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Stock assessment of snapper in SNA 8 for 2021

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EXECUTIVE SUMMARY

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Trends in the distribution of catch and effort from the SNA 8 commercial fishery were summarised from 1989/90 to 2019/20. Prior to 2007/08, most of the snapper catch was taken by bottom trawls targeting snapper spawning aggregations during October-December in the central region of the fishery off the Kaipara and Manukau harbours. In subsequent years, most snapper catch was from trawls targeting trevally and red gurnard over a longer fishing season (October-April) and much larger area. There was a marked decline in the number of vessels operating in the fishery over the same period.

A standardised CPUE analysis of the SNA 8 single trawl fishery catch and effort data was completed for the period: 1996/97–2019/20. The data set comprised individual trawl records (fishing event data) from trawls targeting snapper, trevally, and red gurnard during January-April, i.e., when snapper were not aggregating to spawn. The annual CPUE indices were relatively constant during 1996/97–2003/04. The indices increased over the subsequent years, initially increasing by approximately 70% during 2003/04–2007/08, and then increasing considerably during 2007/08–2014/15. The indices remained at the higher level during 2015/16–2018/19 and then declined in 2019/20. The decline in the terminal year was attributed to a change in the operation (to avoid snapper) of one of the two remaining vessels included in the CPUE data set. It was concluded that the CPUE indices are likely to under-estimate the relative abundance of snapper in recent years.

A stock assessment was conducted for SNA 8 using an age-structured population model implemented in Stock Synthesis. The model incorporated data to the 2020/21 fishing year including: commercial catches from 1931–2021, a time series of recreational catches, absolute biomass estimates from two tagging programmes (in 1990 and 2002), pair trawl CPUE indices (1974–91), the recent single trawl CPUE indices (1997–2020), age compositions from catch sampling of the pair and single trawl fisheries, age-specific (2, 3, 4, and 5 year) abundance indices from *Kaharoa* inshore trawl surveys conducted during the 1990s and in recent years (2018, 2019, and 2020), and length compositions from the recreational fisheries (inside and outside harbours). The time series of trawl surveys provides estimates of relative strength of the 1985–1998 and 2014–2019 year classes.

The assessment reaffirmed the results of previous assessments that estimated the stock was heavily depleted during the 1960s and 1970s and remained at about 10% of SB_0 until the mid-2000s. The more recent data sets provided a coherent signal that stock abundance increased considerably from 2009, primarily due to an increase in recruitment from the mid-2000s. Commercial catches were constrained by the TACC during the period of increasing abundance, although there was a substantial increase in the recreational harvest.

Current (2021 = 2020/21 fishing year) stock status was determined relative to equilibrium, unexploited spawning biomass. Spawning biomass increased considerably over the last 10 years due to above average recruitment during 2005–2019, with exceptionally high recruitments in 2006 and 2016–2018. Current biomass was estimated to exceed the default target (40% SB_0) biomass level (SB_{2021}/SB_0 = 0.54), and the probability of the stock being below the hard (10% SB_0) and soft (10% SB_0) limits was extremely low. There has been a corresponding decline in fishing mortality over the last 10 years and current (2021) fishing mortality is estimated to be below the rate that produces the target biomass level (under equilibrium conditions, i.e., $F_{2021}/F_{SB40\%}$ = 0.81). Current potential yields (at $F_{SB40\%}$) are estimated to be considerably greater than equilibrium yields and exceed current levels of catch. The results were similar for the range of plausible model sensitivities investigated. Stock projections, assuming current levels of catch, indicate biomass will continue to increase over the next five years. Projections at higher catches, corresponding to the $F_{SB40\%}$ fishing mortality rate, predicted a smaller increase in biomass over the 5 year period.

The biomass indices from the three recent trawl surveys (2018–2020) are considerably greater than the indices from the earlier trawl surveys (1989–1999), corroborating the recent increase in stock abundance. However, the variability in the catchability of adult snapper for the three recent trawl surveys has limited the utility of these data in the assessment modelling. The variability in catchability of snapper is likely to have been influenced by the timing of the individual surveys relative to the main spawning period, compounded by the exclusion of trawl sampling within the recently established Māui dolphin trawl exclusion zone. Further, the distribution of adult snapper appears to have expanded seaward in recent years, as the abundance of snapper increased; potentially increasing the proportion of adult snapper in deeper water, and therefore increasing availability of mature snapper to the trawl surveys.

1. INTRODUCTION

SNA 8 supports a commercial inshore trawl fishery and non-commercial hook-and-line fishery for snapper (*Chrysophrys auratus*) along the west coast of the North Island. Annual commercial catches from the fishery peaked at about 4000–5000 t during the mid–late 1970s following the development of the pair trawl fishery (Fisheries New Zealand 2020). Catches declined during the early 1980s and an initial Total Allowable Commercial Catch (TACC) was set at 1331 t in 1986/87. The TACC was increased to 1500 t during 1992/93–2004/05 and annual catches were maintained at about that level. During this period, there was considerable rationalisation of the trawl fleet, and an increase in the dominance of the single trawl method (Kendrick & Bentley 2010, Langley 2017a). Recent survey estimates of recreational catch indicate catches increased considerably over the last decade; the most recent estimate of 892 t was from the 2017/18 National Panel Survey (Wynne-Jones et al. 2019).

Previous stock assessments of SNA 8 were conducted in 1994 (Gilbert & Sullivan 1994), 1997 (Davies 1997), 1999 (Davies 1999), 2000 (Davies et al. 1999), 2001 (Davies & McKenzie 2001), and 2003 (Davies et al. 2006), with the last assessment conducted for the 2004/05 fishing year (Davies et al. 2013). The primary indices of stock abundance included in the previous assessment model were: biomass estimates from the 1990 and 2002 tagging programmes, catch per unit effort (CPUE) indices from the pair trawl fishery 1974–91 (Vignaux 1993), and CPUE indices from the single trawl fishery 1996–2003 (following Davies et al. 2006). The model also incorporated a long time series of age composition data from the trawl fisheries. The assessment estimated that the stock biomass in 2004 was at 9.5–9.8% of the unexploited level (B_{2004}/B_0 = 9.5–9.8%). In 2005/06, the TACC was reduced from 1500 t to 1300 t to ensure a faster rebuild of the stock (Fisheries New Zealand 2020).

During the intervening years, there has been ongoing collection of age composition data (at three year intervals) from the SNA 8 commercial catch (Walsh et al. 2017). A characterisation of the fishery, including an update of the single trawl CPUE analysis to 2007/08, was conducted by Kendrick & Bentley (2010). During 1989/90–2007/08, most of the snapper catch was taken by trawls targeting snapper spawning aggregations during October-December in the central region of the fishery off the Kaipara and Manukau harbours (Kendrick & Bentley 2010). From 2007/08, there was a change in the operation of the inshore trawl fishery with a reduction in the targeting of snapper during October-December. Catches of snapper were increasingly taken as a bycatch of trawls targeting trevally over an extended fishing season (October-April) and expanded area (Langley 2017a, Langley 2020).

Langley (2017a) developed a standardised CPUE series of relative abundance indices based on single trawl fishery catch and effort data from individual bottom trawl records (fishing event based data) targeting snapper, trevally, and red gurnard during 1996/97–2015/16. The analysis was limited to January-April when snapper catches rates were more evenly distributed outside the main spawning period (October-December). The annual indices were relatively constant during the period 1996/97–2003/04 and then increased over the subsequent years, initially increasing by approximately 50% during 2003/04–2007/08, and then increasing by 230% during 2007/08–2015/16. The extended CPUE indices remained at the higher level during 2016/17–2018/19 (Langley 2020). There was also an increase in the snapper biomass indices derived from three recent trawl surveys (in 2018, 2019, and 2020) relative to the results of the earlier series of surveys conducted in the late 1980s and1990s (Drury & McKenzie 1992, Drury & Hartill 1992, Langley 1995, Morrison 1998, Morrison & Parkinson 2001).

Recent single trawl catch and effort data and trawl survey abundance indices enabled the development of a new stock assessment for SNA 8. The initial phase of the project summarised recent trends in the fishery and updated existing CPUE indices to 2018/19. The updated indices were incorporated in a stock assessment model with similar structure to that used for 2004/05 assessment (Davies et al. 2013), incorporating the additional data from the intervening period (catches, CPUE indices, commercial age compositions, trawl survey biomass estimates, and age composition). The initial assessment was conducted in Stock Synthesis (SS) (Methot & Wetzell 2013, Methot et al. 2020) and completed in May 2020 (Langley 2020). For 2021, the assessment was further developed, incorporating an additional year of fishery data (catch and CPUE indices) and the results from the most recent (2020) trawl survey. The project was funded by Fisheries New Zealand under Project SNA2019-03.

2. COMMERCIAL FISHERY CHARACTERISATION

Trends in catch and effort from the SNA 8 fishery have been described in previous reports (Kendrick & Bentley 2010, Langley 2017a, Langley 2020). This section updates previous analyses incorporating data from the 2019/20 fishing year.

2.1 Data set

Commercial catch and effort data from the snapper fishery were sourced from the Fisheries New Zealand EDW database. The scope of the study encompassed the SNA 8 Quota Management Area (QMA) and the data extract included the catch and effort data from any fishing trip that recorded a catch of snapper from this QMA. The extract was supplemented by data from any additional fishing trips that conducted fishing within the statistical areas that constitute the QMA (Statistical Areas 037 and 039–048) (Figure 1) and targeted the range of inshore species that are caught in association with snapper (i.e., tarakihi, flatfish species, trevally, red cod, barracouta, gemfish, blue warehou, red gurnard, and John dory).

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 the 2019/20 fishing year (30 September 2020).

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.

From 1994/95, many of the inshore trawlers operating in SNA 8 reported fishing effort and catch data for individual trawls/tows via the Trawl Catch Effort and Processing Return (TCEPR). 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 8 fishery. The TCEPR and TCER forms record detailed fishing activity, including trawl start location and depth, and associated (estimated) catches from individual trawls. Landed catches associated with trips reported on TCEPR and TCER forms are reported at the end of a trip on the Catch Landing Return (CLR).

More recently, Electronic Reporting Systems (ERS) were introduced for the trawl fleet. ERS was introduced on two of the main trawl vessels operating in the SNA 8 fishery in the 2017/18 fishing year and was subsequently extended to remaining vessels during 2018/19. By mid-2019, ERS had been implemented on almost all the SNA 8 trawl fleet (replacing the TCEPR and TCER reporting formats).

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

1) **Daily** aggregated catch and effort data set from 1989/90–2019/20. 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) (following Starr 2007).

2) **Trawl** based catch and effort data set from 1994/95–2019/20. TCEPR, 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 (when recorded in the five main species caught in the trawl). Snapper landed catches from trips without corresponding estimated catches were distributed equally amongst trawl records.

Total annual catches of SNA 8 under the Quota Management System (QMS) are compiled from Monthly Harvest Returns (MHR) submitted by fishing permit holders (Fisheries New Zealand 2020). The total annual estimated and landed catches included in the SNA 8 catch and effort data sets approximated the QMS annual catches (Figure 1).

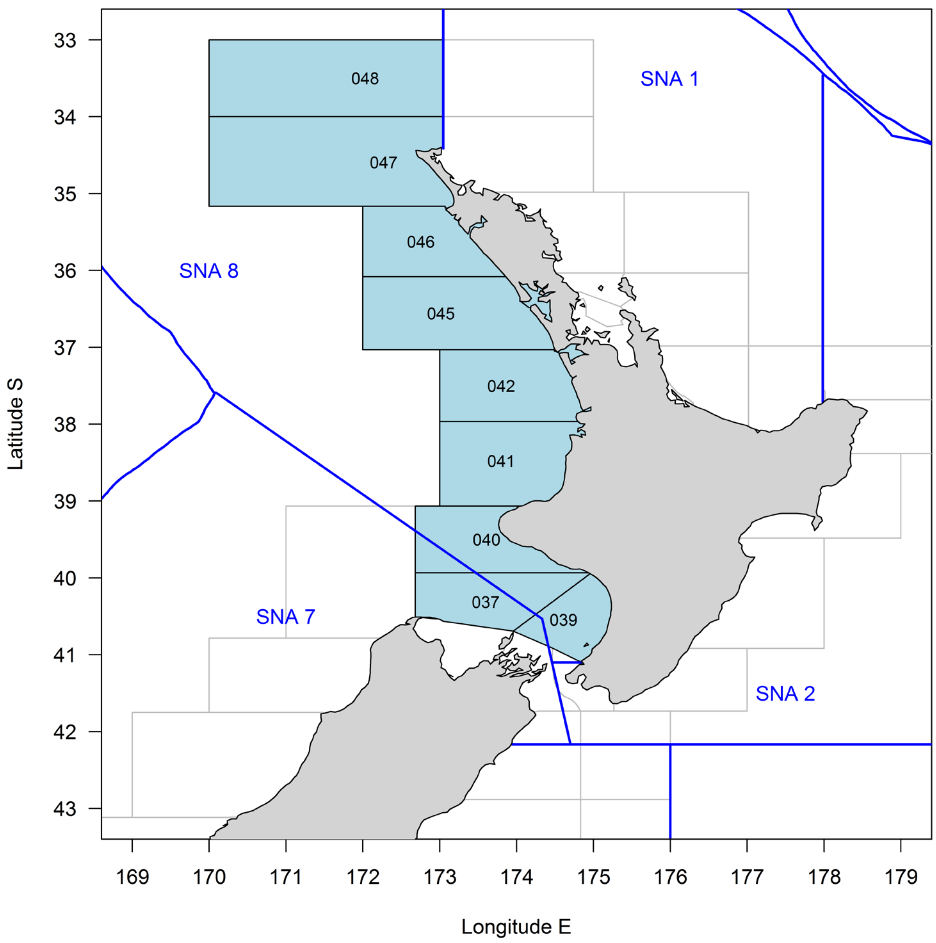

Figure 1: Map of the SNA 8 fishstock area and constituent Statistical Areas.

2.2 Recent trends

This section provides a brief summary of the distribution of catches from the SNA 8 commercial fishery from 1989/90–2019/20. A more comprehensive characterisation of the bottom trawl fishery to 2015/16 is presented by Langley (2017a).

The landed catches from the catch and effort data set approximate the total reported annual catches (MHR) from the fishery (Figure 2), whereas estimated catches represented about 90% of the total landed catch. From 2006/07, annual catches have remained at the level of the TACC of 1300 t (Figure 2).

From 1996/97, a high proportion of the annual catches were reported at the resolution of individual fishing events (trawls), initially in TCEPR format and then including TCER format from 2007/08 (Figure 3). From 2017/18, vessels that were previously reporting via TCEPR forms transitioned to ERS (Figure 3). The ERS accounted for 59% of the total SNA 8 catch in 2017/18–2018/19 and virtually the entire catch in 2019/20.

Overall, the catch of snapper was dominated by the snapper and trevally target trawl fisheries (Figure 4). During 2007/08–2010/11, there was a shift in the relative importance of these two fisheries, with a marked decline in the proportion of the snapper catch taken by the target snapper fishery, and a corresponding increase in the catch from the trevally fishery. The pair trawl fishery also ceased operating at that time (Figure 4). Over the subsequent years, the red gurnard target trawl fishery also accounted for a significant proportion of the snapper catch; this component of the fishery accounted for 10–20% of the snapper catch during 2010/11–2019/20 (Figure 4).

Precision Harvesting bottom trawl gear (PRB) gear was introduced to the SNA 8 trawl fleet in 2015/16 and accounted for 12–17% of the annual snapper catch during 2015/16–2018/19, predominantly from the target trevally fishery (Figure 4). PRB gear replaces the conventional mesh codend of the trawl gear with a Modular Harvest System (MHS). A technical description of the MHS is not publicly available. PRB gear accounted for a minor (2.2%) proportion of the SNA 8 catch in 2019/20 (Figure 4).

Annual catches were predominantly taken in Statistical Areas 045 and 042, encompassing the coastal area off the entrances to the Kaipara and Manukau harbours (Figure 1 and Figure 5). Since 2008/09, there has also been an increase in the proportion of the catch taken off Ninety Mile Beach (Statistical Area 047) with a corresponding reduction in the magnitude of the catch from Statistical Area 045. A smaller proportion of the catch was taken from North Taranaki Bight (041), and limited catch was taken from the southern area of SNA 8 (Statistical Areas 037, 039, and 040) (Figure 1 and Figure 5).

Prior to 2007/08, the snapper catch was concentrated in October-December and this period accounted for about 45–60% of the annual catch (Figure 6). Most of the remainder of the catch was taken during January-April and catches were low during May-August. From 2007/08, snapper catches were relatively evenly distributed throughout October-April and there was an increase in catches during August-September (Figure 6).

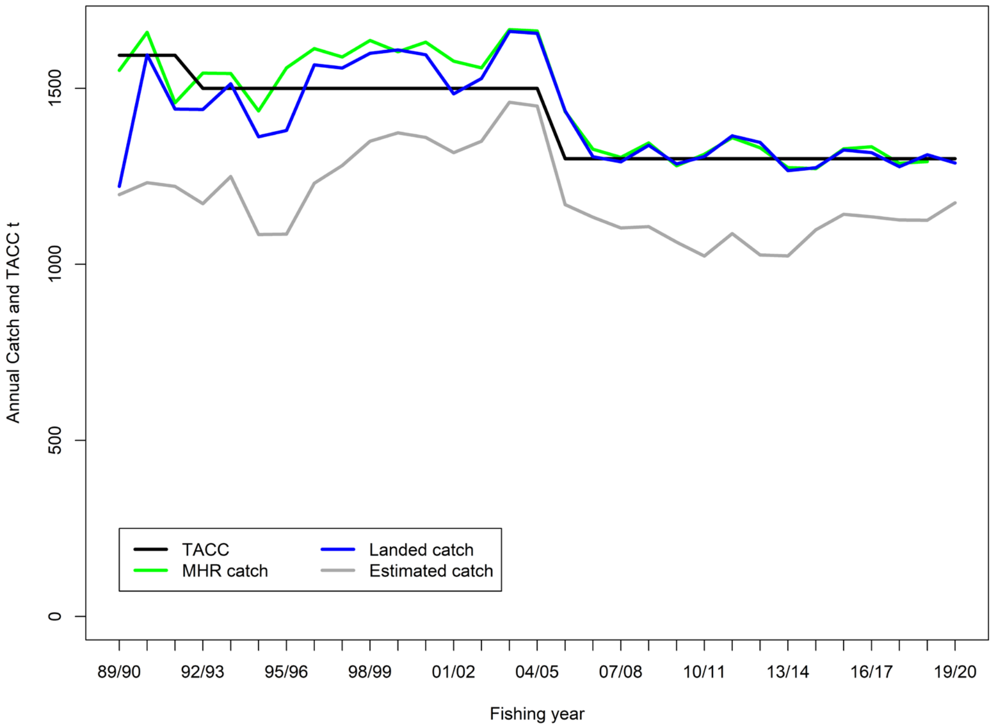

Figure 2: Annual SNA 8 reported catch (MHR catch) and Total Allowable Commercial Catch (TACC) and the landed and estimated catch included in the catch and effort data set.

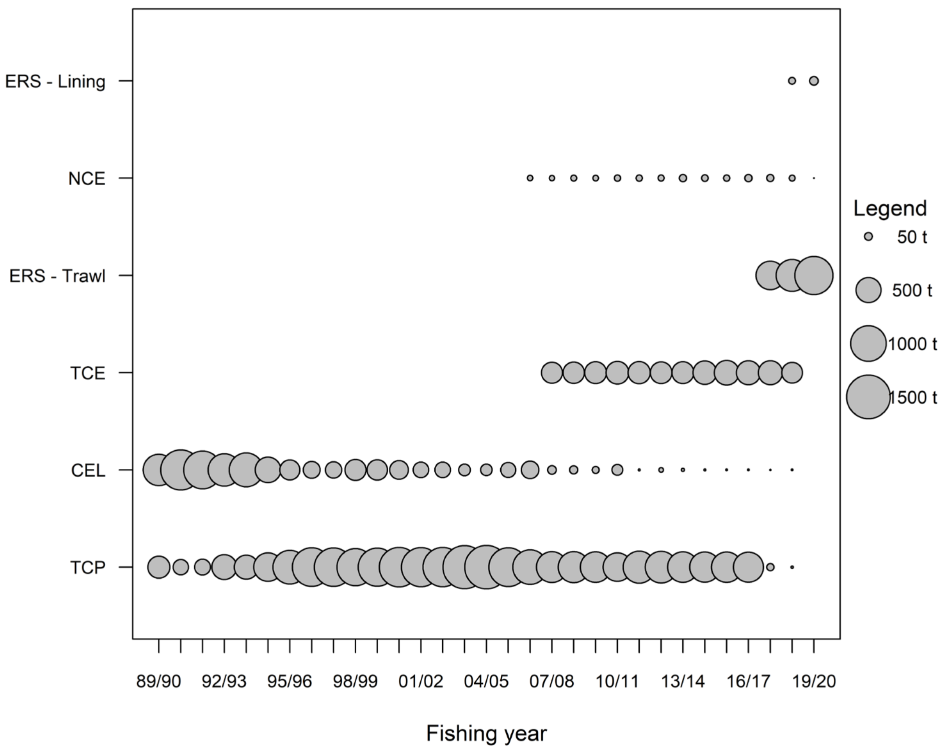

Figure 3: Annual snapper catch from the SNA 8 by reporting format (ERS, Electronic Reporting System; NCE, Netting Catch Effort Returns; TCE, Trawl Catch Effort Returns; CEL, Catch Effort Landing Returns; TCP, Trawl Catch Effort Processing Returns). The area of the circle is proportional to the catch.

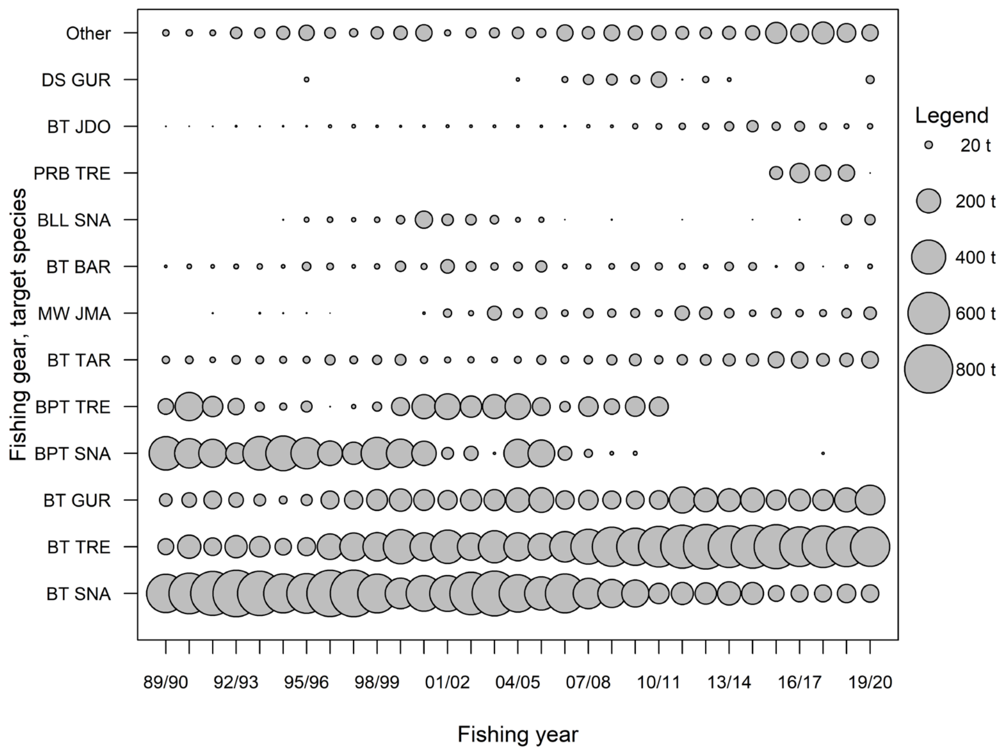

Figure 4: Annual snapper catch from the SNA 8 by fishing gear (BT, bottom single trawl; BPT, bottom pair trawl; MW, mid-water trawl; BLL, bottom longline; PRB, Precision Harvesting bottom trawl gear; DS, Danish seine) and declared target species (SNA, snapper; TRE, trevally; GUR, red gurnard; TAR, tarakihi; JMA, jack mackerel; BAR, barracouta; JDO, John dory). The area of the circle is proportional to the catch.

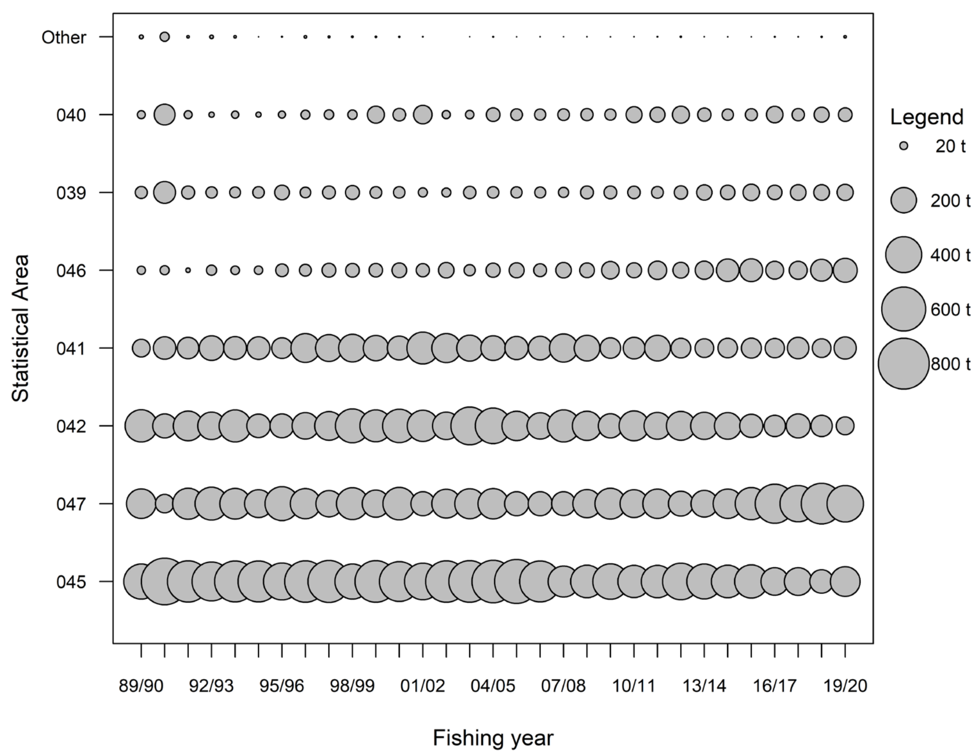

Figure 5: Annual snapper catch from the SNA 8 fishery by Statistical Area. The area of the circle is proportional to the catch.

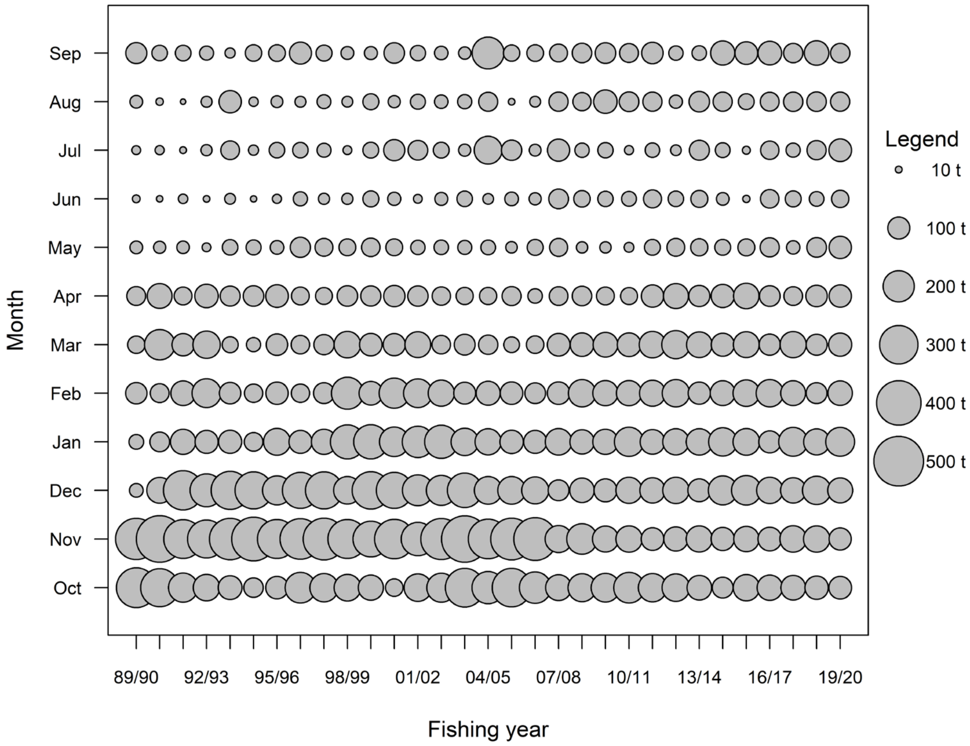

Figure 6: Annual snapper catch from the SNA 8 fishery by month. The area of the circle is proportional to the catch.

