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Tini a Tangaroa

An update of the stock assessment of snapper in SNA 7

New Zealand Fisheries Assessment Report 2020/09

A.D. Langley

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EXECUTIVE SUMMARY

Langley, A.D. (2020). An update of the stock assessment of snapper in SNA 7.

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The commercial snapper (*Pagrus auratus*) fishery in SNA 7 is dominated by the inshore bottom trawl fishery operating in Tasman Bay and Golden Bay (TBGB) during October–April. Snapper is predominantly caught by targeted trawling and by trawls targeting flatfish species and/or red gurnard (*Chelidonichthys kumu*). Annual commercial catches have been at about the level of the Total Allowable Commercial Catch of 200 t during 2002/03–2015/16, increasing to 250 t, following an increase in TACC, in 2016/17.

Annual CPUE indices for snapper in the SNA 7 TBGB trawl fishery were updated in 2019. The CPUE indices were relatively constant during 1989/90 to 2010/11, increased substantially in 2011/12, and remained at the higher level during the subsequent years (to 2018/19).

A stock assessment for SNA 7 was conducted in 2018 using a statistical age-structured population model integrating annual catch, an estimate of absolute biomass from the 1987 Tasman Bay/Golden Bay tagging programme, TBGB trawl CPUE indices, length composition data from the recreational fishery and age compositions from the commercial fishery and the *Kaharoa* trawl survey. This study updated that assessment model with additional data from the last two years. The model provides a relatively coherent integration of the main data sets, although there is some deterioration in the fit to the recent CPUE indices and recent age composition data.

Stock biomass is predicted to have declined substantially from 1950 to the mid-1980s due to high levels of catch, particularly during the late 1970s and early 1980s. The assessment estimates that stock biomass had been reduced to approximately 6% of the unexploited (SB_0) level by the mid-1980s, and the stock remained at about this level throughout the 1990s and early 2000s. Since 2009, stock biomass has increased rapidly and current (SB_{2018} or 2018/19) biomass is estimated to be at 39% of the SB_0 level.

The stock is characterised by high variability in recruitment with episodic periods of strong recruitment occurring at 7–10 year intervals. The recent increase in stock abundance is attributable to the recruitment of an exceptionally strong 2007 (2007/08) year class and a strong 2010 (2010/11) year class, mediated by the large increase in the trawl CPUE indices from 2010/11. The strong 2007 and 2010 year classes are evident in the recent age composition data from the commercial fishery and *Kaharoa* trawl survey. The most recent (2019) trawl survey sampled a strong cohort of 1 year old snapper within the shallower reaches (10–20 m) of TBGB, indicating the presence of a strong 2017 (2017/18) year class. However, the relative strength of this year class is estimated with a high level of uncertainty in the assessment model. This year class will recruit to the fishery over the next few years (from 2020/21–2021/22).

The current stock status was assessed relative to the Ministry for Primary Industries Harvest Strategy Standard. Current (2018/19) biomass is assessed to be well above the soft biomass limit (20% SB_0). There is considerable uncertainty in the magnitude of the recent increase in biomass, although the stock is estimated to be at about the interim target biomass level (40% SB_0). Two model sensitivity runs estimated a current stock status that bracketed the base model estimates; less optimistic current stock status from a model option with a lower level of natural mortality and more optimistic stock status for a model with a lower *SigmaR* for the stock-recruitment relationship. For all model options, current rates of fishing mortality are estimated to be well below the corresponding over-fishing mortality threshold ($F_{SB40\%}$).

Stock projections were conducted for a 5 year period (i.e., 2019/20–2024/25) based on status quo catch and Total Allowable Catch levels. The projections indicated that the stock would remain at about the target biomass (40% SB_0) and well above the soft limit (20% SB_0), although the projections are sensitive to the assumptions regarding the strength of recent recruitment, specifically the 2017/18 year class.

The next assessment for SNA 7 is scheduled for 2021. This assessment will incorporate updated CPUE indices and additional age composition data from the commercial catch (2019/20). The model structure will include refinement of the spatial stratification of the fishery age and CPUE indices to investigate the relatively poor fit to the recent age composition data sets and standardised CPUE.

1 INTRODUCTION

The commercial snapper (*Pagrus auratus*) fishery in SNA 7 is dominated by the inshore bottom trawl fishery operating in Tasman Bay and Golden Bay (TBGB) during October–April (Langley 2018). Snapper is predominantly caught by targeted trawling and by trawls targeting flatfish species and/or red gurnard (*Chelidonichthys kumu*). Annual CPUE indices of abundance for snapper in SNA 7 have been derived from the catch and effort data from the main TBGB trawl fishery (Hartill & Sutton 2011, Langley 2013, 2015a, 2018).

The first accepted stock assessment of snapper in SNA 7 was completed in 2015, following preliminary assessments by Harley & Gilbert (2000) and Gilbert & Phillips (2003). The 2015 assessment was conducted using a statistical age-structured population model integrating annual catch, an estimate of absolute biomass from the 1987 TBGB tagging programme, recent trawl CPUE indices, and commercial age and size composition data (Langley 2015).

Following the 2015 assessment, the Total Allowable Commercial Catch (TACC) for SNA 7 was increased from 200 to 250 t for the 2016/17 fishing year. Further monitoring of the age composition of the commercial catch was conducted in 2016/17 to determine the relative strength of recent recruitment to the fishery (Parsons et al. 2018). These data were incorporated in an update of the SNA 7 stock assessment model in 2018 (Langley 2018).

The 2018 assessment estimated that stock biomass declined substantially from 1950 to the mid-1980s due to high levels of catch, particularly during the late 1970s and early 1980s. Stock biomass was estimated to be approximately 7% of the unexploited (SB_0) level in the mid-1980s and the stock remained at about that level throughout the 1990s and 2000s. From 2009, stock biomass increased rapidly and recent (SB_{2016}) biomass was estimated to be at 39% of the SB_0 level. The recent increase in stock abundance was largely attributable to the recruitment of an exceptionally strong (2007) year class (Langley 2018).

This report presents a further update of the SNA 7 stock assessment incorporating data to the end of the 2018/19 fishing year. Additional data included in the model were: two additional years of catch, two additional years of standardised CPUE indices and age structure from the 2019 TBGB trawl survey. The study was funded by the Southern Inshore Fisheries Management Company.

2 FISHERY CHARACTERISATION

Trends in catch and effort from the SNA7 fishery have been described in previous reports (Hartill & Sutton 2011, Langley 2013, 2015a, 2018). This section updates previous analyses to include data to the 2018/19 fishing year.

Commercial catch and effort data from the snapper fishery were sourced from the Fisheries New Zealand combined *warehou* and EDW databases. The scope of the study encompassed the SNA 7 fishstock area and the data extract included the catch and effort data from any fishing trip that recorded a catch of snapper from the fishstock. The extract was supplemented by data from any additional fishing trips that conducted fishing within the Statistical Areas that comprise SNA 7 (Statistical Areas 017 and 033–039) and targeted the range of inshore species that are caught in association with snapper (i.e., snapper, flatfish species, red cod (*Pseudophycis bachus*), red gurnard, and John dory (*Zeus faber*)).

For the qualifying trips, all effort data records were sourced, regardless of whether or not snapper was landed. The estimated catches and landed catch records of all finfish species were also sourced for the qualifying fishing trips. Data were complete to the end of June of the 2018/19 fishing year. Catches of snapper during July–September represent a small proportion of the total annual catch from SNA 7 (Langley 2013, 2015a). This period is also not included in the data set compiled for the determination of the CPUE indices (October–April). Therefore, it was not considered necessary to delay the analysis until a complete set of catch and effort data was available from 2018/19 fishing year.

From 1989/90, most inshore fishing vessels reported catch and effort data via the Catch Effort Landing Return (CELR) which records aggregated fishing effort and the estimated catch of the top five species. Fishing effort and catch was required to be recorded for each target species and Statistical Area fished during each day, although typically catch and effort data were aggregated by fishing day (Langley 2014). The verified landed green weight that is obtained at the end of the trip was recorded on the Landings section of the CELR form.

In 2007/08, the Trawl Catch and Effort Return (TCER) was introduced specifically for the inshore trawl fisheries and was adopted by most of the inshore trawl vessels within the SNA 7 fishery. The TCER form records detailed fishing activity, including trawl start location and depth, and associated catches from individual trawls. Landed catches associated with trips reported on TCER forms are reported at the end of a trip on the Catch Landing Return (CLR).

Over recent years, Electronic Reporting Systems (ERS) have been introduced for the trawl fleet. Initially, ERS was introduced on the large trawl vessels operating in the offshore fisheries, and relatively small catches from SNA 7 were reported from these vessels from early 2018. From mid-2019, ERS was implemented in the inshore trawl fleet within SNA 7, replacing the TCER statutory reporting form. The catch and effort data set included in the current analysis includes a small number of ERS records from the inshore trawl fishery within SNA 7 (from May–June 2019).

The catch and effort data sets were processed following the methodology described in Langley (2017). Two data sets were configured:

1) **Daily** aggregated catch and effort data set from 1989/90–2018/19.
   Snapper catch and effort data were aggregated by vessel fishing day and fishing method to approximate the CELR data format. The predominant Statistical Area and target species recorded during the fishing day were assigned to the Daily aggregate record. For each trip, the landed catch of snapper was apportioned amongst the daily fishing records in proportion to the estimated catches of snapper (when included within the five main species caught in the day). Snapper landed catches from trips without corresponding estimated catches were distributed amongst daily records in proportion to fishing effort (number of trawls).
2) **Trawl-**based catch and effort data set from 2007/08–2018/19.
   TCER and ERS format catch and effort records. For each trip, the landed catch of snapper was apportioned amongst the individual trawl records in proportion to the estimated catches of snapper. Snapper landed catches from trips without corresponding estimated catches were distributed equally amongst trawl records.

Total annual catches from SNA 7 under the Quota Management System (QMS) are compiled from Monthly Harvest Returns (MHR) submitted by fishing permit holders (Fisheries New Zealand 2019). The total annual estimated and landed catches included in the SNA 7 catch and effort data sets approximated the QMS annual catches (Figure 1).

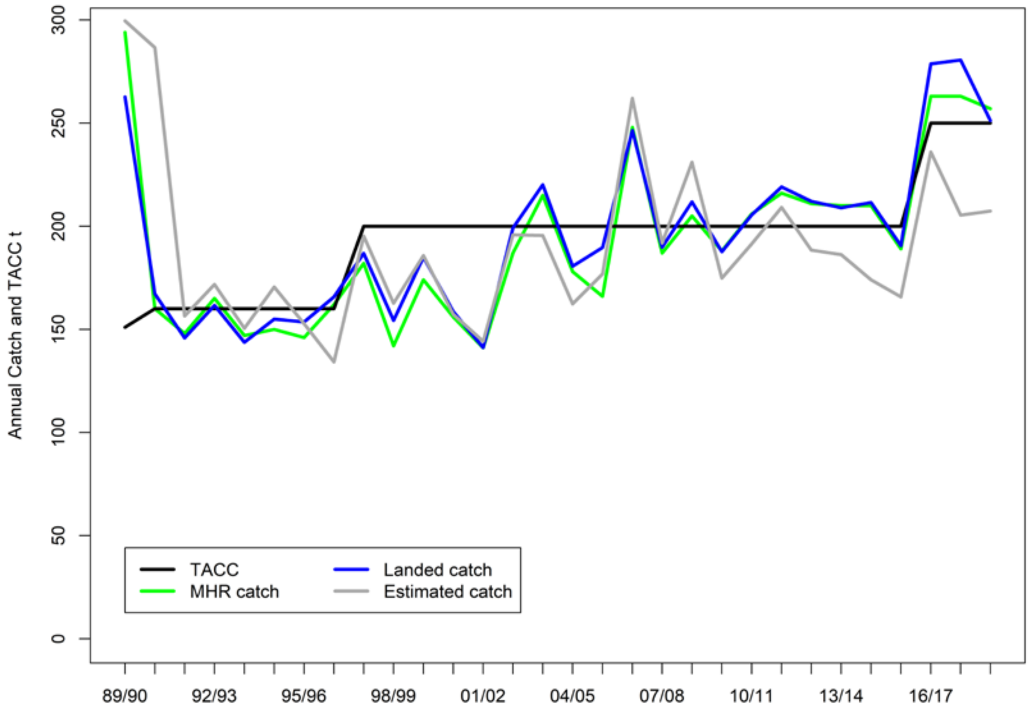

Figure 1: A comparison of total annual SNA 7 estimated and landed catches (t) by fishing year from the catch and effort returns and the total reported landings (t) to the QMS (MHR). Note: the estimated and landed catches are incomplete for the 2018/19 fishing year.

The Daily catch and effort data set was used to characterise the main trends in the catch from SNA 7 during 1989/90–2018/19. A more detailed characterisation of the SNA 7 fishery is available in Langley (2018). Annual catches were dominated by the pair bottom trawls (BPT) targeting snapper and by the single bottom trawls (BT) targeting snapper and other inshore finfish species, primarily flatfish and, to a lesser extent, red gurnard and tarakihi (*Nemadactylus macropterus*) (Figure 2). The pair trawl fishery ceased operation in 2011/12. From 2012/13, there was an increase in the proportion of the snapper catch taken by trawls targeting flatfish and red gurnard (Figure 2).

The annual SNA 7 catch was predominantly (65–80%) taken within TBGB (Statistical Area 038) with most of the remainder (25–30%) from off the northern west coast of the South Island (WCSI) (Statistical Areas 035–037) (Figure 3).

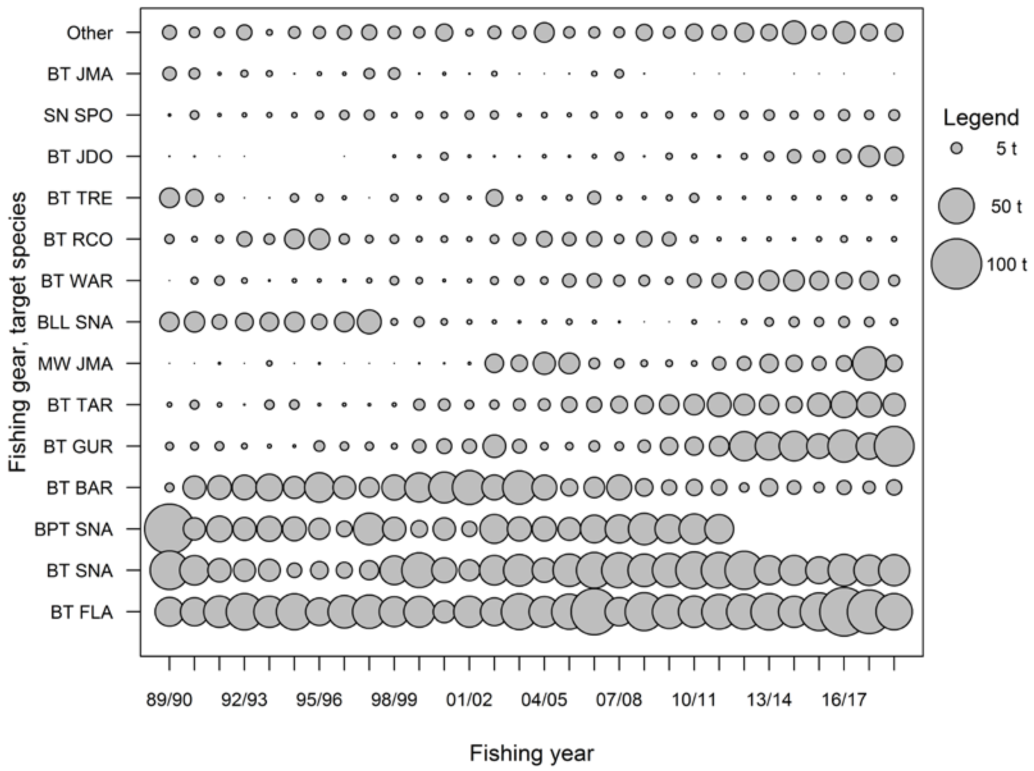

Figure 2: Landed catch of snapper by fishing method/target species and fishing year. Note: the landed catches are incomplete for the 2018/19 fishing year. BLL is bottom longline, BPT is bottom pair trawl, BT is bottom trawl, and MW is midwater. Target species codes: BAR is barracouta, FLA is flatfish species, GUR is red gurnard, JDO is John dory, JMA is jack mackerels, RCO is red cod, SPO is rig, TAR is tarakihi, TRE is trevally, WAR is blue warehou.

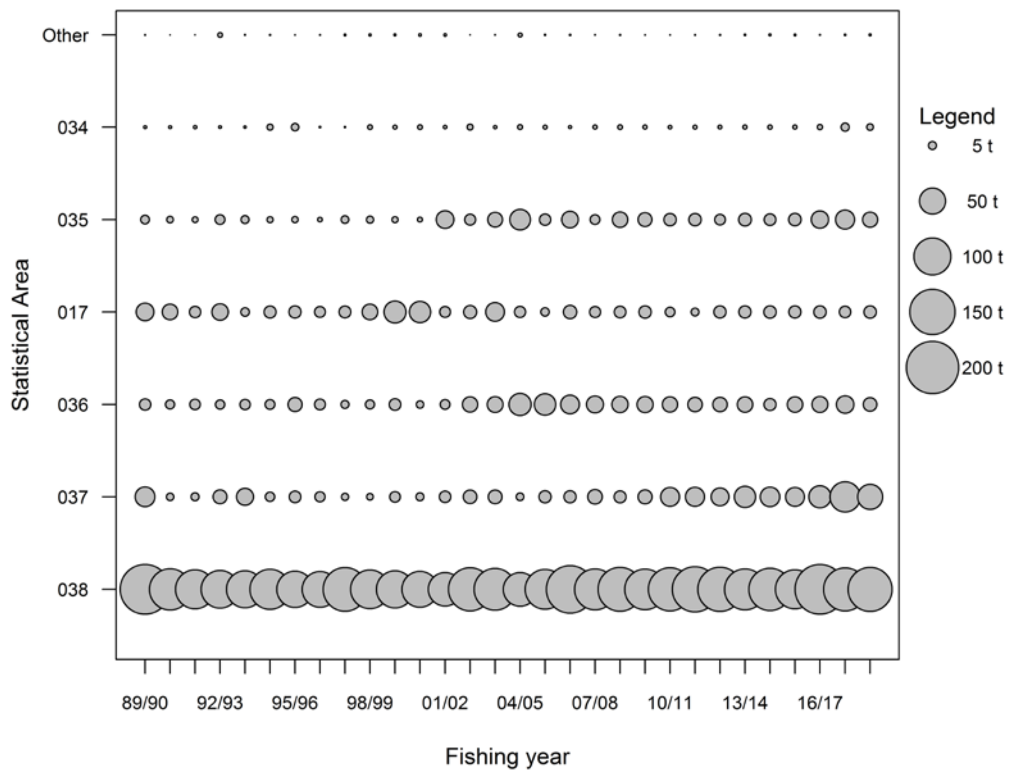

Figure 3: Landed catch of snapper by Statistical Area and fishing year. Note: the landed catches are incomplete for the 2018/19 fishing year.

Most of the snapper catch was taken during October–January with the highest monthly catches taken in November during 2006/07–2012/13 (Figure 4). From 2013/14, catches were more evenly distributed throughout October–April. Catches were relatively small during June–September.

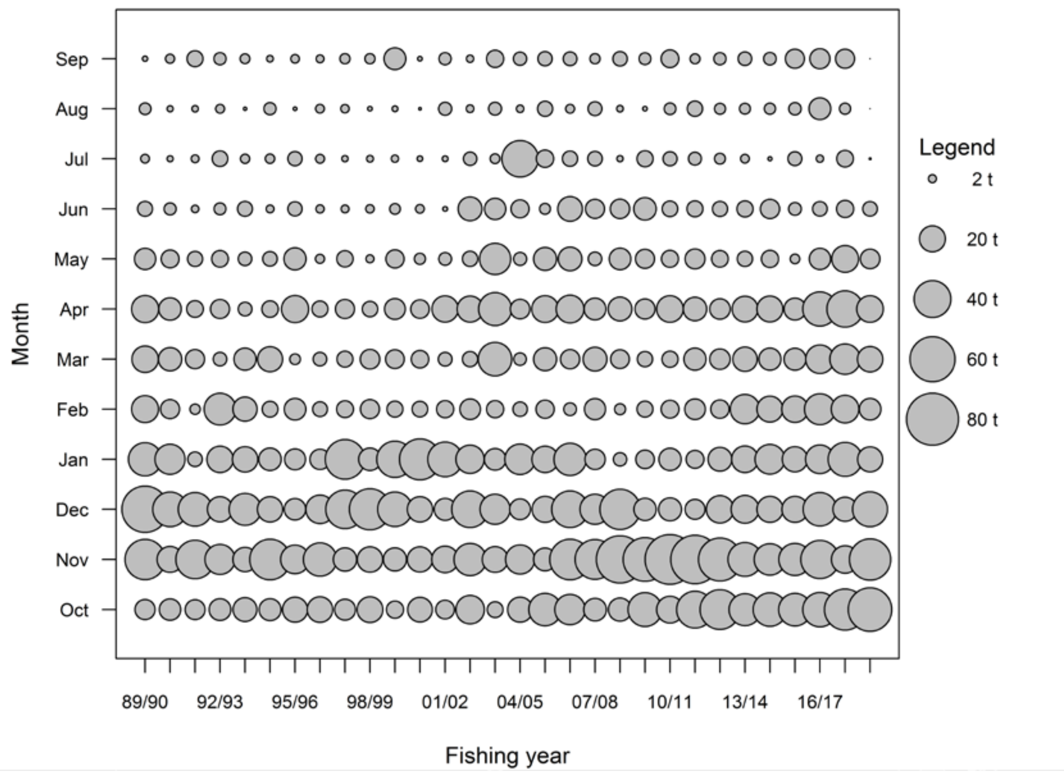

Figure 4: Landed catch of snapper by month and fishing year. Note: the landed catches are incomplete for the 2018/19 fishing year.

3 CPUE ANALYSIS

Standardised CPUE analyses were conducted for the TBGB single trawl fishery, updating the previous study (Langley 2018) to extend the time-series of CPUE indices to the 2018/19 fishing year, i.e., adding two years. The modelling approach was equivalent to the previous study. The primary CPUE analysis was based on the Daily aggregated data set. An additional analysis was conducted using the Trawl-based catch and effort data (TCER format) to investigate the potential influence of changes in the spatial distribution (location and depth) of the fishery during the period 2007/08–2018/19.

The CPUE data sets were selected to represent the main SNA 7 trawl fishery; i.e., single bottom trawl fishing method in Statistical Area 038 during October–April, targeting snapper, flatfish, red gurnard, and/or barracouta (*Thyrsites atun*). Each CPUE data set was further limited to a set of (core) vessels based on the continuity criteria of a minimum of 10 days fishing per year for at least five years.

A Generalised Linear Modelling (GLM) approach was used to separately model the occurrence of snapper catches (presence/absence) and the magnitude of positive snapper catches. The dependent variable of the catch magnitude CPUE models was the natural logarithm of catch. The positive catch CPUE models assumed a lognormal error structure. The presence/absence of snapper catch was modelled based on a binomial distribution.

CPUE modelling was conducted using both the Daily and Trawl (i.e., event based) data formats. The potential explanatory variables available for inclusion in the Daily CPUE models are defined in Table 1, and the Trawl event-based variables are presented in Table 2.

Table 1: The variables included in the Daily format trawl catch and effort data sets.

Variable	Definition	Data type
Vessel	Fishing vessel category	Categoric
FishingYear	Fishing year	Categoric
Month	Month	Categoric
StatArea	Statistical area for day of fishing	Categoric
TargetSpecies	Target species for day of fishing	Categoric
NumTrawl	Natural logarithm of the number of trawls conducted	
Duration	Natural logarithm of total trawl duration (hours)	Continuous
Speed	Trawl speed (kn.)	Continuous
GearWidth	Wingspread of trawl gear (m)	Continuous
GearHeight	Headline height of trawl gear (m)	Continuous
SNAcatch	SNA trawl catch (kg)	Continuous
SNAbin	Presence (1) or absence (0) of SNA catch in day	Categoric

Table 2: The variables included in the Trawl event based CPUE data sets.

Variable	Definition	Data type
Vessel	Fishing vessel category	Categoric
FishingYear	Fishing year	Categoric
Month	Month	Categoric
Loc	Start location of trawl categorised by 0.1 degree latitude/longitude cell.	Categoric
TargetSpecies	Declared target species for trawl.	Categoric
Duration	Natural logarithm of trawl duration (hours)	Continuous
Depth	Fishing depth (m)	Continuous
StartTime	Hour at the start of trawl.	Continuous
Speed	Trawl speed (knots)	Continuous
GearWidth	Wingspread of trawl gear (m)	Continuous
GearHeight	Headline height of trawl gear (m)	Continuous
SNAcatch	Scaled estimated SNA trawl catch (kg).	Continuous
SNAbin	Presence (1) or absence (0) of SNA catch in trawl	Categoric

A step-wise fitting procedure was implemented to configure each of the CPUE models. The fitting procedure considered the range of potential explanatory variables (Table 1 or Table 2) with the continuous variables typically parameterised as third order polynomial functions. Interactions between key variables (*Month:TargetSpecies* and *Month:Depth*) were also included as potential explanatory variables. The categoric variable *FishingYear* was included in the initial model and subsequent variables were included in the model based on the improvement in the AIC. Additional variables were included in the model until the improvement in the Nagelkerke pseudo-R^2 was less than 0.5%.

The influence of each of the main variables in the CPUE models was examined following the approach of Bentley et al. (2011). Annual trends in the residuals of each model were examined with respect to month, target species, and fishing vessel.

The final (combined) indices were determined from the product of the positive catch CPUE indices and the binomial indices following the approach of Stefansson (1996). A recent local study highlighted the importance of incorporating both components in the derivation of the final indices, particularly for bycatch fisheries where the reporting of smaller catches may be variable (particularly over time) (Langley 2019). The confidence intervals associated with the combined indices were determined using a bootstrapping approach.

The primary CPUE analysis was based on the Daily catch and effort data. The core fleet accounted for 88% of the snapper catch included within the defined fishery. The criteria resulted in the selection of 55 unique vessels including 11 vessels that operated in the fishery for at least 15 years (Figure 5). Approximately half of the snapper catch included in the data set was taken by 8 vessels.

