiniatangaroa.org.nz/

18.4.3 PROGRESS ON CHARACTERISATION AND CLASSIFICATION OF BIODIVERSITY

The characterisation and classification of biodiversity requires an assessment of the abundance and distribution of marine life. Building on earlier research to map fish and squid species (Anderson et al. 1998, Bagley et al. 2000) and the biodiversity of the New Zealand ecoregion (Arnold 2004), numerous literature reviews (e.g., Nelson et al. 2019, Twist et al. 2019), taxonomic studies, and habitat mapping surveys have been undertaken, including 'The New Zealand Inventory of Biodiversity' (Gordon 2009, Gordon 2010, Gordon 2012). Field identification guides have also been published by the Ministry of Fisheries on deep sea invertebrates (projects ENV2005-20 and ZBD2010-39, Tracey et al. 2005, 2007, 2011a), macroalgae (Nelson 2020), bryozoans (project IPA2009/14, Smith & Gordon 2011), and on fish species (IDG2006-01, McMillan et al. 2019), which further contribute to the accurate monitoring and identification of biodiversity in New Zealand waters.

Several hundred new species of marine organisms have been discovered, and the known range of species extended, through exploratory surveys such as the NORFANZ project ZBD2002-16 (Clark & Roberts 2008); the Ministry of Science and Innovation (MSI) Seamount Programme, mainly commissioned through public-good science, supplemented by Ministry of Fisheries projects ZBD2000-04 (e.g., Rowden et al. 2002, 2003), ZBD2001-10 (Rowden et al. 2004), ZBD2004-01 (Rowden & Clark 2010), and Ministry projects ENV2005-15, ENV2005-16 (Clark et al. 2010a, Rowden et al. 2008) and the Ocean Survey 20/20 programme (Clark et al. 2009); inshore surveys of bryozoans at Tasman Bay ZBD2000-03 (Grange et al. 2003); Farewell Spit ZBD2002-18 (Battley et al. 2005); Fiordland ZBD2003-04 (Wing 2005); coralline algae ZBD2001-05, ZBD2004-07 (Harvey et al. 2005, Farr et al. 2009, Opresko et al. 2014) and other deep sea invertebrates (Tracey et al. 2011a, Williams et al. 2014); soft sediment environments ZBD2003-08 (Neill et al. 2012); rhodolith community study ZBD2009-03 (Nelson et al. 2012, 2014); offshore surveys of the Chatham Rise and Challenger Plateau funded through whole-of-government Ocean Survey 20/20 Programme, ZBD2006-04 (Nodder 2008) and ZBD2007-01 (Nodder et al. 2011), ZBD2012-03 (Hewitt et al. 2011a, 2011b, Bowden 2011, Bowden & Hewitt 2012, Bowden et al. 2011a, 2011b, 2011c, 2014, Compton et al. 2012). Other national efforts included the Biosecurity New Zealand mapping projects (Beaumont et al. 2008, 2010).

Table 18.5: Other aligned research. More information on Fisheries New Zealand projects listed below can be found in Appendix 19.6 of the full document.

Fisheries New Zealand	HAB2007-01 Biogenic habitats as areas of particular significance for fisheries management (complete). ZBD2006-02 NABIS (ongoing). KAI2016-05 Rocky reef impact quantification and monitoring for the Kaikōura earthquake (complete). KAI2020-01 Monitoring of rocky reef habitats across degrees of uplift caused by the 2016 Kaikōura earthquake (underway). This is effectively a continuation of KAI2016-05. SEA2020-14 Pelorus multibeam ground-truthing and analysis (complete). BEN2018-03 Automated image analysis for habitat classification and species distribution investigation (complete). Taxonomic identification of benthic samples (DAE2018-04 completed; BEN2021-03 underway). Useful data related to defining potential vulnerable marine ecosystems (VMEs) are collected by Fisheries New Zealand scientific fisheries observers working on New Zealand authorised fishing vessels that operate on the high seas in the South Pacific.
NIWA Marine platform and MBIE funding	NIWA Strategic Science Investment Funding (SSIF) **Coasts & Estuaries Centre** programmes: Programme 1 – Sea level rise and coastal hazards Programme 2 – Ecosystem Services Programme 3 – Aquaculture environmental effects Programme 4 – Marine biosecurity Programme 5 – Catchment to Coast Connectivity NIWA Strategic Science Investment Funding (SSIF) **Oceans Centre** programmes: Programme 1 – Oceanic ecosystem structure and function Programme 2 – Oceanic physical processes Programme 3 – Ocean Atmosphere Interactions Programme 4 – Marine Geological processes and Habitat characterisation NIWA Strategic Science Investment Funding (SSIF) **Coasts, Estuaries & Oceans Cross-Centre** programme: Programme 1 – Biological Resources (Documenting biota, spatial tools, SDM, etc.) NIWA Strategic Science Investment Funding (SSIF) **Fisheries Centre** programme: Programme 1 – Stock monitoring & assessment Programme 2 – Fisheries and ecosystems Programme 3 – International Fisheries NIWA Strategic Science Investment Funding (SSIF) **Aquaculture Centre** programme: Programme 1 – Aquaculture production species MBIE funding: C01X1618 - Removing fisheries juvenile habitat bottlenecks C01X1710 - RAMPing-up protection of the Ross Sea (RossRAMP) C01X1913 - Novel high-tech underwater selection tools for environmentally and economically sustainable fishing C01X2107 Transforming coastal lowland systems threatened by sea-level-rise into prosperous communities. C01X2108 Transforming scallop fishing: Non-destructive surveying and harvesting for economic acceleration and kaitiakitanga (Smart Idea) C01X2109 Carbon sequestration via NZ's estuarine sediments: Implications for GHG budgets (Smart Idea) C01X2110 RotoTurf – seeding freshwater restoration (Smart Idea)
Central government	MEC development and application to MPAs, Regional surveys; refined habitat suitability modelling for protected coral species in the New Zealand EEZ has been undertaken along with the development of a pilot ecological risk assessment for protected corals. DOC – Delineation of Key Ecological Areas DOC – New Zealand Seafloor Community Classification DOC – Development of a thematic habitat classification DOC – Deep reef biodiversity DOC – Surfacing of geospatial biodiversity data DOC – Climate change impacts on biodiversity DOC – Refined habitat suitability modelling for protected coral species in the New Zealand EEZ DOC – Development of a pilot ecological risk assessment for protected corals DOC – Identification of protected coral hotspots using species distribution modelling DOC – Coastal Sediment Research Priorities Report DOC – New National Marine Receiving Environment Sediment Tool

	DOC – National analysis of 18 years of satellite plume imagery to detect offshore hotspot increases and reductions DOC – Marine reserve monitoring: Key species monitoring (BUV, UVC, intertidal and subtidal quadrats) or (Reef fish, pāua, kina, kōura, intertidal communities) DOC – Marine reserve monitoring: Habitat monitoring (multibeam, drop camera, UVC) or (biogenic habitats, habitat maps) DOC - Marine reserve monitoring: Ocean acidification monitoring DOC – Spyfish Aotearoa: a citizen science and machine learning project to analyse BUV data

Research in the Ross Sea Region (BioRoss projects) have also generated records of new species including MPI projects ZBD2000-02 (Page et al. 2001), ZBD2001-03 (Norkko et al. 2002), ZBD2002-02 (Sewell et al. 2006, Sewell 2005, 2006), ZBD2003-02 (Cummings et al. 2003, 2006b), ZBD2003-03 (Rowden et al. 2012a, 2013), ZBD2005-03 (MacDiarmid & Stewart 2012), ZBD2006-03 (Cummings et al. 2003, 2006a), ZBD2008-23 (Nelson et al. 2010), and IPY2007-01 (Bowden et al. 2011a, Clark et al. 2010b, Eakin et al. 2009, Hanchet 2009, 2010, Hanchet et al. 2008a, 2008b, 2008c, 2008d, 2013, Koubbi et al. 2011, Lörz et al. 2009, Mitchell 2008, O'Driscoll 2009, O'Driscoll et al. 2011, 2012, O'Loughlin et al. 2011).

The development of the Marine Environment Classification or 'MEC' (Snelder et al. 2006) was an important step in the delineation of areas with similar environmental attributes in the offshore environment. However, significant environmental drivers of variability in marine biodiversity, such as substrate type for seafloor organisms, were absent from the classification. In 2005, DOC and Ministry of Fisheries jointly commissioned a project to optimise the MEC using fish distribution data. This project (ZBD2005-02) demonstrated a substantial improvement in the MEC classification for offshore habitats (Leathwick et al. 2006a, 2006b, 2006c). In addition, the Ministry implemented spatial management tools (Benthic Protection Areas; https://www.mpi.govt.nz/protection-and-response/sustainable-fisheries/protected-areas/benthic-protection-areas), on the basis of the Marine Environment Classification (Snelder et al. 2006) to address broader statutory responsibilities on the environmental effects of fishing on biodiversity.

In 2006, three projects to map coastal biodiversity were completed in the Coromandel scallop, Foveaux Strait oyster, and southern blue whiting fisheries around the sub-Antarctic islands as part of fishery plan development for these fisheries (ZBD2005-04, ZBD2005-15 and ZBD2005-16). These projects found that the biological distribution of organisms and their habitats were not well predicted by the MEC. Ministry project (BEN2006-01) aimed to further optimise the MEC by producing a methodology for a Benthic Optimised MEC (Leathwick et al. 2012). Ecological studies to improve habitat classification and vulnerability indices have also been completed through Aquatic Environment Working Group (AEWG) projects on seamounts (ENV2005-15, ENV2005-16) (e.g., Clark et al. 2010c, 2011), and to supplement other studies funded by the Ministry and MSI (e.g., ZBD2004-01, ZBD2001-10, ZBD2000-04, and CO1X0508).

Distribution maps providing indicative abundance and characterisation of biodiversity are now emerging and have been produced through projects using predictive modelling tools, e.g., Compton et al. 2012, ZBD2010-40; the fish optimised MEC in project ZBD2005-02 (Leathwick et al. 2006a, 2006b, 2006c); the benthic optimised MEC (BOMEC; Leathwick et al. 2012); macroalgal diversity associated with soft sediment habitats ZBD2008-05 (Rowden et al. 2012b); deep sea benthic biodiversity in trench, canyon and abyssal habitats below 1500 m depth ZBD2008-27 (Lörz et al. 2012); and rhodolith distribution and associated biodiversity ZBD2009-03 (Nelson 2009, Neill et al. 2014). A joint project supported by Fisheries New Zealand, DOC, and NIWA on the state of knowledge of deep-sea corals in New Zealand has been recently published (Tracey & Hjorvarsdottir 2019).

18.4.4 WORKSTREAM 1: IWI AND COMMUNITY-BASED BIODIVERSITY RESEARCH

A major theme of Te Mana o te Taiao and a focus for Fisheries New Zealand is collaboration, partnerships, and engagement between Treaty Partners, local communities, whānau, hapū, iwi, and Māori organisations to promote research efforts that connect biodiversity to local knowledge and decision-making. This workstream includes projects related to indigenous/taonga species and aims to improve understanding through multiple scientific

disciplines and knowledge systems including mātauranga Māori and citizen science.

Currently, Fisheries New Zealand is in the process of developing research projects under this workstream and future editions of the AEBAR will report on the status of these projects.

18.4.5 WORKSTREAM 2: BASELINE KNOWLEDGE FOR EBFM

Since 2000, much progress has been made towards characterising and quantifying the abundance and distribution of marine biodiversity throughout New Zealand waters. Marine ecosystems are complex and changes in diversity and community composition may be driven by multiple variables. Interactions between variables are likely to be non-linear, with disturbance thresholds and the potential for multiple stable states. As a consequence, it is often difficult to distinguish 'natural' from 'anthropogenic' impacts affecting ecosystem dynamics, and research is needed to help disentangle this complexity. This is particularly so closer to shore where complexity and natural variability seems to be greatest. Furthermore, the concept of 'shifting baselines' requires researchers to be explicit about whether they are referring to a historical or shifted baseline (Soga & Gaston 2018).

Marine ecosystems influence, and are influenced by, a wide array of oceanic, climatic, and ecological processes across a broad range of spatial and temporal scales. Marine communities are generally dynamic, can occur over large areas, and have strong links to other communities through processes such as migration and long-distance physical transport (e.g., of larvae, nutrients, and biomass). Patterns observed on a small scale can interact with larger- and longer-scale processes that in turn result in large-scale patterns. Marine food webs are usually complex and dynamic over time (Link 1999). To distinguish useful descriptors of long-term ecosystem change from short-term fluctuations requires innovative approaches that integrate broad-scale correlative studies from smaller-scale manipulative experiments (Hewitt et al. 1998, 2007).

Recent theoretical and technical advances show great promise toward the goal of understanding the role of biodiversity in ecosystems. Technologies for remote sensing and deep-water surveying, combined with powerful integrative and interpretive tools such as GIS, climate modelling, qualitative ecosystem modelling, and trophic ecosystem modelling, will contribute to the development of an ecosystem-based approach to management (Thrush et al. 1997, 2000), with potential benefits for marine conservation and management. Ecosystem modelling of species distribution (and habitats) with respect to known and projected environmental parameters will improve predictability for both broad- and fine-scale biodiversity distribution. This has already resulted in improved definition of environmental classifications addressing biodiversity assessment. It is also important to make progress in establishing the links between biodiversity and the long-term viability of fish stocks under various harvesting strategies. Further, modellers should consider processes from all ecosystem function perspectives, i.e., top-down effects such as predation (e.g., trophic modelling), bottom-up effects such as the environment (e.g., habitat classification based on environmental variables), and mixed effects. Effective management of marine resources through EBFM requires sound baseline knowledge of New Zealand's marine biodiversity.

For a list of past projects and outputs, please refer to Appendix 19.6. Current and recently completed projects are as follows:

ZBD2020-08 *Role of low- and mid-trophic level fish in the Hauraki Gulf ecosystem* [Underway]

Competition between seabirds and fisheries for prey is a known issue in other parts of the world and concerns have been raised about the potential impact of fisheries on seabirds in the Hauraki Gulf. Some information suggests that there have been decreases in chick survival, reduced body condition and increases in foraging effort for some wide-foraging seabirds, and these changes may be due to changes in the abundance or availability of seabird prey, which include low- and mid-trophic level fish such as anchovy, pilchard, jack mackerel, and mullet.

This project is producing a new food-web model of the Hauraki Gulf, specifically tuned to look at interactions between small pelagic fish and their predators, including seabirds, snapper, and cetaceans. It is intended to support and contribute to Sea Change and will also inform ecosystem-based fisheries management.

ZBD2016-04 *Organic Carbon Recycling in Deepwater* [Completed]

Time incremental sediment traps from long-term moorings in subtropical and Subantarctic waters north and south of the Chatham Rise have opportunistically collected and preserved mobile nektonic crustaceans over 3- to 16-day sampling periods from 2000 to 2012. These data provide a unique opportunity to examine the ecology and functioning of deep-water communities in the 'twilight zone', a habitat that is poorly sampled globally. Throughout this time-series, amphipods have been a conspicuous component of the 'trapped' fauna, with notable variations in abundance and speciation depending on water mass and season. During the project, 43 species of amphipod were identified from the trap samples, with 28 known from previous studies and 15 either new to science or unidentifiable, mainly due to sample preservation issues (Peart & Nodder 2018). About 70–90% of the temporal patterns in amphipod abundance and biomass were accounted for statistically by the combination of several environmental factors, such as organic carbon flux, sea-surface temperature, primary productivity, and Southern Oscillation Index. It is therefore anticipated that amphipod communities in the 'twilight zone' will be impacted by future climate change-related alterations to the physical and chemical characteristics of oceanic waters and marine productivity around New Zealand.

18.4.6 WORKSTREAM 3: TOOLS AND METHODS FOR BIODIVERSITY AND ECOSYSTEM ASSESSMENT

The development of new tools and methods for biodiversity and ecosystem assessment allows us to continually understand more about marine biodiversity and the way ecosystems function. They are also useful in detecting and monitoring changes that may have been unobservable using previous techniques, thus allowing early intervention to address threats to biodiversity.

This workstream promotes the development of tools such as ID guides (hard copy or online; e.g., Identification guides | NIWA), ecological maps or atlases of seabed habitats, ecosystem and biodiversity indicators, and report cards. These tools provide an efficient means of assessing biodiversity, whether that means using ID guides to quickly identify specimens, or using machine learning methods to observe the distribution of marine macroalgae that could be ecological indicators for marine health assessments (e.g., D'Archino et al. 2019, 2021). Emerging technology (e.g., electronic monitoring, cameras on boats) and genetic tools are also included in this workstream.

Genetic biodiversity can be measured directly at the scale of genes and chromosomes or indirectly by measuring physical features at the organism scale (assuming they have a genetic basis). Genetic diversity is fundamental to the long-term survival, stability, and success of a species. Central to this is the 'metapopulation' concept where populations are sufficiently genetically distinct from each other to be identifiable as individual units. A low level of recruitment between populations counters the effects of both random genetic drift and inbreeding depression of genetic diversity.

Human activities can profoundly affect genetic diversity both within populations and between populations. For example, shipping activity (movement across the globe) and aquaculture practices (transfer of organisms to different areas) can increase population connectivity such that genetic biodiversity may decrease between populations. In extreme cases, populations can become the same genetically (homogeneous) although considerable within-population diversity may remain. In the event of increased genetic connectivity, a species may become more susceptible to extinction through biological or catastrophic stochasticity. That is, in the absence of between-population diversity there is insufficient genetic variance to adapt to the effects of climate change, disease epidemics, and other pressures.

In contrast, under the much more common scenario of habitat fragmentation caused by human activities (fishing, pollution), decreased connectivity between populations will result in greater between-population diversity, but a reduction of within-population diversity. This also results in a decrease in a species survival (fitness) because fragmented or isolated populations may become extinct through environmental and genetic stochasticity or localised depletion. Periodic fluctuations in annual temperature for example can lead to small-scale population extinction, which in the absence of recruitment between populations will result, over time, in the demise of all populations.

To reduce the risk of species loss, information about the genetic diversity both within populations (population isolation) and between populations (population connectivity) is needed. Without such information, the effects of perturbation on a species persistence and survival

cannot be predicted. Furthermore, the links between genetic diversity, the dispersal capacity (mode of reproduction and life history development) of a species and the minimum viable population (MVP) size required in the marine environment to ensure population persistence, are little understood. For example, the MVP size for a species with a large dispersal capacity is likely to be quite different from that of a species with a relatively restricted dispersal capacity. Examining the connectivity between populations in the marine environment is fundamental to resolving some of the central challenges in ecology and has almost been ignored in the management of New Zealand fisheries and protection of biodiversity.

Understanding marine genetic diversity is also being enhanced through phylogenetic investigations of the relationships of the New Zealand marine biota using molecular sequence data. With some groups of the flora and fauna, genetic data are essential to understanding relationships and species identities. The research undertaken to date has important applications in both the documentation of diversity and in the recognition of foreign taxa (e.g., central to investigations of diversity of coralline algae in New Zealand: ZBD2001-05, ZBD2004-07; recognition of diversity: D'Archino et al. 2011; distinguishing native and foreign taxa: Heesch et al. 2009). Projects have also interpreted genetic population structure of five coastal species (tuatua, pipi, yellowbelly flounder and sand flounder, and scallop) (ZBD2009-10) (Gardner et al. 2010, Constable 2014, Hannan 2014, Hannan et al. 2016, Silva & Gardner 2014), created a DNA database for commercial marine fish (Smith et al. 2008), and assessed the genetic connectivity of deep-sea corals in vulnerable marine ecosystems (Holland et al. 2020).

ZBD2019-11 *Development of Electronic Automated Reporting System (EARS) to improve seabird bycatch monitoring* [Underway]

The current bycatch levels of seabirds, including the Antipodean albatross is poorly known, but international distant-water longline fishing fleets are likely to be the major cause of Antipodean albatross mortality. Other factors may play a role in seabird decline but reducing bycatch mortality will address the most direct human impact on seabirds.

The Western and Central Pacific Fisheries Commission (WCPFC) has jurisdiction over most of the Antipodean albatross foraging area and requires fishers to employ mitigation techniques to reduce seabird bycatch in certain areas. The WCPFC requires the use of at least two of the following mitigation techniques: tori (bird scaring) lines, weighted branch lines (hooks), and setting hooks at night. These mitigation techniques have been shown to reduce seabird bycatch by up to 80-90% if used appropriately (e.g., Melvin et al. 2004).

An Electronic Automated Reporting System (EARS) has been developed which monitors compliance with bycatch mitigation techniques using GPS trackers and RFID tags. The data collected from these devices is automatically sent from the vessel by satellite connection to regulatory authorities to monitor compliance. As part of project ZBD2019-11, trials are currently underway to determine the best configuration of this mitigation monitoring system prior to future widespread use of this robust sensor technology on fishing vessels in international waters.

ZBD2016-11 *Quantifying benthic biodiversity across natural gradients* [Completed]

Quantitative data on the distribution and abundance of benthic species are sparse in New Zealand waters, resulting in high levels of uncertainty in status and trends in benthic biodiversity. This project supported opportunities both for limited field validation of existing models (e.g., those developed from the Chatham-Challenger OS20/20 surveys; Bowden et al. 2021) and development of new abundance-based models. These new models (Bowden et al. 2019a, 2019b) have improved predictive ability to better inform management options, and the data and models generated by the project also informed a benthic risk assessment developed under a separate Ministry project (BEN2014-01; Mormede et al. 2021).

ZBD2019-01 *Quantifying benthic habitats Phase2* [Completed]

At the completion of the Chatham Rise work under ZBD2016-11, Fisheries New Zealand commissioned further work under the *Quantifying Benthic Biodiversity* initiative, with this subsequent project, ZBD2019-01 (Stephenson et al. 2021), the overall Objective of which was:

- To expand and develop initiatives to improve confidence in predictive models of seabed fauna and habitat distributions started under ZBD2016-11 '*Quantifying benthic biodiversity to improve benthic habitat modelling potential*'.

This was achieved via four Specific Objectives:

1. Predict gradients in benthic faunal turnover across Campbell Plateau (CP) using relationships between faunal distributions and environmental gradients developed for Chatham Rise (CR) under ZBD2016-11;
2. Run a dedicated photographic survey of seabed habitats and fauna across CP, structured on the basis of predictions from (1);
3. Use quantitative data from the CP survey to assess the utility of existing CR models when applied to a neighbouring area of the EEZ;
4. Generate updated models with a spatial domain encompassing both regions by merging data from the CP survey with existing CR dataset.

The survey of the Campbell Plateau took place in May-June 2020. While predictions for most of the individual taxa modelled were not reliable guides to actual distributions in this region, a community-level classification developed using Gradient Forests provided useful discrimination of changes in community composition. These results indicated that, using currently available methods and data, applications of habitat suitability modelling in New Zealand's marine realm should be based on sample data from within the area for which predictions are required, with sample locations spanning the full range of environmental conditions within the prediction area. While predictive species-environment modelling methods provide our best current estimates of the spatial distribution of seafloor biodiversity, their credibility remains limited by the paucity of quantitative survey data on which to train them.

18.4.7 WORKSTREAM 4: FUNCTIONAL THREATS TO BIODIVERSITY

Many marine ecosystems in New Zealand have been modified in some way through the harvesting of marine biota, the selective reduction of certain species and size/age classes, modification of food webs, including the detritus components, and habitat destruction. Epifaunal-dominated benthic communities including seamount communities, volcanic vent communities, bryozoans, corals, hydroids and sponges, and benthic communities dominated by infaunal structure (e.g., shellfish beds, tub-forming polychaetes or amphipods, large burrowing infauna) are vulnerable to human disturbance (Lundquist et al. 2017). The mechanical disturbance of marine habitats that occurs with some activities such as trawling, dredging, dumping, and oil, gas, and mineral exploration and extraction can substantially change the structure and composition of benthic communities. Indirect effects of mechanical disturbance (e.g., sediment resuspension, change in sediment grainsize) also impact on marine communities and their ecological functioning. The invasion of alien species into New Zealand waters is also a real threat, with evidence of nuisance species already well established.

A number of inshore marine ecosystems (especially estuaries and other sheltered waters) have been modified by sediment, contaminants, and nutrients derived from human land-use activities (Morrison et al. 2009). Coastal margin development has had a major impact on some inshore marine communities.

A project commissioned by the Aquatic Environment Programme, which identifies key threats to the marine environment (BEN2007-05) is complete and has listed and ranked the top threats to New Zealand's marine environment, as perceived by expert opinion. Relevant findings are that the highest-ranking threats are ocean acidification, increasing sea water temperatures, and bottom trawling (across all habitats), and that the most threatened habitats are intertidal reef systems in harbours and estuaries (MacDiarmid et al. 2012). Ecological risk assessment (ERA) methods have also been reviewed (under ENV2005-15, Rowden et al. 2008), and a trial Level 2+ risk assessment was completed for Chatham Rise seamounts to estimate the relative risk to seamount benthic habitat from bottom trawling (under ENV2005-16, Clark et al. 2011).

An existing spatially explicit patch dynamic model was expanded upon as a framework to explore effects of disturbance on functional diversity in benthic marine ecosystems, and ultimately, other elements of biodiversity and ecosystem function (such as the abundance of rare species, ecosystem productivity, and the provisioning of biogenic habitat structure) (Lundquist et al. 2013). The model was validated against available inshore (Tasman Bay and Golden Bay) and offshore (Chatham Rise and Challenger Plateau) empirical datasets, demonstrating the value of this tool for investigating disturbance and recovery dynamics in seafloor communities.

In recent times, the threat that climate change poses to marine biodiversity has been more widely recognised. Cyclical changes or trends in climate and oceanography and associated effects (such as increased ocean acidification) and how they affect the marine ecosystem as a whole have

long-term implications for trophic interactions and biodiversity, as well as functional aspects of the system, e.g., biogeochemical processes. With significant improvement in remote sensing tools and global monitoring of climate change, new patterns are emerging indicating that there are long-term cycles. Examples include the Interdecadal Pacific Oscillation as well as shorter periods of change in relation to the El Niño Southern Oscillation that affect ocean ecosystems. Further, physical phenomena such as the deep subtropical gyre 'spin-up' in the South Pacific Ocean, which resulted in a warmer ocean around New Zealand from 1996 to 2002, and recent heatwaves in the Tasman Sea (see Climate Change Chapter 12 and https://www.moanaproject.org/marine-heatwave-forecast) can have flow-on effects on ecosystem functioning.

Ocean acidification trends and projections, and implications, have been reviewed extensively in the most recent IPCC report (IPCC 2018). One key projection of increasing ocean acidification is that by 2100 some 70% of cold-water corals, which provide a key refuge and feeding ground for some commercial fish species, will be exposed to corrosive waters (see also Tracey et al. 2011b, 2013). In addition, given the current greenhouse gas emission rates, it is predicted that the surface water of the highly productive Arctic Ocean will become under-saturated with respect to essential carbonate minerals by the year 2032, and the Southern Ocean by 2050 with disruptions to large components of the marine food source, in particular those calcifying species, such as foraminifera, pteropods, and coccolithophores, which rely on calcium carbonate.

Emerging research suggests that many of the effects of ocean acidification on marine organisms and ecosystems will be variable and complex and will affect different species in different ways. Evidence from naturally acidified locations confirms, however, that although some species may benefit, biological communities in acidified seawater conditions are less diverse and calcifying (calcium-reliant) species are absent, whereas algae tend to dominate. BRAG funded projects have improved understanding of the impacts of ocean acidification on deep-sea coral growth (ZBD2014-01), testing physiological responses (e.g., growth) to ocean acidification manipulations in a laboratory setting. Another project (ZBD2013-06) has examined shell generation and maintenance of important aquaculture species including pāua and flat oysters.

Many questions remain regarding the biological and biogeochemical consequences of ocean acidification for marine biodiversity and ecosystems, and the impacts of these changes on ecosystems and the services they provide, for example, in fisheries, coastal protection, tourism, carbon sequestration, and climate regulation (Tracey et al. 2013).

Studies to predict changes in biodiversity in relation to climate change in more than a rudimentary way are beyond the state of current knowledge in New Zealand. Nevertheless, surveys of biodiversity that have occurred or are planned will provide a snapshot against which future research results or trends can be compared.

Meeting the challenges of climate change and identifying crucial issues for marine biodiversity is an area of high political interest internationally and has been identified as a gap in biodiversity research in New Zealand (Green & Clarkson 2006). A revised action plan (2016–2020) to support the New Zealand Biodiversity Strategy includes a chapter on climate change (Department of Conservation 2016).

Recognising threats and changes to marine biodiversity requires effective monitoring and the establishment of suitable indicators for detecting changes. In the mid-1990s, monitoring of marine biodiversity and the marine environment was a topic of considerable discussion, yielding several reports on developing MfE indicators. However, since the publication of MfE's indicators in 2001, a reduced set of core indicators that relate to the marine environment have been reported (Ministry for the Environment 2007). A new international initiative launched in 2010: 'Biodiversity Indicators Partnership' (https://www.bipindicators.net) provides guidelines and examples of biodiversity indicators developed around the globe, however, Oceania does not appear to have any partnership identified. The link between this initiative and OECD environmental indicators is unclear.

A serious gap identified by Green & Clarkson (2006) in their review of progress on implementation of the NZBS was the lack of development of an integrated national monitoring system. Efforts to respond to this gap within the Biodiversity Programme resulted in the immediate initiation of a five-year Continuous Plankton Recorder project, and a project that convened a series of workshops to determine how best to approach monitoring on a national scale (ZBD2008-14) (Hewitt et al. 2014). One

objective of monitoring would be to test the effectiveness of management measures.

Current and recently completed projects are as follows:

ZBD2014-03 *Sub-lethal effects of environment change on fish populations* [Completed]

This project (co-funded with MBIE) investigated the potential effects of ocean acidification (caused by elevated CO_2) on New Zealand's fish and fisheries, with a focus on snapper. In 2015–16 a workshop for key collaborators completed a review of existing information on ocean acidification effects on fish and how these known effects are likely to play out in New Zealand's temperate setting. Following on from the review, tank experiments were conducted to assess the response (e.g., mortality, morphology, energy utilisation, behaviour) of snapper larvae to different acidification scenarios. A range of responses were measured, with some of the most notable being a strong positive effect of elevated temperature on growth and a positive effect of elevated CO_2 on survival in the absence of other real-world factors (McMahon et al. 2020a), negative effects of elevated CO_2 on swimming ability and metabolic performance and a positive effect of temperature on swimming ability (McMahon et al. 2020b), and a negative effect of elevated CO_2 on hearing ability (Radford et al. 2021). Finally, the findings of the review and tank experiments were combined in a deterministic model to assess the effects of acidification at the broader population level (Parsons et al. 2021).

ZBD2018-02 *Climate change, fish distribution meta-analysis* [Completed]

Climate change effects on wild renewable marine resources essentially take place through changes in species distribution and their productivity. To date, changes in distribution seem to be the most pronounced and measurable response; for example, warming off southeast Australia with extension of the east Australian Current and associated fauna southwards by about 350 km. Other reports of changes include ranges of some warm-water species, temperature mediated impacts on benthic invertebrates, and localised regions of warming. Understanding the shifts in New Zealand fish species in relation to fisheries management area boundaries and stock productivity is key to adaptation and management under a changing environment. The overall objective of this project was to assess the resilience and diversity of marine living resources under regime shifts and climatic trends in New Zealand waters.

This was achieved via three Specific Objectives:

1. Explore data time series and biological data for evidence of spatial change in living marine resources that may be consistent with climate change or regime shifts.
2. Investigate novel approaches to identify ecologically relevant change by examining species and community relationships between the organisms and their environment.
3. Identify fisheries, communities, and locations that are most vulnerable or will remain stable under the response to climate change effects on the ocean.

ZBD2018-03 *Climate variability, trends, and fish population parameters* [Completed]

Ongoing climate change is predicted to have both direct and indirect effects on individual organisms, including fish during all life stages, thereby affecting populations of a species, communities, and the functioning of ecosystems. However, current methods of stock assessment assume that recruitment and productivity parameters such as natural mortality, steepness, von Bertalanffy growth curves, length-weight relationships, recruitment variability, and the mean number of recruits remain constant over time. This project investigated whether this assumption is valid as climate change related impacts on the ocean progress, how parameters may change, and what changes are likely to have a significant impact on fisheries sustainability. By identifying suitable indicators to monitor significant change for important fisheries (e.g., the top 20 species by value including finfish, rock lobster, and pāua), individual stock assessment groups will eventually be able to assess the impacts of environmental change on stock projections. A model was used to investigate the effects of climate change on different aspects of fisheries productivity. This model provided unbiased estimates of stock status on average despite annual and decadal fluctuations in all production-related parameters. This variability was much greater than that induced by climate change scenarios. The project found that for many stocks, it is difficult to tell if specific changes in productivity parameters are due to climate processes or demographic responses to fishing pressure (Neubauer et al. 2021a, b).

ZBD2018-05 *Ecosystem function and regime shifts in the Subantarctic* [Completed]

Anecdotal and scientific information from a range of sources suggest that there have been major environmental shifts in the Subantarctic over the past 40 years, but no meta-analyses or whole-of-system modelling has been conducted to determine how these shifts may be influencing different biota, including megafauna, top predators, protected species, and fish. This project examines all potential sources of data and develops a suitable modelling approach to identify synchronous trends, cycles, tipping points, and regime shifts in the Subantarctic. The project also investigates the feasibility of testing or ground-truthing aspects of the model through survey work in the area. The project develops ecosystem models to understand the effects of environmental variability and change at the scale of decades affecting ecosystem function in the Subantarctic, including effects on a protected species (New Zealand sea lion) and on ecologically and economically important fish (hoki, squid, and southern blue whiting), including potential effects on fish abundance, recruitment, and spatio-temporal movements. Preliminary results show minimal evidence for long-term shifts in the atmospheric or oceanographic climate of the Subantarctic. However, observed changes in phytoplankton productivity and predictive modelling suggest that oceanic warming will have opposing effects on primary productivity; increasingly productive in the Subantarctic, but decreasingly productive off the west coast of the South Island. The negative effects of warming off the west coast on the productivity of New Zealand fur seals and the recruitment of hoki are also identified from predictive modelling, as is the positive effect of increased productivity on the abundance of southern arrow squid along the sub-tropical front. Sea temperatures both at the surface and the seabed are identified as potential indicators of ecosystem change. Progress in this project has shown the importance of environmental cycles that occur beyond the boundaries of resident populations, particularly when a species life cycle straddles many different parts of the ocean.

ZBD2016-07 *Multiple stressors on coastal ecosystems in situ* [Completed]

Increasing acidity (lower pH) and water temperatures are two major stressors that will influence the future structure and function of coastal ecosystems. Prior research has primarily focused on the response of different faunal groups to acidified conditions in isolation. To advance understanding and the capacity to predict the future status of coastal ecosystems in New Zealand, a series of long-term mesoscale manipulation studies of coastal planktonic water column, in which pH and other parameters were altered, was carried out as part of aligned research in the MBIE funded CARIM Project. In the project described here, laboratory experiments were used to examine whether future changes in water temperature and pH projected for the New Zealand region will influence coastal phytoplankton biomass and speciation, and thus the nutritional value of plankton for green-lipped mussels (Law et al. 2021). Phytoplankton biomass was unaffected by lower pH but showed a significant increase of 10-25% in the combined low pH and elevated temperature treatment, suggesting potential for increased food availability in the lower food web in the future. However, a decrease in food quality was observed. Green-lipped mussel larvae were grown in chambers within the mesocosms during the experiment, and despite smaller maximum final shell size due to lower pH, modelling predicted future increases in food uptake rate, energy allocation, shell length, and flesh weight for green-lipped mussels resulting from increased temperatures. The results of this project provide an understanding of how a key species in New Zealand may be affected directly by future ocean climate changes, and indirectly through the influence of these changes on the lower food web.

ZBD2014-09 *Climate change risks and opportunities in the marine environment, New Zealand* [Completed]

The overall aim of this project was to identify risks and opportunities that are likely to arise for the seafood sector as a consequence of climate change effects in coastal and offshore New Zealand waters.

This study (Cummings et al. 2021), conducted in stages over four years, synthesised available information on CO_2- and climate-induced changes that affect the New Zealand region and our fisheries. Knowledge of changes to the physical and oceanographic system in the coming decades, and of how specific fisheries are influenced by these parameters, was assessed to determine potential risks to these fisheries.

The state of knowledge of climate change-associated predictions for components of New Zealand's marine environment that are most relevant to fisheries were examined. Past and future projected changes in coastal and ocean properties, including temperature, salinity, stratification, and water masses, circulation, oxygen, ocean productivity, detrital flux, ocean acidification, coastal

erosion and sediment loading, and wind and waves, were reviewed.

A complete understanding of the response of key New Zealand fisheries species to climate-associated change, based on scientific data, is ambitious given the paucity of information on most New Zealand Quota Management species, the ecosystems that support them and the potential threats they face. The biological and ecological characteristics of 31 commercial fisheries species or species groups important in the New Zealand region were collated and evaluated as to how they might be affected by changes to selected properties of New Zealand's oceanic and coastal waters expected over the remainder of this century. Regardless of the data limitations, a number of species that may be affected by warming, and/or ocean acidification were identified, supporting previous findings that these are the two greatest anthropogenic CO_2-associated threats facing the New Zealand marine environment.

A range of decision support tools in use overseas were evaluated with respect to their applicability for dissemination of the state of knowledge on climate change and fisheries. Three species, for which there was a relatively large amount of information available, were chosen from the main fisheries sectors for further analysis. These were pāua, snapper, and hoki (shellfish, inshore, and middle-depths/deepwater fisheries, respectively). Evaluations of each species' sensitivity and exposure to climate change-associated threats, based on currently available published literature and expert opinion, assessed pāua vulnerability as 'very high', snapper as 'moderate', and hoki as 'low'. Potential adaptation and management options, and their effectiveness and feasibility, were also examined.

This project has summarised a large amount of cross disciplinary information, always with the fishery and effective management in a changing environment in mind. It has demonstrated the value of research into direct influences of the different parameters on the species (e.g., temperature, acidification), and the need for information across the life cycle of the species to enable robust evaluations and predictions of future impacts to be made.

ZBD2019-04 ***Plastics and marine debris across the ocean floor in New Zealand waters*** [Completed]

Plastic debris in the ocean is a pollution-related issue attracting worldwide concern. As well as unsightliness, the debris is on a scale that causes harm to many marine species and threatens the health of marine ecosystems across the globe. All species are affected, but attention has particularly focused on marine mammals, seabirds, other protected species, and fish. New Zealand is no exception, and plastic debris is visible along much of our coastline. Within New Zealand, beach surveys and clean-up events for visible (macro) plastics are underway and the findings are available online (https://litterintelligence.org/).

Far less is known about the occurrence of plastics in our offshore environment. Microplastics have been found in the plankton recorder time series samples between New Zealand and the Ross Sea (Antarctica) and are being quantified as part of the ongoing Continuous Plankton Recorder Programme supported by Fisheries New Zealand and Sanford Limited.

This project used NIWA's database of seafloor images collected with their Deep-Towed Imaging System (DTIS) dating back to 2006 to quantify the occurrence and distribution of macroplastics in New Zealand's sub-tidal marine environment from shallow to deep water (Behrens et al. 2021). Litter was classified according to the UNEP guidelines for monitoring and surveying marine litter (benthic) https://www.nrc.govt.nz/media/10448/unepioclittermonitoringguidelines.pdf. There were 149 occurrences of marine litter observed in seafloor images around New Zealand consisting of plastic rope (75%), glass bottles (7%), plastic sheeting (5%), and metal fishing-related litter (4%); the remaining item categories were very rare (≤ 1%). Most observations of litter were within 25 km of the coast, but litter was also recorded on remote seamounts more than 1500 km from the coast.

Only a small proportion of the seafloor in New Zealand has been surveyed photographically, leaving large data gaps and uncertainties around litter density in un-surveyed areas. Litter density across New Zealand was estimated at ~133–430 pieces per km^2 based on observed litter from DTIS imagery which is at the lower end for densities reported from other areas (e.g., Mediterranean, North Sea).

This project was exploratory in scope but there is considerable potential to increase the quality and quantity of data on marine litter by adjusting analysis protocols for photographic surveys to include the identification of marine litter according to UNEP guidelines.

ZBD2020-09 ***Cumulative effects of stressors on scallops and scallop habitats in the Marlborough Sounds*** [Underway]

Annual dredge surveys of scallops in the Marlborough Sounds (1997–2019) have revealed a declining trend in recruited biomass since 2009 (Williams et al. 2019). The fishery was closed in 2016 due to sustainability concerns and will remain closed until the scallop population has recovered. The most recent recruited biomass estimate, based on the 2019 dredge survey, is the lowest on record (Williams et al. 2019), indicating that despite closures, there has been no recovery of scallops in surveyed areas.

Project ZBD2020-09 has recently begun and seeks to assess the cumulative effect of key stressors on habitats and ecological processes that support scallops. The results of this work should provide insight into the recovery potential of scallops in the Marlborough Sounds, guidance as to whether the creation of refuges from bottom-fishing methods may enhance recovery, and an idea of the realistic timeframes required for recovery.

This project supports the Draft Southern Scallop Strategy (Marlborough Sounds) which proposes to "get better information" particularly around "what constitutes good scallop conditions" and has synergies with the work proposed under project 1.1 'Ecological responses to cumulative effects' of Phase II of the Sustainable Seas Challenge.

ZBD2020-11 *Review of land-based effects on coastal fisheries and kaimoana and their habitats* [Underway]

Substantial changes in coastal habitats and ecosystems have occurred over the last 100 or more years and continue to occur (Morrison et al. 2009). Land-based activities are a key driver of change to coastal habitats, and both directly and indirectly impact coastal fisheries and kaimoana species. Due to the growing awareness of emerging pressures on fisheries resources and the marine environment, Fisheries New Zealand are seeking to progress New Zealand towards ecosystem-based fisheries management (EBFM). A key focus area in advancing EBFM is "improving environmental performance with a focus on protecting habitats of significance for fisheries management from the impacts of fishing and land-based effects, and ensuring the long-term viability of protected species."

Since the last review (Morrison et al. 2009), there have been various programmes of work to assess the effects of land-based stressors on coastal ecosystems. Phase I of the Sustainable Seas Challenge included a range of projects which assessed the effects of numerous stressors and how coastal habitats and species responded to change (e.g., Blain et al. 2020, Douglas et al. 2018, Gladstone-Gallagher et al. 2018, Schiel et al. 2018). MBIE Endeavour Fund Research Programme 'Removing juvenile fish bottlenecks' (C01X1618) commenced in 2016 and is exploring how 'habitat bottlenecks' to fish species work, how fish respond, where they occur, their links to adult populations, and the stressors that affect them.

The purpose of ZBD2020-11 is to review the outputs of programmes and projects which contribute to the state of knowledge of how land-based stressors impact coastal fisheries and kaimoana, and to collate and summarise available information on the current status and trends in sediment and nutrient run-off at local, regional, and national scales in New Zealand.

ZBD2018-01 *5-year Continuous Plankton Survey (Phase 3)* [Underway]

The overall objective of the Continuous Plankton Recorder (CPR) series of projects is to map changes in the quantitative distribution of epipelagic plankton, including phytoplankton, zooplankton, and euphausiid (krill) life stages, in New Zealand's EEZ and transit to the Ross Sea, Antarctica.

The original project was established in 2008 for a five-year period with sampling carried out annually in the Austral summer. Sanford Limited continues to provide the FV *San Aotea II* and crew to take the samples, and sample analysis is carried out by the laboratory at NIWA Christchurch. A second project further funded this long-term series (ZBD2013-03) (Robinson et al. 2014). Analyses conducted after the first two phases suggest that a changing Southern Ocean environment may benefit some zooplankton taxa (e.g., copepods, foraminifera, and *Fritillaria* spp.) but disadvantage others (e.g., pteropods) (Pinkerton et al. 2020, Robinson et al. 2021)

The current project, ZBD2018-01, continues this annual programme of CPR sampling and is funded for a further five years (2018–2023). This will enable a continuation of the data time series and provide a more robust dataset with which to make comparisons with the Southern Ocean CPR survey and potentially determine any latitudinal and/or temporal trends in the plankton community. Of interest, CPR surveys have detected microplastics, showing the broad impact of these pollutants across the global oceans. Microplastic content is being analysed retrospectively and will be part of the routine analysis from now on.

The data generated from this series of projects contributes to reports on the status and trends of zooplankton across the whole Southern Ocean for the Scientific Committee on Antarctic Research; the latest report can be viewed here.

18.4.8 WORKSTREAM 5: SUSTAINABILITY FOR FUTURE GENERATIONS

With global biodiversity declining due to multiple threats, it is now clearer than ever that sustainability must be at the forefront of decision-making about natural marine resources. There is a great need to balance extractive use of these resources with environmental protection, although this balance can sometimes be difficult to achieve. Finding the right balance is essential in ensuring that marine biodiversity is sustained and ideally thriving for future generations.

Science and research underpin this important concept and allow decision-makers to manage natural marine resources in a way that promotes sustainability. Research under this workstream includes understanding the effectiveness of protected/closed areas, preserving cultural practices as they relate to fisheries and biodiversity, maintaining a social licence to operate, and identifying creative solutions that allow for sustainable development of the marine economy with biodiversity at its core.

Current and recently started projects are as follows:

ZBD2020-06 *Recovery of biogenic habitats: assessing the recovery potential offered by spatial planning scenarios proposed in the Sea Change Plan* [Underway]

The Sea Change process was initiated in 2013 to develop a marine spatial plan (https://www.seachange.org.nz/read-the-plan/) that seeks to restore the health of the Hauraki Gulf Marine Park (HGMP). The plan, released in 2016, describes numerous stressors that negatively affect Hauraki Gulf and provides overall visions, objectives and proposals to address environmental decline, particularly the loss of biogenic habitats which support juvenile fish (Morrison et al. 2014). The plan proposes to use a variety of spatial management tools to mitigate key stressors (e.g., bottom fishing) and allow for the natural regeneration of biogenic habitats to increase fish population size. A number of scenarios for Marine Protected Area (MPA) placement and design are proposed in the plan.

Project ZBD2020-06 has recently begun and will assess how well the various MPA scenarios proposed in the plan may support the recovery of biogenic habitats and will identify feasible options for the restoration of habitat functions. The results of this project will inform future consultation on spatial planning and may inform an ecosystem-based approach to fisheries management in the HGMP.

ZBD2020-07 *Recovery of seamount communities* [Underway]

Seamounts, knolls, and hills are prominent features of underwater topography in the New Zealand region and are often sites of high biodiversity and productivity. They are the focus of important commercial fisheries for deepwater species, with about 80% of known seamount features at suitable depths for deepwater fisheries having been exploited. Benthic faunal communities on deepwater seamount features are commonly characterised by extensive growth of cold-water corals but impacts from bottom trawl gear have substantially reduced biogenic habitat formed by corals on fished seamounts (Clark et al. 2016). The overall resilience of such benthic communities, and the time frame required for recolonisation and re-growth is uncertain, yet such information is important for evaluating appropriate options for management of fishing impacts.

Project ZBD2020-07 aims to understand the nature and timescale of changes and recovery dynamics of benthic invertebrate communities on seamounts following the closure of certain seamounts around the Chatham Rise to bottom trawling in 2001. The area was surveyed using towed cameras in 2001, 2006, 2009, 2015, and again under the current project in August 2020. Analysis of the first 4 surveys showed little evidence of resilience of the benthic community, nor signs of settlement or recruitment of the main coral species (Clark et al. 2019a). However, initial observations from the most recent survey in 2020 showed very small scleractinian corals (the same species as form the large climax-community reef structures on these seamounts) estimated at between 2 and 10 years old. Images from this survey are currently being processed.

The survey links strategically to assessing the efficacy of Benthic Protection Areas and Seamount Closures (Clark et al. 2019b), and also provides an understanding of the biodiversity and recovery rates of deepwater environments and Vulnerable Marine Ecosystems (VMEs) that are part of Fisheries New Zealand international obligations.

18.4.9 PROGRESS ON BIODIVERSITY IN ANTARCTICA

Antarctic research funded by BRAG (historically known as BioRoss) aimed to improve understanding of the biodiversity and functional ecology of selected marine communities in the Ross Sea. Due to lack of resources, no research has been funded for the last 5 years and no new research is planned for the Antarctic through the Biodiversity Research Programme.

18.5 EVALUATION OF RESEARCH EFFECTIVENESS

The Fisheries New Zealand Biodiversity Programme has been running for more than 20 years and a number of new strategic documents and directions are emerging throughout government. Here the programme is evaluated with respect to its initial strategic outcomes, and its alignment with more recent strategic documents.

In 2000, five strategic outcomes were built into the Ministry of Fisheries Biodiversity Research Programme.