2.3 CPUE Analysis

2.3.1 Data set

The analysis updates the CPUE indices with the inclusion of an additional year (2019/20) from the previous study (Langley 2020). The data set included in the CPUE analysis was selected based on the criteria defined by Langley (2017a). The analysis was based on the single trawl fishery because this provides the only continuous time series of catch and effort data, including the most recent period. Trawls conducted using PRB gear were excluded because the performance of the PRB gear is considered to differ from standard bottom trawl gear. The data set was limited to individual trawl records only (i.e., excluding CELR records) which provide detailed information regarding fishing location and depth.

The CPUE data set was further restricted to records for January-April, the main fishing period outside the October-December spawning period. The spatial distribution of snapper during January-April appears to be more homogeneous (Langley 2017a) and snapper catch rates during that period are likely to be less sensitive to changes in targeting/avoidance behaviour.

Langley (2017a) described changes in fishing operation that were related to a shift towards targeting of red gurnard by some of the vessels in the fleet, most notably a decline in trawling speed. These changes were likely to be linked to an increased avoidance of snapper and trawl records with particularly slow trawling speeds were excluded from the data set.

From the selected data set, a group of core vessels that operated in the fishery for a continuous period was selected for the final CPUE data set.

Thus, the CPUE data set (Appendix 1 Table A1) was defined by the following criteria:

- Fishing method BT (not including PRB).
- Reporting format TCEPR, TCER, or ERS.
- Declared target species SNA, TRE, or GUR.
- Fishing years 1996/97–2019/20.
- Fishing season January-April.
- Fishing effort was restricted to the main depth range of the snapper catch (less than 120 m).
- Fishing location north of Cape Egmont because there was limited trawling in the southern area of SNA 8 during 1996/97–2019/20.
- Trawls conducted with a slower trawl speed (less than 2.75 knots) were excluded.
- Fishing effort limited to (core) vessels completing a minimum of 8 trips in at least five years based on records meeting the specified criteria.

The core fleet, defined based on the continuity criteria, accounted for 82% of the total snapper catch included in the January-April data set. The criteria resulted in the selection of 16 unique vessels including 6 vessels that operated in the fishery for at least 10 of the 24 years (Figure 7). A substantial proportion (45%) of the snapper catch included in the core vessel data set was taken by a single vessel.

The number of vessels included in the core fleet declined during the early 2000s and the core fleet comprised a relatively small number (about 6) of vessels operating in the fishery each year during 2010/11–2015/16 (Figure 8). The number of vessels operating in the defined fishery declined further in more recent years with only two core vessels participating in 2017/18–2019/20.

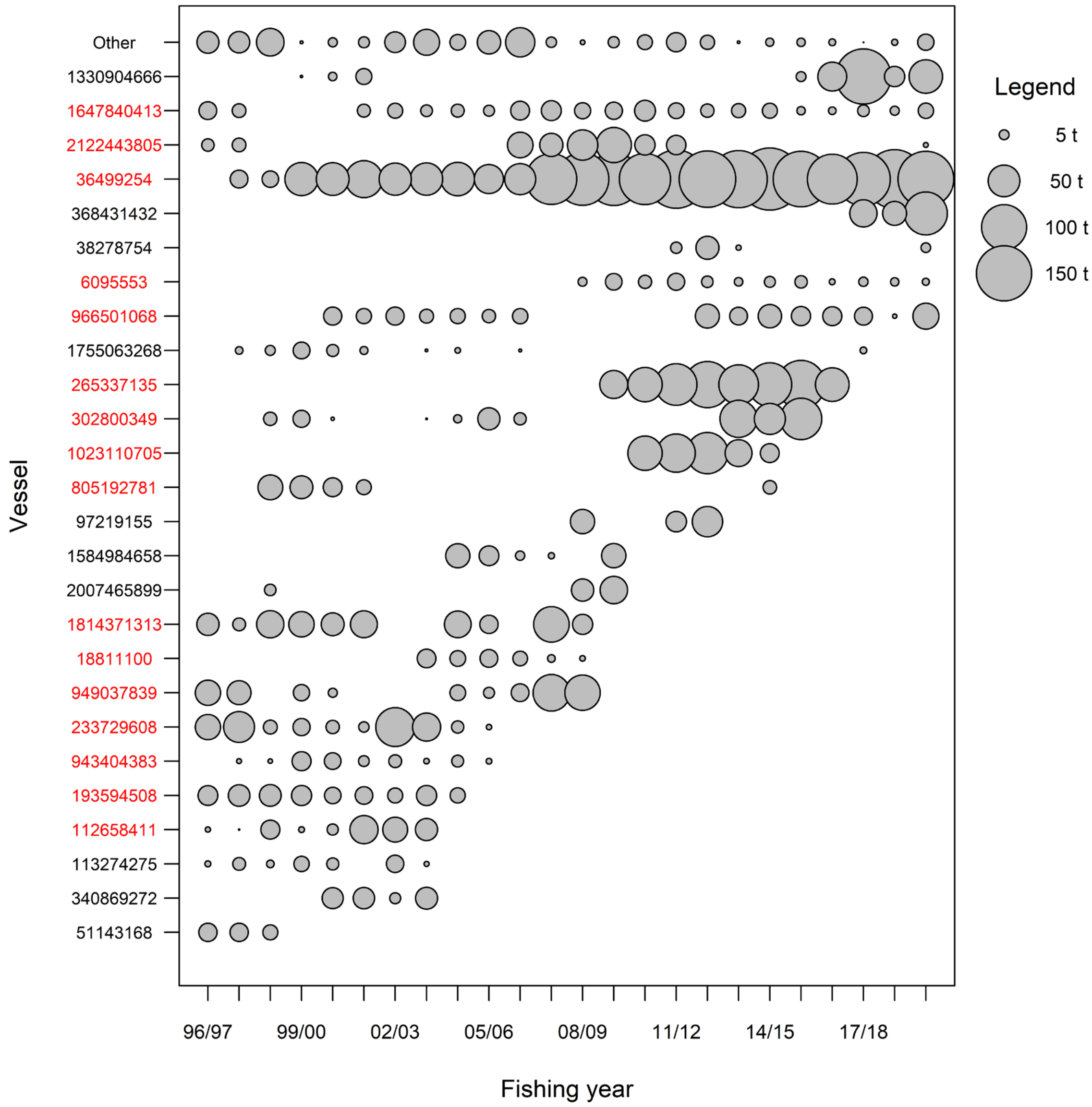

Figure 7: Annual snapper catch during January-April from the event based bottom trawl data set. The area of the circle is proportional to the snapper catch. The vessels included in the core vessel data set are highlighted in red.

During 2001/02–2015/16, fishing effort (number of trawls) by the core fleet fluctuated between 600–800 trawls per annum. The annual snapper catches included in the January-April core vessel data set were about 130–200 t during 1996/97–2006/07 and then increased to a peak of about 350–400 t during 20011/12–2012/13. Catches in the four most recent years were considerably less than the peak level (Figure 8, Appendix 1 Table A1).

Most of the core vessels operating in the fishery reported catch and effort via the TCEPR form until 2017/18 when the ERS was introduced. A smaller portion of the core fleet reported catch and effort via the TCER form (from 2007/08). Almost all the snapper catch was allocated to the fishing effort records based on the distribution of the estimated catch within individual fishing trips. For most (77%) of the fishing event records, snapper was included within the three main species recorded in the estimated catch. There was no appreciable change in the recording of snapper catches associated with the introduction of the TCER reporting form in 2007/08 or the ERS in 2017/18; i.e., there was no apparent difference in the frequency of zero catches of snapper reported by reporting type and no difference in the ranking of snapper in the catch of species reported from individual trawls between reporting types.

Trawls with no associated snapper catch represented 8–26% of the records during 1996/97–2006/07. Over the subsequent years, there was a steady decline in the proportion of zero catch records to only 2–3% in 2011/12–2016/17 before increasing in the more recent years (Figure 8). Prior to 2004/05, fishing effort was dominated by trawls targeting trevally and snapper (Figure 9). Snapper target trawls represent a small proportion of the data from 2005/06, and trawls targeting red gurnard have represented an increasing proportion of the records since 2014/15. Red gurnard trawls accounted for most of the fishing effort conducted by one of the two vessels operating in the fishery in the last few years.

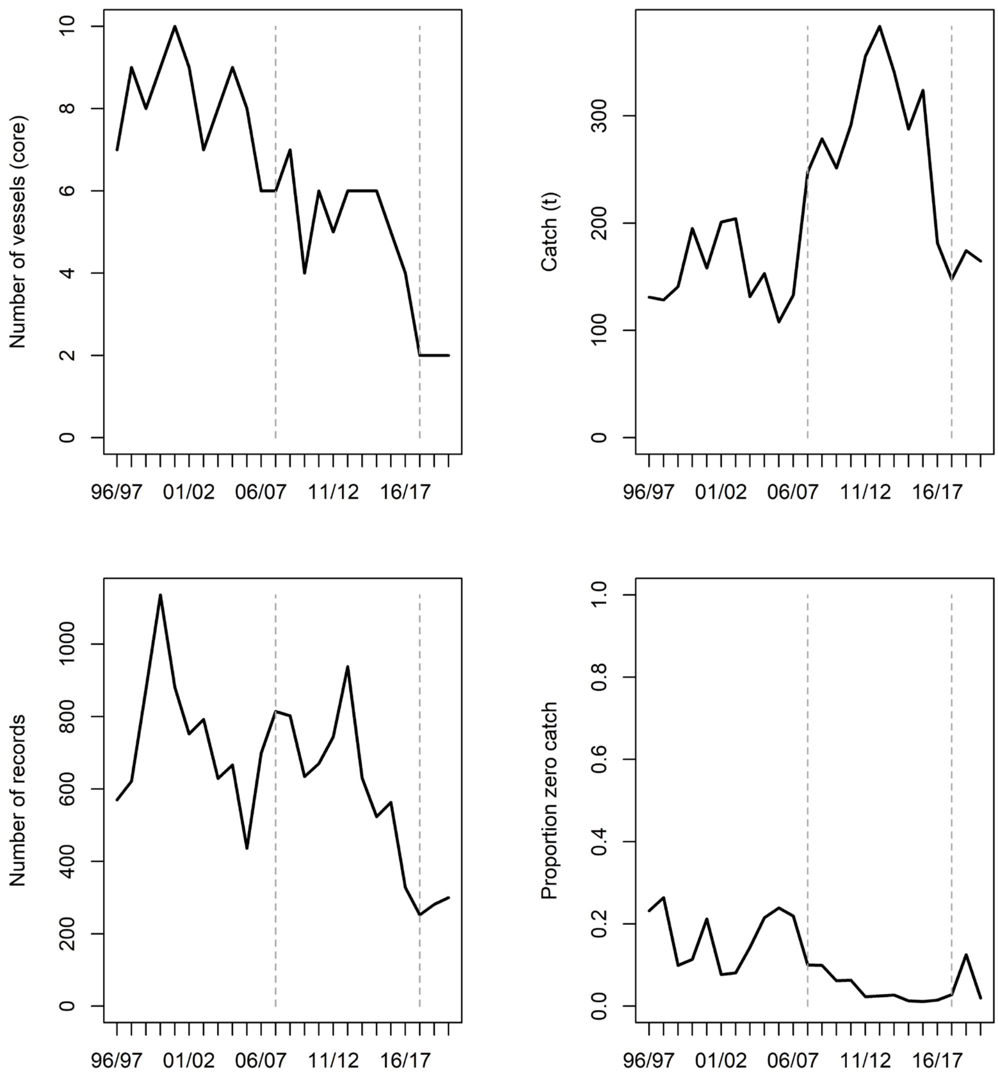

Figure 8: A summary of the data included in the January-April SNA 8 core vessel data set by fishing year. The dashed vertical line represents the years the TCER and ERS reporting formats were introduced.

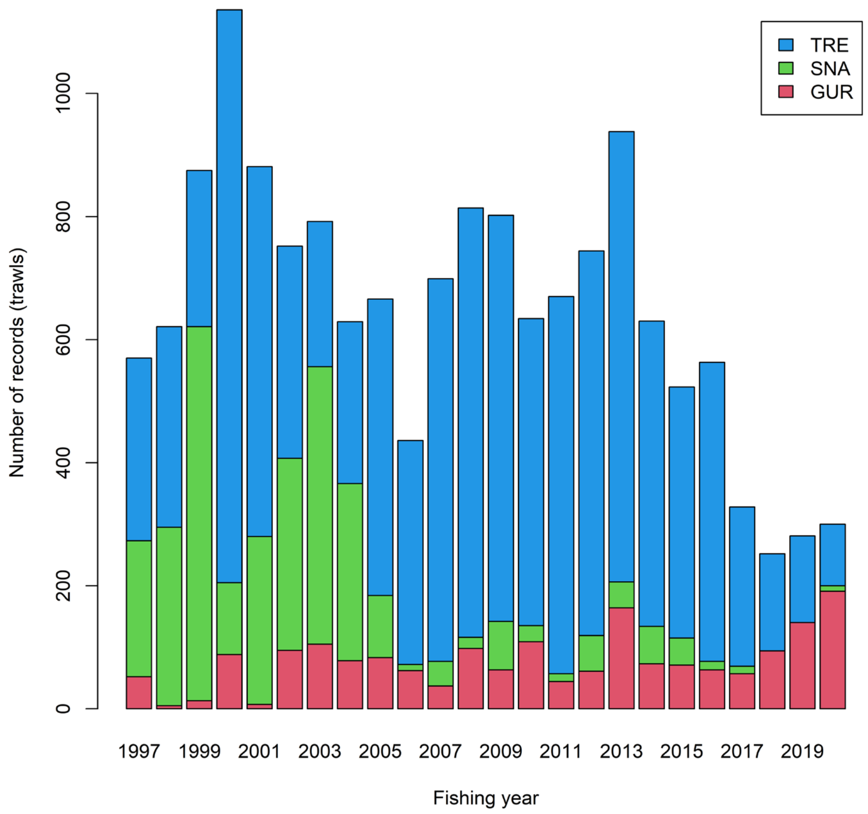

Figure 9: Distribution of data included in the January-April SNA 8 core vessel data set by target species and fishing year.

The spatial distribution of trawl effort varied over time (Figure 10). From 2007/08 there was a general reduction in the proportion of trawl records in the central area of the fishery off Kaipara and Manukau harbours, and a corresponding increase in effort off Ninety Mile Beach (Figure 10). Fishing effort in the North Taranaki Bight was limited during 2010/11–2016/17, although this area accounted for a significant proportion of the fishing effort in 2017/18–2019/20 (Figure 10).

Since 2007/08, a lower proportion of the trawls was conducted in the shallower depth range (10–30 m) (Figure 10). This coincides with the introduction in 2008 of the prohibition of trawling close to the coast (within 2 nm or 4 nm) as a measure for the protection of Māui dolphins. From 2012/13, there has been a continued shift towards fishing in deeper water (Figure 10).

Trawl speed was higher during 2013/14–2016/17 (Figure 10) corresponding to the higher trawling speeds for trawls targeting trevally which dominated the data set in those years. Trawl speed was more variable in the three most recent years with one of the main vessels predominantly targeting red gurnard at slower trawling speeds. Trawl duration has remained relatively constant since 2009/10 (Figure 10).

There was a marked reduction in the headline height of the trawl gear during 2006/07–2019/20 (Figure 10). The reduction in the average headline height was initially driven by the entrance of two vessels into the fishery in 2006/07 and 2007/08, both of which had low opening trawl gear. More recently, in 2012/13 two of the other vessels in the fleet changed the configuration of the trawl gear (to gear with a lower headline height).

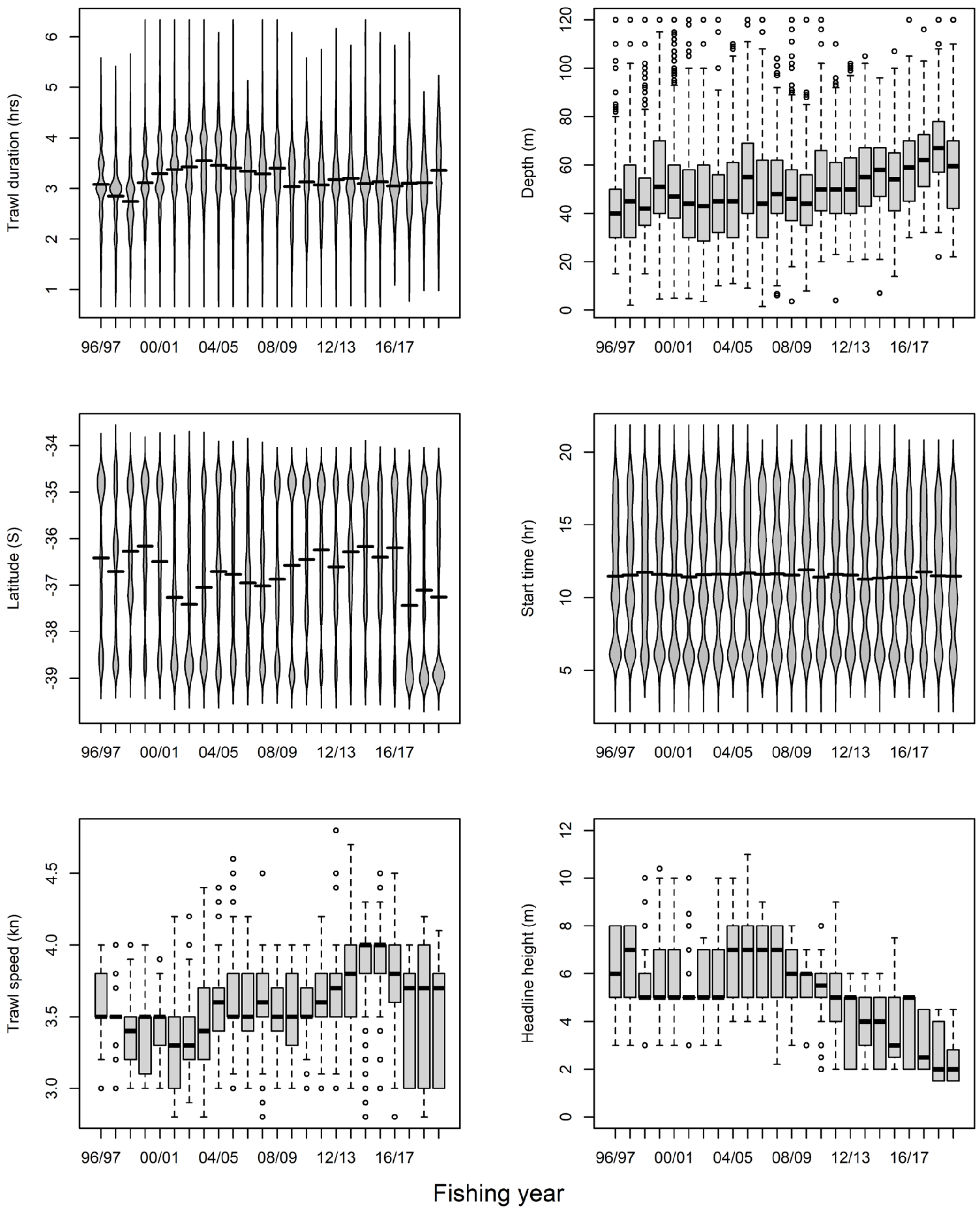

Figure 10: Annual distributions (bean or box plots) of the main continuous variables included in the core vessel data set.

Generalised Linear Models (GLMs) were used to model the occurrence of snapper catches (presence/absence) and the magnitude of positive snapper catches. The structure and parameterisation of the two CPUE models were equivalent to the previous studies (Langley 2017a, 2020).

The positive catch CPUE model included the predictor variables *FishingYear*, *Vessel*, *Latitude*, *Depth*, the natural logarithm of *Distance*, and *TargetSpecies.* The annual indices derived from the positive catch CPUE model were relatively constant during 1996/97–2003/04 (Figure 11). The CPUE indices increased over the subsequent years, initially increasing by approximately 50% during 2003/04–2007/08, and then increasing considerably during 2007/08–2014/15. The indices remained at about the higher level during 2015/16–2018/19 and then declined by 23% in 2019/20. The trend in the

CPUE indices was generally comparable with the trend in the nominal (unstandardised) catch rates of snapper (Figure 11).

The occurrence of snapper in the SNA 8 trawl catch was predicted by the binomial model including the explanatory variables: *FishingYear, Depth*, *Vessel, TargetSpecies, Latitude*, and *StartTime*. The resulting annual indices derived from the binomial model are generally comparable with the annual proportion of positive catch records, with a higher probability of catching snapper from 2007/08 onwards (Figure 11).

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). The confidence intervals associated with the combined indices were determined using a bootstrapping approach. The trend in the combined CPUE series is similar to the lognormal CPUE series, although the magnitude of the increase in the combined CPUE series is increased by about 20% with the inclusion of the increase in the binomial series (Appendix 2 Table A2).

The decline in the CPUE index for the most recent year is primarily attributable to a decline in the catch rates of snapper by one of the two vessels included in the data set, whereas the remaining vessel maintained catch rates at the higher level. This is apparent in the trend in the applied coefficients (annual index + residuals) derived for each main vessel from the lognormal CPUE model (Figure 12). The decline in the implied coefficients for Vessel E coincides with the increased targeting of red gurnard (and, correspondingly, slower trawl speeds) in recent years. Refinements in the CPUE modelling (including additional explanatory variables) did not resolve these issues indicating that the lognormal CPUE model does not adequately account for the marked change in fishing operation by one of the main vessels. The vessel operator stated that their trawl net had been redesigned specifically to reduce the catch of snapper, and changes in hauling practice were introduced to allow the escapement of snapper from the trawl gear. Hence, it is considered that the CPUE indices are likely to under-estimate the relative abundance of snapper in recent years.

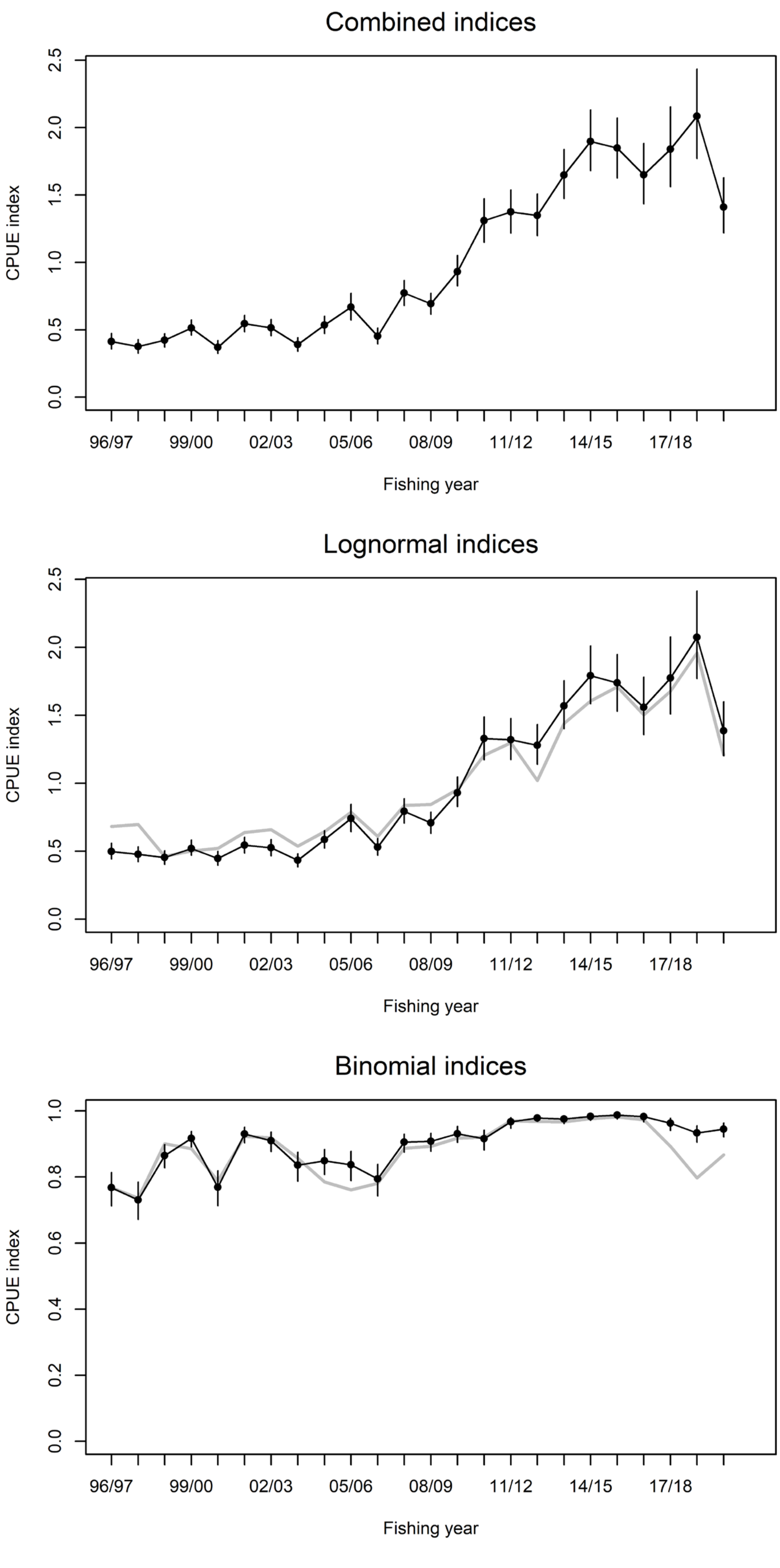

Figure 11: A comparison of: (middle panel) the SNA 8 single trawl positive index and the geometric mean of the annual catch per day (grey line); (bottom panel) the binomial index and the annual proportion of positive catch records (grey line) in the data set; and (top panel) the combined index. The error bars represent the 95% confidence intervals associated with each index. The annual indices are provided in Table A2 (Appendix 2).

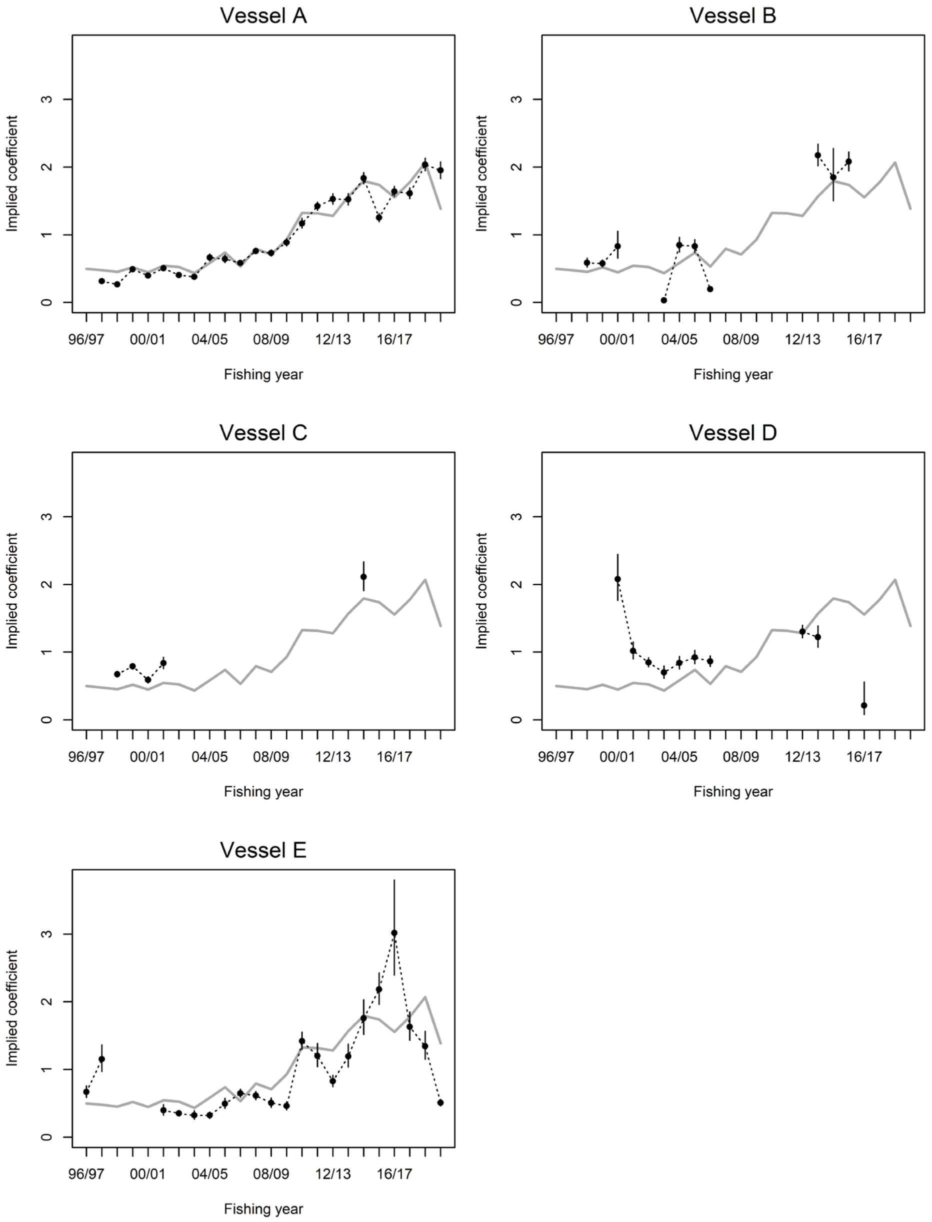

Figure 12: Implied coefficients (points and confidence intervals) from the lognormal CPUE model for a subset of the vessels included in the CPUE data set.