The annual catch included in the Daily core vessel CPUE data set increased from the mid-2000s, whereas the proportion of effort records with no associated snapper catch declined (Figure 6, Table A1 in Appendix 1). Almost all of the snapper catch was allocated to the daily aggregated fishing effort records based on the distribution of the estimated catches within individual fishing trips (Figure 6), although prior to 2010/11 a considerable proportion (30–40% by number) of the positive catch records were allocated based on the distribution of fishing events amongst trips (i.e., those trips with no estimated catches of snapper). These records were dominated by flatfish target trawl records and the associated snapper catches were generally small (median catch of 4.3 kg). Overall, the average daily catch of snapper increased considerably between 2010/11 and 2011/12 and remained at the higher level during the subsequent years (to 2018/19) (Figure 7).

The number of trawls conducted per fishing day remained relatively stable throughout the study period, and there was an increase in the average trawl duration during the early 1990s (Figure 7). There was no appreciable change in either of the main fishing effort metrics corresponding with the introduction of the TCER reporting form in 2007/08.

Figure 5: Distribution of TBGB snapper trawl catch by year and fishing vessel. The vessels comprising the core fleet included in the final Daily CPUE data set are highlighted in red.

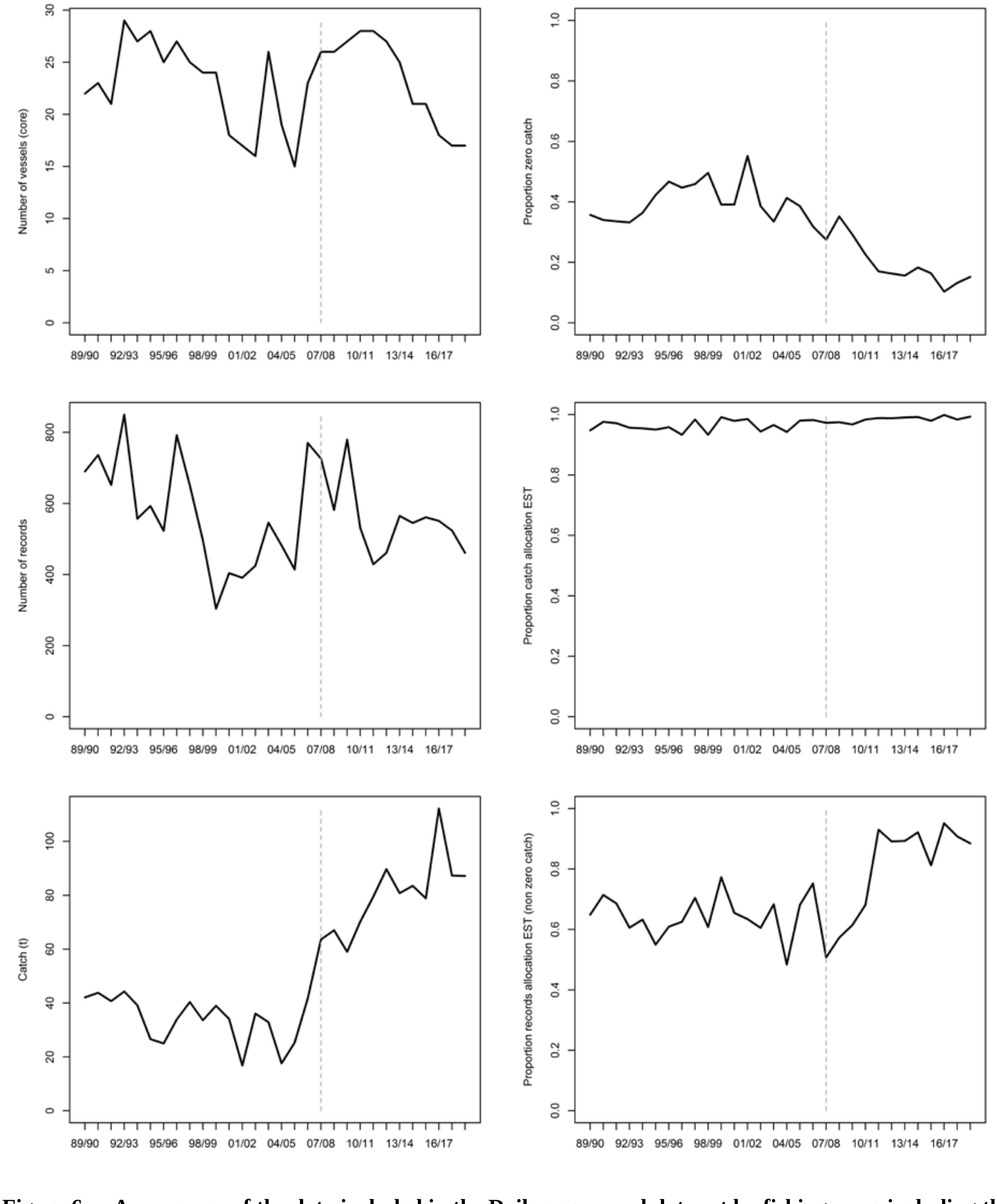

Figure 6: A summary of the data included in the Daily core vessel data set by fishing year, including the proportion of the catch and effort records with snapper catches allocated based on the distribution of estimated snapper catch (rather than fishing effort). The dashed vertical line represents the year the TCER reporting form was introduced.

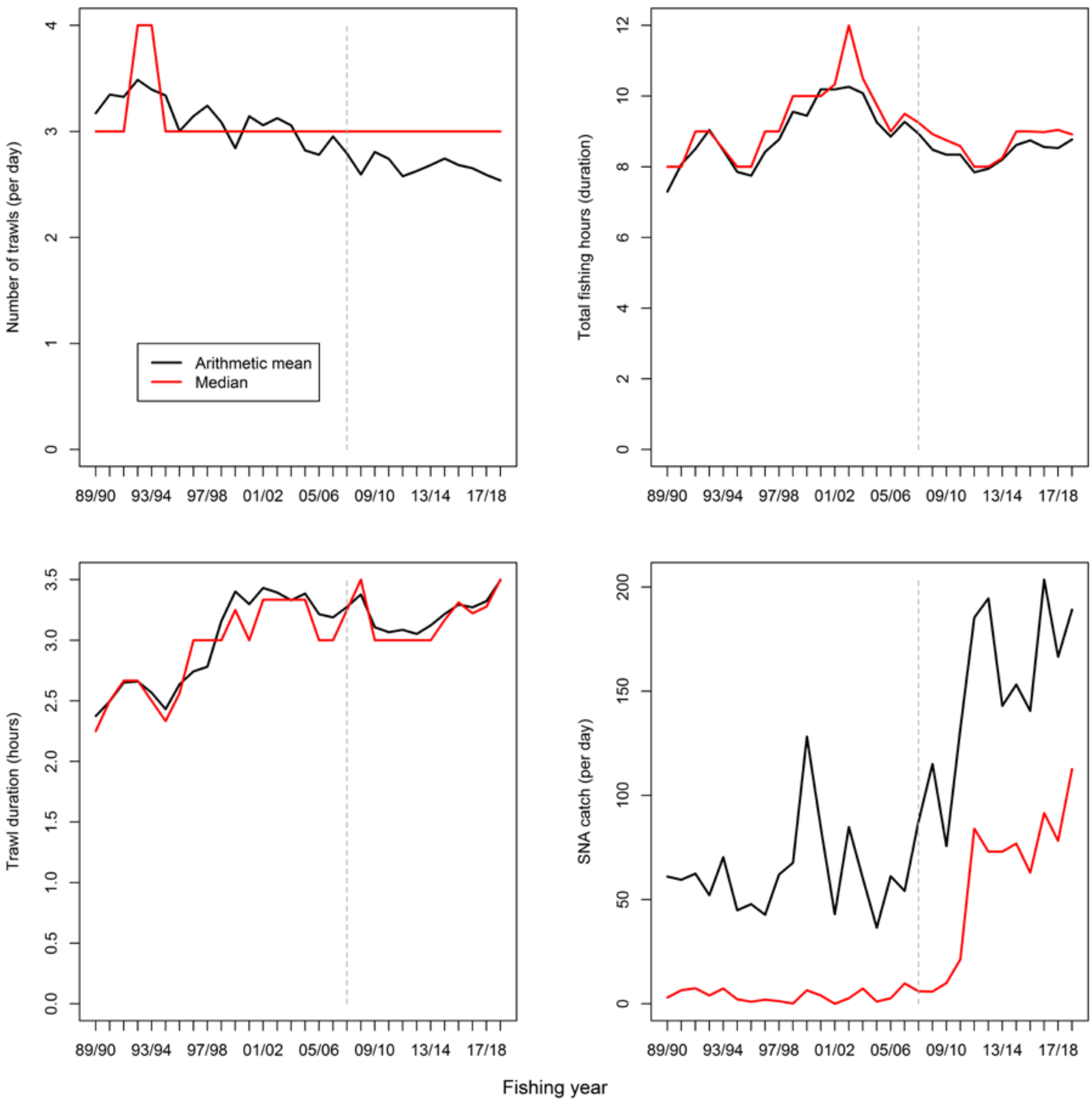

Figure 7: Annual trends in the main fishing effort and snapper catch rates (average and median) for the Daily core vessel data set. The dashed vertical line represents the year the TCER reporting form was introduced.

For the analysis of the Daily data set, the dependant variable of the positive catch CPUE model was the natural logarithm of the snapper catch. The final model included the predictor variables *FishingYear*, *Vessel*, *TargetSpecies*, natural logarithm of *Duration*, *GearHeight*, and the *Month:TargetSpecies* interaction term (Table 3). Overall, the model explained 41.6% of the variation in the positive catch of snapper (Nagelkerke pseudo-R^2), with the *FishingYear* variable accounting for 11.6% of the total variation. The distribution of the CPUE model residuals is generally consistent with the assumption of normality (Figure 8).

Table 3: Summary of stepwise selection of variables included in the snapper positive catch CPUE model for the Daily data set. Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion.

Term	DF	Log likelihood	AIC	Nagelkerke pseudo-R^2 (% Improvement)
FishingYear	29	-23,280	46,622	0.116
Vessel	54	-22,205	44,581	0.269
Month:TargetSpecies	27	-21,299	42,823	0.377
Duration	3	-20,982	42,194	0.411
GearHeight	3	-20,941	42,118	0.416

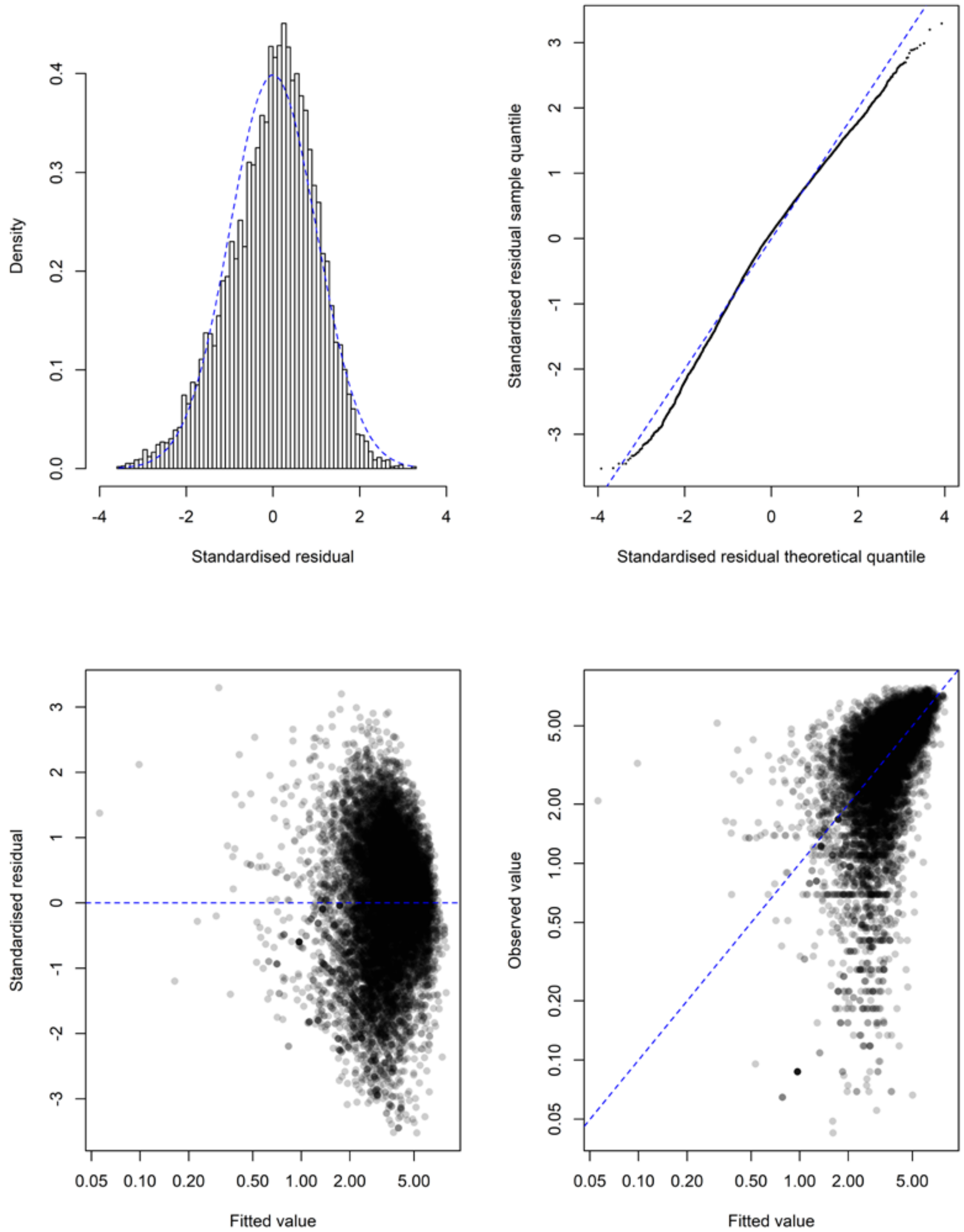

Figure 8: Residual diagnostics for the positive catch CPUE model for the Daily data set. Top left: histogram of standardised residuals compared with the standard normal distribution. Bottom left: quantile-quantile plot of standardised residuals. Top right: fitted values versus standardised residuals. Bottom right: observed values versus fitted values.

The occurrence of snapper catches in the Daily data set was predicted by the binomial model including the explanatory variables *FishingYear*, *Month:TargetSpecies* interaction, and *Vessel* (Table 4).

Table 4: Summary of stepwise selection of variables included in the snapper catch occurrence CPUE model (binomial model). Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion.

Term	DF	Log likelihood	AIC	Nagelkerke pseudo-R^2 (% Improvement)
FishingYear	29	-10,104	20,267.6	0.085
Month:TargetSpecies	27	-9,667	19,448.1	0.151
Vessel	54	-9,439	19,099.8	0.184

The lognormal CPUE indices are relatively constant during 1989/90 to 2010/11, increase considerably in 2011/12 (by 382%) and remain at the higher level during the subsequent years (Figure 9). The trend in the lognormal CPUE is comparable to the unstandardised (nominal) CPUE from the fishery, although the increase in the recent CPUE indices is more pronounced, primarily due to the inclusion of the *Vessel* and *EffortHeight* variables in the model.

From 2011/12, there was an increase in the relative proportion of fishing effort by individual vessels with a lower overall catch rate of snapper (Figure 10, Appendix 1 Figure A1). During the same period, there was an increase in the proportion of effort records from trawls with a lower headline height (*EffortHeight*) which are predicted to yield lower catch rates of snapper (Figure 10, Appendix 1 Figure A4). The influence of the main variables remained relatively constant over the last 8–10 years, with the exception of the continued decline in the *EffortHeight* variable.

An examination of the residuals from the Daily lognormal CPUE model revealed that the annual CPUE trends are generally comparable amongst the individual *Target Species*, *Month*, and the main *Vessel* categories (Appendix 1 Figures A5–A7). However, in the two most recent years the CPUE from the snapper target fishery has been lower than predicted by the CPUE model, and a number of the main vessels in the fleet also attained lower CPUE than predicted by the model.

The annual indices derived from the Daily binomial model were generally comparable to the annual proportion of positive catch records. The binomial indices declined during the 1990s and increased steadily from the early 2000s (Figure 9).

The final (combined) CPUE indices were comparable to the trend in the lognormal CPUE indices, although the increase in the indices from 2010/11 was more pronounced due to the influence of the recent binomial indices (Figure 9).

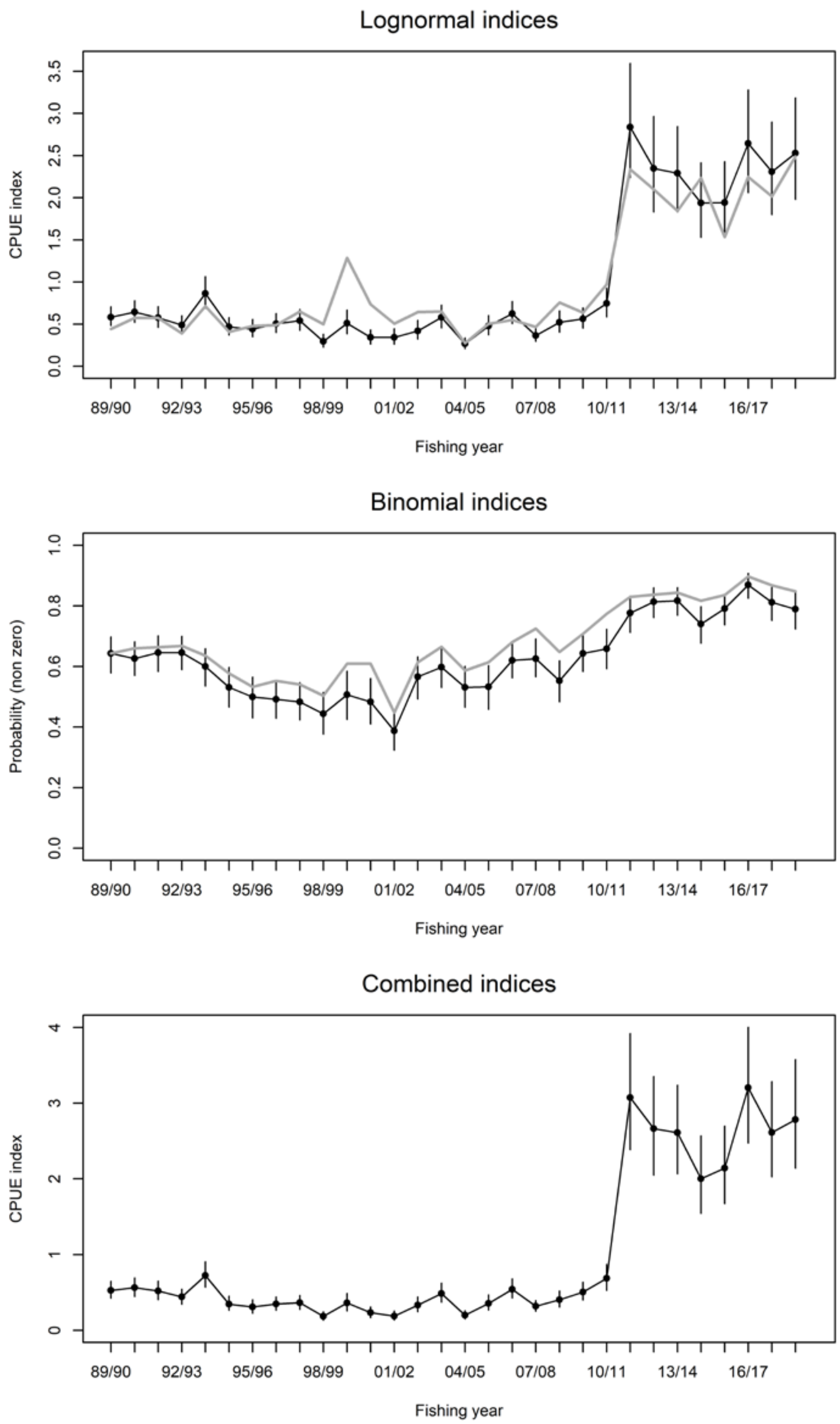

Figure 9: A comparison of the standardised Daily CPUE indices and the geometric mean of the annual catch per day (grey line) (top panel), a comparison of the binomial indices and the annual proportion of positive catch records (grey line) in the data set (middle panel), and the combined index (bottom panel) . The error bars represent the 95% confidence intervals associated with each index. The annual indices are provided in Table A2 (Appendix 1).

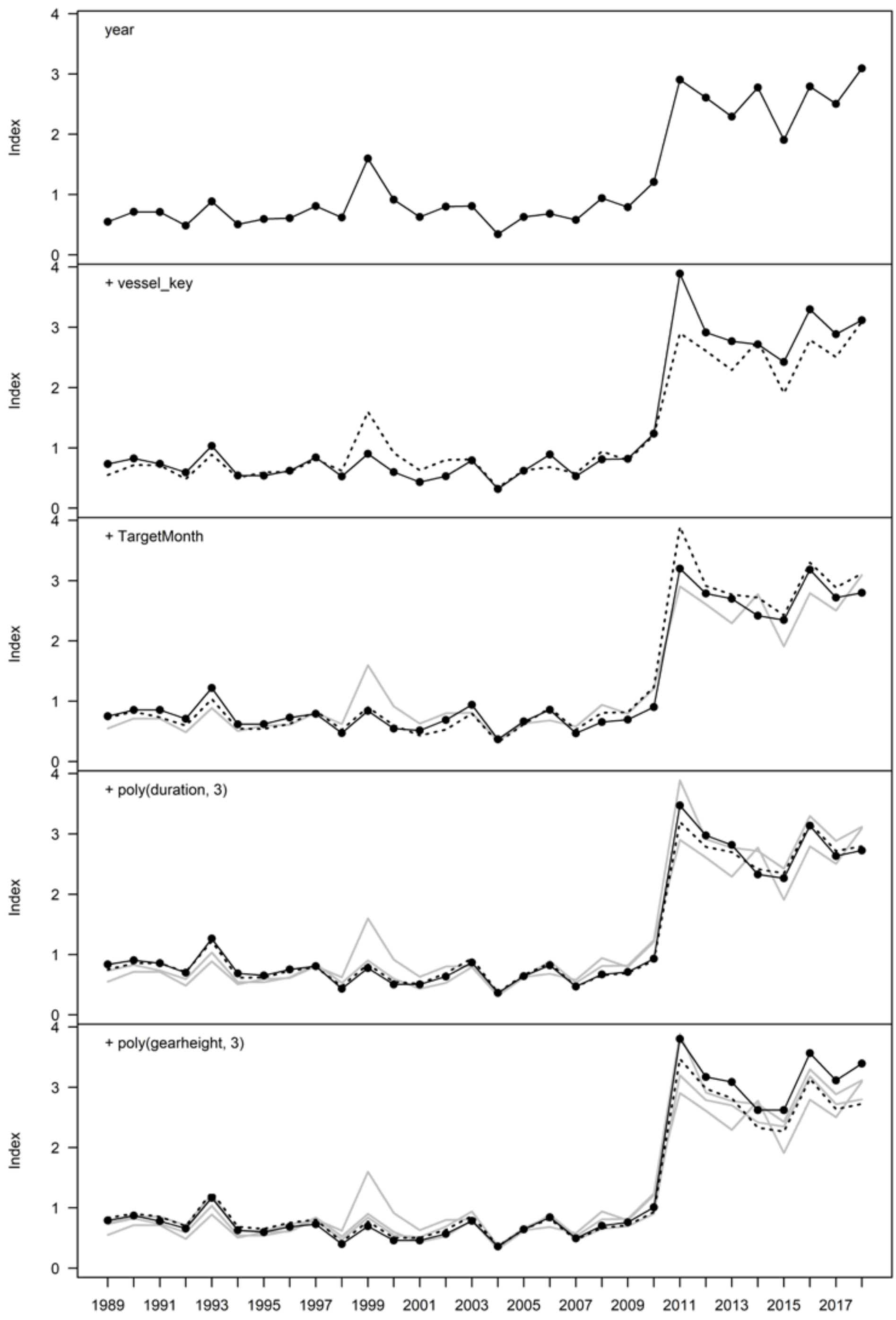

Figure 10: The change in the annual coefficients with the step-wise inclusion of each of the significant variables in the positive catch CPUE model for the Daily data set (from top to bottom panel). The solid line and points represent the annual coefficients at each stage. The fishing year is denoted by the calendar year at the beginning of the fishing year (e.g. 1989 denotes the 1989/90 fishing year).

For the Trawl event-based data set, lognormal and binomial CPUE models were derived, incorporating the potential explanatory variables included in Table 4. Both models included a similar set of predictor variables to the Daily CPUE models, specifically *FishingYear*, *Vessel*, *TargetSpecies*, natural logarithm of *Duration*, *GearHeight,* and the additional variables fishing location (*Loc*) and *Month:Depth* interaction.

The resulting combined (delta-lognormal) CPUE indices were similar to the combined Daily CPUE indices for the corresponding period (2007/08–2018/19) (Figure 11), although the magnitude of the increase in CPUE indices between 2010/11 and 2011/12 was slightly lower for the Trawl-based indices.