That by 2010:

i. *The Ministry of Fisheries Biodiversity Programme will have become an integral part of the research effort devoted to understanding New Zealand's marine environment.*
ii. *Research planning will benefit from close cooperative relationships within the Ministry of Fisheries, with other government agencies, and with external stakeholders.*
iii. *Mutually beneficial collaborative research projects will be carried out alongside other New Zealand and international research providers, especially for vessel-based research.*
iv. *Ministry of Fisheries Biodiversity projects will have contributed substantially to an improved understanding of New Zealand's marine biodiversity and its role in marine ecosystem function, yielding scientifically rigorous outputs for a national and international professional audience.*
v. *Results generated by MFish Biodiversity projects will be incorporated into management policy, with clear benefits for the New Zealand marine environment.*

The Biodiversity Programme has been highly effective in delivering the first four and part of the fifth of these five outcomes, though currently there is no clear metric to evaluate the measure of whether the Programme is providing *"clear benefits for the New Zealand marine environment"*. In recent years, significant whole-of-government projects have been administered through the programme, and one-off funding applications made jointly with other stakeholders have been successful. The programme has made a significant contribution to increasing understanding about biodiversity in the marine environment. Achievements in each outcome are addressed below.

i. *Has the Biodiversity Research Programme become integrated with New Zealand's research effort to understand the marine environment?*

Seven science objectives were developed by multiple stakeholders through the Biodiversity Research Advisory Group. The original objectives included: 1) ecosystem-scale studies in the New Zealand marine environment, 2) the classification and characterisation of the biodiversity of near-shore and offshore marine habitats, 3) the role of biodiversity in the functional ecology of marine communities, 4) connectivity and genetic marine biodiversity, 5) the assessment of the effects of climate change and increased ocean acidification, 6) identification of indicators of biodiversity that can be used to monitor change, and 7) identification of key threats to biodiversity, identification of threats and impacts to biodiversity and ecosystem functioning beyond natural environmental variation.

Projects ranged from localised experiments on seabed communities of shellfish and echinoderms, to integrated studies of rocky reef systems (Schwarz et al. 2006) and offshore fishery-scale trophic studies. The effects of ocean climate change (temperature, acidification) have been explored on shellfish, rhodolith communities, plankton productivity, and the microbial productivity engines of polar waters. A major project to investigate shelf communities in relation to climate over the past 1000 years has resulted in the development of new methods and insights into past changes and the human impact on New Zealand's marine environment.

A total of 95 projects were commissioned and managed within this 20-year period, yielding over 100 final research reports, most of which have been published through

Ministry publications (Marine Biosecurity and Biodiversity Reports and Aquatic Environment and Biodiversity Reports), books, identification guides, and mainstream scientific literature. Additional publications continue to be added to the scientific literature. In addition, several workshops have been run through the Programme, including on qualitative modelling techniques, how to set up a marine monitoring programme, and predictive modelling. A large number of science providers, including NIWA, Cawthron Institute, University of Auckland, Auckland University of Technology (AUT), University of Waikato, Victoria University of Wellington, University of Otago, University of Canterbury, and Massey University have been directly commissioned or sub-contracted to take part in or conduct research projects through the Programme during the 20-year period. For some, the projects have provided critical synergies with aligned research, whereas others have provided one-off opportunities for marine biodiversity investigation or opportunistic leveraging for research voyages.

Research into the biodiversity of habitats such as seamounts has been completed and new methods to assess the vulnerability of seabed habitats have been developed. The land-sea interface is being investigated and projects have shown how land use in a given catchment can affect nutrient transfer and living conditions, and impact the diversity and functioning, of estuarine and coastal organisms. Publication and presentation of the results from these projects has resulted in widespread contribution to the development of marine science in New Zealand. Partnership with overseas researchers and presentations to international meetings and conferences has added to the growing global initiatives on marine biodiversity research questions.

Feedback from stakeholders has indicated that the move to a five-year research planning horizon was welcomed by research providers, but some stakeholders felt that Requests for Proposals should be at a higher level than individual projects to safeguard intellectual property on new ideas and methods.

ii. Does research planning now benefit from close cooperative relationships within the Ministry of Fisheries, with other government agencies, and with external stakeholders?

The Biodiversity Programme is highly cooperative. Of 38 projects underway in the last five years, 14 have formal collaborative components across government departments, with other stakeholders or multiple research providers and 10 have formal linkages to international research programmes. Within Fisheries New Zealand and with other stakeholders (NGOs, industry, other government departments), the Biodiversity Projects have contributed to Marine Stewardship Council certification processes, decision papers on aspects of Antarctic management under CCAMLR, and fulfilling Ministry commitments to the New Zealand Biodiversity Strategy. There are many other examples, e.g., the Programme has contributed towards DOC and Ministry decisions on marine protected areas. The interaction at the research and policy advice stages of resource management feeds back into the BRAG planning for future research.

There are close links with the Fisheries New Zealand Aquatic Environment research programme, the National Aquatic Biodiversity Information System (NABIS), a web-based interactive data access and mapping tool, and the Fisheries New Zealand Antarctic Research programme. These and other links have enabled contributions resulting from progress on land-sea interface research, habitats of significance to fisheries management, trophic studies (Marine Stewardship Council Certification), climate change (effects on shellfish), and habitat classification (fish optimised MEC, testing of MEC and BOMEC). The successful involvement of the Biodiversity Programme in major whole-of-government projects such as Ocean Survey 20/20 and IPY-CAML has also raised the profile of Fisheries New Zealand and the research it has commissioned both within New Zealand and internationally.

Datasets, voucher specimens, and samples from all biodiversity research projects have resulted in a substantial amount of material that has been physically preserved and housed in the Te Papa National Fish Collection, the NIWA Invertebrate Collection, and the Te Papa Herbarium (macroalgae). All data are held in databases either at Fisheries New Zealand, NIWA, or Te Papa, and accessibility is being improved. The recent Bay of Islands Ocean Survey 20/20 Portal was very well received and nominated for New Zealand Government Open Source awards. It also incorporates data access from Chatham Challenger and IPY projects. Data from a number of Ministry biodiversity projects have also been entered into international biodiversity databases such as OBIS and from there into the Global Biodiversity Information Facility (GBIF).

Biodiversity Research planning receives regular input from DOC, Seafood New Zealand, MfE, Cawthron Institute, NIWA, GNS, LINZ, Fisheries New Zealand, Te Papa Tongarewa, University of Auckland, AUT, University of Otago, MBIE, MFAT, regional councils, civil society, and others. Research planning for 2018–19 and beyond has included a re-alignment of the current research programme to take account of new developments such as The Future of Our Fisheries, MfE's environmental reporting programme, DOC's integrated marine protected area monitoring programme, and international commitments such as the Convention for Biological Diversity (CBD) COP10 Aichi-Nagoya Agreement.

Feedback and support for projects by external stakeholders has shown that the Programme has been effective in promoting inter-agency collaboration.

iii. Have mutually beneficial collaborative research projects been carried out alongside other New Zealand and international research providers, especially for vessel-based research?

As discussed above, collaborative research projects throughout government and among research providers have resulted in many mutually beneficial data and specimen collections; surveys of New Zealand marine biodiversity in New Zealand Territorial Sea, the EEZ, and the Ross Sea; ground-breaking research into seamount biodiversity and the identification of VMEs; and research for international collaboration, particularly vessel-based studies. Large-scale vessel-dependent oceanic research projects have made significant gains in baseline knowledge about the distribution and abundance of biodiversity in the EEZ/Ross Sea region. Vessel-based projects include: NORFANZ (Norfolk Island-Australia-New Zealand survey of biodiversity on Norfolk Ridge and Lord Howe Rise); BioRoss (MFish-LINZ, first New Zealand survey of biodiversity in the Ross Sea); Chatham-Challenger (LINZ-MFish-NIWA-DOC first Ocean Survey 20/20 project); NZ IPY-CAML (MFish-LINZ-NIWA; with international and New Zealand-wide collaboration) survey of the Ross Sea as part of International Polar Year; and biodiversity of seamounts (MFish-NIWA-LINZ-MBIE voyages to the Kermadec Arc and the Chatham Rise). These projects have generated huge geo-referenced datasets and thousands of specimens for Te Papa Tongarewa and the NIWA Invertebrate Collection. They have also resulted in the identification of new species, new genera, and new families, as well as new records extending the known distribution of species. These surveys have contributed to habitat classification, identified areas of high biodiversity, and challenged paradigms on the environmental drivers that determine biodiversity. More recently they have provided new information on the effects of ocean acidification on the productivity of polar seas, and in New Zealand waters.

Vessel-dependent coastal projects have also generated significant new understanding about the distribution of inshore biota, and the role they play in maintaining a healthy ecosystem. Experimental field work on the productivity of the seabed has been carried out in New Zealand waters (Fiordland, Otago, Bay of Islands, Hauraki Gulf, and Kaipara and Manukau harbours) and along the coast of the western Ross Sea. The impact of land practices on the land-sea interface has also highlighted real downstream effects on the productivity of the coastal environment. These projects have provided new insights into the connectivity between different species groups, and data are being used in a number of ways to assist with spatial planning by RMAs.

Feedback from stakeholders has indicated that the collaborative voyages administered through the Programme have successfully created synergy and opportunity for New Zealand scientists as well as facilitating new international collaborations.

iv. Have MFish Biodiversity projects contributed substantially to an improved understanding of New Zealand's marine biodiversity and its role in marine ecosystem function, yielding scientifically rigorous outputs for a national and international professional audience?

In the early years, the Programme focused primarily on taxonomy and the description of marine biodiversity. As the Programme matured, projects to address biodiversity roles in ecosystem function were introduced. Some were experimental and on a local scale whereas others were on a regional scale. Recent projects have addressed patterns of marine biodiversity in relation to environmental drivers and ecosystem function. These projects enabled modelling to predict the distribution of biodiversity in un-surveyed areas of ocean, evaluate the vulnerability of biodiversity to perturbations such as climate change, as well as model the trophic interactions among key fish species. Presentations of research results have been made to numerous overseas and New Zealand science audiences, and publications in the mainstream literature have been encouraged.

v. *Have results generated by Ministry of Fisheries Biodiversity projects been incorporated into management policy, with clear benefits for the New Zealand marine environment?*

Examples of incorporation into management policy with clear benefits for the marine environment include the increased awareness of research topics initiated in the biodiversity programme by policy analysts to core Aquatic Environment research projects and Fishery Plans (land-use effects, climate change in the ocean, habitat classification); links to the Antarctic research programme and uptake into CCAMLR (ecotrophic studies, ecosystem baselines, VME risk assessment, bioregionalisation), spatial management (seamount closures, BPAs, MPAs, RMAs); and the need by MfE to report on the marine environment at a national scale (plankton recording programme, Marine Environmental Monitoring Programme). Fisheries New Zealand biodiversity advice is frequently requested to contribute to cross-government initiatives including Ocean Survey 20/20, DOC Sub-Antarctic Islands Forum National Monitoring, Statistics New Zealand Tier 1 statistic review and Environmental Domain Stocktake, International Year of Biodiversity, OECD and CBD reports, International Oceans Issues, SPRFMO, NRS marine issues paper, the Antarctic Science Framework, Ocean Fertilisation, and IPCC. Finally, the Programme has contributed to New Zealand's efforts in the international Census of Marine Life and an ongoing assessment of New Zealand's progress in Marine Biodiversity has been proposed as a new Tier 1 Environmental Statistic.

However, the benefits to the marine environment are more inferred than demonstrated. There is increased awareness within Fisheries New Zealand and throughout government, that the health of fisheries and other valued uses of the sea depend on intact ecosystem services provided by the diversity of organisms, the diversity of habitats, and the genetic diversity found in the marine environment. Future biodiversity research will need to be tuned to Fisheries New Zealand Strategic Directions as well as Te Mana o te Taiao.

18.6 CONCLUDING REMARKS

Since its inception 21 years ago, the research in this Biodiversity Programme has evolved from defining and mapping the biological diversity of the sea, to elucidating the role of biodiversity in marine ecosystem function, threats to these roles, and how best biodiversity and its successful protection can be measured. Advances have been made in the provision of new identification tools for major groups (e.g., coralline algae), and progress has been made in raising the profile of biodiversity in coastal and ocean environmental management, in particular within new environmental legislation such as the Exclusive Economic Zone and Continental Shelf (Environmental Effects) Act (2012) and the Environmental Reporting Act (2015). As fisheries management moves towards EBFM, the role of biodiversity information will inevitably change towards informing EBFM.

As the CBD updates the Aichi-Nagoya Agreement with new post-2020 Biodiversity strategy and associated biodiversity and environmental targets, New Zealand must continue to progress our understanding of the marine biodiversity and the ecosystem services provided by the marine environment to inform national and international decision-making. This will continue to require a coordinated cross-government approach to link science to policy needs. Essentially, we need to know four things: what is out there in the marine environment to use, protect, or manage; how does the ecosystem function; what are the impacts of natural- and human-induced changes; and what tools will allow for effective monitoring and management of environmental change? For example, there is a compelling need for large-scale projects such as mapping seafloor habitats and establishing long-term nationwide monitoring and reporting schemes to measure the effects of ocean climate change, and regular assessment of the cumulative effects of anthropogenic activities and multiple stressors in the ocean and the effectiveness of their management. Without these, we face the risks that New Zealand's 'green' branding will be increasingly challenged, and that tipping points in the health of the aquatic environment may be reached before evasive action can be taken.

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19 APPENDICES

Status of chapter	This chapter has been updated for AEBAR 2021

19.1 GLOSSARY OF TERMS AND ACRONYMS

19.1.1 GLOSSARY

Term	Definition
Aquaculture	The practice of farming aquatic organisms such as salmon, freshwater prawns, or shellfish in marine and freshwater environments.
Benthic Protection Area (BPA)	Any area established by the Fisheries (Benthic Protection Areas) Regulations 2007 as being a BPA.
Biodiversity	The variety of species, and the ecological systems in which they reside. Includes diversity within and between species, and diversity of habitat. This term is defined in the Resource Management Act 1991 and the Fisheries Act 1996.
Biomass	The total quantity or weight of organisms in a given area or volume.
Bycatch	Species not targeted by a fishery but caught incidentally during fishing operations. Once caught, they are either landed, discarded or released.
Chondrichthyan	A member of the Chondrichthyes class, often referred to as cartilaginous fishes. Members of this class include sharks, rays, skates and chimaeras.
Continental Shelf	The submerged border of a continent that slopes gradually and extends to a point of steeper descent to the ocean bottom.
Continental Slope	A region on the outer edge of a continent between the generally shallow continental shelf and the deep-ocean floor, usually demarcated from the shelf by a 200m isobath.
Cryptic Mortality	Interactions that result in mortality which are unobserved or unobservable.
Ecosystem	An interacting system of living and non-living parts such as sunlight, oxygen, water and nutrients. Ecosystems can vary in size and longevity (e.g., a raft of detached seaweed floating in the open ocean that supports a small community, or a seamount and its associated flora and fauna).
El Niño-Southern Oscillation (ENSO)	An irregularly recurring climate pattern that results in changes in the temperature of waters in the central and eastern tropical Pacific Ocean. The warming phase of sea temperature is known as El Niño and the cooling phase as La Niña, with each period lasting up to several years.
Endemic	An organism that occurs naturally only in one place or region.
Exclusive Economic Zone (EEZ)	An area of the ocean extending from 12 to 200 nautical miles from shore, including the seabed and subsoil. 1982 United Nations Convention on the Law of the Sea (UNCLOS).
Habitat	The place or type of area in which an organism resides. Can be biogenic/living (e.g., kelp forest) or abiotic/non-living (e.g., a rocky reef).
Indicator	A measure against which some aspects of performance can be assessed.
Indicator Species	A species whose presence or absence is indicative of a particular habitat, community or set of environmental conditions. The presence/absence of such a species is sometimes used as a proxy for characteristics of the environment.
Interdecadal Pacific Oscillation (IPO)	A pattern of climate variability in the Pacific Ocean with phases lasting 20-30 years.

Term	Definition
Intergovernmental Panel on Climate Change (IPCC)	An international body that assesses the science related to climate change. IPCC assessments are written by hundreds of leading scientists from around the world.
Invertebrate	An animal without a backbone or spinal column. Corals, sponges and jellyfish are common marine examples.
Kaitiakitanga	The act of stewardship, guardianship or trusteeship; usually in reference to species and the environment.
Longline Fishing	A method of fishing using lines that trail back behind a boat for a set distance, with baited hooks set at fixed intervals.
Marine Protected Area (MPA)	Protected areas of seas, oceans, or estuaries that restrict human activity for a conservation purpose, typically to protect natural or cultural resources.
Mātauranga Māori	The knowledge, comprehension or understanding of everything visible and invisible; often used to mean 'wisdom'. Includes contemporary, historic, local and traditional knowledge.
Monitoring	The act of measuring change in the state, characteristics, number or presence of something.
Overfishing	A situation where observed fishing mortality (or exploitation) rates are higher than target or threshold levels.
Productivity	Productivity is a function of the biology of a species and the environment in which it lives. Generally, species with a high productivity are more resilient and take less time to rebuild from a depleted state.
Quota Management System (QMS)	A system established in 1986 to control the total commercial catch by allocating set amounts of catch or 'quota' for most of the main fish stocks in New Zealand's Exclusive Economic Zone.
Seamount	An isolated rise in elevation of 1,000 metres or more from the surrounding seafloor.
Seine Fishing	A method of fishing that uses a net which hangs vertically in the water with its bottom edge held down by weights and its top edge buoyed by floats. Purse-seines have a number of rings on their bottom edge with a line running through.
Species	A group of genetically isolated interbreeding populations, that typically share an ecological niche
Territorial Sea	A belt of coastal waters extending at most 12 nautical miles from the baseline (usually the mean low-water mark) of a coastal state.
Threat Classification Sytem	The New Zealand Threat Classification System classifies species as Not Threatened, Not Assessed or Threatened. Threatened includes three subcategories: Nationally Critical, Nationally Endangered and Nationally Vulnerable.
Trawling	A method of fishing that involves towing a large net through the water behind a boat for a set period before hauling on deck. Some operate in midwater, others touch the seafloor.

19.1.2 MĀORI NAMES MARINE SPECIES

Table 2. List of Aotearoa moana taxa in te reo Māori, English common names, and recognised scientific names to lowest level of taxonomic resolution.

Māori Name	English Common Name	Scientific Name
Aihe	Common dolphin	*Delphinus delphis*
Arokehe/kirirua/orea	Longfin eel	*Anguilla dieffenbachii*

Māori Name	English Common Name	Scientific Name
Ehouhounamu/ngutere/nanua/manua/maratea/ngutere	Red moki	*Cheiliodactylus spectabilis*
Hānea	Black mussel	*Xenostrobus pulex*
Hangenge/Ihe/takeke	Piperfish/garfish	*Hyporhamphus ihi*
Hanikura	Wedge clam	*Macomona liliana*
Hao/matamoe	Shortfin eel	*Anguilla australis*
Hāpuka/hāpuku/whapuku	Groper/wreckfish	*Polyprion oxygeneios*
Hoiho	Yellow-eyed penguin	*Megadyptes antipodes*
Hoka	Red cod	*Pseudophycis bachus*
Honu	Loggerhead sea turtle	*Caretta caretta*
Honu	Leatherback sea turtle	*Dermochelys coriacea*
Hoka/Hokorari	Ling	*Molva molva*
Hoki	Blue grenadier/blue hake/whiptail /hoki	*Macruronus novaezelandiae*
Hopuhopu/Kanae	Grey mullet	*Mugil cephalus*
Huangi/tuangi	New Zealand cockle	*Austrovenus stutchburyi*
Kakau moana	Gummy weed	*Splachnidum rugosum*
Kāeo	Cook's turban shell	*Cookia sulcata*
Kāeo	Snail whelk	*Haustrum haustorium*
Kahawai (hapukupuku)	Kahawai (juvenile form)	*Arripis trutta*
Kaikaikaroro	Triangle Shell	*Spisula aequilatera*
Kaitangata	Cat's eye	*Turbo smargdus*
Kakere/mangō pare	Hammerhead shark	*Sphyrna zygaene*
Kapetā	School shark	*Galeorhinus galeus*
Karahiwa/marariwha	Queen pāua/austral abalone/yellow-footed pāua	*Haliotis australis*
Karengo/parengo/tupata	Southern laver	*Porphyra columbina*
Kataha/makawhiti/maraua/mokowhiti	Yellow-eye mullet	*Aldrichetta forsteri*
Kāunga	Hermit crab	Superfamily: Paguroidea
Kawikawi/Kehe/Koeae/ngehe	Marblefish	*Aplodactylus arctidens*
Karoro	Black-backed gull	*Larus dominicanus*
Kehe	Hake	*Merluccius australis*
Kekeno	New Zealand fur seal	*Arctocephalus forsteri*
Kina	Common sea urchin	*Evechinus chloroticus*
Koakoa/tītī/totorore/hakoko	Muttonbird/sooty shearwater	*Puffinsus griseus*
Koinga/mango tara/pioke	Spiny dogfish	*Squalus acanthias*
Koio/marapeka	Virgin/white foot pāua	*Haliotis virginea*
Kōiro/ kōriro/ngōiro	Southern conger eel	*Conger verreauxi*
Kōkiri	Leatherjacket	*Parika scaber*
Kōrama	Winkle/cat's eye	*Turbo smaragdus*
Korokoro/piharau/puhikorokoro/tuna korokoro	Lamprey	*Geotria australis*
Kororā	Little blue penguin/fairy penguin	*Eudyptula minor*
Kōtore moana	Red sea anemone	*Actinia tenebrosa*
Kōura papatea/matapara	Red rock lobster/spiny craysfish	*Jasus edwardsii*

Māori Name	English Common Name	Scientific Name
Kuku/kūtai/pōrohe	Green-lipped mussel	*Perna canaliculus*
Kuku-mau-toka	Banded mussel	*Modiolarca impacta*
Kumukumu/pūwhaiau	Red gurnard	*Chelidonichthys kumu*
Kūpā	Horse mussel	*Atrina pectinata zelandica*
Kupae	Sprat	*Sprattus* spp.
Kuparu	John Dory	*Zeus faber*
Kuwha	Elegant venus shell	*Irus elegans*
Kuwharu	Purple sunset shell	*Gari stangeri*
Kōpūpūtai roa	Long finger sponge	*Callyspongia ramosa*
Kōpūpūtai nui	Large cup sponge	*Gellius imperialis*
Kūtoro/moamoa/kourepoua	Spotted stargazer	*Genyagnus monopterygius*
Maki	Orca/killer whale	*Orcinus orca*
Mako	Shortfin mako	*Isurus oxyrinchus*
Makō/pioke	Rig/spotted dogfish/gummy shark	*Mustelus lenticulatus*
Mangō pounamu	Blue shark	*Prionace glauca*
Mangō ripi	Thresher shark	*Alopias vulpinus*
Mangō ururoa/mango tuatini	Great white shark/white shark/white pointer shark	*Carcharodon carcharias*
Mararī/rarī	Greenbone butterfish	*Odax pullus*
Moamoa/kourepoua	Giant stargazer/monkfish	*Kathetostoma giganteum*
Mohimohi	Pilchard	*Sardinops sagax*
Ngaeti	Common periwinkle	*Nodilittorina antipodum*
Ngerungeru/reremai	Bronze whaler	*Carcharhinus brachyurus*
Ngutoro/moeone	Bass	*Polyprion americanus*
Paea	Swordfish	*Xiphias gladius*
Pahiwihiwi	Kelpfish	*Chironemus marmoratus*
Paikea	Humpback whale	*Megaptera novaeangliae*
Pākirikiri/pātutuki/rāwaru	Blue cod/rock cod	*Parapercis colias*
Pākirikiri	Spotty	*Notolabrus celidotus*
Pāmu wēra/parāoa	Sperm whale	*Physeter macrocephalus*
Pāpaka	Paddle crab	*Ovalipes catharus*
Parakipīhi/tukuperu/upokohue/whāngai mokopuna	Pilot whale	*Globicephala melas*
Pātangaroa	Sun star	*Stichaster australis*
Pātiki	Flounder	*Rhombosolea* spp.,
Pātiki	Lemon sole	*Pelotretis flavilatus*
Pātiki	New Zealand turbot	*Colistium nudipinnis*
Pātiki tōtara/pātōtara	Yellowbelly flounder	*Rhombosolea leporina*
Pātiki mohoao/mohoao	Black flounder	*Rhombosolea retiaria*
Pawharu	Packhorse rock lobster	*Jasus verreauxi*
Pekapeka rau	Medusa-headed starfish	*Gorgonocephalus novaezelandiae*
Pōrohe	Blue mussel	*Mytilus edulis*

Māori Name	English Common Name	Scientific Name
Popoto	Māui dolphin	*Cephalorhynchus hectori maui*
Porotaka moana	Globe sponge	*Tethya aurantium*
Puhikorokoro	Yellow moray	*Gymnothorax prasinus*
Pūngorungoru/kōpūpūtai	Sponge	Phylum: Porifera
Purewha	Hairy mussel	*Modiolus areolatus*
Pūpū terakihi/muheke	Paper nautiluses	*Argonauta* spp.
Rātāhuihui	Sunfish	*Mola ramsayi*
Raiti wēra/tohora/kewa	Southern right whale	*Eubalaen australis*
Rāpoka	New Zealand Sea Lion	*Phocarctos hookeri*
Rau wheke	Sea lily	*Comanthus novaezelandiae*
Repe/reperepe	Elephantfish	*Callorrhinchus milii*
Rimu/rimurimu	Seaweed	Divisions: Rhodophyta, Phaeophyta, Chlorophyta
Rimurapa/kōauau	Bull kelp	*Durvillaea antarctica*
Rimurehia	Eelgrass/seagrass	*Zostera* spp.
Rori whiore	Tailed sea cucumber	*Caudina coriacea*
Taketake/tarāpunga	Red-billed seagull	*Larus noaehollandiae scopulius*
Tāmure	Snapper	*Chrysophrys auratus*
Tāngahangaha/tāngāngā	Banded wrasse	*Notolabrus fucicola*
Tarakihi	Ocean bream	*Nemadactylus macropterus*
Taranui	Caspian tern	*Hydroprogne caspia*
Tawaki/tawhaki/pokotiwha	Firodland crested penguin	*Eudpytes pachyrhynchus*
Tiikati	Hake	*Merluccius australis*
Tio reperepe/karauria ngakihi	Rock oyster	*Saccostrea glomerata*
Tītī	Cook's petrel	*Pterodroma cooki*
Totorore/tōtōrore	Antarctic prion	*Pachyptila desolata*
Toroa	Black-browed mollymawk	*Diomeda melanophrys*
Toroa	Northern royal albatross	*Diomeda sanfordi*
Toroa/toroa ingoingo/toroa whakaingo	Southern royal albatross	*Diomeda epomophora*
Toroa	Wandering albatross	*Diomedea exulans*
Toroa pango/pēō/kōputu	Light-mantled sooty albatross	*Phoebetria palpebrata*
Toheroa/moeone	-	*Paphies ventricosa*
Tuare/tuere	Common hagfish	*Eptatretus cirrhatus*
Tuatini	Sevengill shark	*Notorynchus cepedianus*
Tuatini	Sixgill shark	*Hexanchus griseus*
Tuatua/kahitua	-	*Paphies subtriangulata*
Tutumairekurai/tūpoupou/upokohue/pehipehi/ahoaho/waiaua	Hector's dolphin	*Cephalorhynchus hectori*
Warehenga	Kingfish	*Seriola lalandi*

Māori Name	English Common Name	Scientific Name
Whai	Stingray/skate	Order: Myliobatiformes, rajiformes
Whai keo/whai repo	Eagle ray	*Myliobatis tenuicaudatus*
Whai repo	Short-tail stingray	*Dasyatis brevicaudata*
Whai repo	Long-tail stingray	*Dasyatis thetidis*
Wheke	Octopus/squid	Subclass: Coleodiea

19.2 MEMBERSHIP AND PROTOCOLS FOR ALL SCIENCE WORKING GROUPS

Terms of Reference for Fisheries Assessment Working Groups (FAWGs) in 2021

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 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.

7. Where appropriate and practical, to conduct projections of likely future stock status using alternative fishing mortality (or exploitation) rates, or catches, or 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" 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, bycatch 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.

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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 these three quantities.

[2] Link to the Harvest Strategy Standard: https://www.mpi.govt.nz/dmsdocument/728-harvest-strategy-standard-for-new-zealand-fisheries

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 stock 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).

19.3 TERMS OF REFERENCES FOR THE AQUATIC ENVIRONMENT WORKING GROUPS (AEWG) FOR 2021

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, include:

- 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. The Ministry'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 the Aquatic Environment and Biodiversity Annual Review

10. To include in contributions to the Aquatic Environment and Biodiversity Annual 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, bycatch 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 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 are other Science Working Groups (see separate document).

19.4 TERMS OF REFERENCE FOR THE BIODIVERSITY RESEARCH AND ADVISORY GROUP (BRAG) IN 2021

Overall purpose

Since 2000, the objectives of the Biodiversity Research Programme had been drawn directly from Fisheries New Zealand commitments to Theme 3 of the New Zealand Biodiversity Strategy (NZBS) 2000. The refresh of the NZBS (Te Mana o te Taiao – The Aotearoa New Zealand Biodiversity Strategy 2020) was released in 2020 and Fisheries New Zealand subsequently developed new workstreams within the Biodiversity Research Programme to align with the objectives and goals of this strategy. Within this framework, the workstreams will adapt over time as new issues emerge, to build on synergies with other research programmes and work where biodiversity is under greatest threat from fishing or other anthropogenic activities, within the constraints of the overall purpose of the programme which is:

> "To improve our understanding of New Zealand marine ecosystems in terms of species diversity, marine habitat diversity, and the processes that lead to healthy ecosystem functioning, and the role that biodiversity has for such key processes"

The science currently commissioned broadly aims to:

- Describe and characterise the distribution and abundance of fauna and flora, as expressed through measures of biodiversity, and improving understanding about the drivers of the spatial and temporal patterns observed;

- Determine the functional role of different organisms or groups of organisms in marine ecosystems, and assess the role of marine biodiversity in mitigating the impacts of anthropogenic disturbance on healthy ecosystem functioning; and

- Identify which components of biodiversity must be protected to ensure the sustainability of a healthy marine ecosystem as well as to meet societal values on biodiversity.

Fisheries New Zealand also convenes an Aquatic Environment Working Group (AEWG) which has a similar review function to BRAG. 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 marine issues related to the functionality of the marine ecosystem and its productivity, whereas projects considered by AEWG are more commonly focused on the direct effects of fishing.

BRAG may identify natural resource management issues that extend beyond fisheries management and make recommendations on priority areas of research that will inform Fisheries New Zealand or other government departments of emerging science results that require the attention of managers, policymakers, and decision-makers in the marine sector. BRAG 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. Prior to the beginning of BRAG meetings each year, Fisheries New Zealand fisheries scientists will produce a list of issues for which new research projects are likely to be required in the forthcoming financial year. The BRAG Chair will determine the final timetables and agendas.

2. The Ministry's research planning processes should identify most information needs well in advance but, if urgent issues arise, Fisheries New Zealand fisheries managers will alert the Aquatic Environment and Biodiversity Science Manager and the Principal Advisor Fisheries Science at least three months prior to the required meetings where possible.

BRAG technical objectives

3. It is the responsibility of the BRAG to review, discuss, and convey views on the results of marine biodiversity research projects contracted by Fisheries New Zealand. The review process is an evaluation of how existing research results can be built upon to address emerging research issues and needs. It is essentially an evaluation of "what we already know" and how this can be used to obtain "what we need to know". This information should be used by BRAG to identify gaps in our knowledge and for developing research plans to address these gaps.

4. It is the responsibility of BRAG participants to discuss, evaluate, make recommendations, and convey views on particular research areas as required. Individual related projects on a species or fishery or research topic need to be aligned with relevant strategic and policy directions.

5. The recommendations on project proposals for the next financial year will be submitted via the Chair of BRAG to the Principal Science Advisor Fisheries.

6. The Biodiversity Research Programme includes research in New Zealand's TS, EEZ, Extended Continental Shelf, the South Pacific Region, and the Ross Sea region. There are five scientific work streams as follows:

    - Iwi and community-based biodiversity projects
    - Baseline knowledge for Ecosystem-Based Fisheries Management (EBFM)
    - Tools and methods for biodiversity and ecosystem assessment
    - Functional threats to biodiversity
    - Sustainability for future generations

BRAG input to the Fisheries Assessment Plenary and the Aquatic Environment and Biodiversity Annual Review

7. To contribute to and summarise progress on biodiversity research in the Aquatic Environment and Biodiversity Annual Review. This contribution is analogous to Working Group Reports from the Fisheries Assessment Working Groups.

8. To summarise the assessment methods and results, along with estimates of relevant standards, references points, or other metrics that may be relevant to biodiversity objectives, the Biodiversity Strategy, and international obligations.

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

10. To advise the Principal Science Advisor Fisheries about issues of particular importance that may require review by a Plenary meeting or summarising in the Aquatic Environment and Biodiversity Annual Review. The general criterion for determining which issues should be discussed by a wider group include:
    - Emerging issues, recent or current biodiversity status assessments, trends, or projections;
    - The development of a major trend in the marine environment that will impact on marine productivity or ecosystem resilience to stressors; and
    - Any new studies or data that impact on international obligations.

Membership and Protocols for all Science Working Groups

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

19.5 TERMS OF REFERENCE FOR THE ANTARCTIC WORKING GROUP (ANTWG) IN 2021

Overall purpose

The purpose of the ANTWG is to review science and research information intended for submission to or use by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR). CCAMLR is an inter-governmental organisation that is committed to conserving the marine life of the Southern Ocean while allowing rational use of marine resources, including commercial fishing. The CCAMLR Convention requires that management considers the effects of fishing on dependent and associated species as well as on the target species. The area of jurisdiction of the CCAMLR Convention is approximately south of the circumpolar Antarctic Polar Front in the Southern Ocean. Science and research requested or used by CCAMLR may include, *inter alia*, fisheries characterisations, abundance indices, catch-at-age or catch-at-length data, and stock assessment modelling to assess the status of fish stocks managed by CCAMLR; bycatch and unobserved mortality of protected species, fish, and other marine life; effects on biodiversity and benthic biodiversity, species, and habitat; and changes to ecosystem structure and function as a result of fishing, including trophic effects. The ANTWG also undertakes scientific review of documents and papers that may be submitted to the scientific working groups of CCAMLR to aid and inform its management. The ANTWG does not make management recommendations or decisions; these responsibilities lie with CCAMLR's Scientific Committee and the Commission.

Preparatory tasks

1. Prior to the first meeting of the ANTWG each year, the ANTWG Chair will produce a list of stocks/issues for which new stock assessments, evaluations, impact assessments, risk assessments, or other scientific analyses have been requested by the CCAMLR Scientific Committee or the Commission (including its contributing bodies), fishing industry, or other stakeholders. The ANTWG Chair will determine the final timetables and agendas of the working group each year, taking account of the available time and resources.

Technical objectives

2. To review new research information on stock structure, productivity, abundance, and related topics for each fish stock or environmental issue under the purview of the ANTWG.
3. Where possible, to derive yields or reference points requested by CCAMLR's Scientific Committee or Commission related to fish stocks or environmental issues relevant to CCAMLR fisheries.

4. To conduct stock assessments or evaluations for selected stocks to determine the precautionary yields and status of the stocks relative to the requested reference points or, if no such reference points are specified by CCAMLR, MSY-compatible reference points and associated limits, based on the "Guide to Biological Reference Points for Fisheries Assessment Meetings" and New Zealand's Harvest Strategy Standard.
5. For stocks where the status is unknown, the ANTWG should, where possible, use any existing data and analyses to draw conclusions about likely future trends in biomass levels and/or fishing mortality (or exploitation) rates if current catches and/or TACs are maintained, or if fishers or CCAMLR are considering modifying them in other ways.
6. Where requested by the CCAMLR Scientific Committee or Commission, to conduct projections of likely future stock status using alternative fishing mortality (or exploitation) rates or catches and other relevant management actions, based on input from the ANTWG and any guidance from the CCAMLR Scientific Committee or Commission.
7. Where requested by the CCAMLR Scientific Committee or Commission, in relation to specified stocks, to develop and report on alternative rebuilding scenarios.
8. To conduct environmental impact assessments and qualitative or quantitative risk assessments in relation to bycatch species, other species of concern, benthic systems, or vulnerable marine ecosystems to support the work of the CCAMLR Scientific Committee and Commission.

Working Group reports

9. To review, and update if necessary, the "Status of the Stocks" tables in the Fisheries Assessment Plenary report based on new data or analyses, or other relevant information.
10. To complete (and/or update) the Status of Stocks tables using the template provided in the Introductory chapter of the most recent May Plenary report.
11. To review, and update if necessary, the "Antarctic Science" chapter of the Aquatic Environment and Biodiversity Review (AEBAR) based on new data or analyses, or other relevant information.
12. It is desirable that full agreement amongst technical experts is achieved on the text of the ANTWG reports. If full agreement amongst technical experts cannot be reached, the Chair will determine how this will be depicted in the ANTWG report, will document the extent to which agreement or consensus was achieved, and record and attribute any residual disagreement in the meeting notes.

Papers and reports to CCAMLR

13. Papers and reports summarising work reviewed by the ANTWG are generally submitted to CCAMLR's Scientific Committee, and their content varies widely. It is desirable that full agreement amongst technical experts is achieved on the content of such papers or reports, noting that deadlines for submission to CCAMLR may require the Chair to finalise text after a meeting of the ANTWG has considered and resolved scientific issues. If full agreement amongst technical experts cannot be reached, the Chair will determine how this will be depicted in the paper or report to be submitted to CCAMLR. In such cases, the Chair will also 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

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

FISHERIES ASSESSMENT WORKING GROUPS: MEMBERSHIP 2021

Antarctic Working Group

Convenors: Marine Pomarède and Nathan Walker

Members: Matthew Baird, Stephanie Brown, Jennifer Devine, Alistair Dunn, Jack Fenaughty, Greig Funnell, Simon Hoyle, Leyla Knittweis-Mifsud, Dan MacGibbon, Bradley Moore, Monique Messina, Phillip Neubauer, Richard O'Driscoll, Steve Parker, Matt Pinkerton, Brodie Plum, Darryn Shaw, Andy Smith, Perry Smith, Josh Van Lier, Tim Vaughan-Sanders, Barry Weeber, D'arcy Webber.

Species: Antarctic toothfish

Aquatic Environment Working Group – Protected Species

Convenors: William Gibson and Ben Sharp

Members: Ed Abraham, Carolyn Aguilar, Owen Anderson, Sonja Austin, Hilary Ayrton, Karen Baird, Barry Baker, Scott Baker, Joshua Baller, Josh Barclay, Steve Beatson, Erik Behrens, Elizabeth Bell, Mike Bell, Katrin Berkenbusch, Tiffany Bock, Laura Boren, Christine Bowden, David Bowden, Erin Breen, Paul Breen, Anthony Brett, Tom Brough, Curly Brown, Ian Brown, Sarah Bury, Glen Carbines, Susan Chalmers, Mark Chambers, Simon Childerhouse, Malcolm Clark, Tom Clark, Katie Clemens-Seely, Deanna Clement, George Clement, Damian Cloeter, Rochelle Constantine, Justin Cooke, Vonda Cummings, Roberta D'Archino, Steve Dawson, Igor Debski, Jessica Desmond, Jennifer Devine, Christopher Dick, Peter Dillingham, Clinton Duffy, Alistair Dunn, Matt Dunn, Charles Edwards, Mark Edwards, Pablo Esobar-Flores, Jack Fenaughty, Brit Finucci, David Foster, Allen Frazer, Debbie Freeman, Richa Garg, Sharleen Gargiulo, Shane Geange, Mark Geytenbeek, Dave Goad, Bruce Hartill, Barb Hayden, Jeremy Helson, Hannah Hendriks, Kristina Hillock, Freyda Hjorvarsdottir, Lyndsey Holland, Steven Holmes, Simon Hoyle, Lucy Jacob, Emma Jones, Daniel Kerrigan, Brianna King, Kirstie Knowles, Jo Lambie, Todd Landers, Kath Large, Laws Lawson, Mary Livingston, Carolyn Lundquist, Dave Lundquist, Greg Lydon, Darryl MacKenzie, Lucy Manning, Thomas Mattern, Sue Maturin, Gemma McGrath, Andy McKenzie, Stefan Meyer, Karen Middlemiss, David Middleton, Jodi Milne, Janice Molloy, Kiri Morgan, Mark Morrison, Rikki Mules, Philip Neubauer, Richard O'Driscoll, Enrique Pardo, Graham Parker, Steve Parker, Darren Parsons, Michael Patrick, Heiko Philippi, Johanna Pierre, Matt Pinkerton, Tiffany

Plencner, Will Rayment, Trish Rea, Nathan Reid, Yvan Richard, Jesse Rihia, Peter Ritchie, Jim Roberts, Ashley Rowden, Richard Saunders, Carol Scott, Katherine Short, Liz Slooten, Andy Smith, Paul Starr, Kevin Sullivan, Darryl Sykes, John Taunton-Clark, Graeme Taylor, David Thompson, Finlay Thompson, Hamish Tijsen, Rob Tilney, Geoff Tingley, Rob Tinkler, Di Tracey, Ian Tuck, Dominic Vallieres, Anton Van Helden, Josh van Lier, Adam Watson, Shannon Weaver, D'Arcy Webber, Trudi Webster, Barry Weeber, Richard Wells, Tamar Wells, James Williams, Oliver Wilson, Inge Wisselink, Jeanne Wissing, Andrew Wright, Jingjing Zhang.

Aquatic Environment Working Group – Benthic and Habitats

Convenors: Karen Tunley

Members: Ed Abraham, Carolyn Aguilar, Owen Anderson, Sonja Austin, Hilary Ayrton, Karen Baird, Barry Baker, Scott Baker, Joshua Baller, Josh Barclay, Steve Beatson, Erik Behrens, Elizabeth Bell, Mike Bell, Katrin Berkenbusch, Tiffany Bock, Laura Boren, Christine Bowden, David Bowden, Erin Breen, Paul Breen, Anthony Brett, Tom Brough, Curly Brown, Ian Brown, Sarah Bury, Glen Carbines, Susan Chalmers, Mark Chambers, Simon Childerhouse, Malcolm Clark, Tom Clark, Katie Clemens-Seely, Deanna Clement, George Clement, Damian Cloeter, Rochelle Constantine, Justin Cooke, Vonda Cummings, Roberta D'Archino, Steve Dawson, Igor Debski, Jessica Desmond, Jennifer Devine, Christopher Dick, Peter Dillingham, Clinton Duffy, Alistair Dunn, Matt Dunn, Charles Edwards, Mark Edwards, Pablo Esobar-Flores, Jack Fenaughty, Brit Finucci, David Foster, Allen Frazer, Debbie Freeman, Richa Garg, Sharleen Gargiulo, Shane Geange, Mark Geytenbeek, Dave Goad, Bruce Hartill, Barb Hayden, Jeremy Helson, Hannah Hendriks, Kristina Hillock, Freyda Hjorvarsdottir, Lyndsey Holland, Steven Holmes, Simon Hoyle, Lucy Jacob, Emma Jones, Daniel Kerrigan, Brianna King, Kirstie Knowles, Jo Lambie, Todd Landers, Kath Large, Laws Lawson, Mary Livingston, Carolyn Lundquist, Dave Lundquist, Greg Lydon, Darryl MacKenzie, Lucy Manning, Thomas Mattern, Sue Maturin, Gemma McGrath, Andy McKenzie, Stefan Meyer, Karen Middlemiss, David Middleton, Jodi Milne, Janice Molloy, Kiri Morgan, Mark Morrison, Rikki Mules, Philip Neubauer, Richard O'Driscoll, Enrique Pardo, Graham Parker, Steve Parker, Darren Parsons, Michael Patrick, Heiko Philippi, Johanna Pierre, Matt Pinkerton, Tiffany Plencner, Will Rayment, Trish Rea, Nathan Reid, Yvan Richard, Jesse Rihia, Peter Ritchie, Jim Roberts, Ashley Rowden, Richard Saunders, Carol Scott, Katherine Short, Liz Slooten, Andy Smith, Paul Starr, Kevin Sullivan, Darryl Sykes, John Taunton-Clark, Graeme Taylor, David Thompson, Finlay Thompson, Hamish Tijsen, Rob Tilney, Geoff Tingley, Rob Tinkler, Di Tracey, Ian Tuck, Dominic Vallieres, Anton Van Helden, Josh van Lier, Adam Watson, Shannon Weaver, D'Arcy Webber, Trudi Webster, Barry Weeber, Richard Wells, Tamar Wells, James Williams, Oliver Wilson, Inge Wisselink, Jeanne Wissing, Andrew Wright, Jingjing Zhang.

Aquatic Environment Working Group – Non-Target Fish and Invertebrate Catch

Convenors: Marco Milardi and Josh van Lier

Members: Owen Anderson, Hilary Ayrton, Ian Brow, Tiff Bock, Glen Carbines, Mark Chambers, Simon Childerhouse, Tom Clark, Damien Cloeter, Rochelle Constantine, Jean Davis, Jennifer Devine, Clinton Duffy, Charles Edwards, Rosa Edwards, Malene Felsing, Jack Fenaughty, Brit Finucci, David Foster, Dave Goad, Kat Goddard, Phil Heath, Lyndsey Holland, Aaron Irving, Emma Jones, Brianna King, Todd Landers, Kath Large, Mary Livingston, David Lundquist, Greg Lydon, Stefan Meyer, Karen Middlemiss, David Middleton, Sophie Mormede, Mark Morrison, Campbell Murray, Richard O'Driscoll, Enrique Pardo, Darren Parsons, Trent Rasmussen, Nathan Reid, Jesse Rihia, Carolyn Scott, Fabrice Stephenson, Karli Thomas, Rob Tilney, Rob Tinkler, Ian Tuck, Karen Tunley Te Aomihia Walker, Cath Wallace, Barry Weeber, Richard Wells, Tamar Wells, John Willmer, Jeanne Wissing

Biodiversity Research and Advisory Group (BRAG)

Convenor: Mary Livingston

Members: Teresa A'mar, Owen Anderson, Tara Anderson, Erik Behrens, Katrin Berkenbusch, Tiffany Bock, David Bowden, Paul Breen, Sarah Bury, Glen Carbines, Malcolm Clark, Tom Clark, George Clement, Damien Cloester, Vonda Cummings, Roberta D'Archino, Moira Decima, Matt Dunn, Pablo Escobar-Flores, Jack Fenaughty, Debbie Freeman, Jonathan Gardner, Sharleen Gargiulo, Shane Geange, William Gibson, Britt Graham, Barb Hayden, Lyndsey Holland, Steven Holmes, Aaron Irving, Emma Jones, Daniel Kerrigan, Brianna King, Kirstie Knowles, Todd Landers, Cliff Law, Daniel Leduc, Carolyn Lundquist, Dave Lundquist, Greg Lydon, Alison MacDiarmid, Jeremy McKenzie, David Middleton, Marco Milardi, Te Taiawatea Moko-Mead, Wendy Nelson, Philip Neubauer, Richard O'Driscoll, Enrique Pardo, Darren Parsons, Michael Patrick, Rachael Peart, Matt Pinkerton, Nathan Reid, Jesse Rihia, Peter Ritchie, Jim Roberts, Karen Robinson, Ashely Rowden, Carol Scott, Andy Smith, Aroha Spinks, Kevin Sullivan, Phil Sutton, Rob Tilney, George Tingley, Di Tracey, Karen Tunley, Josh van Lier, Trudi Webster, Richard Wells, Tamar Wells, Oliver Wilson, Inge Wisselink, Jeanne Wissing.

19.6 AQUATIC ENVIRONMENT AND BIODIVERSITY FUNDED AND RELATED PROJECTS

The AEBR citations in the following table can be found in an online repostitory here, and FRR and other reports may be found here.