3. DATA COMPILATION

3.1 Commercial catch history

Reported commercial catches for 1931–1990 are compiled by Gilbert & Sullivan (1994) and Fisheries New Zealand (2020). These catches include estimates of reported foreign catches for 1968 to 1979 (Gilbert & Sullivan 1994). Annual commercial catches for the 1986/87–2019/20 fishing years were available from catch reporting under the QMS and compiled by Fisheries New Zealand (2020).

Previous snapper assessments have included an additional component of catch to account for unreported commercial catches (Davies et al. 2006). Annual unreported catches were assumed to represent an additional 20% of the reported catch in the period prior to the introduction of the QMS and 10% of the reported catch in the subsequent years. The commercial catch for 2021 was assumed to be equivalent to the catch from 2020 (2019/20 fishing year).

The commercial catch was dominated by two main fishing methods: single trawl and pair trawl. The pair trawl fishery developed in the mid-1970s and was the dominant method during 1976–1989, accounting for an average of 75% of the annual catch (Fisheries New Zealand 2020). The proportion of the catch taken by the pair trawl method during 1989/90–2018/19 was determined from the fishery characterisation (section 2.2). The proportion of the SNA 8 catch taken by the pair trawl fishery declined from about 40% in 1989/90 to be negligible from 2011/12 onwards. The catch proportions were applied to partition the commercial catch history into the two method fisheries (Figure 13).

The compiled commercial catch history includes estimates of foreign catch; i.e., trawl catches from 1967 to 1977 and longline catch from 1975 to 1977 were included at the reported levels (Davies 1999). However, catch reports from the Japanese longline fleet were not available for 1965–1974 (Davies et al. 2006). Following previous assessments (e.g., Davies et al. 2006), an additional catch of 2000 t per annum was assumed for the Japanese fleet for that period. Alternative levels of Japanese catch (1000 t and 3000 t) were evaluated as model sensitivities in the 2020 assessment (Langley 2020) (Figure 13).

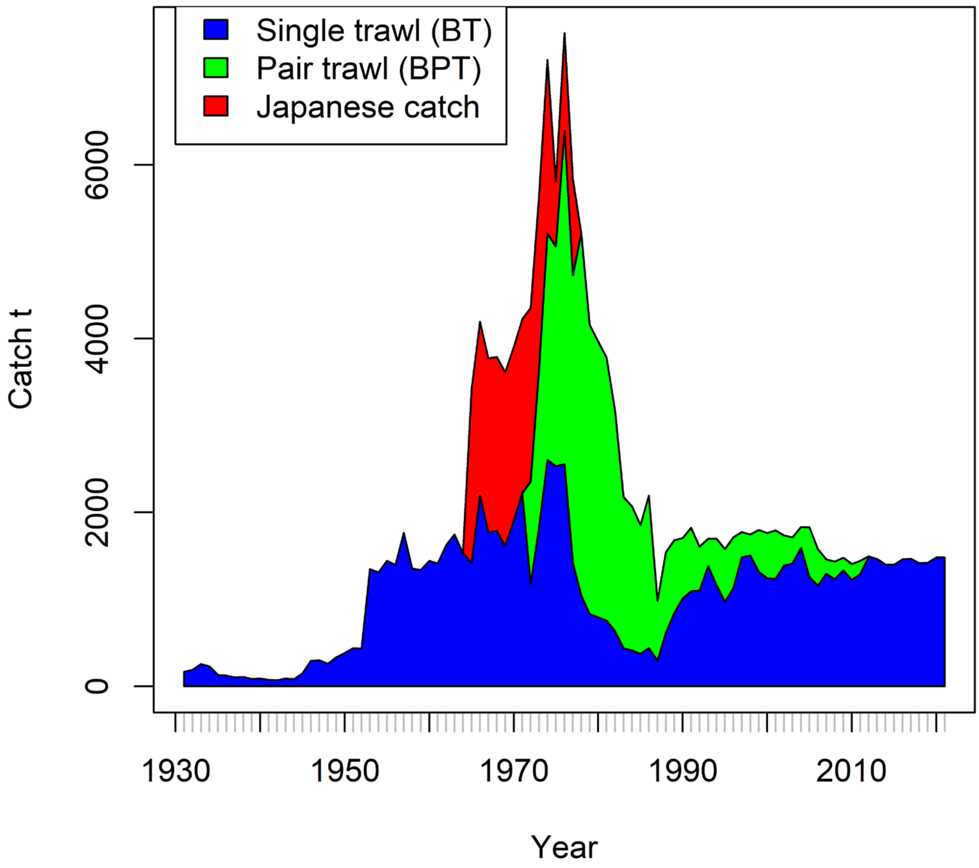

Figure 13: Commercial catch history included in the assessment model partitioned by fishery with an allowance for unreported catches and an assumed level of Japanese catch of 2000 t.

3.2 Customary catch

The customary allowance for SNA 8 was established in 1998 at 50 tonnes. The customary allowance was reduced to 43 t in proportion to the reduction in the TACC in 2005/06. There are no estimates of annual customary catch from SNA 8 available for inclusion in the assessment model. Although a component of the customary catch is probably included within the time series of recreational catch estimates, there is no reliable time-series of estimates of customary catches available. Documentation of the customary catch has improved over the last decade, including the recording of catch taken via pātaka whata by the Taranaki Iwi. The quantity of fish harvested under this system has been small compared to the overall SNA 8 catch.

3.3 Recreational catches

The first estimate of recreational catch was derived from the results of the 1990 tagging programme (Table 1). Subsequent recreational catch estimates are available from a series of telephone diary surveys, although the results from the 2000 and 2001 surveys are not considered reliable and have been rejected by the Marine Amateur Fisheries Working Group. The 1993/94 and 1995/96 telephone diary surveys yielded recreational catch estimates that were very similar to the 1990 tagging programme estimate. However, there remains concern regarding the reliability of these earlier survey estimates because they applied the same methodological approach to the 2000 and 2001 surveys.

Recreational catch estimates for SNA 8 are also available from the aerial-access survey conducted in 2006/07 and National Panel Surveys (NPS) conducted in 2011/12 and 2017/18. There is a large (343%) increase in the estimates of recreational catch between 2006/07 and 2017/18 (Table 1). The magnitude of the increase is very similar to both the increase in the CPUE indices from the commercial fishery over the same period (345%) and consistent with the recent increase in the biomass indices from *Kaharoa* trawl survey (section 3.5). These comparisons suggest that the increases in recreational catch are generally consistent with an overall increase in the abundance of snapper.

Table 1: A summary of the recreational catch estimates for SNA 8.

Fishing year	Methodology	Catch estimate	Reference	Additional comments
1989/90	Tagging programme	239 t	Gilbert & Sullivan 1994	
1993/94	Telephone diary	238 t		
1995/96	Telephone diary	240 t		
2000	*Telephone diary*	*661 t*		*Excluded*
2001	*Telephone diary*	*1 133 t*		*Excluded*
2006/07	Aerial Access	260 t	Hartill et al. 2011	
2011/12	National Panel Survey	630 t	Wynne-Jones et al. (2014)	
2017/18	National Panel Survey	892 t	Wynne-Jones et al. (2019)	

The catch estimates indicate that the recreational fishery accounted for a significant proportion of the total SNA 8 catch over the last decade. There is, however, no information available regarding earlier (pre-1990) levels of recreational catch. Previous assessments formulated annual catches for this period based on an assumed initial (1931) level of recreational catch of 60 t and a linear increase in catch over subsequent years to the level of the 1990 recreational catch estimate (239 t) (following Davies et al. 2006, 2013) (Figure 14). Annual catches were assumed to remain at the same level during 1990–1996.

Recreational catches in 2007, 2012, and 2018 were assumed to be equivalent to the point estimates from the respective recreational surveys, assumed known without error. A preliminary catch history was generated assuming that recreational catches increased linearly between each successive survey.

The resultant catch history was incorporated in a preliminary configuration of the assessment model to generate a biomass trajectory that provided estimates of the exploitation rate for the recreational fishery corresponding to each survey estimate.

The resultant estimates of exploitation rate were then used to iteratively regenerate the recreational catches in the years between the survey estimates (for 1997 to 2017) (Figure 14). Exploitation rates were assumed to change linearly between successive surveys and the interpolated exploitation rate was applied to the annual biomass estimates to determine the recreational catches for the intervening years. For the 2020 assessment, the recreational catch in 2019 was derived, based on the exploitation rate corresponding to the recreational catch estimate from 2018. The recreational catch in 2020 was assumed to be equivalent to the 2019 catch.

For the current assessment, two alternative catch scenarios were assumed for 2019–2021: 1) constant annual catches at the 2019 level and 2) using the exploitation rate derived from the 2018 recreational catch estimate to derive annual catches based on the stock biomass from 2019–2021. The latter approach yielded recreational catches that increased by 34% between 2018 and 2021 (Figure 14).

The recreational catch estimates derived from NPS are considered to include the catches from charter fishing trips, although the catch taken by non-New Zealand residents on charter vessels is not included in those catch estimates. Nonetheless, it is considered that the non-New Zealand resident catch accounts for a trivial component of the recreational catch from SNA 8, and no additional allowance was made for that component of the catch.

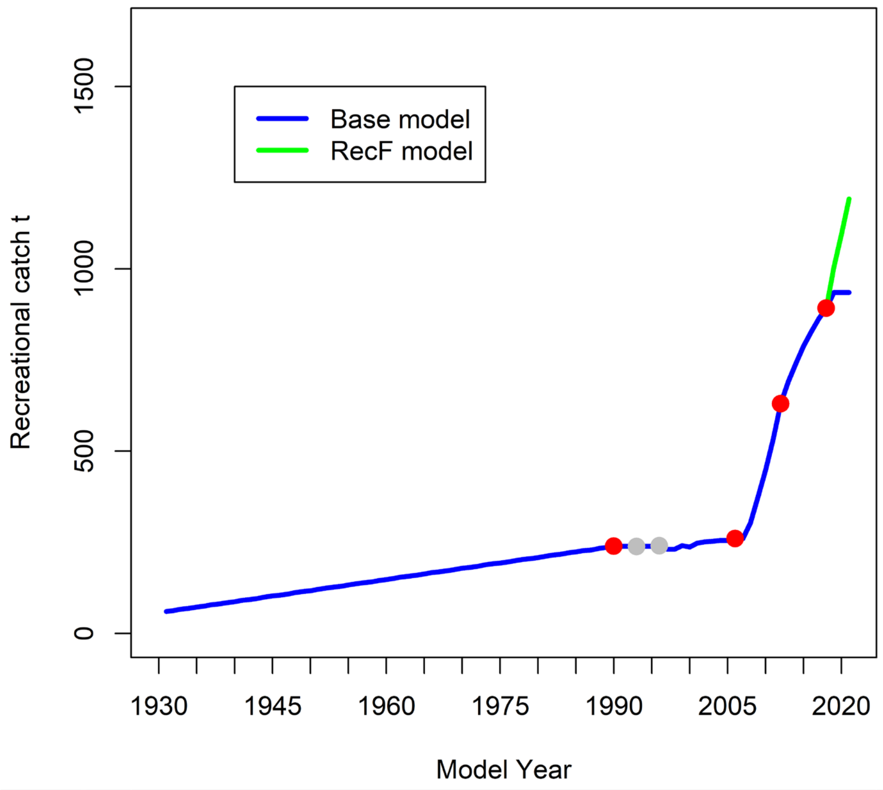

Figure 14: Recreational catch estimates from SNA 8 (red points) used in the derivation of the recreational catch history (blue and green lines). The grey points are additional recreational catch estimates from the 1993/94 and 1995/96 telephone diary surveys (presented for comparison only).

Length samples of the recreational catch of snapper have been collected at boat ramps throughout SNA 8 from 1990/91 to 2017/18 (e.g., Davey et al. 2019) (Table 2). The sampling data were assigned to three main areas of the SNA 8 recreational fishery: inside the west coast harbours (Hokianga, Kaipara, Manukau, Raglan, and Kawhia) and the coastal area outside the harbours partitioned North and South of Albatross Point (Waikato) (Bruce Hartill, NIWA unpublished data).

The length compositions of the catch from within the harbours are dominated by fish in the 27–32 cm length mode (Figure 15). By comparison, the samples from the two coastal areas (North and South) share a similar distribution, dominated by 30–45 cm fish, that differs considerably from the fish sampled from within the harbours. This indicates that the selectivity of the recreational fishery differs considerably between the harbour and coastal areas of SNA 8. These definitions were applied to partition the recreational fishery in the assessment model. Annual length compositions for the two fisheries were derived from the samples collected from the respective areas (Figure 16).

The two recent NPS estimated that 22% and 28% of the recreational catch (in numbers) was taken within the harbour areas. As an approximation, it was assumed that 25% of the recreational catch was taken from within the harbours and the total annual recreational catches were allocated between the two fisheries accordingly.

Table 2: Number of snapper sampled for length from the SNA 8 recreational fishery, by fishing year and area (inside harbours and the northern and southern areas outside the harbours) (Bruce Hartill, NIWA, unpublished data).

Fishing year			Area	Total
	Harbours	North	South	
1990–91	2 825	455	237	3 517
1993–94	2 425	500	0	2 925
1995–96	1 563	373	23	1 959
1996–97	56	7	0	63
2005–06	693	307	188	1 188
2006–07	2 026	2 252	858	5 136
2011–12	1 583	1 894	946	4 423
2012–13	1 920	54	180	2 154
2013–14	1 273	360	509	2 142
2014–15	1 189	411	610	2 210
2015–16	725	567	531	1 823
2016–17	1 132	261	737	2 130
2017–18	779	179	1 273	2 231

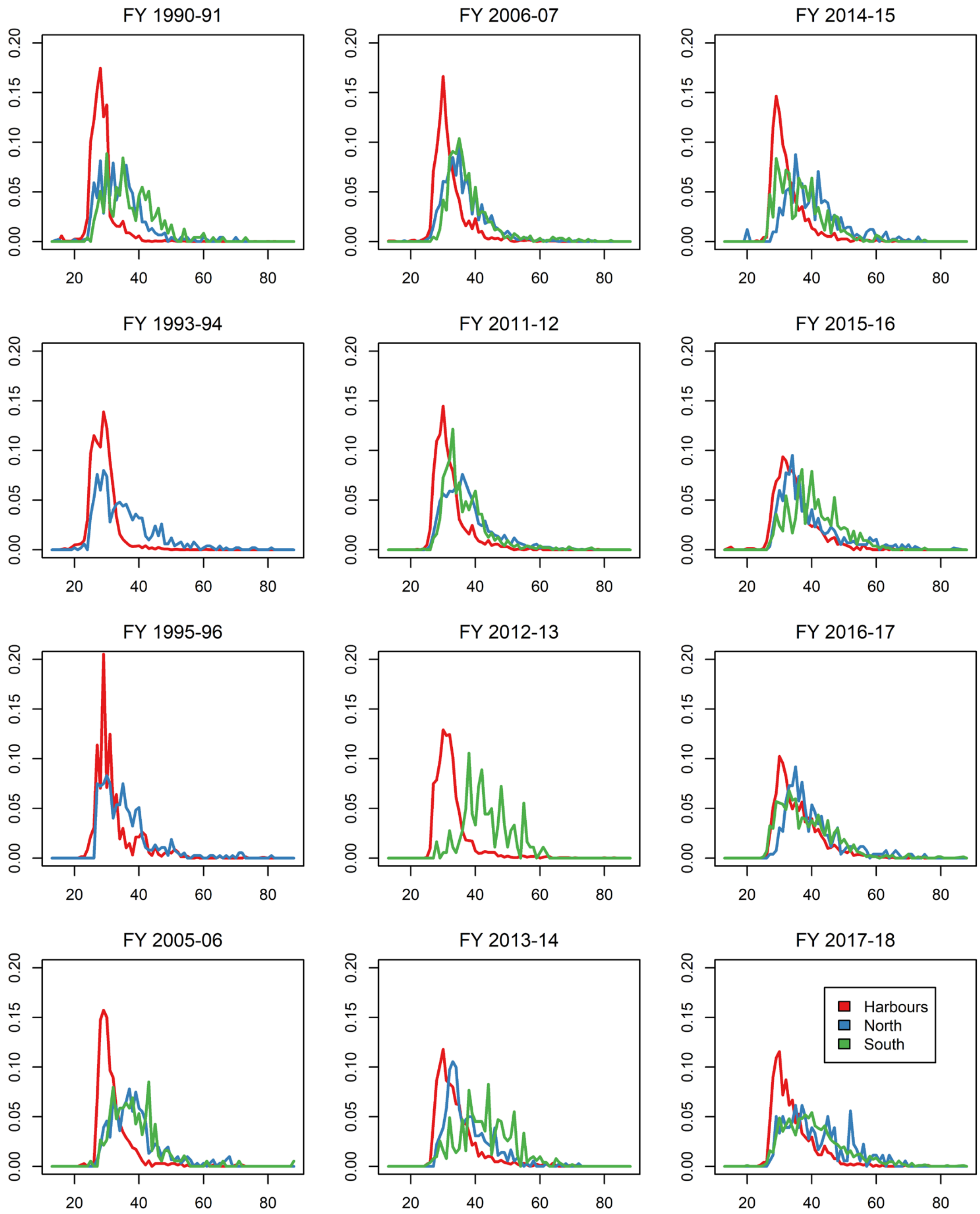

Figure 15: Proportional length compositions of snapper from the SNA 8 recreational fishery, by fishing year and area (inside harbours and the northern and southern areas outside the harbours).

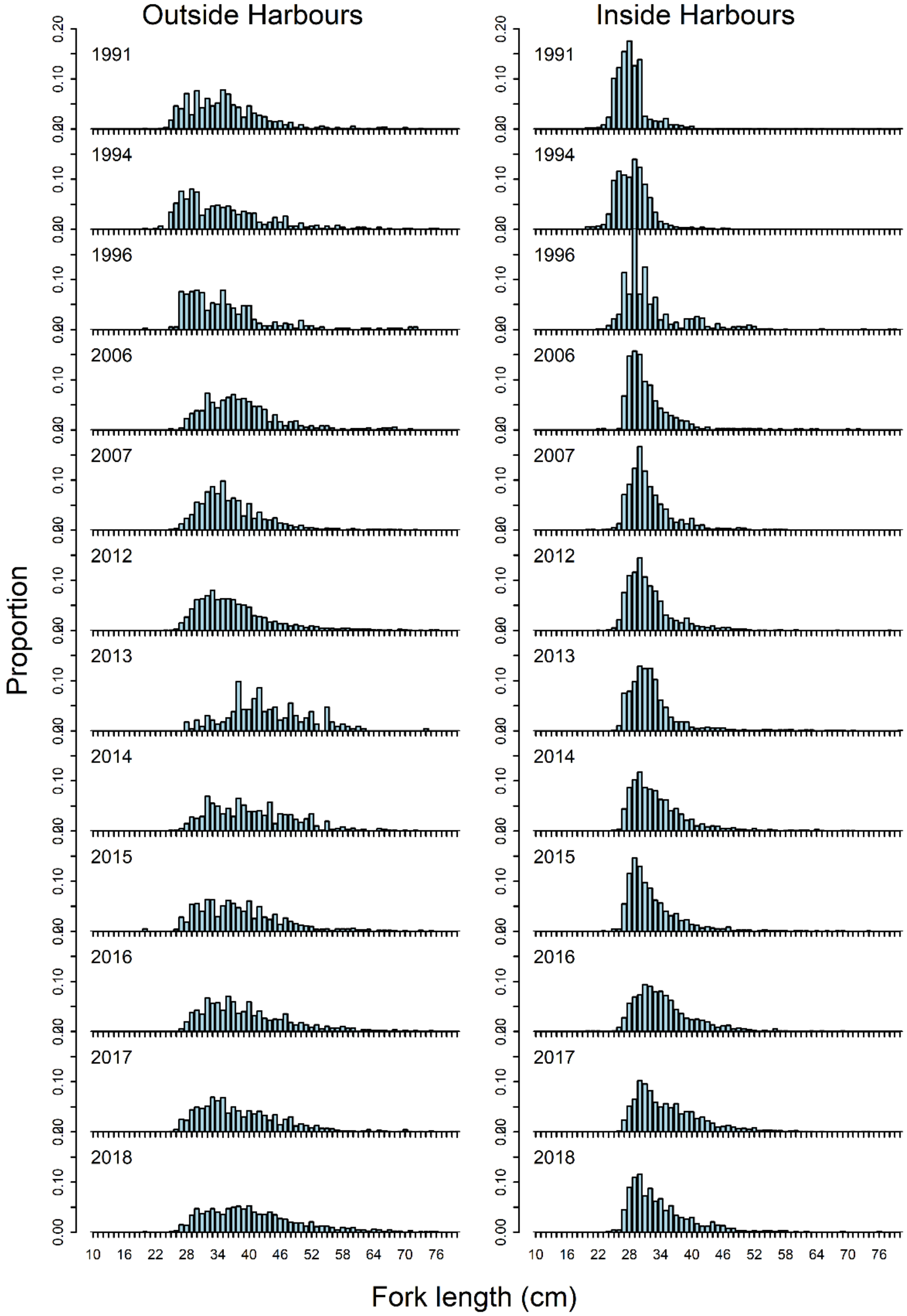

Figure 16: Distribution of annual length compositions of snapper from the SNA 8 recreational fishery (model year) partitioned outside (left) and inside (right) the harbours.

3.4 Fishery age compositions

There is a long time series of annual age compositions available from the single trawl (N. obs = 26) and pair trawl fisheries (N. obs = 18), including samples from the mid-late 1970s (Table 3 and Table 4). Those samples are characterised by a high proportion of fish in the oldest, aggregated age group (20+ ‘plus group’) (Figure 17 and Figure 18). The ageing of these older fish is not considered sufficiently reliable to provide a more comprehensive age composition (Cameron Walsh, pers. comm.).

Fish older than 20 years represented a trivial proportion of the sampled catch from 1990 onwards (Figure 17 and Figure 18). The more recent age compositions tended to be dominated by relatively strong year classes that are evident in successive samples. For example, the 1985 year class is evident as a strong cohort of 4 year old fish in 1989 and persists in the fishery until 1995; and the 1998 year class enters the fishery at age 3 years in 2001 and persists until 2008. More recently, the 2006 year class recruited to the fishery in 2010 (at 4 years) and was subsequently sampled in 2013 (7 years old) and 2016 (10 years old) (Figure 17).

Sampling of the pair trawl fishery ceased in 2006. During 2000–2006, there was concurrent sampling of both the single and pair trawl fisheries following earlier sampling in 1990–1992. A comparison of the distribution of annual age compositions from the two methods does not indicate an appreciable difference in the age structure of the catch from the two methods (Figure 19). There is also no indication of an appreciable difference of the proportion of fish in the ‘plus group’ between the two methods from the samples from the 1970s.

Table 3: A summary of the age composition data from the SNA 8 single trawl fishery. The season of the sampling is denoted spring (Spr) and/or summer (Sum).

Fishing year	Model year	Season	No. landings	Publication
1974/75	1975	Spr	6	Davies et al. 2013
1975/76	1976	Spr	4	Davies et al. 2013
1989/90	1990	Sum	3	Davies & Walsh 1995
1990/91	1991	SprSum	28	Davies & Walsh 1995
1991/92	1992	SprSum	11	Davies & Walsh 1995
1992/93	1993	SprSum	22	Davies et al. 1993
1993/94	1994	Spr	14	Davies & Walsh 1995
1994/95	1995	Spr		Walsh et al. 1995
1995/96	1996	Spr		Walsh et al. 1997
1996/97	1997	Spr		Walsh et al. 1998
1997/98	1998	Spr		Walsh et al. 1999
1998/99	1999	SprSum		Walsh et al. 2000
1999/00	2000	SprSum	17	Walsh et al. 2001
2000/01	2001	SprSum	15	Walsh et al. 2002
2001/02	2002	SprSum	15	Walsh et al. 2003
2002/03	2003	SprSum	27	Walsh et al. 2004
2003/04	2004	SprSum	15	Walsh & Davies 2004
2004/05	2005	SprSum	15	Walsh et al. 2006a
2005/06	2006	SprSum	13	Walsh et al. 2006b
2006/07	2007	SprSum	14	Walsh et al. 2009a
2007/08	2008	SprSum	15	Walsh et al. 2009b
2008/09	2009	SprSum	15	Walsh & Buckthought 2010
2009/10	2010	SprSum	15	Walsh et al. 2011
2012/13	2013	SprSum	15	Walsh et al. 2014b
2015/16	2016	SprSum	16	Walsh et al. 2017
2018/19	2019	SprSum	15	Walsh et al. 2019

Table 4: A summary of the age composition data from the SNA 8 pair trawl fishery. The season of the sampling is denoted spring (Spr) and/or summer (Sum).

Fishing year	Model year	Season	No. landings	Publication
1974/75	1975	Spr	4	Davies et al. 2013
1975/76	1976	Spr	5	Davies et al. 2013
1977/78	1978	Sum	4	Davies et al. 2013
1978/79	1979	SprSum	13	Davies et al. 2013
1979/80	1980	Spr	2	Davies et al. 2013
1985/86	1986	?		Davies 1999
1986/87	1987	?		Davies 1999
1988/89	1989	SprSum	13	Davies & Walsh 1995
1989/90	1990	Spr	18	Davies & Walsh 1995
1990/91	1991	Spr	13	Davies & Walsh 1995
1991/92	1992	Sum	7	Davies & Walsh 1995
1999/00	2000	SprSum	21	Walsh et al. 2001
2000/01	2001	Sum	17	Walsh et al. 2002
2001/02	2002	Sum	10	Walsh et al. 2003
2002/03	2003	SprSum	17	Walsh et al. 2004
2003/04	2004	SprSum	14	Walsh & Davies 2004
2004/05	2005	SprSum	11	Walsh et al. 2006a
2005/06	2006	SprSum	11	Walsh et al. 2006b

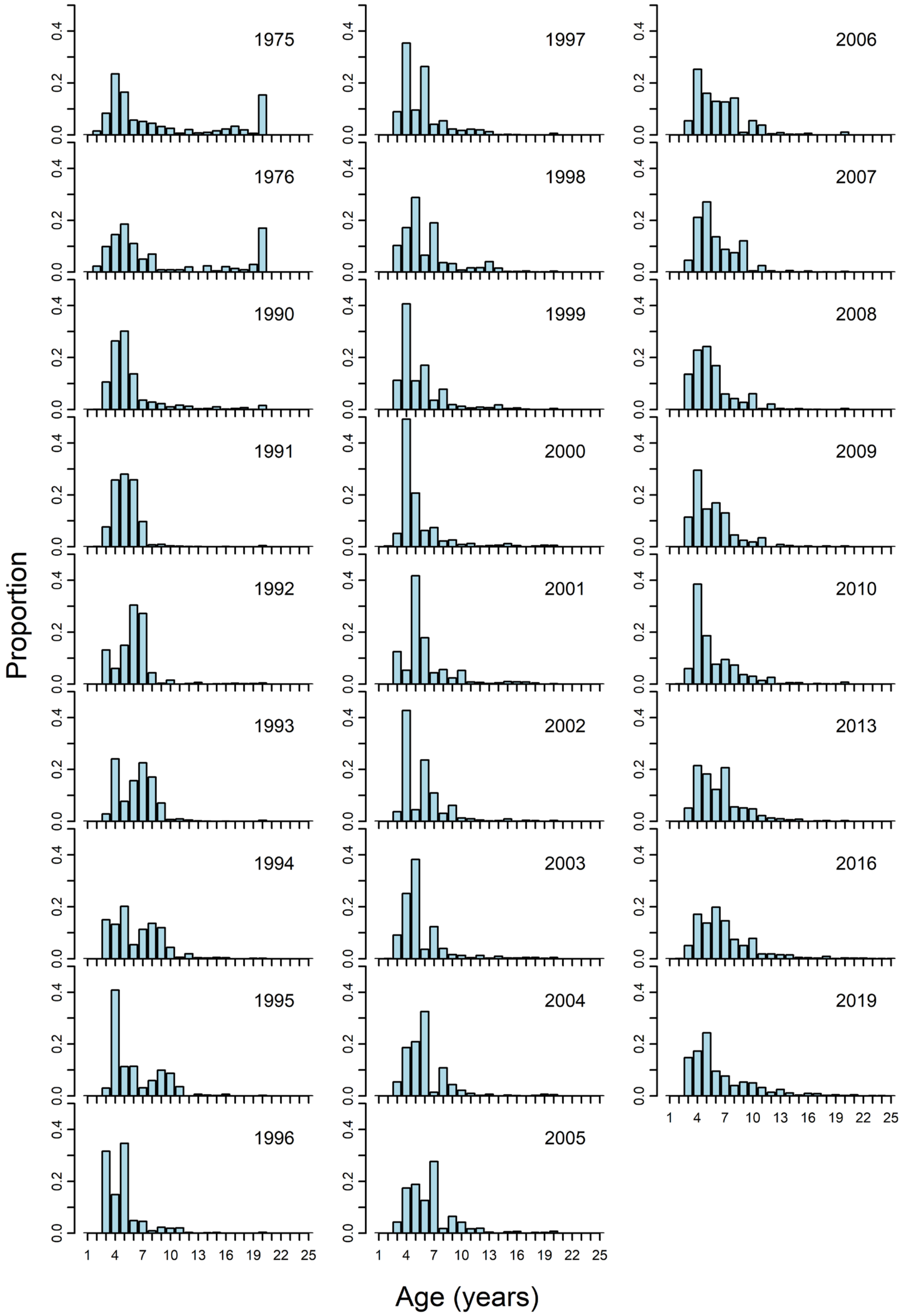

Figure 17: Distribution of annual age compositions derived from the catch of the single trawl fishery. The oldest age class in each year is an aggregated group including older age classes (plus group). The minimum age of the plus group varies amongst sample years. The year represents the model year (2019 represents the 2018/19 fishing year).