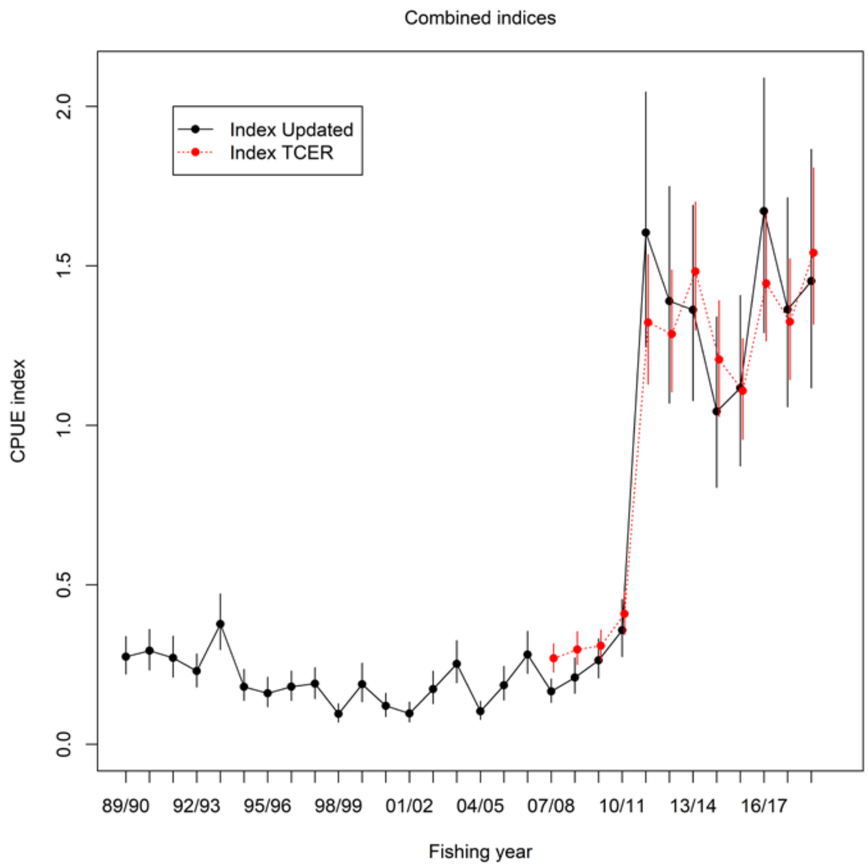

Figure 11: A comparison of the combined Daily and combined Trawl-based CPUE indices (and associated 95% confidence intervals).

The residuals from the Trawl-based lognormal CPUE indices revealed differential trends in relative CPUE amongst areas of TBGB partitioned by depth (10 m depth categories). The CPUE data set is dominated by trawls in the 10–19 m and 20–29 m depth categories and the overall CPUE indices are consistent with the trends in relative CPUE from these two areas, with the exception of a decline in CPUE in the 10–19 m category over the last two years (Figure 12). By comparison, the shallower areas (0–9 m depth) revealed a somewhat larger increase in relative CPUE during 2010/11–2011/12 and a decline in CPUE over the more recent years. In contrast, the snapper CPUE from the deepest area of TBGB remained at a lower level throughout 2007/08–2012/13 and then increased considerably during 2013/14–2016/17 (Figure 12). The relative increase in CPUE in the deeper area was greater than the increase in the overall CPUE indices, although absolute catch rates of snapper in the area remained lower than for the core area of the fishery. These results suggest a seaward expansion of the SNA 7 population as the strong year class grew older, perhaps resulting in a disproportionate increase in CPUE (relative to biomass) in water deeper than 40 m.

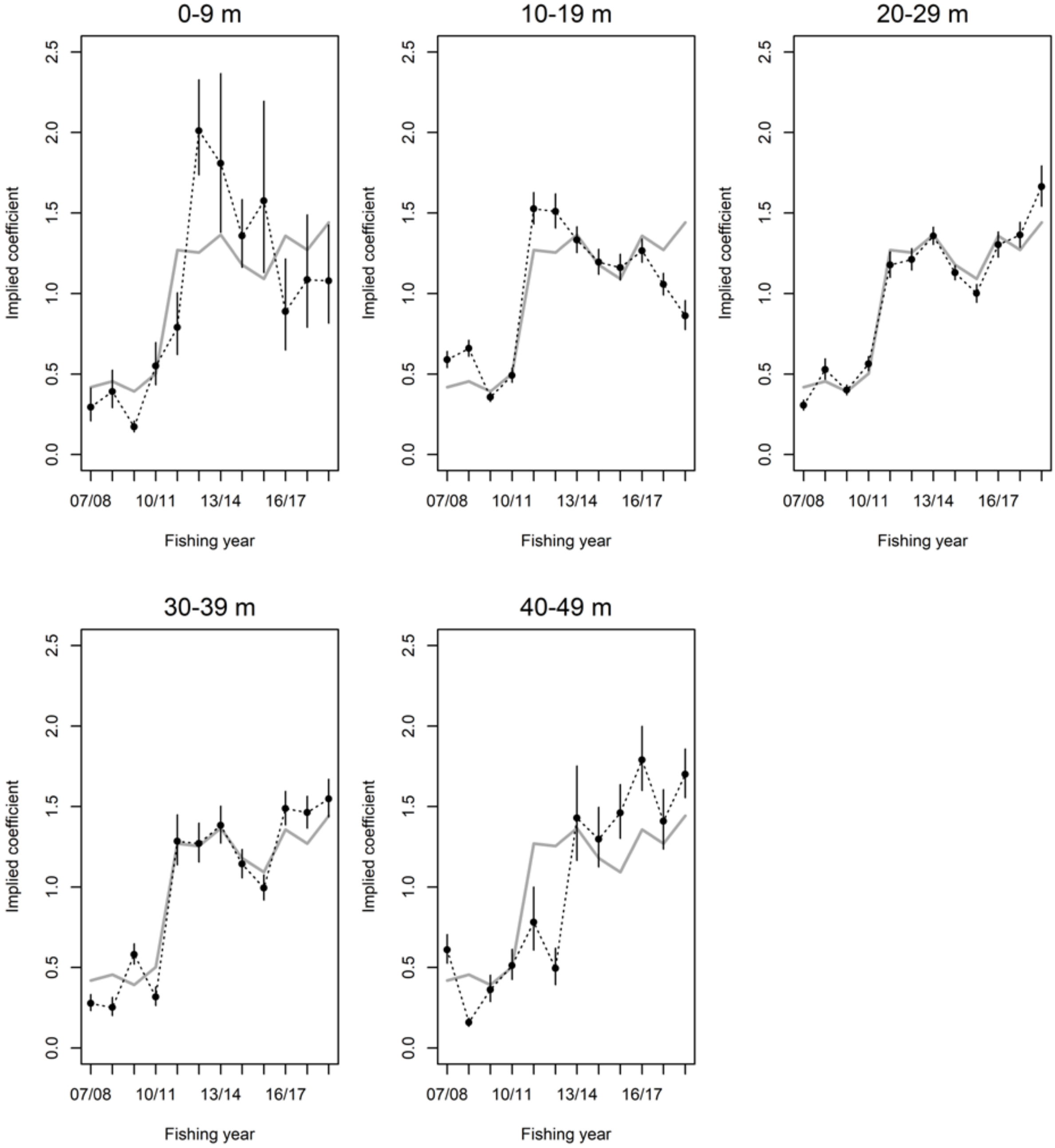

Figure 12: A comparison of the Trawl-based lognormal CPUE indices (grey line) and the annual implied coefficients for each 10 m depth category derived from the residuals of the CPUE model (points). Each series is normalised to the average of the series.

4 STOCK ASSESSMENT

The 2018 stock assessment model (Langley 2018) was updated with the inclusion of additional data from 2017/18 and 2018/19 fishing years. The assessment model integrates annual catch, an estimate of absolute biomass from the 1987 TBGB tagging programme, trawl CPUE indices, and age and length composition data from the commercial and recreational fisheries and the *Kaharoa* west coast South Island trawl surveys (core strata including Tasman Bay and Golden Bay). Additional recreational and commercial catches, CPUE indices, and the 2019 trawl survey age composition were available for inclusion in the model update. In addition, snapper length and age composition data were available from the two most recent (2017 and 2019) *Kaharoa* west coast South Island trawl surveys which were extended to include the shallower areas of Tasman Bay and Golden Bay (SNA strata). These two observations had not been included in the previous (2018) assessment model.

The Daily trawl CPUE indices represent the primary abundance index included in the model. The derivation of the CPUE series is described in the previous section (Section 3). The Daily CPUE indices represent a considerably longer time series than the Trawl-based CPUE indices, although the two sets of indices are comparable for the corresponding period. The other model data sets are described in sections 4.1–4.7.

4.1 Commercial catch

Commercial catch data are available for the SNA 7 fishery from 1931 to the 2018/19 fishing year. The time-series of annual reported commercial catches were derived from Fisheries New Zealand (2019).

The model data set was configured to include two main commercial fisheries: a single trawl fishery (BT) and a pair trawl fishery (BPT). The SNA 7 catch taken by the purse-seine method during the late 1970s and early 1980s was assigned to the pair trawl fishery, because both methods are considered to harvest the full range of adult age classes in the population (Figure 13).

The reported commercial catches from 1931–86 were increased by 20% to account for an assumed level of under-reporting. Since the introduction of the Quota Management System (QMS), the accuracy of the reporting of commercial catches has improved considerably, although a degree of under-reporting may persist. For 1987–2016, reported catches were increased by 10% to account for the assumed level of under-reporting in the more recent period. These assumptions are consistent with the formulation of the commercial catch histories incorporated in other inshore finfish stock assessments (based on assumptions for SNA 1 made according to quota appeals when the QMS was first introduced).

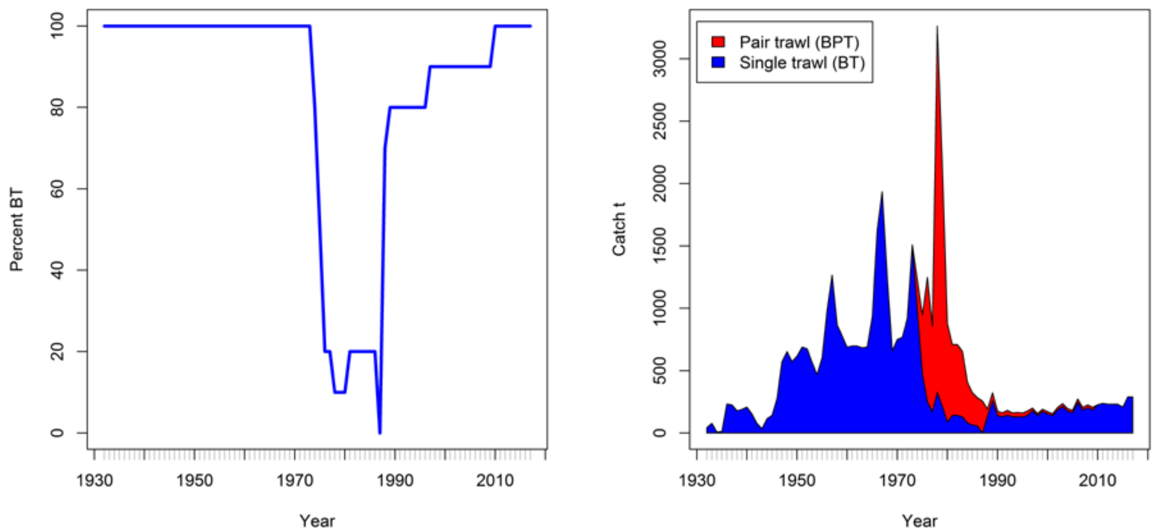

Figure 13: The proportion of the total SNA 7 catch allocated to the BT fishery by year (left panel) and the total annual commercial catch by fishing method (right panel), including an allowance for unreported catches.

4.2 Non-commercial catch

The model included a non-commercial fishery that encompasses catches from the recreational and customary sectors. The catch history for the non-commercial fishery was derived following the approach used in Langley (2015a, 2018) updated to include an additional estimate of recreational catch from 2017/18 (Wynne-Jones et al 2019). The approach is detailed in the following steps:

i. Recreational catch (point) estimates from the SNA 7 tagging programme (1987, 15 t), aerial over flight (2005/06, 42.6 t), panel (2011/12, 88 t, Wynne-Jones et al. 2014), aerial access (2015/16 83.1 t; Hartill et al. 2017), and panel (2017/18, 147 t, Wynne-Jones et al. 2019) surveys were used to determine the annual non-commercial catch in specific years. Previous telephone/diary estimates of recreational catch are considered unreliable and were disregarded (Fisheries New Zealand 2019) (Figure 14).

ii. A time-series of annual snapper (recruited) biomass was obtained from a preliminary iteration of the SNA 7 stock assessment model.

iii. Estimates of the exploitation rate (ER) of the non-commercial fishery were determined for the years with point estimates of recreational harvest (model years 1987, 2005, 2011, 2015, and 2017) (recreational catch divided by total recruited biomass).

iv. The non-commercial exploitation rate (from iii) for 2005 was considerably higher than 1987. It was assumed that there was a linear increase in the annual exploitation rate from 1987 to 2005. The annual recreational catch in those intervening years was determined by multiplying the annual ER by the annual estimate of recruited biomass from the preliminary assessment model (ii. above).

v. Similarly, the recreational exploitation rate was interpolated between the successive recreational catch estimates (i.e., between 2005–2011, 2011–2015, and 2015–2017) to derive the annual recreational catches for the intervening years.

vi. The non-commercial exploitation rate in 2018 was assumed to be equivalent to the 2017 level, yielding a similar estimate of recreational catch for the two years (Figure 14).

vii. Prior to 1987, the ER is assumed to decrease at 10% per year to 1931 and the corresponding recreational catch determined (ER_{year} multiplied by model biomass in each year).

viii. A minimum annual recreational catch was set at 10 t. Annual recreational catch in 1931–1986 was set as the maximum of 10 t (prior to 1962) or the catch determined from ER (vii).

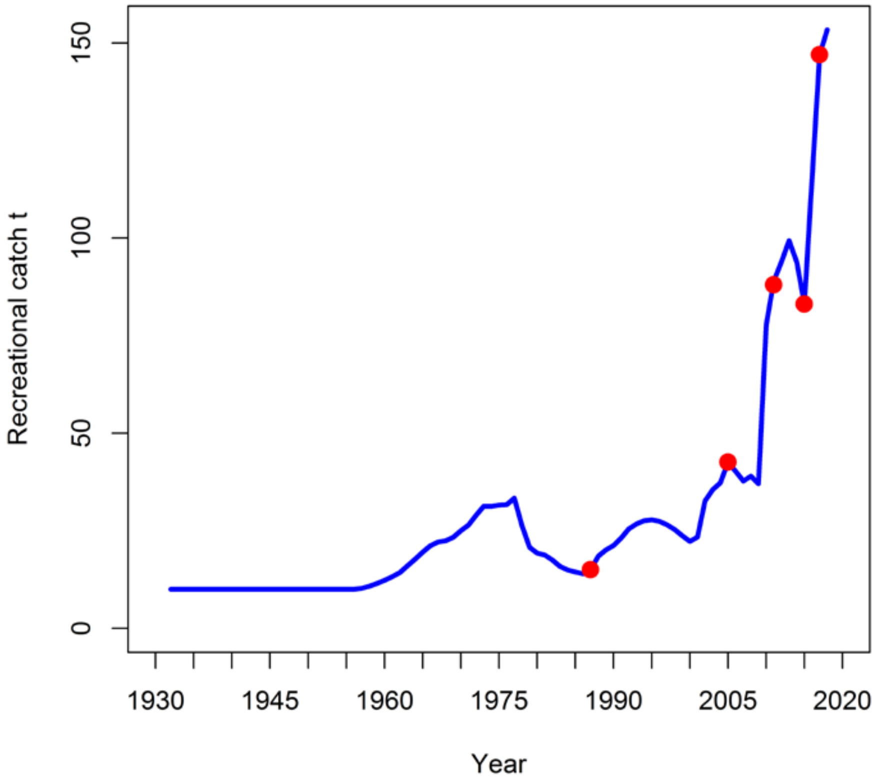

Figure 14: Annual non-commercial catch from SNA 7 included in the stock assessment model. The red points represent individual estimates of recreational catch for SNA 7 (see text for details).

4.3 Tagging programme data

An estimate of SNA 7 stock biomass is available from a tag release and recapture programme that was conducted in Tasman Bay/Golden Bay during 1986 and 1987 (Kirk et al. 1988). An estimate of the stock biomass in 1987/88 was determined using the Petersen estimator (Kirk et al. 1988). A subsequent reanalysis of the tagging data by Harley & Gilbert (2000) yielded a very similar estimate of snapper biomass (1549 t).

Harley & Gilbert (2000) expressed concerns regarding the reliability of the 1987 tag biomass estimate and considered that the biomass estimate was "*quite imprecise and possibly an underestimate*". The main factors considered likely to introduce a negative bias in the tag biomass estimate were spatial heterogeneity and the lack of tag releases in deeper water (Harley & Gilbert 2000).

The 2015 assessment included the tag biomass estimate from Harley & Gilbert (2000) and the equivalent level of uncertainty (CV 30%). The tagged biomass was assumed to represent the total biomass of snapper that had recruited to the commercial BPT fishery. During the 2015 assessment, a range of model options were investigated which indicated that the assessment results were insensitive to the inclusion of the tag biomass estimate.

The 2018 and current assessments incorporated the tag biomass estimate in an equivalent manner to the 2015 base assessment model.

4.4 Commercial catch age composition data

The time series of age composition data available from the commercial catch of the SNA 7 fishery, described by Langley (2015a) and with the addition of the most recent (2016/17) sample from the fishery, are listed in Table 5. The 2016/17 sample was included in the 2018 assessment. For all samples, the proportions at age were combined for both sexes because there is no indication of variation in growth rates between male and female snapper.

Table 5: A summary of the age composition data from the SNA 7 commercial fishery. BPT is bottom pair trawl, BT is bottom trawl, PS is purse seine.

Fishing season	Model year	No. otoliths	No. landings	Comments, source	Fishery assignment
1974/75	1974	85	1	Additional landings sampled during April-June, not included.	BPT
1978/79	1978	295	4	Otoliths collected from 4 landings. Additional length sampling of BPT and PS landings.	BPT
1979/80	1979	84	1	Otoliths collected from 1 BPT trip. Additional length sampling of 19 landings, mostly BPT.	BPT
1980/81	1980	348	4	Otoliths collected from BPT (2), PS (1) and BT (1). Additional (19) landings sampled for length.	BPT
1983/84	1983	265	2	Otoliths collected from two BPT landings. Six landings sampled for length.	BPT
1992/93	1992	364	NA	Harley & Gilbert (2000)	BT
1997/98	1997	1 439	47	Blackwell et al. (1999)	BT
1998/99	1998	913	34	Blackwell et al. (2000)	BT
1999/2000	1999	1 004	56	Blackwell & Gilbert (2001)	BT
2000/01	2000	1 035	60	Blackwell & Gilbert (2002)	BT
2003/04	2003	1 007	59	Blackwell & Gilbert (2005)	BT
2006/07	2006	1 007	60	Blackwell & Gilbert (2008)	BT
2013/14	2013	848	21	Parker et al. (2015)	BT
2016/17	2016	1440	27	Parsons et al. (2018)	BT

4.5 Commercial size grading data

A large proportion of the total annual commercial catch from SNA 7 is processed by Talley Group Ltd. in Motueka. A considerable proportion (45–70%) of this component of the landed catch is graded by fish size and packed in 10 kg cartons. The five grading categories are based on the number of fish packed in each carton (2–5 fish, 6–7 fish, 8–15 fish, 16–25 fish, and 26+ fish).

Commercial grading data were included in the 2015 assessment, but were excluded from the 2018 base assessment model. For consistency with the 2018 assessment, the current assessment model did not include these data.

4.6 Recreational length compositions

Recreational catches of snapper from TBGB have been sampled for length at boat ramps during recreational harvest surveys (e.g., Hartill et al. 2017). Length samples were collected in 2005/06, 2011/12, 2015/16, 2016/17, and 2017/18 with a small number of snapper also measured in 2006/07 and 2014/15 (Bruce Hartill, NIWA unpublished data). The sampling at the boat ramp also recorded whether or not the fish were caught by rod-and-line (stationary boat) or by longline or set net.

The samples collected during 2005/06 and 2011/12 were dominated by fish caught by rod-and-line (approx. 95%) and catches were predominantly comprised of 27–35 cm (fork length, FL) fish (Figure 15). A broader length range of fish was caught in 2015/16–2017/18. This corresponded to a higher proportion of the sampled fish being taken by longline (41% in 2015/16, 52% in 2016/17, and 25% in 2017/18). In each year, the longline-caught fish were generally larger than fish caught by rod-and-line (Hartill et al. 2017).

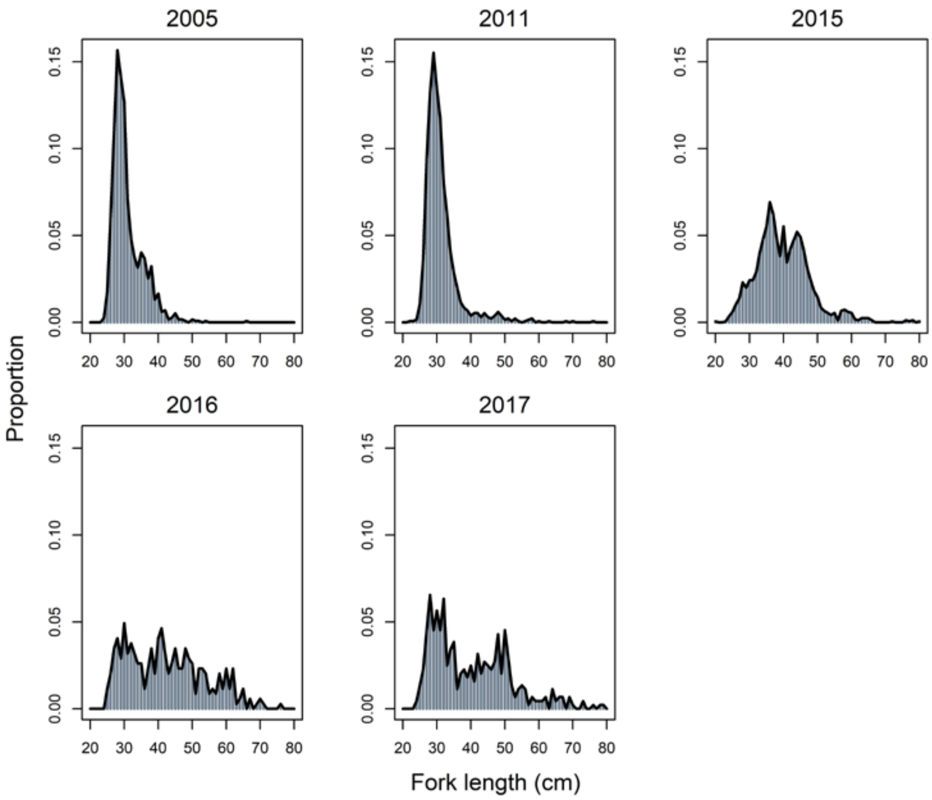

Figure 15: Length compositions of SNA 7 recreational catches by model year (e.g., 2005 represents the 2005/06 fishing year).

4.7 Trawl survey length and age compositions

Since 1992, a time-series of inshore trawl surveys has been conducted off the west coast South Island (WCSI), including Tasman Bay/Golden Bay, within the 20–70 m depth range (Stevenson & Hanchet 2000, MacGibbon & Stevenson 2013, Stevenson & MacGibbon 2015, 2018). Trawl surveys are conducted during March–April and the most recent survey was conducted in 2019 (MacGibbon 2019) (i.e., the 2018 model year).

Prior to 2017, snapper was not a specified target species for the survey and the catch rates of juvenile and adult snapper were low for most surveys. The shallower areas of Tasman Bay/Golden Bay represent the prime habitat for juvenile snapper and these areas were not included within the survey area. In 2017, the survey design was modified to investigate the potential for monitoring snapper. For this purpose the survey area was expanded to include the 10–20 m depth range within Tasman Bay and Golden Bay and additional trawl stations were allocated to existing/core strata within TBGB. The 2019 trawl survey adopted an equivalent design to the 2017 survey (MacGibbon 2019).

Snapper length composition data are available from all trawl surveys. However, prior to the 2008 survey only small numbers of snapper were sampled and the resulting length compositions are uninformative. These length compositions were not included in the assessment data sets. Length compositions were included from the surveys conducted in the 2008, 2010, 2012, and 2014 model years (Figure 16). For the two subsequent trawl surveys (2016 and 2018 model years) the survey length compositions from the core strata were converted to age compositions with the application of specific age-length keys (Figure 17).

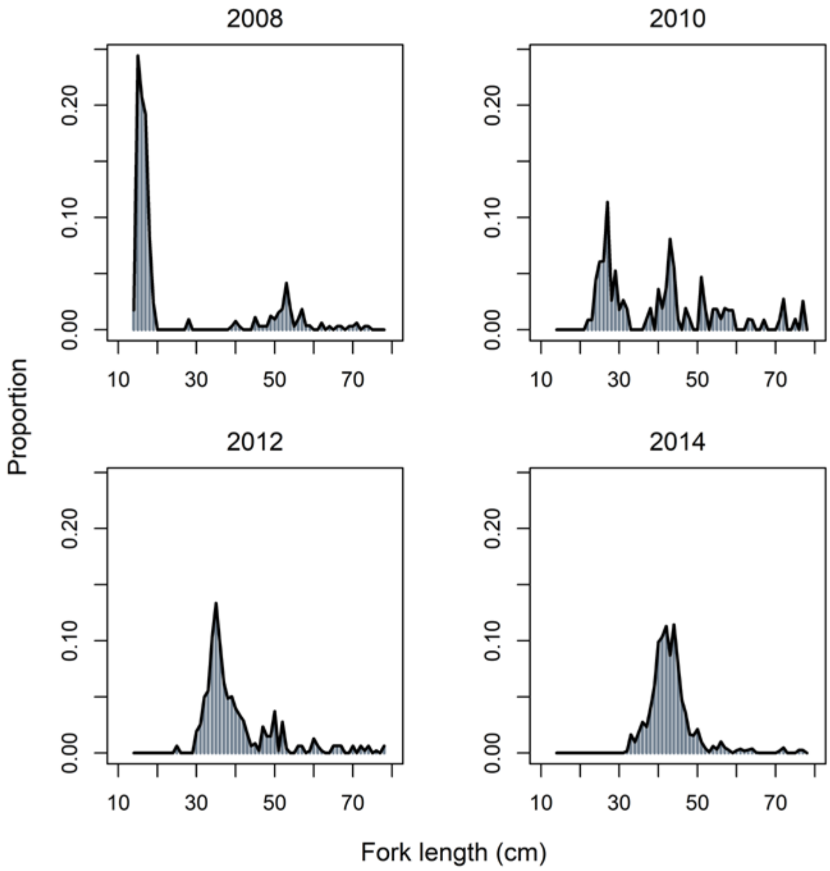

Figure 16: Length compositions of snapper from *Kaharoa* WCSI trawl surveys (core strata) by model year (e.g., 2008 represents the 2008/09 fishing year and the survey conducted in March-April 2009).

For the 2018 trawl survey, an age composition was also derived for the entire survey area, including the shallower areas of Tasman Bay and Golden Bay (Core strata + SNA strata). The age composition was dominated by 1 year old fish; 2 year old fish were not present in the survey age composition (Figure 17).