Theme	Project code	Project title	Specific objectives	Status	Citation/s
BEN	BEN2021-03	Taxonomic identification of benthic invertebrate samples	1. To taxonomically identify deepwater benthic invertebrates to species level where possible in samples taken during research trawls and by observers on fishing vessels targeting deepwater stocks. 2. To update relevant databases recording the catch of invertebrates in research trawls and commercial fishing.	In progress	
BYC	BYC2021-02	Protected Chondrichthyan captures characterisation	1. Describe and characterise captures of all protected Chondrichthyans in New Zealand waters, using all available data. 2. Analyse gears/fisheries, locations, status at release, and capture trends, and identify factors that appear to lead to captures.	In progress	
BYC	BYC2021-03	Bycatch monitoring and quantification in deepwater fisheries	Estimate catch composition in target deepwater fisheries (various fisheries to be addressed cyclically). This should include an estimation of the quantity of non-target fish species caught, and the target and non-target fish species discarded, in a format that meets management needs. Estimated rates and amounts of bycatch and discards in the different deepwater fisheries are to be compared with previous estimates to identify trends over time.	In progress	
BYC	ENV2020-20	Temporal and spatial distribution of non-target catch, and non-target species, in deepwater fisheries	1. A spatially- and temporally-detailed representation of non-target catch in deepwater fisheries around New Zealand, coupled with catch data and fishery information on the location of non-target catch hotspots; the influence of seasonal factors on non-target catch hotspots; and the species and fishing methods that may be driving these hotspots. 2. A spatial distribution of some of the most representative non-target species, modelled from catch and survey data, as well as environmental data.	In progress	

Theme	Project code	Project title	Specific objectives	Status	Citation/s
BEN	KAI2020-01	Monitoring of rocky reef habitats across degrees of uplift caused by the 2016 Kaikoura earthquake	1. Repeat three annual surveys of 16 intertidal areas across degrees of uplift. 2. Repeat three annual surveys of 6 subtidal sites across degrees of uplift. 2. Assess the recovery of nearshore rocky reef communities.	In progress	Falconer et al. (2021) FRR 4243
BEN	SEA2020-14	Pelorus multibeam groundtruthing and analysis	1. Generate BTM classifications from attributes, including depth, depth statistics (standard deviation), depth range (difference between minimum and maximum depth), slope (angular units from the horizontal), slope statistics (standard deviation), curvature (a measure of the change of slope), aspect (direction of the downslope dip) and rugosity (ratio of surface area to planar area, roughness) or a measure of terrain complexity. 2. Data compilation of marine mammal sighting into the integrated GIS project. 3. Production of GIS layers for MPI and compilation of a digital summary document that provides an overview of the BTM results and appropriate examples.	Complete	Maier et al. (2021) FRR 4202
ZBD	ZBD2020-06	Recovery of biogenic habitats	1. Assess the potential for the recovery of habitats, offered by various spatial planning scenarios, taking into account meta-community dynamics, habitat condition, and ongoing stressors at local and regional scales and the interactive effects thereof. 2. Identify feasible strategies for the recovery and maintenance of habitats in the Hauraki Gulf Marine Park and suggest principles for future spatial planning processes to enhance recovery potential.	In progress	
ZBD	ZBD2020-07	Recovery of Seamount Communities	1. To repeat the quantitative photographic survey of benthic invertebrate communities on features of the Graveyard Knolls complex. 2. To assess changes in benthic communities since the first survey in 2001.	In progress	
ZBD	ZBD2020-08	Role of low and mid trophic fish in the Hauraki Gulf	1. The project should deliver a model describing the role of low- and mid-trophic level fish in terms of energy transfer through the food web of the Hauraki Gulf.	In progress	

Theme	Project code	Project title	Specific objectives	Status	Citation/s
ZBD	ZBD2020-09	Cumulative effects of stressors on scallops and scallop habitats in the Marlborough Sounds	1. Use experimental and modelling techniques to assess the cumulative effect of a range of physical, biological, and ecological stressors (including fishing) on scallops and scallop habitat in the Marlborough Sounds.	In progress	
ZBD	ZBD2020-11	Review of land-based effects on coastal fisheries and kaimoana and their habitats	1. To review current state of knowledge of land-based effects on coastal fisheries and kaimoana species in New Zealand. 2. To collate information on land-based stressors to coastal ecosystems, mitigation measures taken, and to provide a detailed list of all available datasets and spatial layers at regional and national scales	In progress	
BEN	BEN2019-01	Monitor the extent and intensity of bottom contact by trawl and dredge fishing in the Territorial Sea and Exclusive Economic Zone	1. To help MPI groom data, develop and compile summary statistics for all deepwater and inshore trawl and dredge fishing by year, depth zone, sediment categories, fishable area, and any other agreed habitat classifications or proxies, and to identify any trends or changes and meet management needs. 2. To update any relevant sections of the Aquatic Environment and Biodiversity Annual Review and Environmental and Ecosystem considerations sections of the Fisheries Assessment Plenary documents with new results.	Complete	Baird & Mules (2021b) AEBR 260
BEN	BEN2019-05	Spatial decision support tool development for managing the impacts of bottom fishing on in-zone, particularly vulnerable or sensitive habitats.	1. Compile relevant inputs to be used in a spatial planning tool. This should include benthic biodiversity inputs, naturalness and the value to resource users. 2. Apply the outputs of objective 1 to a spatial decision support tool to be used by fisheries management that will enable scenario testing and allow for the cost to fishing to be determined. 3. Update any relevant sections in the Aquatic Environment and Biodiversity Annual Review with new results.	In progress	
PRO	PMM2019-10	Update Campbell Island NZSL (Population Sustainability Threshold) estimation.	1. Compile and update population demographic data indicative of population size and trend, and indicators of relevant demographic rates, from the Campbell Islands New Zealand Sea Lion population 2. Update population models available from previous and ongoing research projects (i.e.,	In progress	

Theme	Project code	Project title	Specific objectives	Status	Citation/s
			Roberts et al. 2014 and PRO2018-01) to approximate the current population consistent with Objective 1 and simulate future population trajectories under alternate management and climatic scenarios, applying a range of sensitivities chosen in consultation with FNZ. 3. Apply the model(s) and sensitivities in Objective 2 to estimate Population Sustainability Threshold (PST) values consistent with a range of relevant population outcomes (selected in consultation with FNZ).		
PRO	PRO2019-01	Preparation and documentation of standardized linked database – including commercial fisheries effort data, fisheries observer data, and protected species captures.	1. Describe and catalog existing MPI databases (including their history and custody chain) containing data relevant to understanding protected species/ commercial fisheries interactions. 2. Host a data linking/grooming workshop (including FNZ, industry, research providers, and technical/database experts) to discuss, document, and modify existing data linking and grooming algorithms used to combine and modify these databases (especially regarding the linking of trip level data from COD and WAREHOU). 3. Utilising existing databases, prepare a comprehensive database linking data from commercial catch/effort databases (e.g., WAREHOU), fisheries observer databases (i.e., COD), and protected species captures databases owned by MPI (e.g., OREO, sea lion SLED database, etc). 4. Audit, document, and catalog in a standardised way the error-trapping and grooming code that are applied to modify these data before they are used in protected species research, both for the standard 'root' database and at the 'branch' level, i.e., as applied in the course of delivering individual research projects. 5. Build and update a standardised and easily queried repository for metadata documenting the database, its genesis and structure, version control, and all grooming/linking/error-trapping code, including those arising from future protected species research projects.	In progress	
PRO	PRO2019-02	Maintenance of PSC (protected species captures) website displaying updated	To maintain a public website displaying a time series of fishing effort, observer effort, observed captures and available estimates of total captures/mortalities	In progress	

Theme	Project code	Project title	Specific objectives	Status	Citation/s
		observer commercial fisheries captures, and total estimated captures for selected species.	in trawl, longline, set net and purse seine fisheries within the New Zealand EEZ.		
PRO	PRO2019-09	Spatial distribution modelling of at-risk seabirds in New Zealand commercial fisheries.	1. Secure access to existing satellite telemetry for New Zealand seabird populations, including via the Global Procellariform Tracking Database. 2. Compile available data indicative of seabird distributions -- including satellite telemetry, sightings data, fisheries captures, and colony-specific population estimates -- for up to ten seabird species chosen in consultation with FNZ. 3. Apply spatial modelling techniques to estimate the spatial distribution and density of selected seabird species (including seasonal variation, and estimated separately for breeding and non-breeding birds), using seabird data from Objective 2 and spatially comprehensive environmental data layers available from other FNZ funded projects. 4. In collaboration with researchers delivering updated parameterisation of the seabird SEFRA model, examine the spatial goodness-of-fit of captures estimates using the updated spatial distribution layers from Objective 3, and modify these layers as appropriate where poorly fitted patterns seem to reflect poorly estimated spatial distribution layers.	In progress	
PRO	PRO2019-10	Refine SEFRA model parameterization for at-risk protected species (seabirds).	1. Use available published and unpublished data to test and refine biological input parameterisation (i.e., definition of priors) in the multi-species seabird risk assessment model produced under project PRO2016-06, with an emphasis on at-risk and high-capture species. 2. Within the existing Risk Atlas platform, test and refine the underlying structural assumptions affecting the estimation of vulnerability in the multi-species seabird risk assessment model (i.e., the definition of fisheries vulnerability groups, species vulnerability groups, and time periods over which vulnerability is estimated). 3. Illustrate the effects of input and structural changes applied under Objectives 1 and 2 in a transparent way, using sensitivities, and document their scientific justification.	In progress	

Theme	Project code	Project title	Specific objectives	Status	Citation/s
			4. Using the Risk Atlas platform, query, disaggregate and summarise the outputs of the updated multi-species seabird risk assessment in consultation with FNZ scientists and managers, to inform relevant questions at the scale of particular fisheries or to address the particular information needs of fisheries managers at smaller scales, rather than only at the species scale. 5. Create a publicly accessible online repository of risk assessment inputs (biological parameters, spatial data layers, and vulnerability group definitions under objectives 1 and 2) and summarised risk assessment outputs, with a simple user interface to facilitate transparency.		
PRO	PRO2019-11	Historical reconstruction and characterization of spatially explicit historical set-net fishing effort data.	1. Compile and summarise available fisheries catch/effort data, landings data, and other historical data indicative of spatial patterns of setnet fishing (including subsistence, recreational, and commercial setnetting) in the period before there were requirements to report fisheries catch and effort data at finer spatial scales (and as early as 1900). 2. Compile and summarise available data indicative of historical protected species capture rates in setnet fisheries, especially in the period before there were requirements to report protected species captures in a standardised way. 3. Host a workshop including fisheries managers, scientists, fishing industry experts and historians to identify relevant data under Objectives 1 and 2 and to discuss its interpretation, with the aim of turning qualitative or summarised data into spatially and temporally resolved estimates of historical setnet effort and protected species captures. 4. Using spatial modelling approaches, generate spatially explicit estimates of setnet fishing effort intensity at decadal scales during the 20th and 21st centuries, within fishery groups corresponding to gear or deployment characteristics likely to affect protected species capture rates (e.g., net material, mesh size, target species). 5. Consistent with the SEFRA approach, intersect spatial effort characterisations under Objective 4 with protected species and fish distribution layers available from other projects, to estimate spatially resolved estimates of historical encounter rates (i.e., spatial overlap) at a decadal scale.	In progress	

Theme	Project code	Project title	Specific objectives	Status	Citation/s
			6. Combining estimated encounter rates from Objective 5 with evidence of historical captures from Objectives 1 and 2, estimate catchability, total captures, and population-level risk in historical setnet fisheries for up to four species of interest, chosen in consultation with FNZ (including Hector's – Māui dolphins).		
PRO	PSB2019-01	Estimation of total seabird captures using standardized estimation methods.	To estimate capture rates and total captures of seabirds (plus fur seals) by method, area, and target fishery, and where possible, by species for the 2019/20, 2020/21 and 2021/22 fishing years.	In progress	
PRO	PSB2019-02	Distributional study of Antipodean albatross using satellite reporting GPS tags.	To collect spatial data to allow refinement of the spatial overlap with fishing throughout New Zealand's EEZ and the South Pacific, with tracking devices to be deployed on a wider range of ages/breeding stages.	In progress	
PRO	PSB2019-04	Black petrel population monitoring and distributional study.	1. To collect information on population size, adult survival, age at first reproduction and key demographic parameters for black petrel to reduce uncertainty or bias in estimates of risk. 2. To collect spatial data to allow refinement of the spatial overlap with fishing, with tracking devices to be deployed on a wider range of ages/breeding stages.	In progress	
PRO	PSB2019-06	Review footage collected from the 2018/19 Black Petrel Electronic Monitoring project.	1. To conduct footage review of electronic monitoring footage collected from the snapper and bluenose bottom longline fisheries in FMA1. 2. To conduct a comparative analysis of the various datasets collected regarding seabird captures.	In progress	
PRO	PSB2019-07	Continuation of the Black Petrel Electronic Monitoring Project for the 2019/20 summer.	1. To collect footage via an electronic monitoring programme on snapper and bluenose bottom longline fisheries in FMA1. 2. To review footage. 3. To conduct a comparative analysis of the various datasets collected regarding seabird captures.	In progress	

Theme	Project code	Project title	Specific objectives	Status	Citation/s
PRO	PSB2019-08	Feasibility trial of underwater baitsetter.	1. Feasibility trial of the underwater baitsetter in New Zealand surface longline. 2. Assessment of the behavioural response of seabirds to the underwater baitsetter.	In progress	
PRO	PSB2019-09	Aerial survey of white-capped albatross on the Auckland Islands.	1. To undertake aerial surveys of the white-capped albatross on Auckland Islands in 2019/20 and 2020/21, and undertaking analysis of total counts for each field season. 2. Based on the counts in Objective 1 and previous counts on the resulting dataset covering 14 years, assess the population trend, taking into account the proportion of loafers identified in the photo montages and by ground counts.	In progress	
PRO	SEA2019-06	Increased fisher-reporting of seabird captures during an electronic monitoring trial.	1. To conduct comparative analysis of fisher reporting of protected species captures for vessels in the SNA BLL fishery in FMA1 for vessels in the electronic monitoring pilot fleet	Complete	Tremblay-Boyer & Abraham (2020) AEBR 238
ZBD	ZBD2019-01	Quantifying Benthic Biodiversity – Phase 2	1. Predict gradients in benthic faunal turnover across Campbell Plateau (CP) using relationships between faunal distributions and environmental gradients developed for Chatham Rise (CR) under ZBD2016-11; 2. Run a dedicated photographic survey of seabed habitats and fauna across CP, structured on the basis of predictions from (1); 3. Use quantitative data from the CP survey to assess the utility of predictions from the existing CR models when applied to a neighbouring area of the EEZ; 4. Generate updated models with a spatial domain encompassing both regions by merging data from the CP survey with the existing CR dataset.	Complete	Stephenson et al. (2021) AEBR 276
ZBD	ZBD2019-04	Plastics and marine debris across the ocean floor in New Zealand waters.	1. Create a metadatabase of all potential sources of data on plastics and marine debris in New Zealand waters. 2. Select and analyse appropriate sets and subsets of data that will provide density estimates of plastics and map debris on the seabed.	Complete	Behrens et al. (2021) AEBR 267

Theme	Project code	Project title	Specific objectives	Status	Citation/s
			3. Provide summary statistics of benthic debris density, types of debris, and heat maps of occurrence throughout the TS and EEZ.		
ZBD	ZBD2019-08	Sources of suspended sediment load and impact on coastal kaimoana.	Compare and contrast sedimentation datasets from different estuaries and determine how different sedimentation histories have impacted on a range of kaimoana species.	Procurement not initiated	
ZBD	ZBD2019-11	Development of Electronic Automated Reporting System (EARS) to improve seabird bycatch monitoring.	1. Develop and ruggedize technology and test on NZ domestic vessel. 2. At sea trials in New Zealand and Japan.	In progress	
BEN	BEN2018-01	Monitoring of trawl footprint (including coastal).	1. To help MPI groom data, develop and compile summary statistics for all deepwater and inshore trawl fishing by year, depth zone, fishable area, and any other agreed habitat classifications or proxies, and to identify any trends or changes to meet management needs. 2. To update any relevant sections in the Aquatic Environment and Biodiversity Annual Review and Environmental and Ecosystem considerations sections of the Fisheries Assessment Plenary documents with new results.	Complete	Baird & Mules (2021a) AEBR 259
BEN	BEN2018-03	Best practice in marine image analysis for determining taxa, habitat or substrate distribution.	To complete a desktop analysis to determine how high-quality data on taxonomic, habitat or substrate occurrence can be best collected or extracted from deep sea video imagery.	Complete	Bowden et al. (2020) AEBR 239
BYC	DAE2018-01	Catch composition in deepwater fisheries.	1. To estimate the catch composition in specified fisheries. This should include the quantity of non-target fish species caught, and the target and non-target fish species discarded, using data from MPI Observers to the end of the most recent complete fishing year in a format that meets management needs. 2. To compare estimated rates, amounts, and trends of bycatch and discards over time in specified fisheries. 3. To update any relevant sections of the Aquatic Environment and Biodiversity Annual Review and Environmental and Ecosystem considerations sections of the Fisheries Assessment Plenary documents with new results from this work.	Complete	Finucci et al. (in press)

Theme	Project code	Project title	Specific objectives	Status	Citation/s
NPB	DAE2018-04	Taxonomic identification of benthic samples.	1. To identify deepwater benthic invertebrates in samples taken during research trawls and by observers on fishing vessels targeting deepwater stocks. 2. To update relevant databases recording the catch of invertebrates in research trawls and commercial fishing.	Complete	Schnabel et al. (2021) AEBR 269
NPB	ENV2018-06	Improved distribution information for higher risk non-QMS shark species.	1. To update, using new analytical techniques where applicable, predictive layers of distribution from Leathwick et al. (2006) for the seven demersal shark species listed below. 2. To analyse and discuss any patterns in distribution in regards to depth, sex and stage (where possible) for the seven shark species below. 3. To compare the patterns from specific objectives 1 and 2 above with observer records and patterns observed from overseas in order to better understand the reliability of these predictions.	In progress	Finucci et al. (2021) AEBR 271
PRO	PMM2018-04A	Estimate spatial distribution for at-risk mammals to assess fisheries overlap and risk: New Zealand fur seals.	1. Summarise available information indicative of population structure for New Zealand fur seals, and population trend (i.e., stable, increasing, decreasing) at different colonies. 2. Characterise the spatio-temporal foraging distribution of New Zealand fur seals (including by sex and by season) using available telemetry, sightings, captures, and other data to parameterise spatially comprehensive habitat utilisation models. 3. Apply the Spatially Explicit Fisheries Risk Assessment (SEFRA) method to estimate encounter rate with fisheries, fishery related deaths, and population risk to New Zealand fur seals at biologically relevant scales.	Complete	Large et al. (2019) AEBR 224
PRO	PMM2018-04B	Estimate spatial distributions for at-risk marine mammals to assess potential fisheries overlap and risk: Mainland and Stewart Island New Zealand Sea Lions.	1. Characterise and estimate the spatio-temporal foraging distributions of New Zealand sea lions at mainland and Stewart Island colonies, using satellite telemetry and other available data to parameterise spatially comprehensive habitat utilisation models, including variation by sex and season. 2. Apply the Spatially Explicit Fisheries Risk Assessment (SEFRA) method to estimate overlap with commercial fisheries, fishery related deaths,	In progress	

Theme	Project code	Project title	Specific objectives	Status	Citation/s
			and population risk to mainland sea lion subpopulations. 3. Characterise current mainland and Stewart Island haul-out locations for New Zealand sea lions, and identify likely future haul-out and colony locations based on observed or known habitat preference functions 4. Apply the analyses in Objectives 1 and 2 to potential future haul out locations identified in Objective 3, to estimate fisheries overlap and risk associated with potential future haul out locations as the mainland and Stewart Island sea lion population expands.		
PRO	PMM2018-07	Updated spatially explicit fisheries risk assessment for New Zealand marine mammal populations.	1. Assemble and prepare new spatial distributions for marine mammal species (including on a season and/or sex-specific basis where appropriate), and updated demographic parameterisation (e.g., population size, adult survival), as inputs to an updated Marine Mammal Risk Assessment (MMRA) using the SEFRA method. 2. Produce and fit a multi-species multi-fishery MMRA model using the updated inputs, including model diagnostics to evaluate fishery group definitions, species group definitions, structural assumptions, and spatial goodness of fit. 3. Produce a model interface to facilitate automated/routine update of the model as new fisheries data and updated inputs become available, to allow interrogation of the model to produce user-defined outputs and diagnostics, and to facilitate evaluation of alternate management scenarios.	In progress	
PRO	PMM2018-08	Update SEFRA risk assessment tool – build observer coverage optimization function.	1. Update the SEFRA risk assessment tool 'Risk Atlas' to include a fisheries observer coverage simulation tool and power analysis, to evaluate the consequences of assigning different levels of fisheries observer coverage or digital monitoring for the estimation of non-target species captures and risk under different user-defined scenarios 2. In close collaboration with MPI, run the working model to evaluate particular observer scenarios as requested by MPI fishery managers.	Procurement not initiated	
PRO	PMM2018-09	Desktop estimation of New Zealand sea lion cryptic	1. Summarise existing data to assign priors for various parameters within a simple transition matrix model to estimate cryptic mortality of sea lions in	Complete	Meyer (2019) AEBR 222

Theme	Project code	Project title	Specific objectives	Status	Citation/s
		mortality in trawls using SLEDs.	trawls using SLEDs, including rates of: live escape survival; death by drowning in the net; death by post-escape drowning; and death by mild traumatic brain injury; as well as rates of body retention vs. body non-retention in the net. 2. Construct a simple Bayesian model combining the parameter estimates from Objective 1, and fit to available data (e.g., pre- vs. post-SLED observed capture rates; results of deployed net camera trials) to estimate cryptic mortality.		
PRO	PMM2018-11	Update Auckland Islands New Zealand sea lion demographic population model.	1. Update the existing Auckland Islands New Zealand sea lion population demographics model including new data up to and including from the 2018-19 summer field season. 2. Project future population trajectories and estimate Population Sustainability Threshold values (PSTs) to meet a range of specified population reference outcomes, including for a best estimate base case and sensitivities.	Complete	Roberts (2019) AEBR 223
PRO	PRO2018-01	Protected species population dynamics model and simulations to estimate Population Sustainability Threshold (PST).	1. Construct a generalised population dynamics model, consistent with the SEFRA framework, to estimate likely population recovery or stabilisation outcomes associated with different levels of anthropogenic impact and estimated risk. 2. Run simulations to test the sensitivity of expected population outcomes to variation across the full range of plausible life history parameters for different taxonomic or life history groups (e.g., seabirds, marine mammals, protected fish, harvested fish, benthic organisms). 3. Develop the means to generate comparable risk ratios reflecting non-lethal impacts (i.e., impacts affecting demographic parameters other than adult survival), including across different life history groups. 4. Test the sensitivity of expected population outcomes (i.e., also Risk Ratios and PSTs) to environmental stochasticity at different time scales, and investigate what range of environmental stochasticity is plausible for different life history groups and in different environments.	In progress	

Theme	Project code	Project title	Specific objectives	Status	Citation/s
PRO	PSB2018-01A	Habitat use and spatial distribution of Antipodean albatross.	1. Design a sampling plan to achieve a statistically robust spatial and temporal distribution across age/breeding stages. 2. To collect spatial data on a wider range of ages/breeding stages of Antipodean albatross to allow refinement of the spatial overlap with fishing throughout New Zealand's EEZ and the South Pacific. 3. To produce an updated species distribution suitable for use in spatial risk assessment.	In progress	
PRO	PSB2018-09	Monitoring trial: comparing obersevers v Electronic Monitoring (EM) for seabirds on FMA1 bottom longlinge vessels.	1. To conduct an audit of electronic monitoring footage collected from the bottom longline fishery. 2. To conduct a comparative analysis of the observer and electronic monitoring review datasets of seabird captures.	Complete	McKenzie (2021) AEBR 251
PRO	PSB2018-10	Deepwater net capture analysis.	To complete model-based analyses to examine the influence of various factors that could potentially lead to the trawl net captures of seabirds on larger trawl vessels (>28m).	Complete	Edwards & Dunn (2021) AEBR 266
PRO	PSB2018-13	Multi-threat risk assessment for yellow-eyed penguin.	1. Construct population models for yellow-eyed penguin at the appropriate colony/sub-population scale (as possible given data availability). 2. Map fishery and non-fishery threats to yellow-eyed penguins and estimate the overlap between penguin distributions and threats. 3. Apply the SEFRA method to estimate fisheries impact and risk to yellow-eyed penguins, using the new information from specific objectives 1 and 2, including at a regional sub-population level. This analysis should include estimation and partition of total mortalities attributable to different threats (with uncertainty) at a regional sub-population level. 4. In consultation with government scientists and managers examine alternate candidate spatial management scenarios through both modelling and participation in a multi-threat risk assessment workshop.	On hold until 2021, under de velopment as PRO2022-01	

Theme	Project code	Project title	Specific objectives	Status	Citation/s
PRO	PSB2018-14	Development and testing of mitigation techniques to reduce penguin captures in setnets.	To develop and test mitigation techniques to reduce penguin captures in setnets, including the assessment of any impact on target species catch.	On hold until 2022	
ZBD	ZBD2018-01	Five-year continuous plankton survey (Phase 3).	1. Conduct annual return transits with the CPR to the Ross Sea during the austral summer in collaboration with Sanford Limited, and contribute the data collected to the SCAR Southern Ocean CPR Survey (SO-CPR). 2. Combine the data collected during phase 1 and phase 2(years 1–10) with the data collected during phase 3 (years 11–15) to: (i) determine zooplankton and phytoplankton trends in the full dataset; and (ii) compare results with datasets available through the SCAR SO-CP Survey. 3. Characterise latitudinal and temporal changes in phytoplankton and zooplankton populations in New Zealand's EEZ and transit to the Ross Sea. 4. Complete couple analysis of phytoplankton and zooplankton with environmental data to investigate causes of variations between the Ross Sea and other Southern Ocean zones. 5. Describe broad similarities and differences observed between NZ, and other southern hemisphere data with patterns or trends observed in the northern hemisphere.	In progress	
ZBD	ZBD2018-02	Climate change, fish distribution meta-analysis.	1. Explore data time series and biological data for evidence of spatial change in living marine resources that may be consistent with climate change or regime shifts. 2. Investigate novel approaches to identify ecologically relevant change by examining species and community relationships between the organisms and their environment. 3. Identify fisheries, communities and locations that are most vulnerable or will remain stable under the response to climate change effects on the ocean.	In progress	

Theme	Project code	Project title	Specific objectives	Status	Citation/s
ZBD	ZBD2018-03	Climate variability, trends and fish population parameters.	1. Determine and review how productivity parameters commonly used in New Zealand stock assessments may be affected by climate change, or long-term environmental variability. 2. Review how these productivity parameters are likely to change, and determine what level of change is likely to be important for stock assessment advice. 3. Identify methods of monitoring to detect important levels of change using existing data sources.	In progress	
ZBD	ZBD2018-05	Environmental variability, regime shifts, and ecosystem function in the Sub-Antarctic.	1. Explore and identify datasets that provide environmental and biological signals about environmental change affecting the state of the marine environment in the Subantarctic. Known datasets of interest include from population monitoring programmes (e.g., New Zealand sea lions; Antipodean albatrosses); trawl survey time series; commercial catch and stock assessment time series of important species (e.g., squid, southern blue whiting) and remotely-sensed environmental and oceanographic data. 2. Explore the various data for synchronous changes and analyse these signals to identify likely environmental drivers or mechanisms affecting ecosystem function and change 3. Construct one or more ecosystem models incorporating change mechanisms identified in Objective 2 4. Design and conduct RV Tangaroa survey to test structural assumptions and inform parameterisation of ecosystem models produced under Objective 3. 5. Identify likely indicators of important environmental change, such as regime shifts, environmental tipping points or persistent trends affecting the distribution and productivity of marine living resources in the area, to inform the design of environmental monitoring.	In progress	
PRO	PRO2017-01A	Research into the demographic parameters for at-risk seabirds as identified	1. To collect information on population size, adult survival, age at first reproduction and key demographic parameters for black petrel to reduce uncertainty or bias in estimates of risk.	Complete	Bell et al. (2020) AEBR 246

Theme	Project code	Project title	Specific objectives	Status	Citation/s
		by the Risk Assessment (black petrels)	2. To collect spatial data to allow refinement of the spatial overlap with fishing, with tracking devices to be deployed on a wider range of ages/breeding stages.		
PRO	PRO2017-01B	Research into the demographic parameters for at-risk seabirds as identified by the Risk Assessment (Southern Buller's/Snares)	To collect information on population size, adult survival, age at first reproduction and key demographic parameters for southern Buller's on The Snares to reduce uncertainty or bias in estimates of risk.	Complete	Thompson & Sagar (2019)
PRO	PRO2017-04	Risk Assessment to support the development of revised NPOA seabirds	1. To explore the recommendations made by the expert review of the risk assessment framework due to occur in June 2017, via trialling any suggested changes to the methodology or undertaking sensitivity runs. 2. Following the methods as described in the AEBAR and agreed changes from the expert review, construct a spatially explicit fisheries risk assessment for seabirds.	Withdrawn	
PRO	PRO2017-05A	Population specific modelling of adult survival of black petrels	To update previous population modelling of black petrels to produce an updated population trend and estimate of adult survival.	Complete	Zhang et al. (2020) AEBR 244
PRO	PRO2017-05B	Population specific modelling of adult survival of Chatham island albatross	To compile all mark-recapture data collected for the Chatham Island albatross and produce an adult survival estimate for the time period corresponding to that used by the risk assessment.	Contracted, in progress	
PRO	PRO2017-06	Characterisation of yellow eyed penguin / fishery interactions	To undertake a review and characterisation of all available information to better understand when, where and how yellow-eyed penguins become caught in set nets, and to the extent possible, the frequency of occurrence.	Complete	Mattern (2020) AEBR 243
PRO	PRO2017-08A	Research into the demographic parameters for at-risk marine mammals as identified by the marine	Characterise population structure and estimate population size for New Zealand common dolphin population(s), with an emphasis on populations that are most exposed to fisheries risk.	Contracted, in progress	

Theme	Project code	Project title	Specific objectives	Status	Citation/s
		mammal risk assessment (common dolphins)			
PRO	PRO2017-08C	Research into the demographic parameters for at-risk marine mammals as identified by the marine mammal risk assessment (sea lions)	1. To investigate the likely causes and consequences of changing New Zealand sea lion pup mass and pup survival, using biological and population monitoring data collected at the Auckland islands both before and after the advent of population decline (i.e., pre- and post-2000). 2. To investigate the extent to which indices derived from the analyses in Objective 1 can be used to predict sea lion population trends, by incorporation into the existing sea lion population model and/or as a relevant indicator for future population monitoring efforts.	Complete	Roberts et al. (2021) AEBR 255 Edwards & Roberts (2021) AEBR 256
PRO	PRO2017-10	Analysis of New Zealand sea lion tracking data to estimate overlap with fisheries	1. Characterise the foraging behaviour of Auckland Islands sea lions in a spatially and temporally explicit manner using available satellite telemetry data. 2. Apply spatial overlap methods to inform improved estimation of encounter rate, strike rate, and cryptic mortality rate of Auckland Islands sea lions with commercial fisheries over time, including for fishing effort with and without the use of Sea Lion Exclusion Devices (SLED). 3. Apply estimates from Objective 2 (with uncertainty) to inform spatially explicit estimates of fishery related deaths in association with current fishing effort patterns.	Contracted, in progress	
PRO	PRO2017-12	Hector's and Māui dolphin multi-threat risk assessment to support review of the TMP	1. Construct population models for Māui dolphins, and for Hector's dolphins in those regional sub-populations where data are sufficient. 2. Map potential non-fishery threats to Māui and Hector's dolphins and estimate the overlap between dolphin distributions and both fishery and non-fishery threats. 3. Apply the Spatially Explicit Fisheries Risk Assessment (SEFRA) method to estimate fisheries impact and risk to Māui and Hector's dolphins, using the new information in the objectives above, including at a regional sub-population level. This analysis should include estimation and partition of total mortalities attributable to different threats (with uncertainty) at a regional sub-population level.	Complete	Roberts et al (2019) – AEBR 214

Theme	Project code	Project title	Specific objectives	Status	Citation/s
			4. In consultation with government scientists and managers examine alternate spatial management scenarios through both modelling and participation in a multi-threat risk assessment workshop.		
PRO	PRO2017-15	Use of innovative tag technology to examine foraging patterns of seabirds and association with fishing vessels	To undertake tagging programs alongside other field programs monitoring populations of relevant seabird species using tags that can detect radar strength and potentially depth of dives to examine the relative occurrence of seabird foraging close to fishing vessels.	Contracted, in progress	
PRO	PRO2017-19	Factors affecting capture rate of black petrels and flesh-footed shearwaters	Build a spatially and temporally explicit commercial fisheries risk model estimating capture/ rates of black petrels and flesh-footed shearwaters as a function of multiple spatial, temporal, and vessel- or effort-specific variables potentially affecting capture rates, for fishery groups generating considerable risk to these species. Identify what factors most strongly drive fisheries risk, and evaluate risk reduction options.	Contracted, in progress	
PRO	SEA2017-10	Black petrel Electronic Monitoring; Audit and Analysis	Audit, data analysis, and report of the footage of seabird captures recorded electronically and by on-board observers collected as a result of the collaborative Black Petrel Electronci Monitoring trial.	Complete	McKenzie (2019) – FRR held by FNZ
PRO	SEA2017-08	A synthesis of the population work carried out as part of PRO2006-01	Preparation of a report which summarises work under the PRO2006-01 A to E Mfish contracts including White-chinned petrel and grey petrel on Antipodes Island, Salvin's albatross on Snares, Northern buller's albatross, northern royal albatross and northern giant petrel on Fourty-Fours and Sisters, and Chatham Island albatross on the Pyramid.	Complete	Thompson (2019) – AEBR 228
PRO	SEA2017-03	Shark qualitative analysis for risk assessment rerun	Collection from post November 2014 for each shark species assessed in Ford et al. (2015) of plenary chapters, data files, summaries and maps of reported captures over last 5 complete fishing years up to 30 September 2016, heat maps as generated for NABIS layers, trawl survey information on distribution and trends and papers or summaries of	Complete	Ford et al. (2018) AEBR 201

Theme	Project code	Project title	Specific objectives	Status	Citation/s
			biology, age, growth, fecundity and general productivity.		
BEN	KAI2016-05	Rocky reef impact quantification and monitoring for the Kaikoura earthquake	1. Determine the impact of the Kaikōura earthquake on rocky reef systems, this may also include sub-lethal responses where methodologies to test this exist. 2. Assess long-term monitoring sites to quantify the recovery from the earthquake in order to inform future marine management decisions. 3. Compare impacts across the range of uplift and habitats impacted on the rocky shore. 4. Continue monitoring sediment cover to suggest causation between short-term uplift and potentially longer-term increased sedimentation as a result of the Kaikōura earthquake. 5. Where possible include local participation in the recovery package work and specifically refer to relevant South Island iwi (Te Rūnanga o Kaikōura and Te Tau Ihu), and local community.	Complete	Alestra et al. (2019) AEBR 212 Alestra et al. (2020) FAR2020/01 Alestra et al. (2021) AEBR 253
PRO	KAI2016-6	Sperm Whale impact quantification and monitoring for the Kaikoura earthquake	1. Determine the impact of the Kaikōura earthquake on the local sperm whale population, through surveys that include resighting of known whales, their spatial distribution, behaviour and collection of samples to investigate potential trophic impacts. 2. Process samples to investigate potential trophic impacts of the Kaikōura earthquake on the local sperm whale population.	Complete	Guerra et al. (in prep)
PRO	KAI2016-08	Hutton's Shearwater Survey after the Kaikoura Earthquake	1. To survey Hutton's shearwater populations in colonies around Kaikoura 2. To assess ongoing threats and limits to recovery from recent earthquake impacts of the colonies of Hutton's shearwater around Kaikoura	Complete	Cuthbert (2018) AEBR 209 Scofield et al. (in prep)
PRO	KAI2016-10	Hector's Dolphin Survey after the Kaikoura Earthquake	1. To survey Hector's dolphins along Kaikoura coast in 2017/18 in a manner consistent with previous surveys (Weir and Sagnol 2015) 2. To analyse historical and 2017/18 Hector's dolphin survey information to characterise any impact of the 2016 Kaikoura earthquakes.	Complete	Weir & MacKenzie (2021) AEBR 252

Theme	Project code	Project title	Specific objectives	Status	Citation/s
PRO	PRO2016-01A	Demographic parameters of black petrels	To collect or analyse information on population size, distribution, or key demographic parameters to reduce uncertainty or bias in estimates of risk for selected at-risk seabirds.	Complete	Bell (2018) AEBR 199
PRO	PRO2016-02	Factors affecting capture rate of black petrels and flesh-footed shearwaters	Build a spatially and temporally explicit commercial fisheries risk model estimating capture/kill rates of black petrels and flesh-footed shearwaters as a function of multiple spatial, temporal, and vessel- or effort-specific variables potentially affecting capture rates, for fishery groups generating considerable risk to these species. Identify what factors most strongly drive fisheries risk, and evaluate alternate risk reduction options.	Withdrawn	
PRO	PRO2016-03	Estimation of captures of protected species in New Zealand Fisheries	To summarise fishing effort, observer effort, and observer reported captures in trawl, longline, set net and purse seine fisheries within the New Zealand EEZ, for the 2016/17, 2016/17 and 2017/18 fishing years. To estimate capture rates and total captures of protected species by method, area, and target fishery, and where possible, by species for the 2016/17, 2016/17 and 2017/18 fishing years.	Complete	Abraham & Berkenbusch 2020 AEBR 237, Abraham & Berkenbusch 2019 AEBR 234, Abraham & Berkenbusch 2019 AEBR 233, Abraham & Richard 2019 AEBR 226, Abraham & Richard (2019a) – AEBR 211; Abraham & Richard (2019b) – AEBR 226, Abraham & Berkenbusch (2019), Abraham et al. (2019)
PRO	PRO2016-04	Characterisation and quantification of non-fishing threats on seabirds	To characterise and quantify the non-fishing threats to seabirds.	Withdrawn	
PRO	PRO2016-06	Spatially explicit risk assessment query and simulation tool	Build an interactive user-driven query and simulation tool to enable MPI fisheries managers and government scientists to: i) access, query, display, and disaggregate spatially explicit data layers and outputs of the L2 seabird risk assessment for user-defined combinations of fishery groups, species, and/or areas; ii) define and examine the	Contracted, in progress	

Theme	Project code	Project title	Specific objectives	Status	Citation/s
			consequences of alternate assumptions and alternate risk management scenarios, including spatial and temporal effort controls, mitigation uptake, and/or new research to reduce biological and statistical uncertainty -- and iii) for each alternate scenario, estimate seabird captures, fatalities, uncertainty, and corresponding risk; iv) simulate the assignment of fisheries observer coverage within user defined scenarios and estimate the power to accurately estimate seabird captures and risk under different observer coverage levels.		
PRO	PRO2016-09	Abundance and distribution of Hector's and Māui dolphins	1. To develop and refine designs and methods for summer and winter surveys for Hector's dolphins along the SCSI. 2. To estimate the abundance of Hector's dolphins along the SCSI applying an agreed survey and analysis methodology. 3. To estimate the distribution of Hector's dolphins along the SCSI applying an agreed survey and analysis methodology.	Complete	MacKenzie & Clement (2019)
PRO	SEA2016-29	Analysis for the White-capped albatross Aerial Survey	1. Prepare photo montages and count nesting and loafing albatross according to existing methodology (as presented to CSP TWG and AEWG previously) for the aerial surveys undertaken during the summers of 2015/16 and 2016/17 (undertaken under contract to DOC, Deepwater Group and MPI), 2. Based on the counts in objective 1 and previous counts, assess the population trend, taking into account the proportion of loafers identified in the photo montages and by ground counts. 3. Analyse the trends shown by sub-areas for the entire time series of aerial surveys to assess whether selected sub-areas could be monitored and represent the trend of the wider population.	Contracted, in progress	
PRO	SEA2016-19	Spatial methods development to support risk assessment (part II). Estimation of capture and retention efficiency for non-target fish species in commercial trawl fisheries	1. Exploration and testing of alternative methods for species density estimation. 2. Incorporation and propagation of uncertainty in species density estimates. 3. Application of the model with environmental attribute data assigned to individual fishing events.	Contracted	

Theme	Project code	Project title	Specific objectives	Status	Citation/s
PRO	SEA2016-20	Helicopter based aerial surveys of the Auckland Islands	Helicopter based aerial surveys of the Auckland Islands.	Complete	
PRO	SEA2016-21	Stocktake of Status of development of Mitigation measures applicable to New Zealand commercial fisheries	Stocktake of Status of development of Mitigation measures applicable to New Zealand commercial fisheries.	Complete	
PRO	SEA2016-21	Stocktake of Status of development of Mitigation Measures applicable to New Zealand commercial fisheries	Report summarising (by fishing method) the bycatch mitigation measures and hurdles to uptake in New Zealand, including development, testing and cost.	Complete	
PRO	SEA2016-24	SEA2016-24 Supplemental sea lion population modelling to support an updated Squid Trawl Fishery Operational Plan	Update the existing Auckland Islands sea lion population model with two additional years of pup count data and estimate population trajectories corresponding to alternate management and hypothetical mortality scenarios.	Contracted	
PRO	SEA2016-26	SEA2016-26 SPRFMO bottom fishing impact assessment	1. Use NZ bottom trawl data from the entire SPRFMO area and apply the plotImpact method developed for CCAMLR to the SPRFMO area using NZ bottom trawl data. 2. The overall dataset will be divided into the type of fishing (slope, seamount, or mixed) and the impact summaries and histograms of percent impact will be generated for each fishing type at the four spatial scales. 3. The relationship between the cell size and estimated percentage impact will be evaluated for two selected habitats (slope and seamount). For this exercise, the data for a given habitat will be summarised as a distribution of impact percentages for the cells included, and profiled across cell sizes starting at 100m and with increasing cell size to show the relationship between estimated percent impact and cell size. 4. If time allows, illustrate the potential impact and recovery dynamics of an example VME taxon using an assumed spatial distribution and demographic parameters in one area of interest, and an assumed single move on rule (trigger and distance) to redistribute fishing effort to the remaining areas.	Complete	

Theme	Project code	Project title	Specific objectives	Status	Citation/s
PRO	SEA2016-30	Hector's and Māui dolphin risk disaggregation tool	1. Expand the custom risk assessment disaggregation and query tool (contract PRO2016-06) to include Hector's and Māui dolphins, incorporating all data inputs for Hector's and Māui dolphins utilised in the Marine Mammal Risk Assessment. Risk estimation will be carried out via a single-species application of the SEFRA method (2017 MPI AEBAR, Chapter 3) for both the setnet and inshore trawl fishery groups. 2. Expand the capability of the risk query tool to include a sub-population definition function that subdivides a population according to user-defined boundaries, and automatically generates separate outputs for each. 3. Expand the capability of the risk query tool to include analysis of hypothetical scenarios using alternate species spatial distribution layers and/or alternate fishing effort distribution layers (provided as user-defined inputs, e.g., as GIS layers) with standardised diagnostic outputs comparing alternate scenarios with the base case scenario. 4. Expand the capability of the risk query tool to allow the fishing effort and observed captures database query and display function to be applied to any protected species in the groomed and linked effort and captures database. This objective is for the visual display outputs only; it does not include risk assessment modelling for species other than Hectors and Māui dolphins.	Contracted	
ZBD	ZBD2016-04	Organic Carbon Recycling in Deepwater	1. To describe the biodiversity of large nektonic crustaceans in subtropical and subantarctic waters. 2. To assess the environmental drivers of nektonic plankton crustacean abundance and diversity over weekly to sub-decadal time scales in subtropical and subantarctic waters	Complete	
PRO	DAE2015-01	Characterisation of seabird capture data	To collate and characterise the seabird capture information from deepwater trawl fisheries to improve understanding of potential risk factors for captures of seabirds, with a focus on net captures.	Complete	
PRO	PRO2015-01	Improving estimates of cryptic mortality for use in seabird risk assessments	1. To develop guidelines for the production of estimates of total seabird captures from observer data, with methods varying based on the level and quality of data.	Complete	Baker et al. (2021) AEBR 268

Theme	Project code	Project title	Specific objectives	Status	Citation/s
			2. To increase the capability of other countries to produce robust estimates of seabird captures.		
PRO	PRO2015-04	Addressing key information gaps for Māui dolphins	1. To collect information on spatial distribution and overlap with fisheries to decrease uncertainty in our understanding and estimates of risk to Māui dolphins.	Contracted, in progress	
PRO	SEA2015-06	Additional aerial survey effort for Hector's dolphins on the West Coast South Island	Following increased Hector's dolphin sightings over the summer survey this project allows for extra effort in the Grey (0-4nm), Hector (4-12nm) and Okarito (4-12nm) strata (Plan A). If time and weather permit, this will also allow for extra effort in the 4-12nm strata off Whanganui, Jackson Bay and Milford.	Completed as part of PRO2013-06	Clement & MacKenzie (2016)
PRO	SEA2015-10	Sea lion prey survey	1. Undertake a demersal trawl survey of the Auckland Islands and Stewart/Snares shelf to determine the spatial and bathymetric distribution and abundance of the main prey species of NZ sea lions in the areas used by benthic and pelagic foraging lactating females. 2. Conduct a potting feasibility study to determine the distribution, abundance and biology of yellow octopus (Enteroctopus zealandicus). 3. Conduct a benthic habitat characterisation based on acoustic swath mapping of the seafloor in the area immediately surrounding demersal trawl stations. 4. Deploy underwater cameras to visually survey seafloor habitat and sea lion prey species at a representative subsample of habitat types, identified from the acoustic swath habitat characterisation. 5. Make oceanographic observations to quantify physical characteristics of sea lion foraging habitat.	Complete	Roberts et al. (2018) AEBR 204
PRO	SEA2015-12	Potential impacts of fisheries restrictions for the NZ sea lion TMP	1. To estimate the likely impact on catch rates and total catches of squid, scampi, and hoki of a range of specified potential fishing restrictions. 2. To estimate the likely impact on sea lion interactions and captures of the specified fishing restrictions.	Complete	Roux & Roberts (2016) FRR

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PRO	SEA2015-15	Stewart Island sea lion survey	1. To determine the feasibility of monitoring pup production in January, concurrent with the monitoring of other colonies. 2. While testing the feasibility of using thermal technology in finding sea lion pupping locations. 3. To screen for Klebsiella pneumonia. 4. Determine common causes of death for Stewart Island pups.	Complete	Boren et al. (2016)
PRO	PRO2014-06	Update of level-2 seabird risk assessment	1. To update the level-2 seabird risk assessment using all new information on bird population size, productivity, and distribution, and all relevant fishing effort and observer data for the 2009/10 to 2013/14 fishing years. 2. To identify key drivers of uncertainty and opportunities to reduce uncertainty in the risk ratios for species at high or very high risk. 3. To participate in, and provide data for, a workshop to review the findings relative to other available data and results. 4. To update the level-2 seabird risk assessment using all new information on bird population size, productivity, and distribution, and all relevant fishing effort and observer data for the 2010/11 to 2014/15 fishing years. 5. To identify key drivers of uncertainty and opportunities to reduce uncertainty in the risk ratios for species at high or very high risk.	Complete	Richard et al. (2017)
PRO	PRO2014-03	Research in response to advice from the Māui's dolphin research advisory group	1. To be developed through the MRAG process: agreed project was genetic mark recapture estimation of Māui dolphin abundance with field effort in 2014/15 and 2015/16.	Complete	
PRO	PRO2014-02	Risk assessment modelling for fishing-related mortality of sea lions to underpin the TMP	1. To review existing models of New Zealand sea lions that have been used to estimate key demographic rates and their variability. 2. Based on the results of Objective 1, develop an operating model of the Auckland Island population of New Zealand sea lions suitable for use in management strategy evaluation. 3. To use a management strategy evaluation to assess the risk posed by commercial fishing to New	Complete	Roberts & Doonan (2016) AEBR 166

Theme	Project code	Project title	Specific objectives	Status	Citation/s
			Zealand sea lions, including assessing the likely performance of candidate management approaches against current or agreed performance criteria. 4. To extend the modelling to other populations and risks as information permits.		
PRO	PRO2014-05 Co-funded with DOC POP2015-01	Reducing uncertainty in biological components of the risk assessments for at-risk seabird species	1. Species, population, and information requirements to be determined based on the prioritisation procedures in the NPOA-seabirds and the table of priorities from the outputs of the review workshop.	Complete	Bell et al. 2016
PRO	PRO2014-01	Improving information on the distribution of key protected species	1. To produce an agreed list of seabird and marine mammal species for inclusion and compile all available spatial data for these species. 2. To model and map the distribution of the species identified in objective 1 from available spatial data, reflecting any temporal changes (seasonality or trends). 3. To refine the results of the mapping for priority species by developing and implementing predictive habitat distribution models.	Ongoing	
PRO	SEA2014-12	NZ sea lion stable isotope analysis	1. Locate the ideal NZ sea lion teeth for stable isotope analysis from that will provide the best temporal coverage. 2. Prepare and micro-drill the NZ sea lion teeth within the annual bands to document changes in their foraging and changes in ocean conditions through time using stable isotope analysis. 3. Assess the stable isotope datasets in combination with existing diet studies, prey abundance estimates and climate indices to best examine temporal patterns.	Ongoing	
PRO	SEA2014–15	Sensitivity of the Seabird Risk Assessment to selected scenarios	1. Assess the sensitivity of the Seabird Risk Assessment to assumptions about Buller's albatrosses. 2. Assess the ability of the Seabird Risk Assessment to detect changes in the capture rates.	Complete	Abraham & Richard 2017