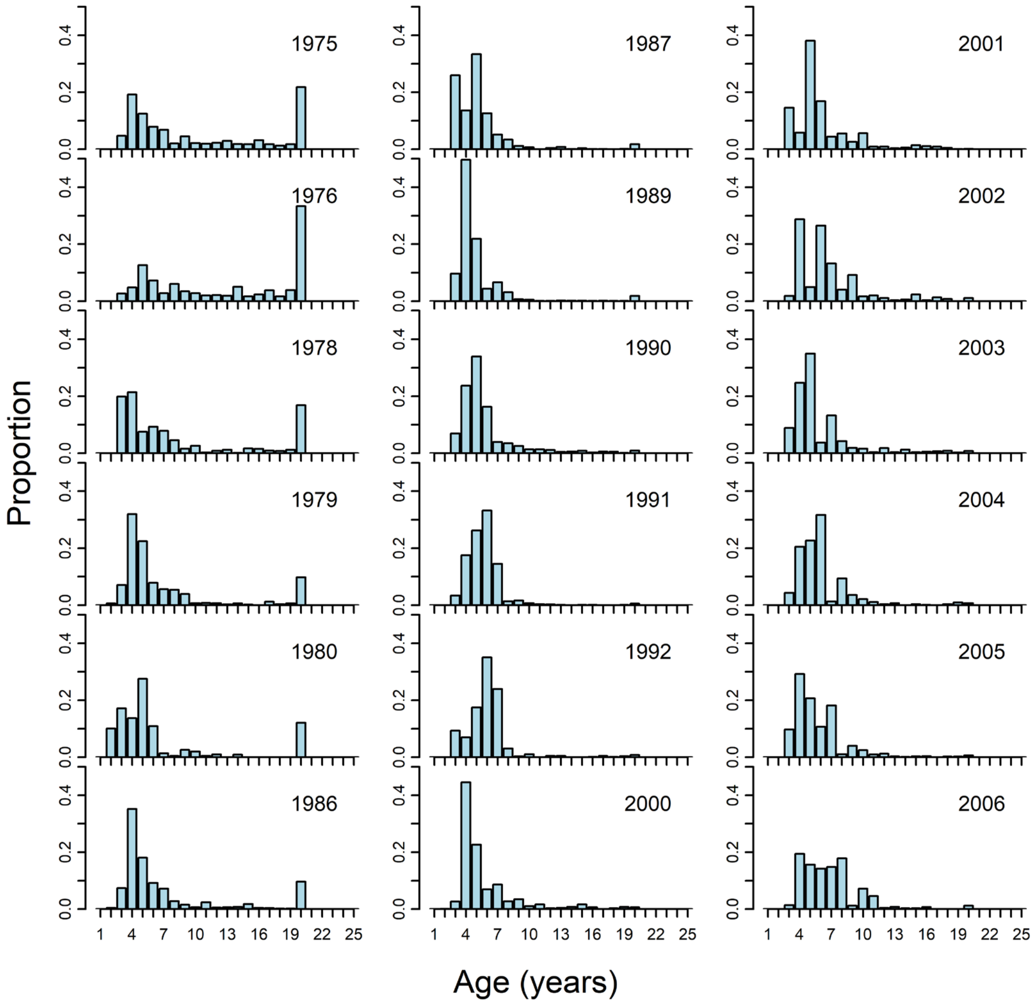

Figure 18: Distribution of annual age compositions derived from the catch of the pair trawl fishery. The oldest age class in each year is an aggregated group including older age classes (plus group). The minimum age of the plus group varies amongst sample years. The year represents the model year (2006 represents the 2005/06 fishing year).

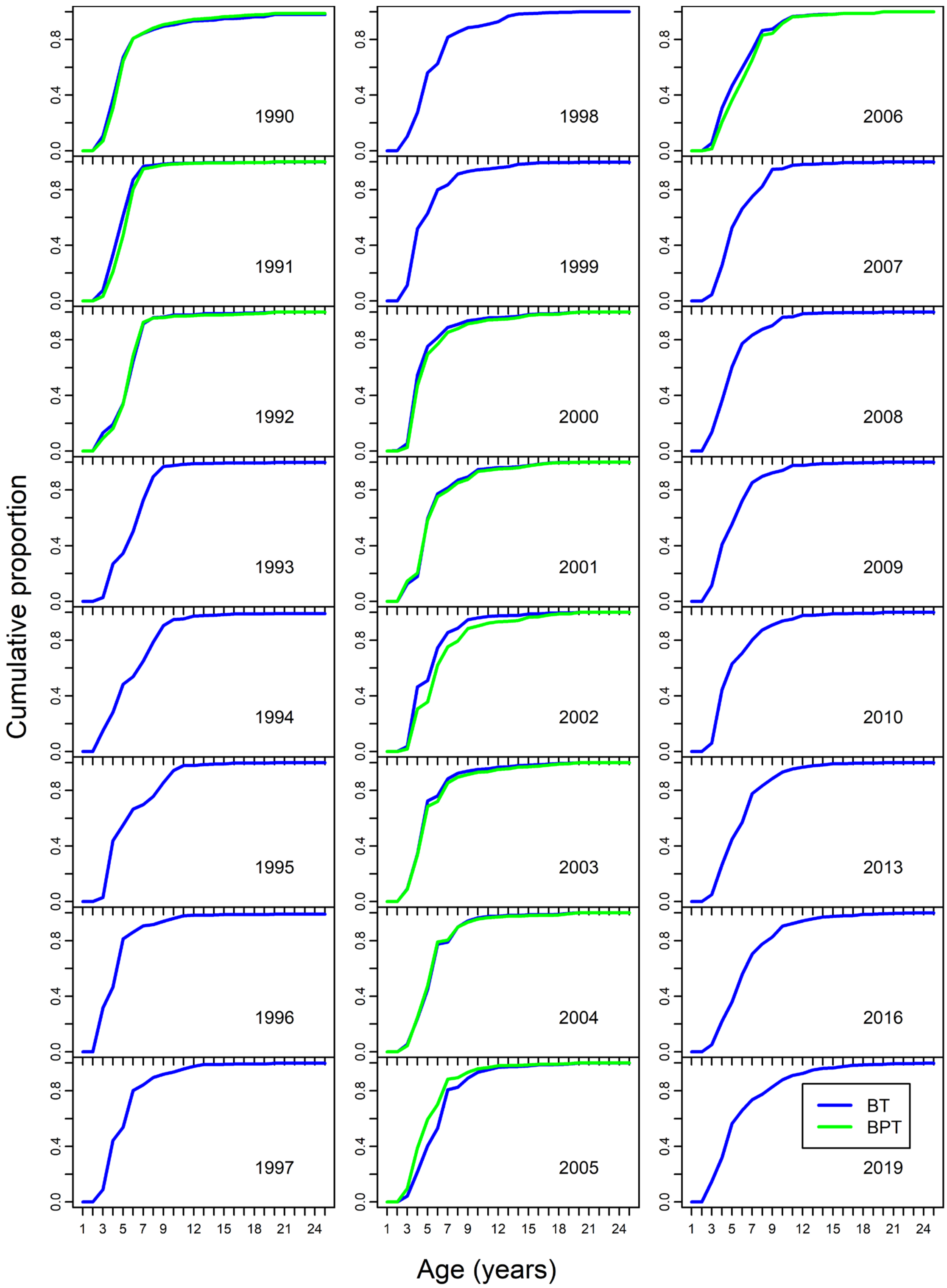

Figure 19: Cumulative proportions of the annual age compositions sampled from the single bottom trawl (BT) and pair bottom trawl (BPT) fisheries. The year represents the model year (2019 represents the 2018/19 fishing year).

3.5 *Kaharoa* trawl surveys

Trawl surveys of inshore finfish species, including snapper, off the west coast of the North Island were first conducted by R.V. *Kaharoa* in October-November 1986 and 1987. The spatial extent of these initial surveys was relatively limited and did not encompass the broader distribution of snapper. The survey area was extended for the subsequent series of trawl surveys that were conducted in 1989 (Drury & McKenzie 1992), 1991 (Drury & Hartill 1992), 1994 (Langley 1995), 1996 (Morrison 1998) and 1999 (Morrison & Parkinson 2001). The *Kaharoa* trawl surveys were reinstated with three annual surveys in October-November 2018, 2019, and 2020 (Emma Jones, NIWA, unpublished data).

Since 1989, all surveys have encompassed a core area (from Ninety Mile Beach to North Taranaki Bight extending seaward to the 100 m depth contour) and utilised a similar spatial stratification. The spatial domain of the core area was refined to account for the removal of the Māui dolphin trawl exclusion area (introduced in 2008) which was not sampled by the 2018 and 2019 trawl surveys. The Māui dolphin trawl exclusion area was extended in October 2020, further limiting the extent of the shallower, inshore areas sampled by the 2020 trawl survey.

A core survey area, excluding the full extent of the Māui dolphin trawl exclusion area, was defined to derive a comparable time series of survey biomass indices and scaled length compositions for all eight trawl surveys (Emma Jones, NIWA, unpublished data). The length compositions were converted to age compositions using an age-length key derived from otoliths collected from the core area of the survey.

The surveys were conducted at the beginning of the fishing year (October-November) and have been assigned to the corresponding model year following the calendar year of the survey. For example, the trawl survey conducted in November 2018 was assigned to the 2019 model year (and denoted the 2018/19 survey). Correspondingly, the ages of the sampled fish were incremented to the age at 1 January following the survey (e.g., fish aged 1+ at the time of the survey were assigned an age of 2 years).

The five biomass indices from the earlier surveys are substantially lower than the biomass estimates from the three recent surveys (Figure 20), although there is also a considerable difference in the magnitude of the biomass indices from the three recent indices (Figure 20). The corresponding age compositions from the surveys reveal that the earlier surveys were dominated by 2–5 year old fish. For the recent surveys, the age compositions comprised a higher proportion of fish older than 6 years, particularly for the two most recent (2019/20 and 2020/21) surveys (Figure 21).

The survey age compositions were partitioned to derive estimates of numbers of fish in each age class (Figure 22). Survey estimates of 1 year old fish (0+) are relatively imprecise compared with estimates of numbers of fish in the older age classes. There are a limited number of year classes for which successive estimates of relative abundance (numbers of fish) are available from across a range of age classes from successive surveys (Table 5 and Figure 22). However, estimates of the numbers of 1 year old fish are generally substantially lower than subsequent estimates of the same year class at older ages and the individual estimates are poorly correlated. This indicates that the survey estimates of 1 year old fish probably do not provide a reliable index of the relative abundance of an individual year class (Figure 22), which is possibly because the primary nursery area is in harbours and shallow coastal areas not covered by the survey.

In contrast, there is a reasonable correspondence between successive trawl survey estimates of the number of fish in individual year classes for ages 2–5 years (Figure 22 and Table 5). For example, the three estimates of abundance of the 2016 year class (at ages 3, 4, and 5 years) from the recent trawl surveys indicated that the year class was one of the strongest indices from the respective series. This indicates that the trawl surveys consistently sampled fish within those age classes. The time series of trawl surveys provides estimates of relative strength of the 1985–1998 and 2014–2019 year classes.

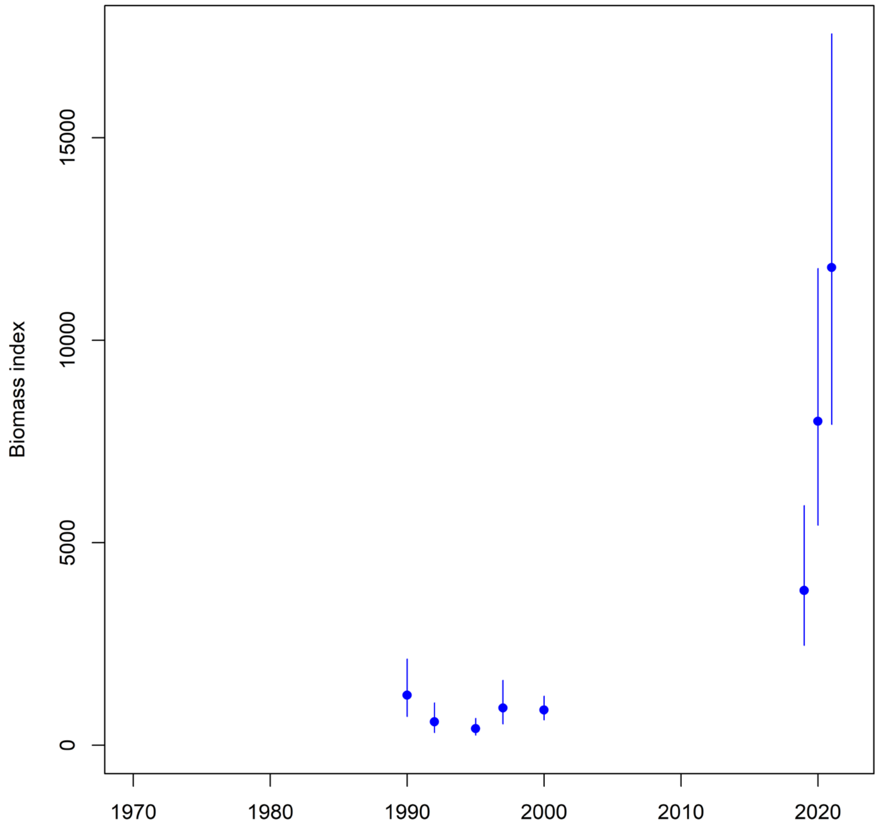

Figure 20: The time series of *Kaharoa* trawl survey biomass indices (assigned to model years). The error bars represent 95% confidence intervals.

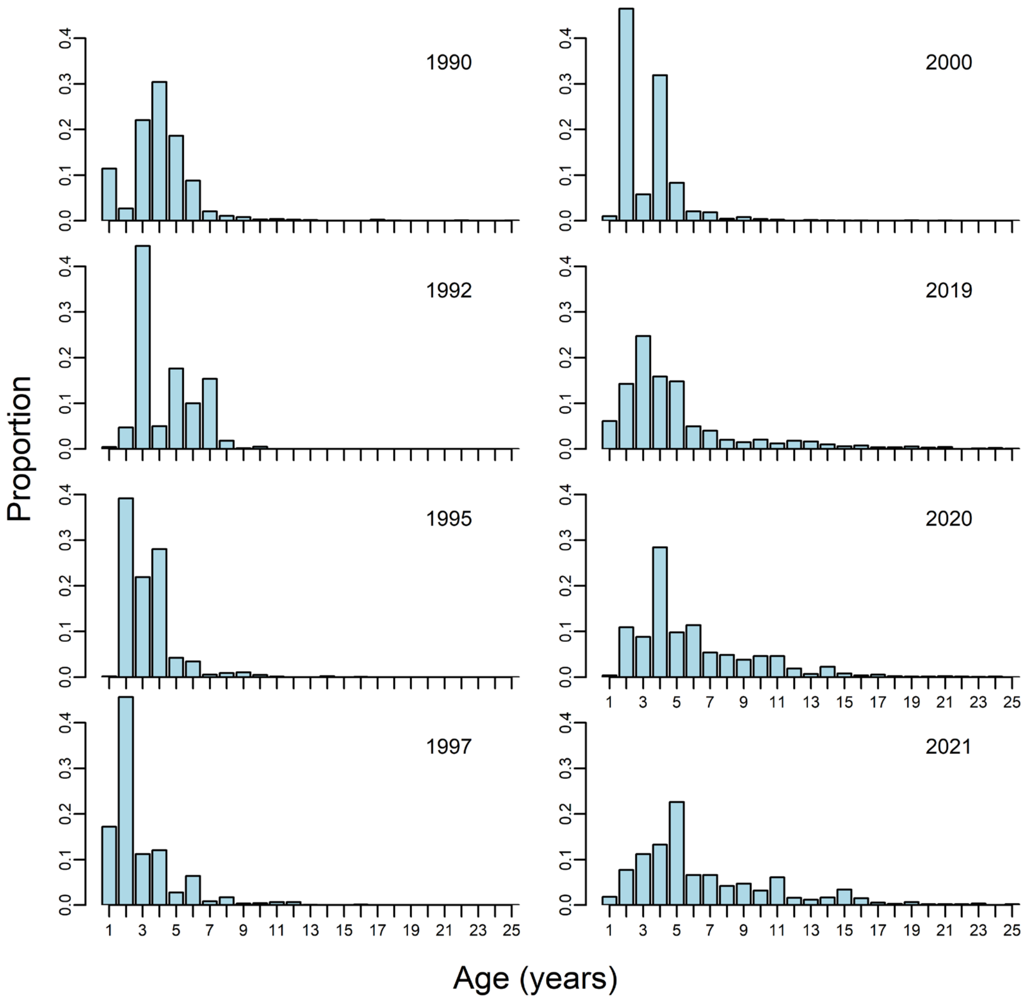

Figure 21: Distribution of the proportional age compositions of snapper from the time series of *Kaharoa* trawl surveys. The years denote model years (e.g., the 2021 model year represents the trawl survey conducted in November 2020). Ages are assigned as at 1 January following the survey; e.g., fish aged 1 year were 0+ at the actual time of the survey.

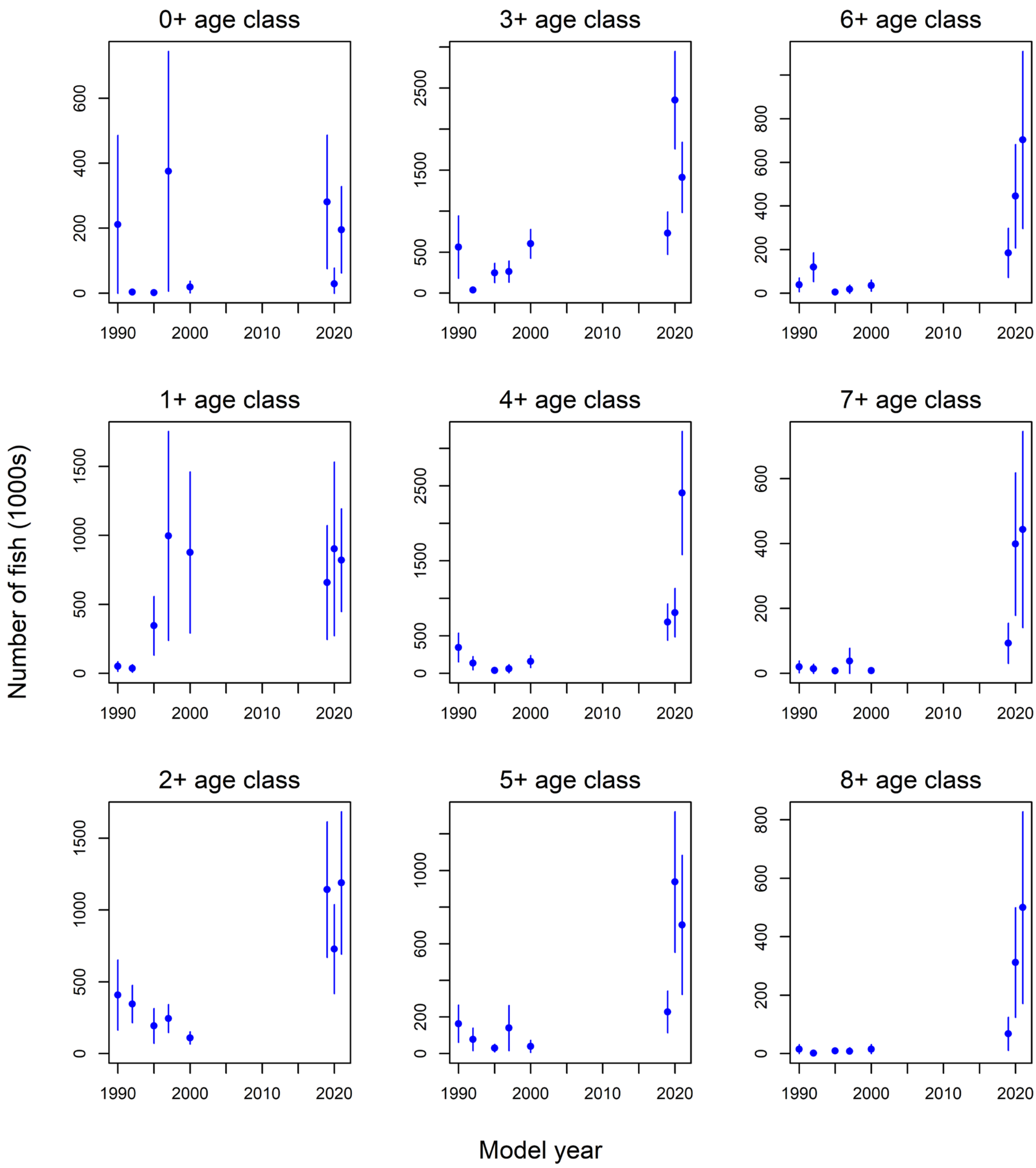

Figure 22: Estimates of the number of fish (thousands) in individual age classes (panels) derived from the time series of *Kaharoa* trawl surveys. The error bars represent 95% confidence intervals. The years denote model years (e.g., the 2021 model year represents the trawl survey conducted in November 2020).

Table 5: Estimates of numbers of fish (thousands) for age classes 1+, 2+, 3+, and 4+ and fish older than 4+ years from the time series of *Kaharoa* trawl surveys (core area). The shading identifies successive estimates of the abundance of the 2016 year class.

Year		Age (years)				
Survey	Model	1+	2+	3+	4+	>4+
		2	3	4	5	>5
1989	1990	50.1	407.7	562.0	343.9	255.6
1991	1992	36.3	344.9	38.7	136.6	215.4
1994	1995	344.9	192.7	247.3	36.9	57.7
1996	1997	996.0	244.0	262.6	60.7	241.1
1999	2000	876.3	109.2	601.8	157.2	113.9
2018	2019	658.2	1 141.9	731.6	683.2	925.0
2019	2020	902.0	727.6	2 353.1	809.4	3 246.8
2020	2021	820.4	1 188.6	1 410.7	2 404.4	3 802.8

Most of the large increase in the biomass indices between the 2018/19 and 2019/20 trawl surveys was attributable to an increase in the abundance of fish surveyed in the 8–12 year-old age-range. The comparison of successive estimates of the individual year classes indicates that the catchability of these older fish was greater for the 2019/20 survey than for the 2018/19 survey (Figure 23). There is some concern regarding the timing of the 2018/19 trawl survey relative to the other surveys in the series. The distribution of snapper catches and the gonadal maturation data suggested that the 2018/19 survey may have coincided with the main spawning period; consequently, a significant proportion of the adult biomass may have been concentrated in areas not adequately sampled by the survey, in particular the shallower areas in the vicinity of harbour entrances.

Similarly, there was a considerable increase in the snapper biomass indices between the 2019–20 and 2020–21 trawl surveys (see Figure 20), including an increase in the abundance of older fish (> 10 year) (Figure 23). Most of the increase in biomass was in the 50–100 m depth range in the vicinity of Kaipara and Manukau harbours (Figure 24). This may indicate an expansion of the main distribution of mature snapper, from the shallower areas not fully sampled by the current trawl survey, thereby increasing the overall availability of snapper to the trawl survey. By comparison, the depth distribution of smaller snapper (20–29 cm) remained relatively stable over the entire time series of trawl surveys, with a general decline in the catch rate of smaller snapper in depths greater than 40 m (Figure 24).

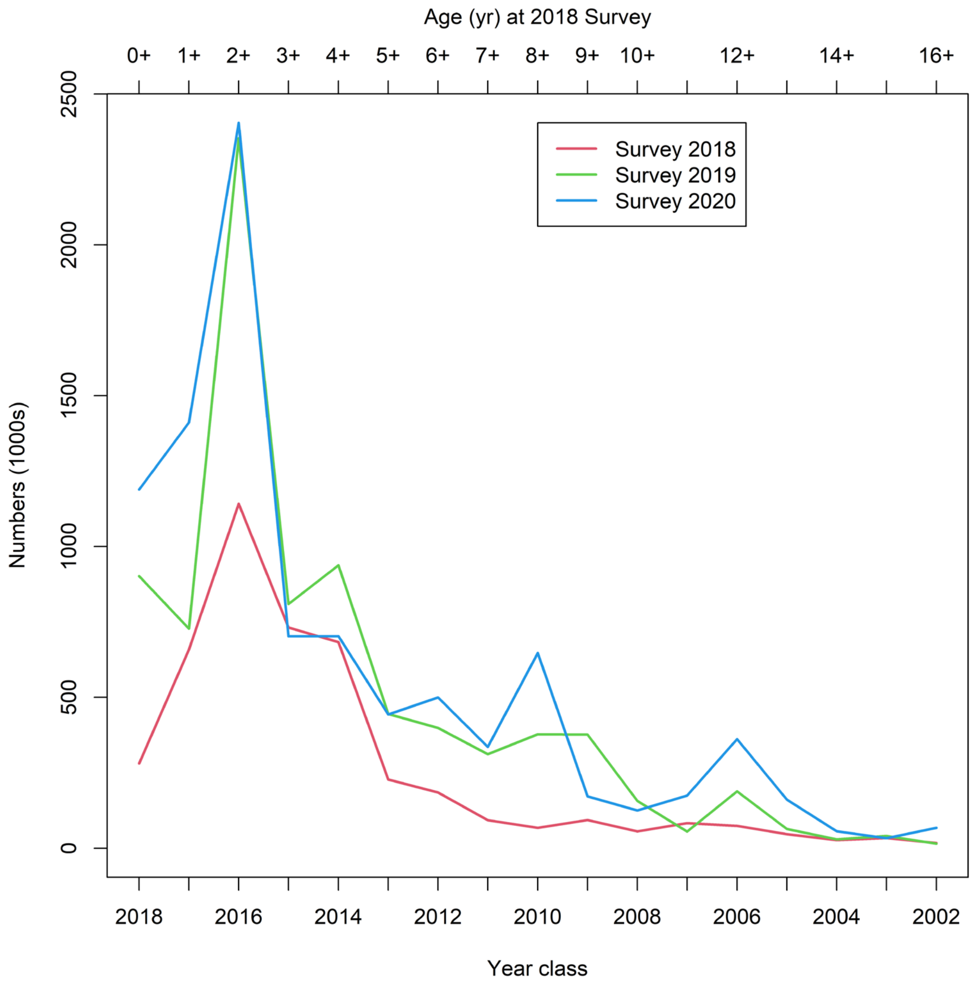

Figure 23: Trawl survey estimates of numbers of fish (thousands) in individual year classes from the three recent surveys. The year class is also indexed by the age of the fish in the 2018 survey.

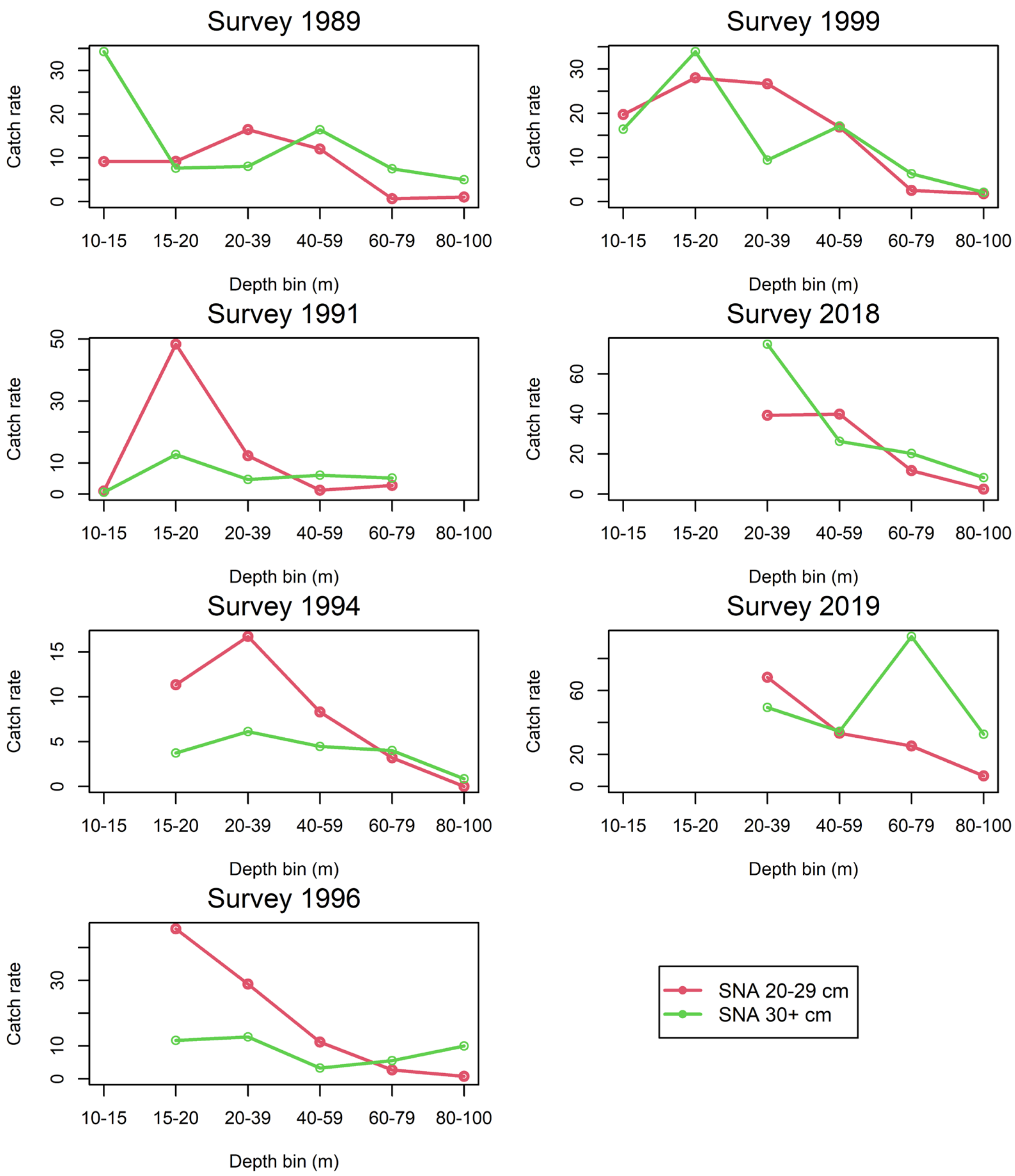

Figure 24: Catch rates (number per nautical mile) of small (20–29 cm) and larger (> 29 cm) snapper from *Kaharoa* trawl surveys averaged by depth interval. Data were not available for the 2020 survey.