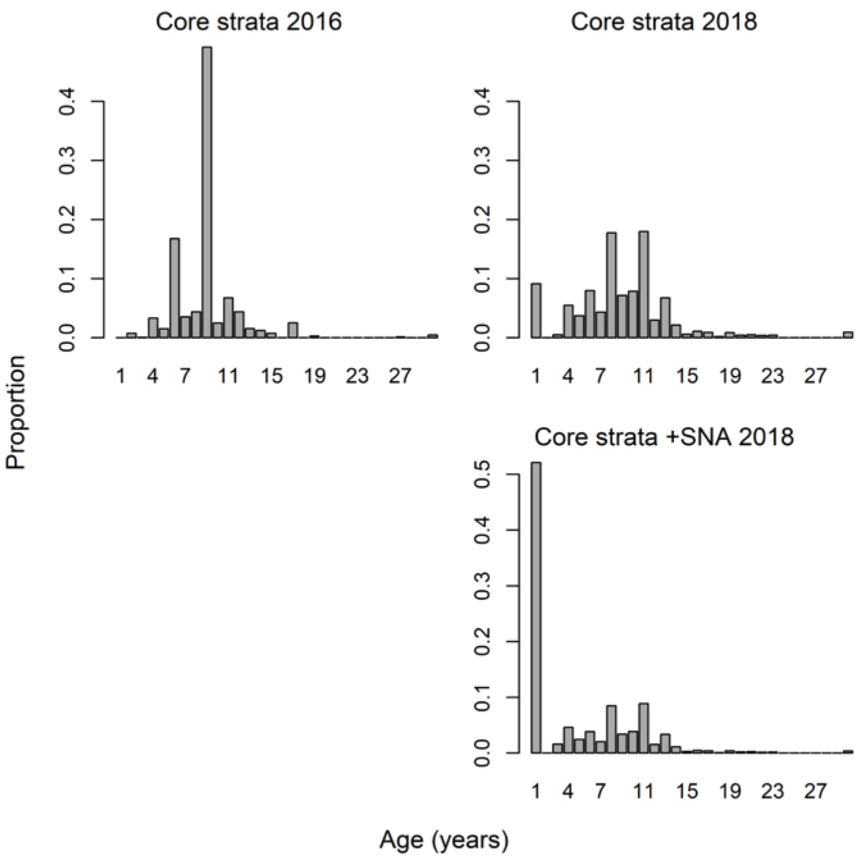

Figure 17: Age compositions of snapper from 2016 and 2018 *Kaharoa* WCSI trawl surveys (core strata) and the extended survey (core+SNA strata) in 2018 (2018 represents the 2018/19 fishing year and the survey conducted in March-April 2019).

A comparison of the age composition from the entire 2018/19 survey area (core + SNA strata) and the 10–20 m SNA strata revealed that a very high proportion (approximately 90%) of the fish aged 0–3 years were within the shallower area (SNA strata) (Figure 18). The proportion of fish in the 4–6 year age classes sampled from the shallower strata declined with increasing age. For older ages (7+ years) about 20–30% of the fish were within the shallower strata (i.e., 70–80% of the fish by number were estimated to be outside the 10–20 m TBGB depth strata) (Figure 18).

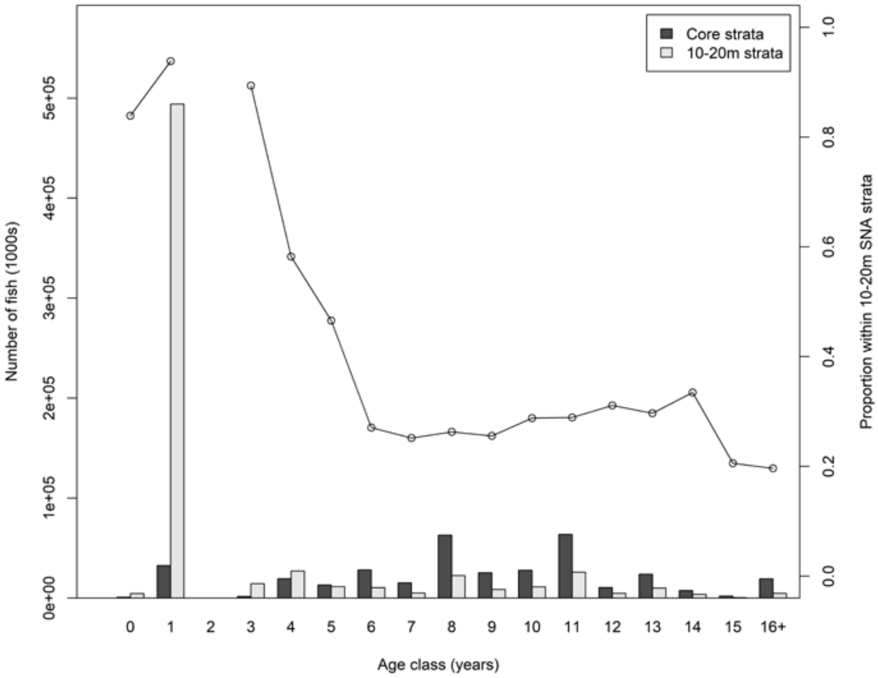

Figure 18: The estimated numbers of fish at age from the core strata and the 10–20 m SNA strata from the 2018/19 trawl survey. The proportion of the total number of fish (Core + SNA strata) in each age class within the SNA strata is also presented (points and line).

For comparative purposes, the trawl survey biomass estimates of snapper were included in the model input data sets. However, the indices were not included in the model estimation (i.e., excluded from the model likelihood) because the time-series of surveys does not include the entire distribution of the snapper stock, particularly the shallower areas of Tasman Bay and Golden Bay. Trawl survey biomass in the core strata increased by a factor of 11.3 between 2006/07–2010/11 and 2014/15–2018/19 (Figure 19). The increase in the trawl survey abundance indices is considerably greater than the increase in the CPUE indices (which encompass the full extent of the snapper distribution within Tasman Bay/Golden Bay). For the 2016/17 and 2018/19 trawl surveys the 10–20 m SNA strata accounted for 16% and 31% of the total trawl survey biomass, respectively.

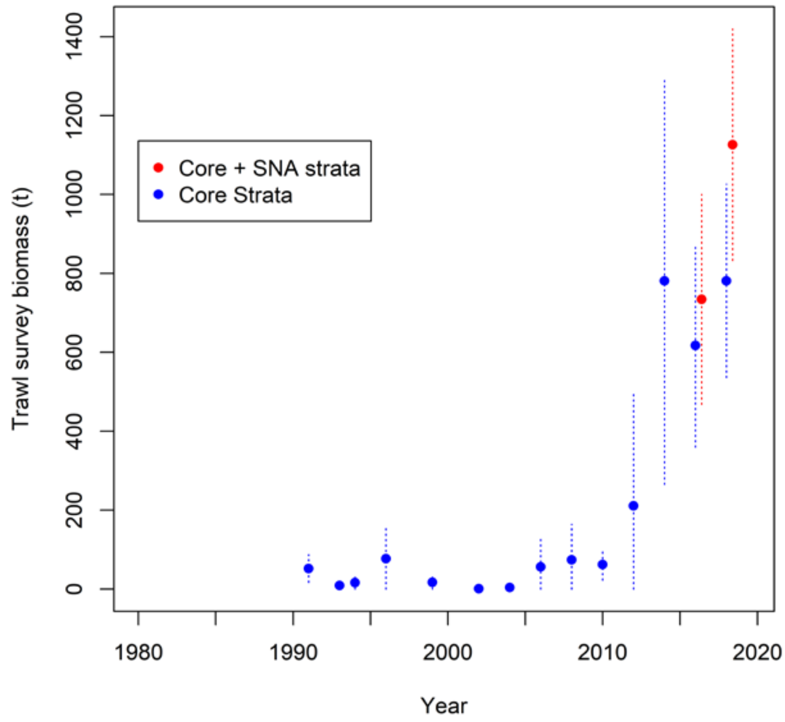

Figure 19: Time series of snapper biomass indices from *Kaharoa* WCSI trawl surveys (core strata and core + SNA strata) by model year (e.g., 2008 represents the 2008/09 fishing year and the survey conducted in March-April 2009).

4.8 Assessment model configuration

The assessment modelling was conducted using the Stock Synthesis (SS) software (version 3.30.13), a flexible platform for implementing statistical, age-structured population models (Methot & Wetzell 2013, Methot et al. 2019).

The configuration of the 2020 assessment model is very similar to the previous (2018) assessment. The assessment model included the entire SNA 7 catch history (from 1931) and assumed that the initial population age structure was in an equilibrium, unexploited state. The population was structured by sex and included 30 age classes, the oldest age class representing an aggregated "plus" group (30 years and older). The model data period extended to the 2018 year (2018/19 fishing year).

The key biological parameters for the SNA 7 stock assessment are presented in Table 6. Following previous assessments, natural mortality (*M*) was assumed to be 0.075 for the base model options. Von Bertalanffy growth parameters for SNA 7 are provided by Fisheries New Zealand (2019). There is no evidence of sexual dimorphism in snapper growth and the growth parameters have been determined for both sexes combined. Growth parameters were assumed to be temporally invariant. An examination of length-at-age from six otolith collections (1978, 1979, 1980, 1983, 2006, and 2016) did not reveal an appreciable difference in growth rates between the samples. These otolith collections were also used to determine the variation in length-at-age; approximated by a constant CV of 7.5% of the mean length-at-age. Maturity was assumed to be age-specific with all fish reaching sexual maturity at age 3 years.

The model was structured with an annual time-step comprised of two seasons (October-January and February-September). The seasonal structure partitions the main spawning period and commercial catch (season 1). Spawning is assumed to occur instantaneously at the start of the year and recruitment is a function of the spawning biomass at the start of the year. A Beverton-Holt spawning stock-recruitment relationship (SRR) was assumed with steepness (*h*) fixed at 0.90 for the base assessment model. Recruitment deviates (1950–2017) from the SRR were estimated assuming a standard deviation of the natural logarithm of recruitment (σ_R) of 1.5. This represents a high level of recruitment variability that is consistent with the high variation in the strength of individual year classes in the SNA 7 age composition data sets. The value of σ_R was informed from the results of a likelihood profile of this parameter in the 2015 assessment (Langley 2015).

The model was configured to encompass three fisheries: single trawl (BT), pair trawl (BPT), and non-commercial. Age composition data are available from the single trawl fishery (9 observations), pair trawl fishery (5 observations), and two *Kaharoa* trawl surveys (Table 7). For all age compositions there was assumed to be no error associated with the age determination.

The two commercial fisheries were associated with age-specific, sex-invariant selectivity functions. For the 2015 assessment, the selectivity of the BT fishery was parameterised using a double normal function, although the estimated selectivity function approximated full selectivity of the oldest age classes. On that basis, the current assessment adopted a logistic selectivity function for the BT fishery and the associated CPUE indices (Table 6). A separate logistic selectivity function was estimated for the BPT fishery.

A comparison of the length and age compositions from the trawl survey and commercial fishery indicated that the trawl survey is sampling the full range of length and age classes that have recruited to the commercial fishery. The length and age compositions derived from the core strata of the *Kaharoa* trawl surveys were fitted in the model using a separate age-specific, logistic selectivity function (Table 6). A separate logistic selectivity function was used for the length and age compositions from the wider area of the 2016/17 and 2018/19 *Kaharoa* trawl surveys (core strata plus SNA strata).

For the recreational fishery, selectivity was parameterised using a length-based, double normal function, enabling considerable flexibility in the estimation of the selectivity form (see Methot et al. 2019). There has been an apparent shift in the overall selectivity of the recreational fishery in recent years with an increase in the catch of larger fish associated with increased fishing by recreational longline. To account for this potential change in selectivity, temporal deviates were estimated for the parameters mediating the width of the descending limb of the selectivity function and the selectivity of the largest length class (terminal selectivity). The temporal deviates were estimated for three time blocks (1932–2012, 2013–2015, and 2016–2018) (see Table 6).

The tagging biomass estimate was assumed to represent the biomass of the proportion of the population vulnerable to the BPT fishery in 1987 (catchability coefficient of 1.0). The tagging biomass estimate had an assumed CV of 30% (see section 4.3). The single trawl CPUE indices are assumed to have a lognormal error distribution and represent the relative abundance of the biomass of snapper vulnerable to the BT fishery.

Table 6: Model parameters and priors for the base model.

Component	Parameters	Value, Priors	
Biology	*M*	0.075	Fixed
	VB Growth	*k* = 0.122, *Lmax* = 69.6 cm	Fixed
	CV length-at-age	0.075	Fixed
	Length-wt	*a* = 4.4467e-005, *b* = 2.793	Fixed
	Maturity	0.0 ≤2 yr, 1.0 ≥3 yr	Fixed
Recruitment	Ln*R0*	Uniform[0-10]	Estimated (1)
	B-H SRR steepness *h*	0.90	Fixed
	SigmaR σR	1.5	Fixed
	Recruitment deviates	Lognormal deviates (1950–2017)	Estimated (68)
Selectivity			
BT fishery	Logistic parameterisation		Estimated (2)
	p1 – age at inflection	Norm(4,2.0)	
	p2 – width for 95% selection	Norm(1,1.0)	
BPT fishery	Logistic parameterisation		Estimated (2)
	p1 – age at inflection	Norm(4,2.0)	
	p2 – width for 95% selection	Norm(1,1.0)	
Trawl survey	Logistic parameterisation		Estimated (2)
(Core strata)	p1 – age at inflection	Norm(4,3.0)	
	p2 – width for 95% selection	Norm(4,2.0)	
Trawl survey	Logistic parameterisation		Estimated (2)
(Core+SNA strata)	p1 – age at inflection	Norm(2,2)	
	p2 – width for 95% selection	Norm(2,2)	
Non comm fishery	Double Normal		Estimated (8)
	p1 – length at peak	Norm(30,5)	
	p2 – width of peak	Fixed (-3)	
	p3 – width of ascending limb	Norm(2,2)	
	p4 – width of descending limb	Norm(4.5,3)	
	p6 – selectivity at max length	Norm(-5,5)	
	p4 – dev time block 3	No prior	
	p6 – dev time block 3	No prior	
Abundance			
CPUE indices	*CPUEq*	Nuisance parameter	Estimated (1)
Tag biomass	Catchability *TAGq*	1.0 (fixed)	Fixed (1)

Fishing mortality was modelled using a hybrid method that calculates the harvest rate using Pope's approximation and then converts it to an approximation of the corresponding fishery specific *F* (see Methot & Wetzell 2013 for details). The timing of the fisheries and CPUE indices within the year was specified so that annual catches were taken instantaneously halfway through the first season (October-January). This is generally consistent with the period of the main commercial catch.

The main data inputs were assigned relative weightings equivalent to those used in the 2018 assessment which were determined based on the approach of Francis (2011) (see Table 7).

The changes in the recreational fishery meant that the corresponding length compositions were unlikely to represent the snapper population. On that basis, the recreational length compositions were assigned a low Effective Sample Size (ESS) (1) to minimise any influence these data had in the estimation of stock population dynamics.

Table 7: Summary of input data sets for the assessment model. The relative weighting includes the Effective Sample Size (ESS) of age/size composition data and the coefficient of variation (CV) associated with the abundance data. The commercial size grade data were excluded from the final model options. BPT is bottom pair trawl, BT is bottom trawl.

Data set	Model year(s)	No. observations	Relative weighting
BT CPUE indices (Oct-May)	1989–2018	30	CV 25%
BPT age comp	1974, 1978, 1979, 1980, 1983	5	ESS 8.5
BT age comp	1992, 1997, 1998, 1999, 2000, 2003, 2006, 2013, 2016	9	ESS 10
Tag biomass	1987	1	CV 30%
Trawl survey age comp (core)	2016, 2018	2	ESS 10
Trawl survey age comp (core+SNA)	2018	1	ESS 10
Trawl survey length comp (core)	2008, 2010, 2012, 2014	4	ESS 10
Trawl survey length comp (core+SNA)	2016	1	ESS 10
Recreational length comp	2005, 2011, 2015, 2016, 2017	5	ESS 1

There are seven main components to the model likelihood objective function:

i. BT CPUE indices. The fit to the CPUE indices assuming a lognormal error structure.
ii. Age composition data sets. The fit to the age composition data assuming a multinomial error structure.
iii. Length composition data set. The fit to the length composition data assuming a multinomial error structure.
iv. Tag biomass estimate. The fit to the 1987 tag biomass estimate, assuming a lognormal error structure.
v. Size composition data. The fit to the commercial size grade data assuming a multinomial error structure. This component of the likelihood was excluded in the final base model option.
vi. Recruitment deviations. The likelihood is formulated to constrain recruitment deviations relative to the (assumed) standard deviation (*sigmaR*).
vii. Parameter priors. Deviation of estimated parameter(s) from assumed prior distribution(s).

The formulation of the individual likelihood components is documented by Methot & Wetzell (2013). The estimation procedure minimises the negative log-likelihood of the objective function.

Model uncertainty was determined using Markov chain Monte Carlo (MCMC) implemented using the Metropolis-Hastings algorithm. For each model option, 1000 MCMC samples were drawn at 1000 intervals from a chain of 1.1 million following an initial burn-in of 100 000. The performance of the MCMC sample was evaluated using a range of diagnostics.

Stock status was determined relative to the equilibrium, unexploited spawning (mature) biomass of female fish (SB_0). Current biomass was defined as the biomass in the 2018 model year (2018/19 fishing year) ($SB_{current}$ or SB_{2018}).

Following the MPI Harvest Strategy Standard (HSS), current biomass was assessed relative to the default soft limit of 20% SB_0 and hard limit of 10% SB_0 (Ministry of Fisheries 2008). The HSS includes a default target biomass level of 40% SB_0 for stocks with low productivity where an operational ("real world") SB_{MSY} has not been fully evaluated. The Inshore Fishery Assessment Working Group accepted 40% SB_0 as an appropriate SB_{MSY} proxy for SNA 7. Current stock biomass is reported relative to the default target biomass level ($SB_{40\%}$) and current levels of fishing mortality are reported relative to the level of fishing mortality that result in $SB_{40\%}$ under equilibrium conditions (i.e., $F_{SB40\%}$). The reference level of age-specific fishing mortality is determined from the composite age-specific fishing mortality from the last year of the model data period (2018/19). Estimates of equilibrium yield are determined from the level of fishing mortality that produces the target biomass level ($F_{SB40\%}$).

4.9 Model results

Detailed results are presented for the base assessment model which is very similar to the 2018 base model, with the addition of the length and age compositions from the full area (core + SNA strata) of the trawl survey. In addition, a limited number of model sensitivity runs were conducted to encompass the main sources of uncertainty identified in the 2018 and current stock assessment.

4.9.1 Parameter estimation

Priors were formulated for fishery selectivity parameters based on a qualitative examination of the age composition data (i.e., age-at-recruitment and the proportion of older fish in the samples). Relatively uninformative, normally distributed priors were adopted for the selectivity parameters for the BT fishery (logistic), BPT fishery (logistic), and two sets of *Kaharoa* trawl survey length and age compositions (logistic).

For the BT and BPT fisheries, snapper are estimated to be fully selected at age 4 years and 6 years, respectively (Figure 20).

For the *Kaharoa* trawl survey core area, the selectivity of the youngest age classes is estimated to be very low (Figure 20) reflecting the low proportion of the age 0–3 year fish caught in the area during the two most recent trawl surveys (including the SNA strata). Full selectivity for the core area is attained at about 10 years, and 50% selectivity was estimated at about age 6 years (Figure 20).

By contrast, the selectivity function for the wider area of the recent *Kaharoa* trawl surveys (core + SNA strata) estimated selectivity to be substantially higher for the younger age classes (1–2 years) with full selectivity at age 3 years (Figure 20). However, selectivity of the younger age classes is poorly determined, reflecting the limited number of length and age observations (two surveys).

The selectivity of the recreational fishery increases sharply from the Minimum Legal Size (MLS) of 25 cm (FL) and full selectivity is reached at 28 cm (Figure 21). For the period prior to 2012, the fishery is estimated to predominantly select fish from a relatively small length range of 28–35 cm. For 2013–2015, a broader selectivity function is estimated, with the descending limb of the function extending to include fish up to 60–80 cm (see Figure 21). An intermediate selectivity function was estimated for 2016–2018 with a peak in selectivity about 28–35 cm and a lower selectivity for fish larger than 40 cm.

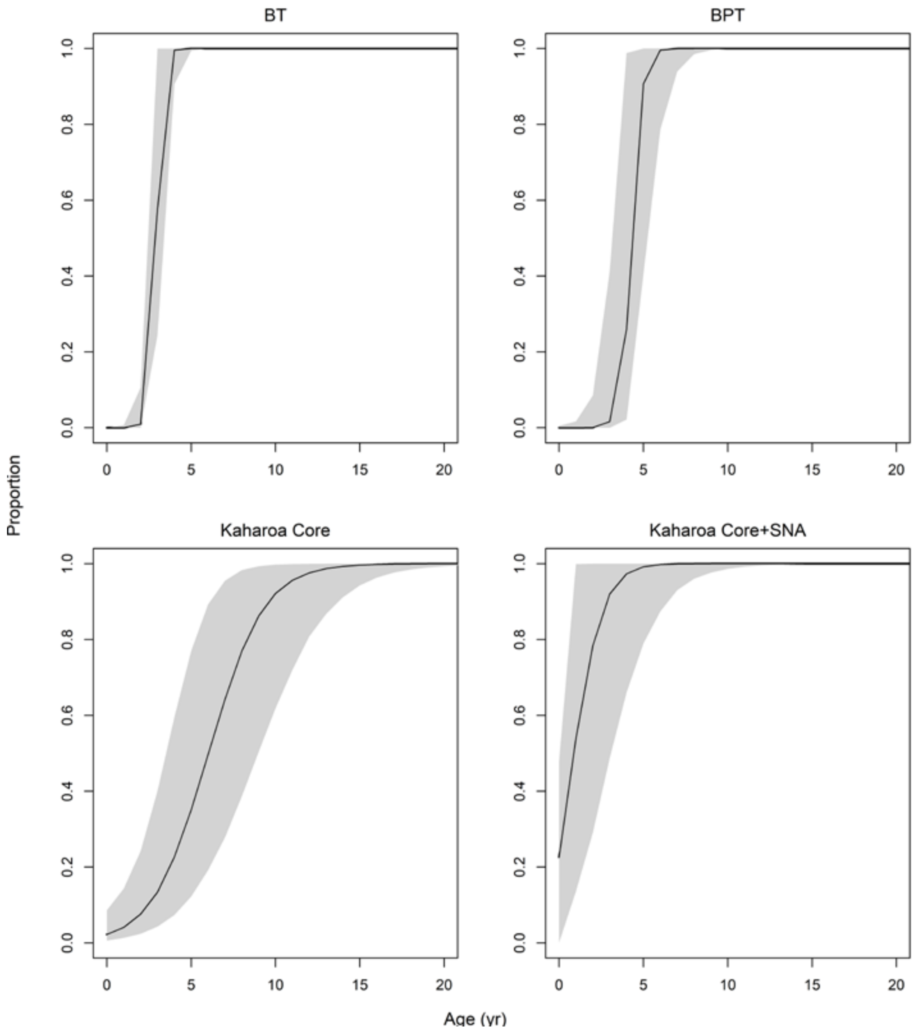

Figure 20: Age specific selectivity functions estimated for the BT (top left), BPT (top right) fisheries, and *Kaharoa* trawl survey core strata (bottom left), and all strata (core + SNA) (bottom right) from the base assessment model. The lines represent the median of the MCMC samples and the grey shaded area represents the 95% confidence interval.

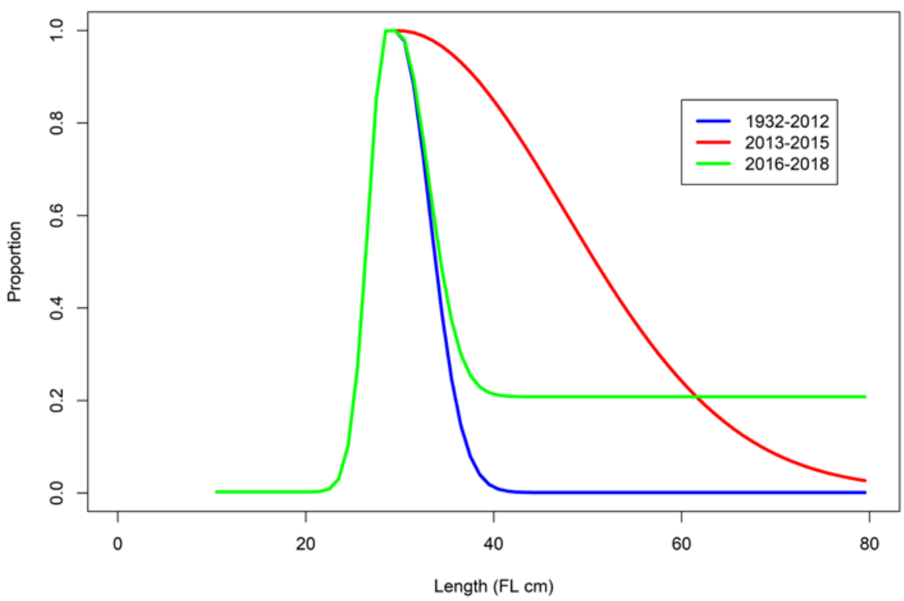

Figure 21: Estimates (mode of the posterior distribution, MPDs) of length based selectivity of the Recreational fishery for the three time periods (blocks).

The base case model estimates episodic recruitment during the 1950–2008 period with strong recruitment occurring in 1960, 1969, 1974, 1985–87, 1999, and 2010 and exceptionally strong recruitment in 2007 and 2017, although the estimate of recruitment for the latter year is highly uncertain (Figure 22 and Figure 23). A recruitment deviate was not estimated for the terminal year of the model (2018) and recruitment was assumed to be at the equilibrium level (rec dev = 0) (Figure 22).