Theme	Project code	Project title	Specific objectives	Status	Citation/s
			3. Assess the sensitivity of the risk assessment to live captures.		
PRO	SEA2014-16	Observer coverage power analysis for NPOA	1. Assess the level of observer coverage required to detect a change in the estimated risk of fisheries to New Zealand seabirds, for varying levels of decrease in fishing-related fatalities, for selected seabird species and fisheries.	Complete	
PRO	SEA2014-19	Development and production of smaller hook pods for trial in NZ	To modify the current Hook Pod to New Zealand version without the LED incorporated. This will result in a smaller and more robust Hook Pod that will be equally effective at reducing seabird bycatch in New Zealand's surface longline fisheries.	Complete	
PRO	SEA2014-21	Additional analyses to support the New Zealand sea lion risk assessment	1. The effect of past mortality resulting from key threats for which data are available (such as disease and fishing mortality), or for which plausible estimates are available (such as cryptic mortality), will be explored by fitting the historical demographic model including data on mortality arising from known threats to estimate starting (1960) and current population structure. Threat-derived mortality will then be excluded from the model and re-run from the estimated starting population to predict population structure in the absence of such mortality. 2. Questions were raised about the most appropriate way to deal with animals of unknown pupping status in the model. At present, decision rules are used to determine pupping status from observations (observed suckling, at least 3 sightings with a pup or 3 sightings without a pup) to determine pupping status, with the remaining animals classified as unknown and divided in the proportion of known pupping/non-pupping. Exclusion of animals of unknown status results in increased estimates of pupping rate. Alternative approaches should be considered and the sensitivity of pupping rate to relaxing the decision rules should be explored, such as relaxing the decision rules used to determine pupping status to 2 or 1 observations with or without a pup, or use of other information such as females calling to pups. (Linked to the following item). 3. Similar questions were raised about determining pupping status before an animal that has moved between colonies is used to estimate migration	Complete PRO2014-02.	Roberts & Doonan (2016) AEBR 166

Theme	Project code	Project title	Specific objectives	Status	Citation/s
			(translocation) rates. As an alternative, these requirements could be relaxed to include animals simply observed (but not confirmed to be pupping) at another colony to be included in migration rate estimation. 4. The assumption of a CV of 0.06 for pup census indices, as the only way of specifying a relative weighting between census and tag-recapture data, was questioned. Alternative CVs and weighting approaches should be determined using something like standard deviations of Pearson residuals. 5. Incorporation of time-varying re-sighting probability was noted to improve model fits, indicating that re-sighting probabilities did vary over time. One could explore whether the number of days on which re-sightings were conducted each year are correlated with effort days, in which case effort days could be used to estimate re-sight probabilities for recent years that have not been back-corrected. 6. It was recommended that the effect of incorporation of 'phantom tags' on parameters such as re-sighting probability should be explored. An alternative approach would be to simply multiply the survival rate from tagging to age 1 yr by the directly estimated proportion of pups that die prior to tagging. The latter is, after all, the basis for how many phantom tags are added.		
PRO	SEA2014-23	An assessment of thermal aerial survey techniques on fur seals	1. Undertake field work component. 2. Submit draft report and present to the Aquatic Environment Working Group.	Complete	
PRO	SEA2014-25	Black petrel distribution and fisheries overlap	1. Geographical Information Systems (GIS) data, giving the distribution of black petrel. 2. GIS data giving the overlap of black petrel with bottom longline, surface longline, set net, and trawl fisheries.	Complete	
PRO	SEA2013-06	Black Petrel Distribution Modelling	1. To use the best available information to develop a spatial and seasonal distribution of black petrel, in New Zealand waters.	Complete	Abraham et al. (2015) AEBR 161

Theme	Project code	Project title	Specific objectives	Status	Citation/s
PRO	SEA2013–14	Re-Run of Level-2 Seabird Risk Assessment 2014	1. To provide an update of the Seabird Risk Assessment, including observer and fisheries data to the end of the 2012/13 fishing year.	Complete	Richard & Abraham (2015) AEBR 162
PRO	SEA2013-08	Data preparation for protected species bycatch estimation	1. Groom catch effort, observer, and protected species capture data. 2. Provide web-based interface to allow exploration, display, and reporting on the data.	Completed: preparation for PRO2013-01	
PRO	PRO2013-01	Protected species capture estimation	1. To estimate capture rates and total captures of seabirds, marine mammals, turtles, and protected fish species by method, area, and target fishery, and where possible, by species for the fishing years 2012/13, 2013/14 and 2014/15. 2. To estimate factors associated with the capture of seabirds and marine mammals. 3. To estimate, where possible, the nature and rate of warp strike incidents and total number of seabirds affected.	Complete	Abraham et al. (2016) AEBR 169 Abraham & Richard (2017) AEBR 184 Thompson et al. (2017) AEBR 192 Abraham & Richard (2018) AEBR 197 Abraham & Berkenbusch (2017) AEBR 188
PRO	PRO2013-06	Abundance and distribution of WCSI Hector's dolphins	1. To develop and refine designs and methods for summer and winter aerial surveys for Hector's dolphins along the WCSI consistent with the recent ECSI surveys. 2. To estimate the abundance of Hector's dolphins along the WCSI in summer 2013/14 applying an agreed aerial survey methodology. 3. To estimate the distribution of Hector's dolphins along the WCSI in summer 2013/14 applying an agreed aerial survey methodology. 4. To estimate the abundance of Hector's dolphins along the WCSI in winter 2014 applying an agreed aerial survey methodology. 5. To estimate the distribution of Hector's dolphins along the WCSI in winter 2014 applying an agreed aerial survey methodology.	Complete	MacKenzie & Clement (2016) AEBR 168
PRO	PRO2013-08	Reanalysis of Hector's dolphin line transect aerial survey data	1. To collate sightings and effort data for all Hector's dolphin aerial surveys that applied different approaches to estimating the detection function. 2. To assess the impact of different approaches to estimating the detection function on estimates of	Included in PRO2013-06	

Theme	Project code	Project title	Specific objectives	Status	Citation/s
			abundance and distribution and develop correction factors. 3. To reanalyse all relevant survey data to estimate Hector's dolphin abundance and distribution applying the agreed approach to estimating the detection function.		
PRO	PRO2013-13	Global seabird risk assessment (for New Zealand species)	1. Evaluate relative exposure to commercial fisheries at a global scale for New Zealand seabird populations applying a seasonally-disaggregated spatial overlap approach (i.e., accessing global seabird spatio-temporal distribution data and compiling comprehensive global fisheries effort databases) for different categories of fishing effort. 2. Apply estimates of population PBR (from the updated NZ-EEZ seabird risk assessment (including uncertainty), and species- or guild-specific estimates of seabird Vulnerability (i.e., as estimated in the updated NZ-EEZ seabird risk assessment, modified to the extent possible by data indicative of relative seabird bycatch rates in comparable fishing effort inside vs. outside the New Zealand EEZ (including uncertainty), to estimate global fisheries risk for New Zealand seabird populations. 3. For each New Zealand seabird population estimate what proportion of global fisheries risk is attributable to mortalities occurring inside vs. outside the NZ-EEZ, and what proportion is likely to be unaccounted for in the analysis (e.g., due to incomplete global fisheries data or risk from IUU fishing). 4. For that portion of species risk outside the NZ-EEZ, summarise the source of that risk to the extent possible, for example by RFMO (or other relevant management agency), and by fishery group, geographic area, season, vessel size, and other relevant categories.	Contracted, ongoing	Abraham et al. 2017 (CCBST ERS paper) Francis & Hoyle (2019) AEBR 213
PRO	PRO2013-17	Repeat quantitative modelling of southern Buller's albatross	1. To update the fully quantitative population model of southern Buller's albatross to assess population trend and key demographic rates for this population. 2. To use the model to predict future trends assuming recent average demographic rates.	Complete	Fu & Sagar (2016) AEBR 165
PRO	PRO2013-18	Authoritative Sea Lion Capture List	To produce a definitive data set of New Zealand sea lion captures and to reconcile data from the different sources, and resolve any discrepancies.	Complete	Thompson et al. (2015) AEBR 145

Theme	Project code	Project title	Specific objectives	Status	Citation/s
PRO	SEA2013-08	Data preparation for protected species bycatch estimation	1. Groom catch effort, observer, and protected species capture data 2. Provide web-based interface to allow exploration, display, and reporting on the data	Completed: preparation for PRO2013-01	
PRO	No project number	A risk assessment of threats to Māui's dolphins	To evaluate of the risks posed to Māui's dolphin to support the review of the TMP.	Complete	Currey et al. 2012
PRO	PRO2012-02	Assessment of the risk to marine mammal populations from New Zealand commercial fisheries	1. To scope the risk assessment, including producing an agreed list of marine mammal populations (in concert with MAF and DOC). 2. To review the literature, compile the required information and evaluate the appropriate level of risk assessment for the marine mammal populations identified in objective 1. 3. To conduct a risk assessment for the marine mammal populations identified in objective 1 using, where possible, a risk index reflecting the ratio of fisheries-related mortality to the level of potential biological removal. 4. To refine the results of the risk assessment for priority marine mammal populations by incorporating spatially and temporally-explicit abundance, distribution and capture information.	Complete	Berkenbusch et al. (2013) AEBR 119 Abraham et al. (2017) AEBR 189
PRO	PRO2012-07	Cryptic mortality of seabirds in trawl and longline fisheries	1. To review available information from international literature and unpublished sources to characterise and inform estimation of cryptic mortality and live releases for at-risk seabirds in New Zealand trawl and longline fisheries 2. To review the extent to which fisheries observer data informing current estimates of seabird captures may be used to also estimate cryptic mortalities in different fishery groups in the seabird risk assessment, and identify key assumptions and associated uncertainty in the estimation of cryptic mortalities. 3. To identify those species and/or fishery groups for which current uncertainty regarding cryptic mortality contributes most strongly to high-risk scores for at-risk seabird species, and recommend options to improve estimation of cryptic mortality for those species / fishery group combinations.	Complete	Pierre et al. 2015
PRO	PRO2012-10	Level 3 risk assessment for Antipodean albatross	1. Develop an Antipodean albatross population model. 2. Assess the effect of fisheries mortality on	Complete	Edwards et al. (2017) AEBR 180

Theme	Project code	Project title	Specific objectives	Status	Citation/s
			population viability. 3. As information permits, assess the effect of alternative management strategies.		
PRO	ENV2011-01	NPOA-sharks science review	1. To collate and summarise information in support of a review of the National Plan of Action for the Conservation and Management of Sharks (NPOA-sharks). 2. To identify research gaps from objective 1 and suggest cost-effective ways these could be addressed.	Complete	Francis & Lyon (2012) AEBR 102 Francis & Lyon (2013) AEBR 107
PRO	SEA2011-14	CCSBT Seabird risk assessment	To undertake an Ecological Risk Assessment for seabird interactions in surface longline fisheries managed under the Convention for the Conservation of Southern Bluefin Tuna.	Complete	Waugh et al. 2012
PRO	SRP2011-03	Probabilistic modelling of sea lion interactions	1. Estimate the probability that a sea lion suffers mild head trauma following a collision with a SLED grid.	Complete	Abraham (2011) FRR
PRO	SRP2011-04	HSL Modelling	1. Revise Breen-Fu-Gilbert sea lion model.	Complete	Breen et al. 2010
PRO	PRO2010-01	Estimating the nature and extent of incidental captures of seabirds, marine mammals and turtles in New Zealand commercial fisheries	1. To estimate the nature and extent of captures of seabirds, marine mammals and turtles, and the warp strikes of seabirds in New Zealand fisheries for the fishing years 2009/10, 2010/11 and 2011/12.	Complete	Thompson et al. (2012) FRR Thompson et al. (2013) AEBR 105 Thompson et al. (2016) AEBR 167 Richard & Abraham (2015)
PRO	PRO2010-02	Research into key areas of uncertainty or development of mitigation techniques for the revised NPOA-seabirds	1. To provide the information necessary to underpin the revised NPOA-seabirds or develop mitigation techniques to reduce risk identified via the revised NPOA-seabirds.	Complete	Richard & Abraham (2013a) AEBR 108 Richard & Abraham (2013b) AEBR 109 & 109s Richard & Abraham (2013c)

Theme	Project code	Project title	Specific objectives	Status	Citation/s
					Berkenbusch et al. 2013
PRO	No project number	A risk assessment framework for incidental seabird mortality associated with New Zealand fishing in the New Zealand EEZ	To describe the conceptual and methodological framework of this risk assessment approach to guide the completion of similar risk assessments elsewhere.	Complete	Sharp et al. 2011
PRO	SRP2010-03	Fur Seal interactions with a SED excluder device	1. Fur seal interactions with SED excluder device (Dr J Lyle).	Complete	Lyle 2011
PRO	SRP2010-05	Fur seal interaction with an SLED excluder device	1. Using a series of 10-15 impact tests at a maximum collision speed of 5 or 6 ms-1, develop a 'HIC map' for the SLED grid to enable the consequences of collisions with different parts of the grid by sea lions of different head masses to be predicted (scaling values (for eq 3) will include -1/3, -2/3, and -3/4). 2. Using a small number of collision tests, verify that the HIC for a glancing blow can be predicted with sufficient accuracy by resolving vectors. 3. Calculate the maximum possible sensitivity to different boundary conditions using the relative masses of the SLED grid and sea lion heads. 4. Clarify in the final research report that undertaking tests in air (as opposed to underwater) should not affect the results.	Complete	Ponte et al. 2011
PRO	IPA2009-09	Sea Lion bioenergetics modelling	1. To review and collate data on growth, metabolism, diet and reproductive parameters of NZ sea lions or, if data are inexistent, of other sea lion species. 2. To analyse the energy density of various NZ sea lion prey items. 3. To incorporate the data acquired in Objectives 1. and 2. into a bioenergetics model to estimate the energy and food requirements of NZ sea lions.	Complete	Meynier 2010
PRO	IPA2009-16	Preliminary impact assessment of NZ sea lion interaction with SLEDS	1. Preliminary impact assessment of New Zealand sea lion interactions with SLEDs.	Complete	Ponte et al. 2010
PRO	IPA2009-19/20	Level 2 seabird risk assessment rerun	1. To examine the risk of incidental mortality from commercial fishing for 64 seabird species in New Zealand trawl and longline fisheries.	Complete	Richard et al. 2011

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PRO	No project number	External review of NZ sea lion bycatch necropsy data and methods	The primary purposes of this review were to determine whether, in the opinion of a group of independent experts: - the interpretation of necropsy findings and trauma classification system used by Dr Wendi Roe are valid - sea lions recovered from trawl nets have sustained clinically significant trauma - some or all of the sea lions exiting through SLEDs are likely to survive.	Complete	Roe 2010a
PRO	PRO2009-01A	Abundance & distribution of Hector's & Māui's dolphins (5-year project)	1. To estimate the distribution of the South Coast South Island Hector's dolphin sub-population in both winter and summer. 2. The work for this sub-project was subsequently extended to include data collection necessary to estimate abundance.	Complete	Clement & Mattlin (2010) FRR
PRO	PRO2009-01B	Abundance, distribution, and productivity of Hector's (and Māui's) dolphins	1. To estimate the likely precision of abundance estimates from summer aerial surveys for Hector's dolphins along the East Coast South Island (ECSI; from Farewell Spit to Nugget Point) under different levels of sampling intensity and stratification. 2. To estimate the likely precision of abundance estimates and the likely quality of distribution information from winter aerial surveys for Hector's dolphins along the ECSI under different levels of sampling intensity and stratification. 3. To identify and quantify trade-offs between the precision of abundance estimates and the quality of distribution information as well as between overall precision and likely cost (e.g., based on the number of flying hours required). 4. To identify key areas and times for which it would be particularly useful to have information on Hector's dolphin distribution (e.g., where risk may come from overlap with particular fisheries) and quantify trade-offs between the precision of ECSI-wide surveys and collecting such fine-scale information. 5. Assess the extent to which two-phase or adaptive approaches would be useful to improve the surveys' utility for assessing dolphin distribution, particularly the seaward limit.	Complete	MacKenzie et al. (2013) FRR
PRO	PRO2009-01C	Abundance, distribution and productivity of Hector's (and Māui) dolphins	1. To estimate critical aspects of the biology, abundance and distribution of Hector's and Māui's dolphin populations to assess the effects of fishing-related mortality on these populations including the abundance of Hector's dolphins along the ECSI in	Complete	MacKenzie & Clement (2014) AEBR 123 & 123s

Theme	Project code	Project title	Specific objectives	Status	Citation/s
			summer 2012/13 applying an agreed aerial survey methodology. 2. To estimate critical aspects of the biology, abundance and distribution of Hector's and Māui's dolphin populations to assess the effects of fishing-related mortality on these populations including the distribution of Hector's dolphins along the ECSI in summer 2012/13 applying an agreed aerial survey methodology. 3. To estimate critical aspects of the biology, abundance and distribution of Hector's and Māui's dolphin populations to assess the effects of fishing-related mortality on these populations including the abundance of Hector's dolphins along the ECSI in winter 2013 applying an agreed aerial survey methodology. 4. To estimate critical aspects of the biology, abundance and distribution of Hector's and Māui's dolphin populations to assess the effects of fishing-related mortality on these populations including the distribution of Hector's dolphins along the ECSI in winter 2013 applying an agreed aerial survey methodology.		
PRO	PRO2009-04	Development and efficacy of seabird mitigation measures	1. To test the efficacy of a variety of configurations of mitigation techniques at reducing seabird mortality (or appropriate proxies for mortality) in longline fisheries.	Complete	No reports specified as required output
PRO	ENV2008-03	Bycatch of basking sharks in New Zealand fisheries	1. To review the productivity of basking sharks. 2. To describe the nature and extent of fishery-induced mortality of basking sharks in New Zealand waters and recommend methods of reducing the overall catch.	Complete	Francis & Smith (2010) AEBR 49
PRO	PRO2008-01	Risk assessment of protected species bycatch in NZ fisheries	1. To provide an assessment of the risk posed by different fisheries to the viability of New Zealand protected species, and to assign a risk category to all New Zealand fishing operations.	Complete	Waugh et al. 2009
PRO	PRO2008-03	Necropsy of marine mammals captured in New Zealand	1. To necropsy marine mammals captured incidentally to New Zealand fishing operations in the SQU6T fishery during the 2008/09 fishing year to determine life-history characteristics such as sex-reproductive status and the likely cause of mortality- and to determine the species- and sex of captured animals returned for necropsy. 2. To determine, through examination of returned	Complete	Roe (2010) AEBR 47 Roe & Meynier (2012) AEBR 98

Theme	Project code	Project title	Specific objectives	Status	Citation/s
			carcasses, the species, sex, reproductive status, and age-class of sea lions and fur seals captured in the SQU6T New Zealand fishery. 3. To detail any injuries and, where possible, the cause of mortality of sea lions and fur seals returned from New Zealand fisheries, and examine relationships between injuries and body condition, breeding status, and other associated demographic characteristics. 4. To review and collate data from previous NZ sea lion autopsy programmes.		
PRO	SAP2008-14	Sea lion population modelling, additional	1. To assess the likely performance of different bycatch control rules for the SQU6T fishery. 2. To correct and update the Breen-Fu-Gilbert (2008) sea lion model, including assessment of the performance of 200-series and 300-series management control rules. 3. To document the development of the model, including all four objectives of project IPA2006/09 and objective 1 of this project, in a single report suitable for an international review.	Complete	Breen et al. 2010
PRO	Deepwater Group	Necropsy of marine mammals captured in New Zealand fisheries in the 2007–08 fishing year	Necropsy of marine mammals captured in New Zealand fisheries in the 2007–08 fishing year.	Complete	Roe 2009a
PRO	IPA2007-09	Protected species risk assessment	To provide an assessment of the risk posed by different fisheries to the viability of NZ protected species, and to assign a risk category to all NZ fishing operations.	Complete	Waugh et al. 2008
PRO	PRO2007-01	Estimating the nature and extent of incidental captures of seabirds in New Zealand commercial fisheries	1. Estimate capture rates per unit effort and total captures of seabirds for the New Zealand EEZ and in selected fisheries by method, area, target fishery, in relation to mitigation methods in use, and, where possible, by seabird species for the fishing year 2006/07, 2007/08 and 2008/09. 2. Examine the incidence of seabird warp strike in trawl fisheries where these data are available from fisheries observers, and estimate the rate of incidents (birds affected per hour) and total number of seabirds affected by fishery, area and method. Examine the factors (fishery, environmental, seasonal, mitigation, area) that influence the probability of warp-strike occurring.	Complete	Abraham (2010) AEBR 60 Abraham & Thompson (2009) AEBR 33 Abraham & Thompson (2010) FRR Abraham & Thompson (2010) AEBR 80

Theme	Project code	Project title	Specific objectives	Status	Citation/s
					Abraham & Thompson (2011a) AEBR 79 Thompson & Abraham (2009) Abraham et al. (2010) AEBR 45
PRO	PRO2007-02	Estimating the nature and extent of incidental captures of mrine mammals in New Zealand commercial fisheries	1. Describe the nature and extent of marine mammal captures in New Zealand commercial fisheries. 2. Estimate the total numbers, releases, and deaths of selected marine mammals, where possible by species, fishery, and fishing method, caught in commercial fisheries for the fishing years 2006–07, 2007–08, and 2008–09.	Complete	Abraham et al. (2010) AEBR 45 Thompson & Abraham (2009a) AEBR 36 Thompson & Abraham (2009b) AEBR 41 Thompson & Abraham (2010a) AEBR 61 Thompson & Abraham (2010b) AEBR 66 Thompson et al. (2010a) Was AEBR 63, became FRR 2014/02 Thompson et al. (2010b) AEBR 52 Thompson et al. (2010c) AEBR 56
PRO	ENV2006-05	The use of electronic monitoring technology in New Zealand longline fisheries	1. Trial the deployment of electronic monitoring systems in selected longline fisheries, monitoring incidental take of protected species. 2. Evaluate the efficacy of electronic monitoring in allowing enumeration and identification of protected species captures. 3. Recommend options for data management and information transfer arising from the deployment of electronic monitoring in selected fisheries.	Complete	McElderry et al. 2008

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PRO	IPA2006-02	The efficacy of warp strike mitigation devices: trials in the 2006 squid fishery	1. Groom the mitigation trial data and produce a summary of the data. 2. Examine strike rates and capture rates on warps and mitigation devices. 3. Determine the relative efficacy of mitigation devices tested in the trial. 4. Make recommendations regarding future trials. 5. Compare seabird warp strike data for 2005 and 2006. 6. Work with SeaFIC and the mitigation trials TAG to produce analyses and outputs.	Complete	Middleton & Abraham 2007
PRO	IPA2006-09	Modelling interactions between trawl fisheries and New Zealand Sea lion interactions	1. Model the New Zealand sea lion population and explore alternative management procedures for controlling New Zealand sea lion bycatch in the SQU 6T fishery. 2. Collate and review all available sea lion biological data, fisheries data, and sea lion bycatch data relevant to a population model and management strategy evaluation for the Auckland Islands sea lion population. 3. Update and improve the existing Breen and Kim sea lion population model (2003) to incorporate all relevant data and address model uncertainties including but not necessarily limited to those identified by the AEWG. 4. Fit the revised model to all available data and test sensitivity including but not necessarily limited to runs identified by the AEWG. 5. Test a range of management procedures (rules) with the model to determine if they meet agreed management criteria.	Complete	Breen 2008
PRO	IPA2006-13	Identification of Marine Mammals Captured in New Zealand Fisheries	1. To determine, through examination of returned marine mammal carcasses, the species, sex, reproductive status, and age-class of marine mammals returned from New Zealand fisheries. 2. To detail any injuries and, where possible, the cause of mortality of marine mammals returned from New Zealand fisheries, and examine relationships between injuries and body condition, breeding status, and other associated demographic characteristics.	Complete	Roe 2009b
PRO	PRO2006-01	Data collection of demographic, distributional and trophic information on selected seabird species to allow estimation of effects of fishing on population viability	1 To gather demographic, distributional and dietary information on selected seabird species to allow assessment of effects of fishing on population viability.	Complete	Sagar & Thompson 2008 Sagar et al. 2009a, 2009b,

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					2010a, 2010b, 2010c Baker et al. 2008, 2009, 2010 Baker et al. (2020) AEBR 242
PRO	PRO2006-02	Modelling of the effects of fishing on the population viability of selected seabirds	1. Model the effects of fisheries mortalities on population viability compared with other sources of mortality or trophic effects of fishing. 2. Examine the overlap of fishing activity with species distribution at sea for different stages of the breeding and life-cycle and for different sexes, and assess the likely risk to species or populations from fisheries (by target species fisheries, fishing methods, area and season) in the New Zealand EEZ.	Complete	Francis & Bell (2010) AEBR 51 Francis (2012) AEBR 104 Francis et al. (2015) AEBR 152
PRO	PRO2006-04	Estimation of the nature and extent of incidental captures of seabirds in New Zealand commercial fisheries	1. To estimate the nature and extent of captures and warp-strikes of seabirds in New Zealand fisheries for the fishing year 2005/06.	Complete	Baird & Smith 2008
PRO	PRO2006-05	Estimating the nature and extent of marine mammal captures in New Zealand commercial fisheries	1. To estimate and report the total numbers, releases and deaths of marine mammals where possible by species, fishery and fishing method, caught in commercial fisheries for the years 1990 to the end of the fishing year 2005/06. 2. To analyse factors affecting the probability of fur seal captures for the years 1990 to the end of the fishing year 2005/06. 3. To classify fishing areas, seasons and fishing methods into different risk categories in relation to the probability of marine mammal incidental captures for the years from 1990 through to the end of the fishing year 2005/06.	Complete	Mormede et al. 2008 Baird 2008a, 2008b Baird (2011) AEBR 72 Smith & Baird (2009) AEBR 40 Smith & Baird (2011) AEBR 71
PRO	PRO2006–07	Characterise non-commercial fisheries interactions	1. To characterise non-commercial fisheries interactions with seabirds and marine mammals. 2. Characterise non-commercial fisheries risk to seabirds and marine mammals by area and method. Recommend mitigation measures appropriate for uptake in non-commercial fisheries in which seabird or marine mammal captures occur.	Complete	Abraham et al. (2010) AEBR 64 Thompson & Abraham 2009a, 2009b, 2009c, 2010, 2011 Thompson et al. 2010a, 2010b, 2010c

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PRO	ENV2005-01	Estimation of the nature and extent of incidental captures of seabirds in New Zealand fisheries	1. To estimate the nature and extent of captures of seabirds in selected New Zealand fisheries for the fishing year 2004/05.	Complete	Baird & Smith (2007) Baird & Gilbert (2010) AEBR 50
PRO	ENV2005-02	Estimation of the nature and extent of marine mammal captures in New Zealand fisheries	To examine the nature and extent of the captures of marine mammals in New Zealand fisheries, for the whole New Zealand EEZ, by Fishery Management Area and fishing season, and by smaller metrics as appropriate for the fishing year 2004/05. 2. Examine alternative methods for estimating sea lion captures and recommend one or more alternative standardised methods for describing and estimating sea lion captures in the SQU 6T fishery.	Complete	Abraham 2008 Baird 2007 Smith & Baird 2007 Baird & Smith 2007
PRO	ENV2005-04	Identification of marine mammals captured in New Zealand	1. To determine the species, sex, and where possible, age and reproductive status of marine mammals captured in New Zealand fisheries. 2. To necropsy marine mammals captured incidentally in New Zealand fishing operations to determine life-history characteristics and the likely cause of mortality. 3. To determine, through examination of returned marine mammal carcasses, the taxon to species level, sex, and reproductive status, and age-class of marine mammals captured in New Zealand fisheries. 4. To detail the injuries and where possible the cause of mortality of marine mammals returned from New Zealand fisheries, along with their body condition and breeding status, and other associated demographic characteristics. 5. To detail the protocol used for the necropsy of marine mammals, to provide a standardised procedure for autopsy to determine species, age, sex and associated demographic characteristics for fishery-killed specimens.	Complete	Roe 2007
PRO	ENV2005–06	Estimation of protected species captures in longline fisheries using electronic monitoring	1. To provide estimates of seabird and marine mammal mortalities from longline fisheries in New Zealand using electronic monitoring systems and to recommend deployment and data management options for ongoing use of these systems for estimation of protected species incidental take.	Complete	McElderry et al. 2007

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PRO	ENV2005-09	Data collection to estimate key performance indicators in the Chatham albatross, *Diomedea eremita*.	1. To gather data on key population parameters for Chatham albatross *Diomedea eremita,* to enable population viability to be assessed, and the responses of key parameters to fisheries mortality and fisheries management activities to mitigate fisheries related risk. 2. To undertake field research to collect data on population growth rates, adult survival, inter-breeding season survival, mortality due to predation at the colony, fecundity, and associated parameters for Chatham Albatross following the study design project. 3. To undertake field research to determine the range and extent foraging movements of Chatham albatrosses within New Zealand fishing waters, and examine the nature and extent of any association between Chatham albatrosses and fishing activities.	Complete	No reports specified as required output
PRO	ENV2005-13	Assessment of risk to yellow-eyed penguin *Megadyptes antipodes* from fisheries incidental mortality	1. To review existing data on yellow-eyed penguin *M. antipodes* population performance and fisheries information and provide an analysis of the potential effect of fishing mortality and other factors on population viability. 2. To recommend data collection requirements and protocols for the assessment of the effects of fishing on yellow-eyed penguins.	Complete	Maunder 2007
PRO	ENV2004-02	Estimation of New Zealand sea lion incidental captures in New Zealand Fisheries	1. To estimate the level of New Zealand sea lion (*Phocartos hookeri*) incidental capture in New Zealand fisheries	Complete	Smith & Baird 2007a
PRO	ENV2004-04	Characterisation of seabird captures in New Zealand fisheries	1. Characterisation of seabird captures in New Zealand fisheries.	Complete	MacKenzie & Fletcher 2006
PRO	ENV2004–05	Modelling of impacts of fishing-related mortality on New Zealand seabird populations	1. To examine and identify modelling approaches to analyse seabird demographic impacts that may be occurring as a result of fisheries mortality. 2. To compile databases of available demographic and distributional data on selected seabirds affected by fisheries mortality and New Zealand fisheries and estimate key population parameters and seasonal distribution for each species. 3. To estimate rates of removals related to fishing activities in New Zealand for selected seabird species, where possible by age class and sex. 4. To describe the spatial overlap of seabird distributions at sea, with fisheries where the risk of incidental mortality has been demonstrated to be	Complete	Fletcher et al. 2008

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			moderate to high. 5. To examine the potential for factors other than fisheries removals within the New Zealand zone to influence the population dynamics of the selected study species. 6. To characterise selected seabird populations' abilities to sustain removals related to fishing operations within the New Zealand EEZ, and to recommend, where possible environmental standards for assessing the sustainability of selected fishing operations in relation to impacts on seabird populations.		
PRO	ENV2004-06	Māui's dolphin study	1. To quantify and compare summer and winter distribution of Māui's dolphin.	Complete	Slooten et al. 2005
PRO	IPA2004-14	Seabird warp strike in the southern squid trawl fishery	1. To document seabird warp strike in the southern squid trawl fishery, 2004–05.	Complete	Abraham & Kennedy 2008
PRO	ENV2003-05	Review of the Current Threat Status of Associated or Dependent Species	1. To assess the current threat status of selected associated or dependent species.	Complete	Baird et al. 2010
PRO	No project number	QMA SQU6T New Zealand sea lion incidental catch and necropsy data for the fishing years 2000–01, 2001–02 and 2002–03	Report on New Zealand sea lion incidental catch and necropsy data for the fishing years 2000–01, 2001–02 and 2002–03	Complete	Mattlin 2004
PRO	MOF2002–03L	Exploring alternative management procedures for controlling bycatch of Hooker's sea lions in the SQU 6T squid fishery	Report on exploring alternative management procedures for controlling bycatch of Hooker's sea lions in the SQU 6T squid fishery.	Complete	Breen & Kim 2006
PRO	ENV2001-01	Estimation of seabird incidental captures in New Zealand fisheries	1. To estimate the level of seabird incidental capture in New Zealand fisheries. 2. To recommend appropriate levels of observer coverage for estimation of seabird incidental capture in New Zealand fisheries.	Complete	Baird 2004a, 2004b, 2004c Smith & Baird 2008b
PRO	ENV2001–02	Incidental capture of *Phocarctos hookeri* (New Zealand sea lions) in New Zealand commercial fisheries, 2001–02.	1. To estimate and report the total numbers of captures, releases, and deaths of *Phocarctos hookeri* caught in fishing operations, including separate estimates for SQU 6T and other areas, as appropriate, during the 2001-02 fishing year,	Complete	Baird 2005a, 2005b Baird & Doonan 2005

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			including confidence limits and an investigation of any statistical bias in the estimate.		
PRO	ENV2001 -03	Estimation of *Arctocephalus forsteri* (New Zealand fur seal) incidental captures in New Zealand fisheries	1. To estimate the level of *Arctocephalus forsteri* incidental capture in New Zealand fisheries. 2. To recommend appropriate levels of observer coverage for estimation of *Arctocephalus forsteri* incidental capture in New Zealand fisheries.	Complete	Smith & Baird 2008a Baird 2005c, 2005d, 2005e
PRO	ENV2000 –01	Protected species bycatch	1. To estimate the total numbers of captures, releases, and deaths of seabirds and marine mammals by species caught in fishing operations during the 1999–2000 fishing year.	Complete	Baird 2003
PRO	ENV2000 -02	Estimation of incidental mortality of New Zealand sea lions in New Zealand fisheries	1. To examine the factors that may influence the level of incidental mortality of New Zealand sea lion in New Zealand fisheries. 2. To recommend appropriate levels of observer coverage for estimation of incidental mortality of New Zealand sea lion in New Zealand fisheries.	Complete	Doonan 2001 Bradford 2002 Smith & Baird 2005a, 2005b
PRO	ENV2000 -03	ENV 2000-A Estimation of seabird and marine mammal incidental capture in New Zealand fisheries	1. To estimate the level of seabird and marine mammal incidental capture in New Zealand fisheries. 2. To determine the factors that influence the level of seabird and marine mammal incidental capture in New Zealand fisheries. 3. To recommend appropriate levels of observer coverage for estimation of seabird and marine mammal incidental capture in New Zealand fisheries.	Complete	Bradford 2002, 2003 Francis et al. 2004
PRO	ENV99-01	Incidental capture of seabirds, marine mammals and sealions in commercial fisheries in New Zealand waters	To estimate the level of seabird and marine mammal incidental captures in New Zealand fisheries.	Complete	Baird 2001 Doonan 2000
PRO	No project number	Factors influencing bycatch of protected species	To determine the factors that influence the level of seabird and marine mammal incidental capture in New Zealand fisheries.	Complete	Baird & Bradford 2000a, 2000b
PRO	ENV98-01	Estimation of non-fish bycatch in commercial fisheries in New Zealand waters, 1997–98	To estimate the level of non-fish bycatch in New Zealand fisheries.	Complete	Baird 1999b Baird & Bradford 1999

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PRO	No project number	Annual review of bycatch in southern bluefin and related tuna longline fisheries in the New Zealand 200 n. mile Exclusive Economic Zone	Review bycatch in New Zealand's southern bluefin and related tuna longline fisheries.	Complete	Baird et al. 1998
PRO	SANF01	Report on the incidental capture of nonfish species during fishing operations in New Zealand waters	To report on incidental captures of non-fish species in New Zealand fisheries.	Complete	Baird 1997
PRO	No project number	Non-fish Species and Fisheries Interactions	To estimate the level of non-fish bycatch in New Zealand fisheries.	Complete	Baird 1996
PRO	No project number	Analyses of factors which influence seabird bycatch in the Japanese southern bluefin tuna longline fishery in New Zealand waters, 1989-93	1. To assess the influence that 15 monitored environmental and fishery related factors had on seabird bycatch rates, and to gauge the effectiveness of various mitigation measures.	Complete	Duckworth 1995
PRO	No project number	Incidental catch of Hooker's sea lion in the southern trawl fishery for squid, summer 1994	Report on the incidental catch of Hooker's sea lion in the southern trawl fishery for squid, summer 1994.	Complete	Doonan 1995
PRO	No project number	Nonfish Species and Fisheries Interactions	To estimate the level of non-fish bycatch in New Zealand fisheries.	Complete	Baird 1995
PRO	No project number	Nonfish Species and Fisheries Interactions	To estimate the level of non-fish bycatch in New Zealand fisheries.	Complete	Baird 1994
PRO	No project number	Incidental catch of fur seals in the west coast South Island hoki trawl fishery, 1989-92	To report on incidental captures of fur seals in the west coast South Island hoki trawl fishery 1989–92.	Complete	Mattlin 1993
PRO	No project number	Incidental catch of non-fish species by setnets in New Zealand waters	To report on incidental captures of non-fish species in New Zealand setnet fisheries.	Complete	Taylor 1992

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PRO	No project number	Seabird bycatch by Southern Fishery longline vessels in New Zealand waters	1. To describe the tuna longline fishery in the New Zealand EEZ and how seabirds are caught by longline vessels. 2. To summarise information available on seabird population trends, and estimate the scale of the incidental capture of seabirds in the larger of two tuna longline fisheries in the EEZ. 3. To describe measures which could reduce the number of seabirds caught by tuna longlines.	Complete	Murray et al. 1992
NPB	DAE2017-01	Bycatch monitoring and quantification in deepwater fisheries (HOK/HAK/LIN)	1. To estimate the catch composition in target trawl fisheries for hoki, hake and ling. This should include the quantity of non-target fish species caught, and the target and non-target fish species discarded, using data from MPI Observers to the end of the most recent complete fishing year in a format that meets management needs. 2. To compare estimated rates, amounts, and trends of bycatch and discards over time in the hoki, hake, and ling trawl fisheries. 3. To update any relevant sections of the Aquatic Environment and Biodiversity Annual Review and Environmental and Ecosystem considerations sections of the Fisheries Assessment Plenary documents with new results from this work.	Complete	Anderson et al. (2019) AEBR 220
NPB	DAE2016-01	Total catch composition in deepwater fisheries (squid & scampi)	1. To estimate the catch composition in the target fisheries for squid and scampi. This should include the quantity of non-target fish species caught, and the target and non-target fish species discarded, using data from MPI Observers and commercial fishing returns to the end of the most recent complete fishing year in a format that meets management needs. 2. To compare estimated rates, amounts, and trends of bycatch and discards from this study with previous projects on bycatch in the squid and scampi fisheries. 3. To update any relevant sections of the Aquatic Environment and Biodiversity Annual Review and Environmental and Ecosystem considerations sections of the Fisheries Assessment Plenary documents with new results from this work.	Complete	Anderson & Edwards (2018) AEBR 199
NPB	SEA2016-19	Spatial methods for development to support risk assessment (part II). Estimation of capture and retention efficiency for non-	1. To implement and test a spatially-explicit two-part delta-gamma statistical model (e.g., Thorson et al. 2015) for estimating species density and capture and retention efficiency in the commercial fishing gear. 2. To estimate relative densities and fishery groups catchability (with uncertainty) in a number of non-	Contracted, in progress	

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		target fish species in commercial trawl fisheries	target fish species in Chatham Rise trawl fisheries. 3. To perform a simulation self-test of the model. 4. To submit the results for publication in the primary literature.		
NPB	ENV2015-01	Updating tools for at-sea fish identification	1. To review the level of information required by the seafood sector and other users of fish identification guides in New Zealand. 2. To evaluate the most beneficial and cost-effective methods of delivery that are practicable and consistent with MPI policy directions. 3. To review, revise and produce the appropriate information tools on fish identification.	Ongoing	
NPB	ENV2015-03	Addressing key information gaps identified by the shark qualitative risk assessment	1. To collect and analyse biological information to improve estimates of risk for inshore and deepwater shark species identified as being at relatively high risk.	Complete	McMillan et al. (2018) AEBR 203
NPB	No Project Code	Qualitative Shark risk assessment	To produce a qualitative risk assessment for all shark species possible within the New Zealand EEZ.	Complete	Ford et al. 2015
NPB	ENV2014-02	NPOA-sharks: age and growth of selected at-risk species	1. To estimate basic biological parameters for high risk, high uncertainty chondrichthyans.	Ongoing	Francis et al. (2018) AEBR 195 Francis et al. (2018) AEBR 196
NPB	No project code	Mitigation options for shark bycatch in longline fisheries	Conduct a literature review and assess the options for improvements in the practice of fisheries to mitigate shark bycatch.	Complete	Howard 2015
NPB	SEA2013-16	Data collation for shark risk assessments	1. To assemble and collate all available information on the distribution and intensity of all fishing methods for the most recent five full fishing years that potentially cause fishing-related mortality of chondrichthyans. 2. To assemble and collate all available information on the distribution, abundance, demographics and productivity of all New Zealand chondrichthyans.	Complete	Francis (2015) AEBR 156

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NPB	ENV2013-01	Development of model-based estimates of fish bycatch	1. To develop a statistical modelling approach to estimate total captures of fish and invertebrates using observer and catch-effort information from selected fisheries. 2. To compare estimates of total captures, confidence limits, and trends for selected species, species groups, and fisheries made using existing ratio-based methods and statistical models. 3. To estimate, within a simulation framework, the potential for bias in ratio-based and model-based methods, the sizes of confidence limits for estimates from the two approaches in comparable situations, and identify the factors associated with good and poor performance.	Complete	Edwards et al. (2015) AEBR 154
NPB	DAE2010-02	Bycatch monitoring & quantification for scampi bottom trawl	1. To estimate the quantity of non-target fish species caught, and the target and non-target fish species discarded in the specified fishery, for the fishing years since the last review, using data from Ministry of Fisheries Observers and commercial fishing returns. 2. To compare estimated rates and amounts of bycatch and discards from this study with previous projects on bycatch in the specified fishery. 3. To compare any trends apparent in bycatch rates in the specified fishery with relevant fishery independent trawl surveys. 4. To provide annual estimates of bycatch for nine Tier 1 species fisheries and incorporate into the Aquatic Environment and Biodiversity Report specified in Objective 3 for SQU, SCI, HAK, HOK, JMA, ORH, OEO, LIN, SBW.	Complete	Anderson (2017) AEBR 181 Anderson (2012) AEBR 100 Anderson (2013a) AEBR 112 Anderson (2013b) AEBR 113 Anderson (2014a) AEBR 138 Anderson (2014b) AEBR 139 Ballara (2015) AEBR 158 Ballara & O'Driscoll (2015) AEBR 163
NPB	ENV2009-02	Bycatch and discards in oreo and orange roughy trawl fisheries	1. To estimate the quantity of non-target fish species caught, and the target and non-target fish species discarded, in the trawl fisheries for oreos for the fishing years 2002/03 to 2008/09 using data from Scientific Observers and commercial fishing returns. 2. To estimate the quantity of non-target fish species caught, and the target and non-target fish	Complete	Anderson (2011) AEBR 67

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			species discarded, in the trawl fisheries for orange roughy for the fishing years 2004/05 to 2008/09 using data from Scientific Observers and commercial fishing returns.		
NPB	IDG2009-01	Finfish field identification guide	1. To complement the field identification guide under IDG2006/01 with the remaining 120 fish species caught by commercial fishers in New Zealand waters.	Complete	McMillan et al. (2011a) AEBR 78, 2011b, 2011c
NPB	ENV2008-01	Fish and invertebrate bycatch and discards in southern blue whiting fisheries	1. To estimate the quantity of non-target fish species caught, and the target and non-target fish species discarded, in the trawl fisheries for southern blue whiting for the fishing years 2002/03 to 2006/07 using data from Scientific Observers and commercial fishing returns.	Complete	Anderson (2009b) AEBR 43
NPB	ENV2008-02	Estimation of non-target fish catch and both target and non-target fish discards in hoki, hake and ling trawl fisheries	Estimates of the catch of non-target fish species, and the discards of target and non-target fish species in the hoki (*Macruronus novaezelandiae*), hake (*Merluccius australis*), and ling (*Genypterus blacodes*) trawl fisheries for the fishing years 2003–04 to 2006–07 using data from Scientific Observers and commercial fishing returns.	Complete	Ballara et al. (2010) AEBR 48
NPB	ENV2008-04	Productivity of deepwater sharks	1. To determine the growth rate, age at maturity, longevity and natural mortality rate of shovelnose dogfish (*Deania calcea*) and leafscale gulper shark (*Centrophorus squamosus*).	Complete	Parker & Francis (2012) AEBR 103
NPB	ENV2007-01 & ENV2007-02	Bycatch and Discards in Squid Trawl Fisheries	1. To estimate the quantity of non-target fish species caught, and the target and non-target fish species discarded, in the trawl fisheries for squid for the fishing years 2001/02 to 2005/06 using data from MFish Observers and commercial fishing returns.	Complete	Ballara & Anderson (2009) AEBR 38
NPB	ENV2007-03	Productivity and Trends in Rattail Bycatch Species	1. To estimate growth, longevity, rate of natural mortality, and length at maturity of four key rattail bycatch species in New Zealand trawl fisheries. 2. To examine data from trawl surveys and other data sources for trends in catch rates or indices of relative abundance for species in Objective 1.	Complete	Stevens et al. (2010) AEBR 59
NPB	DEE2006-03	Monitoring the abundance of deepwater sharks	1. To monitor the abundance of deepwater sharks taken by commercial trawl fisheries.	Complete	Blackwell 2010

Theme	Project code	Project title	Specific objectives	Status	Citation/s
NPB	ENV2006-01	Bycatch and discards in ling longline fisheries	To estimate the quantity of non-target fish species caught, and the target and non-target fish species discarded, in the longline fisheries for ling for the fishing years 1998/99 to 2005/06 using data from MFish Observers and commercial fishing returns.	Complete	Anderson 2008
NPB	IDG2006-01	Finfish field identification guide	1. To produce a field guide for fish species in New Zealand. 2. To produce a field identification guide for all QMS and other fish species commonly caught in commercial and non-commercial fisheries.	Complete	McMillan et al. (2011a) AEBR 78, 2011b, 2011c
NPB	TUN2006-02	Estimation of non-target fish catches in the tuna longline fishery	1. To estimate the catches, catch rates, and discards of non-target fish in tuna longline fisheries data from the Observer Programme and commercial fishing returns for the 2005/06 fishing year. 2. To describe bycatch trends in tuna longline fisheries using data from this project and the results of previous similar projects.	Complete	Griggs et al. 2008
NPB	ENV2005-17	Estimation of non-target fish catch and both target and non-target fish discards in jack mackerel trawl fisheries	1. To estimate the quantity of non-target fish species caught, and the target and non-target fish species discarded, in the trawl fisheries for jack mackerel for the fishing years 2001/2002 to 2004/05 using data from Mfish observers and commercial fishing returns.	Complete	Anderson 2007a
NPB	ENV2005-18	Estimation of non-target fish catch and both target and non-target fish discards in orange roughy trawl fisheries	1. To estimate the quantity of non-target fish species caught, and the target and non-target fish species discarded, in the trawl fisheries for orange roughy for the fishing years 1999/2000 to 2003/04 using data from Scientific Observers and commercial fishing returns.	Complete	Anderson 2009a
NPB	TUN2004-01	Estimation of non-target fish catches in the tuna longline fisheries	1. To estimate the catch rates of non-target fish in the longline fisheries for tuna using data from the Observer Programme and commercial fishing returns for the 2002/03, 2003/04 and 2004/05 fishing years. 2. To estimate the quantities of non-target fish caught in the longline fisheries for tuna using data from the Observer Programme and commercial fishing returns for the 2002/03, 2003/04 and 2004/05 fishing years. 3. To estimate the discards of non-target fish caught in the longline fisheries for tuna using data from the Observer Programme and commercial fishing returns for the 2002/03, 2003/04 and 2004/05	Complete	Griggs et al. 2007