3.6 Tag biomass estimates and population length compositions

Two estimates of absolute biomass are available from tagging programmes conducted in 1990 and 2002. The current assessment used the equivalent biomass estimates included in the previous assessment, i.e., 1990, 9505 t (CV 0.18) and 2002, 10 442 t (CV 0.12) (Gilbert et al. 2005, Davies et al. 2013, McKenzie, NIWA, unpublished data). The biomass estimates were calculated to represent all fish in the population 3 years and older, corresponding to fish above 25 cm fork length (F.L.) in length.

The two tagging programmes also provided estimates of the population length composition (Davies et al. 2013). These length compositions represented fish aged 3 years and older and, accordingly, were truncated at a lower bound of 25 cm (F.L.), which approximates the lower length range of 3 year old fish. The length compositions were derived from estimates of the population in length categories and the overall length composition was determined from linear interpolation between the larger length categories (Davies et al. 2006) (Figure 25).

The population length compositions are dominated by fish in the 27–40 cm length range (Figure 25). There is a long tail in the distribution of larger fish, extending to 70–75 cm. The precision of the estimates of the proportion of fish in the larger length classes is considerably lower than for the mode of the distribution (Davies et al. 2006).

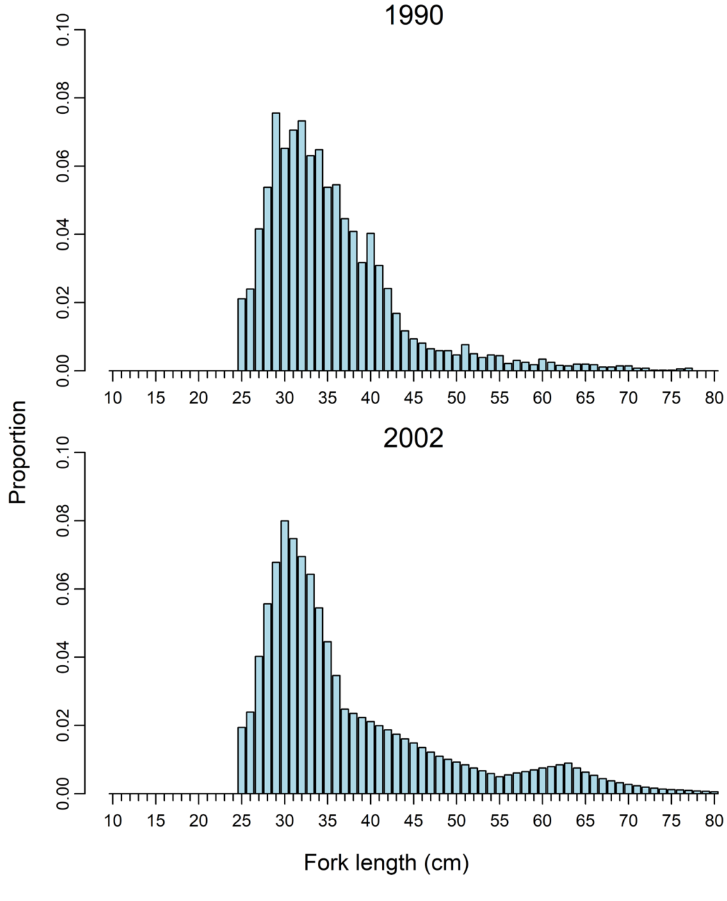

Figure 25: Distribution of estimates of the population length composition (for fish aged 3 years and older) from the 1990 and 2002 tagging programmes (source: Davies et al. 2013).

For the 2002 tagging programme, the disaggregated tag release and recovery data were available from the original analysis of Gilbert et al. (2005). Stock Synthesis has the facility to integrate tag observational data in the modelling framework, structured by age-specific release groups (Methot & Wetzell 2013, Methot et al. 2020). The release groups were defined based on tag release zone (5 zones: Ninety Mile Beach, Kaipara, Manukau, North Taranaki Bight, and South Taranaki Bight) and assigned to an approximate age class based on the length of fish at the time of release, using an age-length key. The number of tags in each release group was corrected for the initial tag mortality, based on the established relationship incorporating depth capture and the magnitude of the catch (Gilbert et al. 2005). The final release data set included a total of 14 134 tags partitioned between 65 Zone/Age release groups.

The recovery data set included all tags recovered from the sampled (scanned) catch of the SNA 8 commercial trawl fishery during October-July 2002/03. The recoveries were aggregated by initial release group (Zone/Age) and by zone of recovery, representing a total of 995 tags from 145 recapture groups. The total scanned catch from each zone was partitioned into six recovery fisheries (five zones and one comprising catches from multiple zones). For each fishery, a tag reporting rate of 85% was assumed to account for the estimated detection rate of the Passive Integrated Transponder tags by the scanning equipment.

Sampling of the catches during the tag recovery phase yielded estimates of the age composition of the monitored catch by zone (Ninety Mile Beach, Kaipara and Manukau combined, North Taranaki Bight, and South Taranaki Bight) (Walsh et al. 2006c). The age composition of the catch sampled from each of these zones was similar with a predominance of younger fish (4–7 years) (Figure 26).

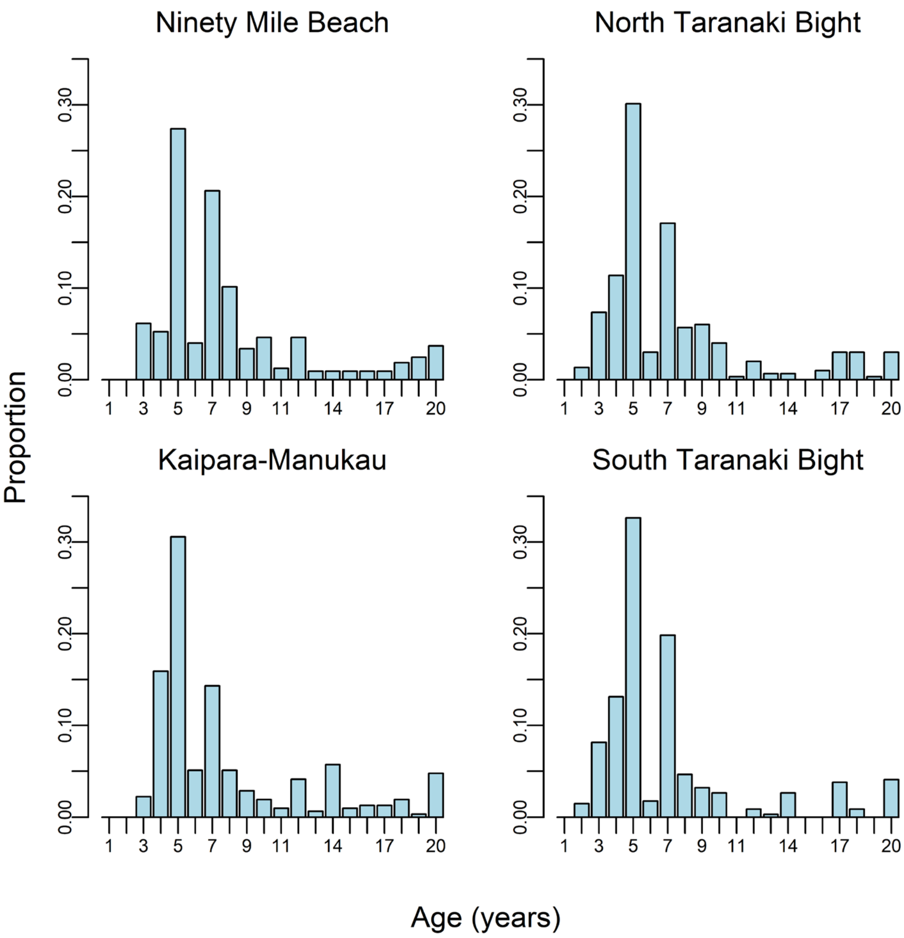

Figure 26: Distribution of area specific age compositions of snapper sampled during the recovery phase of the 2002/03 tagging programme. The 20 year age class represents an aggregated age class of fish aged 20+ years ('plus group') (source: Walsh et al. 2006c).

3.7 CPUE indices

Vignaux (1993) derived CPUE indices for the pair trawl fishery for 1974–1991 and the CPUE indices were first incorporated in a stock assessment of SNA 8 by Gilbert & Sullivan (1994). The CPUE indices decline considerably during 1974–1986 and then recover somewhat over the subsequent years (Figure 27). The CPUE indices have an associated CV of 0.13–0.30 (Vignaux 1993) and the most recent assessment (Davies et al. 2013) assumed an additional process error of 0.20.

Single trawl CPUE indices are available from the current study for 1997–2020 (section 2.3) (Figure 27). In recent years, there have been a limited number of vessels operating in the inshore trawl fishery and the operation of the vessels has changed in response to the increase in the abundance of snapper (increased avoidance). The standardised CPUE analysis has not adequately accounted for the change in fishing operation, particularly in the most recent year, as indicated by a divergence in the CPUE trends from the two main vessels in the fishery (section 2.3).

The recent trawl CPUE indices have an associated CV of 0.12–0.18. From the results of preliminary modelling, the CPUE indices were assigned a process error of 0.1.

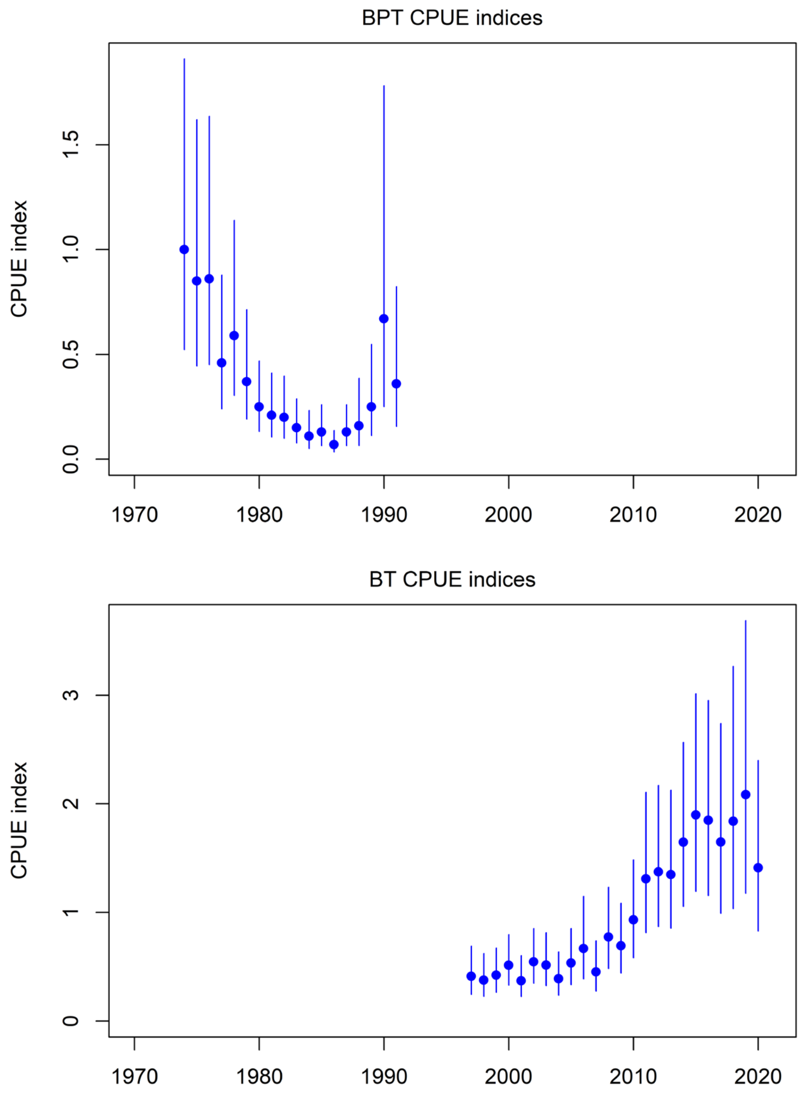

Figure 27: CPUE indices from the bottom pair trawl (BPT) fishery (top panel) and single bottom trawl (BT) fishery (bottom panel). The error bars represent the 95% confidence intervals and include the series specific process error (BPT 0.2, BT 0.1).

3.8 Mean length-at-age

There is a large data set of age-length observations (N = 25 987) from the age determination of otoliths collected from market sampling, tagging programmes, and trawl surveys (Table 6). These data were sourced from the Fisheries New Zealand *age* database (extracted 13 Feb 2020). The otolith data set is dominated by 3–7 year old fish, with comparatively small numbers of fish older than 10 years and few fish older than 15 years from the late 1980s onwards (Figure 28).

Previous analyses of these data have indicated temporal trends in the growth of snapper in SNA 8, particularly for fish aged older than 8 years (Walsh et al. 2019). The data set was summarised to determine the average length of fish in each age class by year of sampling (Figure 29). The resultant average length-at-age was compared with the predicted length-at-age from the established von Bertalanffy (VB) growth model for SNA 8, which was derived from age-length observations from 1989–1992 (McKenzie et al. 1992). The parameters of the VB growth model are k = 0.108, $Linf$ = 66.87 and $t0$ = -0.159.

Since the early 2000s, growth rates of fish older than about 5 years have generally been lower than predicted by the VB growth model (Figure 30). There is some indication that the patterns in growth rates may be associated with individual cohorts because the year classes spawned in the mid-1990s appear to have somewhat higher growth rates than the year classes spawned in the adjacent periods.

The age-length observations from the mid-late 1970s also indicate that growth rates in the preceding years were considerably lower than derived from the VB growth model, especially for fish older than about 7 years (Figure 30). Those age classes represent cohorts that would have been spawned prior to 1970, i.e., prior to the period of highest catches from the fishery.

The age-length data set was also used to determine the variation in the average length-at-age (expressed as the coefficient of variation, CV) for each age class and sample year (Figure 31). For samples from the late 1980s onwards, the CV of the mean length-at-age was comparable amongst all age classes and sampled years (median value of 0.079), although the variation in length-at-age was somewhat higher from samples collected in the 1970s (median value 0.099) (Figure 31).

Table 6: Number of aged snapper otoliths available from SNA 8 by year and data source (KAH, *Kaharoa* trawl surveys; SMP, market sampling programme; TAG, tagging programme).

Year	Source KAH	SMP	TAG	Total	Year	Source KAH	SMP	TAG	Total
1974	0	1 662	0	1 662	2000	0	507	0	507
1975	0	807	0	807	2001	0	535	0	535
1978	0	2 507	0	2 507	2002	0	614	933	1 547
1979	0	1 020	0	1 020	2003	0	1 157	753	1 910
1985	0	828	0	828	2004	0	533	0	533
1986	0	726	0	726	2005	0	323	0	323
1988	0	540	0	540	2006	0	406	0	406
1989	739	754	0	1 493	2007	0	600	0	600
1990	0	1 443	0	1 443	2008	0	586	0	586
1991	558	0	0	558	2009	0	452	0	452
1993	0	459	0	459	2010	0	199	0	199
1994	469	206	0	675	2012	0	392	0	392
1995	0	638	0	638	2013	0	173	0	173
1996	0	1 006	0	1 006	2015	0	234	0	234
1997	0	1 095	0	1 095	2016	0	351	0	351
1998	0	502	0	502	2018	0	340	0	340
1999	516	184	0	700	2019	0	240	0	240

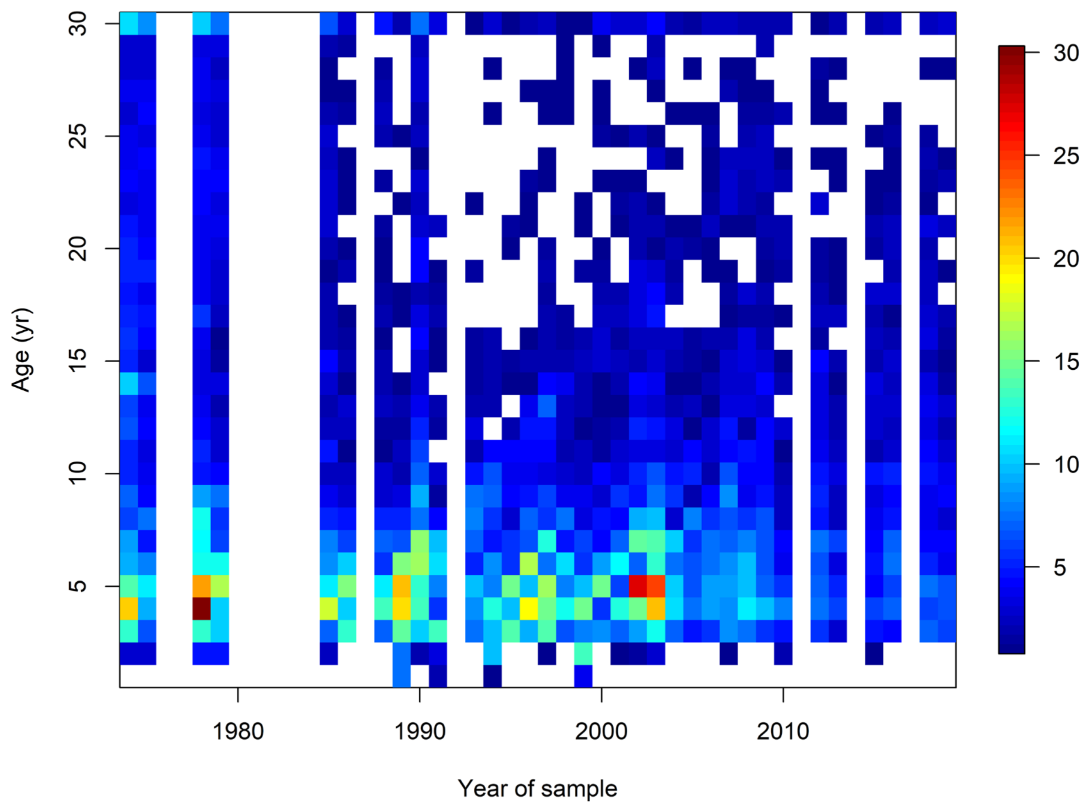

Figure 28: Distribution of the number of aged otoliths by fish age and sample year. The sample size represents the square root of the number of otoliths in each cell.

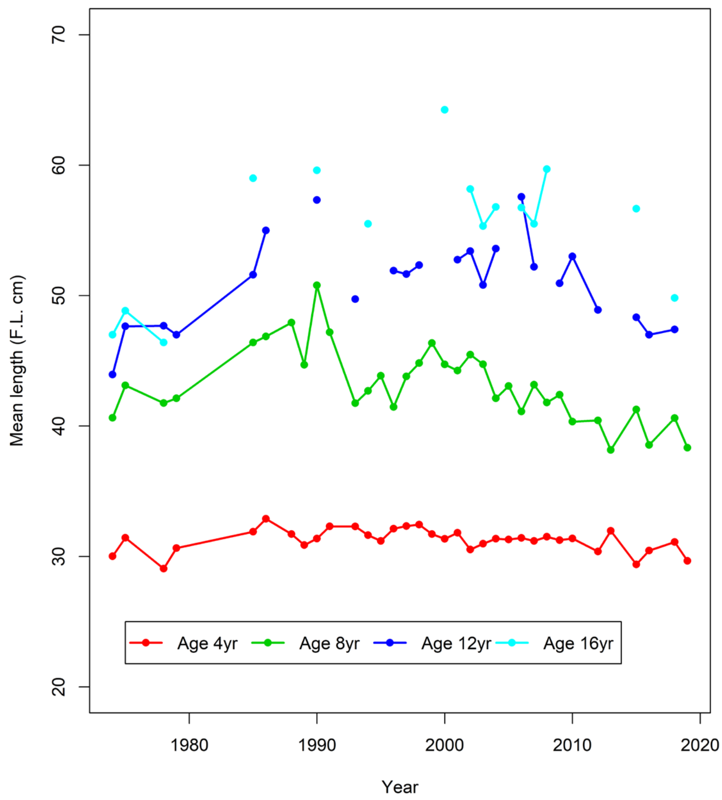

Figure 29: Average fish length-at-age (cm, F.L.) for selected age classes by year from the combined SNA 8 otolith data set.

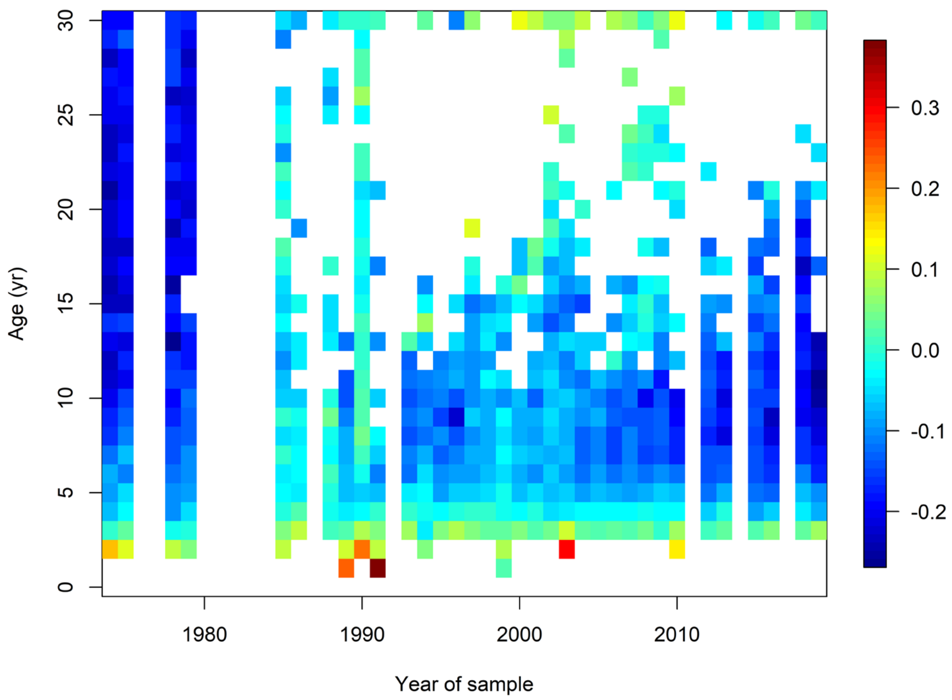

Figure 30: Proportional difference in the annual mean length-at-age (observed) from the otolith data set and the length predicted from the established growth function for SNA 8 ((observed-predicted)/predicted).

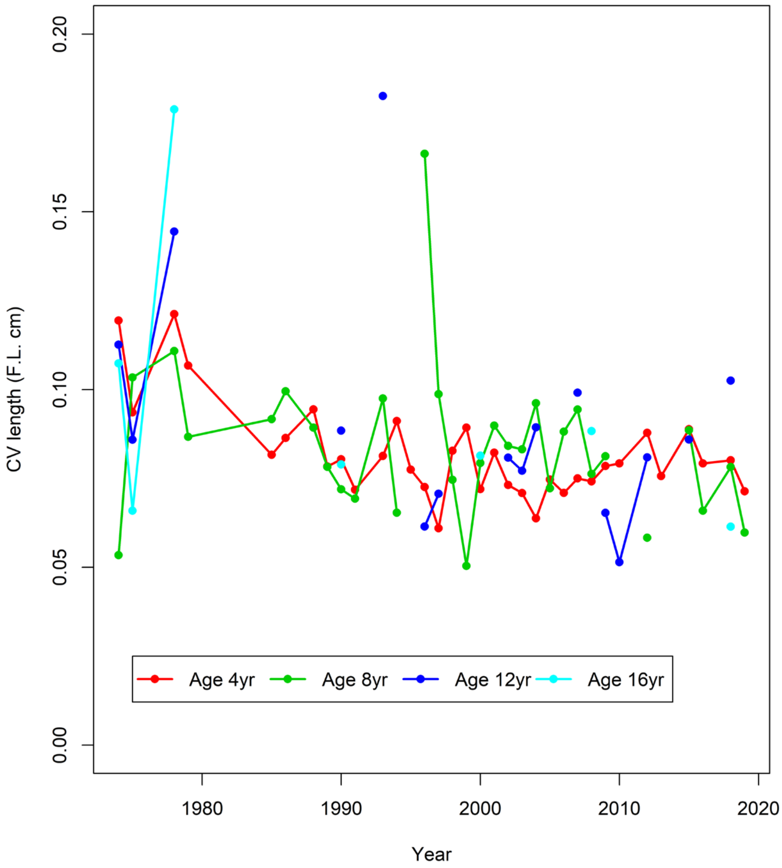

Figure 31: Coefficient of variation (CV) associated with the average fish length-at-age for selected age classes by year from the combined SNA 8 otolith data set.

4. STOCK ASSESSMENT

The assessment model integrates annual catches, estimates of absolute biomass from the 1990 and 2002 tagging programmes, trawl CPUE indices, abundance indices from *Kaharoa* west coast North Island trawl surveys, age composition data from the commercial fisheries and trawl surveys, and length composition data from the recreational fisheries.

The current stock assessment model is essentially an update of the stock assessment conducted in 2020 (Langley 2020), with the inclusion of an additional year of data, including the data from the 2020 west coast North Island (WCNI) trawl survey.

4.1 Stock structure

For the purpose of the stock assessment, SNA 8 is considered to comprise a discrete, homogeneous stock. Tagging studies indicate that there is limited mixing between SNA 8 and SNA 1 (Fisheries New Zealand 2020). A tagging programme was also undertaken in Tasman Bay and Golden Bay (SNA 7) in 1986/87 (Kirk et al. 1988). A small number of the released fish (4 tags, 0.2% of all recoveries) were recovered from catches taken from the South Taranaki Bight; this indicates that movement rates of snapper from SNA 7 northwards into SNA 8 are likely to be relatively low.

Since 1989/90, the area north of Cape Egmont has accounted for 90–95% of the SNA 8 commercial catch. Most of the observational data included in the model are also from the northern area of the fishery, including: the CPUE indices, trawl survey indices, and the commercial age composition data. Conversely, there are very limited data available from the southern area of the fishery, south of Cape Egmont. Prior to the mid-1980s, this area accounted for approximately 30% of the commercial catch (Francis & Paul 2013).

The 2002 tagging programme estimated that 21% of the SNA 8 biomass resided in the southern area (Gilbert et al. 2005) and that, although most movements of tagged fish were relatively limited, there were northward movements of tagged fish from the South Taranaki Bight and reciprocal movements of fish from the areas north of Cape Egmont (Walsh et al. 2006c). There was no monitoring of tagged fish in the catches of snapper from SNA 7 during the 2002 tagging programme.

Similar patterns in the age structure of snapper from South Taranaki Bight and northern areas of the SNA 8 fishery were apparent from commercial catch-at-age data (Walsh et al. 2006c). However, the results of the recent *Kaharoa* trawl surveys have identified some differences in the age structure of the snapper population between the two areas, including differences in the relative strength of individual year classes (NIWA, unpublished data). This may indicate some degree of spatial structure in the SNA 8 population and, potentially, linkages between the southern area of SNA 8 and the SNA 7 (Tasman Bay/Golden Bay) stock.

4.2 Model structure

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. 2020).

The assessment model included the entire SNA 8 catch history (from 1932) and assumed that the initial population age structure was in an equilibrium, unexploited state. The population structure included 30 age classes (both sexes combined), and the oldest age class represented an aggregated ‘plus group’ (30 years and older). The model data period extended to the 2021 year (2020/21 fishing year).

The key biological parameters for the SNA 8 stock assessment are presented in Table 7. Natural mortality (M) was specified as a constant value of 0.075 based on the analysis by Hilborn & Starr (published as appendix 4 of Langley 2020).