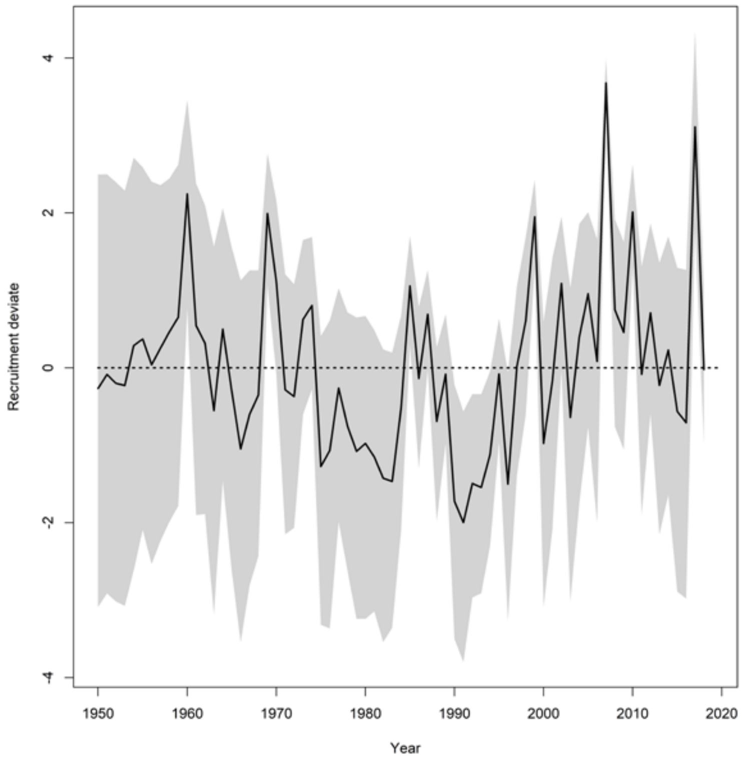

Figure 22: Estimates of annual recruitment deviates from the base assessment model. The line represents the median of the MCMC samples and the shaded area represents the 95% confidence interval.

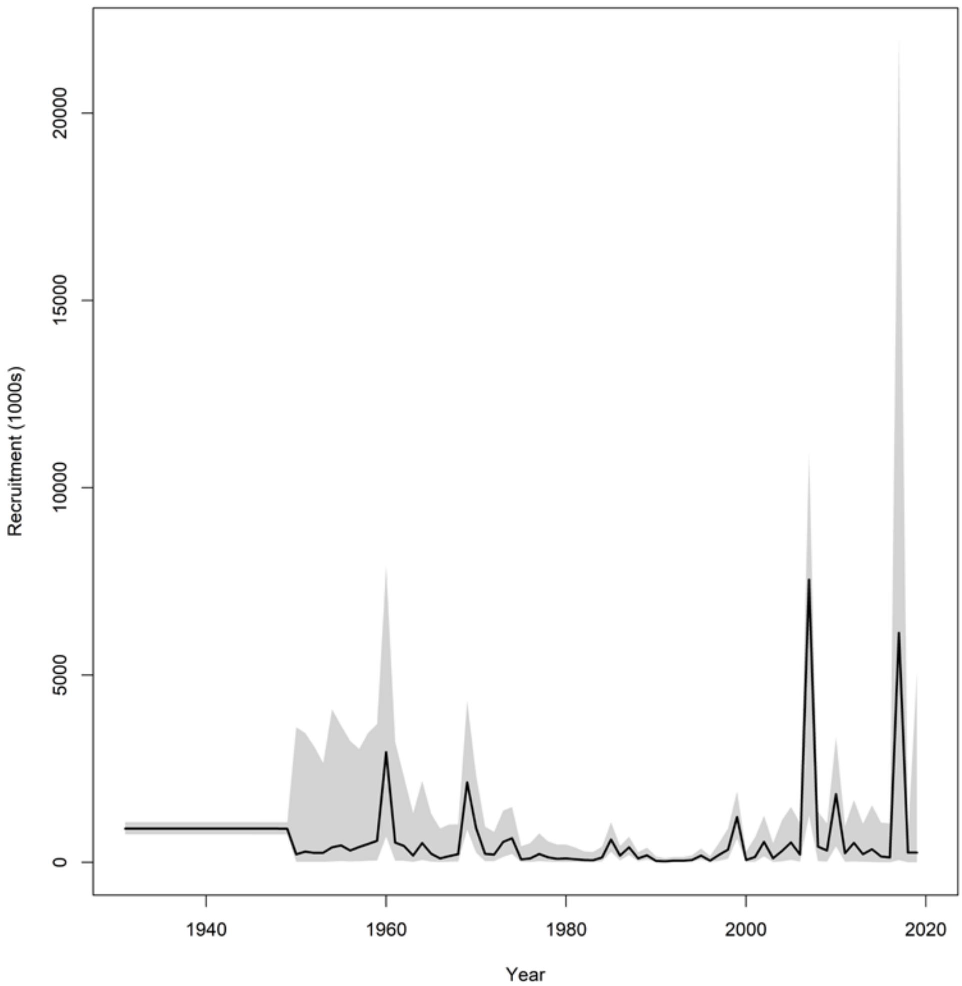

Figure 23: Estimates of annual recruitment (numbers of fish) from the base assessment model. The line represents the median of the MCMC samples and the shaded area represents the 95% confidence interval.

4.9.2 Fit to observational data

The base model provides a reasonable fit to the overall trend in the time-series of BT CPUE indices (Figure 24). The main signal in the CPUE indices is the large increase from 2009 to 2011. The base model estimates a strong increase in stock abundance during this period, although the extent of the increase is less than the increase in CPUE, and hence there is a large positive residual for the 2011 index. The model also does not adequately fit the inter-annual variation in the CPUE indices during 2011–2016 (Figure 24). The degree of fit to the CPUE indices is reflected in the CV associated with the time series (based on the initial root-mean-square deviation).

The estimate of vulnerable biomass in 1987 from the base model approximated the biomass estimate from the tag release/recovery programme (Figure 25).

The model age structure in 1987 is primarily informed by the age composition data from the sampling of the BPT fishery in the preceding years (Figure 26). The base model provided a reasonable fit to these data, particularly the presence of the strong year classes (e.g., 1960, 1969, and 1974) in the older age range (8–25 years) (Figure 26). However, the fit to the proportions in the younger age classes (4–6 years) is poor and variable among years. This may indicate that the selectivity of the younger age classes in the BPT fishery was variable among years and/or that there was considerable variability in the proportion of young fish amongst the sampled landings.

The model also consistently over-estimated the proportion of fish in the BPT aggregate 30+ age class (Figure 26). Previous model trials (in 2018) that applied alternative weightings to improve the fit to these data did not result in an appreciable difference in estimates of stock status (Langley 2018).

The age compositions from the BT fishery during 1992–2000 are dominated by the progression of the relatively strong 1985 and 1987 year classes (Figure 27). Fish older than 10 years represented a minor proportion of the age composition of the sampled catch during 2003–2016 as the model age structure became dominated by recruitment from 1998 onwards, with higher recruitment estimated for the 1999, 2002, 2005, 2007, and 2010 year classes (Figure 27).

Overall, the model provided a reasonable fit to the time-series of recent BT age samples. However, the proportion of older fish in the sampled catch is under-estimated for 1999 and 2000 and the fit to the youngest age classes (3–4 years) is variable among years (Figure 27).

The model fitted the dominant 6 year old age class in the 2013 age composition (representing the 2007 year class), although the 3 year old age class, representing the 2010 year class, is under-estimated by the model (Figure 27, Figure 28). The 2010 year class is also under-estimated for the 2016 age composition (age 6 years), and the model over-estimates the proportion at age 9 years (2007 year class).

The model provided a considerably better fit to age composition from the core strata of the 2016 *Kaharoa* trawl survey, including the relative proportions of the 2007 and 2010 year classes (Figure 29). However, the model considerably over-estimates the proportion of 11 year old fish (2007 year class) in the age compositions from the 2018 trawl survey. There is an under-estimation of the proportion of 1 year old fish in the age composition from the 2018 extended area trawl survey (core + SNA strata) (Figure 29).

Additional model trials were conducted to attempt to improve the fit to the recent age composition data, using alternative selectivity parameterisations and relative weighting of the age composition data sets. These trials were not successful in simultaneously fitting the age compositions from 2016 and 2018 (commercial and trawl survey) and in all cases the model wanted to estimate a large mode for the 2007 year class. This relates to the large increase in the CPUE indices between 2010 and 2011. Some overall improvement in the fit to the recent age compositions was achieved when these data were up-weighted in conjunction with down-weighting the CPUE indices. These changes did not appreciably influence the biomass trajectory relative to the base model.

The model approximates the length compositions from the earlier trawl surveys (Figure 30), although the proportion of fish in the smaller length classes tends to be over-estimated with trivial numbers of fish sampled in length classes below 30 cm in 2012 and 2014.

The 2005 and 2011 length compositions from the recreational fishery are approximated by the model, reflecting the relatively narrow selectivity function estimated for the earlier period of the fishery (pre 2013) (Figure 31). The model also approximates the broader length range of fish sampled in the latter years (2015, 2016, and 2017), although there is a deterioration of the fits compared with the previous years.

The core area trawl survey biomass estimates are not included in the model-fitting procedure. However, the indices are included in the input data sets to enable a comparison between the indices and the model prediction of survey vulnerable biomass (from the estimated selectivity function). The model predicts the trawl survey biomass has increased considerably from 2010 (by about 6 fold); however, the predicted increase is considerably lower than the actual increase in the trawl survey indices (about 10–12 fold) (Figure 32).

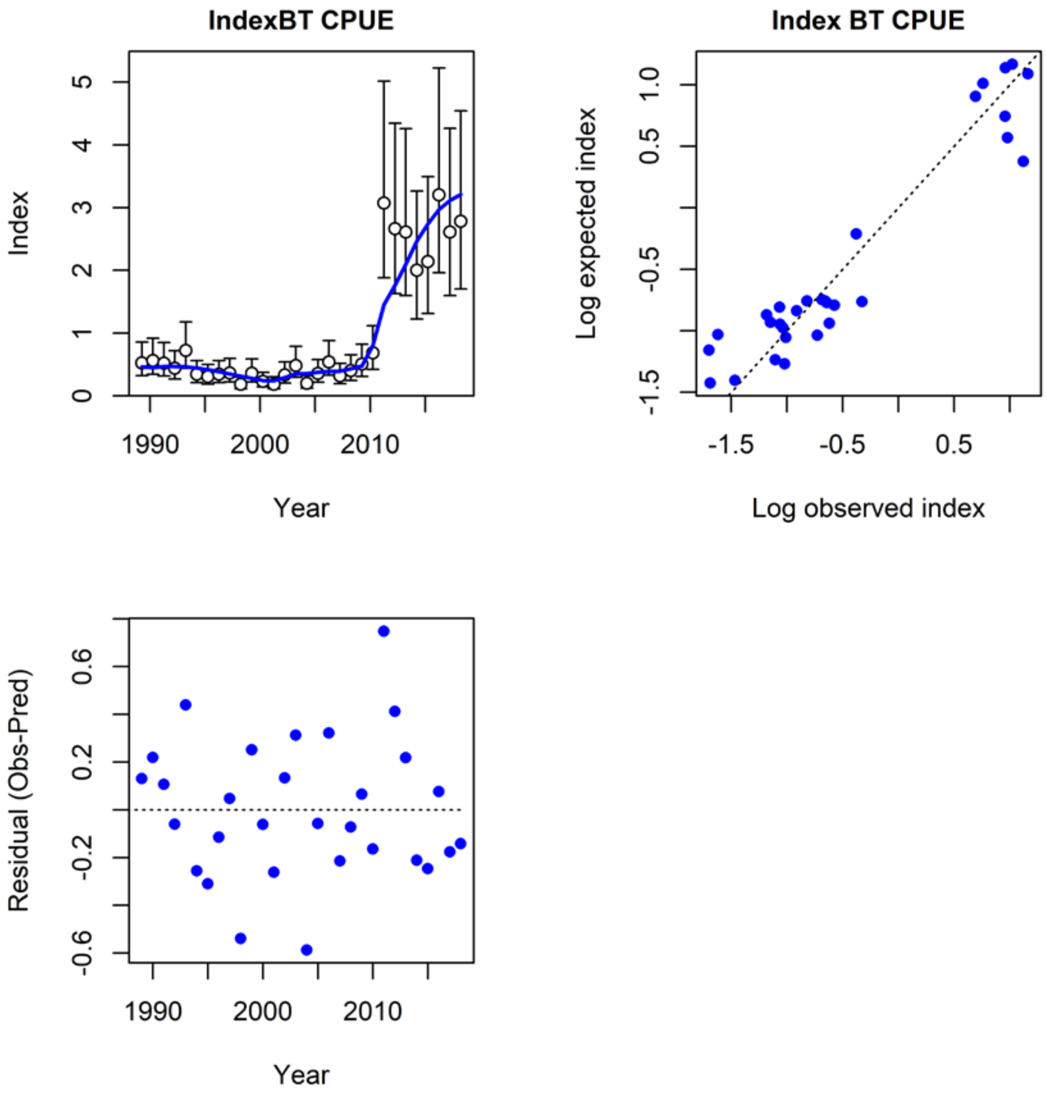

Figure 24: Fit to the CPUE indices and associated diagnostics for the base model. The year represents the model year denoted by the start of the fishing year (e.g., 1990 denotes the 1990/91 fishing year).

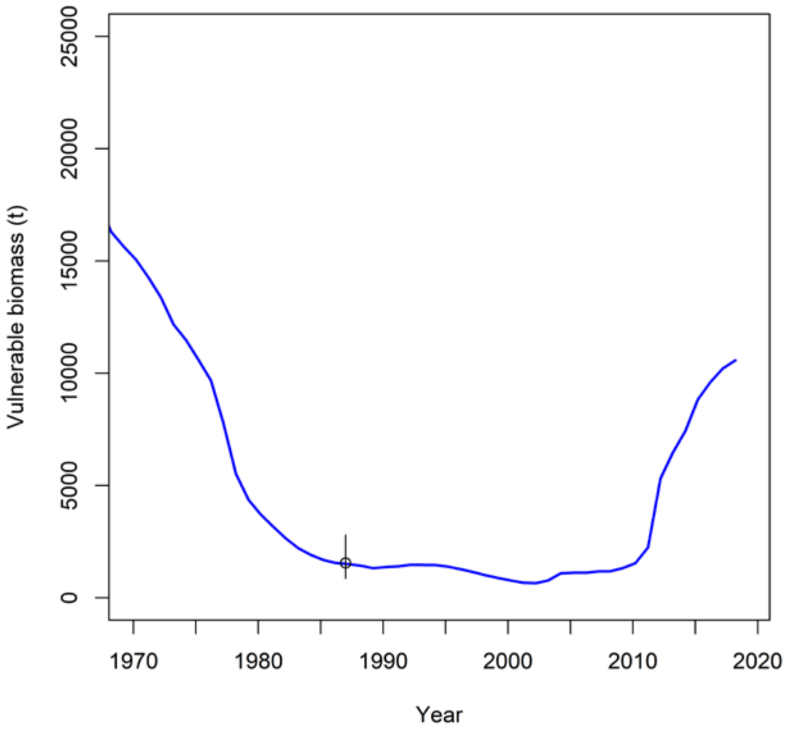

Figure 25: Base model fit to the tagging biomass estimate (point) and associated confidence interval. The vulnerable biomass is determined based on the estimated selectivity function for the BPT fishery.

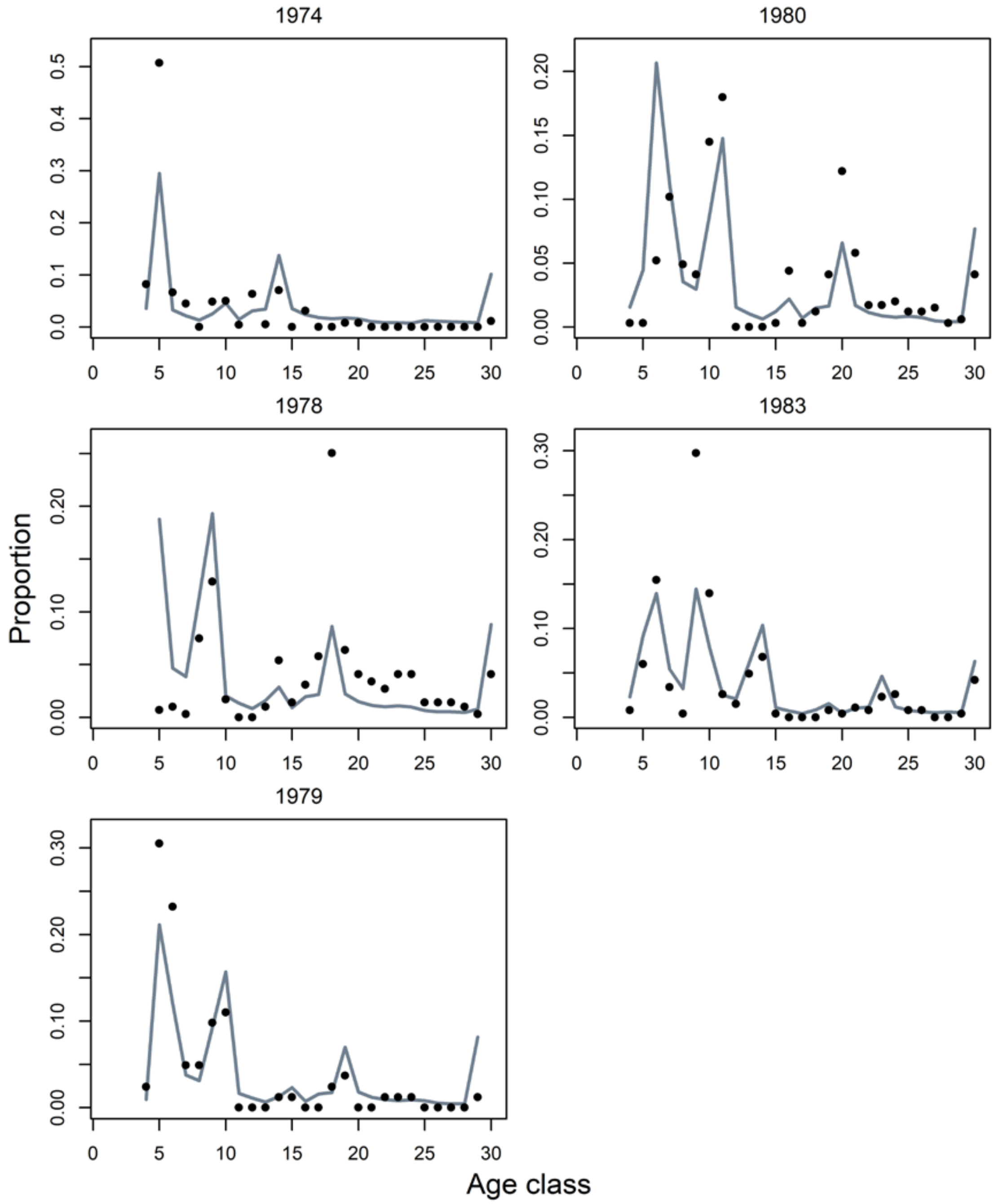

Figure 26: Observed (points) and predicted (line) proportions at age for the bottom pair trawl (BPT) catch-at-age data included in the base model.

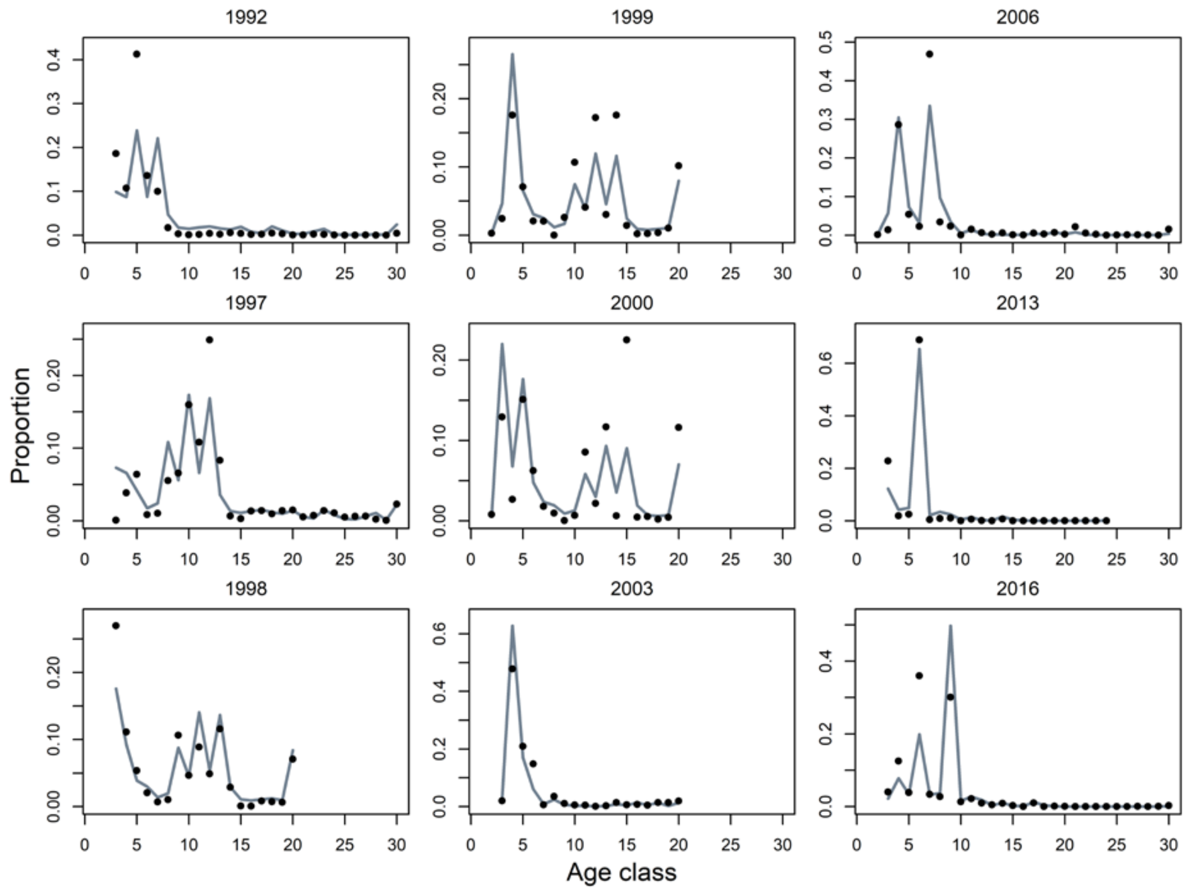

Figure 27: Observed (points) and predicted (line) proportions at age for the bottom single trawl (BT) catch-at-age data included in the base model.

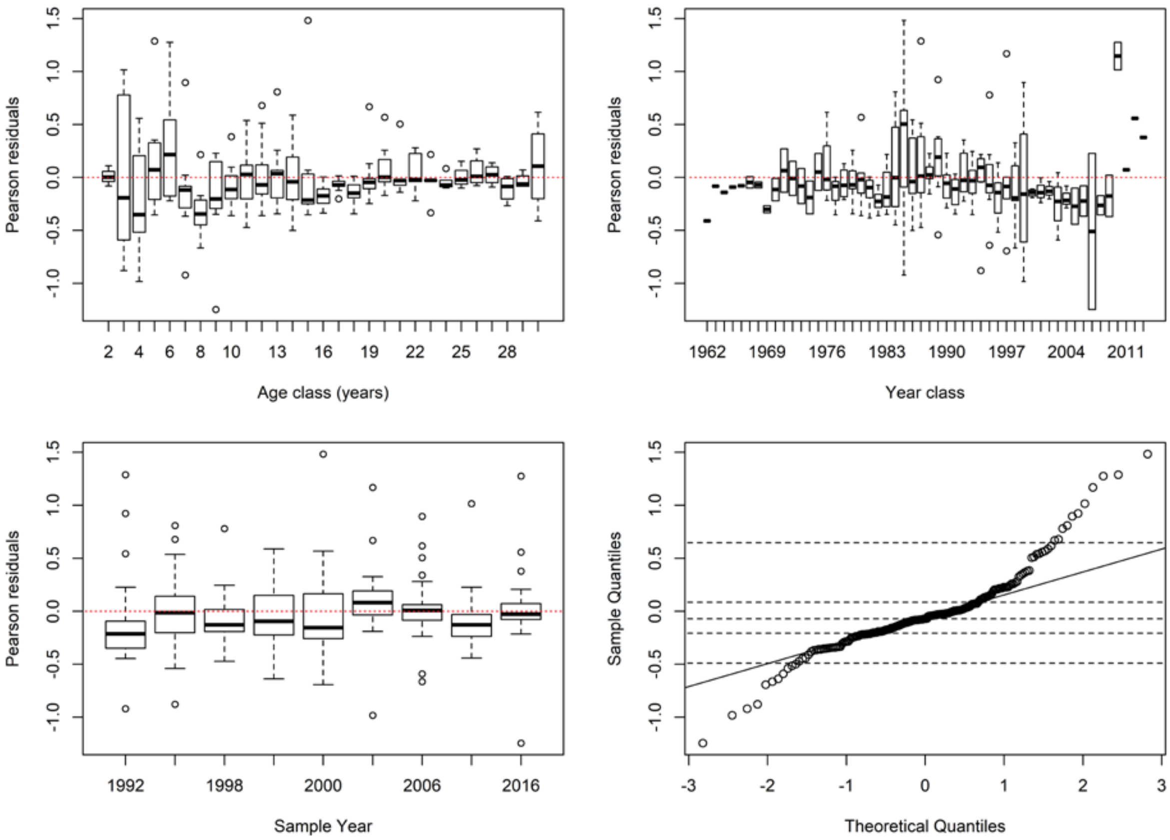

Figure 28: Boxplots of the standardised residuals from the fits of the BT age compositions aggregated by age class (top left panel), year class (top right panel), year of sample (bottom left panel), and the QQ plot of the residuals (bottom right panel).