Theme	Project code	Project title	Specific objectives	Status	Citation/s
			fishing years. 4. To describe trends in the non-target fish catches in the tuna longline fisheries using data from this project and the results of previous similar projects.		
NPB	ENV2003-01	Estimation of non-target catches in the hoki fishery	1. To estimate the catch rates, quantity and discards of non-target fish catches and the discards of target fish catches in trawl fisheries for hoki, using data from the Observer Programme and commercial fishing returns for the 1999/00 to 2002/03 fishing years. 2. To compare and contrast the estimates from the four years of data in Specific Objective 1 above with the 1990/91 through 1998/99 series previously reported.	Complete	Anderson & Smith 2005
NPB	ENV2002-01	Estimation of non-target fish catch and both target and non-target fish discards for the tuna longline fishery	1. To estimate the catch rates, quantity and discards of non-target fish, particularly oceanic shark species, broadbill swordfish and marlin species, caught in the longline fisheries for tuna, using data from Scientific Observers and commercial fishing returns for the 2000/01 and 2001/02 fishing years.	Complete	Ayers et al. 2004
NPB	ENV2001-04	Non-target fish catch and discards in selected New Zealand fisheries	To generate estimates of the catch of non-target fish species, and the discards of target and non-target fish species in three important New Zealand trawl fisheries: arrow squid (*Nototodarus sloani* & *N. gouldi*), jack mackerel (*Trachurus declivis*, *T. novaezelandiae*, & *T. symmetricus murphyi*) and scampi (*Metanephrops challengeri*).	Complete	Anderson 2004
NPB	ENV2001-05	To assess the productivity and relative abundance of deepwater sharks	1. To review the relative abundance, distribution and catch composition of the most commonly caught deepwater shark species: shovelnose dogfish (*Deania catcea*), Baxter's dogfish (*Etmopterus baxten*), Owston's dogfish (*Cenhoscymnus owstoni*), longnosed velvet dogfish (*Centroscymnus crepidater*), leafscale gulper shark (*Cenhophom squamosus*), and the seal shark (*Dalatias ticha*).	Complete	Blackwell & Stevenson 2003
NPB	ENV2001-07	Reducing bycatch in scampi trawl fisheries	1. Collate and review the international literature on methods of reducing bycatch in crustacean trawl fisheries. 2. Review and analyse the data from New Zealand studies. 3. Develop recommendations on future approaches to reducing bycatch in the New Zealand scampi	Complete	Hartill et al. 2006

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			fishery, including some general thoughts on the experimental design of field trials.		
NPB	PAT2000–01	Review of rattail and skate bycatch, and analysis of rattail standardised CPUE from the Ross Sea toothfish fishery in Subarea 88.1, from 1997-1998 to 2001–02	Report on review of rattail and skate bycatch, and analysis of rattail standardised CPUE from the Ross Sea toothfish fishery in Subarea 88.1, from 1997-1998 to 2001–02.	Complete	Fenaughty et al. 2003 Marriot et al. 2003
NPB	ENV99-02	Estimation of non-target fish catch and both target and non-target fish discards in selected New Zealand fisheries	1. To estimate the quantity of non-target fish species caught in the trawl fisheries for hoki and orange roughy for the fishing years 1990-91 to 1998-99 using data from Scientific Observers, commercial fishing returns and from research trawl surveys. 2. To estimate the quantity of target and non-target fish species discarded in the trawl fisheries for hoki and orange roughy for the fishing years 1990-91 to 1998-99 using data from Scientific Observers, commercial fishing returns and from research trawl surveys. 3. To explore the effects of various factors on the total catch of non-target fish species and the discards of target and non-target fish species in the trawl fisheries for hoki and orange roughy for the fishing years 1990-91 to 1998-99. 4. To recommend appropriate levels of observer coverage for estimation of non-target fish catch and discards of target and non-target fish species in the hoki and orange roughy fisheries.	Complete	Anderson et al. 2001
NPB	ENV99-05	To identify trends in abundance of associated or dependent species from selected commercial fisheries	To estimate trends in abundance of associated and dependent species, including invertebrates, from deepwater and middle depth fisheries on the Chatham Rise.	Complete	Livingston et al. 2003
NPB	ENV98-02	Pelagic shark bycatch in the New Zealand tuna longline fishery	To determine pelagic shark bycatch in the New Zealand tuna longline fishery.	Complete	Francis et al. 2001
NPB	No project number	Fish bycatch in New Zealand tuna longline fisheries	To report on fish bycatch in New Zealand tuna longline fisheries.	Complete	Francis et al. 1999, 2000

Theme	Project code	Project title	Specific objectives	Status	Citation/s
NPB	ENV97-01	Estimation of nonfish bycatch in New Zealand fisheries	To estimate non-fish bycatch in New Zealand fisheries.	Complete	Doonan 1998; Baird 1999a; Baird et al. 1999
NPB	SCI97-01	Scampi stock assessment for 1998 and an analysis of the fish and invertebrate bycatch of scampi trawlers	1. To summarise catch, effort, observer, and research information for scampi fisheries in QMAs 1,2,3,4 (east and western portions), and 6A in 1998.	Complete	Cryer et al. 1999
BEN	BEN2017-01	Monitoring of deepwater trawl footprint	1. To help MPI groom data, develop summary statistics, for Tier 1 deepwater fisheries and the aggregate of all Tier 1 and Tier 2 deepwater fisheries, of the extent and frequency of fishing by year, by depth zone, by fishable area, and by predicted BOMEC habitat class, and to identify any trends or changes to meet management needs. 2. To update any relevant sections in the Aquatic Environment and Biodiversity Annual Review and Environmental and Ecosystem considerations sections of the Fisheries Assessment Plenary documents with new results from this work.	Complete	Baird & Mules (2019) AEBR 229
BEN	SEA2016-08	Power Analysis - Benthic Fauna in Spirits Bay	Using previous survey results, conduct a power analysis to estimate the likelihood of a range of survey designs consistent with the monitoring programme from project ENV2005/23 detecting changes in key indicators of the state of the benthic communities in Spirits Bay and Tom Bowling Bay since the last survey.	Complete	
BEN	SEA2016-12	SEA2016-12 GLM Spat composition	Half funding of GLM spat composition study for 90 mile beach (aquaculture unit funding the other half).	Complete	
BEN	DAE2016-05	Monitoring the trawl footprint for deepwater fisheries	1. To estimate the trawl footprint and map the spatial and temporal distribution of trawling on or near the seabed throughout the EEZ between 1989/90 and the most recent completed fishing year. 2. To produce summary statistics, for Tier 1 deepwater fisheries and the aggregate of all Tier 1 and Tier 2 deepwater fisheries, of the extent and frequency of fishing by year, by depth zone, by fishable area, and by predicted BOMEC habitat class, and to identify any trends or changes to meet management needs. 3. To update any relevant sections in the Aquatic	Complete	Baird & Wood (2018) AEBR 193

Theme	Project code	Project title	Specific objectives	Status	Citation/s
			Environment and Biodiversity Annual Review and Environmental and Ecosystem considerations sections of the Fisheries Assessment Plenary documents with new results from this work.		
BEN	BEN2014-01	Risk assessment for benthic habitats, biodiversity, and production	1. To review the design and implementation of management frameworks, including objectives and targets, to manage the effects of mobile bottom fishing methods on vulnerable benthic taxa and habitats. 2. To complete spatially explicit quantitative impact assessments for benthic taxa and/or habitats affected by bottom fisheries, within spatially distinct or overlapping zones within the New Zealand EEZ, consistent with available databases and the outputs of existing projects. 3. To compile and combine impact assessments from Objective 2, to inform a spatially explicit quantitative risk assessment with reference to potential management targets for benthic taxa and/or habitats (from Objective 1) combined across all bottom fisheries in the New Zealand EEZ. 4. To conduct spatially explicit Management Strategy Evaluation to simulate and evaluate the effects of alternate fisheries management scenarios on benthic taxa and/or habitats in the EEZ.	Complete	Mormede et al. (2021) AEBR 274
BEN	BEN2014-02	Monitoring recovery of benthic fauna on the Graveyard complex	1. To repeat the quantitative photographic survey of benthic invertebrate communities on the Graveyard complex. 2. To assess changes in benthic communities since the first survey in 2001.	Ongoing analysis	
BEN	BEN2014-03	Monitoring recovery of benthic fauna in Spirits Bay	1. Using previous survey results, conduct a power analysis to estimate the likelihood of a range of survey designs consistent with the monitoring programme from project ENV2005/23 detecting changes in key indicators of the state of the benthic communities in Spirits Bay and Tom Bowling Bay since the last survey. 2. To survey Spirits Bay and Tom Bowling Bay benthic invertebrate communities in accordance with an agreed design from Objective 1. 3. To assess changes in benthic communities inside and outside of the closed area since 1997.	Complete	Tuck et al. (2019) AEBR 206

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BEN	SEA2014-09	Review of New Zealand's SPRFMO VME protocol	1. To prepare a review of the scientific basis for the 'biodiversity component' of the move-on-rule thresholds comprising the current New Zealand Vulnerable Marine Ecosystem Evidence Process.	Complete	Penney 2014
BEN	BEN2012-02	Spatial overlap of mobile bottom fishing methods and coastal benthic habitats	1. To use existing information and classifications to describe the distribution of benthic habitats throughout New Zealand's coastal zone (0–200 m depth). 2. To rank the vulnerability to fishing disturbance of habitat classes from Objective 1. 3. To describe the spatial pattern of fishing using bottom trawls, Danish seine nets, and shellfish dredges and assess overlap with each of the habitat classes developed in Objective 1.	Complete	Baird et al. 2015
BEN	DEE2010-06	Design a camera / transect study	1. To design and provide indicative costs for a programme to monitor trends in deepwater benthic habitats and communities. 2. To explore the feasibility of using existing trawl and acoustic surveys to capture data relevant to monitoring trends in deepwater benthic habitats and communities.	Complete	Bowden et al. (2015) AEBR 143
BEN	DAE2010-04	Monitoring the trawl footprint for deepwater fisheries	1. To estimate the 2009/10 trawl footprint and map the spatial and temporal distribution of bottom contact trawling throughout the EEZ between 1989/90 and 2009/10. 2. To produce summary statistics, for major deepwater fisheries and the aggregate of all deepwater fisheries, of the spatial extent and frequency of fishing by year, by depth zone, by fishable area, and by habitat class, and to identify any trends or changes.	Ongoing analysis	Black et al. (2013) AEBR 110 Black & Tilney (2015) AEBR 142
BEN	Internally funded 1	SPRFMO	1. To develop detection criteria for measuring trawl impacts on vulnerable marine ecosystems in high sea fisheries of the South Pacific Ocean.	Complete	Parker and Bowden 2010
BEN	Internally funded 2	SPRFMO	1. To document protection measures implemented by New Zealand for vulnerable marine ecosystems in the South Pacific Ocean.	Complete	Penney et al. 2009
BEN	Internally funded 3	CCAMLR	1. An Impact Assessment Framework for Bottom Fishing Methods in the CCAMLR Convention Area.	Complete	Sharp et al. 2009

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BEN	Internally funded 4	SPRFMO	1. To develop a bottom Fishery Impact Assessment: Bottom Fishing Activities by New Zealand Vessels Fishing in the High Seas in the SPRFMO Area during 2008 and 2009.	Complete	Ministry of Fisheries 2008
BEN	BEN2009-02	Monitoring recovery of benthic communities in Spirits Bay	1. To survey Spirits Bay and Tom Bowling Bay benthic invertebrate communities according to the monitoring programme designed in ENV2005/23. 2. To assess changes in benthic communities inside and outside the closed area since 1997.	Complete	Tuck & Hewitt (2013) AEBR 111
BEN	IFA2008-04	Guide for the rapid identification of material in the process of managing Vulnerable Marine Ecosystems	To produce a guide for the rapid identification of material in the process of managing Vulnerable Marine Ecosystems.	Complete	Tracey et al. 2008
BEN	BEN2007-01	Assessing the effects of fishing on soft sediment habitat, fauna, and processes	1. To design and test sampling and analytical strategies for broad-scale assessments of habitat and faunal spatial structure and variation across a variety of seafloor habitats. 2. To design and carry out experiments to assess the effects of bottom trawling and dredging on benthic communities and ecological processes important to the sustainability of fishing at scales of relevance to fishery managers.	Complete	Tuck et al. 2016
BEN	IFA2007-02	Development of a Draft New Zealand High-Seas Bottom Trawling Benthic Assessment Standard	1. To generate data summaries and maps of New Zealand's recent historic high-seas bottom trawling catch and effort in the proposed convention area of the South Pacific Regional Fisheries Management Organization (SPRFMO). 2. To map vulnerable marine ecosystems (VMEs) in the SPRFMO area. 3. To develop a draft standard for assessment of benthic impacts of high-seas bottom trawling on VMEs in the proposed SPRFMO convention area.	Complete	Parker (2008) FRR
BEN	BEN2006-01	Mapping the spatial and temporal extent of fishing in the EEZ	1. To update maps and develop GIS layers of fishing effort from project ENV2000/05 to show the spatial and temporal distribution of mobile bottom fishing throughout the EEZ between 1989/90 and 2004/05. 2. To produce summary statistics of major fisheries and the aggregate of all bottom impacting fisheries in terms of the extent and frequency of fishing by year, by depth zone, by fishable area, and, to the extent possible, by habitat type.	Complete	Baird et al. 2009 Baird et al. (2011) AEBR 73 Baird & Wood 2010

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			3. To identify and document any major trends or changes in fishing effort or fishing behaviour. 4. To identify, discuss the implications of, and make recommendations on data quality and other problems with current reporting systems that complicate characterisation and quantification of bottom fishing effort. 5. To integrate information on the distribution, frequency, and magnitude of fishing disturbance with habitat characteristics throughout the EEZ, using information stored in national databases, expert opinion, and the MEC.		Baird & Wood (2012) AEBR 89 Leathwick et al. 2010 Leathwick et al. (2012) AEBR 88
BEN	ENV2005-15	Information for managing the Effects of Fishing on Physical Features of the Deep-sea Environment	1. To provide an updated database that identifies all known seamounts in the 'New Zealand region', encompassing the area from 24°00' – 57°30'S, 157°00'E – 167°00'W. The database will catalogue relevant data (e.g., physical, biological, location, fishing effort) for individual seamounts. 2. To identify indicators and measures suitable for the assessment of risk pertaining to the effects of fishing disturbance on the benthic biota of seamounts, and review suitable ecological risk assessment methods, that can be derived or utilise information contained within the seamount database.	Complete	Rowden et al. 2008 Clark et al. 2010b
BEN	ENV2005-16	Investigate the Effects of Fishing on Physical Features of the Deep-sea Environment	1. To monitor changes in fauna and habitats over time on selected UTFs in the Chatham Rise area that have a range of fishing histories. 2. To continue development of the risk assessment model to predict the effects of fishing, and provide options for the management of UTF ecosystems.	Complete	Clark et al. (2010a) AEBR 46, 2010b, 2010c, Clark et al. (2011) AEBR 74
BEN	ENV2005-20	Benthic invertebrate sampling and species identification in trawl fisheries	1. To produce identification guides for benthic invertebrate species encountered in the catches of commercial and research trawlers.	Complete	Tracey et al. 2007; Williams et al. 2010; Clark et al. 2009
BEN	ENV2005-23	Monitoring recovery of the benthic community between North Cape and Cape Reinga	1. To design a monitoring programme that will provide the following quantitative estimates: i) Estimates of the nature and extent of past fishing impacts on the benthic community between North Cape and Cape Reinga; ii) Estimates of change over time in areas previously fished but subsequently closed to fishing. Estimated parameters will include indices representing biodiversity, community composition, and biogenic structure; iii) Estimates of change over time in areas	Complete	Tuck et al. (2010) AEBR 53

Theme	Project code	Project title	Specific objectives	Status	Citation/s
			environmentally comparable to those assessed in (ii), above, but subject to ongoing fishing impacts; and iv) Estimates of change over time in areas comparable to those above, but not impacted by fishing (if any such areas can be found).		
BEN	ZBD2005-04	Information on benthic impacts in support of the Foveaux Strait Oyster Fishery Plan	1. To assess the distribution, vulnerability to disturbance, and ecological importance of habitats in Foveaux Strait, and describe the spatial distribution of the Foveaux Strait oyster fishery relative to those habitats. 2. To assemble and collate existing information on the Foveaux Strait system between the Solander Islands and Ruapuke Island or other area to be agreed with MFish. 3. To map, using best available information, substrate type, bathymetry, wave energy, and tidal flow in this area. 4. To assess the extent to which these data can be used to define useful functional categories that might serve as habitat classes. 5. To rank the vulnerability to fishing disturbance of habitat classes developed in Objective 3 using approximate regeneration times. 6. To describe the functional role and ecosystem services provided by each habitat class developed in Objective 3, including an assessment of the relative importance of each to overall ecosystem function and productivity. 7. To describe the spatial pattern and intensity of dredge fishing for Foveaux Strait oysters over the past 10 fishing years and relate this to natural disturbance regimes and habitat classes developed in Objective 3. 8. To carry out a qualitative video survey of benthic habitats in Foveaux Strait, both within the established commercial oyster fishery area and areas outside the fishery area but within OYU 5.	Complete	Michael et al. 2006
BEN	ZBD2005-15	Information on benthic impacts in support of the Coromandel Scallops Fishery Plan	1. To assemble and collate existing information on the coromandel Scallop Fishery between cape Rodney and Town Point or other, wider area to be agreed with Mfish. 2. To map, using best available information, substrate type, bathymetry, wave energy, and tidal flow in this area. 3. To assess the extent to which data can be used to define useful functional categories that might serves as habitat classes. 4. To rank the vulnerability of fishing disturbance of habitat classes developed in Objective 3 using approximate regeneration times.	Complete	Tuck et al. 2006a, 2006b

Theme	Project code	Project title	Specific objectives	Status	Citation/s
			5. To describe the functional role and ecosystem services provided by each habitat class developed in Objective 3, including an assessment of the relative importance of each to overall ecosystem function and productivity. 6. To describe the spatial pattern and intensity of dredge and trawl fishing within the Coromandel scallop fishery over the past 15 fishing years and relate this to natural disturbance regimes and habitat classes developed in Objective 3.		
BEN	ZBD2005-16	Information on benthic impacts in support of the Southern Blue Whiting Fishery Plan	1. To assemble and collate existing information on the Southern Blue Whiting fishery in SBW6A, SBW6B, SBW6I, and SBW6R or other wider area to be agreed with MFish 2. To map, using best available information, substratum type, bathymetry, wave energy, tides, and ocean currents in these areas 3. To assess the extent to which these data can be used to define useful functional categories that might serve as habitat categories. 4. To rank the vulnerability to fishing disturbance of habitat classes developed in Objective 3 using approximate regeneration times. 5. To describe the functional role and ecosystem services provided by each habitat class developed in Objective 3, including an assessment of the relative importance of each to overall ecosystem function and productivity. 6. To describe the spatial pattern and intensity of trawl fishing within the Southern Blue Whiting fishery over the past 10 fishing years and relate this to natural disturbance regimes and habitat classes developed in Objective 3.	Complete	Cole et al. 2007
BEN	ENV2003-03	Determining the spatial extent, nature and effect of mobile bottom fishing methods	1. To determine the spatial extent, nature and time between disturbances of mobile bottom fishing methods in the Chatham Rise trawl fisheries.	Complete	Baird et al. 2006
BEN	ENV2002-04	Benthic invertebrate sampling and specific identification in trawl fisheries	1. To quantify and map the benthic invertebrate species incidental catch in commercial and research trawling throughout the New Zealand EEZ.	Complete	Tracey et al. 2005
BEN	ENV2001-09	The effects of mobile bottom fishing gear on bentho-pelagic coupling	To describe any effects of fishing that might modify bentho-pelagic coupling (a complex, interlinked suite of processes transferring energy, oxygen, carbon, and nutrients between pelagic and benthic systems), to consider the scale of such possible	Complete	Cryer et al. 2004

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			effects, and to put the summary in a New Zealand context.		
BEN	ENV2001-15	The effects of bottom impacting trawling on seamounts	1. To design a programme in New Zealand waters previously trawled and now closed to trawling to monitor the rate of regeneration of benthic communities on seamounts.	Complete	Clark & O'Driscoll 2003 Clark & Rowden 2009
BEN	OYS2001-01	Foveaux Strait oyster stock assessment	1. To carry out a survey and determine the distribution and absolute abundance of pre-recruit and recruited oysters in both non-commercial and commercial areas of Foveaux Strait. The target coefficient of variation (c.v.) of the estimate of absolute recruited abundance is 20%. 2. To estimate the sustainable yield for the areas of the commercial oyster fishery in Foveaux Strait for the year 2002 oyster season. 3. To identify and count benthic macro-biota collected during the dredge survey.	Complete	Rowden et al. 2007
BEN	ENV2000-05	Spatial extent, nature and impact of mobile bottom fishing methods in the New Zealand EEZ	1. To determine the spatial extent, nature and impact of mobile bottom fishing methods within the New Zealand EEZ.	Complete	Cryer and Hartill 2002 Baird et al. 2002
BEN	ENV2000-06	Review of technologies and practices to reduce bottom trawl bycatch and seafloor disturbance in New Zealand	To review technologies and practices to reduce bottom trawl bycatch and seafloor disturbance in New Zealand.	Complete	Booth et al. 2002 Beentjes & Baird 2004
BEN	ENV98-05	The effects of fishing on the benthic community structure between North Cape and Cape Reinga	1. To determine the effects of fishing on the benthic community structure between North Cape and Cape Reinga.	Complete	Cryer et al. 2000
ECO	ANT2017-03	Antarctic Research - Ross Sea region MPA	1. To provide advice and scientific knowledge to MPI that would allow the CCAMLR Scientific Committee to advise the Commission on: (i) the degree to which the specific objectives of the MPA are being achieved. 2. To provide advice and scientific knowledge to MPI that would allow the CCAMLR Scientific Committee to advise the Commission on the degree to which the MPA objectives are still relevant in different areas of the MPA. 3. To provide advice and scientific knowledge to MPI that would allow the CCAMLR Scientific Committee	Approved	

Theme	Project code	Project title	Specific objectives	Status	Citation/s
			to advise the Commission on what management actions may be required to improve the achievement of the objectives for this MPA.		
ECO	MDC2015-01	MDC Benthic coring	To support benthic coring in the Marlborough Sounds by the Marlborough District Council (MDC). The results of this will provide historical information to support environmental restoration and reporting goals. It will also support potential restoration using empty mussel shell disposal.	Complete	
ECO	ENV2014-09	Spatial decision support tools for multi-use and cumulative effects	To provide a customised GIS decision support tool to help assess the cumulative effects of fishing.	Ongoing	
ECO	SEA2013-01	Provision of identification guides (sea pens and black corals)	To produce identification guides for sea pens and black corals electronically as AEBR (including MPI review).	Complete	Tracey et al. (2014) FRR 2014/6 Williams et al. (2014) AEBR 132 Opresko et al. (2014) AEBR 131 Clark et al. (2015) AEBR 149
ECO	ENV2012-01	A literature review of nitrogen levels and adverse ecological effects in embayments in temperate regions.	1. To complete a literature review of nitrogen levels and adverse ecological impacts from temperate embayments in order to assist aquaculture consenting authorities in determining at what concentration of nitrogen adverse effects may be expected.	Complete	Hartstein & Oldman (2015) AEBR 159
ECO	SEA2012-17	NPOA Sharks extension work	NPOA Sharks extension work.	Complete	Clarke et al. (2013) FAR 2013/65
ECO	ZBD2012-02	Tier 1 statistic: Ocean	1. To identify candidate oceanographic variables for potential development as part of the proposed Tier 1 Statistic, Atmospheric and Ocean Climate Change.	Complete	Pinkerton et al. (2015a) AEBR 151
ECO	DAE2010-01	Taxonomic identification of benthic specimens	1. To identify benthic invertebrates in samples taken during research trawls and by Observers on fishing vessels. 2. To update relevant databases recording the catch	Complete	Mills et al. (2013) FRR 2013/17

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			of invertebrates in research trawls and commercial fishing.		Tracey et al. (2014) FRR 2014/17
ECO	DEE2010-04	Development of a methodology for Environmental Risk Assessments for deepwater fisheries	1. To review approaches to Ecological Risk Assessments (ERA) and methods available for deepwater fisheries both QMS and non-QMS. 2. To develop and recommend a generic, cost effective, method for ERA in deepwater fisheries by using or modifying methods identified in Objective 1.	Complete	Clark et al. submitted; Mormede & Dunn (2013) AEBR 106
ECO	DEE2010-05	Development of a suite of environmental indicators for deepwater fisheries	1. To review the literature and hold a workshop to recommend a suite of ecosystem and environmental indicators that will contribute to assessing the performance of deepwater fisheries within an environmental context. 2. To examine available data and design a data collection programme to enable future calculation of the indicators identified in Specific Objective 1.	Complete	Tuck et al. (2014) AEBR 127
ECO	ENV2010-03	Habitats of particular significance for inshore finfish fisheries management	1. To review the literature to determine the most important juvenile or reproductive (spawning, pupping or egg-laying) areas for inshore finfish target species. 2. To use a gap analysis to prioritise areas for future research concerning the important juvenile or reproductive (spawning, pupping or egg-laying) areas for target inshore finfish fisheries.	Complete	Morrison et al. (2014b) AEBR 125
ECO	ENV2010-05A&B and SEA2010-15	Habitats of particular significance for fisheries management: shark nursery areas	1. Identify, from the literature, important nursery grounds for rig in estuaries around mainland New Zealand. 2. Design and carry out a survey of selected estuaries and harbours around New Zealand to quantify the relative importance of nursery ground areas. 3. Identify threats to these nursery ground areas and recommend mitigation measures.	Complete	Francis et al. (2012) AEBR 95 Jones et al. (2015) AEBR 150
ECO	ZBD2010-42	Development of a National Marine Environment Monitoring Programme	1. To design a Marine Evnvironment Monitoring Programme (MEMP) to track the physical, chemical and biological changes taking place across New Zealand's marine environment over the long term. 2. To prepare an online inventory (metadatabase) of repeated (time series) biological and abiotic marine observations/datasets in New Zealand. 3. To review, evaluate fitness for purpose, and identify gaps in the utility and interoperability of	Complete	Hewitt et al. (2014) AEBR 141

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			these datasets for inclusion in MEMP from both science and policy perspectives. 4. To design a MEMP that includes relevant existing data collection and proposed new time series.		
ECO	ENV2009-04	Trends in relative mesopelagic biomass using time series of acoustic backscatter data from trawl surveys	1. To evaluate relative changes in abundance of mesopelagic fish and other biological components from acoustic records collected during Chatham Rise and Sub-Antarctic trawl surveys. 2. To explore links between trends in mesopelagic biomass and climate variables and variations, and condition indices of commercial species in the Chatham Rise and Sub-Antarctic areas.	Complete	O'Driscoll et al. (2011) AEBR 76
ECO	ENV2009-07	Habitats of particular significance for fisheries management: Kaipara harbour	1. Collate and review information on the role and spatial distribution of habitats in the Kaipara Harbour that support fisheries production. 2. Assess historical, current, and potential anthropogenic threats to these habitats that could affect fisheries values, including fishing and land-based threats. 3. Design and implement cost-effective habitat mapping and monitoring surveys of habitats of particular significance for fisheries management in the Kaipara Harbour.	Complete	Morrison et al. (2014d) AEBR 129
ECO	GMU2009-01	Spatial Mixing of GMU1 using Otolith Microchemistry	1. To determine the level of spatial mixing and connectivity of grey mullet (*Mugil cephalus*) populations using otolith microchemistry. 2. To collect and analyse the chemical composition of grey mullet otoliths. 3. To analyse the otoliths collected under Objective 1 to determine if the samples can be spatially separated.	Complete	Morrison et al. (2016) FAR 2016/15
ECO	IPA2009-11	Trophic studies publication of review	1. To publish the comprehensive review of New Zealand-wide trophic studies completed in 2000 that was prepared by NIWA.	Complete	Stevens et al. (2011) AEBR 85
ECO	FLA2009-01	Assess the feasibility of using juvenile netting surveys to predict adult yellow-belly & sand flounder	1. Assess the feasibility of using juvenile netting surveys to predict adult yellow-belly and sand founder abundance in the Manukau Harbour and Firth of Thames (this also examined correlations between juvenile catch and environmental factors).	Complete	McKenzie et al. (2013) FAR 2013/10

Theme	Project code	Project title	Specific objectives	Status	Citation/s
ECO	AQE2008-02	Review of ecological effects of farming shellfish and other species	1. To collate and review information on the ecological effects of farming mussels (*Perna canaliculus*), including offshore mussel farming and spat catching, in the New Zealand marine environment. 2. To collate and review information on the ecological effects of farming oysters in the New Zealand marine environment. 3. To collate and review information on the ecological effects of farming species other than mussels (*Perna canaliculus*), oysters, and finfish, in the New Zealand marine environment.	Complete	Keeley et al. 2009
ECO	IFA2008-08	Inputs to the Ross Sea bioregionalisation	1. To produce one or more benthic invertebrate classifications of the Ross Sea region. 2. To use fishery catch data to examine spatial distributions of major demersal fish species. 3. To prepare other biological or environmental spatial data layers for use in the Ross Sea workshop.	Complete	Pinkerton et al. 2009a
ECO	TOH2007-03	Toheroa Abundance	1. To investigate variations in the abundance of toheroa. 2. To investigate sources of mortality of toheroa and factors affecting the recruitment of toheroa	Complete	Williams et al. (2013) AEBR 114
ECO	BEN2007-05	Risk assessment framework for assessing fishing & other anthropogenic effects on coastal fisheries	1. To collate existing information on the distribution, intensity, and frequency of anthropogenic disturbances in the coastal zone that could be used in a risk assessment model to estimate their likely aggregate effect on ecosystem function across habitats and over different scales of ecosystem functioning and biological organisation. 2. To develop a risk assessment framework in conjunction with a variety of stakeholders and environmental scientists.	Complete	MacDiarmid et al. (2012) AEBR 93
ECO	ENH2007-01	Stock enhancement of blackfoot paua	1. To assess the survival rate of enhanced paua from introduction into the wild through to harvest. 2. To assess the genetic diversity of hatchery spawned juvenile paua bred for enhancement purposes. 3. To assess interactions between introduced and wild paua populations and to recommend research and monitoring to quantify those impacts that are potentially adverse.	Complete	McCowan 2013

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ECO	ENV2007-04	Climate and Oceanographic Trends Relevant to New Zealand Fisheries	1. To summarise, for fisheries managers, climatic and oceanographic fluctuations and cycles that affect productivity, fish distribution and fish abundance in New Zealand.	Complete	Hurst et al. (2012) AEBR 90
ECO	ENV2007-06	Trophic Relationships of Commercial Middle Depth Species on the Chatham Rise	1. To quantify the inter-annual variability in the diets of hoki, hake and ling on the Chatham Rise 1992–2007. 2. To quantify seasonal dietary cycles for hoki, hake and ling that have been collected from the commercial fleet throughout the year.	Complete	Horn & Dunn (2010) AEBR 54
ECO	HAB2007-01	Biogenic habitats as areas of particular significance for fisheries management	1. To collate and review available information on the location, value, functioning, threats to, and past and current status of biogenic habitats that may be important for fisheries production in the New Zealand marine environment. 2. To identify information gaps, in the New Zealand context, and recommend measures to address those important to an ecosystem approach to fisheries management.	Complete	Morrison et al. (2014a) AEBR 130
ECO	IPA2007-07	Land Based Effects on Costal Fisheries	1. To review and collate scientific knowledge and research on the impacts of land-based activities on coastal fisheries and biodiversity.	Complete	Morrison et al. (2009) AEBR 37
ECO	ENV2006-04	Ecosystem indicators for New Zealand fisheries	1. To carry out a literature review of potential fish-based ecosystem indicators and identify a suite of indicators to be tested in Objective 2. 2. To test a suite of fish-based ecosystem indicators (identified by Objective 1) on existing trawl survey time series in New Zealand. The utility of these indicators for monitoring the effects of fishing in New Zealand should also be evaluated.	Complete	Tuck et al. 2009
ECO	GBD2006-01	DNA database for commercial marine fish and invertebrates	1. To collect DNA sequences for vouchered specimens of commercially important marine fishes and submit the DNA data to the international Barcode of Life Database (BOLD). 2. To collect DNA sequences for vouchered specimens of commercially important marine invertebrates and submit the DNA data to the international Barcode of Life Database (BOLD). Note: The funding was limited to $60 000 for this Objective. Therefore, MFish agreed to omit the invertebrate species (Objective 2) from this project and reduce the number of fish species sequenced from 100 to 80 (up to 5 specimens per species).	Complete	No reports specified as required output

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			During the course of the project MFish staff asked NIWA to identify smoked eel product, suspect shark fillets, and possible paua slime with DNA markers, consequently the project was modified to accommodate these requests.		
ECO	IPA2006-08	Review of the Ecological Effects of Marine Finfish aquaculture: Final Report	1. Summarise and review existing information on ecological effects of finfish farming on the marine environment in New Zealand and overseas.	Complete	Forrest et al. 2007
ECO	SAP2006-06	West Coast South Island review	1. To publish a review document summarising oceanic and environmental research information particularly relevant to hoki, but also other fisheries, that spawn off Westland in winter. 2. Update the draft chapters prepared in 2004 by oceanographers, modellers, and scientists towards the overall objective. 3. Incorporate a section on other west coast spawning fisheries.	Complete	Bradford-Grieve & Livingston (2011) AEBR 84
ECO	ENV2005-08	Experimental design of a programme of indicators	1. To assess the utility/feasibility of using demographic information to assess the effects of fishing on seabird populations. 2. To identify population indicators and to provide sampling protocols and experimental design for selected high to medium priority seabird populations. 3. To recommend experimental protocols for sampling of selected seabird populations in New Zealand influenced by fisheries mortality, employing robust design methodology and including recommendations for inclusions of data into Ministry of Fisheries databases.	Complete	MacKenzie & Fletcher (2010) FRR
ECO	IPA2005-02 and MOF2003-03A	A guide to common offshore crabs in New Zealand Waters	1. Develop a guide to common offshore crabs in New Zealand waters	Complete	Naylor et al. 2005
ECO	SAM2005-02	Effects of climate on commercial fish abundance	To examine the possible effects of climate on fishery yields and abundance indices for commercial fisheries around New Zealand.	Complete	Dunn et al. 2009a
ECO	HOK2004-01	Hoki Population modelling and stock assessment	To investigate the prediction of year class strength from environmental variables.	Complete	Francis et al. 2005

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ECO	AQE2003-01	Effects of aquaculture and enhancement stock sources on wild fisheries resources and the marine environment.	1. To identify, discuss the effects and qualitatively assess the risks of aquaculture and enhancement stocks improved by hatchery technology on New Zealand's wild fisheries resources and the marine environment. 2. To identify, discuss the effects and qualitatively assess the risks associated with the translocation of aquaculture and enhancement stocks on New Zealand's wild fisheries resources and the marine environment. 3. To make recommendations on priority issues, risks, or research to be undertaken, as a result of information discussed and evaluated in Objectives 1–2.	Complete	Speed 2005
ECO	EEL2003-01	Non-fishing mortality of freshwater eels	1. To undertake a feasibility study on establishing an estimate of the mortality of eels caused by hydroelectric turbines and other point sources of mortality caused by human activity.	Complete	Beentjes et al. 2005
ECO	MOF2003-01	The implications of marine reserves for fisheries resources and management in the New Zealand context	Investigations of the implications of marine resources for fisheries resources and management in the New Zealand context.	Complete	Speed et al. 2006
ECO	ENV2002–03	Beach cast seaweed review	1. To collate existing information on the role of beach-cast seaweed in coastal ecosystems to assess the nature and extent of the impacts that the removal of beach cast seaweed may have on the marine environment. 2. On the basis of the review in Specific Objective 1 above, to identify key research gaps related to any marine environment impacts that the removal of beach cast seaweed may have.	Complete	Zemke-White et al. (2005) FAR2005/44
ECO	ENV2002-07	Energetics and trophic relationships of important fish and invertebrate species	1. To quantify food webs supporting important fish and invertebrate species.	Complete	Livingston 2004
ECO	CRA2000–01	Rock lobster stock assessment	Objective 11: To conduct a desktop study to identifi and explore data needs associated with managing the effects of rock lobster fishing on the environment.	Complete	Breen 2005
ECO	ENV2000-04	Identification of areas of habitat of particular significance for fisheries	1. To review literature and existing data for all significant fish species, including all QMS species, encountered from the 200-1500 m contour within	Complete	O'Driscoll et al. 2003

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		management within the New Zealand EEZ	the New Zealand EEZ to: a) determine areas of important juvenile fish habitat; b) determine areas of importance to spawning fish populations; and c) determine areas of importance for shark populations for pupping or egg laying. 2. To review literature and existing data for all significant pelagic fish species (excluding highly migratory species) encountered within the New Zealand EEZ to: a) determine areas of important juvenile fish habitat; b) determine areas of importance to spawning fish populations; and c) determine areas of importance for shark populations for pupping or egg laying 3. To review literature and existing data for all significant marine invertebrate species encountered within the New Zealand EEZ to: a) determine areas of important juvenile habitat; and b) determine areas of importance to spawning populations.		
ECO	MOF2000-02A	Future research requirements for the Ross Sea Antarctic toothfish (*Dissostichus mawsoni*) fishery.	To recommend future research requirements for the Ross Sea Antarctic toothfish (*Dissostichus mawsoni*) fishery.	Complete	Hanchet 2000
ECO	ENV99-03	Identification of areas of habitat of particular significance for fisheries management within the NZ EEZ.	1. To determine areas of habitat of importance to fisheries management within the New Zealand EEZ for selected fish species in selected areas.	Complete	Hurst et al. 2000
ECO	ENV99-04	A framework for evaluating spatial closures as a fisheries management tool	To design a framework for evaluating spatial closures as a fisheries management tool.	Complete	Bentley et al. 2004
ECO	No project number	The fishery for freshwater eels (*Anguilla* spp.) in New Zealand	To review the fishery for freshwater eels (*Anguilla* spp.) in New Zealand.	Complete	Jellyman 1994
ZBD	ZBD2017-02	Linking primary and secondary production in the sea	1. Investigate the role that the p-ratio and the z-ratio play in modifying the relationship between	Withdrawn	

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			primary and secondary productivity at fishery-relevant scales in New Zealand 2. Improve and refine the methodology for the projection of climate change scenarios on primary and secondary productivity.		
ZBD	ZBD2017-04	Implications of ocean acidification on the capacity of carbonates in sediments to buffer eutrophication effects	1. Determine how the carbonate content of coastal benthic sediments affects sediment biogeochemistry and processes such as nitrogen recycling and removal. 2. Improve understanding of what the loss of carbonate materials from sediments in an acidified world (through dissolution) will mean for critical marine ecosystem functions.	Withdrawn	
ZBD	ZBD2016-07	Multiple stressors on coastal ecosystems – in situ	To assess the effects of global warming and ocean acidification on coastal productivity processes in New Zealand	Complete	Law et al. (2021) AEBR 277
ZBD	ZBD2016-11	Quantifying benthic biodiversity	1. Collect quantitative data about seabed habitats and fauna by undertaking a survey of unsampled areas on Chatham Rise. 2. Process and compile seabed habitat and fauna data from the survey and merge these with comparable data from previous quantitative surveys on Chatham Rise. 3. Use merged data to assess the utility of existing community and species distribution models for Chatham Rise. 4. Use merged data to build new community and species distribution models for Chatham Rise.	Completed	Bowden et al. (2019a) AEBR 221 Bowden et al. (2019b) AEBR 235
ZBD	DAE2015-05	Taxonomic ID of benthic samples	To identify benthic invertebrates in samples taken during research trawls and by observers on fishing vessels.	Complete	Tracey & Mills (2016) FRR
ZBD	ZBD2014-01	Live corals: Age and growth study of deepsea coral in aquaria.	Ocean acidification and temperature manipulation are now underway to look at the physiological responses (e.g., growth) of deepsea corals to future predicted environmental conditions.	Complete	Tracey et al. 2016

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ZBD	ZBD2014-03	Sublethal effects of environment change on fish populations	Co-funded by MBIE, this project explores the effects of ocean acidification on the behaviour of young snapper with a view to scaling up these effects to model long-term effects on the snapper population.	Complete	Parsons et al. (2021) AEBR 275
ZBD	ZBD2014-04	Isoscapes for Trophic and Animal Studies	1. To generate a new tool for fisheries management and conservation. Specifically, to produce a validated, modelled, south-west Pacific and Southern Ocean carbon and nitrogen isotopic map, referred to as an 'isoscape', which will improve our understanding of trophic interactions and its relationship with marine animals.	Complete	Graham & Bury (2019) AEBR 218
ZBD	ZBD2014-05	Modelling the effects of ocean acidification.	1. Determine how much the aragonite and calcite saturation horizons (ASH and CSH) have changed over the industrial era for the southwest Pacific, including New Zealand's EEZ.	Complete	Mikaloff-Fletcher et al. (2017) AEBR 187
ZBD	ZBD2014-06	Macroalgae mapping and potential as national scale indicators	Many countries use seaweeds to monitor the state of the marine environment, however this approach has not been explored in New Zealand. In this project, seaweeds will be selected according to their mapped distribution and availability, and assessed for their indicator potential.	Complete	D'Archino et al. (2019) AEBR 207
ZBD	ZBD2014-07	Southern coralline algae shellfish habitat	Coralline algae are a structurally important component of coastal habitats and play an important role in ecosystem processes. They produce chemicals which promote the settlement of the larvae of certain herbivorous invertebrates, particularly paua. Coralline algae appear to enhance larval metamorphosis and the survival of larvae through the critical settlement period. The first objective is to document critical baseline information on the diversity of coralline algae in southern New Zealand using morphological and molecular identification.	Complete	Nelson et al. (2019) AEBR 232
ZBD	ZBD2014-09	Climate change risks and opportunities	1. To prepare a technical report that explains the most up to date issues and hypotheses with regard to observed and predicted changes to the physical, chemical and biological properties of New Zealand coastal and offshore waters. 2. To prepare a synthesis of the Technical Report that will be informative and provide guidance on	Complete	Cummings et al. (2021) AEBR 261

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			what can be done, for stakeholders, policymakers and resource managers.		
ZBD	ZBD2014-10	BPA Biodiversity	1. To update the inventory of benthic samples and biodiversity data available within BPA and Seamount Closure areas. 2. To process and identify undescribed samples and material in selected BPAs and for selected taxonomic groups. 3. To identify gaps in sample coverage, evaluate priority areas and design a sampling programme to collect appropriate data. 4. To undertake an objective spatial management planning exercise to assess the effectiveness of the current BPAs to protect biodiversity.	Complete	Clark et al. (2019) AEBR 227
ZBD	ZBD2013-02	VME Genetic Connectivity	This project addresses the critical lack of data concerning deep sea genetic connectivity of VME indicator taxa, and will clarify the spatial relationships and distribution of biodiversity of several protected invertebrate VME species within New Zealand's EEZ and beyond.	Complete	Holland et al. (2020) AEBR 245 Rowden et al. 2015
ZBD	ZBD2013-03	Continuous Plankton Recorder - Phase 2	The overall objective of the CPR programme is to map changes in the quantitative distribution of epipelagic plankton, including phytoplankton, zooplankton and euphausiid (krill) life stages, in New Zealand's EEZ and transit to the Ross Sea, Antarctica. To enable trend analysis, the Contractor will continue the annual time series for a further 5-year period (years 6–10).	Complete	Robinson et al. (2021) AEBR 257
ZBD	ZBD2013-08	NZ-Ross sea connectivity Humpback whales	1. To determine the migration path and Antarctic feeding grounds for New Zealand humpback whales.	Complete	Riekkola et al. 2018, 2019
ZBD	ZBD2013-06	Shell generation and maintenance of aquaculture species	Shells of individuals of NZ paua, flat oysters and cockles will undergo detailed analysis to determine how the decreased pH/increased temperature modified their shell (i) thickness, (ii) mineralogy and (iii) construction.	Complete	Cummings et al. 2013

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ZBD	ZBD2013-07	Interactive keys for easy identification keys of amphipods	Generate interactive identification keys for marine Amphipoda families Synopiidae and Epimeriidae for easy and free use online.	Complete	
ZBD	ZBD2012-01	Development of a Tier 1 National Reporting Statistic for New Zealand's Marine Biodiversity	To perform a preliminary investigation of the utility and feasibility of developing the variables published by Costello et al. (2010) as a Tier 1 statistic.	Complete	Lundquist et al. (2015) AEBR 147
ZBD	ZBD2012-03	Chatham Rise Benthos - Ocean Survey	1. In relation to the Fishing Intensity Effects Survey, determine whether there are quantifiable effects of variations in seabed trawling intensity on benthic communities. 2. In relation to the Crest Survey, conduct seabed mapping and photographic surveys in previously un-sampled areas on the central crest of the Chatham Rise.	Complete	Bowden & Leduc (2017) AEBR 183 Pinkerton et al. 2016
ZBD	SRP2011-02	IDG 2009-01 MPI fish ID field guide	1. IDG 2009-01 field guide.	Complete	McMillan 2011a, 2011b, 2011c
ZBD	ZBD2011-01	Evaluation of ecotrophic and environmental factors affecting the distribution and abundance of highly migratory species in NZ waters	Evaluation of ecotrophic and environmental factors affecting the distribution and abundance of highly migratory species in New Zealand waters.	Complete	Horn et al. (2013) AEBR 116 McGregor & Horn (2015) AEBR 146
ZBD	ZBD2010-39	Improved benthic invertebrate species identification in trawl fisheries	1. To revise and update the document 'A guide to common deepsea invertebrates in New Zealand waters (second edition)' to allow a third edition of this guide to be printed.	Complete	Tracey et al. 2011a
ZBD	ZBD2010-40	Predictive modelling of the distribution of vulnerable marine ecosystems in the South Pacific Ocean region.	1. To develop and test spatial habitat modelling approaches for predicting distribution patterns of vulnerable marine ecosystems in the convention Area of the South Pacific Regional Fisheries Management Organisation with agreed international partners. 2. To collate datasets and evaluate modelling approaches which are likely to be useful to predict the distribution of vulnerable marine ecosystmes in the South Pacific Ocean region.	Complete	Rowden et al. (2013b) AEBR 120

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ZBD	ZBD2010-41	Ocean acidification in fisheries habitat	1. To assess the risks of ocean acidification to deep-sea corals and deepwater fishery habitat. 2. To determine the carbonate mineralogy of selected deep-sea corals found in the New Zealand region. 3. To assess the distribution of deep-sea coral species in the New Zealand region relative to improved knowledge of current and predicted aragonite and calcite saturation horizons, assessment of potential locations vulnerable to deep water upwelling. 4. Through a literature search and analysis, determine the most appropriate tools to age and measure the effects of ocean acidification on deep sea habitat-forming corals, and recommend the best approach for future assessments of the direct effects.	Complete	Tracey et al. (2013) AEBR 117
ZBD	ZBD2009-25	Predicting impacts of increasing rates of disturbance on functional diversity in marine benthic ecosystems	1. Further develop the landscape ecological model of disturbance/recovery dynamics in marine benthic communities, incorporating habitat connectivity, based on existing model by Lundquist, Thrush, and Hewitt. 2. Predict impacts of increasing rates of disturbance on rare species abundance, functional diversity, relative importance of biogenic habitat structure, and ecosystem productivity. 3. Use literature and expert knowledge to quantify rare species abundance, biomass, functional diversity, habitat structure, and productivity of various successional community types in the model. 4. Field test predictions of the model in appropriate marine benthic communities where historical rates of disturbance are known, and benthic communities have been sampled.	Complete	Lundquist et al. 2010, (2013) AEBR 118
ZBD	IPA2009-14	Bryozoan identificaiton guides	1. For each of ~50 species of common bryozoans, provide photos and text to allow for identification. Provide information on distribution and habitat (as far as is known) and further references for each species and on bryozoans as a whole. 2. Submit these data for publication in the Ministry of Fisheries series New Zealand Aquatic Environment and Biodiversity Research.	Complete	Smith & Gordon (2011) AEBR 75
ZBD	ZBD2009-03	To evaluate the vulnerability of New Zealand rhodolith species to environmental stressors and to characterise diversity of rhodolith beds.	1. To characterise the distribution and physical characteristics of two New Zealand rhodolith beds and characterise the associated biodiversity. 2. To measure the growth rates and evaluate the	Complete	Nelson et al. 2012