There is no evidence of sexual dimorphism in snapper growth and the growth parameters have been determined for both sexes combined. There is a large data set of age-length observations from snapper sampled from the mid-1970s to recent years. These data indicate the growth of snapper has varied over time, characterised by three periods: slower growth rates of fish sampled during the 1970s, higher growth rates during the 1980s, 1990s, and early 2000s, and slower growth rates since the mid-2000s. Separate growth parameters (k and $Linf$) of the von Bertalanffy function were estimated for these three time blocks (1931–1979, 1980–2005, 2006–2021) during the preliminary modelling phase of the 2020 assessment. The model was informed by the time series of age-length data aggregated as annual mean length-at-age observations. The resultant growth parameters were fixed in the final set of model options (and the mean length-at-age observations were not included in the input data sets) (Table 7). The estimated growth parameters were very similar for the early and recent periods, whereas the growth parameters for the intervening period, describing faster growth during the period when biomass was lowest, were comparable with the published growth parameters previously derived from the same period (McKenzie et al. 1992).

The parameterisation of growth in Stock Synthesis constrains annual growth increments to be greater than or equal to zero (Methot et al. 2020). Thus, the decline in growth rates between 2005 and 2006 resulted in a transition in the growth of individual cohorts with the length of the older cohorts remaining constant for several years.

Maturity was assumed to be age-specific with all fish reaching sexual maturity at age 3 years. The age of maturity was constant for the entire model period.

Table 7: Biological parameters and priors for the Base Case model.

Component	Parameters	Value, Priors	
Biology	*M*	0.075	Fixed
	VB Growth	*Len1* = 13.1 cm	Fixed
	1931–1979	*k* = 0.146, *Linf* = 54.5 cm	Fixed
	1980–2005	*k* = 0.112, *Linf* = 69.6 cm	Fixed
	2006–2021	*k* = 0.150, *Linf* = 54.4 cm	Fixed
	CV length-at-age	0.08	Fixed
	Length-wt	*a* = 4.467e-5, *b* = 2.793	Fixed
	Maturity	0.0 ≤2 yr, 1.0 ≥3 yr	Fixed
Recruitment	*lnR0*		Estimated (1)
	B-H SRR steepness *h*	0.95	Fixed
	SigmaR σR	0.6	Fixed
	Recruitment deviates	Lognormal deviates (1960–2019)	Estimated (60)

The model was structured with an annual time step that comprised 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 a fixed value of steepness (*h*). Recruitment deviates (1960–2019) from the SRR were estimated assuming a standard deviation of the natural logarithm of recruitment (σ_R) of 0.6.

For the 2020 assessment, a value of steepness of 0.85, equivalent to the default value of steepness used in the SNA 1 stock assessment, was initially assumed for the SRR. However, an evaluation of initial model options revealed that a significant proportion of Markov chain Monte Carlo (MCMC) samples crashed the population during the 2000s, due to very low recruitments resulting from the combination of very low spawning biomass and the low value of steepness assumed for the SRR. Subsequent model options specified a higher value of steepness of 0.95, which eliminated the MCMC runs that crashed the population and did not appreciably change the model likelihood components.

The model was configured to encompass three commercial fisheries: single bottom trawl (BT), bottom pair trawl (BPT), and Japanese longline. In addition, there were two recreational fisheries (inside and outside harbours). Age composition data are available from the single bottom trawl fishery (23 observations) and the bottom pair trawl fishery (18 observations) (Table 8). For all age compositions there was assumed to be no error associated with the age determination.

A comparison between the age compositions from the single and pair bottom trawl fisheries revealed no appreciable difference in the age structure of the catch from the two methods (Figure 17). A common age-specific selectivity function was assumed for the two fisheries and the associated sets of CPUE indices. Previous assessments have assumed a dome-shaped selectivity function for the trawl fisheries based on the estimates of fishery selectivity obtained from the two tagging programmes (Davies et al. 2013). The current assessment parameterised selectivity using a flexible, double-normal selectivity function, enabling the estimation of the age of peak selectivity, the widths of both ascending and descending limbs, and the selectivity of the terminal (oldest) age class (Methot et al 2020).

There are no size composition data from the Japanese longline fishery and the levels of catch are assumed. The selectivity function for the fishery was defined to approximate the selectivity of a generalised snapper longline fishery, with a knife-edge selectivity at age 5 years and full selection of the older age classes.

The two recreational fisheries are characterised by differences in length composition. The length composition data were included in a preliminary model option and the selectivity of each fishery was estimated using a length-based double-normal selectivity function. The resultant estimate of selectivity for the harbour fishery was tightly constrained around a mode of 28–32 cm, whereas the recreational fishery outside the harbours was estimated to have a broader selectivity, including greater proportions of larger fish. The selectivity parameters were fixed in the final model options and the recreational fishery length-frequency observations were excluded from the estimation procedure.

The 1994 and 2002 tagging biomass estimates and associated population length observations were derived for all fish aged 3 years and older (Gilbert et al. 2005). An age-specific, knife-edged selectivity function was assumed with an associated catchability of 1.0.

Initially, the time series of *Kaharoa* trawl survey biomass indices and associated age compositions were included in preliminary modelling, and the selectivity of the survey was estimated using an age-specific double-normal selectivity function. There was, however, a persistent lack of fit to the two most recent (2019/20 and 2020/21) trawl survey biomass indices, related to a difference in the catchability of older fish between the two recent surveys (section 3.5). The trawl survey data were consequently reconfigured to provide estimates of the relative abundance of those individual age classes which appear to be consistently sampled by the trawl survey; i.e., fish aged 2 (1+), 3 (2+), 4 (3+), and 5 (4+) years. Four separate sets of indices were derived from the trawl survey data, expressed as the number of fish at age from each survey (with an associated coefficient of variation). The indices were incorporated in the model with a corresponding age-specific selectivity and separate catchability coefficients.

Table 8: Summary of input data sets for the Base Case 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.

Data set	Model years	Nobs	Error structure	Observation error/ESS	Process error
Tag biomass	1990, 2002	2	Lognormal	0.18, 0.12	–
BT CPUE indices	1997–2019	23	Lognormal	0.12–0.18	0.1
BPT CPUE indices	1974–1991	18	Lognormal	0.12–0.30	0.2
Trawl survey age 2yr	1990, 1992, 1995, 1997, 2000, 2019, 2020, 2021	7	Lognormal	0.26–0.48	–
Trawl survey age 3yr	1990, 1992, 1995, 1997, 2000, 2019, 2020, 2021	7	Lognormal	0.16–0.38	–
Trawl survey age 4yr	1990, 1992, 1995, 1997, 2000, 2019, 2020, 2021	7	Lognormal	0.12–0.38	–
Trawl survey age 5yr	1990, 1992, 1995, 1997, 2000, 2019, 2020, 2021	7	Lognormal	0.18–0.45	–
BT age comp	1975, 1976, 1990–2010, 2013, 2016, 2019	26	Multinomial	ESS 20	
BPT age comp	1975, 1976, 1978–1980, 1986, 1987, 1989–1992, 2000–2006	18	Multinomial	ESS 10	
Tag length comp	1990, 2002	2	Multinomial	ESS 10	

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 based on the approach of Francis (2011) (Table 8). The two sets of trawl CPUE indices (BPT and BT) were assumed to have a lognormal distribution with observation error specified as the standard error of the individual CPUE indices. Based on initial model fits the indices were assigned an additional process error of 0.1 for the BT CPUE indices and 0.2 for the BPT CPUE indices. The tagging biomass indices and age-specific trawl survey indices were assigned the native coefficient of variation from each index with no additional process error (Table 8).

For the two sets of fishery age compositions, the individual age compositions were each assigned an Effective Sample Size (ESS) approximating the value derived from Method TA1.8 of Francis (2011).

The model likelihood objective function includes the following components:

i. The fit to the BT and BPT CPUE indices assuming a lognormal error structure.
ii. The fit to the fishery (BT and BPT) age composition data assuming a multinomial error structure.
iii. The fit to the two tag biomass estimates (lognormal error structure).
iv. The fit to the tag population length composition data assuming a multinomial error structure.
v. The fit to the trawl survey age-specific abundance indices (lognormal error structure).
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 MCMCs 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 2021 model year (2020/21 fishing year) ($SB_{current}$ or SB_{2021}).

Following the 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 8. 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 (2020/21). Estimates of equilibrium yield are determined from the level of fishing mortality that produces the target biomass level ($F_{SB40\%}$).

4.3 Preliminary modelling

During the 2020 assessment, a range of exploratory models were implemented to investigate the conflict between the biomass indices and age compositions from the 2018 and 2019 *Kaharoa* trawl surveys and the recent CPUE indices (Langley 2020). These models were not able to adequately reconcile the differences in the biomass indices and the age composition from the two recent trawl surveys. Further, the magnitude of the increase in survey biomass between the two time periods (1989–1999 and 2018–2020) was not compatible with the magnitude of the increase in the CPUE indices (Langley 2020), as well as the annual age composition of the commercial catch.

During the current assessment, further scenarios were investigated that incorporated the trawl survey biomass indices and age compositions, with the addition of the data from 2020 trawl survey. Given the apparent variability of the availability of older snapper in the recent trawl surveys, model options were investigated that introduced variability into either the selectivity or catchability of the individual trawl surveys.

Incorporating temporal variation in the estimation of the RH limb of the trawl survey selectivity allowed the model to simultaneously fit the trawl survey biomass indices and the CPUE indices, while also fitting the age composition data from the trawl survey. The model estimated that selectivity varied considerably between the three recent surveys, progressively broadening the right hand limb of the selectivity function (Figure 32). This result supported the assertion that the availability of older snapper varied considerably between the three recent trawl surveys. However, the model has a large amount of flexibility to fit these data, effectively reducing the information content in the trawl survey data for the older component of the population. Consequently, the resulting model yielded estimates of stock status that were very similar to the model options with the age-specific trawl survey indices (SB_{2021}/SB_0 = 0.498 compared with 0.532).

Further model options were investigated that linked the variation in the parameters of the selectivity function with potential covariates that may be correlated with the relative availability of adult snapper in each survey. A range of potential covariates were considered, including: the timing of the individual trawl surveys (median day of the year), sea surface temperature (median SST at trawl stations), ovarian development (proportion of adult female fish in ripe stages of ovarian development), and a range of metrics related to the depth distribution of adult snapper during the trawl surveys (based on snapper biomass from the survey depth strata) (Emma Jones, NIWA, unpublished data). None of these metrics were strongly correlated with the magnitude of adult biomass from the three most recent trawl surveys. Consequently, the inclusion of these variables as covariates in the estimation of the selectivity parameters did not appreciably improve the fit to the trawl survey biomass indices and age compositions.

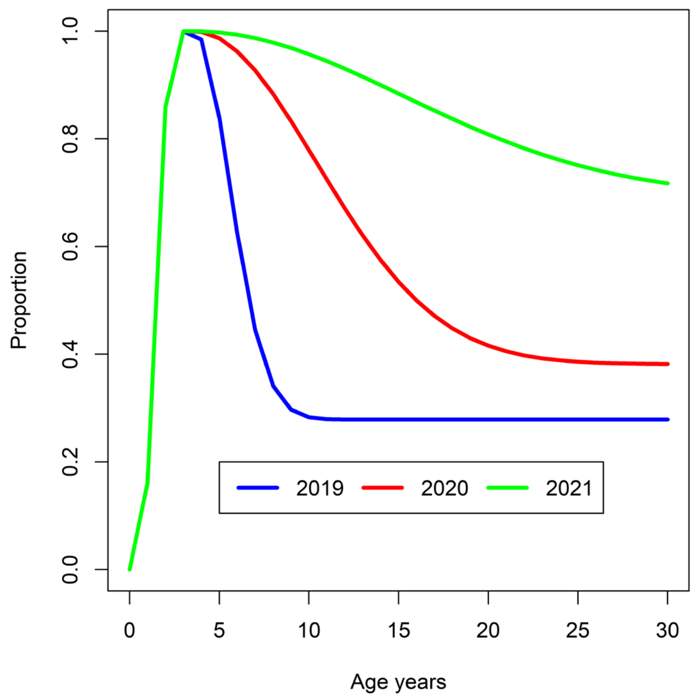

Figure 32: Estimated age-specific selectivity functions for the recent *Kaharoa* trawl survey biomass indices from a model option including variability in the selectivity of older fish.

Previous SNA 8 assessment models have included the results from the 1990 and 2002 tagging programmes as estimates of population biomass derived from external analyses of the tag release and recovery data sets. Stock Synthesis has the flexibility to incorporate the tag observational data within the modelling framework to integrate these data in the estimation process (Methot & Wetzell 2013, Methot et al. 2020).

The tag release/recovery data were available from the 2002 tagging programme (Gilbert et al. 2005, Jeremy McKenzie, NIWA). A comparative model was configured to incorporate these data in the current assessment model (*Tag2002*). Following Gilbert et al. (2005), the tag releases were structured by release areas (five) and the age of fish at release was estimated using a corresponding age-length key. Individual tag releases were aggregated in release groups defined by area and age class. The tag recovery phase occurred during the subsequent model time step (season 1, 2003). A separate recovery fishery was defined for each release area that incorporated the portion of the catch that was monitored (scanned) for tags. The selectivity of each recovery fishery was assumed to be equivalent to the main trawl commercial fishery. The tag recovery rate for each fishery was 0.85 to account for the observed tag detection rate of the scanning equipment (Gilbert et al. 2005).

The number of tags recovered from the catch in each area were aggregated by release group. The model likelihood is based on the observed number of recoveries by release group compared with the predicted number of recoveries from the tag population, mediated by the fishery selectivity and fishing mortality rate (Methot & Wetzell 2013).

Overall, the *Tag2002* model provided a very good estimate of the number of tag recoveries by age class combined from the five release regions (Figure 33) and area of recovery (Figure 34). However, the fits to the number of recoveries for the 4 yr and 5 yr releases were variable between the individual areas of release; recoveries were over-estimated for the North Taranaki Bight (NTB) and South Taranaki Bight (STB) releases and under-estimated for the Kaipara (KAI) and Ninety Mile Beach (NMB) releases (Figure 33). The model population is not spatially structured and assumes homogeneous mixing of the tag releases. These results indicate lower mixing rates of the younger age classes. Overall, most tag recoveries occurred in the area of release, although there was a considerably higher level of mixing for the set of tags recovered from the Manukau (MAN) area.

The *Tag2002* model estimated the stock biomass in 2002 at 11 235 t closely approximating the estimated biomass from the external analysis (10 442 t, CV 0.12 from Gilbert et al. 2005). The resulting estimates of stock status from the *Tag2002* model were also very similar to the model option including the point estimate from Gilbert et al. (2005) (see section 4.4). Given the similarities in the modelling results, the base model option was preferred due to the lower computational requirements compared to the *Tag2002* model.

Although the results of the 2002 tagging programme indicate relatively low mixing rates, it appears that the tagging programme provides a relatively robust estimate of total biomass when analysed at an appropriate spatial resolution. This indicates that the release phase of the programme is likely to have distributed tags throughout the population approximately in proportion to the spatial distribution of the population.

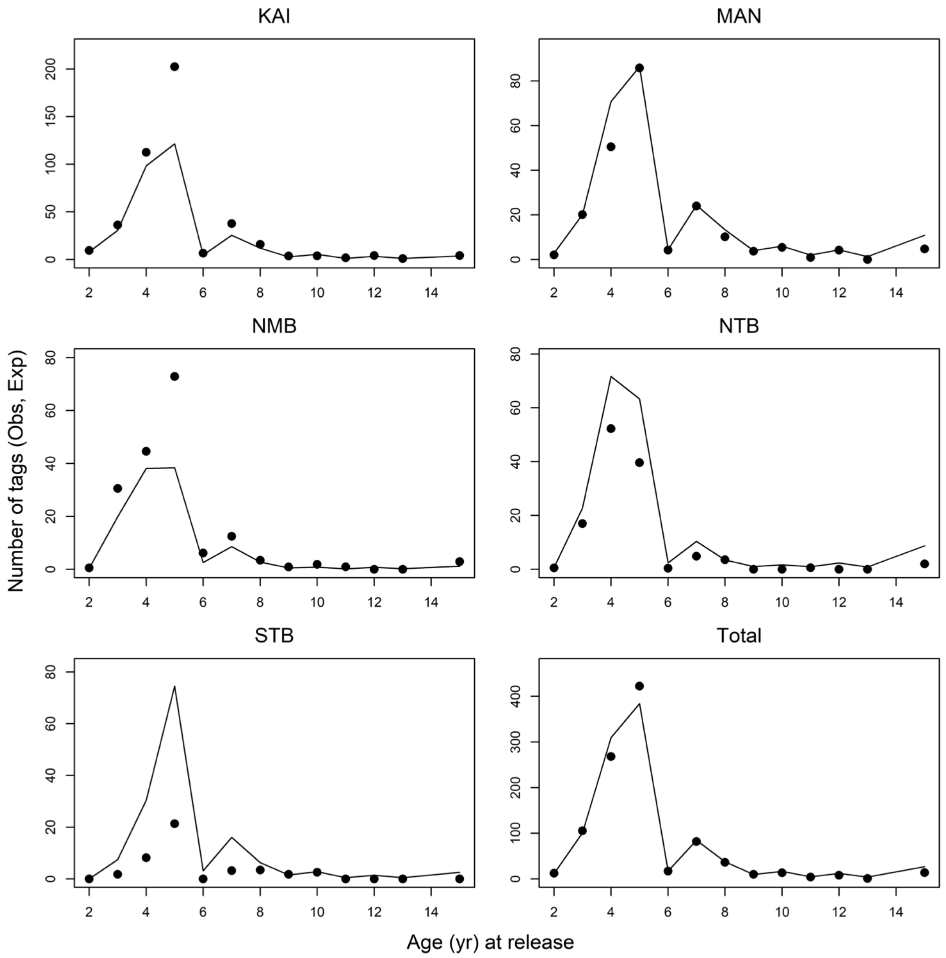

Figure 33: Observed (points) and predicted (lines) number of tag recoveries from the 2002 tagging programme by area and age of release and aggregated across areas from the *Tag2002* model option.

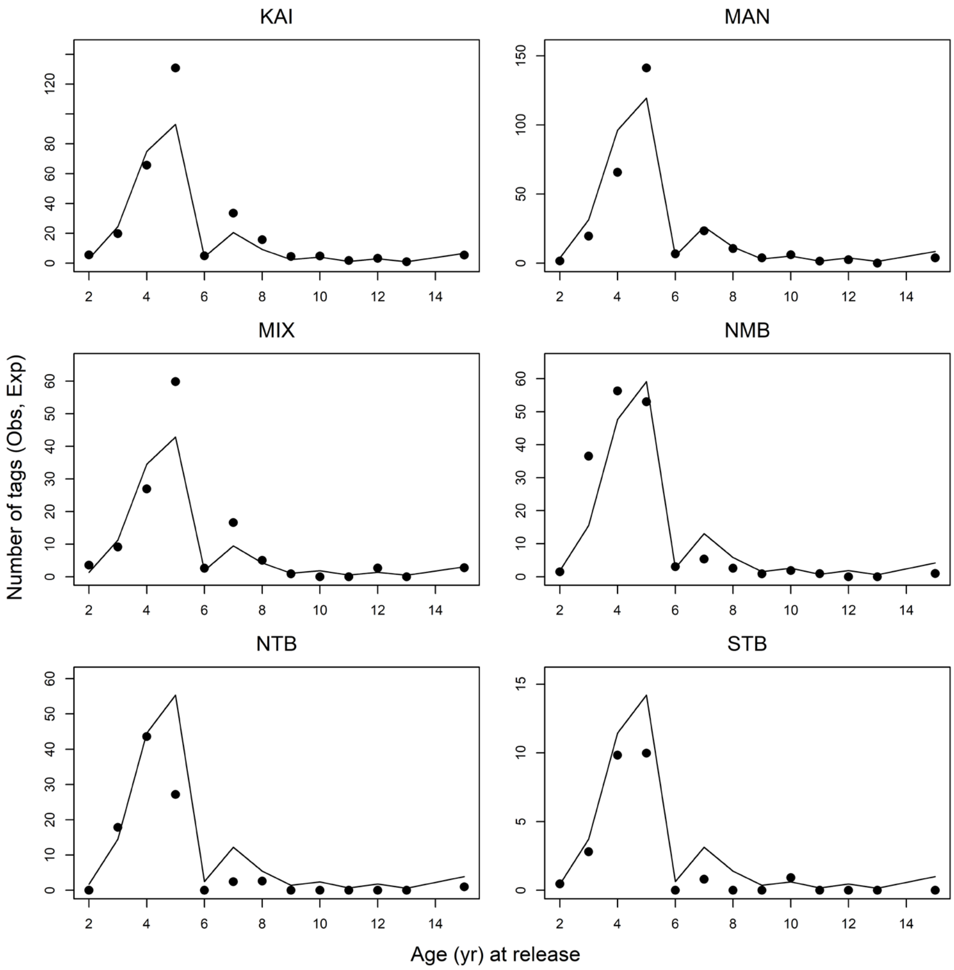

Figure 34: Observed (points) and predicted (lines) number of tag recoveries from the 2002 tagging programme by recovery area and age of release from the *Tag2002* model option.

4.4 Base Case model

For 2021, the Inshore Working Group adopted the *TrawlSurveyAgeIndices* model as the Base Case assessment model. The model is equivalent in structure to the Interim Base Case assessment model from 2020. The structure of the model is detailed in section 4.2 and incorporates the four sets of age-specific abundance indices (2, 3, 4, and 5 year olds) from the inshore trawl survey (and excludes the total trawl survey biomass indices and age compositions).

Model parameterisation

The model estimates the overall population scaling parameter (*lnR0*), recruitment deviates from the spawner-recruitment relationship and the selectivity function for the main commercial fishery (Table 9). The catchability parameters are unconstrained with the exception of the fixed catchability coefficient for the tag biomass estimates ($q = 1.0$).

Table 9: Estimated parameters for the Base Case model.

Parameter		Distribution	Initial Value
lnR0		No prior	10
RecDevs	1960:2019 (N=60)	Devvector	*SigmaR* 0.6
BT select	Peak	Norm(5,1)	5.0
	Top width	Fixed	-5.0
	Ascending	Norm(0.5, 1)	0.5
	Descending	Norm(3, 2)	3.0
	Terminal	Norm(-0.3, 2)	-0.3
Catchability	CPUE (2)	Free (=Float)	
	Trawl survey (4)	Free (=Float)	
	Tag biomass (1)	Fixed	1.0

The selectivity function for the trawl fisheries (shared for the single and pair trawl fisheries) estimated a peak selectivity at 5–6 years and a declining selectivity for the older age classes (Figure 35). A terminal selectivity (of about 50%) was estimated for all age classes older than 15 years. The selectivity of the older fish is informed, in part, by the magnitude of the 20+ year ‘plus group’ in the trawl age composition samples from the 1970s. The observed proportions of fish in this ‘plus group’ from these samples is considerably lower than the corresponding proportion of fish in the age group from the equilibrium, unexploited population.

The selectivity functions for the recreational fisheries, tagging programme, and age-specific survey indices were not estimated in the model (see section 4.2) (Figure 35). The catchability coefficients for the four sets of age-specific trawl survey indices were similar in magnitude, although the catchability coefficients for the 4 and 5 year indices were slightly higher than for the 2 and 3 year indices (Figure 36).

The temporal variation in the parameterisation of growth results in a considerably higher growth rate for fish older than 10 years during 1982–2010, although the model estimates that there was a relatively small number of fish in that portion of the population during that period (Figure 37). For fish older than about 14 years, there is a strong negative correlation between the mean length-at-age and the natural logarithm of the number of fish in the corresponding age class (for 1975–2010). This supports density dependent growth in the SNA 8 stock (Walsh et al. 2019). For fish younger than about 7 years, there was limited variation in estimated growth rates between the three time blocks (Figure 37).

Recruitment deviates from the spawner-recruit relationship were estimated for 1960–2019 (Figure 38). There is a strong temporal trend in the recruitment deviates: recruitment deviates were estimated to be below the average level during 1960–1980; estimated deviates were considerably more variable during 1985–1998; and recruitment deviates were above average during 2005–2019, with exceptionally high recruitment estimated for 2006 and 2014–2016 (Figure 38). Recruitment deviates were estimated with relatively high precision during 1985–1998, corresponding to the period when the year classes were intensively sampled from the catch sampling of the commercial trawl fishery (during 1990–2010).

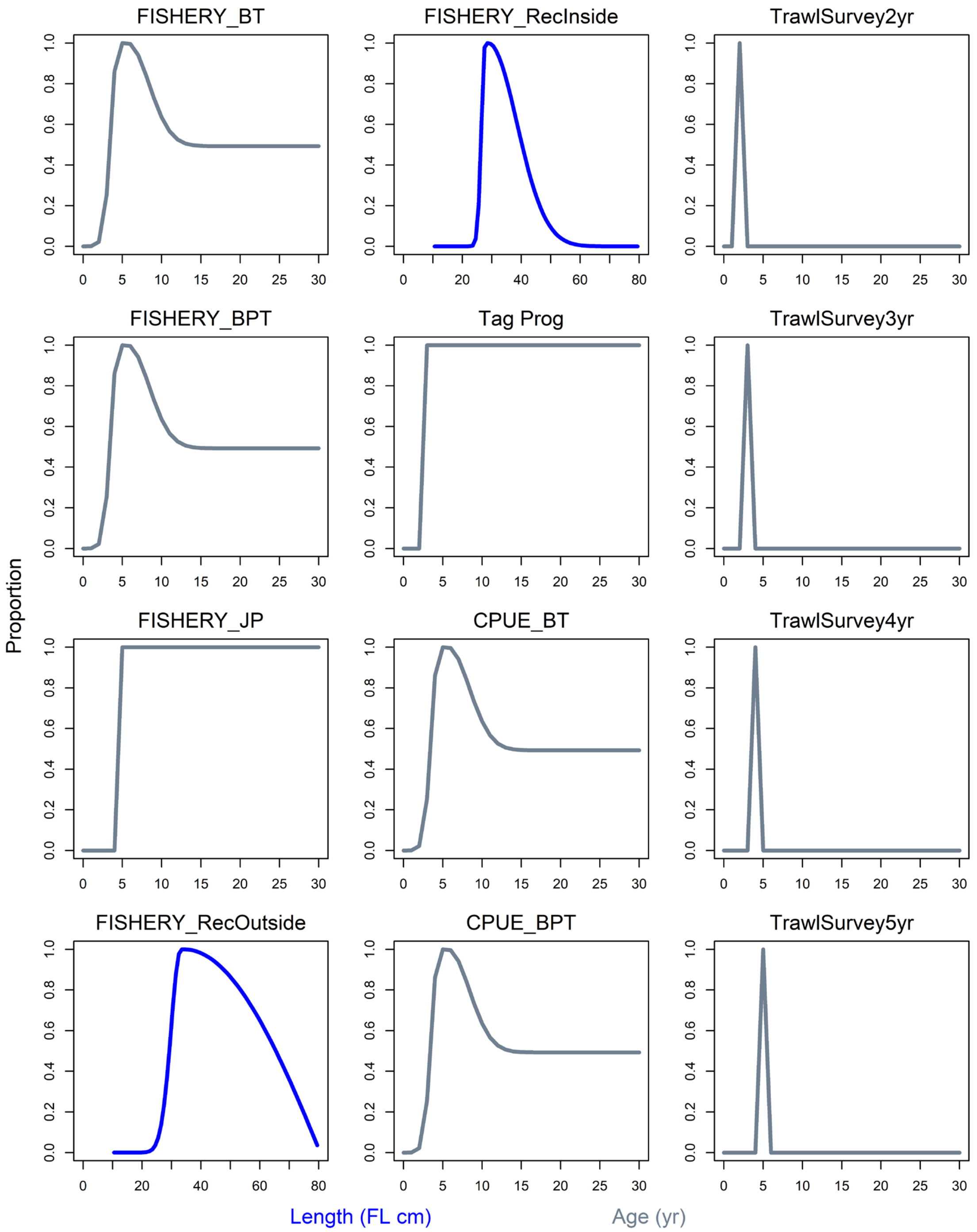

Figure 35: Age (grey) and length (blue) selectivity functions for the model fisheries and surveys. The shared BT and BPT selectivity function was estimated in the assessment model; all other selectivity functions were fixed.

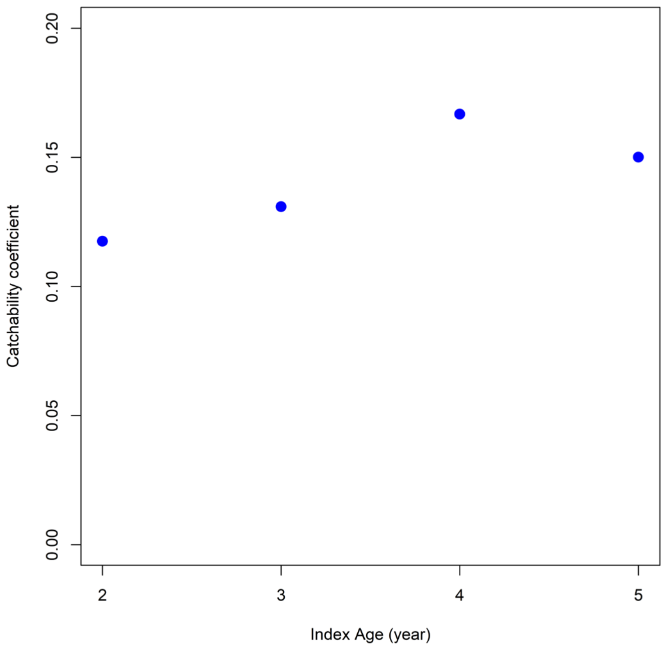

Figure 36: Catchability coefficients (*q*) for the four sets of age-specific trawl survey indices.