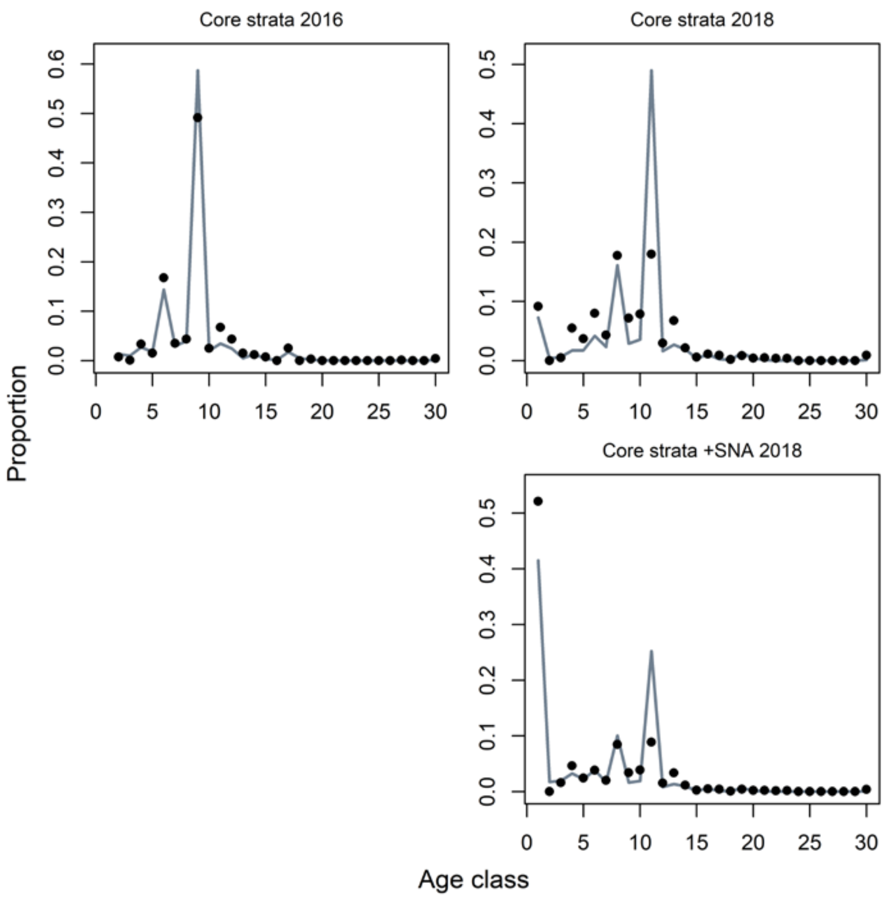

Figure 29: Observed (points) and predicted (line) proportions at age for *Kaharoa* trawl survey age compositions from the base model.

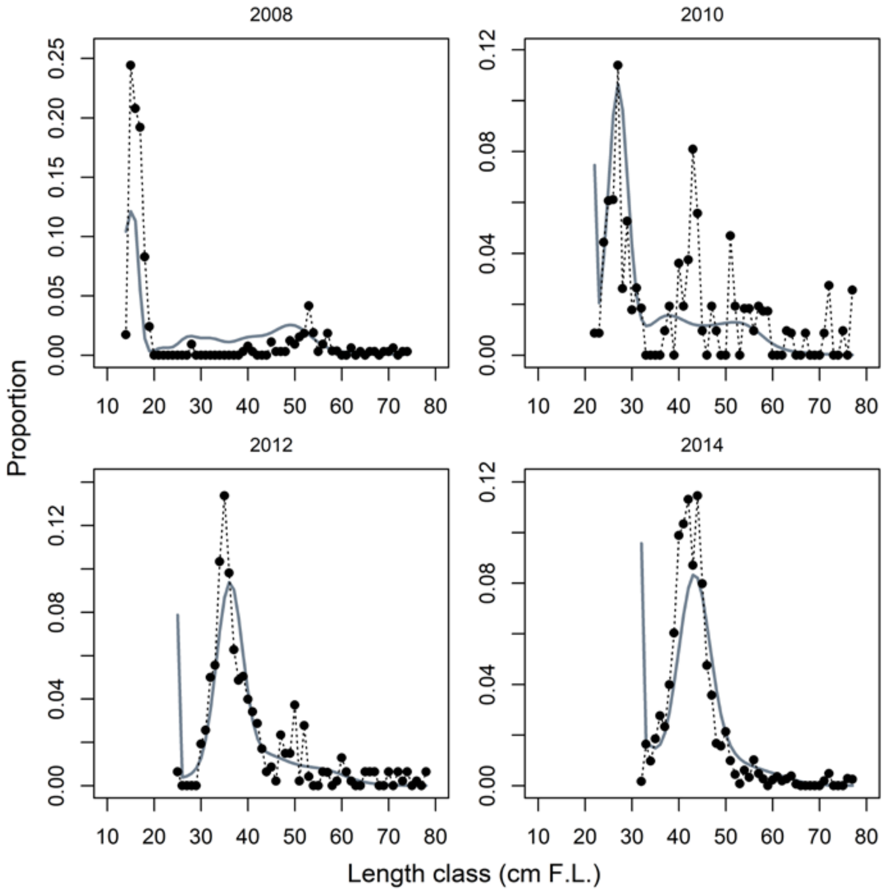

Figure 30: Observed (points) and predicted (grey line) proportions at length for *Kaharoa* trawl survey length compositions (core strata) from the base model.

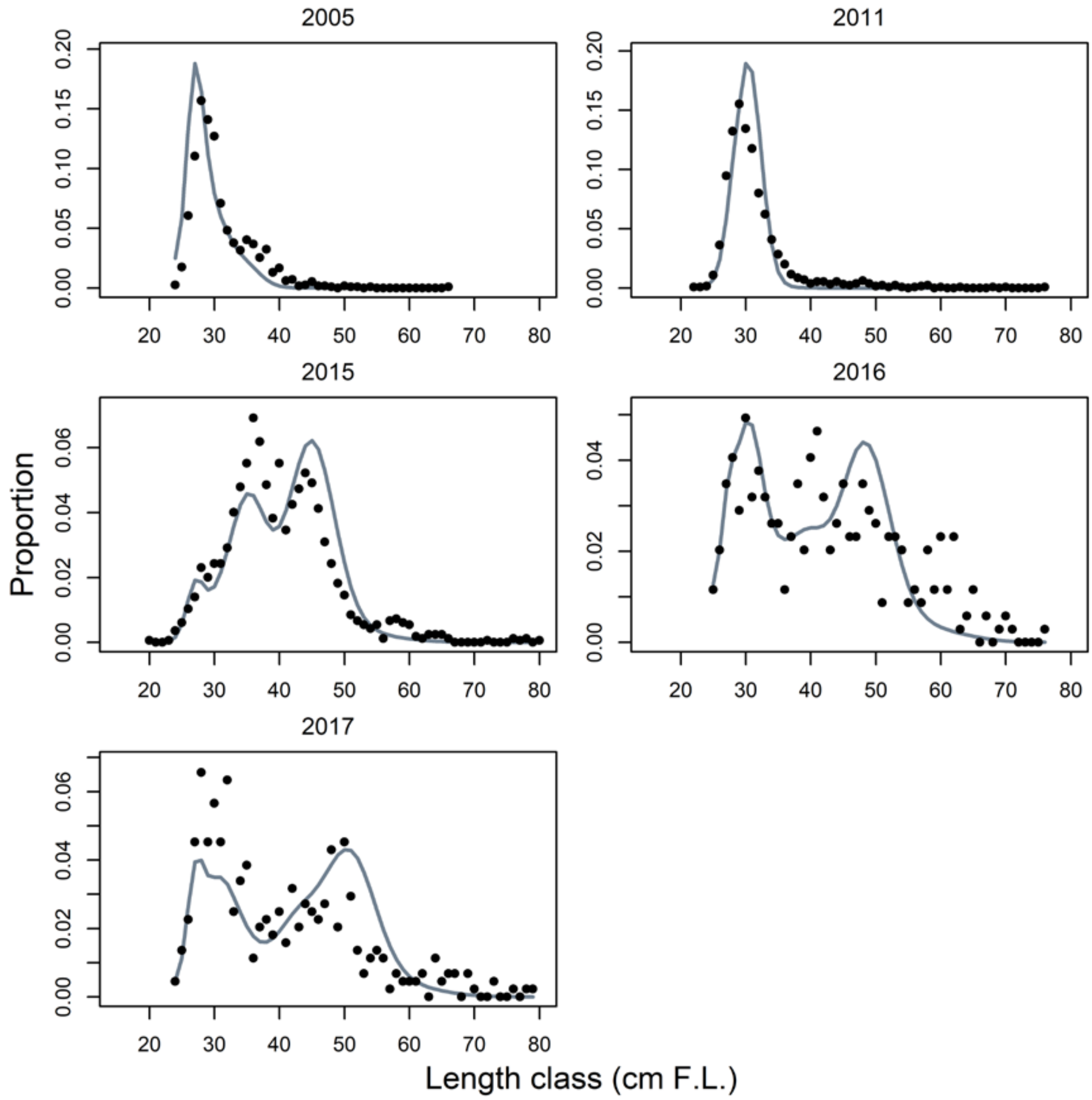

Figure 31: Observed (points) and predicted (line) proportions at length for the recreational fishery length composition from the base model.

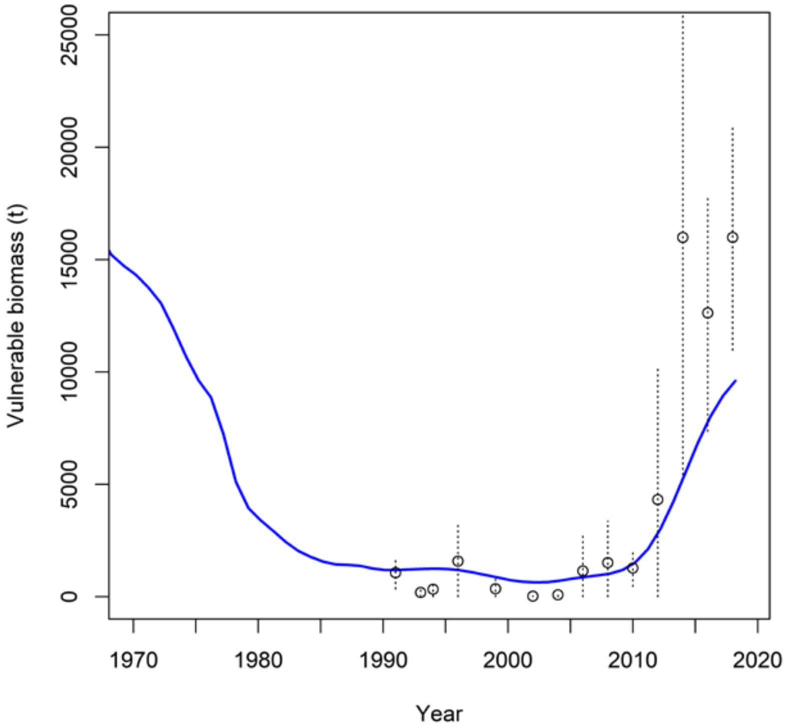

Figure 32: A comparison of the *Kaharoa* trawl survey biomass estimates (core strata) (points and associated confidence intervals) and the trawl survey vulnerable biomass derived from the assessment model based on the estimated selectivity function for the survey. The trawl survey indices are not included in the model likelihood function.

4.9.3 Model sensitivity analyses

During the development of the 2018 assessment model, a wide range of model options were investigated, including differential weightings on the various age composition data sets and the CPUE indices and varying key (fixed) parameters. Most of the alternative options did not result in an appreciable difference in the estimate of current stock status. It was considered that the relatively broad confidence intervals associated with the base model adequately represented the uncertainty associated with most of the additional model options. On that basis, the final set of sensitivity analyses was limited to two model options that yielded substantially different results from the base model: 1) a less optimistic scenario with a lower natural mortality (M = 0.06 compared with 0.075 for the base model) (*LowM*), and 2) a more optimistic scenario with a lower value of *SigmaR* (1.0 compared with 1.5 for the base model) (*SigmaR 1.0)*. The projections for the current assessment model are also likely to be sensitive to the relative strength of the 2017 year class which is estimated to be exceptionally strong in the base model. Consequently, an additional sensitivity was implemented that excluded the estimation of 2017 recruitment deviate (*Recruit2016).*

Overall, the model sensitivities did not result in a large difference in the overall fit to the main abundance and age composition data sets (Table 8). Most of the difference in the total likelihoods was attributable to the contribution from the recruitment deviations component of the likelihood. Reducing the *SigmaR* parameter from 1.5 to 1.0 reduced this component of the likelihood from 33.9 to 23.4.

Table 8: Model log likelihoods for the base model and selected sensitivity runs.

Model	Likelihood component					
	Total	CPUE indices	Tag	BT age composition	BPT age composition	Survey age composition
base	65.3	-21.9	-1.2	12.1	14.2	3.5
lowM	68.6	-21.2	-1.2	11.9	16.3	3.7
SigmaR 1.0	60.5	-21.4	-1.1	14.8	14.6	3.5
Recruit2016	68.8	-22.0	-1.2	12.5	14.1	4.1

4.10 Stock status

The base assessment model estimated that the spawning biomass declined substantially from 1950 to the mid-1980s when the stock biomass is estimated to have been approximately 6% of the virgin (SB_0) level (Figure 33). The stock biomass is estimated to have remained at about that level throughout the 1990s and 2000s and then increased rapidly from 2009 to reach 39% of the SB_0 level in 2018 (SB_{2018}).

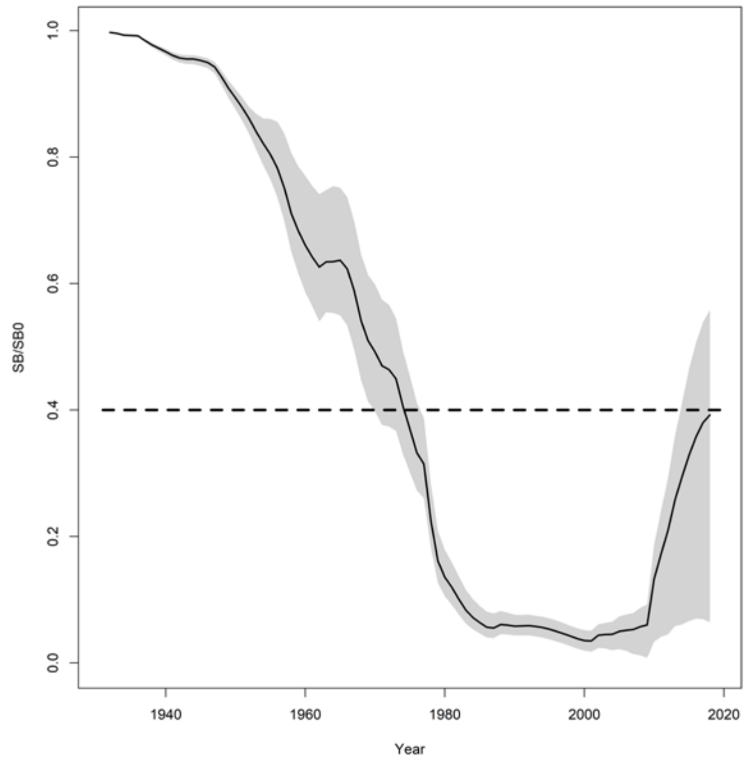

Figure 33: Spawning biomass relative to the default target spawning biomass reference point from the base assessment model. The solid line represents the median of the MCMC samples and the shaded area represents the 90% confidence interval. The horizontal line represents the default target biomass level.

The stock status of SNA 7 is currently assessed relative to a default target biomass level of 40% SB_0 ($SB_{40\%}$) and associated soft limit and hard limit of 20% and 10% of SB_0, respectively (Ministry of Fisheries 2008). Stock status (current 2018 and forecast to 2024) for spawning biomass is reported relative to the default hard and soft limits and the target biomass level. Fishing mortality (in 2018 and 2024) is reported relative to the corresponding interim target biomass level (i.e., $F_{SB40\%}$) based on the 2018 age-specific exploitation pattern.

For the base model, biomass is estimated to have increased considerably from 2010 and current (2018) biomass is well above the soft limit (20% SB_0). There is considerable uncertainty in the magnitude of the recent increase in biomass, although the stock is estimated to be at about the interim target biomass level (40% SB_0) (Figure 33 and Table 9). The model sensitivity runs estimated current stock status that bracketed the base model estimates: more optimistic stock status from the lower *SigmaR* sensitivity run and less optimistic current stock status from the lower natural mortality and recent recruitment sensitivities.

The 95% confidence intervals associated with estimates of current biomass indicate that there is considerable uncertainty in the estimates of current stock status (Table 9). While the confidence intervals indicate that there is some probability that the stock has remained at a low level, the probability distributions of the stock status metrics are asymmetric and there is a very low (approximately 5%) probability of the stock being below 10% SB_0 (Table 9).

For all model options, current rates of fishing mortality are below the corresponding fishing mortality threshold ($F_{SB40\%}$) (Table 9 and Figure 34).

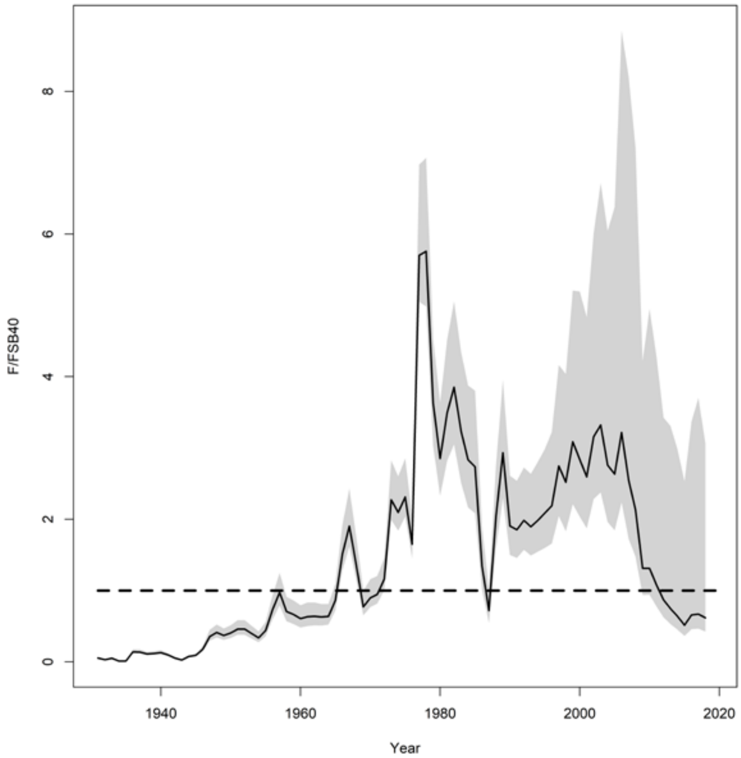

Figure 34: Annual fishing mortality relative to the level of fishing mortality that corresponds to the default target spawning biomass from the base assessment model. The solid line represents the median of the MCMC samples and the shaded area represents the 90% confidence interval. The horizontal dashed line represents the $F_{SB40\%}$ fishing mortality.

Estimates of current and equilibrium yield were derived for the stock based on the fishing mortality rate that corresponds to the interim target biomass level (Table 10). Equilibrium yields at the interim target biomass level (40% B_0) are estimated to be about 500–750 t per annum. $F_{SB40\%}$ yields at 2018–19 biomass levels are comparable to the yields at 40% B_0. Current $F_{SB40\%}$ yields are higher than the level of current catch (the 2018/19 model catch is 428 t).

Table 9: Stock status in 2018 (2018/19 fishing year) relative to default target (*SB40%*) biomass and corresponding fishing mortality level ($F_{SB40\%}$) for the base model and main model sensitivity runs. The probability of current biomass being above default limit biomass reference levels and below the level of fishing mortality associated with the interim target biomass level is also presented. The values represent the median and the 95% confidence interval from the MCMCs.

Model	SB_0	SB_{2018}	SB_{2018}/SB_0	$SB_{2018}/SB_{40\%}$	Pr(SB_{2018} > $X\%SB_0$)			$F_{SB40\%}$	$F_{2018}/F_{SB40\%}$	Pr(F_{2018} <$F_{SB40\%}$)
					40%	20%	10%			
Base	16 150	6 348	0.392	0.981	0.468	0.905	0.945	0.0545	0.617	0.869
	(13 367–19 242)	(1–9 480)	(0–0.594)	(0–1.486)				(0.0412–0.0569)	(0.402–8.357)	
lowM	18 503	6 187	0.333	0.833	0.209	0.856	0.932	0.0464	0.743	0.780
	(16 212–21 081)	(1–9 181)	(0–0.5)	(0–1.251)				(0.036–0.0484)	(0.493–10.137)	
SigmaR 1.0	12 401	6 212	0.504	1.26	0.745	0.899	0.924	0.0534	0.661	0.824
	(10 827–14 117)	(1–9 086)	(0–0.749)	(0–1.872)				(0.0366–0.0568)	(0.426–12.203)	
Recruit2016	16 527	5 787	0.349	0.872	0.287	0.882	0.931	0.0545	0.697	0.808
	(14 258–19 504)	(1–8 842)	(0–0.524)	(0–1.311)				(0.0378–0.057)	(0.439–13.575)	

Table 10: Estimates of annual yield (t) at $F_{SB40\%}$ for $SB_{40\%}$ and SB_{2018} (2018/19) biomass levels, for the base model and the model sensitivity runs. The values represent the median and the 95% confidence interval from the MCMCs.

Model option	Annual yield	
	$SB_{40\%}$	SB_{2018}
Base	700 (526–855)	670 (0–1 032)
lowM	685 (524–791)	558 (0–838)
SigmaR 1.0	529 (366–612)	636 (0–988)
Recruit2016	720 (495–850)	612 (0–972)

For the base model option, stock projections were conducted for the 5-year period following the terminal year of the model (i.e., 2020–2024) with the catches in each year set at the level of the 2018 catches (2018 = 2018/19 fishing year), i.e. commercial catch equivalent to the TACC of 250 t, recreational catch 153 t, and other mortality 25 t (10% of TACC) representing a total catch of 428 t. During the projection period, recruitments were resampled from the lognormal distribution around the geometric mean.

The projections are largely driven by the continued increase in the biomass of the 2007 and 2010 year classes followed by the recruitment of the exceptionally strong 2017 year class, resulting in an increase in total biomass during the projection period. For all scenarios, spawning biomass in 2024 is forecast to be well above the soft limit (20% SB_0) and there is a high probability of being above the target biomass (*SB40%*) level for all scenarios that estimate recruitment for 2017 (Table 11). There is a considerably lower probability of being above the target biomass level when recruitment in 2017 is assumed to be at the equilibrium level.

Table 11: Stock status in the terminal year 2024 (2024/25 fishing year) of the 5-year forecast period for the four projection scenarios.

Scenario	*Pr (SB2024 > X% SB0)*		
	10%	20%	40%
Base	0.961	0.950	0.842
lowM	0.957	0.929	0.737
SigmaR 1.0	0.940	0.933	0.877
Recruit2016	0.938	0.892	0.387

5 DISCUSSION

The updated CPUE indices are very comparable to the previous iteration (Langley 2018) and have remained at a similar level over the last eight years. These indices are the primary index of stock abundance included in the assessment model. Consequently, the results of the current assessment are very similar to the previous (2018) stock assessment. The current assessment estimates that biomass has continued to increase over the last few years, although the rate of increase has attenuated as the stock approached the default target biomass level. Recent stock trends and the estimate of current stock status are dependent on the estimates of recruitment of the strength of the 2007 year class and, to a lesser extent the 2010 year class.

All indications are that 2007 was a very strong year class which has dominated the catch over the last eight years (from 2011). However, there remains considerable uncertainty associated with the estimated abundance of this year class. The estimates of recent recruitment are primarily informed by the trawl CPUE indices (from 2008/09) and the age compositions from the BT fishery and trawl surveys. However, the stock assessment model reveals a relatively poor fit to recent observations from these data sets, indicating lower precision of these observations and/or deviation from the structural assumptions of the model. For example, trends in the CPUE indices from 2012/13 have not followed the continued increase in the biomass estimated by the assessment model. A possible explanation is that the snapper CPUE indices initially increased rapidly due to an increase in the targeting of snapper as abundance increased following the recruitment of the 2007 year class. However, there is likely to have been a degree of avoidance of snapper over the following years because abundance continued to increase as catches were increasingly constrained by the TACC (with limited annual catch entitlement available to cover snapper bycatch).

The fit to the 2016/17 BT age composition is also poor, particularly the fits to the relative strength of the 2007 and 2010 year classes. The age composition includes snapper catches from both the target FLA and SNA trawl fisheries (Parsons et al. 2018). However, between the two main components of the trawl fishery there is a marked difference in the relative strength of the 2007 and 2010 year classes in the constituent age compositions which was not consistent with the previous catch sampling in 2013/14 (Parker et al. 2015). This suggests that there is considerable variation in the age composition of the catches from the two fisheries (FLA and SNA), and changes in the operation of the BT fishery may potentially influence the overall age composition of the catch.

The current assessment model incorporated the snapper age compositions derived from the 2017 and 2019 *Kaharoa* trawl survey (core strata). These age compositions also reveal differences in the relative proportions of the 2007 and 2010 year classes between the successive samples. The increase in the proportion of the 2010 year class in the core survey age composition may be attributable to the movement of these fish to deeper water between successive surveys. However, the fit to the latest age composition was poor which indicates that the selectivity of the trawl survey is poorly determined in the model and there is a degree of conflict with other key data sets, principally the CPUE indices. Additional model trials were conducted to better fit the recent age composition data, but the results did not change the fundamental conclusions of the assessment, especially stock status.

Differences in the spatial (depth) distribution of snapper by length and/or age may explain the differences in the timing of the increase in the trawl survey biomass indices and CPUE indices; the trawl survey biomass indices increased markedly in 2015, several years after the initial large increase in the CPUE indices (in 2011/12) (Figure 32). The increase in the trawl survey biomass indices corresponded with the presence of the 2007 year class in the survey age composition (in 2015 at age 8 years) (Langley 2015), several years after the year class was first observed in the commercial age composition (2013). This delay is consistent with the extension of the distribution of the cohort into the deeper area sampled by the trawl survey.

Thus, the core area trawl survey biomass estimates are presumed to be dominated by the older age classes, whereas recent recruits (25–35 cm, 3–5 year olds) appear to be under-represented in the core area survey. The core-area time-series of trawl survey biomass indices are not included in the current stock assessment on the basis that the survey was considered unlikely to adequately monitor juvenile and adult snapper abundance because the surveys did not sample the shallower areas of Tasman Bay/Golden Bay and catch rates of snapper were variable, resulting in broad confidence intervals associated with the biomass estimates. Recent modifications of the trawl survey design (in 2017) to include the shallower areas of Tasman Bay/Golden Bay are likely to improve the utility of the survey for monitoring SNA 7, particularly for juvenile snapper. It may also be possible to accommodate the existing time series of trawl survey biomass estimates by reconsidering the age- or length-based selectivity of the survey.