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			vulnerability of New Zealand species of rhodoliths to environmental stressors.		
ZBD	ZBD2009–10	Multi-species analysis of coastal marine connectivity	1. Determine overall patterns of regional connectivity in a broad range of NZ coastal marine organisms to define the geographic units of genetic diversity for protection and the dispersal processes that maintain this diversity. 2. Review previous studies of marine connectivity and population genetics in NZ coastal organisms to determine the preliminary range of patterns observed and the principal gaps (taxonomic geographic and ecological) in our understanding. 3. In a range of invertebrate and vertebrate marine organisms determine geographic patterns of genetic variation using standardised sampling and molecular techniques. 4. Analyse data across past and present studies to reveal both common and unique patterns of connectivity around the NZ coastline and the locations of common barriers to dispersal.	Complete	Gardner et al. (2010) AEBR 58 Hannan et al. (2016) AEBR 172
ZBD	ZBD2009-13	Ocean acidification impact on key NZ molluscs	1. Controlled laboratory experiments will be used to determine the effect of pCO2 levels that are predicted to occur in NZ waters over the next few decades on appropriate life history stages of at least two key NZ mollusc species. A number of response variables will be assessed. 2. Implications of these responses to the local and broader ecosystems will be assessed.	Complete	Cummings 2011; Cummings et al. 2011, 2013
ZBD	ZBD2008-01	Biogenic large–habitat–former hotspots in the near-shore coastal zone (50–250 m); quantifying their location, identity, function, threats and protection	1. To collect and integrate existing knowledge on biogenic habitat-formers in the <5–150 m depth zone of New Zealand's continental shelf, from sources including structured fisher interviews, primary and grey literature, and other sources as available. 2. Using the findings of Objective 1, design and deploy a series of sampling voyages to selected locations, to map and characterise locations of significant biogenic structure (either still existing, or historical), and collect relevant biological samples (both through visual census, and physical collection). 3. Process and analyse the samples collected in Objective 2, to provide a hierarchical, quantitative description of the biogenic habitats and associated species encountered. 4. Using the findings from Objective 1–3, assess the present status, likely extent, ecological role, and threats to, biogenic habitat formers in the <5–150	Complete	Jones et al. (2016) AEBR 174 Jones et al. (2018) AEBR 202

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			m depth zone. This should include a spatial modelling and risk assessment framework. Integrate (as appropriate) with other information sources and/or approaches that may exist by the year 2010/11.		
ZBD	ZBD2008-05	Macroalgal diversity associated with soft sediment habitats	1. Conduct a targeted collection programme across diverse soft sediment environments to develop a permanent reference collection of representative macroalgae. 2. Examine algal distribution in soft sediment habitats in relation to selected environmental variables. 3. Prepare an annotated checklist of macroalgae found in soft sediment environments in the New Zealand region.	Complete	Neill et al. (2012) AEBR 87
ZBD	ZBD2008-07	Carbonate sediments: the positive and negative effects of land-coast interactions on functional diversity	1. To quantify shifts in community structure and functional diversity in mollusc dominated habitats along gradients associated with an estuary-coast interface in two locations. 2. To characterise the influence of estuary-derived food sources across these gradients for key species. 3. To measure changes in growth of key species in relation to changes in food supply and land-derived sediment impacts. 4. To quantify carbon and nitrogen uptake and tissue turnover rates of key species in laboratory experiments.	Complete	Thrush et al. 2011 Savage et al. 2012
ZBD	ZBD2008-11	Predicting changes in plankton biodiversity and productivity of the EEZ in response to climate change-induced ocean acidification	1. To document the spatial and inter-annual variability of coccolithophore abundance and biomass- and assess in terms of the phytoplankton abundance- biomass and community composition in sub-tropical and sub-Antarctic water. 2. To document the seasonal and inter-annual variability of foraminifera and pteropod abundance and biomass at fixed locations in sub-tropical and sub-Antarctic water by analysis of sediment trap material from time-series data collection. 3. To document the spatial and seasonal distribution of the key coccolithophore species, *Emiliana huxleyi*, using both archived and ongoing ingestion of satellite images of Ocean Colour, and ground-truth the reflectance. 4. To determine the sensitivity and response of *E. huxleyi* and other EEZ coccolithophores to pH under a range of realistic atmospheric CO2 concentrations in perturbation experiments, using monocultures and mixed populations from in situ sampling. 5. To document the spatial variability of diazotrophs (nitrogen-fixing organisms) and associated nitrogen	Complete	Law et al. (2012) FRR Boyd & Law 2011

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			fixation rate, and assess in terms of phytoplankton abundance, biomass and community composition in sub-tropical waters north of the STF. 7. To determine the sensitivity of, and response of *Trichodesmium* spp. and other diazotrophs to pH under a range of realistic atmospheric CO2 concentrations in perturbation experiments using monocultures.		
ZBD	ZBD2008-14	What and where should we monitor to detect long-term marine biodiversity and environmental changes, remote sensing, biota, context, inshore offshore workshop	1. Identify the key questions to be addressed by long-term monitoring of marine biodiversity and environment. 2. Identify appropriate monitoring indices, how they should be spatially distributed and their sampling frequency. 3. Identify relevant existing monitoring programmes across the range of New Zealand agencies and science providers and identify gaps. 4. Provide those agencies setting environmental goals/ standards or research needs (MoRST, FRST, MFish, DOC, MfE, Commissioner for the Environment) with a thorough situational analysis, including a list of priority monitoring projects/plans.	Complete	Livingston 2009
ZBD	ZBD2008-15	Continuous plankton recorder project: implementation and identification	1. To set up a time series of annual CPR data collection by deployment from a toothfish vessel on the annual summer transit between New Zealand and the Ross Sea. 2. To identify phytoplankton and zooplankton according to strict observation protocols determined by the SAHFOS[1] CPR Survey and SO-CPR[2]. 3. To enter species data, frequency and location along the transect into a spreadsheet that will allow spatial mapping of the plankton density and distribution. 4. To analyse the full dataset after 5 years of data collection to: (a) determine trends in the dataset and (b) compare results with Australian datasets available through SO-CPR. 5. To evaluate the continuation of the programme.	Complete	Robinson et al. (2014) AEBR 128
ZBD	ZBD2008-20	Ross sea benthic ecosystem function: predicting consequences of shifts in food supply	1. To increase understanding of Ross Sea coastal benthic ecosystem function. 2. Conduct in situ investigations into responses to and utilisation of primary food sources by key species, at two contrasting coastal Ross Sea locations.	Complete	Cummings & Lohrer 2011 Cummings et al. 2011 Lohrer et al. 2013

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ZBD	ZBD2008-22	Acidification and ecosystem impacts in NZ and southern ocean waters (data collected during IPY).	1. To assess the response of cocolithophorids, and their replacement by non-calcifying organisms during incubation under a range of dissolved CO2 concentrations. 2. To describe and characterise changes in abundance and biodiversity of microbial components of the samples incubated at sea under a range of dissolved CO2 concentrations. 3. To predict the likely impacts of higher acidity on foodwebs and on carbon fixation under scenarios to be encountered in the Southern Ocean under forecasted trends associated with climate change.	Complete	Maas et al. 2010b
ZBD	ZBD2008-23	Macroalgae diversty and benthic community structure at the Balleny Islands	1. To describe and characterise macroalgae diversity from the Balleny Islands and the Western Ross Sea. 2. To describe and quantify benthic community structure from one location at the Balleny Islands 3. To complete anatomical and morphological investigations & molecular sequencing required for the identification of macroalgae samples from the Balleny Islands & western Ross Sea coastline to describe & characterise macroalgae diversity in Balleny Islands. 4. To process and analyse samples collected at the Balleny Islands, to analyse them using ICECUBE methodology and compare results with those from other ICECUBE sampling locations along the Ross Sea coastline	Complete	Nelson et al. (2010) AEBR 55
ZBD	ZBD2008-27	Scoping investigation into New Zealand abyss and trench biodiversity	1. Review what is already known of abyssal, canyon and trench faunas in NZ. 2. Review what is already known of abyssal, canyon and trench faunas around the world. 3. Prioritise science questions and locations for exploration. 4. Assess NZ capacity to sample at the required depths; identify sampling equipment needs. 5. Design a suitable vessel-based sampling programme.	Complete	Lörz et al. (2012b) AEBR 92
ZBD	ZBD2008-50	OS2020 Chatham Rise Biodiversity Hotspots	1. To improve understanding of the effects of trawl fishing in New Zealand on the biodiversity of seamounts, knolls and hills. 2. To describe differences in benthic biodiversity between northwestern and eastern regions of the Chatham Rise. 3. To continue the time series of observations in the NW Chatham Rise to demonstrate recovery in terms of biodiversity. 4. To extend the observations on fished-unfished contrasts and recovery of fauna on protected	Complete	Clark et al. 2009

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			seamounts to an oceanographically distinct location.		
ZBD	IPY2007-01	International polar year census of antarctic marine life post-voyage analysis: Ross Sea - Southern Ocean Biodiversity	1. To measure seabed depth and rugosity using the multibeam system to identify topographic features such as bottom type, iceberg scouring, seamounts etc and to determine areas for targeted benthic faunal sampling. 2. To continue the analysis of opportunistic seabird and marine mammal distribution observations from this and previous BioRoss voyages and published records, and in relation to environmental variables. 3. To identify and determine near-surface spatial distribution, diversity and abundance of phytoplankton, and zooplankton, based on Continuous Plankton Recorder samples collected during transit to and from the Ross Sea. 4. To collect & analyse data collected both underway, & at stations for salinity, temperature nutrient and chlorophyll-a data, spot optical measurements with the SeaWiFS. 5. To identify and determine the spatial distribution, abundance (biomass), diversity, and size structure of epipelagic, mesopelagic (and possibly bathypelagic) species using acoustics and net sampling. 6. To identify and measure diversity, distribution & densities of mesozooplankton, macrozooplankton & meroplankton (as collected by all plankton sampling methods except transit CPR samples). 7. To determine diversity, distribution & densities of viral, bacterial, phytoplankton & microzooplankton species in the water column. 8. To determine the spatial distribution, abundance (biomass), diversity, and size structure of shelf and slope demersal fish species and associated invertebrate species using a demersal survey. 9. To determine the diversity, abundance/density, spatial distribution, and physical habitat associations of benthic assemblages across a body size spectrum from megafauna to bacteria, for shelf, slope, seamounts, and abyssal sites in Ross Sea. 10. To describe trophic/ecosystem relationships in the Ross Sea ecosystem (pelagic and benthic, fish and invertebrates). 11. Assess molecular taxonomy and population genetics of selected Antarctic fauna and flora to estimate evolutionary divergence within and among ocean basins in circumpolar species. Provide DNA barcoding.	Complete	Allcock et al. 2009, 2010, submitted; Alvaro et al. 2011; Baird & Mormede 2014; Bowden et al. 2011a, in prep; Clark et al. 2010a; Dettai et al. 2011; Eakin et al. 2009; Eléaume et al. 2011, in prep; Ghiglione et al. 2012; Gordon 2000; Grotti et al. 2008; Hanchet et al. 2008a, 2008b, 2008c, 2008d, 2013 ; Hanchet 2009, 2010; Heimeier et al. 2010; Hemery et al. in prep; Koubbi et al. 2011; Leduc et al. 2012a, 2012b, 2012c, 2013, 2014; Linse et al. 2007; Lörz 2009, 2010a, 2010b; Lörz & Coleman 2009; Lörz et al. 2007, 2009, 2012a, 2012b, 2012c, in prep; Maas et al. 2010a; McMillan et al. 2012; Mitchell 2008; Nielsen et al. 2009; Norkko et al. 2005; O'Driscoll 2009; O'Driscoll et al. 2009, 2010, 2012; O'Loughlin et al. 2011; Pakhomov et al. 2011; Pinkerton

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					et al. 2007a, 2009b, 2010, 2013; Schiaparelli et al. 2006, 2008, 2010; Smith et al. 2011a, 2011b; Stein 2012; Strugnell et al. 2012
ZBD	IPY2007-02	International polar year census of antarctic marine life post-voyage analysis: Ross Sea - Southern Ocean Biodiversity	1. To measure and describe key elements of species distribution, abundance (density or biomass) & biodiversity for the Ross Sea and Southern Ocean for main habitats and key functional ecosystem roles, for major groups, viruses, bacteria, and archaea. 2. To report on the diversity of Antarctic Cephalopoda (Octopus and Squid), including a complete inventory of taxa, & reports on ontogenetic & sexual variation in species, their systematics, diversity, distribution, life histories, & trophic importance. 3. To Beak/Biomass Regression Equations. 4. Life cycle determination.	Complete	Garcia 2010
ZBD	ZBD2007-01	Chatham-Challenger Oceans 20/20 Post-Voyage	1. To quantify in an ecological manner, the biological composition and function of the seabed at varying scales of resolution, on the Chatham Rise and Challenger Plateau. 2. To elucidate the relative importance of environmental drivers, including fishing, in determining seabed community composition and structure. 3. To determine if remote-sensed data (e.g., acoustic) and environmentally derived classification schemes (e.g., marine environmental classification system) can be utilised to predict bottom community composition, function, and diversity. 4. To count, measure, and identify to species level (where possible, otherwise to genus) all macro invertebrates (> 2 mm) and fish collected during Oceans 20/20 voyages. 5. To count, measure and identify to species level (where possible, otherwise to genus or family) all meiofauna (> 2 mm) from multicore samples collected during the Oceans 20/20 voyages. 6. To count, measure and identify to species level (where possible, otherwise to genus or family) all fauna collected by hyper-benthic sled during the Oceans 20/20 voyages. 7. To count, measure, and identify to species level all macrofauna observed on DTIS images collected during the Oceans 20/20 voyages. The number of biogenic features (burrows/mounds) and habitat	Complete	Bowden (2011) AEBR 65 Bowden et al. (2011b) AEBR 77 Bowden et al. (2014) AEBR 126 Bowden & Hewitt 2012 Coleman & Lörz 2010 Compton et al. 2012 Floerl et al. (2012) AEBR 97 Hewitt et al. (2011a) AEBR 81 Hewitt et al. (2011b) AEBR 83 Lörz 2011a, 2011b

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			(spatial) complexity should also be estimated. 8. To count, measure, and identify to species level (where possible, otherwise to genus or family) all macrofauna observed on DTIS video footage collected during the Oceans 20/20 voyages. 9. To calculate and compare the performance of a suite of diversity measures (species and taxonomic-based) at varying levels of resolution. 10. To estimate particle size composition and organic content of sediment samples. Sediment samples should be aggregated over the top 5 cm of sediment. 11. To measure the bacterial biomass (top 2 cm) of the sediment and in the sediment surface water samples, collected during the Oceans 20/20 voyages. 12. To elucidate the relationships, patterns and contrasts in species composition, assemblages, habitats, biodiversity and biomass (abundance) both within and between stations, strata and areas. 13. To define habitats (biotic) encountered during the survey and assess their relative sensitivity to modification by physical disturbance, their recoverability, and their importance to ecosystem function/production. 14. To quantify the productivity, energy flow (trophic networks) and the energetic coupling (bentho pelagic or otherwise) of the area surveyed areas at various levels of resolution. 15. To assess the extent to which patterns of species distributions and communities can be predicted using environmental data (including fishing) collected during the Ocean 20/20 voyages or held in other databases. 16. To provide an interactive, high resolution mapping facility for displaying & plotting all data collected & derived indices. Includes environmental data, the abundance of species, indices of biomass or diversity, and statistically derived groupings. 17. To assess the extent to which acoustic, environmental or other remote-sensed data can provide cost-effective reliable means of assessing biodiversity at the scale of the Oceans 20/20 surveys. 18. To assess the extent to which the 2005 MEC and subsequent variants can provide cost-effective reliable means of assessing biodiversity at the scale of the Oceans 20/20 surveys. 19. Collating all information and analysis from all objectives, devise a series of statistically supported recommendations for surveying marine biodiversity in the future. Including – but may not be limited to – statistical analyses and modelling.		Nodder et al. (2011) AEBR 70

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ZBD	ZBD2006-02	Ongoing NABIS development	As part of NABIS, users will be able to identify spatial information relating to the annual distribution (average distribution over the period of a year) of particular species within the waters around New Zealand and in the terrestrial environment (including offshore islands) of New Zealand. Users will also be able to interrogate metadata and attribute data related to the information layers presented. Users will employ NABIS to identify where a particular species is found, to identify what species are found within an area of interest, and be able to compare the spatial distribution of a particular species with other information layers. 2. Some species may have notable changes in their spatial distribution throughout a year. For such species, users of NABIS will be able to view spatial information relating to the seasonal distribution of particular species within the waters around New Zealand and in the terrestrial environment (including offshore islands) of New Zealand. Users will also be able to interrogate metadata and attribute data related to the information layers presented. For species with a seasonal component to their biological distribution, users will employ NABIS to identify where a particular species is found within the waters around New Zealand and in the terrestrial environment (including off shore islands) of New Zealand at a particular time of the year, to identify what species are found within an area of interest at a particular time of year, or be able to compare the distribution of a particular species at a particular time of year, with other information layers. 3. To provide analysis of the data used in determining the hotspot distribution.	Complete	Anderson 2007
ZBD	ZBD2006-03	Antarctic coastal marine systems	1. Quantify patterns in benthic community structure and function at two coastal Ross Sea locations (Terra Nova Bay and Cape Evans). 2. Quantify benthic community structure and function at selected locations in Terra Nova Bay and Cape Evans.	Complete	Cummings et al. 2003, 2006b, 2008 Thrush & Cummings 2011 Thrush et al. 2010
ZBD	ZBD2006-04	Chatham/Challenger oceans 20/20	1. To collect seabed fauna, sediment samples and photographic images along transects in the Chatham Rise and the Challenger Plateau, as determined by the sampling protocol described in the Voyage Programmes for Voyages 2 and 3 of the project. Multibeam data should be collected	Complete	Nodder 2008 Nodder et al. 2011

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			opportunistically as time allows. 2. To describe the distribution of broad macro epifauna groups (ID level to be determined at sea during Surveys 2 & 3), their relative abundance, the substrate and habitat types, including representative photographic images of each sea-bed habitat and associated fauna along transects in the survey areas. 3. To provide a description of the observed evidence of fishing along transects. 4. To provide indicative measures of alpha biodiversity (richness, number of taxonomic groups) at appropriate scales within and between transects, and between the Chatham Rise and the Challenger Plateau. 5. To determine broad scale variability in sea-bed habitats and associated biodiversity within and between MEC classes at 20 class levels. 6. To process and archive biological samples and data into databases and collections for future analysis in meeting the Overall Objectives above.		
ZBD	ZBD2005-01	Balleny Islands Ecology Research, Tiama Voyage (2006)	1. To characterise shallow benthic communities across a range of habitat settings around the Balleny Islands, utilising a range of data collection methodologies (including SCUBA-based rock-wall suspension feeder photo quadrats, SCUBA-based linear video transects, and drop camera photography), and to analyse community patterns with reference to possible physical/oceanographic, biological, and/or biogeographic influences on community structure. 2. To characterise aspects of the marine food web of the Balleny Islands area, using stable isotope analysis of specimens from important functional groups, and to make inferences about factors affecting ecosystem-scale trophodynamics in the Balleny Islands area and potential implications for the function of the wider ecosystem. 3. To characterise the spatial and temporal distributions of higher-level consumer species (birds, seals and whales) and of dominant pelagic prey (i.e., krill swarms) by opportunistically recording all at-sea sightings, and by systematic observation of landbased top predators (birds and seals) while sailing along the coast of the islands. 4. To collect and photograph and/or retain fish specimens from shallow benthic environments using a range of fishing methods, including food-baited fish traps, lightbaited fish traps, rotenone sampling, and/or baited lines. 5. To continuously collect bathymetric data and water-column acoustic data (i.e., mesopelagic acoustic marks) throughout the voyage, using an	Terminated	Smith 2006

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			acoustic sounder. 6. To opportunistically collect a variety of data/materials during shore-based landings, including wherever possible: i) breast feathers from living penguins; ii) tissue samples/feathers/bones from dead seals/penguins/other sea birds; iii) seal scats; iv) visual estimates of adult and juvenile penguin numbers; v) visual assessments of penguin colony status; vi) photographs of penguin colonies; vii) sediment excavations of occupied and abandoned colonies. (Where appropriate these data will contribute to Objective 2).		
ZBD	ZBD2005-02	Marine Environment Classification Project	1. Co-fund the Marine Environment Classification Project (being done by NIWA) with the Department of Conservation.	Complete	Snelder et al. 2005, 2006 Leathwick et al. 2006a, 2006b, 2006c
ZBD	ZBD2005-03	Tangaroa Ross Sea voyage	1. To test the feasibility of obtaining estimates of demersal fish relative abundance using cameras with and without flood lights in areas of high importance for the Ross Sea toothfish fishery (principally 800–1200 m). 2. To utilise deepwater camera transects, supported by other direct sampling methods, to characterise the relative abundance, distribution, and diversity of demersal fish species (assuming Objective 1 yields satisfactory results) and of benthic macro-invertebrates, and to examine relationships between demersal fishes and benthic habitats/communities. Camera transects will be deployed opportunistically, with focus on the following high-priority areas (in order of high to low priority) wherever possible: i) Areas of the continental shelf break at depths of high importance for the toothfish fishery (principally 800-1200 m but also 600-800m & 1200-1500 m if time permits), ii) Shallow (50-200 m) water in the immediate vicinity of the Balleny Islands; iii) Deeper water in the vicinity of the Balleny Islands; iv) seamounts around and between Scott Island and the Balleny Islands; and v) at other locations (<600 m) as opportunity arises (e.g., around Scott Island, western Ross Sea, south-eastern Ross Sea). 3. To collect specimens/tissues of selected benthic and pelagic organisms with priority in the vicinity of the Balleny Islands (and to the east/southeast, for pelagic specimens especially Antarctic krill species) and deliver specimens to other projects for stable	Complete	MacDiarmid & Stewart (2015) AEBR 153 Mitchell & MacDiarmid 2006

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			isotope analysis in order to contribute to understanding of trophic relationships. 4. To acquire a continuous acoustic survey of the water column, opportunistically undertake species verification of acoustic marks, integrate the acoustic marks and produce a GIS map of verified and unverified distributions of functionally important mesopelagic species (e.g., krill, Antarctic silverfish). 5. To undertake routine identification and abundance estimates of marine mammal and seabird species and deliver raw and GIS summarised data to other related projects in order to generate spatially and temporally explicit population biomass and foraging distribution estimates for top air-breathing predators in the Ross Sea. 6. To undertake automated water sampling in order to monitor the identities and spatial and temporal distributions of plankton in the Ross Sea region and to allow ground-truthing of data collection from satellites (e.g., surface seawater temperature, and chlorophyll-a concentration).		
ZBD	ZBD2005-05	Long-term effects of climate variation and human impacts on the structure and functioning of New Zealand shelf ecosystems	1. To estimate changes in marine productivity via fluctuations in ocean climate and terrestrial nutrient input over the last 1000 years. 2. To assess and collate existing archaeological, historical and contemporary data (including catch records and stock assessments) on relevant components of the marine ecosystem to provide a detailed description of change in the shelf marine ecosystem in two areas of contrasting human occupation over last 1000 years. 3. To collect additional oral histories from Māori and non-Māori fishers and shellfish gathers regarding the distribution, sizes and relative abundance (compared to present availability) of key fish and invertebrate stocks in both regions during the first half of the 20th century before the start of widespread modern industrial fishing. 4. To build mass-balance ecosystem models (e.g., Ecopath) of the coastal and shelf ecosystem in each area for five critical time periods: now, 60 years BP (before modern industrial fishing), 250 years BP (before European whaling and sealing), 600 y BP (early Māori phase) and 1000 years BP (before human settlement). 5. To use qualitative modelling techniques to determine the critical interactions amongst species and other ecosystem components in order to identify those that should be a priority for future research.	Complete	Carroll et al. 2015 Lalas et al. 2014 Lalas & MacDiarmid 2014 Lorrey et al. 2013 MacDiarmid et al. (2016a) AEBR 171 MacDiarmid et al. (2016b) AEBR 170 MacDiarmid et al. (2018) AEBR 194 Maxwell & MacDiarmid (2016) AEBR 173 McKenzie & MacDiarmid submitted Neil et al. 2012

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					Parsons et al. 2011 Paul (2012) AEBR 94 Paul (2014) AEBR 124 Pinkerton et al. (2015b) AEBR 160 Smith (2011) AEBR 82
ZBD	ZBD2005-09	Rocky reef ecosystems - how do they function? Integrating the roles of primary and secondary production, biodiversity and connectivity across coastal habitats	1. To develop a qualitative numerical model of how New Zealand's rocky reef systems are functionally structured. 2. To quantify the effects of human predation, and environmental degradation across reef gradients – top-down, or bottom-up functioning? 3. To advance our understanding of how subtidal reef systems are fuelled through primary and secondary production (from a range of sources), the role that biodiversity plays, and how this varies across different reef settings. 4. To quantify how subtidal reef systems are linked with other habitats and ecosystems at broader spatial scales, including the connectivity of MPAs with other habitats and areas.	Complete	Beaumont et al. 2011
ZBD	ZBD2004-01	Baseline information on the diversity and function of marine ecosystems	1. To quantify, and compare, the macro-invertebrate assemblage composition of a number of seamounts at the southernmost end of the Kermadec volcanic arc. 2. To compare the macro-invertebrate diversity of the southernmost end of the Kermadec volcanic arc with that of seamounts already sampled and reported on.	Complete	Rowden & Clark (2010) AEBR 62 Smith et al. 2008
ZBD	ZBD2004-02	Ecosystem-scale trophic relationships: diet composition and guild structure of middle-depth fish on the chatham rise	1. To quantitatively characterise the diets of abundant middle-depth fish species on the Chatham Rise, by analysis of fish stomach contents collected from the January 2005, January 2006 and January 2007 Chatham Rise middle-depths trawl surveys. 2. To quantitatively characterise Chatham Rise fish diets throughout the year, for a period of 24 months, by analysis of fish stomach contents collected opportunistically aboard industry vessels.	Complete	Connell et al. 2010 Dunn 2009 Dunn et al. 2009b, 2010a, 2010b, 2010c

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			3. To describe and examine patterns of diet variation within each fish species as a function of spatial, temporal, and environmental variables, and of fish size. 4. To define and characterise trophic guilds for abundant fish species on the Chatham Rise, using multivariate analysis of fish diet data, and to analyse the nature and relative strength of potential trophic interactions between guilds. 5. To create and populate a diets database to store all of the dietary information collected under Objectives 1 and 2, and for use in subsequent dietary studies.		Forman & Dunn 2010 Horn et al. 2010 Stevens & Dunn 2010
ZBD	ZBD2004–05	Assessment and definition of the biodiversity of coralline algae of northern New Zealand	1. To assess and define the biodiversity of coralline algae in northern New Zealand. 2. To develop rapid identification tools for coralline algae using molecular sequencing data. 3. To contribute representative material to the national Coralline Algal Collections. 4. To produce ID guides to common coralline algae of northern New Zealand.	Complete	Farr et al. 2009
ZBD	ZBD2004-08	Sea-grass meadows as biodiversity and connectivity hotspots	1. Quantify the biodiversity values and functioning of New Zealand sea-grass assemblages. 2. Complete national bio-geographic assessment of sea-grass associated biodiversity. 3. Quantify sea-grass connectivity with surrounding marine landscapes through nursery functions and detritus export. 4. Quantify sea-grass replication connectivity mechanisms. 5. Develop a risk assessment and appraisal model for sea-grass systems.	Complete	Morrison et al. (2014c) AEBR 137
ZBD	ZBD2004-10	Development of bioindicators in coastal ecosystems	1. Investigate linkages between land use patterns in catchments and nitrogen loading to recipient estuaries and coastal ecosystems. 2. Characterise isotopic signatures of selected bioindicator organisms in relation to different terrestrial nutrient loads. 3. Validate the use of bioindicators using controlled laboratory and field experiments.	Complete	Savage 2009
ZBD	ZBD2004-19	Ecological function and critical trophic linkages in New Zealand soft-sediment habitats	1. Define the interactive effects of two functionally important benthic species in maintaining critical trophic linkages in soft-sediment systems from a series of integrated field experiments. 2. Quantify effects of heart urchins (*Echinocardium australe*) on sediment properties, benthic primary	Complete	Lohrer et al. 2010

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			production, and macrofaunal diversity through manipulative field experiments in Mahurangi Harbour. 3. Test for interactions between pinnid bivalves (*Atrina zelandica*) and heart urchins (*Echinocardium australe*) in field experiments, and measure their respective and combined contributions to sediment properties, benthic primary production, and macrofauna. 4. Determine the dependence of results from objectives 1 and 2 (functional contributions of *Echinocardium* and *Atrina*) in an environmental context by conducting experiments along an estuarine-coastal gradient.		
ZBD	ZBD2003-02	Biodiversity of Coastal Benthic Communities of the North Western Ross Sea.	1. Quantify patterns in biodiversity and community structure in the coastal Ross Sea region. 2. Quantify biodiversity in benthic communities at selected locations in the Ross sea north of Terra Nova Bay. 3. Describe ecosystem function at selected locations in the Ross Sea north of Terra Nova Bay.	Complete	Cummings et al. 2003, 2006a, 2010 De Domenico et al. 2006 Guidetti et al. 2006 Norkko et al. 2004
ZBD	ZBD2003-03	Biodiversity of deepwater invertebrates and fish communities of the north western Ross Sea	1. To describe, and quantify the diversity of, the benthic macroinvertebrates and fish assemblages of the Balleny Islands and adjacent seamounts, and to determine the importance of certain environmental variables influencing assemblage composition.	Complete	Rowden et al. (2012a) AEBR 101 Rowden et al. (2013a) AEBR 115 Mitchell & Clark 2004
ZBD	ZBD2003–04	Fiordland Biodiversity Research Cruise	1. How can ecotone boundaries be defined? 2. If you have an ecotone boundary defining the edge of a commercial exclusion zone, how wide is the transition zone across the boundary? 3. If you have an area delineated as a marine protected area or a commercial exclusion zone, does it adequately represent the different habitats or biodiversity of the whole region?	Complete	Wing 2005
ZBD	ZBD2003-09	Macquarie Ridge Complex Research Review	To review and summarise both biological and physical research carried out on or around the	Complete	Grayling 2004

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			section of the Macquarie Ridge Complex that lies between New Zealand and Macquarie Island.		
ZBD	ZBD2002-01	Ecology of Coastal Benthic Communities in Antarctica	To research the ecology of coastal benthic Communities in Antarctica.	Complete	Cummings et al. 2003 Schwarz et al. 2003, 2005 Sharp et al. 2010 Sutherland 2008 Thrush et al. 2006 Thrush & Cummings 2011
ZBD	ZBD2002-02	Whose larvae is that? Molecular identification of planktonic larvae of the Ross Sea.	1. To use molecular sequencing tools in the taxonomic identification of cryptic/invasive marine species. 2. To provide a molecular description and characterisation of gobies that are introduced (*Arenigobius bifrenatus* and *Acentrogobius pflaumii*) cryptogenic (*Parioglossus marginalis*) or native (e.g., *Favonigobius lentiginosus* and *F. expuisitus*). 3. To describe the molecular diversity of the above species throughout their native and introduced distributions, and characterise a range of the greatest potential invasive gobioid and blennioid species from the Australasian region. 4. To develop molecular criteria to rapidly identify invasive or cryptogenic gobioid and blennioid fish.	Complete	Sewell 2005, 2006 Sewell et al. 2006
ZBD	ZBD2002-06A	Impacts of terrestrial run-off on the biodiversity of rocky reefs	1. Conduct field and laboratory experiments to determine relationships between sediment loading, epifaunal assemblages, and mortality of filter feeding invertebrates. 2. Conduct field and laboratory experiments to identify the influence of sediment on early life stages of key grazers. 3. Determine photosynthetic characteristics and survival of large brown seaweeds and understorey algal species in relation to a sediment gradient.	Complete	Schwarz et al. 2006
ZBD	ZBD2002-12	Molecular identification of cryptogenic/invasive marine species – gobies.	1. To use molecular sequencing tools in the taxonomic identification of cryptic/invasive marine species 2. To provide a molecular description and characterisation of gobies that are introduced	Complete	Lavery et al. 2006

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			(*Arenigobius bifrenatus* and *Acentrogobius pflaumii*) cryptogenic (*Parioglossus marginalis*) or native (e.g., *Favonigobius lentiginosus* and *F. expuisitus*). 3. To describe the molecular diversity of the above species throughout their native and introduced distributions- and characterise a range of the greatest potential invasive gobioid and blennioid species from the Australasian region. 4. To develop molecular criteria to rapidly identify invasive or cryptogenic gobioid and blennioid fish.		
ZBD	ZBD2002-16	Joint New Zealand and Australian Norfolk Ridge	1. To describe the marine biodiversity of the Norfolk Ridge and Lord Howe Rise seamount communities. 2. To survey, sample and document the marine biodiversity and environmental data from seamounts on the Norfolk Ridge and Lord Howe Rise to a depth of at least 1000 m depth. 3. To preserve samples of fishes and invertebrates and hold these in accessible curated museum collections to support biosystematic research projects. 4. To provide specimens to support projects which research the identity, diversity, relationships, distributions, and assess uniqueness and conservation value of the marine life. 5. To correlate observed distribution patterns, especially areas of high diversity and areas of endemism, with measured biological and physical parameters.	Complete	Clark & Roberts 2008
ZBD	ZBD2002-18	Quantitative survey of the intertidal benthos of Farewell Spit Golden Bay	1. To undertake a baseline survey of intertidal macrobenthic organisms at Farewell Spit Nature Reserve and adjacent flats. 2. To undertake an initial field survey of *Zostera* distribution at Farewell Spit Nature Reserve and adjacent intertidal flats. 3. To undertake a preliminary survey of sediment characteristics of the intertidal flats at Farewell Spit Nature Reserve and adjacent flats.	Complete	Battley et al. 2005
ZBD	ZBD2001–02	Documentation of New Zealand Seaweed	1. To publish a regional algal flora of Fiordland based on voucher herbarium specimens. 2. To assemble a database of references and to review the current state of knowledge about New Zealand macroalgae.	Complete	Nelson et al. 2002
ZBD	ZBD2001-03	Ecology and biodiversity of coastal benthic communities in Antarctica.	1. To develop sampling protocols for estimating the relative abundance of algae and benthic invertebrates. 2. To quantify patterns in biodiversity and benthic community structure at two locations in McMurdo	Complete	Norkko et al. 2002

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			Sound. 3. To analyse Ross Island Sea-Level data.		
ZBD	ZBD2001-04	'Deep Sea New Zealand'	To help publish the book 'Deep Sea New Zealand'.	Complete	Batson 2003
ZBD	ZBD2001-05	Crustose coralline algae of New Zealand	1. To assess the biodiversity of crustose coralline algae in NZ using modern taxonomic methods and molecular sequence tools. 2. To establish the NZ National Coralline Algal Collection. 3. To produce identification guides to NZ species.	Complete	Harvey et al. 2005 Farr et al. 2009 Broom et al. 2008
ZBD	ZBD2001-06	Biodiversity of New Zealand's soft-sediment communities	1. To review the current knowledge of the biodiversity of macroinvertebrates and macrophytes living in and on soft-sediment substrates in New Zealand's harbours, estuaries, beaches and to 1000 m water depth. 2. To review existing published and unpublished sources of information on soft-sediment marine assemblages around New Zealand. 3. Using the results of Objective 1, identify gaps in the knowledge, hotspots of biodiversity, areas of particular vulnerability, and make recommendations on areas or assemblages that could be the subject of directed research in future years.	Complete	Rowden et al. 2012b
ZBD	ZBD2001-10	Additional Research on Biodiversity of Seamounts	1. To determine the macro-invertebrate assemblage composition on Cavalii seamount, and adjacent seamount W1, by photographic transects and epibenthic sled sampling. 2. To determine the distribution of macro-invertebrate assemblages on the seamounts. 3. To compare the macro-invertebrate species diversity of neighbouring seamounts. 4. To evaluate and collect samples from suitable macro-invertebrate species for genetic analysis. 5. To map bathymetry and habitat characteristics of the seamounts. 6. To compare macro-invertebrate assemblage composition of the seamounts with nearby hard bottom low relief (under 100 m) on the slope, if suitable areas can be located.	Complete	Rowden et. al 2004
ZBD	MOF2000–01	Bryozoan thickets off Otago Peninsula	To research the bryozoan thickets off the Otago Penninsula.	Complete	Batson & Probert 2000

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ZBD	ZBD2000–01	A review of current knowledge describing the biodiversity of the Ross Sea region	1. To review and document existing published and unpublished information describing the biodiversity of the Ross Sea region. 2. To identify and document Ross Sea region marine communities that are under high pressure or likely to come under high pressure from human activities in the near future.	Complete	Bradford-Grieve & Fenwick 2001a, 2001b, 2002 Fenwick & Bradford-Grieve 2002a, 2002b Varian 2005
ZBD	ZBD2000-02	Exploration and description of the biodiversity, in particular the benthic macrofauna, of the western Ross Sea	1. To utilise sampling opportunities provided by the presence of RV *Tangaroa* in the western Ross Sea in February/March 2001 to make collections of (primarily) benthic organisms as a contribution to the understanding of biodiversity in the region. 2. To identify and document the organisms collected and provide for their proper storage in national collections. 3. To describe the logistic constraints of working in the Ross Sea region, and make recommendations for future research to improve understanding of biodiversity in the Ross Sea.	Complete	Page et al. 2001
ZBD	ZBD2000-03	The spatial extent and nature of the bryozoan communities at Separation Point, Tasman Bay	1. To assess the present state and extent of bryozoan communities around Separation Point. 2. To characterise the bryozoan communities around Separation Point.	Complete	Grange et al. 2003
ZBD	ZBD2000-04	Supplementary Research on Biodiversity of Seamounts	1. To determine the biodiversity of seamounts of the southern Kermadec volcanic arc (Rumble V, Rumble 111, Brothers). 2. To describe the distribution of fauna, with an emphasis on mapping the nature and extent, of biodiversity associated with hydrothermal vents. 3. To compare the biodiversity of the three seamounts, and adjacent slope. 4. To collect samples from near the vent sources (if possible, as these are thought to be very localised) to measure chemical and thermal aspects of the environment.	Complete	Rowden et al. 2002, 2003 Clark & O'Driscoll 2003
ZBD	ZBD2000-06	'The Living Reef: The Ecology of New Zealand's Rocky Reefs'	1. Funding to support the publication of this book.	Complete	Andrew & Francis 2003
ZBD	ZBD2000-08	A review of current knowledge describing New	1. To review and document existing published and unpublished reports and data describing New Zealand's deepwater benthic biodiversity.	Complete	Key 2002

Theme	Project code	Project title	Specific objectives	Status	Citation/s
		Zealand's Deepwater Benthic Biodiversity	2. To make recommendations on representative communities and potentially impacted communities that could be the subject of directed research.		
ZBD	ZBD2000-09	Antarctic fish taxonomy	1. Ross Sea fishes processing and identification.	Complete	Roberts & Stewart 2001

19.7 APPENDICES FROM CHAPTER 9 FISH AND INVERTEBRATE BYCATCH

Appendix 19.7.1: Bycatch trends for seven deepwater trawl fisheries and one longline fishery (1990–91 to 2013–14). Regression slopes for each species/species group and fishery. Slopes indicating a decline in bycatch over time are highlighted in red, and slopes indicating an increase in bycatch over time are highlighted in green. Species/species groups are ordered alphabetically; blank cells = not estimated; LLL = ling longline fishery; HHL = hoki/hake/ling fishery. NB: These linear regression slopes should be considered only a simple indicator of general changes as relationships may be non-linear; some trends may be strongly influenced by changes in observer recording of species over time. The main purpose of the highlighted cells is to draw attention to species for which closer examination of trends may be warranted. [Continued on next pages]

	Fishery								
Species	SBW	SQU	SCI	LLL	JMA	ORH	OEO	HHL	Scientific name
ACS		0.01	0.22			0.06		0.19	Actinostolidae
ADT			0.02						*Aphrodita* spp.
AER			0.02						*Aeneator recens*
AFO			0.04						*Aristaeomorpha foliacea*
AGR								-0.18	*Agrostichthys parkeri*
AIR			-0.01						*Argyripnus iridescens*
ALB		0.01			0.45			0.00	*Thunnus alalunga*
ALL			0.07						*Alcithoe larochei*
ANC									*Engraulis australis*
ANT		0.00	-0.09	-0.02		0.03	-0.01	0.11	Anthozoa
ANZ		0.02							*Ecionemia novaezelandiae*
API		-0.03	0.04					0.00	*Alertichthys blacki*
APR		0.01	0.06	-0.02		0.02	0.02	0.09	*Apristurus* spp.
ARE			0.02						*Apatopygus recens*
ASR	0.01	0.11	0.08	-0.04		0.01	-0.02	0.16	Asteroid
AST			-0.02	-0.02					Astronesthinae
ATT					0.49				*Arripis trutta*
AWI			0.05						*Alcithoe wilsonae*
BAC						-0.03			*Bathygadus cottoides*
BAM			0.04						*Bathyplotes* spp.
BAR	0.00	-0.01	-0.01		-0.04			-0.11	*Thyrsites atun*
BAS		-0.01	-0.20	-0.10				0.06	*Polyprion americanus*
BAT		-0.01				0.00	-0.01		*Rouleina* spp.
BBE	-0.02	0.03	-0.03			-0.04	0.03	0.03	*Centriscops humerosus*
BCA		0.00						-0.09	*Magnisudis prionosa*
BCD		0.19	-0.01	-0.12				-0.01	*Paranotothenia magellanica*
BCO	-0.03	0.11	-0.01	-0.04				0.00	*Parapercis colias*
BCR			-0.01					-0.03	*Brotulotaenia crassa*
BDA								-0.01	*Sphyraena novaehollandiae*
BEE			0.00			-0.09	0.11	0.04	*Diastobranchus capensis*
BEL		0.06	-0.01			-0.01		0.13	*Centriscops* spp.

Species	Fishery								Scientific name
	SBW	SQU	SCI	LLL	JMA	ORH	OEO	HHL	
BEN								0.20	*Benthodesmus* spp.
BER			-0.06					0.00	*Typhlonarke* spp.
BES			0.02					0.03	*Benthopecten* spp.
BFE						0.00			*Bathysaurus ferox*
BFI						0.00		0.00	*Bathophilus filifer*
BFL		0.01							*Rhombosolea retiaria*
BGZ		0.11							*Kathetostoma binigrasella*
BIG		0.01						-0.02	*Thunnus obesus*
BJA						-0.02	0.03		*Mesobius antipodum*
BKM								-0.04	*Makaira indica*
BNE								-0.01	*Benthodesmus elongatus*
BNS		-0.07	-0.28	-0.31		-0.19	0.01	-0.10	*Hyperoglyphe antarctica*
BNT								-0.01	*Benthodesmus tenuis*
BOA	-0.03		0.02					-0.01	*Paristiopterus labiosus*
BOC		0.01	0.11						*Bolocera* spp.
BOE						-0.20		0.05	*Allocyttus niger*
BOO						0.01			*Keratoisis* spp.
BOT		0.00						-0.01	Bothidae
BPE			-0.02					-0.01	*Caesioperca lepidoptera*
BPI								0.02	*Benthopecten pikei*
BRA		-0.01						0.01	*Dasyatis brevicaudata*
BRC			-0.08	0.01		-0.02		0.01	*Pseudophycis breviuscula*
BRG						0.08			Brisingida
BRS	-0.01							-0.01	*Echinorhinus brucus*
BRZ			0.04						*Xenocephalus armatus*
BSH	-0.01	-0.06	-0.14	-0.11		-0.11	-0.03	-0.01	*Dalatias licha*
BSK		0.16				-0.02		-0.16	*Cetorhinus maximus*
BSL						-0.12	0.03	0.11	*Xenodermichthys* spp.
BSP				-0.02				0.02	*Taractichthys longipinnis*
BSQ	-0.02					-0.03		-0.08	*Sepioteuthis australis*
BTA			0.09					0.07	*Brochiraja asperula*
BTH	-0.03	0.01	0.05	0.01		0.04	0.01	0.04	*Notoraja* spp.
BTS			-0.02					0.10	*Brochiraja spinifera*
BWH			0.10			0.00			*Carcharhinus brachyurus*
BWS		0.03		-0.08				-0.06	*Prionace glauca*
BYD								0.13	*Beryx decadactylus*
BYS		0.00	0.06	0.01		0.08		0.19	*Beryx splendens*
BYX		0.01	-0.22	-0.04		-0.25		-0.10	*Beryx splendens* & *B. decadactylus*
CAL			0.07						*Caenopedina porphyrogigas*
CAM			0.10						*Camplyonotus rathbunae*
CAR		0.24	0.12	0.02		-0.02		0.14	*Cephaloscyllium isabellum*
CAS		0.06	0.05					-0.04	*Coelorinchus aspercephalus*
CAY							0.01		*Caryophyllia* spp.
CBB		0.02	0.02			0.08			Coral rubble
CBD		0.08				0.01	0.02		Coral rubble - dead
CBE		0.04	-0.03					0.03	*Notopogon lilliei*
CBI							0.00	-0.02	*Coelorinchus biclinozonalis*
CBO	-0.04	0.00	-0.02			0.00		-0.02	*Coelorinchus bollonsi*
CBX								-0.01	*Cubiceps baxteri*
CCA								0.00	*Cubiceps caeruleus*
CCO			0.01					0.02	*Coelorinchus cookianus*
CCR		0.00							*Cetonurus crassiceps*
CCX								0.07	*Coelorinchus parvifasciatus*
CDL						-0.20	-0.01	0.02	Epigonidae
CDO		0.05	0.05		-0.41			0.18	*Capromimus abbreviatus*
CDX			0.13					-0.01	*Coelorinchus maurofasciatus*
CDY			0.01						*Cosmasterias dyscrita*

Species	Fishery								Scientific name
	SBW	SQU	SCI	LLL	JMA	ORH	OEO	HHL	
CEN				-0.01		-0.04			Squalidae
CFA			0.03					0.02	*Coelorinchus fasciatus*
CHA								0.01	*Chauliodus sloani*
CHC		0.02							*Chaceon bicolor*
CHG				0.01		0.02	0.09	0.05	*Chimaera lignaria*
CHI			-0.03	-0.05		0.04	0.00	-0.06	*Chimaera* spp.
CHM								-0.01	Chiasmodontidae
CHP				-0.04		0.01	0.04	-0.01	*Chimaera* sp.
CHQ		0.06						0.02	Cranchiidae
CHR							0.03		*Chrysogorgia* spp.
CHX			-0.04			0.00		0.01	*Chaunax pictus*
CJA			0.09					0.12	*Crossaster multispinus*
CMA								0.02	*Coelorinchus matamua*
CMT		0.02							Comatulida
CMU							0.01	-0.02	*Coryphaenoides murrayi*
COB						0.01			Antipatharia
COD						0.01	-0.01	-0.02	Cod
COF		0.01						0.01	*Flabellum* spp.
COL			0.02			-0.01		0.13	*Coelorinchus oliverianus*
CON	-0.02	0.07	0.00	-0.31		-0.04	0.00	0.11	*Conger* spp.
COR			-0.01			0.00	0.00		Stylasteridae
COU		-0.01	-0.01			-0.04	-0.05	0.01	Alcyonacea, Scleractinia, Antipatharia, Stylasteridae
CPA			0.10					0.06	*Ceramaster patagonicus*
CPD								-0.03	Centrolophidae
CRA		-0.02						-0.02	*Jasus edwardsii*
CRB		-0.16	-0.12	-0.01		-0.03	0.00	0.02	Crab
CRM		0.08						0.02	*Callyspongia* cf *ramosa*
CRN		0.02							Sea lily, stalked crinoid
CRS						-0.01			*Callyspongia ramosa*
CRU		-0.04	-0.07					-0.01	Crustacea
CSH		0.04	0.00	0.01		-0.04	-0.01	0.13	Catshark
CSP		-0.01							*Coelorinchus spathulatus*
CSQ		-0.01	0.02	0.08		0.11	0.04	0.10	*Centrophorus squamosus*
CST								-0.01	*Caristius* sp.
CSU						0.02			*Coryphaenoides subserrulatus*
CTU			-0.01					-0.01	*Cookia sulcata*
CUB							-0.01	-0.01	*Cubiceps* spp.
CUC		-0.02	-0.07					0.00	*Paraulopus nigripinnis*
CVI			0.02						*Pycnoplax victoriensis*
CYL						0.14		0.15	*Centroscymnus coelolepis*
CYO				-0.03		0.14		0.11	*Centroscymnus owstoni*
CYP			0.01	-0.02		0.16	0.13	0.13	*Centroscymnus crepidater*
DAP			0.15						*Dagnaudus petterdi*
DAS			0.01						*Pteroplatytrygon violacea*
DCO			0.02						*Notophycis marginata*
DCS			-0.03	0.00		-0.02		-0.04	*Bythaelurus dawsoni*
DDI			0.06			0.02	0.01		*Desmophyllum dianthus*
DEA	0.00							-0.12	*Trachipterus trachypterus*
DEQ						-0.02		-0.02	*Deania quadrispinosum*
DHO			0.01			0.02		0.01	*Dermechinus horridus*
DIR			0.07						*Diacanthurus rubricatus*
DIS						0.00			*Diretmus argenteus*
DMG			0.11					0.09	*Dipsacaster magnificus*
DPO								-0.02	*Desmodema polystictum*
DSK		0.01	-0.13	0.00		0.01	-0.04	0.10	*Amblyraja hyperborea*
DSP	-0.02	0.03							*Congiopodus coriaceus*
DSS						0.00		-0.01	*Bathylagus* spp.