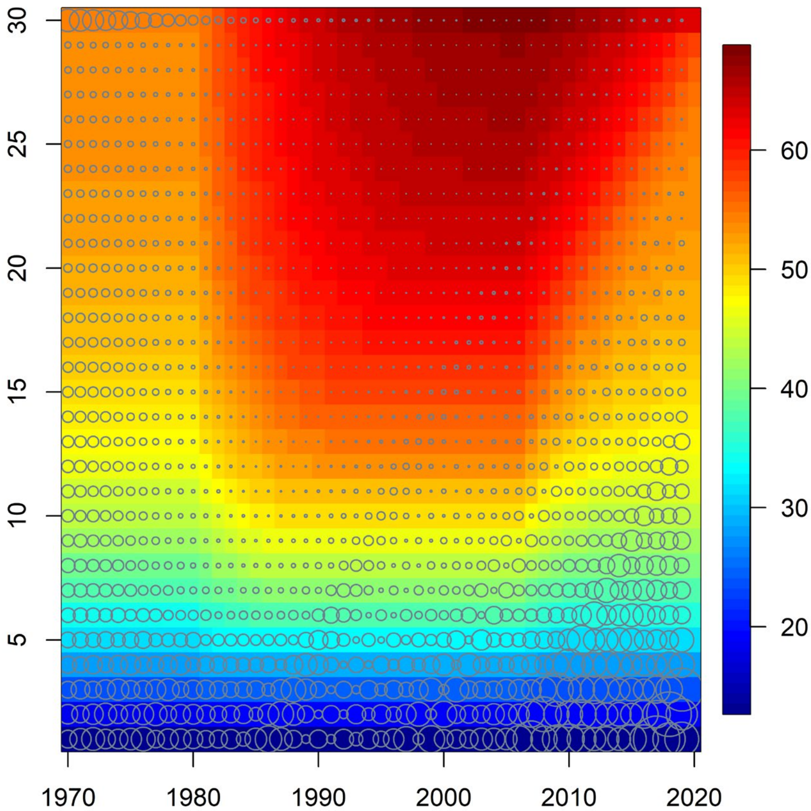

Figure 37: Predicted average length-at-age by year (from 1970 onwards) from the three stanza (time block) growth parameterisation. The grey circles are proportional to the model estimates of the population numbers-at-age.

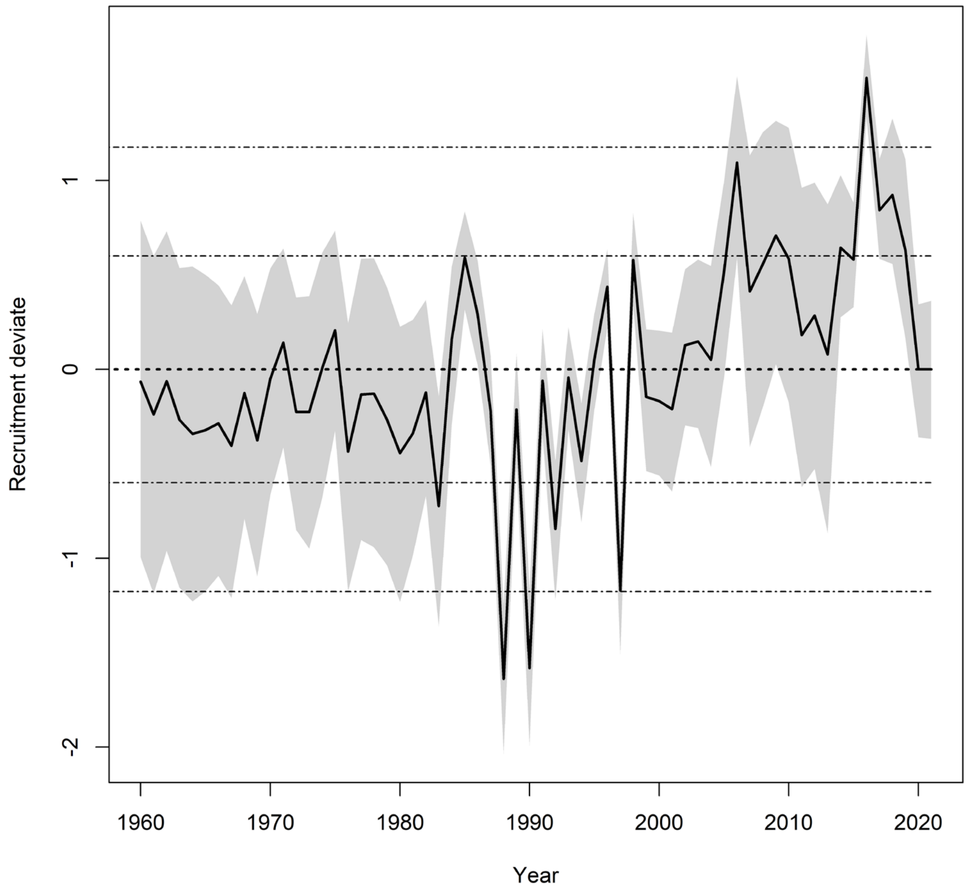

Figure 38: Annual recruitment deviates (median values) and 95% confidence intervals derived from MCMCs. The horizontal lines correspond to the ±1 *sigmaR* (0.6) and ±1.96*sigmaR*.

Diagnostics

The model fits the large decline in the BPT CPUE indices during the mid-late 1970s and the subsequent increase in the indices in the late 1980s (Figure 39), although the model residuals reveal that the magnitude of the temporal variation in the CPUE indices is under-estimated by the model. There are also a couple of the individual indices that deviate significantly from the model predictions. The model also provides a good fit to the increasing trend in the recent BT CPUE indices, although there are a number of indices in the 2000s that are significantly lower than predicted by the model, and some after 2010 that are higher (Figure 39). The model does not fit the lower CPUE index from the most recent year (2020).

The model provides a very good fit to the two estimates of absolute biomass from the 1990 and 2002 tagging programmes (Figure 40).

There is a reasonable fit to each of the four sets of age-specific trawl survey abundance indices with the model estimating higher levels of recent recruitment to fit the increased abundance of each of these age classes observed in the three most recent trawl surveys (Figure 41). The model under-estimates the magnitude of the higher 5 year old index from the most recent trawl survey (2016 year class).

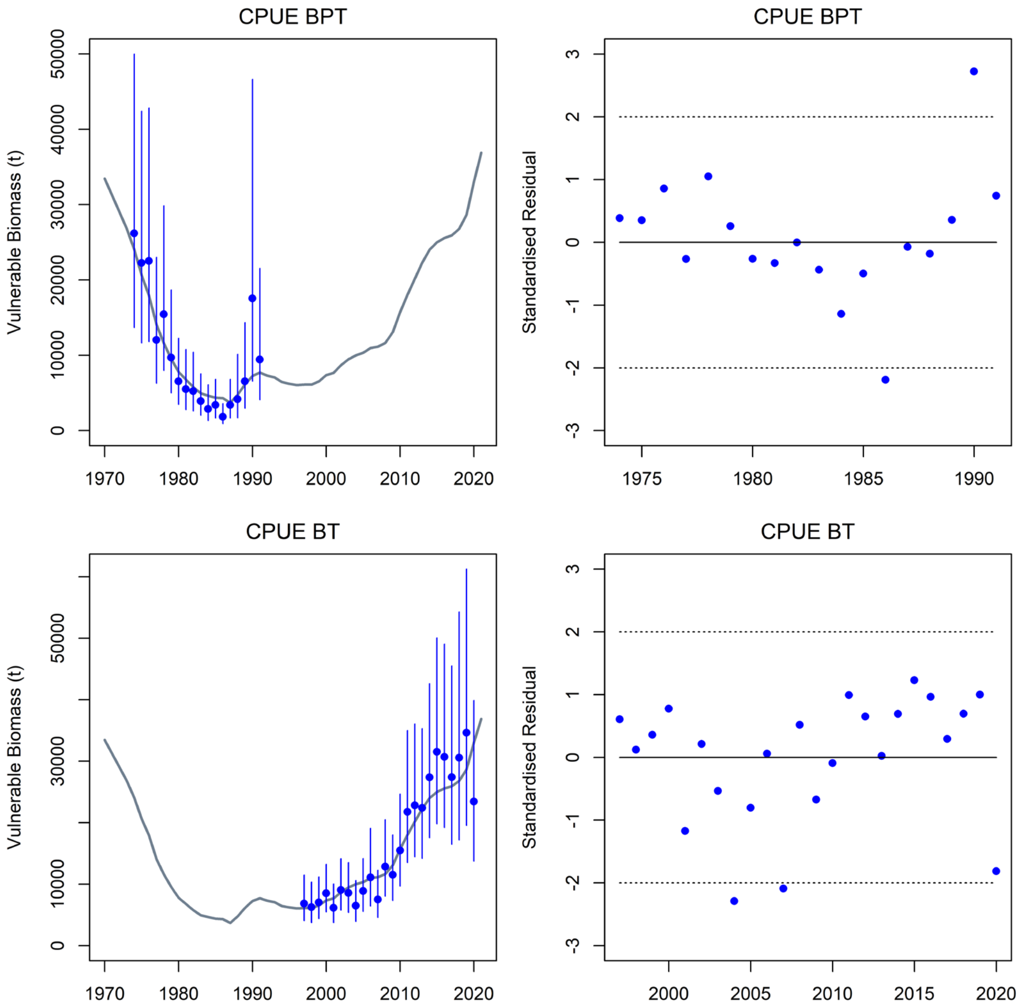

Figure 39: Model fits to the BPT CPUE indices (top) and the BT CPUE indices (bottom). The grey line represents the predicted vulnerable biomass for the respective survey indices.

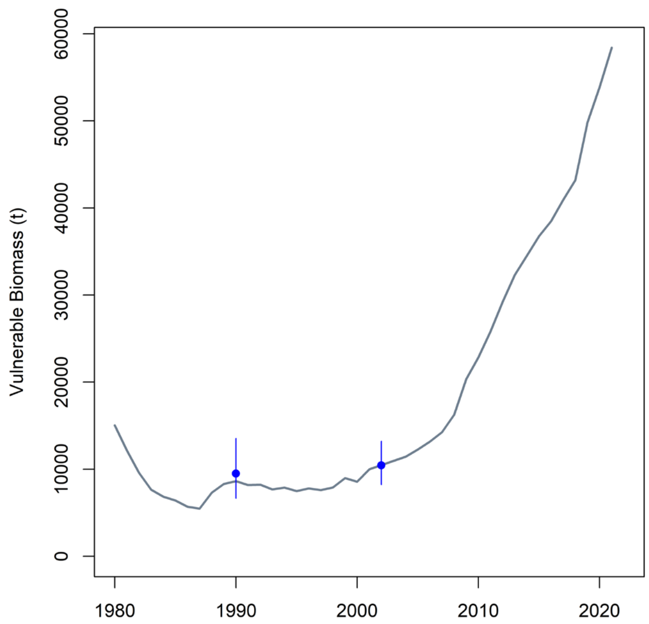

Figure 40: Model fit to the two tag release/recovery biomass estimates (and associated 95% confidence intervals).

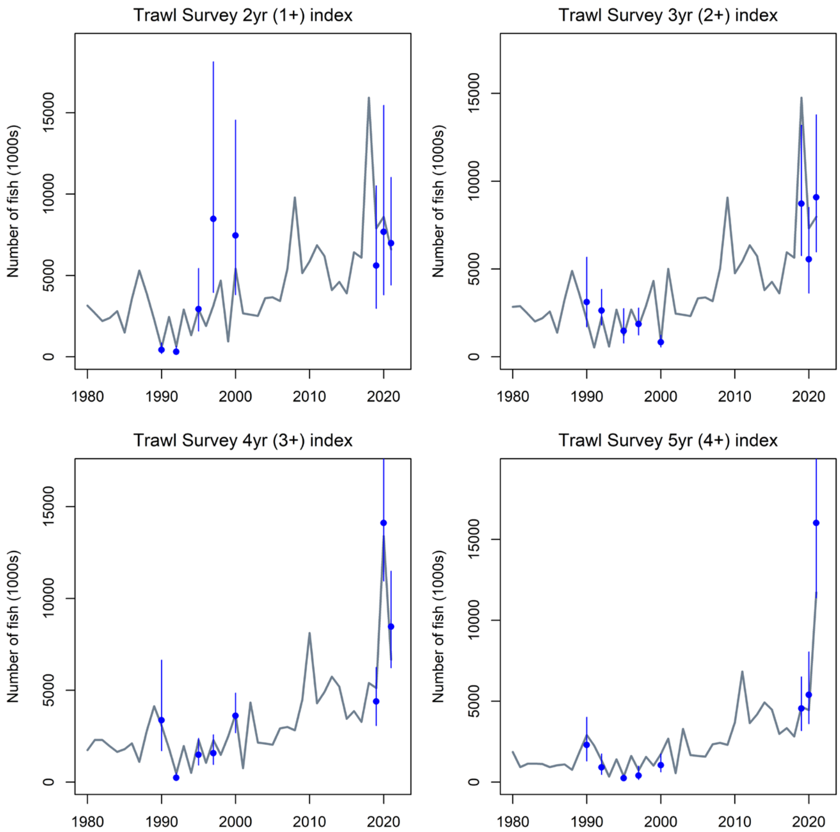

Figure 41: Model fits (grey line) to the four sets of age-specific trawl survey abundance indices (blue points and associated 95% confidence intervals).

The model provides a very good fit to the time series of age compositions from the BT fishery (Figure 42). The residuals from the fit to the proportions-at-age were aggregated over the time series and summarised by age class, the year of sampling, and the individual year class (corresponding to the age of fish and year of sampling). There was no appreciable pattern in the residuals relative to these three categories (Figure 43). The quantile-quantile plot indicates that the residuals approximate a normal distribution (Figure 43). Similarly, there was no appreciable pattern in the distribution of the residuals from the fit to the proportions-at-age from the BPT fishery (Figure 44 and Figure 45).

The model approximates the general structure of the length compositions of the snapper population (3 years and older) derived from the tagging programmes in 1990 and 2002 (Figure 46). There is some deficiency in the fit to the proportions in the individual length classes, particularly for the 2002 tagging population. This may simply reflect the low resolution of the estimated length composition which was derived from the interpolation of a small number of length categories. In future iterations of the model, it is probably more appropriate to fit directly to the base observations, i.e., fit to the proportion of fish in the five length categories, rather than attempting to partition the length categories into smaller (1 cm) length increments.

There is a marked difference between the two population length compositions derived from the tagging programme and the length structure of the model estimate of the equilibrium, unexploited population. The latter is predicted to have a dominant 42–56 cm length mode (accounting for ~60% of the population over 30 cm F.L.). Fish in this length range represented a small proportion of the two population length observations and, hence, are consistent with the length structure of a heavily depleted stock (in the 1990s–early 2000s).

The length compositions from the two recreational fisheries were not included in the final model estimation procedure. Instead, the length-based selectivity for each fishery was fixed at parameter values obtained during the initial modelling phase. Nonetheless, there is a good approximation of the observed length compositions by the model (derived from the model estimates of the annual population length compositions and the fishery specific selectivity function) (Figure 47). There are some discrepancies between the observed and predicted length compositions from the two fisheries in the 1990s, with the model under-estimating the proportion of smaller fish observed in the recreational catch samples. This may be related to the change in the snapper Minimum Legal Size (MLS) for the recreational fishery which increased from 25 cm to 27 cm in October 1994. The selectivity functions for the recreational fisheries are primarily informed by data from the subsequent period and, hence, are likely to under-estimate the proportion of smaller fish in the earlier years.

The mean length-at-age observations, derived from the aged otolith data sets, were not included in the estimation procedure for the final model options. However, a comparison with the model predictions of mean length-at-age indicates that the model provides reasonable approximations of the observations (Figure 48), especially over the main age range of fish in the model population, e.g., fish aged younger than about 15 years from 1990 onwards. Limited observations are available for age classes older than 15 years during this period and the model tends to under-estimate the observed length of those age classes (Figure 48). There is also a discrepancy in the mean length-at-age of 3–6 year fish sampled from the commercial fishery and the *Kaharoa* trawl surveys, with the model under-estimating the length of fish in the trawl survey samples (Figure 48).

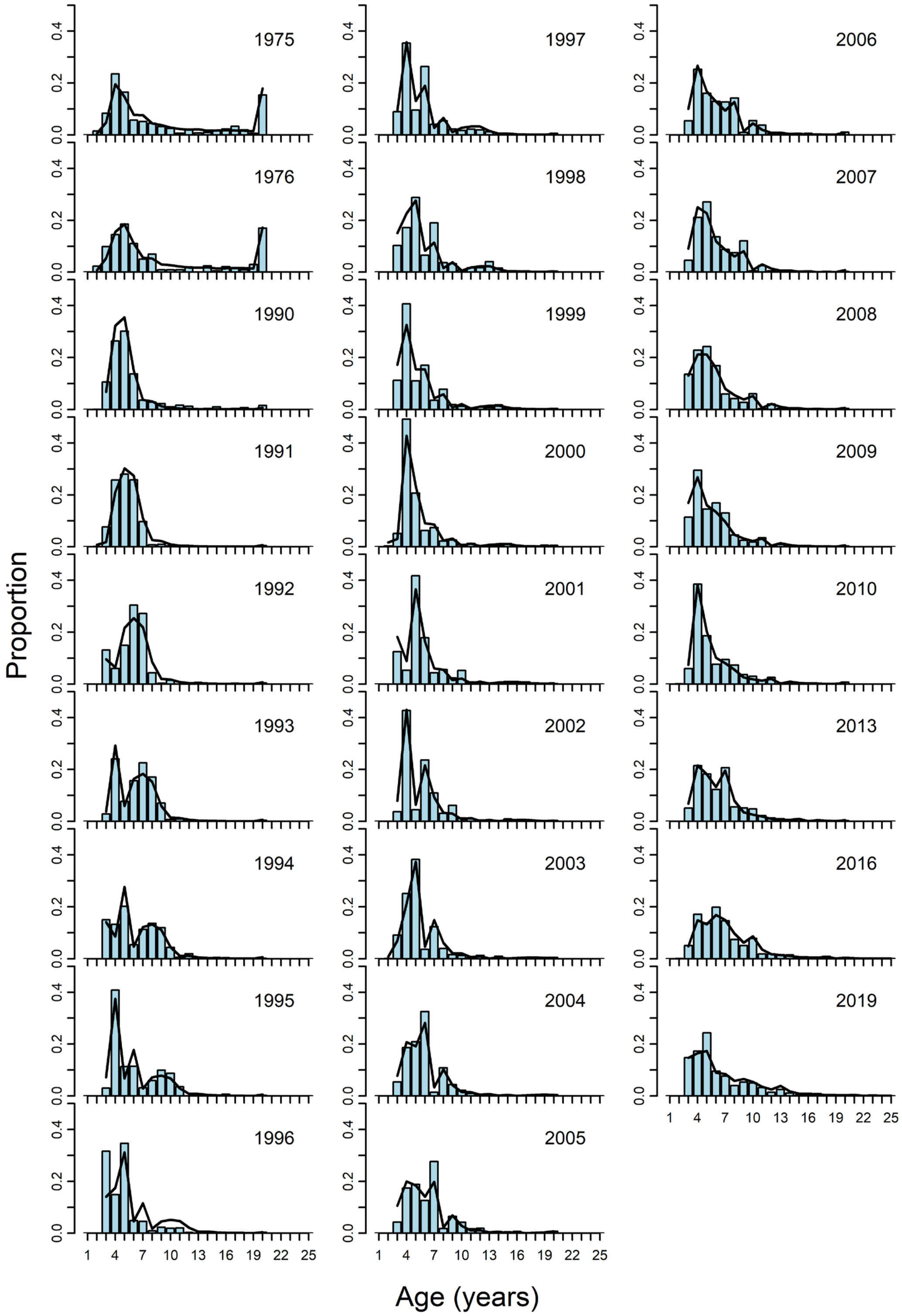

Figure 42: Model fits (lines) to the observed (bars) age composition distributions from the single trawl (BT) fishery.

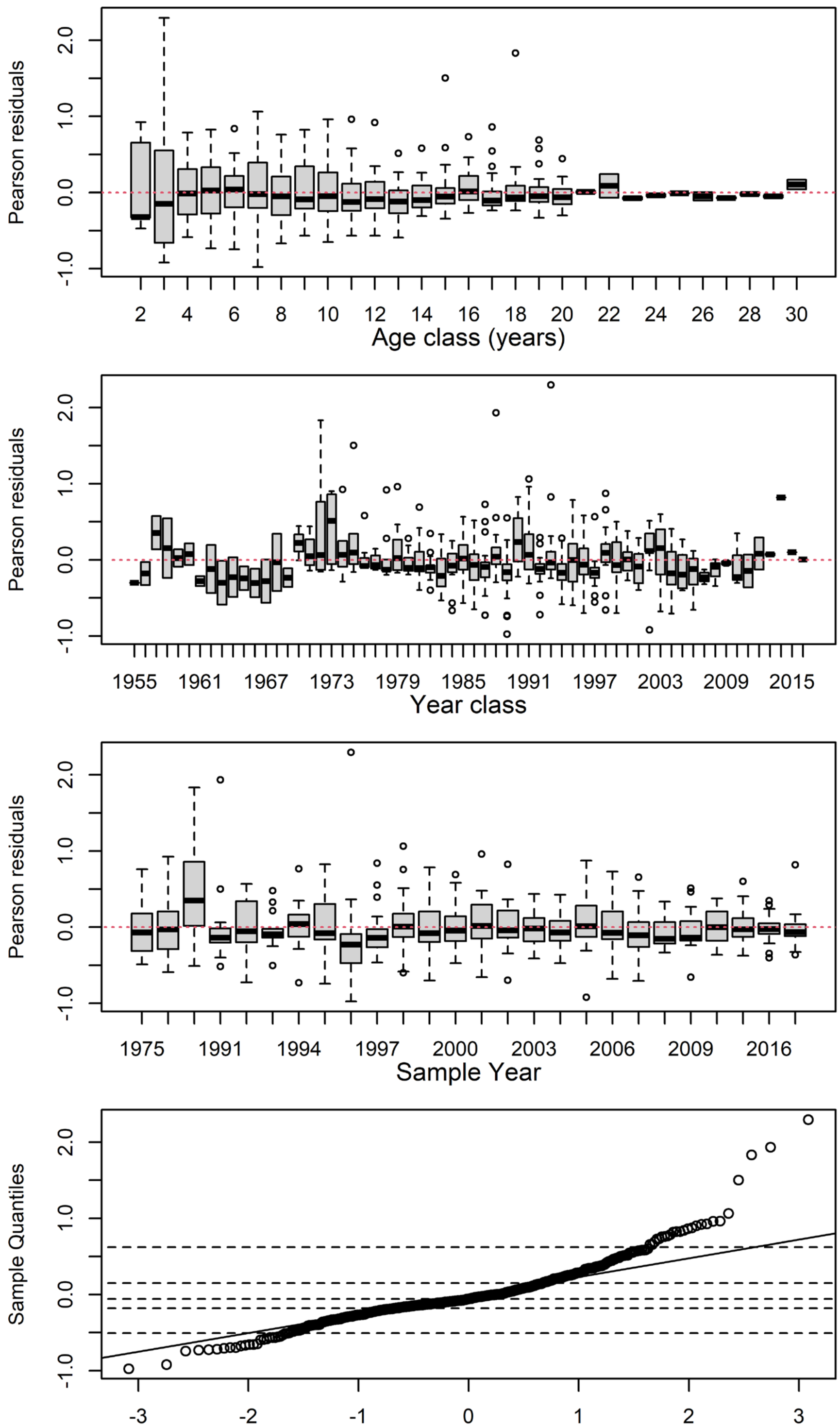

Figure 43: Boxplots of the residuals of the fits to the single trawl (BT) age compositions aggregated by age class, year class, and sample year. The lower panel is a normal quantile-quantile plot for residuals, with the horizontal lines representing the 5, 25, 50, 75, and 95 percentiles.

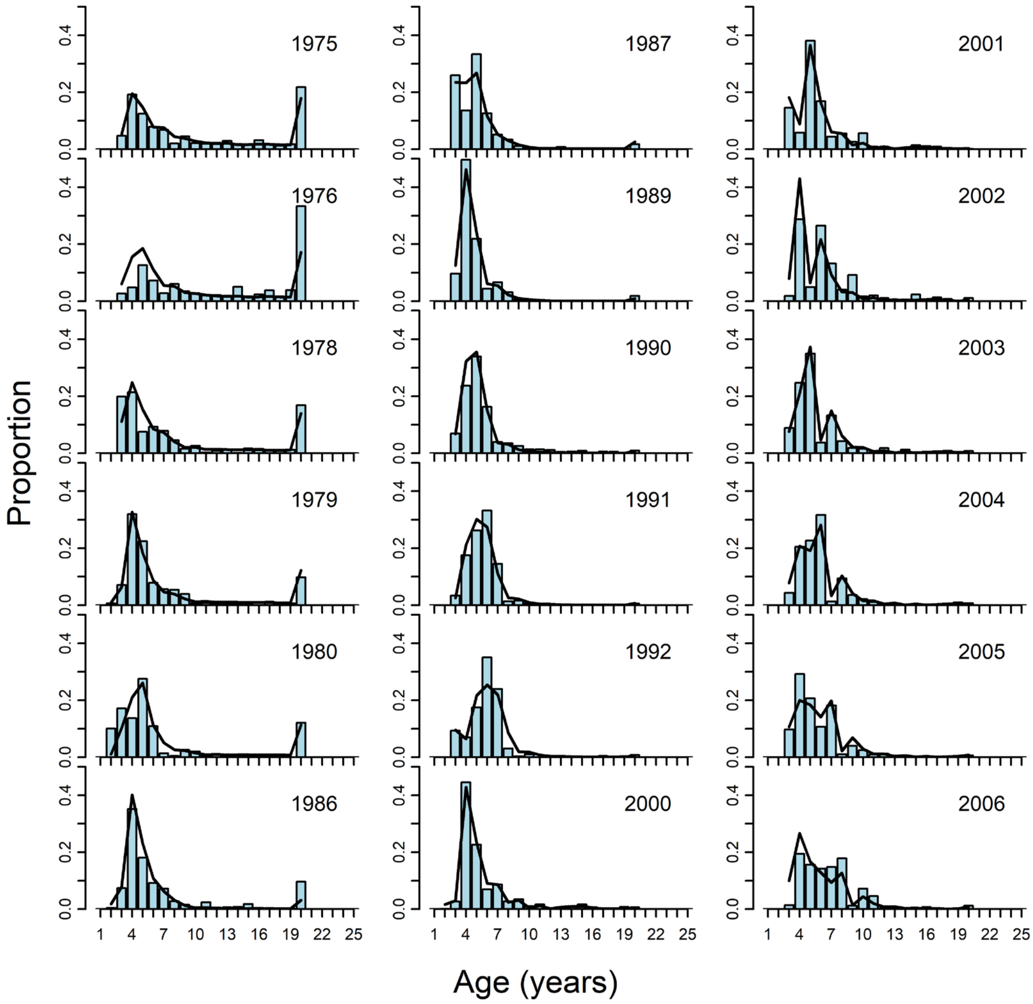

Figure 44: Model fits (lines) to the observed (bars) age composition distributions from the pair trawl (BPT) fishery.