The most recent survey (2019) observed a high abundance of juvenile (1 year old) snapper within the shallower reaches of TBGB. This survey indicated the presence of a strong 2017 year class. However, the stock assessment model is unable to accurately estimate the strength of the year class due to the limited number of surveys (2) that have included the shallower area. This introduces considerable uncertainty in the stock projections because this year class recruits to the fishery from 2021 and projected stock status is sensitive to recent recruitment assumptions. Thus, the next trawl survey (in 2021) will be important for the monitoring of the strength of the 2017 year class and subsequent recruitment (2018–2020).

Overall, the assessment indicates that the SNA 7 stock has recovered from a low level. The large catches during the late 1970s and early 1980s reduced the stock biomass to below 10% of the virgin biomass level and the stock remained at this low level throughout the 1990s and 2000s. The determination of current stock status is dependent on the model estimate of virgin biomass (SB_0) which is strongly influenced by the accumulated catch in the period prior to the mid-1980s. The catch history of snapper has been relatively well documented, particularly during the period of peak catches (late 1970s–early 1980s). However, the results of the assessment will be sensitive to the magnitude of additional unreported catch assumed during the period prior to the introduction of the QMS.

6 FURTHER RESEARCH

Estimates of current (and projected) stock status are relatively uncertain due to the low precision of the recent CPUE indices and, correspondingly, the uncertainty in the estimation of the strength of recent year classes (particularly the 2007 and 2017 year classes). The RV *Kaharoa* trawl survey was modified in 2017 to encompass the shallower areas of Tasman Bay/Golden Bay and, thereby, improve the monitoring of snapper abundance. The results of the 2017 and 2019 surveys were encouraging and the modified trawl survey design may enable snapper abundance to be monitored more accurately, thus improving future estimates of stock biomass.

Further sampling of the snapper age composition would provide additional information regarding the relative strength of the dominant year classes. Additional age composition data will be available from the sampling of the commercial catch in 2019/20. However, the additional sample will not provide information regarding the magnitude of the 2017 year class; these fish will not recruit to the commercial fishery until the following year (from 2020/21).

The 2017 year class will be sampled again by the next trawl survey which is scheduled for March–April 2021. The additional age composition data from this survey, in conjunction with the commercial age composition from 2019/20, will improve model estimates of trawl survey selectivity and may enable the time-series of trawl survey biomass estimates to be incorporated directly in the stock assessment model. The next stock assessment is also scheduled for 2021. It is recommended that the model structure be refined to address the apparent conflict between a number of the key data sets (CPUE indices and age compositions) by incorporating additional spatial structure in the stratification of the commercial fishery.

In recent years, the recreational fishery has accounted for a significant proportion of the total catch from the fishery and it is anticipated that recreational catches will remain relatively high in future years. Regular estimates of recreational catch would improve the precision of current estimates of total catch from SNA 7. The determination of an estimate of recreational catch may also provide the opportunity to collect additional size composition data from the recreational fishery.

In SNA 1, annual recruitment strength has been shown to be positively correlated with sea water temperatures (Francis 1993, Francis et al. 1995). In SNA 7, recruitment variability has also been linked to prevailing environmental conditions (Harley & Gilbert 2000, Langley 2015). The ongoing refinement of recruitment estimates (direct or indirect) and more accurate environmental data may enable the development of a predictive model for snapper recruitment in SNA 7.

7 ACKNOWLEDGEMENTS

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APPENDIX 1: DETAILED RESULTS FROM CPUE ANALYSIS

Table A1: Summary of the catch and effort data from the TBGB Daily single trawl CPUE data set (core vessels only).

Fishing year	Number records	Number vessels	Number trips	Catch (t)	Number trawls	Duration (hrs)	Percent zero catch
1989/90	690	22	366	42.1	2 189	5 036	35.7
1990/91	736	23	336	43.8	2 464	5 940	34.0
1991/92	652	21	296	40.7	2 169	5 545	33.6
1992/93	850	29	400	44.3	2 964	7 688	33.2
1993/94	557	27	263	39.2	1 891	4 713	36.4
1994/95	593	28	330	26.6	1 980	4 659	42.3
1995/96	523	25	253	25.0	1 571	4 052	46.7
1996/97	792	27	347	33.9	2 490	6 670	44.7
1997/98	651	25	260	40.4	2 111	5 711	45.9
1998/99	496	24	191	33.6	1 531	4 740	49.6
1999/2000	304	24	128	39.0	864	2 871	39.1
2000/01	404	18	163	34.1	1 270	4 118	39.1
2001/02	391	17	176	16.8	1 196	3 985	55.2
2002/03	425	16	181	36.1	1 328	4 362	38.6
2003/04	546	26	229	32.9	1 669	5 504	33.5
2004/05	482	19	186	17.6	1 360	4 464	41.3
2005/06	414	15	151	25.3	1 151	3 666	38.6
2006/07	770	23	298	41.7	2 274	7 140	31.9
2007/08	726	26	270	63.6	2 027	6 489	27.5
2008/09	582	26	223	67.0	1 510	4 938	35.2
2009/10	780	27	303	59.0	2 189	6 506	29.2
2010/11	531	28	215	70.2	1 456	4 428	22.6
2011/12	429	28	178	79.5	1 106	3 365	17.0
2012/13	461	27	234	89.7	1 211	3 664	16.3
2013/14	565	25	244	80.8	1 516	4 636	15.6
2014/15	545	21	237	83.5	1 496	4 696	18.3
2015/16	561	21	225	78.9	1 505	4 907	16.4
2016/17	551	18	254	112.2	1 462	4 716	10.3
2017/18	524	17	224	87.3	1 357	4 470	13.2
2018/19	461	17	204	87.2	1 170	4 045	15.2

Table A2: Annual Tasman/Golden Bay snapper bottom trawl Daily CPUE indices and the lower (LCI) and upper (UCI) bounds of the 95% confidence intervals.

Fish year	Model year	Combined			Binomial			Lognormal		
		Index	LCI	UCI	Index	LCI	UCI	Index	LCI	UCI
89/90	1989	0.647	0.520	0.796	0.643	0.579	0.698	1.000	0.832	1.213
90/91	1990	0.692	0.549	0.849	0.626	0.570	0.681	1.105	0.896	1.337
91/92	1991	0.639	0.497	0.799	0.646	0.584	0.701	0.990	0.794	1.216
92/93	1992	0.542	0.424	0.668	0.645	0.590	0.699	0.839	0.682	1.028
93/94	1993	0.888	0.700	1.112	0.600	0.536	0.659	1.481	1.183	1.823
94/95	1994	0.424	0.324	0.553	0.531	0.466	0.597	0.800	0.638	0.993
95/96	1995	0.378	0.278	0.496	0.499	0.430	0.565	0.756	0.602	0.954
96/97	1996	0.426	0.324	0.541	0.492	0.429	0.554	0.865	0.689	1.074
97/98	1997	0.448	0.339	0.566	0.483	0.424	0.547	0.928	0.733	1.157
98/99	1998	0.225	0.165	0.300	0.444	0.377	0.515	0.506	0.392	0.651
99/00	1999	0.444	0.315	0.599	0.507	0.425	0.584	0.877	0.663	1.144
00/01	2000	0.284	0.205	0.377	0.483	0.410	0.560	0.589	0.455	0.742
01/02	2001	0.228	0.166	0.313	0.388	0.323	0.458	0.588	0.449	0.765
02/03	2002	0.408	0.301	0.541	0.566	0.493	0.632	0.720	0.556	0.936
03/04	2003	0.595	0.456	0.767	0.598	0.531	0.660	0.995	0.782	1.245
04/05	2004	0.244	0.185	0.318	0.531	0.466	0.601	0.459	0.359	0.581
05/06	2005	0.436	0.328	0.576	0.533	0.459	0.603	0.818	0.642	1.035
06/07	2006	0.663	0.525	0.835	0.620	0.563	0.677	1.070	0.867	1.322
07/08	2007	0.392	0.310	0.483	0.626	0.566	0.691	0.626	0.509	0.760
08/09	2008	0.494	0.378	0.639	0.553	0.483	0.619	0.894	0.695	1.127
09/10	2009	0.621	0.491	0.780	0.643	0.584	0.702	0.965	0.779	1.188
10/11	2010	0.843	0.648	1.070	0.658	0.593	0.723	1.280	1.008	1.591
11/12	2011	3.779	2.935	4.819	0.777	0.713	0.833	4.866	3.843	6.164
12/13	2012	3.274	2.521	4.121	0.813	0.761	0.860	4.025	3.141	5.087
13/14	2013	3.209	2.540	3.982	0.817	0.769	0.861	3.928	3.140	4.878
14/15	2014	2.459	1.899	3.157	0.740	0.677	0.798	3.324	2.625	4.142
15/16	2015	2.633	2.057	3.316	0.791	0.738	0.838	3.329	2.651	4.163
16/17	2016	3.938	3.041	4.921	0.869	0.826	0.907	4.532	3.536	5.620
17/18	2017	3.212	2.494	4.038	0.812	0.752	0.861	3.957	3.086	4.968
18/19	2018	3.422	2.633	4.395	0.789	0.724	0.843	4.334	3.399	5.460

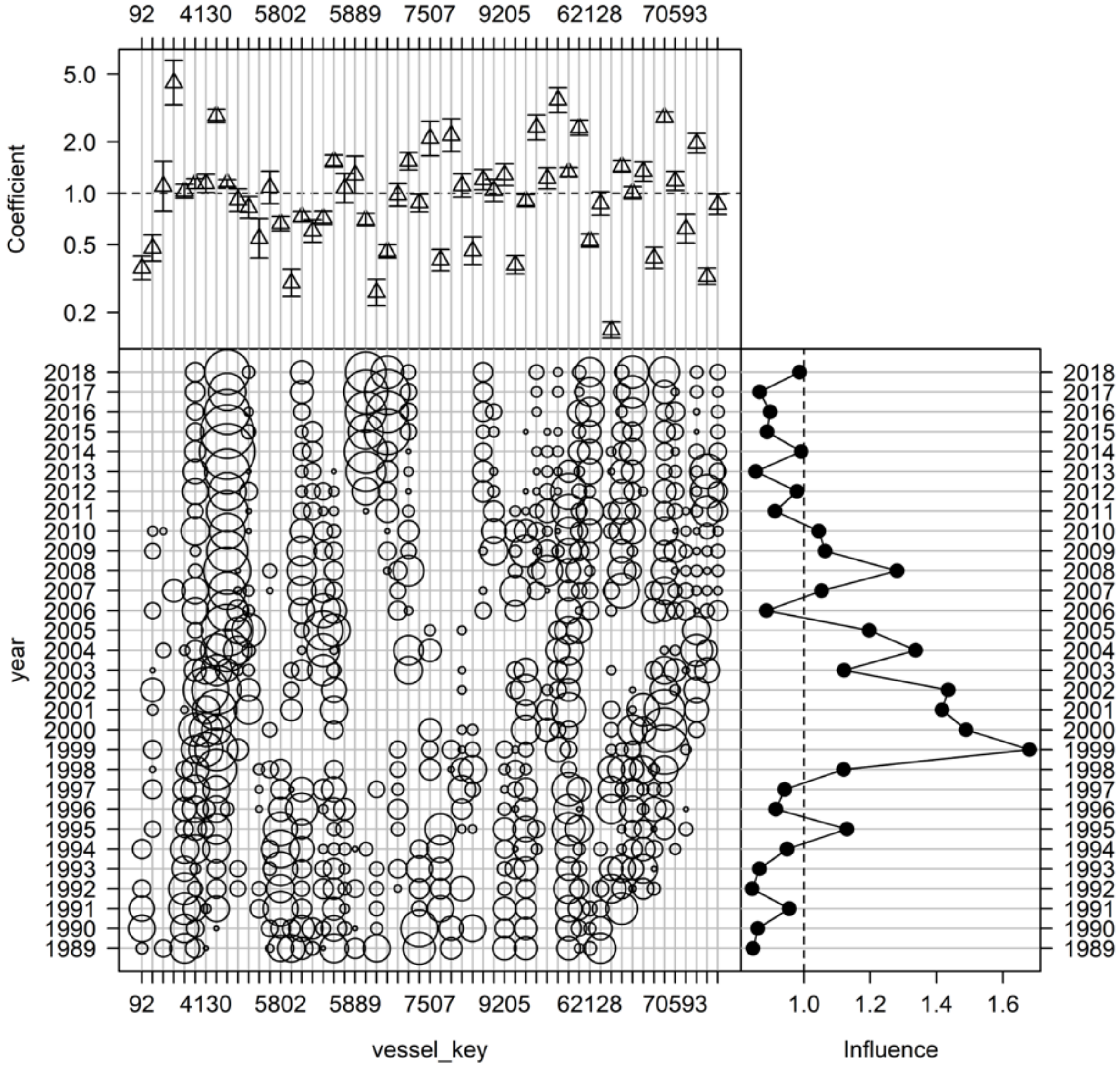

Figure A1: Influence plot for the *Vessel* variable from the Daily lognormal CPUE model.

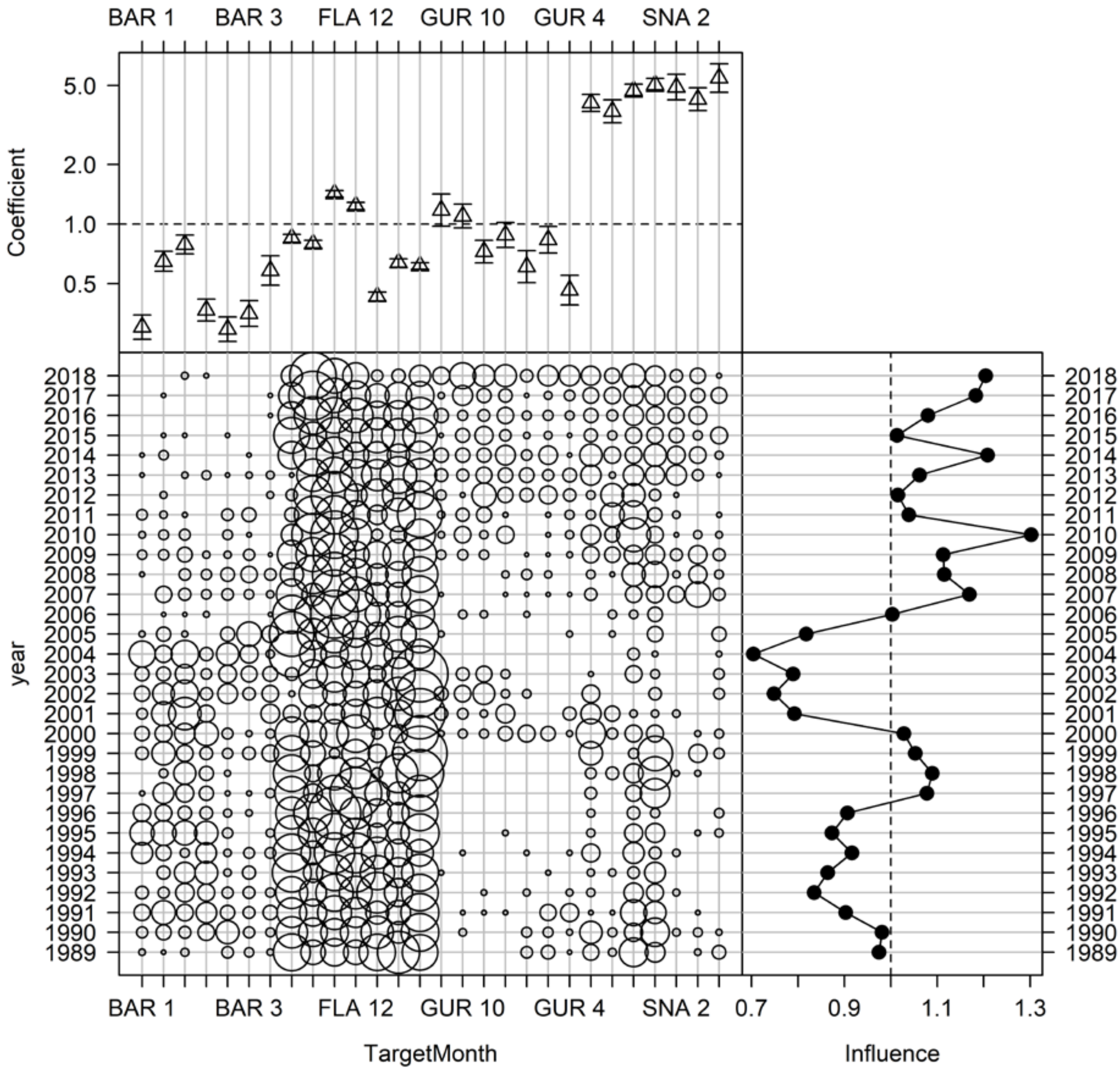

Figure A2: Influence plot for the *TargetSpecies:Month* interactions from the Daily lognormal CPUE model.

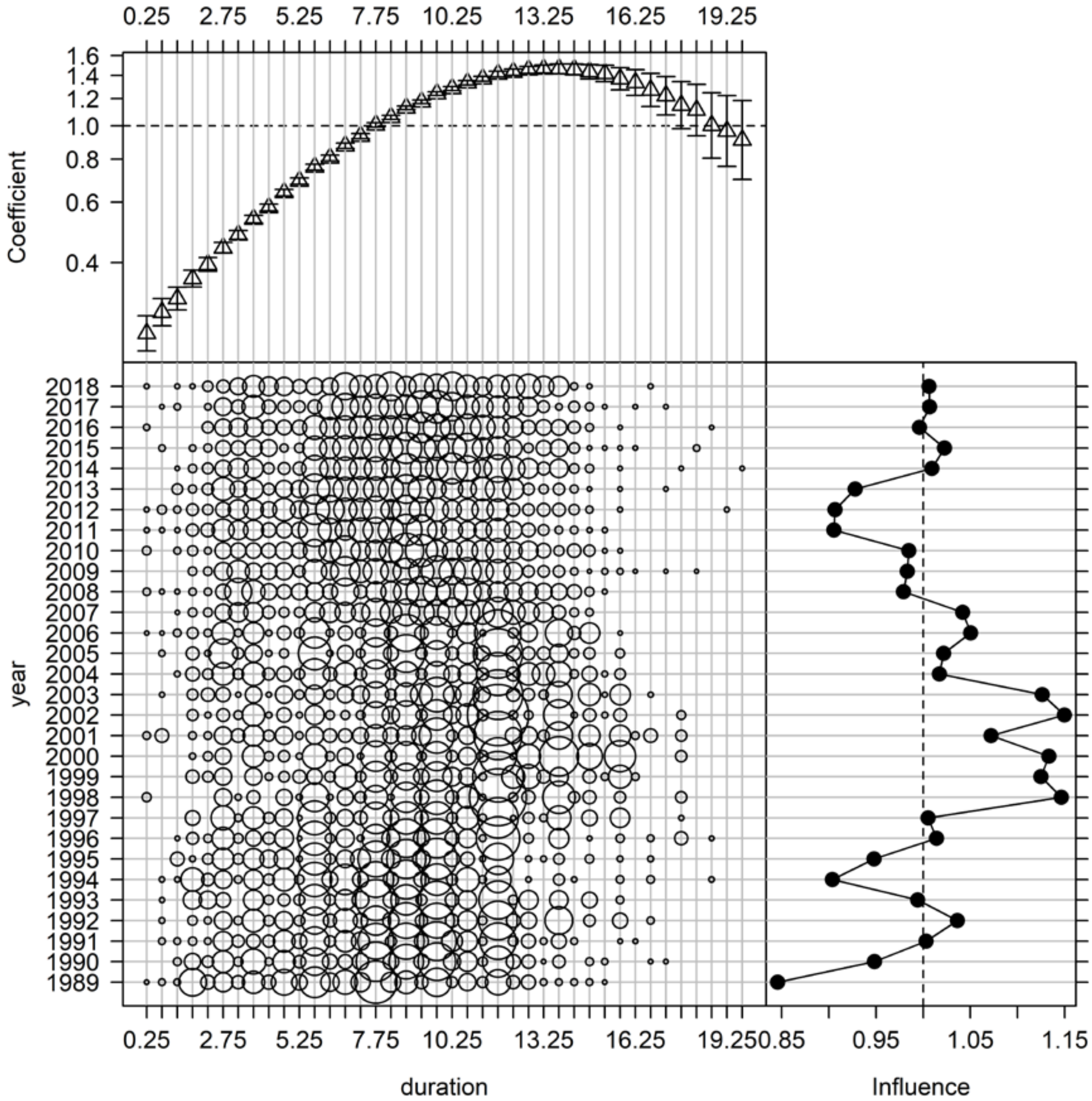

Figure A3: Influence plot for the *Duration* variable from the Daily lognormal CPUE model.

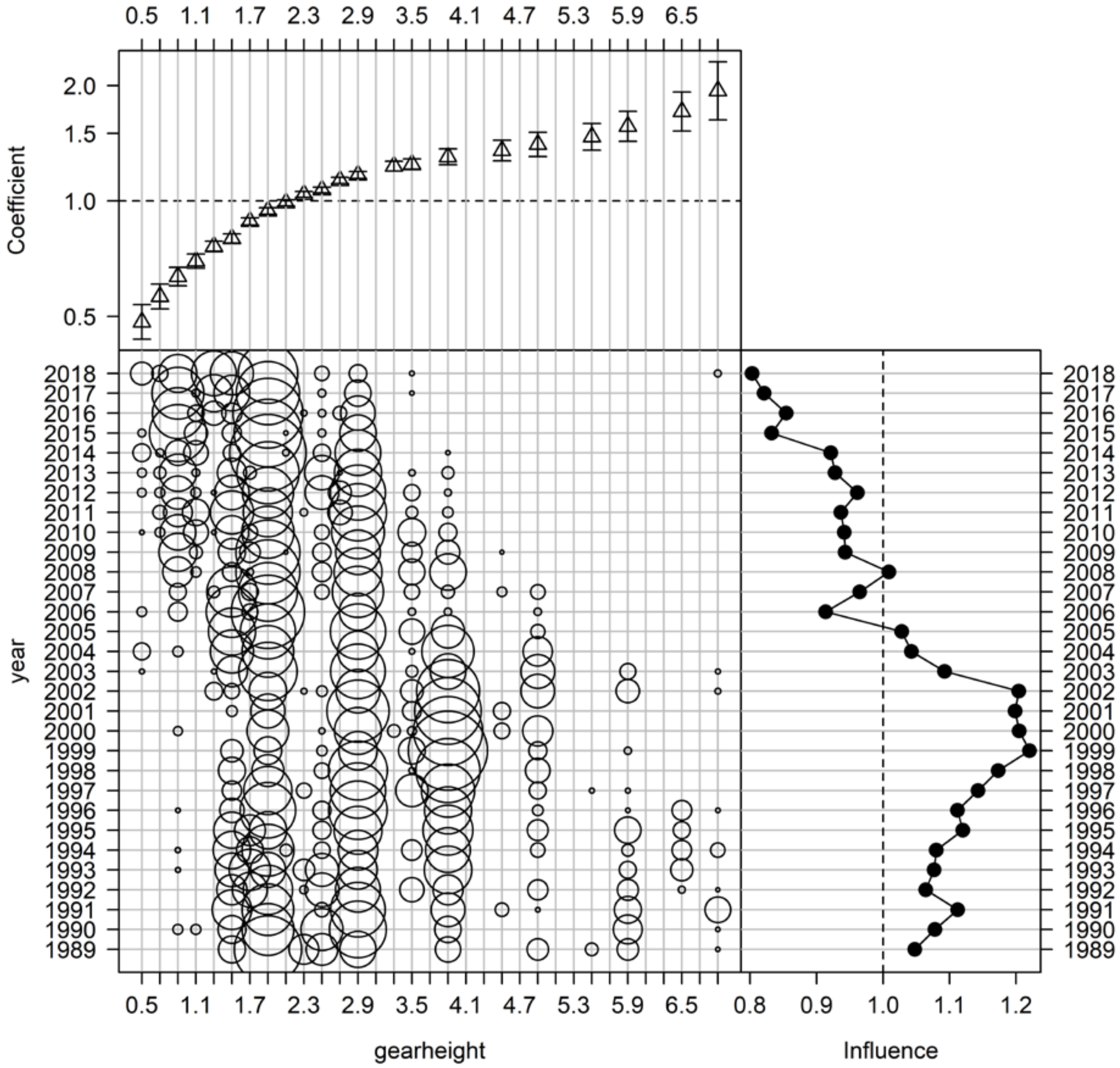

Figure A4: Influence plot for the *GearHeight* variable from the Daily lognormal CPUE model.