Species	Fishery								Scientific name
	SBW	SQU	SCI	LLL	JMA	ORH	OEO	HHL	
DWE			-0.04	-0.04		-0.04	-0.01	0.14	Whelks
DWO								0.18	*Graneledone spp.*
ECH			-0.05	-0.01		-0.01	0.00	-0.04	Echinodermata
ECN			0.01	-0.01		-0.01	-0.02	0.01	Echinoid
EEL			-0.16	-0.01		0.00	-0.01	-0.09	Eels
EEX		0.03							*Enypniastes eximia*
EGA			0.02						*Euciroa galatheae*
EGR					0.20				*Myliobatis tenuicaudatus*
ELE									*Callorhinchus milii*
ELT									*Electrona spp.*
EMA	0.00	0.03			-0.04			-0.20	*Scomber australasicus*
EMO			-0.02			-0.01		0.01	*Etmopterus molleri*
EPD								0.02	*Epigonus denticulatus*
EPL		0.03	0.01			-0.11	-0.03	0.21	*Epigonus lenimen*
EPO			-0.02						*Melanostigma gelatinosum*
EPR			0.02			0.06		0.13	*Epigonus robustus*
ERA		0.02	-0.01		0.24			0.04	*Torpedo fairchildi*
ERO						0.04			*Enallopsammia rostrata*
ETB	-0.02	0.05	0.06	0.03		0.08	0.26	0.24	*Etmopterus baxteri*
ETL		0.03	0.08	-0.18		-0.14	0.04	0.06	*Etmopterus lucifer*
ETM		-0.03	-0.04	-0.09		-0.11	0.01	-0.24	*Etmopterus* sp.
ETP						-0.04	-0.01	-0.01	*Etmopterus pusillus*
EUC			0.05			-0.02		0.13	*Euclichthys polynemus*
EZE		0.07	0.07						*Enteroctopus zealandicus*
FAN								-0.01	*Pterycombus petersii*
FHD		0.03	0.03					0.08	*Hoplichthys haswelli*
FLA		0.13	-0.03					-0.03	Flatfish
FLO		0.01						-0.02	Flounder
FMA		0.01	0.18					0.19	*Fusitriton magellanicus*
FOR								-0.02	*Forsterygion* spp.
FRO	0.00	0.08	-0.05		-0.01	-0.03		-0.10	*Lepidopus caudatus*
FRS						-0.05		-0.02	*Chlamydoselachus anguineus*
FRX								-0.01	Trichiuridae
FTU		0.01							*Auxis thazard*
GAO						0.00			*Gadomus aoteanus*
GAS			0.19					0.05	Gastropoda
GAT			0.03						*Gastroptychus* spp.
GDU			0.02			0.16	0.09		*Goniocorella dumosa*
GFL		0.14							*Rhombosolea tapiri*
GIZ	0.00	0.07	-0.08	-0.01	0.16	-0.03		0.00	*Kathetostoma giganteum*
GLS	0.01					0.03		0.12	Hexactinellida
GMC		0.04	0.23					0.02	*Leptomithrax garricki*
GMU		-0.01							*Mugil cephalus*
GOB							-0.01		*Mitsukurina owstoni*
GON		0.25						0.08	*Gonorynchus forsteri & G. greyi*
GOR								0.05	*Gorgonocephalus* spp.
GOU			0.02			0.03			*Goniocidaris umbraculum*
GPA			0.07						*Goniocidaris parasol*
GRC						0.01	0.04	-0.01	*Tripterophycis gilchristi*
GRM							0.02	0.04	*Gracilechinus multidentatus*
GSA								-0.01	*Hoplostethus gigas*
GSC		0.38	0.13	-0.03		0.00		0.09	*Jacquinotia edwardsii*
GSH	-0.09	0.10	0.03	-0.28	0.25	-0.18	-0.18	-0.09	*Hydrolagus novaezealandiae*
GSP	0.13	0.14	0.14	0.07		0.09	0.17	0.16	*Hydrolagus bemisi*
GSQ	0.00	0.00				0.01		0.02	*Architeuthis* spp.
GUR		-0.01	0.00		-0.07			0.03	*Chelidonichthys kumu*
GVO			0.09					0.01	*Provocator mirabilis*

Species	Fishery								Scientific name
	SBW	SQU	SCI	LLL	JMA	ORH	OEO	HHL	
HAG			-0.08	-0.03				0.18	*Eptatretus cirrhatus*
HAK	-0.05	0.06	-0.06	-0.06		-0.03	-0.02		*Merluccius australis*
HAL								0.01	*Halosauropsis macrochir*
HAP		0.04	-0.05	-0.18				-0.03	*Polyprion oxygeneios*
HAT									Sternoptychidae
HCO		0.02	0.01	0.09		-0.01		-0.01	*Bassanago hirsutus*
HEC			0.02						*Henricia compacta*
HEP			-0.04					0.06	*Heptranchias perlo*
HEX		0.05	-0.06	0.01				0.15	*Hexanchus griseus*
HGB						0.01		0.00	*Hydrolagus* sp. D
HIS			0.02						*Histocidaris* spp.
HJO			0.00			0.05	0.12	0.01	*Halargyreus johnsonii*
HMT			0.21					0.07	Hormathiidae
HOK	-0.12	0.04	-0.06	0.01	-0.19	-0.09	0.13		*Macruronus novaezelandiae*
HOL								0.01	*Holtbyrnia* sp.
HOR								-0.01	*Atrina zelandica*
HPB		-0.08	-0.20	-0.18				-0.16	*Polyprion oxygeneios & P americanus*
HSI			0.13						*Haliporoides sibogae*
HTH		-0.02	0.04			0.07	0.02	0.05	Holothurian unidentified
HTR			0.07					0.08	*Hippasteria phrygiana*
HYA	0.03	0.03	0.07			0.02		0.31	*Hyalascus* sp.
HYB				0.00					*Hydrolagus homonycteris*
HYD						0.00	0.01	-0.01	*Hydrolagus* sp.
HYM			0.07						*Hymenocephalus* spp.
HYP						0.00			*Hydrolagus trolli*
IBR						0.05	0.02	0.00	*Isistius brasiliensis*
ISI							0.01		Isididae
JAV	0.06	0.20	-0.01	-0.03	0.18	0.00	0.08	0.04	*Lepidorhynchus denticulatus*
JDO					0.01			-0.02	*Zeus faber*
JFI		0.00	-0.06		0.04	0.01	0.01	0.05	Jellyfish
JGU		-0.01	-0.03					0.00	*Pterygotrigla picta*
JMA	0.00	-0.16	-0.14			-0.03		-0.25	*Trachurus declivis, T. murphyi, T. novaezelandiae*
KIC			-0.02			0.04	-0.02	0.04	*Lithodes murrayi, Neolithodes brodiei*
KIN			-0.02		0.12			0.01	*Seriola lalandi*
KWH			0.01					0.01	*Austrofucus glans*
LAE			0.00			-0.03	-0.01		*Laemonema* spp.
LAG			0.09						*Laetmogone* spp.
LAN		0.14	0.00			0.00	0.01	0.07	Myctophidae
LCH	0.02		0.01			-0.02	0.03	0.03	*Harriotta raleighana*
LDO	-0.01	0.06	-0.04			-0.05	0.00	0.00	*Cyttus traversi*
LEA		-0.01			-0.19				*Meuschenia scaber*
LEG						-0.06	0.04	0.00	*Lepidion schmidti & Lepidion inosimae*
LHE								-0.02	*Lampanyctodes hectoris*
LHO			0.08					0.02	*Lipkius holthuisi*
LIN	-0.04	0.05	-0.12			-0.08	-0.06		*Genypterus blacodes*
LLC		0.07	0.02					0.02	*Leptomithrax longipes*
LMI			0.03						*Leptomithrax* spp.
LMU						0.01		0.03	*Lithodes murrayi*
LNV								0.05	*Lithosoma novaezelandiae*
LPI							0.02		*Lepidion inosimae*
LPS						0.02	-0.01		*Lepidion schmidti*
LSK		0.01	0.08			-0.02		0.10	*Arhynchobatis asperrimus*
LSO		-0.02	0.04					0.00	*Pelotretis flavilatus*
LUC			-0.04			-0.02		-0.02	*Luciosudus* sp.
MAK	0.03	0.03	-0.01	0.00	0.36	-0.05		-0.06	*Isurus oxyrinchus*
MAN	-0.04	-0.02				0.02		-0.07	*Neoachiropsetta milfordi*
MCA						0.11	0.26	0.00	*Macrourus carinatus*

Species	Fishery								Scientific name
	SBW	SQU	SCI	LLL	JMA	ORH	OEO	HHL	
MDO		0.02	0.02			-0.03		0.03	*Zenopsis nebulosa*
MIC	-0.02								*Microstoma microstoma*
MIQ	-0.05		-0.07			-0.09	-0.01	0.07	*Onykia ingens*
MNI			0.13						*Munida* spp.
MOC						0.06	0.02		*Madrepora oculata*
MOD			0.00			0.15	0.16	0.16	Moridae
MOK		-0.02	-0.01			-0.02		-0.09	*Latridopsis ciliaris*
MOL			-0.02					-0.02	Molluscs
MOO	-0.14	0.01						-0.18	*Lampris guttatus*
MOR						0.00	0.00	-0.01	Muraenidae
MRL								0.00	Muraenolepididae
MRQ								0.04	*Onykia robsoni*
MSL			0.05						*Mediaster sladeni*
MST						0.03		0.02	*Melanostomiidae*
MUR						-0.02			*Muraenolepis marmoratus*
MUU		0.00							Mullet
NCA		0.03							*Nectocarcinus antarcticus*
NCB		0.47						0.01	*Nectocarcinus bennetti*
NEB						0.07		0.01	*Neolithodes brodiei*
NEX								0.00	Nemichthyidae
NMP		0.12	-0.06		0.20			-0.08	*Nemadactylus macropterus*
NOC								0.01	*Notacanthus chemnitzi*
NOR							0.01		*Normichthys yahganorum*
NOT		-0.06	-0.03	-0.26		0.00			Nototheniidae
NSD		0.01	0.00	-0.02		0.00		0.21	*Squalus griffini*
NTO		0.01							*Notomithrax* spp.
NTU								-0.02	*Thunnus thynnus*
NUD			0.04						Nudibranchia
OAR								-0.08	*Regalecus glesne*
OCO			0.02						*Octopus* spp.
OCP			0.01					-0.02	Octopod
OCT	0.00	0.05	-0.04			0.02	-0.01	-0.05	*Pinnoctopus cordiformis*
ODO			0.01					-0.01	*Odontaspis ferox*
OEO						-0.13		-0.09	*P. maculatus, A. niger, & N. rhomboidalis*
OFH			-0.05			0.01		0.00	*Ruvettus pretiosus*
OLY			0.02						*Ophiomusium lymani*
ONG	-0.03	0.15	0.10	0.00		0.07	-0.01	0.06	Porifera
OPA	-0.02	0.15	0.06					0.02	*Hemerocoetes* spp.
OPE		0.17	-0.02		0.20	-0.01		-0.04	*Lepidoperca aurantia*
OPH						-0.02			Ophiuroid
OPI			0.11					0.26	*Opisthoteuthis* spp.
OPL		0.01							Opheliidae
ORH			-0.02				-0.01	-0.08	*Hoplostethus atlanticus*
OSE								0.00	*Ophisurus serpens*
OSK			0.20			0.04		0.18	Rajidae
OSP							0.01	0.00	*Crassostrea gigas*
PAB						0.03	0.07		*Paragorgia arborea*
PAD		-0.30							*Ovalipes catharus*
PAG			0.04						Paguroidea
PAH	0.23							0.00	*Lampris immaculatus*
PAL								-0.01	*Paralepididae*
PAM			0.05						*Pannychia moseleyi*
PAO			0.02					0.01	*Pillsburiaster aoteanus*
PCH			0.05						*Penion chathamensis*
PCO			-0.04						*Auchenoceros punctatus*
PDG		0.06	0.00			-0.06		0.05	*Oxynotus bruniensis*
PDO			0.00						*Paphies donacina*

Species	Fishery								Scientific name
	SBW	SQU	SCI	LLL	JMA	ORH	OEO	HHL	
PDS								0.02	*Paradiplospinus gracilis*
PED			-0.03						*Aristaeopsis edwardsiana*
PFL			0.02						*Pseudechinus flemingi*
PHO		0.03				-0.01		0.02	*Phosichthys argenteus*
PHW		0.02							*Psammocinia cf hawere*
PIG	-0.08	0.20	0.03					0.05	*Congiopodus leucopaecilus*
PIL					0.00				*Sardinops sagax*
PIN						-0.01		0.01	*Idiolophorhynchus andriashevi*
PKN								0.08	*Plutonaster knoxi*
PLS		0.02	0.00	0.05		0.04	0.01	0.04	*Proscymnodon plunketi*
PLT			0.01					0.02	*Plutonaster spp.*
PLY			0.02						*Polycheles* spp.
PLZ			-0.05						*Pleuroscopus pseudodorsalis*
PMO			0.03					0.02	*Pseudostichopus mollis*
PMU			0.08						*Paramaretia peloria*
PNE			0.09						*Proserpister neozelanicus*
PNN			0.02						*Pennatula spp.*
PNO			0.03						*Pteropeltarion novaezelandiae*
POM	0.01								Bramidae
POP					0.02				*Allomycterus jaculiferus*
POR	-0.02	-0.04						-0.23	*Nemadactylus douglasii*
POS	0.02	0.01	0.02	-0.11				-0.08	*Lamna nasus*
PRA			0.08					0.00	Prawn
PRK			0.19						*Ibacus alticrenatus*
PRU			0.04					0.01	*Pseudechinaster rubens*
PSE			0.00				-0.01		*Pseudechinus* spp.
PSI			0.22					0.14	*Psilaster acuminatus*
PSK		0.01	0.06	0.00		0.07	-0.01	0.15	*Bathyraja shuntovi*
PSL						-0.01	0.01		*Paralomis dosleini*
PSO								-0.02	*Psolus* spp.
PSP								0.01	*Psenes pellucidus*
PSQ						0.02		0.09	*Pholidoteuthis massyae*
PSY			-0.04			0.02	0.00	-0.02	*Psychrolutes microporos*
PTO				-0.02			0.00		*Dissostichus eleginoides*
PZE								0.01	*Paralomis zealandica*
QSC		0.15							*Psychrochlamys delicatula subantactica*
RAG						0.03	0.01	-0.09	*Pseudoicichthys australis*
RAT	-0.07	0.07	-0.02	-0.12	0.32	-0.03	0.08	0.02	Macrouridae
RAY			-0.06				-0.02	0.02	Torpedinidae, Dasyatidae, Myliobatidae, Mobulidae
RBM	0.08	-0.11		-0.24	0.09	-0.01		-0.05	*Brama brama*
RBT	0.00	0.01	0.01		-0.05			0.05	*Emmelichthys nitidus*
RBY		0.01	-0.08					-0.18	*Plagiogeneion rubiginosum*
RCH						0.05		0.05	*Rhinochimaera pacifica*
RCK			0.00						Acanthoclinidae
RCO	0.04	0.05	-0.07	-0.24	0.38			-0.07	*Pseudophycis bachus*
RDO		0.11	-0.01		0.07			0.06	*Cyttopsis roseus*
RHY			0.15		0.02	0.06		0.18	*Paratrachichthys trailli*
RIB		0.04	-0.20	-0.27		-0.06	-0.03	0.00	*Mora moro*
RIS								0.05	*Bathyraja richardsoni*
RMU								-0.02	*Upeneichthys lineatus*
ROC		0.01	-0.02			0.02	0.02	0.00	*Lotella rhacinus*
RPE			-0.03						Red perch
RPI									*Bodianus vulpinus*
RSC						0.00			*Scorpaena papillosa*
RSK	0.02	0.23	0.14	0.11		0.01		0.11	*Zearaja nasuta*
RSN			-0.01					-0.02	*Centroberyx affinis*
RSO		-0.11	-0.09	-0.01	0.11			-0.01	*Rexea solandri*

Species	Fishery								Scientific name
	SBW	SQU	SCI	LLL	JMA	ORH	OEO	HHL	
RSQ		0.02				-0.07		0.00	*Ommastrephes bartrami*
RUD			-0.07			-0.06	-0.03	-0.02	*Centrolophus niger*
SNA		-0.05	-0.02		0.07	-0.04		-0.09	*Pagrus auratus*
SAF						0.01			*Synaphobranchus affinis*
SAI								0.01	*Istiophorus platypterus*
SAR						0.00			*Squilla armata*
SAW								-0.02	*Serrivomer* spp.
SBI	0.02					-0.11	-0.02	-0.03	*Alepocephalus australis*
SBK			-0.04			-0.03		0.05	*Notacanthus sexspinis*
SBO	-0.04	-0.01	0.03			0.00		0.06	*Pseudopentaceros richardsoni*
SBR		0.02	-0.06			-0.03	0.01	0.08	*Pseudophycis barbata*
SBW		0.13	-0.01				0.02	0.20	*Micromesistius australis*
SCA		0.02							*Pecten novaezelandiae*
SCD		0.11						0.01	*Notothenia microlepidota*
SCG			-0.06		0.20			0.01	*Lepidotrigla brachyoptera*
SCH		0.11	-0.05	-0.23	0.07	0.03		0.04	*Galeorhinus galeus*
SCI								0.10	*Metanephrops challengeri*
SCM		0.00	0.00	-0.04		0.03	0.01	0.08	*Centroscymnus macracanthus*
SCO			0.02	-0.02		0.01		0.13	*Bassanago bulbiceps*
SDE							0.02	-0.02	*Cryptopsaras couesii*
SDF			0.04					0.02	*Azygopus pinnifasciatus*
SDL						0.01			*Scorpaena cardilis*
SDM			0.14					0.01	*Sympagurus dimorphus*
SDO		0.38	-0.02		-0.18			0.12	*Cyttus novaezealandiae*
SDR						-0.01		0.01	*Solegnathus spinosissimus*
SEE			-0.03	0.04				0.07	*Gnathophis habetus*
SER			0.02						*Sergestes* spp.
SEV		0.04	0.03	-0.02				0.11	*Notorynchus cepedianus*
SFL		0.05							*Rhombosolea plebeia*
SHA	0.00	0.06	-0.12	-0.11		-0.15	-0.12	-0.04	Shark
SHE						-0.01		-0.04	*Scymnodalatias sherwoodi*
SHL			-0.06						*Scyllarus* sp.
SHR			0.00						*Aplysiomorpha*
SIA						0.12	0.06		Scleractinia
SKA	-0.05	-0.08	-0.38	-0.37	0.00	-0.08	-0.04	-0.33	Rajidae & Arhynchobatidae
SKJ		0.01			0.12				*Katsuwonus pelamis*
SLB								0.03	*Scymnodalatias albicauda*
SLC						-0.02			*Slosarczykovia circumantarctica*
SLG			-0.04			0.00			*Scutus breviculus*
SLK						0.01	0.15	0.14	Alepocephalidae
SLR			-0.04			0.00			*Optivus elongatus*
SLS		0.00							*Peltorhamphus tenuis*
SMA		0.01							*Stigmatophora macropterygia*
SMC			0.02			-0.04	0.06	-0.04	*Lepidion microcephalus*
SMI		0.02				0.00		0.07	*Somniosus microcephalus*
SMK		0.02	0.23						*Teratomaia richardsoni*
SMO		0.05							*Sclerasterias mollis*
SMT			0.04						*Spatangus mathesoni*
SND		0.03	-0.11	-0.01		0.03	0.06	-0.01	*Deania calcea*
SNE								0.02	*Simenchelys parasitica*
SNI		-0.03	-0.01					0.01	*Macroramphosus scolopax*
SNO						0.01		0.02	*Sio nordenskjoldii*
SNR				0.01		-0.03	0.03	0.00	*Deania histricosa*
SOL			0.02						Sole
SOM						0.02			*Somniosus rostratus*
SOP	0.02					-0.01		-0.03	*Somniosus pacificus*
SOR						-0.09		-0.01	*Neocyttus rhomboidalis*

Species	Fishery								Scientific name
	SBW	SQU	SCI	LLL	JMA	ORH	OEO	HHL	
SOT			0.02					0.03	*Solaster torulatus*
SPD	0.02	0.03	0.09	-0.18	0.02	-0.18	-0.03	-0.01	*Squalus acanthias*
SPE		0.06	-0.01	-0.25	0.20	-0.09		0.00	*Helicolenus* spp.
SPF								-0.01	*Pseudolabrus miles*
SPI	0.01	-0.06	-0.13	0.00		-0.03	-0.01	-0.08	Spider crab
SPK			-0.01					-0.01	*Macrorhamphosodes uradoi*
SPL								0.00	*Scopelosaurus* sp.
SPO		0.03	-0.09	-0.04				-0.08	*Mustelus lenticulatus*
SPP								0.00	*Callanthias* spp.
SPR								0.00	*Sprattus antipodum, S. muelleri*
SPT			0.19					0.01	*Spatangus multispinus*
SPZ			-0.01					-0.05	*Genyagnus monopterygius*
SQA				0.01		0.02	0.03	0.03	*Squalus spp.*
SQI		-0.03							*Pristilepis oligolepis*
SQU	-0.01		0.03		-0.08	-0.11	-0.03	0.01	*Nototodarus sloanii & N. gouldi*
SQX	0.02		-0.06			0.00	-0.03	0.11	Squid
SRB	0.02							0.02	*Brama australis*
SRH			0.02			-0.01		0.13	*Hoplostethus mediterraneus*
SRI						0.01		0.03	*Scymnodon ringens*
SSC		-0.13	-0.04					0.01	*Leptomithrax australis*
SSH		0.03		-0.03				0.17	*Gollum attenuatus*
SSI	0.00	0.19	0.04		0.24	0.01	-0.04	0.04	*Argentina elongata*
SSK	0.00	-0.01	0.03	-0.15		-0.01	0.06	0.04	*Dipturus innominatus*
SSM						0.00	0.06	-0.01	*Alepocephalus antipodianus*
SSO						-0.19		0.00	*Pseudocyttus maculatus*
SSP								-0.02	*Pecten novaezelandiae*
STG		-0.01	0.03					-0.11	Stargazer
STM								0.02	*Tetrapturus audax*
STN		0.03	-0.02					0.06	*Thunnus maccoyii*
STO								0.01	*Stomias* spp.
STR		0.01	-0.05					-0.01	Stingray
STU	-0.02	-0.06			0.52			-0.10	*Allothunnus fallai*
SUH								-0.01	*Schedophilus huttoni*
SUN		-0.01	0.01		0.20	0.01		0.01	*Mola mola*
SUR			-0.06			0.00		-0.03	*Evechinus chloroticus*
SVA						0.05	0.08		*Solenosmilia variabilis*
SWA	0.06	0.05	-0.18		0.07	-0.03		-0.05	*Seriolella punctata*
SWO						-0.04		0.00	*Xiphias gladius*
SWR						-0.02		0.00	*Coris sandageri*
SYD								0.01	*Systellaspis debilis*
SYN			0.00			-0.03		0.01	Synaphobranchidae
TAM			0.06			0.04	0.08	0.23	*Echinothuriidae & Phormosomatidae*
TAY			0.10					0.04	*Typhlorke aysoni*
TDQ								0.04	*Taningia danae*
TFA			0.19						*Trichopeltarion fantasticum*
THR		-0.09			-0.02			-0.12	*Alopias vulpinus*
TLD								0.03	*Tetilla leptoderma*
TLO			0.01						*Telesto* spp.
TOA		0.10	-0.03	-0.03		0.05	0.00	0.08	*Neophrynichthys* sp.
TOD		0.05	0.03					0.06	*Neophrynichthys latus*
TOP	-0.02		0.03			0.00		0.13	*Ambophthalmos angustus*
TOR		0.06						0.14	*Thunnus orientalis*
TRA								-0.01	Trachichthyidae
TRE					0.06				*Pseudocaranx georgianus*
TRS						-0.02			*Trachyscorpia eschmeyeri*
TRU		0.00		0.00				-0.02	*Latris lineata*
Species	SBW	SQU	SCI	LLL	JMA	ORH	OEO	HHL	Scientific name

Species	Fishery								Scientific name
	SBW	SQU	SCI	LLL	JMA	ORH	OEO	HHL	
TSQ						0.03		0.13	*Todarodes filippovae*
TTA			0.03						*Typhlonarke tarakea*
TUR		0.02							*Colistium nudipinnis*
TVI								0.02	*Trachonurus villosus*
UFISH	-0.07	-0.22	-0.40	0.02		-0.31	-0.08	-0.37	Unidentified fish
URP		0.02	0.02						*Uroptychus* spp.
VCO						0.04	0.09	0.00	*Antimora rostrata*
VIT							-0.01		*Vitjazmaia latidactyla*
VNI								0.02	*Lucigadus nigromaculatus*
VOL			0.00					0.01	Volutidae
VSQ						0.03		0.19	*Histioteuthis* spp.
WAR		-0.01			-0.13	0.00		-0.18	*Seriolella brama*
WHE			0.01					0.02	Witch
WHR						-0.05		-0.05	*Trachyrincus longirostris*
WHX			0.01			0.07		0.18	*Trachyrincus aphyodes*
WIT	-0.01	0.11	0.10			0.04		0.12	*Arnoglossus scapha*
WOE						-0.05	-0.04		*Allocyttus verrucosus*
WPS		0.05				0.01		0.01	*Carcharodon carcharias*
WRA								0.03	*Dasyatis thetidis*
WSE									Labridae
WSQ	-0.02	0.09	0.02			0.03	0.15	-0.03	*Onykia* spp.
WWA	-0.04	0.05	-0.05	-0.04		0.00	0.03	0.06	*Seriolella caerulea*
YBF								0.02	*Rhombosolea leporina*
YBO			0.14					0.12	*Pentaceros decacanthus*
YCO		0.08							*Parapercis gilliesi*
YEM		-0.02							*Aldrichetta forsteri*
YFN		0.00						0.00	*Thunnus albacares*
YSG			0.01						*Pterygotrigla pauli*
YSP			0.02						*Yaldwynopsis spinima*
ZAS						0.03			*Zameus squamulosus*
ZOR			0.14					0.09	*Zoroaster* spp.

Appendix 19.7.2: BYCATCH: Total annual bycatch by fishery area for seven deepwater trawl fisheries and one longline fishery (1990–91 to 2016–17). Where data have not yet been updated for recent years for a fishery, figures from the last available year have been assumed, in order for annual totals to be calculated. LLL = ling longline fishery; HHL = hoki/hake/ling fishery. [Continued on next pages]

	AUCKLAND ISLANDS								
	Fishery								
FY	SCI	SQU	LLL	HHL	JMA	OEO	ORH	SBW	ALL
1991	12	642	24	66	7	0	0	0	750
1992	1 318	300	24	60	0	0	0	0	1 701
1993	1 009	422	24	38	0	24	48	0	1 564
1994	882	497	0	158	0	9	585	0	2 132
1995	866	189	21	127	0	64	2 079	0	3 346
1996	853	5 445	36	166	57	17	996	0	7 570
1997	1 954	1 641	51	198	17	11	503	0	4 374
1998	893	209	15	550	0	18	554	0	2 240
1999	1 040	276	21	255	0	33	1 042	0	2 667
2000	1 084	416	65	130	0	61	290	0	2 046
2001	751	353	64	304	0	12	277	0	1 762
2002	1 191	362	2	546	0	15	62	0	2 177
2003	1 225	1 326	0	501	0	23	20	0	3 095
2004	1 063	2 877	27	262	0	10	47	0	4 286
2005	1 035	2 010	1	187	0	0	16	0	3 249
2006	576	3 283	0	36	0	3	0	0	3 898

AUCKLAND ISLANDS									
	Fishery								
FY	SCI	SQU	LLL	HHL	JMA	OEO	ORH	SBW	ALL
2007	745	1 105	0	39	0	3	0	0	1 892
2008	597	1 349	0	130	0	13	20	0	2 109
2009	876	1 914	0	109	0	18	20	0	2 937
2010	631	1 790	24	29	0	11	53	0	2 538
2011	705	2 574	111	147	0	40	17	0	3 594
2012	604	1 675	10	43	0	7	3	0	2 343
2013	586	1 688	10	56	0	0	0	0	2 340
2014	609	751	10	485	0	54	0	0	1 909
2015	329	713	10	514	0	13	50	0	1 629
2016	519	989	10	207	0	13	50	0	1 788
2017	519	989	10	342	0	13	50	0	1 923

CHATHAM RISE									
	Fishery								
FY	SCI	SQU	LLL	HHL	JMA	OEO	ORH	SBW	ALL
1991	344	1 919	1 831	8 349	1 111	1 430	15 909	0	30 893
1992	4 343	4 000	1 831	8 993	72	356	15 677	0	35 272
1993	5 603	1 781	1 831	6 467	549	592	6 877	0	23 700
1994	2 644	5 273	1 795	3 974	1 019	499	15 043	0	30 247
1995	4 422	2 954	1 870	7 551	1 855	145	12 057	0	30 854
1996	3 865	5 328	1 970	11 340	272	781	8 664	0	32 221
1997	1 191	4 350	1 881	15 042	1 472	444	7 808	0	32 188
1998	585	3 537	2 392	16 757	1 515	1 137	5 685	0	31 609
1999	777	4 819	1 020	17 707	1 944	1 744	2 913	0	30 925
2000	1 548	3 798	1 277	19 485	2 603	414	2 763	0	31 887
2001	1 987	10 277	1 240	16 745	106	236	6 016	0	36 606
2002	1 798	8 014	2 781	16 872	698	153	2 917	0	33 232
2003	1 581	6 876	1 430	20 002	1 549	111	3 265	0	34 814
2004	1 006	2 096	1 239	19 822	168	348	3 873	0	28 552
2005	2 658	4 642	1 518	13 797	73	441	3 134	0	26 263
2006	1 111	6 886	1 576	12 470	5 771	203	2 870	0	30 887
2007	2 458	4 863	849	9 970	1 476	515	2 944	0	23 075
2008	1 635	2 241	1 364	11 551	1 859	199	2 908	0	21 757
2009	1 209	511	1 366	8 766	685	312	3 204	0	16 053
2010	1 572	984	1 587	14 552	677	560	2 854	0	22 786
2011	1 150	2 282	1 751	8 130	528	134	458	0	14 433
2012	1 538	979	1 041	8 772	1 139	316	615	0	14 400
2013	1 953	221	1 041	9 879	1 885	260	314	0	15 553
2014	2 737	72	1 041	15 554	2 378	141	604	0	22 528
2015	2 261	778	1 041	24 659	2 378	340	553	0	32 010
2016	1 300	2 133	1 041	17 227	2 378	340	553	0	24 972
2017	1 300	2 133	1 041	18 530	2 378	340	553	0	26 275

COOK STRAIT									
	Fishery								
FY	SCI	SQU	LLL	HHL	JMA	OEO	ORH	SBW	ALL
1991	0	0	9	1 501	4	9	1 059	0	2 582
1992	0	0	9	1 068	9	7	1 089	0	2 182
1993	0	58	9	1 090	0	2	469	0	1 628
1994	0	0	5	2 621	0	12	878	0	3 517
1995	33	1	9	2 400	0	0	1 060	0	3 504
1996	0	19	8	3 274	0	3	373	0	3 677

COOK STRAIT									
	Fishery								
FY	SCI	SQU	LLL	HHL	JMA	OEO	ORH	SBW	ALL
1997	0	0	3	4 525	0	8	396	0	4 933
1998	0	1	20	2 249	113	9	221	0	2 612
1999	2	90	56	2 035	423	3	181	0	2 791
2000	2	2	67	3 244	155	12	132	0	3 614
2001	0	47	221	1 561	312	12	72	0	2 225
2002	53	0	40	882	26	10	0	0	1 012
2003	7	2	22	3 197	0	6	0	0	3 234
2004	0	0	54	1 396	0	1	0	0	1 452
2005	36	0	103	1 825	0	2	0	0	1 965
2006	0	0	128	507	0	4	0	0	639
2007	1	2	126	1 070	0	1	0	0	1 200
2008	4	0	201	790	0	0	30	0	1 025
2009	0	0	29	660	0	1	0	0	690
2010	0	0	21	700	0	0	0	0	721
2011	0	0	28	325	0	0	20	0	373
2012	0	0	11	532	0	0	0	0	543
2013	0	0	11	645	0	0	0	0	656
2014	0	0	11	706	0	0	0	0	717
2015	0	0	11	650	0	0	23	0	684
2016	0	2	11	239	0	0	23	0	275
2017	0	2	11	231	0	0	23	0	267

EAST COAST NORTH ISLAND									
	Fishery								
Fyr	SCI	SQU	LLL	HHL	JMA	OEO	ORH	SBW	ALL
1991	2 390	0	69	725	12	22	1 438	0	4 655
1992	916	0	69	540	9	22	992	0	2 548
1993	1 466	0	69	561	16	15	509	0	2 636
1994	1 233	0	196	1 563	10	12	732	0	3 747
1995	1 255	0	96	1 137	0	1	1 619	0	4 109
1996	1 508	0	111	2 192	0	34	446	0	4 292
1997	720	0	108	3 402	4	73	1 092	0	5 400
1998	883	0	160	2 960	0	105	3 514	0	7 623
1999	1 043	0	95	1 387	0	31	804	0	3 359
2000	956	2	161	1 146	0	73	1 560	0	3 898
2001	1 365	0	398	1 313	45	45	535	0	3 700
2002	3 733	0	204	736	53	26	65	0	4 816
2003	1 282	10	83	1 035	0	50	182	0	2 642
2004	795	0	247	1 031	0	11	0	0	2 084
2005	845	0	252	680	0	10	168	0	1 956
2006	336	0	399	386	0	8	0	0	1 129
2007	591	0	159	543	0	2	0	0	1 294
2008	391	0	84	401	0	1	142	0	1 019
2009	236	0	283	442	0	1	142	0	1 105
2010	619	0	258	421	0	1	285	0	1 584
2011	441	0	269	730	0	1	169	0	1 610
2012	251	0	229	458	0	0	93	0	1 031
2013	235	0	229	507	0	0	82	0	1 052
2014	321	0	229	998	0	0	0	0	1 548
2015	332	0	229	758	0	0	54	0	1 373
2016	234	0	229	570	0	0	54	0	1 087
2017	234	0	229	697	0	0	54	0	1 214

NORTHLAND									
	Fishery								
FY	SCI	SQU	LLL	HHL	JMA	OEO	ORH	SBW	ALL
1991	1 422	0	75	24	0	0	70	0	1 591
1992	919	36	75	120	4	0	12	0	1 166
1993	667	13	75	104	22	0	19	0	901
1994	456	0	152	83	6	0	50	0	747
1995	1 208	0	81	303	0	0	42	0	1 635
1996	803	0	58	393	0	0	450	0	1 705
1997	584	8	67	1 205	0	0	3 240	0	5 104
1998	392	0	109	959	0	0	569	0	2 030
1999	230	0	29	359	8	0	93	0	718
2000	482	0	24	318	0	0	132	0	956
2001	603	6	70	200	179	0	30	0	1 087
2002	1 085	0	14	270	0	0	14	0	1 383
2003	811	12	29	189	0	0	41	0	1 082
2004	746	8	18	243	0	0	15	0	1 030
2005	948	1	64	155	0	0	23	0	1 191
2006	347	11	37	275	0	0	19	0	689
2007	580	11	36	232	0	0	13	0	872
2008	445	2	46	216	0	0	15	0	724
2009	255	5	38	183	0	0	26	0	507
2010	576	0	38	396	0	0	5	0	1 015
2011	390	0	63	277	0	0	40	0	770
2012	394	0	44	244	0	0	36	0	718
2013	560	9	44	383	0	0	16	0	1 012
2014	566	0	44	216	0	0	26	0	852
2015	479	0	44	302	0	0	16	0	841
2016	318	8	44	404	0	0	16	0	790
2017	318	8	44	395	0	0	16	0	781

PUYSEGUR									
	Fishery								
FY	SCI	SQU	LLL	HHL	JMA	OEO	ORH	SBW	ALL
1991	0	6	30	318	0	82	429	0	865
1992	4	118	30	418	143	53	1 689	0	2 456
1993	35	145	30	144	10	78	909	0	1 352
1994	1	12	60	246	14	59	2 343	0	2 736
1995	8	29	39	414	5	26	444	0	964
1996	0	32	59	153	0	107	921	0	1 272
1997	28	125	103	515	4	35	493	0	1 302
1998	37	38	219	535	0	417	333	0	1 580
1999	212	58	123	658	8	27	53	0	1 138
2000	40	74	93	1 050	0	200	27	0	1 484
2001	148	543	217	2 887	0	134	503	0	4 432
2002	0	887	99	660	0	124	193	0	1 964
2003	165	2 708	81	637	0	252	27	0	3 870
2004	21	487	62	328	0	45	0	0	943
2005	8	497	77	368	0	39	112	0	1 101
2006	0	538	87	971	0	26	131	0	1 753
2007	0	33	71	236	0	7	0	0	347
2008	0	32	190	206	0	64	0	0	492
2009	0	13	25	160	0	5	10	0	214
2010	0	63	5	120	0	1	14	0	204
2011	0	152	95	275	0	7	0	0	529
2012	0	47	21	302	0	3	15	0	388

PUYSEGUR									
	Fishery								
FY	SCI	SQU	LLL	HHL	JMA	OEO	ORH	SBW	ALL
2013	0	66	21	513	0	11	0	0	611
2014	0	127	21	1 609	0	75	42	0	1 874
2015	0	90	21	1 170	0	3	68	0	1 352
2016	0	107	21	1 702	0	3	68	0	1 901
2017	0	107	21	1 269	0	3	68	0	1 468

STEWART-SNARES SHELF									
	Fishery								
FY	SCI	SQU	LLL	HHL	JMA	OEO	ORH	SBW	ALL
1991	0	14 215	28	2 108	65	55	68	0	16 539
1992	1	11 222	28	2 592	536	40	122	0	14 542
1993	11	14 924	28	1 707	114	14	102	0	16 901
1994	0	4 669	85	859	159	16	126	0	5 914
1995	5	1 309	205	1 250	298	8	10	0	3 085
1996	2	5 029	37	1 752	204	49	231	0	7 304
1997	10	7 993	143	1 195	257	124	880	0	10 600
1998	19	5 719	219	3 464	506	114	692	0	10 733
1999	69	14 713	508	2 499	1 559	288	154	0	19 790
2000	8	7 685	198	4 860	4 621	184	90	0	17 646
2001	3	8 536	165	6 069	877	66	165	0	15 881
2002	0	15 158	164	7 148	1 567	248	2	0	24 288
2003	156	15 326	75	2 336	2 063	158	0	0	20 115
2004	40	19 606	166	2 833	723	34	0	0	23 401
2005	6	20 599	112	1 876	527	48	0	0	23 168
2006	0	28 634	48	2 067	1 369	62	0	0	32 180
2007	0	10 859	343	3 883	360	8	0	0	15 454
2008	0	10 356	179	1 866	183	9	5	0	12 598
2009	0	9 670	91	1 673	996	15	0	0	12 445
2010	0	9 100	54	2 211	1 144	27	0	0	12 536
2011	0	13 547	60	2 092	1 081	23	0	0	16 803
2012	0	10 295	514	1 495	1 622	42	0	0	13 968
2013	0	9 000	514	2 269	935	64	0	0	12 782
2014	0	8 482	514	9030	1 135	31	0	0	19 192
2015	0	7 126	514	9369	1 135	1	0	0	18 145
2016	0	5 625	514	4196	1 135	1	0	0	11 471
2017	0	5 625	514	7029	1 135	1	0	0	14 304

SUBANTARCTIC									
	Fishery								
FY	SCI	SQU	LLL	HHL	JMA	OEO	ORH	SBW	ALL
1991	1	38	1 078	433	0	3	33	533	2 120
1992	14	0	1 078	226	0	2	40	1 479	2 839
1993	95	5	1 078	98	0	4	35	206	1 521
1994	85	6	705	139	0	12	31	382	1 360
1995	3	0	549	95	0	26	76	178	928
1996	8	20	641	106	0	49	538	63	1 426
1997	154	0	637	72	0	44	2 986	203	4 096
1998	66	0	132	306	0	152	1 762	296	2 714
1999	27	0	759	166	0	124	231	283	1 590
2000	9	15	905	442	0	312	147	283	2 113
2001	4	21	912	415	0	59	104	223	1 739
2002	53	16	537	1 223	0	63	0	364	2 256

SUBANTARCTIC									
	Fishery								
FY	SCI	SQU	LLL	HHL	JMA	OEO	ORH	SBW	ALL
2003	41	486	609	2 003	0	596	133	230	4 098
2004	58	548	882	1 901	0	69	74	390	3 922
2005	0	103	212	449	0	101	75	250	1 190
2006	0	110	139	86	0	301	172	190	997
2007	0	194	109	197	0	57	66	40	663
2008	0	13	575	820	0	85	49	40	1 582
2009	0	2	474	514	0	126	52	40	1 208
2010	0	9	274	83	0	145	61	40	612
2011	0	18	149	335	0	54	32	40	628
2012	0	5	139	95	0	37	5	40	321
2013	0	24	139	133	0	0	0	40	336
2014	18	4	139	1 214	0	0	0	40	1 415
2015	35	7	139	723	0	0	0	40	944
2016	5	4	139	238	0	0	0	40	426
2017	5	4	139	730	0	0	0	40	918

WEST COAST NORTH ISLAND									
	Fishery								
FY	SCI	SQU	LLL	HHL	JMA	OEO	ORH	SBW	ALL
1991	0	2	2	27	1 839	0	15	0	1 885
1992	4	4	2	28	6 978	0	160	0	7 175
1993	64	9	2	15	8 761	0	474	0	9 324
1994	0	23	2	14	4 924	2	2 397	0	7 362
1995	3	2	0	21	1 791	1	116	0	1 933
1996	0	0	18	100	3 621	0	33	0	3 771
1997	1	2	79	33	1 814	3	200	0	2 132
1998	13	0	1	45	5 784	0	268	0	6 111
1999	11	168	36	24	2 010	0	210	0	2 460
2000	5	553	4	61	360	0	158	0	1 140
2001	0	1 155	16	89	1 826	2	489	0	3 577
2002	10	836	5	48	5 693	0	40	0	6 632
2003	0	89	0	110	7 366	0	72	0	7 637
2004	0	6	1	43	13 310	0	61	0	13 421
2005	8	0	1	20	7 292	0	43	0	7 364
2006	0	0	5	61	10 312	0	51	0	10 429
2007	0	1	36	33	11 015	0	71	0	11 156
2008	0	0	29	94	8 975	0	41	0	9 139
2009	0	0	36	77	6 891	0	39	0	7 043
2010	0	0	25	24	10 760	0	29	0	10 838
2011	0	0	56	26	4 484	0	23	0	4 589
2012	0	0	14	39	5 674	0	60	0	5 788
2013	4	2	14	51	5 696	0	49	0	5 816
2014	0	0	14	80	5 281	0	64	0	5 440
2015	0	0	14	70	5 281	0	30	0	5 396
2016	0	0	14	42	5 281	0	30	0	5 368
2017	0	0	14	99	5 281	0	30	0	5 425

WEST COAST SOUTH ISLAND									
	Fishery								
FY	SCI	SQU	LLL	HHL	JMA	OEO	ORH	SBW	ALL
1991	1	36	164	8 589	2 206	0	516	0	11 513
1992	0	23	164	6 335	2 864	0	1 082	0	10 468

	WEST COAST SOUTH ISLAND								
	Fishery								
FY	SCI	SQU	LLL	HHL	JMA	OEO	ORH	SBW	ALL
1993	95	2	164	3 431	800	0	147	0	4 640
1994	2	5	320	9 426	2 129	9	213	0	12 103
1995	68	1	223	13 187	3 253	0	509	0	17 240
1996	12	0	401	12 211	3 050	2	370	0	16 045
1997	7	2	480	11 341	3 535	5	419	0	15 789
1998	26	2	406	10 964	4 376	24	276	0	16 074
1999	38	5	292	7 028	9 536	8	426	0	17 333
2000	15	0	281	7 168	3 906	14	654	0	12 037
2001	0	38	463	8 222	9 191	2	161	0	18 076
2002	15	5	221	7 245	3 903	0	0	0	11 389
2003	8	1 590	282	6 077	1 902	0	0	0	9 859
2004	0	369	158	6 830	706	0	0	0	8 063
2005	8	764	310	4 554	452	0	7	0	6 095
2006	0	185	255	4 051	1 271	0	0	0	5 762
2007	0	418	264	2 557	3 304	0	0	0	6 543
2008	0	0	364	3 083	1 540	0	0	0	4 987
2009	0	37	370	2 750	1 287	0	18	0	4 462
2010	0	41	386	1 696	506	0	4	0	2 633
2011	0	0	332	3 439	524	0	14	0	4 308
2012	14	0	428	2 755	588	0	23	0	3 808
2013	21	0	428	3 827	889	0	41	0	5 206
2014	31	0	428	5 864	1 003	0	11	0	7 337
2015	34	450	428	7 567	1 003	0	148	0	9 630
2016	39	0	428	6 303	1 003	0	148	0	7 921
2017	39	0	428	5 410	1 003	0	148	0	7 028

Appendix 19.7.3: DISCARDS: Total annual discards by fishery area for seven deepwater trawl fisheries and one longline fishery (1990–91 to 2015–16). Where data have not yet been updated for recent years for a fishery figures from the last available year have been assumed, in order for annual totals to be calculated. LLL = ling longline fishery; HHL = hoki/hake/ling fishery. [Continued on next pages]

	AUCKLAND ISLANDS								
	Fishery								
FY	SCI	SQU	LLL	HHL	JMA	OEO	ORH	SBW	ALL
1991	4	74	17	5	0	0	0	0	100
1992	90	18	17	5	0	0	0	0	130
1993	278	68	17	9	0	9	2	0	383
1994	539	37	0	12	0	1	12	0	601
1995	707	32	12	10	0	47	20	0	829
1996	716	55	18	13	6	5	17	0	830
1997	1 383	183	34	15	2	6	10	0	1 634
1998	517	332	8	42	0	4	14	0	917
1999	645	101	13	19	0	27	15	0	820
2000	790	55	52	47	0	18	8	0	970
2001	421	115	58	69	0	5	6	0	674
2002	610	191	1	41	0	4	14	0	861
2003	832	1 162	0	205	0	7	7	0	2 046
2004	270	1 741	12	71	0	3	5	0	2 052
2005	508	1 234	1	57	0	0	1	0	1 758
2006	414	2 574	0	29	0	0	0	0	2 991
2007	448	812	0	30	0	0	0	0	1 263
2008	316	538	0	3	0	0	1	0	858
2009	412	1 331	0	3	0	1	0	0	1 744
2010	520	1 079	12	3	0	0	0	0	1 614

AUCKLAND ISLANDS									
	Fishery								
FY	SCI	SQU	LLL	HHL	JMA	OEO	ORH	SBW	ALL
2011	545	1 386	66	3	0	0	1	0	1 999
2012	453	662	6	3	0	0	0	0	1 124
2013	439	804	6	4	0	0	0	0	1 253
2014	464	259	6	9	0	1	2	0	740
2015	250	389	6	20	0	0	2	0	667
2016	421	1 130	6	6	0	0	2	0	1 565
2017	421	1 130	6	22	0	0	2	0	1 581

CHATHAM RISE									
	Fishery								
FY	SCI	SQU	LLL	HHL	JMA	OEO	ORH	SBW	ALL
1991	154	241	605	3 239	861	454	2 419	0	7 973
1992	1 364	303	605	6 387	100	201	1 053	0	10 015
1993	2 314	610	605	2 028	360	240	1 186	0	7 344
1994	1 402	1 718	862	1 650	48	302	937	0	6 919
1995	809	453	1 019	2 817	278	184	946	0	6 505
1996	4 126	110	1 107	3 737	24	423	671	0	10 199
1997	783	889	765	3 066	68	372	720	0	6 662
1998	657	1 436	1661	8 244	1 845	364	840	0	15 046
1999	361	990	587	5 314	110	272	1 020	0	8 654
2000	271	825	690	9 829	125	297	787	0	12 825
2001	1 366	2 721	874	6 981	18	151	1 012	0	13 123
2002	1 303	1 698	1 709	9 545	77	48	471	0	14 850
2003	1 056	7 324	1 027	14 762	80	68	478	0	18 598
2004	218	902	806	9 658	5	99	538	0	5 750
2005	2 117	2 156	1 080	3 348	5	95	520	0	6 843
2006	898	2 681	955	4 042	271	93	1 399	0	7 260
2007	2 249	2 392	546	3 089	52	46	491	0	7 590
2008	1 417	864	1 016	7 160	47	28	129	0	5 064
2009	1 041	327	875	12 681	11	26	195	0	5 085
2010	1 418	419	950	3 848	3	27	76	0	9 442
2011	1 002	1 083	879	5 611	3	25	29	0	5 706
2012	1 138	395	517	3 039	4	61	115	0	3 522
2013	1 743	105	517	1 718	32	9	71	0	5 105
2014	2 245	29	517	1 801	3	30	18	0	4 643
2015	1 718	478	517	2 776	3	7	32	0	5 532
2016	1 262	1 859	517	984	3	7	32	0	4 665
2017	1 262	1 859	517	924	3	7	32	0	4 605