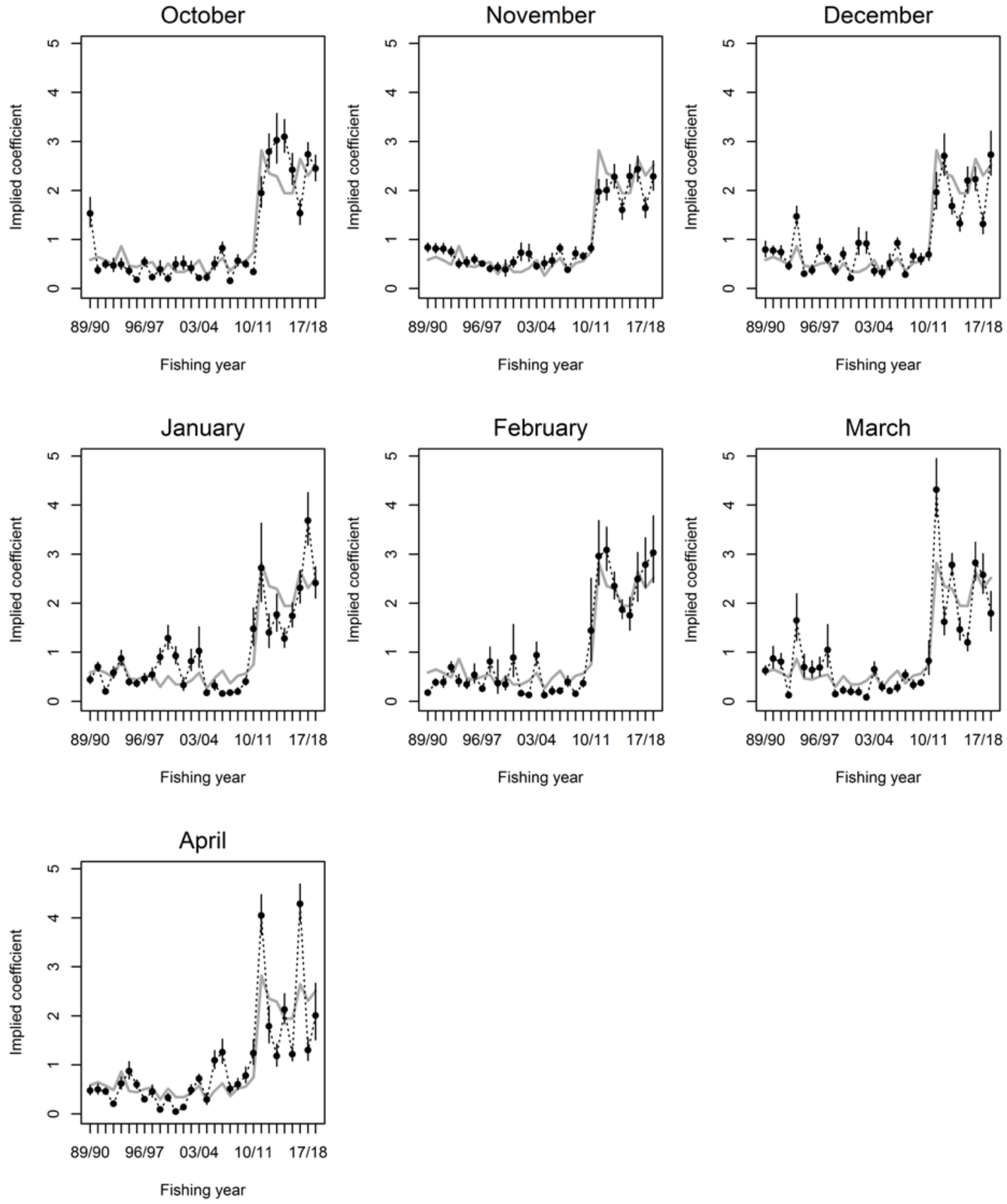

Figure A5: Annual implied coefficients (points) for the individual *Months* included in the Daily lognormal CPUE model (dashed line). The grey line represents the annual CPUE indices derived from the positive catch CPUE model. The confidence intervals represent the standard error of the annual residuals.

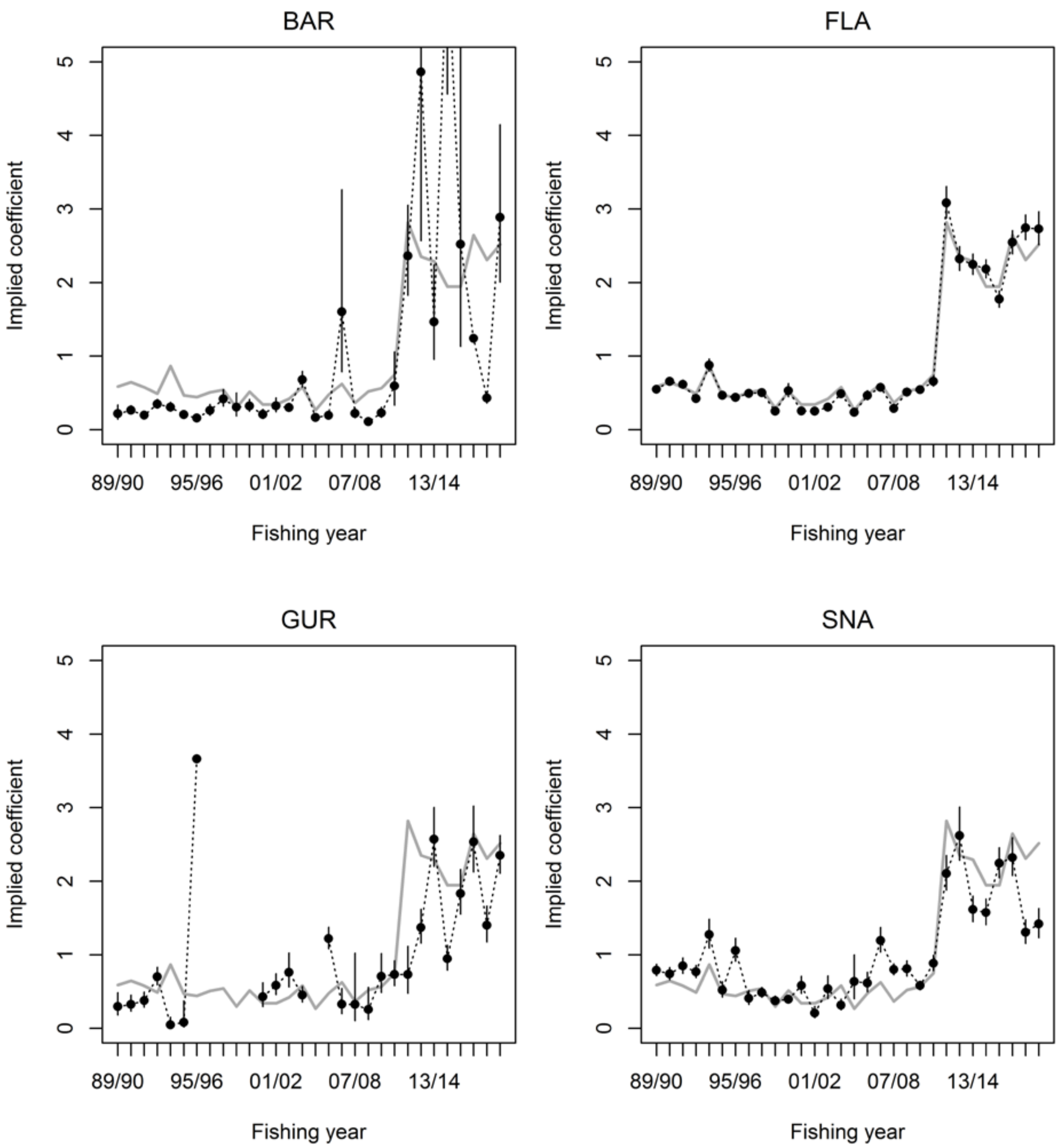

Figure A6: Annual implied coefficients (points) for the individual *TargetSpecies* included in the Daily lognormal CPUE model (dashed line). The grey line represents the annual CPUE indices derived from the positive catch CPUE model. The confidence intervals represent the standard error of the annual residuals.

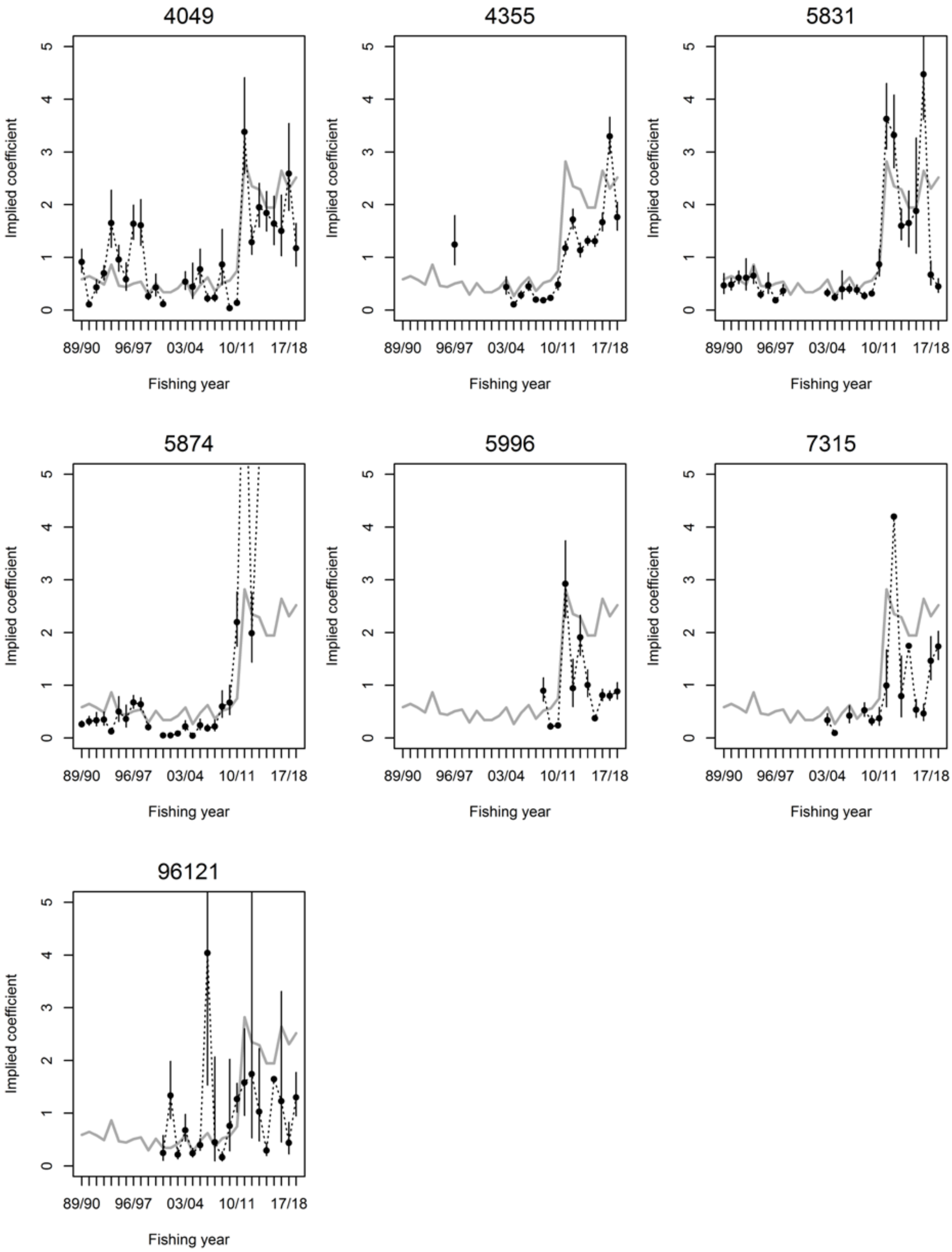

Figure A7: Annual implied coefficients (points) for the main *Vessels* included in the Daily lognormal CPUE model (dashed line). The grey line represents the annual CPUE indices derived from the positive catch CPUE model. The confidence intervals represent the standard error of the annual residuals.

APPENDIX 2: MODEL INPUT DATA SETS

Table A3: Annual snapper catch (t) by fishery (BT, bottom trawl; BPT pair trawl; Rec, recreational) included in the assessment model, including allowances for the under-reporting of the commercial catch. Years are specified as model years and are denoted by the year at the start of the fishing year (e.g., 1986 is the 1986/87 fishing year).

Year	Fishery catch (t)			Year	Fishery catch (t)		
	BT	BPT	Rec		BT	BPT	Rec
1931	83	0	10	1975	473	473	32
1932	43	0	10	1976	250	998	32
1933	78	0	10	1977	171	685	33
1934	8	0	10	1978	326	2 938	26
1935	12	0	10	1979	213	1 918	21
1936	233	0	10	1980	88	791	19
1937	226	0	10	1981	142	568	19
1938	179	0	10	1982	142	567	18
1939	190	0	10	1983	131	522	16
1940	209	0	10	1984	82	326	15
1941	154	0	10	1985	65	259	15
1942	78	0	10	1986	57	226	14
1943	35	0	10	1987	57	199	15
1944	115	0	10	1988	136	58	19
1945	142	0	10	1989	259	65	20
1946	278	0	10	1990	141	35	21
1947	570	0	10	1991	130	33	23
1948	653	0	10	1992	145	36	26
1949	572	0	10	1993	129	32	27
1950	617	0	10	1994	132	33	28
1951	689	0	10	1995	128	32	28
1952	676	0	10	1996	143	36	27
1953	569	0	10	1997	180	20	27
1954	469	0	10	1998	141	16	25
1955	605	0	10	1999	172	19	24
1956	986	0	10	2000	154	17	22
1957	1 266	0	10	2001	140	16	23
1958	865	0	11	2002	185	21	33
1959	780	0	12	2003	213	24	36
1960	688	0	12	2004	176	20	37
1961	700	0	13	2005	164	18	43
1962	698	0	14	2006	246	27	40
1963	683	0	16	2007	185	21	38
1964	689	0	18	2008	203	23	39
1965	936	0	20	2009	186	21	37
1966	1 627	0	21	2010	190	37	78
1967	1 936	0	22	2011	205	33	89
1968	1 244	0	22	2012	232	0	94
1969	659	0	23	2013	231	0	99
1970	751	0	25	2014	231	0	94
1971	768	0	27	2015	208	0	83
1972	920	0	29	2016	289	0	115
1973	1 510	0	31	2017	289	0	147
1974	985	246	31	2018	275	0	153

Table A4: Proportional age compositions for the bottom pair trawl (BPT) fishery. The oldest age class represents an accumulated age class (plus group). Years are specified as model years and are denoted by the year at the start of the fishing season (e.g., 1983 is the 1983/84 fishing season).

Age (yr)	Model year				
	1974	1978	1979	1980	1983
1	0.0000	0.0000	0.0000	0.0000	0.0000
2	0.0000	0.0000	0.0000	0.0000	0.0000
3	0.0000	0.0000	0.0000	0.0000	0.0000
4	0.0819	0.0000	0.0240	0.0030	0.0080
5	0.5071	0.0070	0.3050	0.0030	0.0600
6	0.0663	0.0100	0.2320	0.0520	0.1550
7	0.0449	0.0030	0.0490	0.1020	0.0340
8	0.0000	0.0750	0.0490	0.0490	0.0040
9	0.0485	0.1290	0.0980	0.0410	0.2980
10	0.0501	0.0170	0.1100	0.1450	0.1400
11	0.0043	0.0000	0.0000	0.1800	0.0260
12	0.0633	0.0000	0.0000	0.0000	0.0150
13	0.0051	0.0100	0.0000	0.0000	0.0490
14	0.0705	0.0540	0.0120	0.0000	0.0680
15	0.0000	0.0140	0.0120	0.0030	0.0040
16	0.0309	0.0310	0.0000	0.0440	0.0000
17	0.0000	0.0580	0.0000	0.0030	0.0000
18	0.0000	0.2510	0.0240	0.0120	0.0000
19	0.0080	0.0640	0.0370	0.0410	0.0080
20	0.0080	0.0410	0.0000	0.1220	0.0040
21	0.0000	0.0340	0.0000	0.0580	0.0110
22	0.0000	0.0270	0.0120	0.0170	0.0080
23	0.0000	0.0410	0.0120	0.0170	0.0230
24	0.0000	0.0410	0.0120	0.0200	0.0260
25	0.0000	0.0140	0.0000	0.0120	0.0080
26	0.0000	0.0140	0.0000	0.0120	0.0080
27	0.0000	0.0140	0.0000	0.0150	0.0000
28	0.0000	0.0100	0.0000	0.0030	0.0000
29	0.0000	0.0030	0.0120	0.0060	0.0040
30	0.0111	0.0410	0.0000	0.0410	0.0420

Table A5: Proportional age compositions for the bottom trawl (BT) fishery. The oldest age class represents an accumulated age class (plus group). Model years and are denoted by the year at the start of the fishing year (e.g., 1992 is the 1992/93 fishing year).

Age (yr)	Model year								
	1992	1997	1998	1999	2000	2003	2006	2013	2016
1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	0.0000	0.0000	0.0003	0.0029	0.0079	0.0001	0.0013	0.0000	0.0000
3	0.1861	0.0008	0.2694	0.0244	0.1292	0.0202	0.0139	0.2282	0.0398
4	0.1071	0.0385	0.1111	0.1760	0.0268	0.4780	0.2860	0.0191	0.1250
5	0.4125	0.0640	0.0536	0.0709	0.1512	0.2090	0.0536	0.0253	0.0383
6	0.1358	0.0084	0.0204	0.0207	0.0625	0.1482	0.0229	0.6891	0.3595
7	0.0999	0.0103	0.0068	0.0204	0.0179	0.0062	0.4685	0.0045	0.0336
8	0.0169	0.0553	0.0102	0.0000	0.0097	0.0349	0.0343	0.0092	0.0272
9	0.0031	0.0656	0.1064	0.0259	0.0003	0.0108	0.0231	0.0103	0.3007
10	0.0009	0.1598	0.0465	0.1067	0.0067	0.0052	0.0005	0.0000	0.0130
11	0.0017	0.1083	0.0886	0.0407	0.0854	0.0048	0.0153	0.0059	0.0215
12	0.0040	0.2489	0.0486	0.1722	0.0217	0.0010	0.0064	0.0008	0.0094
13	0.0021	0.0832	0.1157	0.0301	0.1169	0.0028	0.0025	0.0000	0.0048
14	0.0055	0.0067	0.0289	0.1758	0.0062	0.0141	0.0060	0.0070	0.0089
15	0.0039	0.0029	0.0008	0.0142	0.2251	0.0058	0.0011	0.0000	0.0026
16	0.0016	0.0136	0.0005	0.0019	0.0046	0.0073	0.0002	0.0000	0.0000
17	0.0019	0.0141	0.0082	0.0021	0.0053	0.0044	0.0053	0.0000	0.0101
18	0.0048	0.0095	0.0072	0.0034	0.0021	0.0137	0.0027	0.0000	0.0000
19	0.0028	0.0140	0.0063	0.0102	0.0043	0.0140	0.0067	0.0000	0.0009
20	0.0003	0.0148	0.0705	0.1017	0.1162	0.0194	0.0023	0.0000	0.0008
21	0.0005	0.0053					0.0217	0.0000	0.0000
22	0.0021	0.0076					0.0052	0.0000	0.0000
23	0.0018	0.0140					0.0023	0.0000	0.0000
24	0.0003	0.0108					0.0000	0.0006	0.0000
25	0.0000	0.0051					0.0004	0.0000	0.0000
26	0.0000	0.0062					0.0011	0.0000	0.0000
27	0.0002	0.0063					0.0010	0.0000	0.0008
28	0.0001	0.0022					0.0005	0.0000	0.0000
29	0.0000	0.0007					0.0000	0.0000	0.0007
30	0.0042	0.0231					0.0153	0.0000	0.0026

Table A6: Proportional age compositions for the core area of the 2017 and 2019 *Kaharoa* trawl surveys (2016 and 2018 model years) and the extended area (including 10-20 m TBGB) of the 2019 trawl survey. The oldest age class represents an accumulated age class (plus group).

Age (yr)	Core survey area		Include 10-20 m TBGB
	2017	2019	2019
1	0.0000	0.0913	0.5182
2	0.0075	0.0000	0.0000
3	0.0007	0.0048	0.0159
4	0.0333	0.0547	0.0459
5	0.0151	0.0369	0.0242
6	0.1675	0.0795	0.0382
7	0.0352	0.0429	0.0201
8	0.0437	0.1771	0.0841
9	0.4915	0.0714	0.0336
10	0.0251	0.0784	0.0386
11	0.0673	0.1793	0.0883
12	0.0438	0.0296	0.0150
13	0.0152	0.0672	0.0335
14	0.0122	0.0214	0.0113
15	0.0074	0.0059	0.0026
16	0.0000	0.0109	0.0048
17	0.0253	0.0091	0.0041
18	0.0002	0.0020	0.0008
19	0.0030	0.0086	0.0041
20	0.0000	0.0043	0.0021
21	0.0000	0.0049	0.0022
22	0.0000	0.0040	0.0015
23	0.0000	0.0041	0.0017
24	0.0000	0.0000	0.0000
25	0.0000	0.0000	0.0000
26	0.0000	0.0000	0.0000
27	0.0014	0.0000	0.0000
28	0.0000	0.0000	0.0000
29	0.0000	0.0000	0.0000
30	0.0044	0.0092	0.0039

Table A7: Proportional length compositions derived from the *Kaharoa* trawl surveys (core area) included in the assessment model data sets. Model years are denoted by the year at the start of the fishing year (e.g., 2008 is the 2008/09 fishing year and 2009 survey).

Length	Model year				Length	Model year			
(cm)	2008	2010	2012	2014	(cm)	2008	2010	2012	2014
10	0.0000	0.0000	0.0000	0.0000	50	0.0092	0.0000	0.0372	0.0213
11	0.0000	0.0000	0.0000	0.0000	51	0.0154	0.0469	0.0021	0.0099
12	0.0000	0.0000	0.0000	0.0000	52	0.0185	0.0192	0.0277	0.0044
13	0.0000	0.0000	0.0000	0.0000	53	0.0416	0.0000	0.0042	0.0008
14	0.0174	0.0000	0.0000	0.0000	54	0.0190	0.0183	0.0000	0.0061
15	0.2442	0.0000	0.0000	0.0000	55	0.0031	0.0183	0.0000	0.0033
16	0.2078	0.0000	0.0000	0.0000	56	0.0092	0.0096	0.0064	0.0102
17	0.1920	0.0000	0.0000	0.0000	57	0.0184	0.0192	0.0061	0.0048
18	0.0828	0.0000	0.0000	0.0000	58	0.0036	0.0173	0.0000	0.0027
19	0.0242	0.0000	0.0000	0.0000	59	0.0036	0.0173	0.0021	0.0000
20	0.0000	0.0000	0.0000	0.0000	60	0.0000	0.0000	0.0128	0.0023
21	0.0000	0.0000	0.0000	0.0000	61	0.0000	0.0000	0.0064	0.0036
22	0.0000	0.0087	0.0000	0.0000	62	0.0062	0.0000	0.0021	0.0019
23	0.0000	0.0087	0.0000	0.0000	63	0.0000	0.0096	0.0000	0.0027
24	0.0000	0.0443	0.0000	0.0000	64	0.0031	0.0087	0.0000	0.0038
25	0.0000	0.0606	0.0064	0.0000	65	0.0000	0.0000	0.0064	0.0006
26	0.0000	0.0611	0.0000	0.0000	66	0.0031	0.0000	0.0064	0.0000
27	0.0000	0.1138	0.0000	0.0000	67	0.0031	0.0087	0.0064	0.0000
28	0.0092	0.0262	0.0000	0.0000	68	0.0000	0.0000	0.0000	0.0000
29	0.0000	0.0526	0.0000	0.0000	69	0.0031	0.0000	0.0000	0.0000
30	0.0000	0.0178	0.0192	0.0000	70	0.0031	0.0000	0.0064	0.0000
31	0.0000	0.0264	0.0256	0.0000	71	0.0062	0.0087	0.0000	0.0019
32	0.0000	0.0185	0.0499	0.0017	72	0.0000	0.0274	0.0064	0.0048
33	0.0000	0.0000	0.0555	0.0164	73	0.0031	0.0000	0.0021	0.0000
34	0.0000	0.0000	0.1033	0.0097	74	0.0031	0.0000	0.0064	0.0000
35	0.0000	0.0000	0.1336	0.0185	75	0.0000	0.0096	0.0000	0.0000
36	0.0000	0.0000	0.0981	0.0276	76	0.0000	0.0000	0.0021	0.0028
37	0.0000	0.0096	0.0627	0.0233	77	0.0000	0.0256	0.0000	0.0025
38	0.0000	0.0192	0.0486	0.0399	78	0.0000	0.0000	0.0064	0.0000
39	0.0031	0.0000	0.0504	0.0603	79	0.0000	0.0000	0.0000	0.0000
40	0.0077	0.0361	0.0398	0.0988	80	0.0000	0.0000	0.0000	0.0000
41	0.0031	0.0192	0.0341	0.1034					
42	0.0000	0.0375	0.0287	0.1131					
43	0.0000	0.0809	0.0170	0.0871					
44	0.0000	0.0557	0.0064	0.1145					
45	0.0112	0.0096	0.0086	0.0798					
46	0.0031	0.0000	0.0021	0.0475					
47	0.0031	0.0192	0.0234	0.0357					
48	0.0031	0.0096	0.0149	0.0167					
49	0.0123	0.0000	0.0149	0.0156					

Table A8: Length frequency distributions from the snapper sampled from the recreational fishery. Model years are denoted by the year at the start of the fishing year (e.g., 2005 is the 2005/06 fishing year).

Length	Model year				
(cm)	2005	2011	2015	2016	2017
10	0	0	0	0	0
11	0	0	0	0	0
12	0	0	0	0	0
13	0	0	0	0	0
14	0	0	0	0	0
15	0	0	0	0	0
16	0	0	0	0	0
17	0	0	0	0	0
18	0	0	0	0	0
19	0	0	0	0	0
20	0	0	1	0	0
21	0	0	0	0	0
22	0	1	0	0	0
23	0	1	1	0	0
24	3	2	6	1	2
25	20	14	10	3	6
26	69	47	17	4	10
27	126	123	23	7	20
28	179	172	38	5	29
29	161	202	33	9	20
30	145	175	40	7	25
31	81	153	40	9	20
32	55	104	48	6	28
33	43	81	66	8	11
34	36	53	79	3	15
35	46	37	91	2	17
36	42	26	114	5	5
37	29	15	102	9	9
38	37	11	80	4	10
39	15	9	63	8	8
40	19	5	91	13	11
41	7	7	57	8	7
42	8	7	70	5	14
43	2	4	78	7	9
44	3	7	86	11	12
45	6	4	81	5	11
46	2	3	68	8	10
47	2	5	51	9	12
48	1	8	40	8	19
49	0	5	30	8	9
50	2	2	24	1	20
51	1	3	14	7	13
52	1	1	11	6	6
53	0	3	9	5	3
54	1	1	7	2	5
55	0	0	9	3	6
56	0	1	2	2	5
57	0	2	11	5	1
58	0	3	12	4	3
59	0	0	10	7	2
60	0	1	9	4	2
61	0	0	3	7	2
62	0	0	2	0	3
63	0	1	4	0	0
64	0	0	4	3	5
65	0	0	4	0	2
66	1	0	2	2	3
67	0	0	0	0	3
68	0	1	0	1	0
69	0	0	0	2	3
70	0	1	0	1	1
71	0	0	0	0	0
72	0	0	1	0	0
73	0	0	0	0	2
74	0	0	0	0	0
75	0	0	0	1	0
76	0	1	2	0	1
77	0	0	1	0	0
78	0	0	2	0	1
79	0	0	0	0	1
80	0	0	1	0	0