COOK STRAIT									
	Fishery								
FY	SCI	SQU	LLL	HHL	JMA	OEO	ORH	SBW	ALL
1991	0	0	3	1 081	0	3	76	0	1 164
1992	0	0	3	769	0	1	84	0	857
1993	0	4	3	786	0	2	56	0	852
1994	0	0	2	917	0	1	71	0	991
1995	9	0	3	1 729	0	2	84	0	1 826
1996	0	0	2	3 896	0	1	24	0	3 923
1997	0	0	1	3 259	0	6	32	0	3 299
1998	0	0	6	2 033	0	3	15	0	2 057
1999	3	9	16	1 871	31	4	35	0	1 968
2000	1	0	21	2 724	16	3	16	0	2 780

COOK STRAIT									
	Fishery								
FY	SCI	SQU	LLL	HHL	JMA	OEO	ORH	SBW	ALL
2001	0	7	65	1 312	18	6	6	0	1 414
2002	36	0	13	718	0	5	5	0	778
2003	3	2	4	1 982	0	3	3	0	2 585
2004	0	0	15	1 330	0	0	2	0	994
2005	28	0	31	651	0	0	3	0	656
2006	1	0	36	659	0	2	7	0	253
2007	1	0	48	652	0	0	3	0	903
2008	2	0	35	838	0	0	3	0	617
2009	0	0	8	943	0	0	4	0	522
2010	0	0	7	333	0	0	2	0	376
2011	0	0	8	690	0	0	3	0	758
2012	0	0	5	643	0	0	2	0	347
2013	0	0	5	346	0	0	1	0	184
2014	0	0	5	550	0	0	2	0	557
2015	0	0	5	213	0	0	4	0	222
2016	0	2	5	366	0	0	4	0	377
2017	0	2	5	303	0	0	4	0	314

EAST COAST NORTH ISLAND									
	Fishery								
FY	SCI	SQU	LLL	HHL	JMA	OEO	ORH	SBW	ALL
1991	1 535	0	24	178	0	9	664	0	2 411
1992	696	0	24	131	0	4	692	0	1 548
1993	579	0	24	130	0	7	555	0	1 295
1994	540	0	41	351	3	1	689	0	1 625
1995	418	0	27	316	0	13	893	0	1 666
1996	1 083	0	30	582	0	13	969	0	2 677
1997	405	0	31	726	0	57	873	0	2 092
1998	624	0	42	3	0	32	669	0	1 369
1999	1 240	0	24	218	0	36	627	0	2 145
2000	348	0	43	181	0	20	275	0	866
2001	702	0	114	228	3	23	1 093	0	2 163
2002	2 284	0	59	174	6	13	31	0	2 567
2003	699	11	23	71	0	23	0	0	979
2004	161	0	58	57	0	4	5	0	344
2005	585	0	64	26	0	4	7	0	700
2006	247	0	96	24	0	3	56	0	453
2007	470	0	66	32	0	1	59	0	655
2008	289	0	84	23	0	0	59	0	470
2009	186	0	78	40	0	0	83	0	396
2010	601	0	81	33	0	0	100	0	870
2011	423	0	73	55	0	0	22	0	665
2012	209	0	79	39	0	0	32	0	376
2013	238	0	79	37	0	0	57	0	478
2014	301	0	79	71	0	0	37	0	488
2015	285	0	79	11	0	0	13	0	388
2016	255	0	79	70	0	0	13	0	417
2017	255	0	79	104	0	0	13	0	451

NORTHLAND									
	Fishery								
FY	SCI	SQU	LLL	HHL	JMA	OEO	ORH	SBW	ALL
1991	615	0	23	13	0	0	5	0	657

NORTHLAND									
	Fishery								
FY	SCI	SQU	LLL	HHL	JMA	OEO	ORH	SBW	ALL
1992	405	0	23	91	0	0	1	0	520
1993	303	1	23	127	0	0	2	0	457
1994	231	0	44	53	0	0	4	0	332
1995	386	0	23	191	0	0	3	0	604
1996	732	0	18	215	0	0	8	0	974
1997	431	1	22	520	0	0	40	0	1 015
1998	214	0	33	2	0	0	37	0	286
1999	137	0	7	144	0	1	118	0	406
2000	262	0	8	117	0	0	16	0	404
2001	383	1	17	70	9	0	2	0	482
2002	832	0	4	124	0	0	0	0	961
2003	367	35	9	70	0	0	4	0	496
2004	235	2	5	72	0	0	1	0	292
2005	746	0	12	32	0	0	1	0	774
2006	281	4	13	86	0	0	0	0	358
2007	507	5	12	63	0	0	1	0	568
2008	355	1	24	55	0	0	1	0	412
2009	231	2	11	67	0	0	4	0	282
2010	505	0	13	71	0	0	0	0	659
2011	335	0	19	93	0	0	1	0	448
2012	268	0	23	98	0	0	6	0	359
2013	505	3	23	116	0	0	9	0	674
2014	454	0	23	104	0	0	7	0	588
2015	342	0	23	75	0	0	3	0	444
2016	321	6	23	138	0	0	3	0	492
2017	321	6	23	158	0	0	3	0	512

PUYSEGUR									
	Fishery								
FY	SCI	SQU	LLL	HHL	JMA	OEO	ORH	SBW	ALL
1991	0	1	21	225	0	26	34	0	306
1992	1	17	21	512	0	34	139	0	724
1993	13	31	21	208	0	115	118	0	505
1994	0	5	27	248	3	32	268	0	582
1995	2	5	22	227	0	63	38	0	358
1996	0	1	34	567	0	75	117	0	794
1997	21	25	60	429	0	100	34	0	669
1998	27	24	122	293	0	90	8	0	564
1999	196	16	66	270	0	130	5	0	683
2000	15	12	42	307	0	109	3	0	488
2001	84	162	106	253	0	167	76	0	848
2002	0	282	60	297	0	65	32	0	735
2003	32	3 204	45	784	0	172	18	0	3 667
2004	4	122	34	276	0	15	9	0	222
2005	5	196	39	681	0	15	4	0	554
2006	0	147	54	2 074	0	11	1	0	401
2007	0	12	45	484	0	3	0	0	189
2008	0	10	116	622	0	11	1	0	252
2009	0	4	14	152	0	2	2	0	110
2010	0	19	4	267	0	1	2	0	92
2011	0	49	57	199	0	3	3	0	263
2012	0	12	16	417	0	0	2	0	163
2013	0	8	16	378	0	0	0	0	241

PUYSEGUR									
	Fishery								
FY	SCI	SQU	LLL	HHL	JMA	OEO	ORH	SBW	ALL
2014	0	37	16	249	0	2	5	0	309
2015	0	34	16	275	0	0	0	0	326
2016	0	71	16	515	0	0	0	0	603
2017	0	71	16	460	0	0	0	0	548

STEWART-SNARES SHELF									
	Fishery								
FY	SCI	SQU	LLL	HHL	JMA	OEO	ORH	SBW	ALL
1991	0	144	15	1 471	0	14	1	0	1 645
1992	0	83	15	1 531	1 405	21	2	0	3 056
1993	3	1 344	15	1 942	105	11	2	0	3 423
1994	0	99	39	585	13	7	3	0	745
1995	1	79	171	211	64	16	0	0	542
1996	3	4	15	459	502	28	4	0	1 014
1997	6	1 659	55	1 017	51	91	57	0	2 936
1998	14	1 826	96	1 167	0	50	10	0	3 163
1999	64	1 335	132	1 430	40	174	6	0	3 180
2000	2	162	55	1 114	612	140	2	0	2 088
2001	2	928	58	1 852	39	69	3	0	2 950
2002	0	3 145	46	2 221	277	146	1	0	5 836
2003	44	3 383	34	2 853	25	141	0	0	4 661
2004	9	2 858	58	2 528	4	24	0	0	3 452
2005	3	3 277	70	2 179	7	23	0	0	3 768
2006	0	4 713	18	2 008	10	37	1	0	6 077
2007	0	1 892	218	4 774	3	5	0	0	2 553
2008	0	1 096	74	594	1	5	0	0	1 258
2009	0	1 816	34	1 384	7	2	0	0	1 995
2010	0	1 656	23	512	2	4	0	0	1 962
2011	0	2 690	23	724	2	4	0	0	3 526
2012	0	1 513	252	1 019	3	4	0	0	2 362
2013	0	1 544	252	1 288	32	6	0	0	2 449
2014	0	1 152	252	1 525	17	6	0	0	2 952
2015	0	961	252	1 987	17	0	0	0	3 218
2016	0	1 284	252	876	17	0	0	0	2 430
2017	0	1 284	252	2 006	17	0	0	0	3 560

SUBANTARCTIC									
	Fishery								
FY	SCI	SQU	LLL	HHL	JMA	OEO	ORH	SBW	ALL
1991	1	0	317	364	0	1	3	746	1 431
1992	2	0	317	114	0	1	3	1 218	1 656
1993	47	0	317	40	0	2	5	537	948
1994	34	1	235	33	0	4	3	483	793
1995	1	0	318	22	0	38	7	303	689
1996	16	0	346	26	0	20	40	406	854
1997	125	0	427	17	0	22	97	270	958
1998	38	0	10	73	0	55	34	392	602
1999	19	0	471	54	0	46	25	471	1 086
2000	2	0	537	278	0	155	10	471	1 454
2001	2	2	557	147	0	230	10	137	1 085
2002	37	3	296	655	0	38	7	159	1 195
2003	19	497	267	1 002	0	91	14	250	1 661
2004	13	129	329	773	0	58	19	90	847

									SUBANTARCTIC
									Fishery
FY	SCI	SQU	LLL	HHL	JMA	OEO	ORH	SBW	ALL
2005	0	43	136	765	0	78	5	160	530
2006	0	42	66	221	0	121	27	240	518
2007	0	96	53	949	0	51	4	120	371
2008	0	2	62	115	0	32	4	120	343
2009	0	1	151	222	0	33	6	120	322
2010	0	5	115	47	0	36	3	120	299
2011	0	6	20	23	0	12	2	120	175
2012	0	2	86	90	0	9	0	120	218
2013	0	6	86	67	0	0	0	120	224
2014	14	1	86	121	0	0	0	120	342
2015	25	0	86	102	0	0	0	120	333
2016	4	1	86	9	0	0	0	120	220
2017	4	1	86	223	0	0	0	120	434

									WEST COAST NORTH ISLAND
									Fishery
FY	SCI	SQU	LLL	HHL	JMA	OEO	ORH	SBW	ALL
1991	0	0	0	14	0	0	5	0	19
1992	1	0	0	22	100	0	27	0	150
1993	24	1	0	18	915	0	333	0	1 291
1994	0	4	1	9	1 285	0	141	0	1 439
1995	1	0	0	14	317	4	161	0	497
1996	0	0	10	55	109	0	45	0	220
1997	0	1	32	14	0	2	106	0	155
1998	8	0	1	0	0	0	43	0	53
1999	10	18	17	9	837	0	62	0	953
2000	1	26	2	22	16	0	129	0	196
2001	0	148	6	31	51	1	246	0	483
2002	7	181	3	22	230	0	7	0	450
2003	0	140	0	13	183	0	6	0	376
2004	0	2	0	10	133	0	7	0	151
2005	5	0	1	3	98	0	15	0	121
2006	0	0	2	30	77	0	11	0	103
2007	0	1	19	19	165	0	2	0	193
2008	0	0	15	32	166	0	13	0	207
2009	0	0	17	32	97	0	3	0	131
2010	0	0	11	4	264	0	6	0	290
2011	0	0	23	8	76	0	4	0	112
2012	0	0	9	10	140	0	26	0	184
2013	3	1	9	18	113	0	21	0	164
2014	0	0	9	14	165	0	60	0	247
2015	0	0	9	8	165	0	10	0	192
2016	0	0	9	12	165	0	10	0	196
2017	0	0	9	26	165	0	10	0	210

									WEST COAST SOUTH ISLAND
									Fishery
FY	SCI	SQU	LLL	HHL	JMA	OEO	ORH	SBW	ALL
1991	1	0	115	5 904	76	0	195	0	6 291
1992	0	0	115	3 382	201	0	223	0	3 921
1993	36	0	115	4 889	495	0	192	0	5 727
1994	1	1	139	6 671	118	1	422	0	7 353

	WEST COAST SOUTH ISLAND								
	Fishery								
FY	**SCI**	**SQU**	**LLL**	**HHL**	**JMA**	**OEO**	**ORH**	**SBW**	**ALL**
1995	18	0	127	8 327	461	4	147	0	9 084
1996	12	0	220	7 314	363	1	102	0	8 013
1997	5	1	270	7 520	964	3	181	0	8 946
1998	19	1	219	3 587	0	7	145	0	3 979
1999	35	1	223	3 177	520	8	290	0	4 254
2000	6	0	155	2 035	16	4	301	0	2 517
2001	0	6	231	2 421	482	1	71	0	3 211
2002	9	1	128	2 926	100	0	2	0	3 166
2003	3	212	172	3 250	7	0	1	0	3 158
2004	0	9	107	2 882	1	0	1	0	1 773
2005	6	29	165	1 509	3	0	0	0	668
2006	0	5	153	2 676	29	0	7	0	1 608
2007	0	14	157	3 740	84	0	1	0	780
2008	0	0	236	2 167	7	0	0	0	869
2009	0	1	204	2 402	5	0	0	0	689
2010	0	1	234	659	4	0	0	0	719
2011	0	0	183	2 302	1	0	2	0	1 231
2012	9	0	209	3 606	5	0	3	0	1 256
2013	14	0	209	2 727	7	0	6	0	2 319
2014	19	0	209	2 491	9	0	10	0	2 739
2015	21	20	209	2 681	9	0	48	0	2 989
2016	28	0	209	2 106	9	0	48	0	2 401
2017	28	0	209	2 802	9	0	48	0	3 097

19.8 APPENDICES FROM CHAPTER 10 CHONDRICHTHYANS

Appendix 19.8.1: List of New Zealand chondrichthyans, with details of their fisheries management classification, IUCN and Department of Conservation threat classes, and their distribution area. IUCN threat classes: EN, Endangered; VU, Vulnerable; NT, Near Threatened; LC, Least Concern; DD, Data Deficient. DOC threat classes: DD, Data Deficient; NE, Nationally Endangered; NV, Threatened – Nationally Vulnerable; ARNU, At Risk – Naturally Uncommon; MI, Migrant; VA, Vagrant; NOT, Not Threatened. DOC qualifiers: CD, Conservation Dependent; DP, Data Poor; Inc, Increasing; SO, Secure Overseas; S?O, Uncertain Whether Secure Overseas; TO, Threatened Overseas; T?O, Uncertain Whether Threatened Overseas. Sources: IUCN Redlist classes as at July 2013 (L. Harrison, Shark Specialist Group IUCN, pers. comm.); DOC threat classes 2018 (Duffy et al. 2018). [Continued on next page]. NB: IUCN Redlist classes for New Zealand chondrichthyans were last reviewed in 2018.

Group	Family	Species	Authority	Common name	Code	Management class	IUCN Red List class	DoC Threat class	DoC qualifer	Location	Notes
Chimaera	Callorhinchidae	*Callorhinchus milii*	Bory de Saint-Vincent, 1823	Elephantfish	ELE	QMS	LC	NOT	CD, Inc	NZ EEZ	
Chimaera	Rhinochimaeridae	*Harriotta haeckeli*	Karrer, 1972	Smallspine spookfish	HHA	Non-QMS	LC	NOT		NZ EEZ	
Chimaera	Rhinochimaeridae	*Harriotta raleighana*	Goode & Bean, 1895	Longnose spookfish	LCH	Non-QMS	LC	NOT		NZ EEZ	
Chimaera	Rhinochimaeridae	*Rhinochimaera pacifica*	(Mitsukuri, 1895)	Pacific spookfish	RCH	Non-QMS	LC	NOT	DP	NZ EEZ	
Chimaera	Chimaeridae	*Chimaera carophila*	Kemper, Ebert, Naylor & Didier, 2014	Brown chimaera, longspine chimaera	CHP	Non-QMS	LC	NOT		NZ EEZ	
Chimaera	Chimaeridae	*Chimaera lignaria*	Didier, 2002	Purple chimaera, giant chimaera	CHG	Non-QMS	LC	NOT	SO	NZ EEZ	
Chimaera	Chimaeridae	*Chimaera panthera*	Didier, 1998	Leopard chimaera	CPN	Non-QMS	DD	NOT	DP	NZ EEZ	
Chimaera	Chimaeridae	*Hydrolagus bemisi*	Didier, 2002	Pale ghost shark	GSP	QMS	LC	NOT	CD	NZ EEZ	
Chimaera	Chimaeridae	*Hydrolagus homonycteris*	Didier, 2008	Black ghost shark	HYB	Non-QMS	LC	NOT	SO	NZ EEZ	
Chimaera	Chimaeridae	*Hydrolagus novaezealandiae*	(Fowler, 1911)	Dark ghost shark	GSH	QMS	LC	NOT		NZ EEZ	
Chimaera	Chimaeridae	*Hydrolagus trolli*	Didier and Seret, 2002	Pointynose blue ghost shark	HYP	Non-QMS	LC	NOT	SO	NZ EEZ	
Chimaera	Chimaeridae	*Hydrolagus* cf. *affinis*		Giant black ghost shark	HGB	Non-QMS		DD	CD	NZ EEZ	
Shark	Chlamydoselachidae	*Chlamydoselachus anguineus*	Garman, 1884	Frilled shark	FRS	Non-QMS	LC	ARNU	DP,SO	NZ EEZ	

Group	Family	Species	Authority	Common name	Code	Management class	IUCN Red List class	DoC Threat class	DoC qualifer	Location	Notes
Shark	Hexanchiidae	*Heptranchias perlo*	(Bonnaterre, 1788)	Sharpnose sevengill shark	HEP	Non-target	NT	ARNU	DP,SO	NZ EEZ	
Shark	Hexanchiidae	*Hexanchus griseus*	(Bonnaterre, 1788)	Sixgill shark	HEX	Non-QMS	NT	NOT	DP,SO	NZ EEZ	
Shark	Hexanchiidae	*Notorynchus cepedianus*	(Peron, 1807)	Broadnose sevengill shark	SEV	Non-QMS	DD	NOT	DP,SO	NZ EEZ	
Shark	Echinorhinidae	*Echinorhinus brucus*	(Bonnaterre, 1788)	Bramble shark	BRS	Non-QMS	DD	ARNU	DP,SO	NZ EEZ	
Shark	Echinorhinidae	*Echinorhinus cookei*	Pietschmann, 1928	Prickly shark	ECO	Non-QMS	DD	ARNU	DP,SO	NZ EEZ	
Shark	Squalidae	*Cirrhigaleus australis*	White, Last & Stevens, 2007	Southern mandarin dogfish	MSH	Non-QMS	DD	ARNU	DP,TO	NZ EEZ	
Shark	Squalidae	*Squalus acanthias*	Linnaeus, 1758	Spiny dogfish	SPD	QMS	VU	NOT	SO	NZ EEZ	
Shark	Squalidae	*Squalus griffini*	Phillipps, 1931	Northern spiny dogfish	NSD	Non-QMS	LC	NOT	SO	NZ EEZ	
Shark	Squalidae	*Squalus raoulensis*	Duffy & Last, 2007	Kermadec spiny dogfish		Non-QMS	LC	DD		NZ EEZ	
Shark	Squalidae	*Squalus* sp.		Shortspine dogfish		Non-QMS		DD		NZ EEZ	
Shark	Centrophoridae	*Centrophorus harrissoni*	McCulloch, 1915	Harrisson's dogfish		Non-QMS	EN	DD	TO	NZ EEZ	
Shark	Centrophoridae	*Centrophorus squamosus*	(Bonnaterre, 1788)	Leafscale gulper shark	CSQ	Non-QMS	VU	NOT	SO	NZ EEZ	
Shark	Centrophoridae	*Deania calcea*	(Lowe, 1839)	Shovelnose dogfish	SND	Non-QMS	LC	NOT		NZ EEZ	
Shark	Centrophoridae	*Deania hystricosa*	(Garman, 1906)	Rough longnose dogfish	SNR	Non-QMS	DD	DD		NZ EEZ	
Shark	Centrophoridae	*Deania quadrispinosa*	(McCulloch, 1915)	Longsnout dogfish	DEQ	Non-QMS	NT	DD	SO	NZ EEZ	
Shark	Etmopteridae	*Centroscyllium kamoharai*	Abe, 1966	Fragile dogfish		Non-QMS	LC	DD		NZ EEZ	
Shark	Etmopteridae	*Etmopterus granulosus*	(Günther, 1880)	Baxter's dogfish	ETB	Non-QMS	LC	NOT	SO	NZ EEZ	
Shark	Etmopteridae	*Etmopterus lucifer*	Jordan & Snyder, 1902	Lucifer dogfish	ETL	Non-QMS	LC	NOT	DP,SO	NZ EEZ	
Shark	Etmopteridae	*Etmopterus molleri*	(Whitley, 1939)	Moller's lantern shark	EMO	Non-QMS	DD	DD	S?O	NZ EEZ	
Shark	Etmopteridae	*Etmopterus pusillus*	(Lowe, 1839)	Smooth lantern shark	ETP	Non-QMS	LC	ARNU	DP,SO	NZ EEZ	

Group	Family	Species	Authority	Common name	Code	Management class	IUCN Red List class	DoC Threat class	DoC qualifer	Location	Notes
Shark	Etmopteridae	*Etmopterus unicolor*	(Engelhardt, 1912)	Bristiled lantern shark	ETU	Non-QMS	DD	NOT	SO	NZ EEZ	
Shark	Etmopteridae	*Etmopterus viator*	Straube, 2011	Blue-eye lantern shark	EVI	Non-QMS	LC	DD		NZ EEZ	
Shark	Somniosidae	*Centroscymnus coelolepis*	Barbosa du Bocage & de Brito Capello, 1864	Portuguese dogfish	CYL	Non-QMS	NT	NOT	DP	NZ EEZ	
Shark	Somniosidae	*Centroscymnus owstonii*	Garman, 1906	Owston's dogfish	CYO	Non-QMS	VU	NOT		NZ EEZ	
Shark	Somniosidae	*Centroselachus crepidater*	(Barbosa du Bocage & de Brito Capello, 1864)	Longnose velvet dogfish	CYP	Non-QMS	LC	NOT	SO	NZ EEZ	
Shark	Somniosidae	*Scymnodalatias albicauda*	Taniuchi & Garrick, 1986	Whitetail dogfish	SLB	Non-QMS	DD	DD	S?O	NZ EEZ	
Shark	Somniosidae	*Scymnodalatias sherwoodi*	(Archey, 1921)	Sherwood's dogfish	SHE	Non-QMS	DD	DD	S?O	NZ EEZ	
Shark	Somniosidae	*Centroscymnus macracanthus*	Regan, 1906	Plunket's dogfish	PLS	Non-QMS	DD	NOT	T?O	NZ EEZ	
Shark	Somniosidae	*Scymnodon plunketi*	(Waite, 1910)	Knifetooth dogfish	SRI	Non-QMS	VU	DD	S?O	NZ EEZ	
Shark	Somniosidae	*Somniosus antarcticus*	Whitley, 1939	Southern sleeper shark	SSS	Non-QMS	LC	NOT	DP,S?O	NZ EEZ	
Shark	Somniosidae	*Somniosus longus*	(Tanaka, 1912)	Little sleeper shark	SOM	Non-QMS	DD	DD	S?O	NZ EEZ	
Shark	Somniosidae	*Zameus squamulosus*	(Günther, 1877)	Velvet dogfish	ZAS	Non-QMS	DD	DD	S?O	NZ EEZ	
Shark	Oxynotidae	*Oxynotus bruniensis*	(Ogilby, 1893)	Prickly dogfish	PDG	Non-QMS	NT	NOT	DP,SO	NZ EEZ	
Shark	Dalatiidae	*Dalatias licha*	(Bonnaterre, 1788)	Seal shark	BSH	Non-QMS	VU	NOT	SO	NZ EEZ	
Shark	Dalatiidae	*Euprotomicrus bispinatus*	(Quoy & Gaimard, 1824)	Pygmy shark	EBI	Non-QMS	LC	NOT	SO	NZ EEZ	
Shark	Dalatiidae	*Isistius brasiliensis*	(Quoy & Gaimard, 1824)	Cookie cutter shark	IBR	Non-QMS	LC	NOT	SO	NZ EEZ	
Shark	Heterodontidae	*Heterodontus portusjacksoni*	(Meyer, 1793)	Port Jackson shark	PJS	Non-QMS	LC	VA	SO	NZ EEZ	
Shark	Rhincodontidae	*Rhincodon typus*	Smith, 1828	Whale shark	WSH	Protected	EN	MI	SO	NZ EEZ	
Shark	Odontaspididae	*Odontaspis ferox*	(Risso, 1810)	Deepwater (smalltooth) sand tiger shark	ODO	Protected	VU	ARNU	TO	NZ EEZ	

Group	Family	Species	Authority	Common name	Code	Management class	IUCN Red List class	DoC Threat class	DoC qualifer	Location	Notes
Shark	Pseudocarchariidae	*Pseudocarcharias kamoharai*	(Matsubara, 1936)	Crocodile shark	CRC	Non-QMS	LC	DD	SO	NZ EEZ	
Shark	Mitsukurinidae	*Mitsukurina owstoni*	Jordan, 1898	Goblin shark	GOB	Non-QMS	LC	ARNU	DP,SO	NZ EEZ	
Shark	Alopiidae	*Alopias superciliosus*	Lowe, 1841	Bigeye thresher	BET	Non-QMS	VU	NOT	TO	NZ EEZ	
Shark	Alopiidae	*Alopias vulpinus*	(Bonnaterre, 1788)	Thresher shark	THR	Non-QMS	VU	NOT	DP,TO	NZ EEZ	
Shark	Cetorhinidae	*Cetorhinus maximus*	(Gunnerus, 1765)	Basking shark	BSK	Protected	EN	NV		NZ EEZ	
Shark	Laminidae	*Carcharodon carcharias*	(Linnaeus, 1758)	White shark, white pointer	WPS	Protected	VU	NE	DP,TO	NZ EEZ	
Shark	Laminidae	*Isurus oxyrinchus*	Rafinesque, 1810	Mako shark, shortfin mako	MAK	QMS	EN	NOT	S?O	NZ EEZ	
Shark	Laminidae	*Lamna nasus*	(Bonnaterre, 1788)	Porbeagle shark	POS	QMS	VU	NOT	TO	NZ EEZ	
Shark	Pentanchidae	*Apristurus albisoma*	Nakaya & Seret, 1999	Grey roundfin catshark		Non-QMS	LC	DD		NZ EEZ	
Shark	Pentanchidae	*Apristurus ampliceps*	Sasahara, Sato & Nakaya, 2008	Roughskin catshark	AAM	Non-QMS	LC	DD		NZ EEZ	
Shark	Pentanchidae	*Apristurus exsanguis*	Sato, Nakaya & Stewart, 1999	Pale catshark	AEX	Non-QMS	LC	DD		NZ EEZ	
Shark	Pentanchidae	*Apristurus garricki*	Sato, Stewart & Nakaya, 2013	Garrick's catshark	AGK	Non-QMS	LC	DD		NZ EEZ	
Shark	Pentanchidae	*Apristurus melanoasper*	Iglésias, Nakaya & Stehmann, 2004	Flesynose catshark	AML	Non-QMS	LC	DD		NZ EEZ	
Shark	Pentanchidae	*Apristurus pinguis*	Deng, Xiong & Zhan, 1983	Bulldog catshark	APN	Non-QMS	LC	DD		NZ EEZ	
Shark	Pentanchidae	*Apristurus* cf *sinensis*	Chu & Hu, 1981	Freckled catshark	ASI	Non-QMS		DD		NZ EEZ	
Shark	Scyliorhinidae	*Bythaelurus dawsoni*	(Springer, 1971)	Dawson's catshark	DCS	Non-QMS	LC	NOT	DP	NZ EEZ	
Shark	Scyliorhinidae	*Cephaloscyllium isabellum*	(Bonnaterre, 1788)	Carpet shark	CAR	Non-QMS	LC	NOT		NZ EEZ	
Shark	Scyliorhinidae	*Cephaloscyllium* cf *variegatum*	Last & White, 2008	Swellshark		Non-QMS		DD		NZ EEZ	
Shark	Pentanchidae	*Parmaturus macmillani*	Hardy, 1985	McMillan's catshark	PCS	Non-QMS	VU	DD	S?O	NZ EEZ	

Group	Family	Species	Authority	Common name	Code	Management class	IUCN Red List class	DoC Threat class	DoC qualifer	Location	Notes
Shark	Pentanchidae	*Parmaturus* sp.		Rough-backed catshark		Non-QMS		DD		NZ EEZ	
Shark	Pseudotriakidae	*Gollum attenuatus*	(Garrick, 1954)	Slender smooth hound	SSH	Non-QMS	LC	NOT	SO	NZ EEZ	
Shark	Pseudotriakidae	*Pseudotriakis microdon*	de Brito Capello, 1868	False catshark	PMI	Non-QMS	LC	DD	SO	NZ EEZ	
Shark	Triakidae	*Galeorhinus galeus*	(Linnaeus, 1758)	School shark	SCH	QMS	VU	NOT	CD,TO	NZ EEZ	
Shark	Triakidae	*Mustelus lenticulatus*	Phillipps, 1932	Rig	SPO	QMS	LC	NOT	CD	NZ EEZ	
Shark	Triakidae	*Mustulus* sp.		Kermadec rig		Non-QMS		NOT		NZ EEZ	
Shark	Carcharhinidae	*Carcharhinus brachyurus*	(Günther, 1870)	Bronze whaler	BWH	Non-QMS	NT	NOT	CD,DP,SO	NZ EEZ	
Shark	Carcharhinidae	*Carcharhinus galapagensis*	(Snodgrass & Heller, 1905)	Galapagos shark	CGA	Non-QMS	LC	NOT	CD,SO	NZ EEZ	
Shark	Carcharhinidae	*Carcharhinus longimanus*	(Poey, 1861)	Oceanic whtietip shark	OWS	Non-QMS	CR	MI	SO	NZ EEZ	
Shark	Carcharhinidae	*Carcharhinus obscurus*	(Le Sueur, 1818)	Dusky shark	DSH	Non-QMS	EN	MI	SO	NZ EEZ	
Shark	Carcharhinidae	*Carcharhinus plumbeus*	(Nardo, 1827)	Sandbar shark		Non-QMS	VU	DD		NZ EEZ	
Shark	Carcharhinidae	*Galeocerdo cuvier*	(Peron & Lesueur, 1822)	Tiger shark	TIS	Non-QMS	NT	MI	SO	NZ EEZ	
Shark	Carcharhinidae	*Prionace glauca*	(Linnaeus, 1758)	Blue shark	BWS	QMS	NT	NOT	SO	NZ EEZ	
Shark	Carcharhinidae	*Triaenodon obesus*	(Rüppell, 1837)	Whitetip reef shark	TRB	Non-QMS	NT	VA		NZ EEZ	
Shark	Sphyrnidae	*Sphyrna zygaena*	(Linnaeus, 1758)	Hammerhead shark, smooth hammerhead	HHS	Non-target	VU	NOT	SO	NZ EEZ	
Batoid	Narkidae	*Typhlonarke aysoni*	(Hamilton, 1902)	Blind electric ray	TAY	Non-QMS	LC	NOT	DP	NZ EEZ	
Batoid	Torpedinidae	*Tetronarce nobiliana*	(Bonaparte, 1835)	Electric ray	ERA	Non-QMS	DD	DD		NZ EEZ	
Batoid	Torpedinidae	*Tetronarce* cf. *tokionis*	(Tanaka, 1908)	Slender electric ray		Non-QMS		DD		NZ EEZ	
Batoid	Arhynchobatidae	*Arhynchobatis asperrimus*	Waite, 1909	Longtail skate	LSK	Non-QMS	DD	DD		NZ EEZ	

Group	Family	Species	Authority	Common name	Code	Management class	IUCN Red List class	DoC Threat class	DoC qualifer	Location	Notes
Batoid	Arhynchobatidae	*Bathyraja* cf. *eatonii*		Antarctic allometric skate	BEA	Non-QMS				Southern Ocean	
Batoid	Arhynchobatidae	*Bathyraja maccaini*	Springer, 1971	MacCain's skate	MCS	Non-QMS	NT			Southern Ocean	
Batoid	Arhynchobatidae	*Bathyraja pacifica*	Last, Stewart & Seret, 2016	Pacific blond skate		Non-QMS	LC	NOT	DP	NZ EEZ	
Batoid	Arhynchobatidae	*Bathyraja richardsoni*	(Garrick, 1961)	Richardon's skate	RIS	Non-QMS	LC	NOT	DP	NZ EEZ	
Batoid	Arhynchobatidae	*Bathyraja shuntovi*	Dolganov, 1985	Longnose deepsea skate	PSK	Non-QMS	DD	NOT		NZ EEZ	
Batoid	Arhynchobatidae	*Bathyraja* sp.		Antarctic dwarf skate	BHY	Non-QMS				NZ EEZ	
Batoid	Arhynchobatidae	*Brochiraja albilabiata*	Last & McEachran, 2006	Whitemouth skate		Non-QMS	DD	DD		NZ EEZ	
Batoid	Arhynchobatidae	*Brochiraja asperula*	(Garrick & Paul, 1974)	Smooth deepsea skate	BTA	Non-QMS	DD	DD		NZ EEZ	
Batoid	Arhynchobatidae	*Brochiraja heuresa*	Last & Seret, 2012	Eureka skate		Non-QMS	DD	DD		NZ EEZ	
Batoid	Arhynchobatidae	*Brochiraja leviveneta*	Last & McEachran, 2006	Blue skate	BRL	Non-QMS	DD	DD		NZ EEZ	
Batoid	Arhynchobatidae	*Brochiraja microspinifera*	Last & McEachran, 2006	Dwarf skate	BMI	Non-QMS	DD	DD		NZ EEZ	
Batoid	Arhynchobatidae	*Brochiraja spinifera*	(Garrick & Paul, 1974)	Prickly deepsea skate	BTS	Non-QMS	DD	DD		NZ EEZ	
Batoid	Arhynchobatidae	*Brochiraja vittacauda*	Last & Seret, 2012	Ribbontail skate		Non-QMS	DD	DD		NZ EEZ	
Batoid	Arhynchobatidae	*Notoraja alisae*	Seret & Last, 2012	Velcro skate	NAL	Non-QMS	LC	DD		NZ EEZ	
Batoid	Arhynchobatidae	*Notoraja sapphira*	Seret & Last, 2009	Sapphire skate		Non-QMS	DD	DD		NZ EEZ	
Batoid	Rajidae	*Amblyraja georgiana*	(Norman, 1938)	Antarctic starry skate	SRR	Non-QMS	DD			Southern Ocean	
Batoid	Rajidae	*Amblyraja hyperborea*	(Collett, 1879)	Deepwater spiny skate	DSK	Non-QMS	LC	NOT		NZ EEZ	
Batoid	Rajidae	*Dipturus innominatus*	(Garrick & Paul, 1974)	Smooth skate	SSK	QMS	LC	NOT	CD	NZ EEZ	
Batoid	Rajidae	*Zearaja nasutus*	(Müller & Henle, 1841)	Rough skate	RSK	QMS	LC	NOT	CD	NZ EEZ	Now *Dipturus nasutus*

Group	Family	Species	Authority	Common name	Code	Management class	IUCN Red List class	DoC Threat class	DoC qualifer	Location	Notes
Batoid	Dasyatidae	*Bathytoshia brevicaudata*	(Hutton, 1875)	Shorttail stingray	BRA	Non-QMS	LC	NOT	SO	NZ EEZ	
Batoid	Dasyatidae	*Bathytoshia lata*	(Garman, 1880)	Longtail stingray	WRA	Non-QMS	LC	NOT	SO	NZ EEZ	
Batoid	Dasyatidae	*Pteroplatytrygon violacea*	(Bonaparte, 1832)	Pelagic stingray	DAS	Non-QMS	LC	NOT	SO	NZ EEZ	
Batoid	Myliobatidae	*Myliobatis tenuicaudatus*	Hector, 1877	Eagle ray	EGR	Non-QMS	LC	NOT	DP,SO	NZ EEZ	
Batoid	Mobulidae	*Mobula birostris*	(Walbaum, 1792)	Manta ray	RMB	Protected	VU	DD	TO	NZ EEZ	
Batoid	Mobulidae	*Mobula mobular*	(Bonnaterre, 1788)	Spinetail devil ray	MJA	Protected	EN	DD	SO	NZ EEZ	

Appendix 19.8.2: Indicative information on status of stocks for the eleven shark species subject to the QMS.

Species name	Plenary stock	Last assessment date	At or above target levels?	Below the soft limit?	Below the hard limit?	Overfishing?	Corrective management action
Blue shark*	BWS1	2014					-
Elephant fish	ELE2	-					-
Elephant fish	ELE3	2016	●	●●	●●●	■	May be considered for review in 2020
Elephant fish	ELE5	2017	●	●●	●●●	■	-
Elephant fish	ELE7	2019	●	●●	●●●	■	TAC set in 2019
Ghost shark - dark	GSH1, GSH2, GSH7, GSH8	-					-
Ghost shark - dark	GSH3	-					-
Ghost shark - dark	GSH4, GSH5, GSH6	-					-
Ghost shark - pale	GSP1, GSP5	2011		●●	●●●		-
Ghost shark - pale	GSP7	-					-
Hammerhead sharks (smooth)	HHS1	-					-
Mako shark*	MAK1	2014					TAC reduced in 2012
Porbeagle shark*	POS1	2017				●●●●	TAC reduced in 2012
Rig	SPO1, SPO8	2019					-
Rig	SPO2	2019	●●	●●	●●●	●●	-
Rig	SPO3	2019	●	●●●	●●●	■	-
Rig	SPO7	2019	●●	●●●	●●●	●●	-
School shark	SCHN/1E, SCH7, SCH8, SCH1W	2018	●	●●	●●●	■	-
School shark	SCH2/3N, SCH4	2018					-
School shark	SCH3S/5	2018	■■	●●	●●●	■■	-
Skate - rough	RSK1, RSK3, RSK7, RSK8	2007					-
Skate - smooth	SSK1, SSK3, SSK7, SSK8	2007					-
Spiny dogfish	SPD1, SPD3, SPD7, SPD8	-					-
Spiny dogfish	SPD4, SPD5	-					-

***** denotes Highly Migratory Species, for which stock status cannot be determined for the portion of the stock found within New Zealand waters.

NOTES

At or above target levels? The 'at or above target levels' indicator describes the present status of the stock relative to its target (usually B_{MSY}, the average biomass associated with a maximum sustainable yield (MSY) strategy, or F_{MSY}, the associated fishing mortality, or appropriate surrogates or proxies for these metrics, or alternative reference points that will result in higher average biomass – see Maximum Sustainable Yield Harvest Strategies for definitions and explanations of these terms).

Below the soft limit? Below the hard limit? Overfishing? In April 2009, the Ministry's Stock Assessment Methods Working Group adopted a probabilistic scale for categorising the 'at or above target levels', 'below the soft limit', 'below the hard limit' and 'overfishing' indicators (based on the scale developed by the Intergovernmental Panel on Climate Change (IPCC) in 2007). While these probability categories are best applied in situations where models give appropriate quantitative outputs, they can also be used subjectively, based on expert opinion, when such model outputs are not available, or are highly uncertain.

The stock status table uses the IPCC criteria, coded according to the following key:

At or above target levels?	Probability	Description	Below the soft limit? Below the hard limit? Overfishing?
●●●●	> 99 %	Virtually Certain	■■■■
●●●	> 90 %	Very Likely	■■■
●●	> 60 %	Likely	■■
●	40 - 60 %	About as Likely as Not	■
■■	< 40 %	Unlikely	●●
■■■	< 10 %	Very Unlikely	●●●
■■■■	< 1 %	Exceptionally Unlikely	●●●●

Note that green circles indicate a favourable status, while orange squares indicate an unfavourable status, with the number of circles or squares indicating the degree to which the status is favourable or unfavourable.

Whether or not a stock is likely to be at or above the target level, or to be below the soft or hard limits, or subject to overfishing, is based on the most recent stock assessment summarised in the Ministry's Fishery Assessment Plenary Reports. The current (2018) stock status may be better or worse than that indicated by the most recent stock assessment. Where several alternative assessment runs are reported (as is frequently the case), or if the assessment results are contentions, the result reported represents the best judgement on the part of the Chair of the appropriate Fisheries Assessment Working Group, and the Ministry's Principal Advisor Fisheries Science.

Corrective management action: This column describes corrective management action underway for those stocks believed to be below the target level, or the soft or hard limits, or subject to overfishing.

Grey shading indicates that stock status is unknown, because an appropriate quantitative analysis to ascertain stock status relative to a target or limit has not been undertaken, or because such an analysis was not definitive, generally because of insufficient or inadequate data.

Source: based on the Status of the Stocks 2017 data published by the Ministry for Primary Industries on its website (https://www.mpi.govt.nz/growing-and-harvesting/fisheries/fisheries-management/fish-stock-status/).

Appendix 19.8.3: QMS chondrichthyan risk assessment results from Ford et al. (2018). [Continued on next pages]

QMS species risk scores. For the COMPONENTS OF RISK higher numbers indicate greater intensity or consequence of impact (for more details see Table 3 and Table 4). For RISK longer bars and larger numbers indicate higher risk, and for CONFIDENCE more ticks indicate higher confidence in the data, or greater consensus (Two ticks in the consensus column indicate full consensus). Where species scored identical risk scores they are presented in descending order of consequences and then alphabetically

QMS SPECIES RISK

COMPONENTS OF RISK		RISK	CONFIDENCE	
Intensity	Consequence		Data	Consensus
6	3	18 - Dark ghost shark	✓✓	✓✓
6	3	18 - Elephantfish	✓✓✓	✓✓
6	3	18 - Rig	✓✓✓	✓✓
6	3	18 - Rough skate	✓✓✓	✓✓
6	3	18 - School shark	✓✓✓	✓✓
6	3	18 - Spiny dogfish	✓✓✓	✓✓
5	3.5	17.5 - Smooth skate	✓✓	✓✓
5	3	15 - Mako shark	✓✓✓	✓
5	3	15 - Pale Ghost Shark	✓✓	✓
5	3	15 - Porbeagle shark	✓✓✓	✓
4	3	12 - Blue shark	✓✓✓	✓✓

Protected Species Risk scores. For the COMPONENTS OF RISK higher numbers indicate greater intensity or consequence of impact (for more details see Table 3 and Table 4). For RISK longer bars and larger numbers indicate higher risk, and for CONFIDENCE more ticks indicate higher confidence in the data, or greater consensus and a cross indicates a lack of consensus (Two ticks in the consensus column indicate full consensus). Where species scored identical risk scores they are presented so that higher consequences are reported first and then taxa are in alphabetical order. Taxa that scored less than three for consequence were not scored further, see Section 2.3 for more details. See Ford et al. (2015) for available data on shark species not listed in the table above.

PROTECTED SPECIES RISK

COMPONENTS OF RISK		RISK	CONFIDENCE	
Intensity	Consequence		Data	Consensus
3	4.5	13.5 – Basking shark	✓✓	✓
3	4.5	13.5 – Spinetail devil ray	✓	✓
3	4	12 – Great white shark	✓✓	✓

Non-QMS Species Risk scores. For the COMPONENTS OF RISK higher numbers indicate greater intensity or consequence of impact (for more details see Table 3 and Table 4). For RISK longer bars and larger numbers indicate higher risk, and for CONFIDENCE more ticks indicate higher confidence in the data, or greater consensus (Two ticks in the consensus column indicate full consensus). Where taxa risk scores were identical they are presented so that higher consequences are reported first and then in alphabetical order. Taxa that scored less than three for consequence were not scored further, see Section 2.3 for more details. See Ford et al. (2015) for available data on shark species not listed in the table above.

NON-QMS SPECIES RISK

COMPONENTS OF RISK		RISK	CONFIDENCE	
Intensity	Consequence		Data	Consensus
5	4.5	22.5 – Plunket's shark	✓✓	✓
5	4	20 - Baxters dogfish	✓✓	✓✓
5	4	20 - Seal shark	✓✓	✓✓
5	4	20 - Shovelnose dogfish	✓✓	✓
5	4	20 - Thresher shark	✓✓	✓✓
4	4.5	18 - Leafscale gulper shark	✓✓	✓
4.5	4	18 - Longnose velvet dogfish	✓✓	✓✓
6	3	18 - Carpet Shark	✓✓	✓✓
5	3.5	17.5 - Longtail stingray	✓	✓✓
5	3.5	17.5 - Shorttail stingray	✓	✓✓
4	4	16 - Owston's dogfish	✓✓	✓
3.5	4.5	15.75 - Dawsons catshark	✓✓	✓
4.5	3.5	15.75 - Longnose spookfish	✓	✓
5	3	15 - Electric ray	✓✓	✓
3.5	4	14 - Bronze whaler	✓✓	✓
3.5	4	14 - Prickly dogfish	✓✓	✓
4	3.5	14 - Northern spiny dogfish	✓✓	✓
3.5	3.5	12.25 - Prickly deepsea skate	✓✓	✓
3.5	3.5	12.25 - Smooth deepsea skate	✓✓	✓
3	4	12 - *Brochiraja* complex	✓	✓
3	4	12 - Brown chimaera	✓	✓✓
3	4	12 - Catsharks	✓	✓
3	4	12 - Deepwater spiny skate	✓	✓
3	4	12 - Longnose deepsea skate	✓	✓
3	4	12 - Longtail skate	✓	✓
3	4	12 - Lucifer dogfish	✓✓	✓
3	4	12 - Pacific spookfish	✓	✓✓
3	4	12 - Pelagic stingray	✓	✓
3	4	12 - Portugese dogfish	✓✓	✓
3	4	12 - Slender smooth hound	✓	✓
4	3	12 - Hammerhead shark	✓✓	✓
4	3	12 - Blind electric ray	✓✓	✓
4	3	12 - Broadnose sevengill shark	✓✓	✓
4	2.5	10 – Eagle ray	✓✓	✓
3	3	9 – Sharpnose sevengill shark	✓✓	✓
3	2	6 – Sixgill shark	✓✓	✓

Appendix 19.8.3 [Continued]:

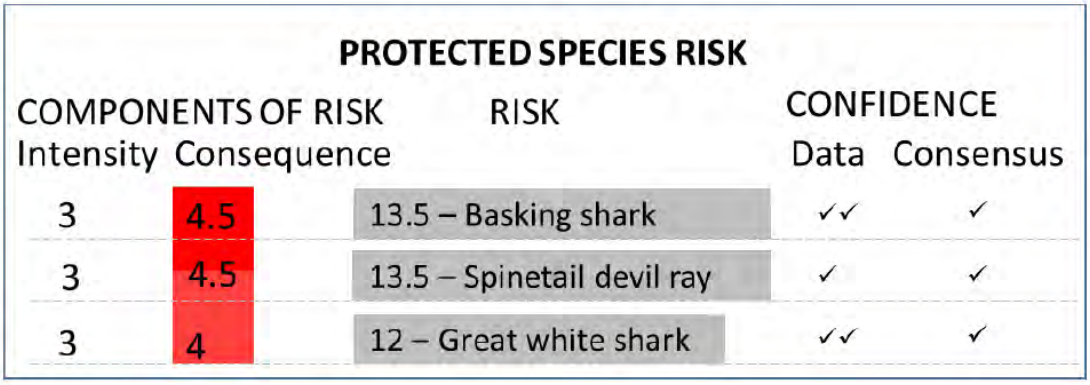


Figure 7: Protected Species Risk scores. For the COMPONENTS OF RISK higher numbers indicate greater intensity or consequence of impact (for more details see Table 3 and Table 4). For RISK longer bars and larger numbers indicate higher risk, and for CONFIDENCE more ticks indicate higher confidence in the data, or greater consensus and a cross indicates a lack of consensus (Two ticks in the consensus column indicate full consensus). Where species scored identical risk scores they are presented so that higher consequences are reported first and then taxa are in alphabetical order. Taxa that scored less than three for consequence were not scored further, see Section 2.3 for more details. See Ford et al. (2015) for available data on shark species not listed in the table above.