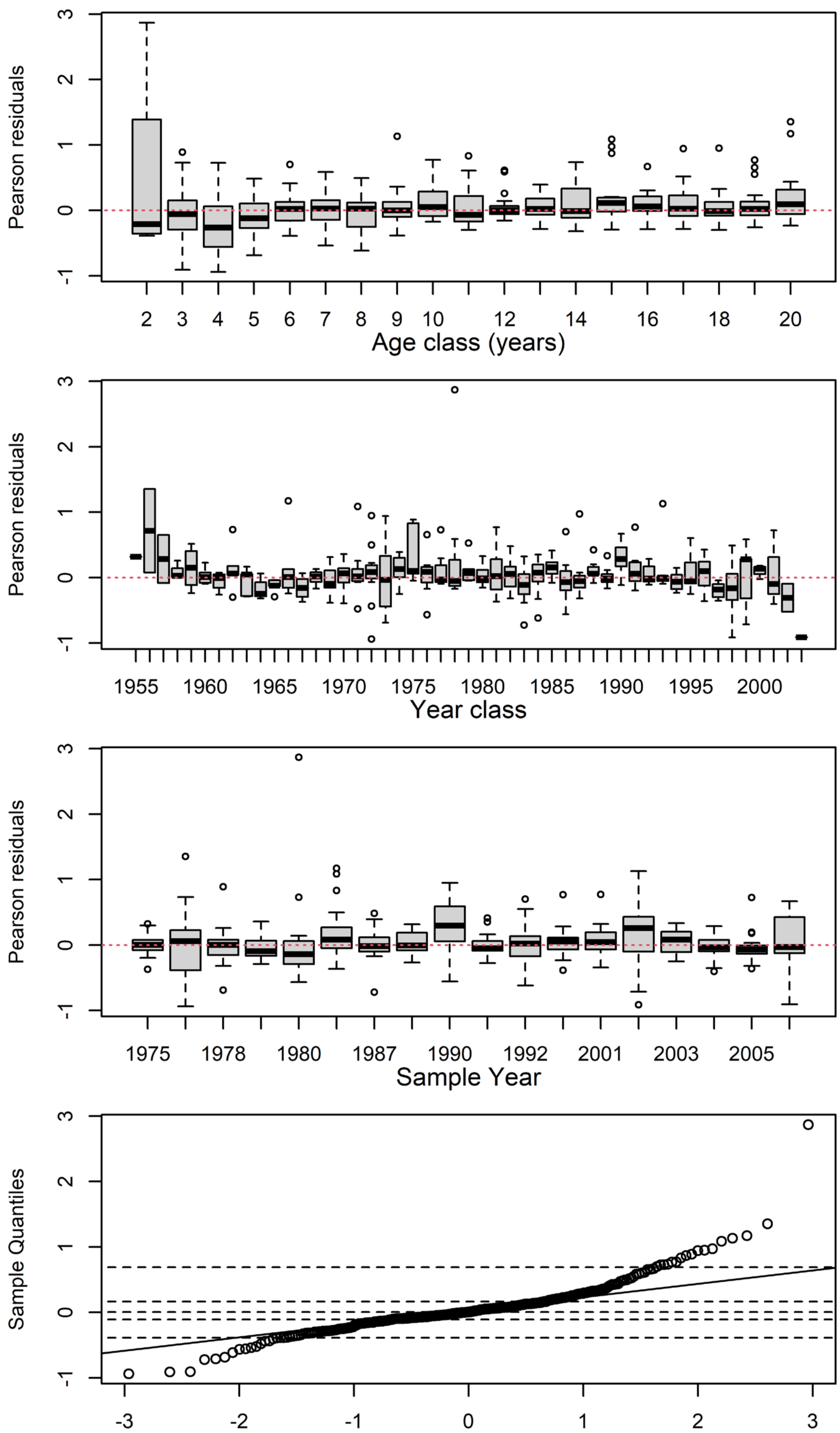

Figure 45: Boxplots of the residuals of the fits to the pair trawl (BPT) age compositions aggregated by age class, year class, and sample year. The lower panel is a normal quantile-quantile plot for residuals, with the horizontal lines representing the 5, 25, 50, 75, and 95 percentiles.

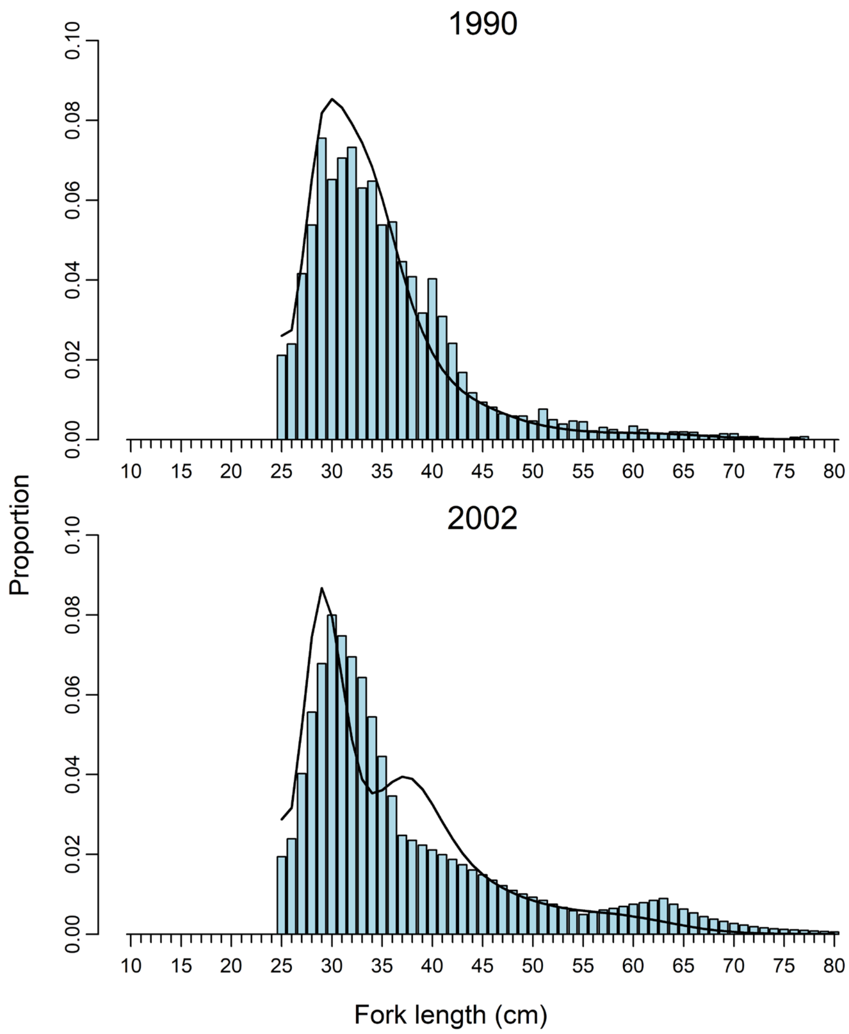

Figure 46: Model fits (lines) to the observed (bars) population length composition distributions (cm) estimated from the 1990 and 2002 tagging programmes.

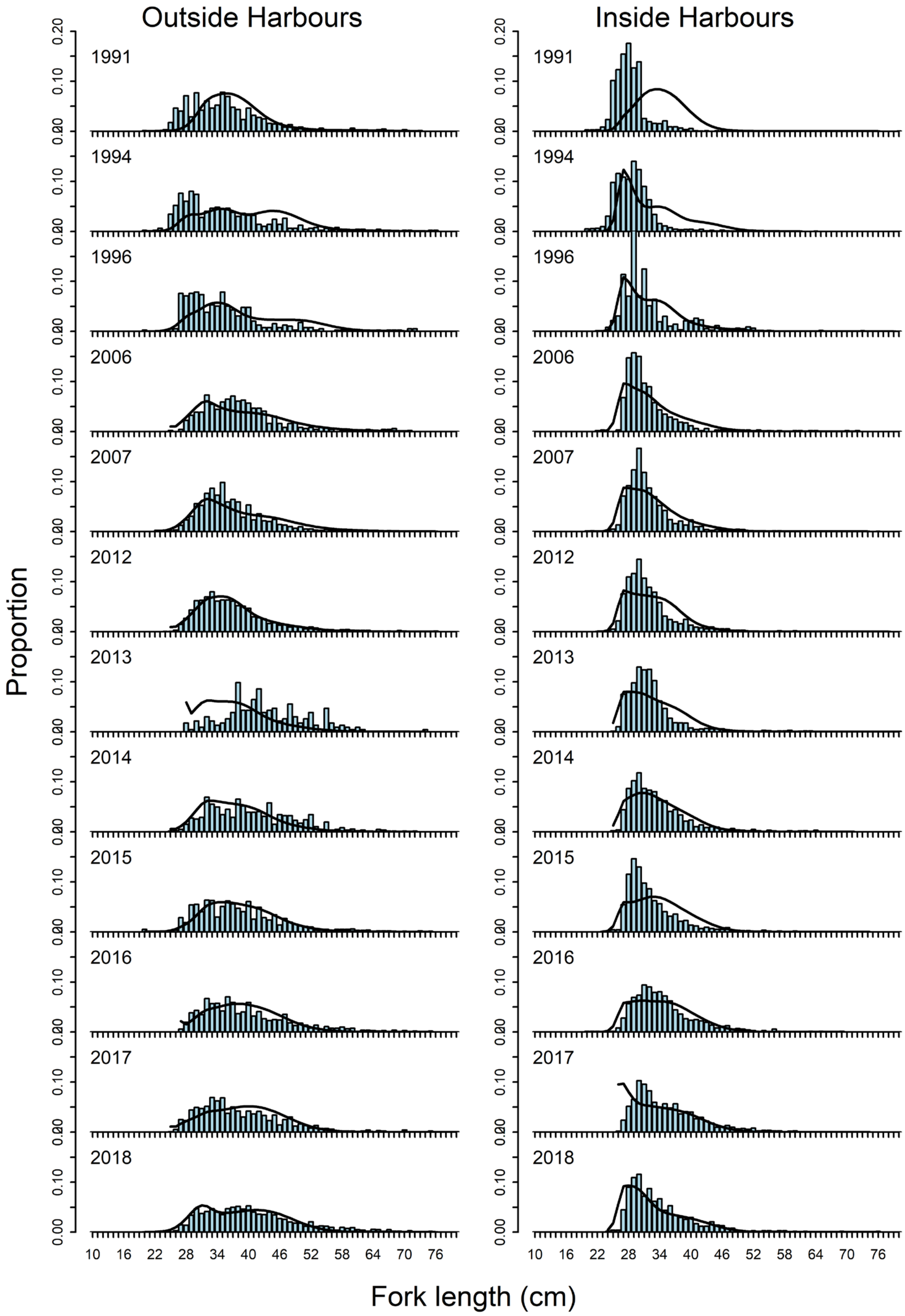

Figure 47: Model fits (lines) to the observed (bars) length composition distributions from the recreational fishery outside (left) and inside the WCNI harbours.

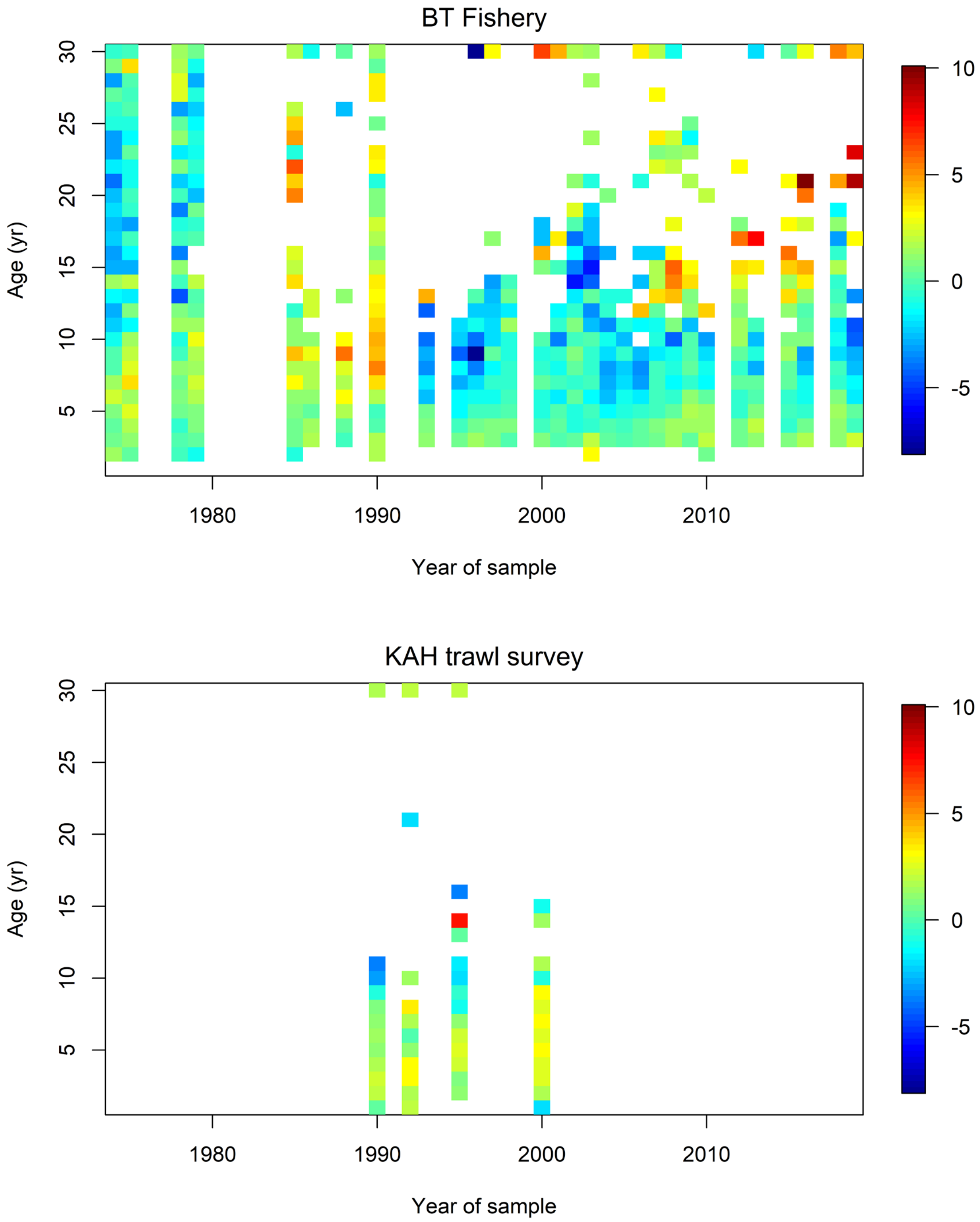

Figure 48: Residuals (cm) in the observed mean length-at-age and the predicted mean length-at-age from the three stanza growth functions incorporated in the assessment model.

Model dynamics

The model fishery catches were assumed to be known without error. The corresponding estimates of fishing mortality increased from the 1950s and reached a peak for the pair trawl fishery in the late 1970s and early 1980s (Figure 49). Fishing mortality rates for the pair trawl fishery declined sharply in the late 1980s and continued to decline through the 1990s and 2000s, whereas fishing mortality rates for the single trawl fishery continued to increase during the 1990s and then steadily declined from 2000 onwards (Figure 49). Since the early 1990s, fishing mortality rates for the two recreational fisheries remained at a relatively constant level (Figure 49).

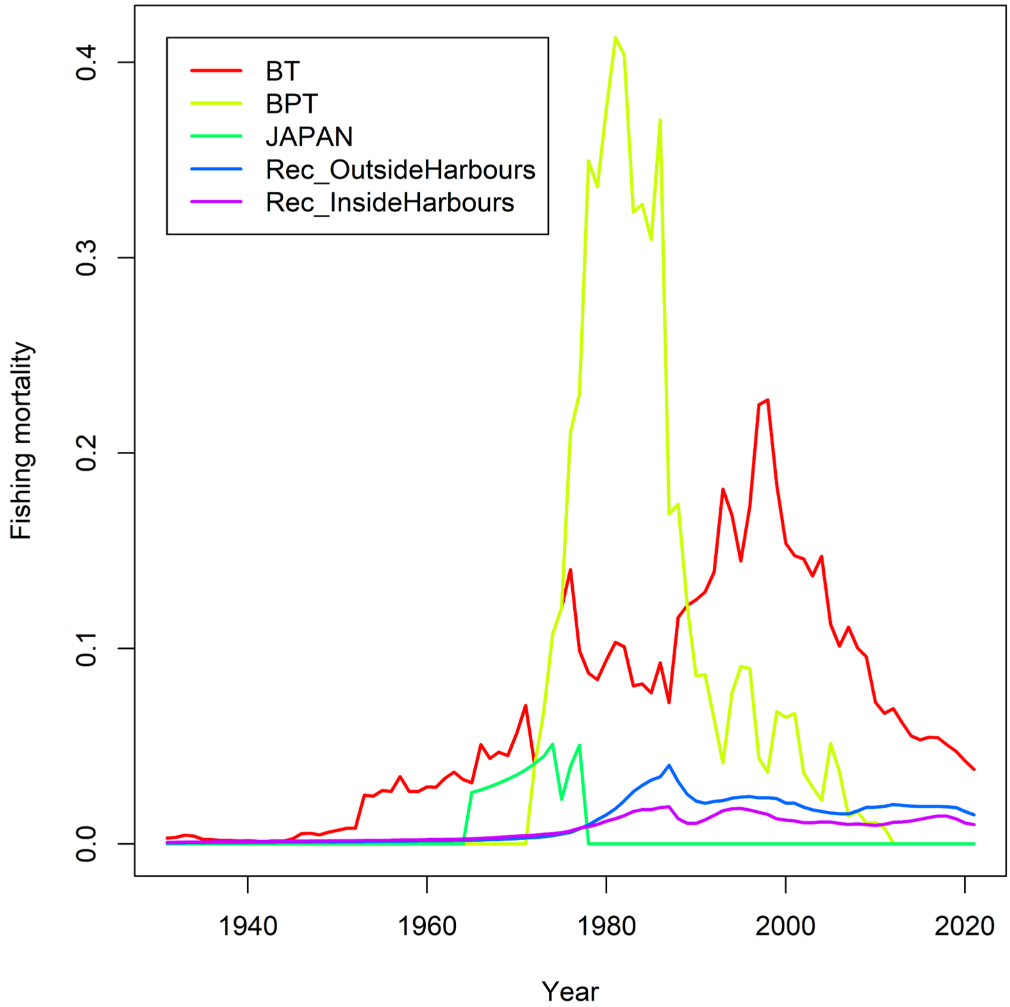

Figure 49: Estimates of annual fishing mortality rates for each fishery from the Base Case model (MPD).

Prior to 1960, annual recruitments were assumed to be at the equilibrium level (Figure 49). Recruitment deviates from the SRR were estimated for the subsequent years. During the 1960s and 1970s, the overall level of recruitment was estimated to be below average, and the precision of the individual estimates of annual recruitment is relatively low.

Recruitments were estimated with a higher degree of precision during the 1980s and 1990s and annual recruitments were highly variable with above average recruitment in 1985, 1996, and 1998 and a sustained period of low recruitment during 1987–1995 (Figure 49). From 2000, recruitment was estimated to increase and recruitment during 2005–2019 was well above average, with very strong recruitments in 2006, 2017, and 2018 and an exceptionally strong recruitment in 2016. The 2016–2019 estimates are primarily informed by the abundance of young fish sampled from the three recent

Kaharoa trawl surveys. Recruitment for 2020 and 2021 was assumed to be at the equilibrium level (Figure 50).

Spawning biomass was estimated to have declined substantially during the 1960s and 1970s (Figure 51) following the large increase in the annual catches. Spawning biomass is estimated to have been heavily depleted by the early 1980s, reaching a nadir in 1987 at about 6% of the virgin biomass level. The spawning biomass increased slightly in the late 1980s, following the recruitment of the strong 1985 and 1986 year classes, and then remained at about 9% of the virgin biomass level throughout the 1990s (Figure 51).

Spawning biomass was estimated to have increased gradually during the 2000s followed by a more rapid increase in biomass from 2009 in response to the recruitment of the strong 2006 year class. The exceptionally strong 2016 year class reached maturity in 2019 and represented 16% of the spawning biomass in the terminal year of the model (2021).

There is considerable contrast over time in the level of spawning biomass estimated from the Base Case model. Recruitment was estimated to have remained relatively constant through the 1960s and 1970s as the stock was depleted, although recruitment was generally lower during the 1980s and 1990s when spawning biomass was at the lowest level (below 10% SB_0) (Figure 52). However, relatively large recruitments were estimated during the mid-2000s when the stock was still at a relatively low level (10–20% SB_0). The highest recruitments were estimated for the most recent period.

Overall, there is some indication that recruitment may have varied with the magnitude of the spawning biomass, although the trends in recruitment are not comparable between the periods of declining biomass (1960–1980) and the subsequent recovery (2000–2019) (Figure 52). Hence, the recruitment dynamics of the stock are poorly represented by the assumed Beverton-Holt spawner-recruit relationship, regardless of the value assumed for steepness.

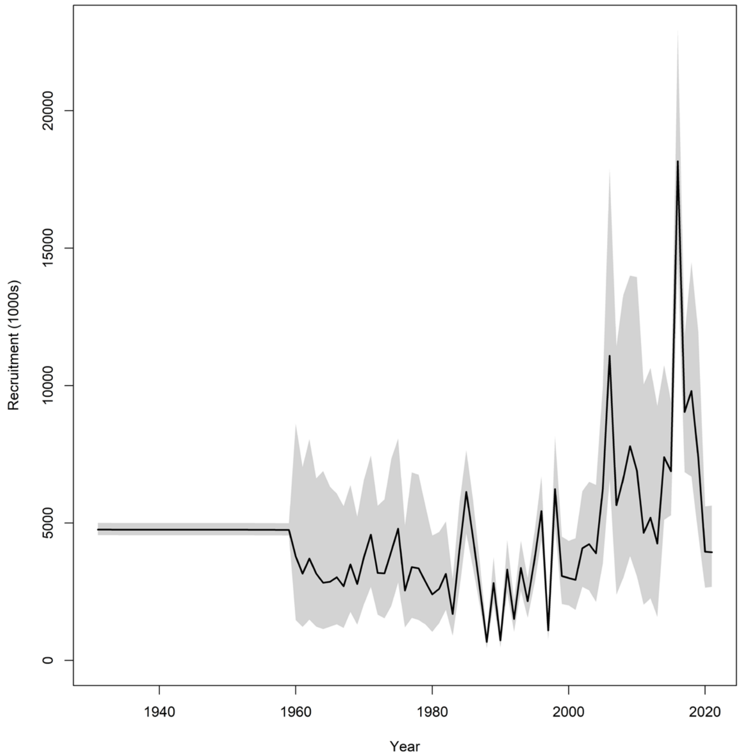

Figure 50: Annual estimates of recruitment (numbers of fish, thousands) from the Base Case model (MCMCs). The black line represents the median of the MCMC estimates and the shaded area represents the 95% confidence interval.

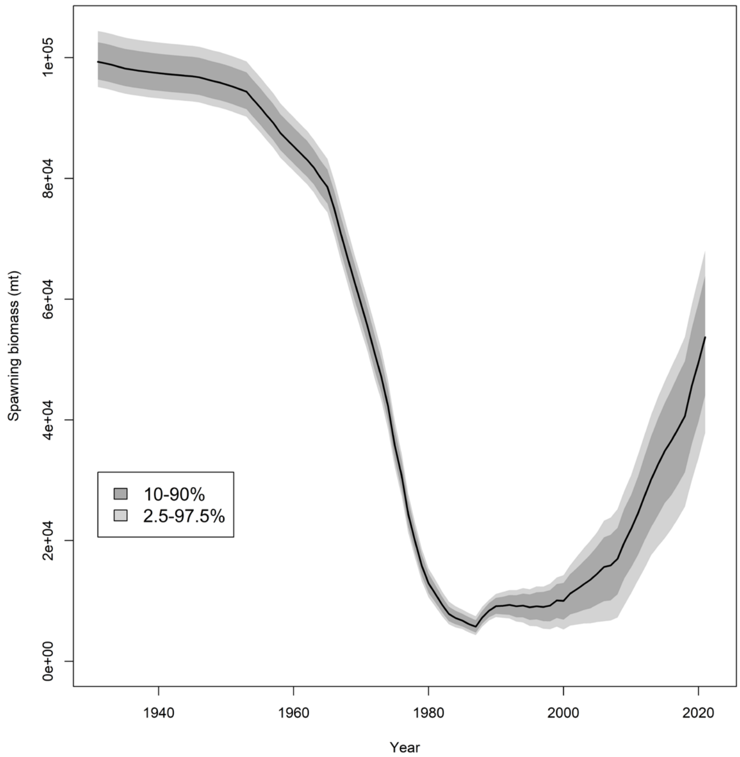

Figure 51: Annual estimates of spawning biomass (tonnes) from the Base Case model (MCMCs). The black line represents the median of the MCMC estimates and the shaded area represents the 90% and 95% confidence intervals.

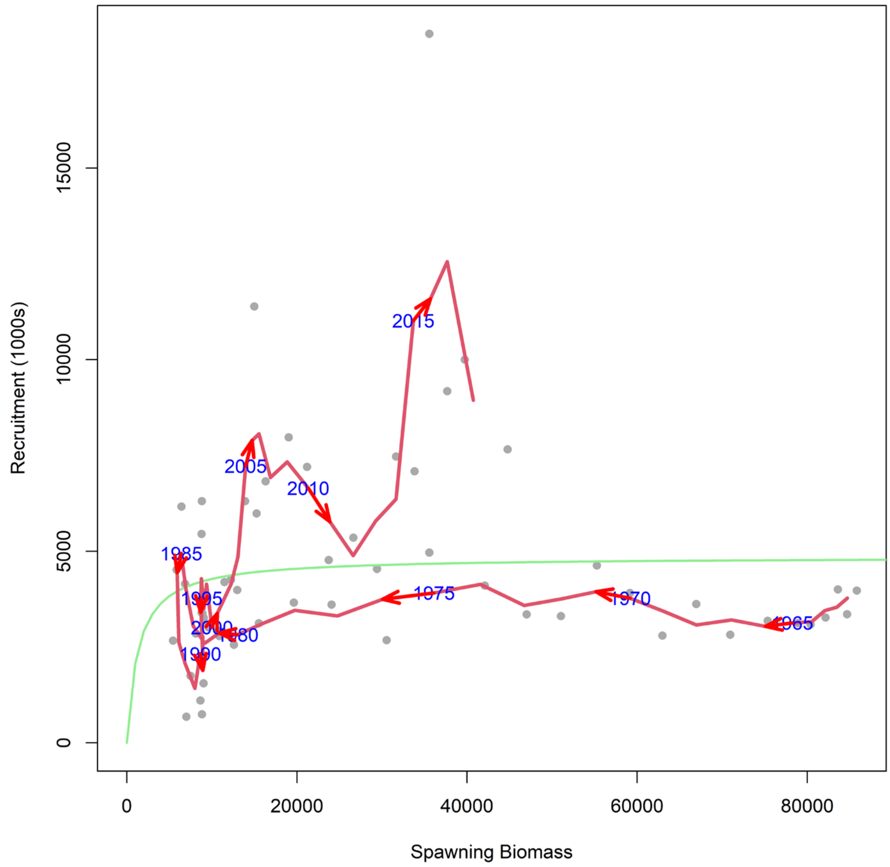

Figure 52: A comparison of the model estimates of annual spawning biomass and annual recruitment (Base Case) for the period of recruitment deviates (1960-2019). The red line represents the three-year moving average of biomass and recruitment (labelled at five year intervals). The green line represents the predicted spawner-recruit relationship, with an assumed steepness of 0.95.

Model Sensitivities

A number of key assumptions of the model were investigated as (single change) sensitivities to the Base Case model. The historical level of Japanese catch is unknown and for the previous (2020) assessment the base level of catch (2000 t) was bracketed by alternative catch levels of 1000 t (*JPcatch1000*) and 3000 t (*JPcatch3000*) following Davies & McKenzie (2001). These sensitivities did not appreciably change the estimate of current stock status (Langley 2020) and were therefore not repeated for the current assessment.

The influence of key stock productivity parameters was also investigated, specifically a lower value of natural mortality of 0.06 (*NatMort06*), a higher variability (sigmaR 0.8) in recruitment deviations (*SigmaR08*), and a lower value of steepness (0.85) of the SRR (*Steep085*). Other model sensitivities investigated the influence of key data sets (Table 10).

Estimates of stock status for the model sensitivities were obtained from MCMC sampling, with the exception of the *Steep085* sensitivity due to the significant proportion of MCMC chains that resulted in the stock crashing at low levels of stock biomass due to the lower value of steepness of the SRR. In that case, model results are presented for the MPD only.

Table 10: Summary of model options and sensitivities

Model	Description	Comment
TSurveyAgeIndices	Age-based trawl survey indices	Base Case 2020 Interim Base Case
BTlogistic	Logistic selectivity for BT and BPT fisheries	DN selectivity in base
CPUEex5yr	Exclude last 5 years CPUE indices (2016–2020)	Recent CPUE indices unreliable index
NatMort06	Natural mortality 0.06	Base M 0.075
RecF	2019–2021 Rec catches based on 2018 ER	Higher recreational catch in 2019–2021
SelexLen	Length based selectivity functions, fishery/survey	Temporal variation in growth
SigmaR08	SRR SigmaR 0.8	Base SigmaR 0.6
Steep085	SRR Steepness 0.85 (problem with MCMCs)	Base Steepness 0.95
Tag2002	2002 Tag Release/recovery data rather than biomass estimate	
TrawlSurveyBiomass	Trawl survey biomass indices and age comps	

Stock status

Current (2021) stock status was determined relative to unexploited equilibrium, spawning biomass. Spawning biomass is estimated to have increased considerably over the last 10 years and, for the Base Case, current biomass exceeds the default target biomass level ($SB_{2021}/SB_{40\%}$ = 1.353, CI = 0.975–1.657) (Table 11 and Figure 53) and the probability of the stock being below the hard (10% SB_0) and soft (20% SB_0) limits is negligible (Table 11). There has been a corresponding decline in the level of fishing mortality over the last 10 years (Figure 54), and the current (2021) level of fishing mortality is estimated to be at about the fishing mortality rate that results in the target biomass under equilibrium conditions ($F_{2021}/F_{SB40\%}$ = 0.810, CI = 0.643–1.136) (Table 11). Overall, the estimates of stock status are slightly more optimistic than the Interim Base Case from the 2020 stock assessment ($SB_{2020}/SB_{40\%}$ = 1.217, $F_{2020}/F_{SB40\%}$ = 0.907) (Langley 2020).

The *SigmaR08* model provided very similar estimates of current stock status to those of the Base Case, although overall equilibrium yields are slightly higher than for the Base Case. The two lower productivity options (*NatMort06* and *Steep085*) estimated lower levels of current biomass (relative to virgin spawning biomass) compared with the Base Case, although for both model options the level of biomass approaches the default target level and there was a very low probability of the stock being below the hard and soft limits. For the lower natural mortality option (*NatMort06*), current fishing mortality rates were above the reference level.

The influence of key data sets was also investigated. The trawl CPUE indices from the last five years (2016–2020) were excluded due to concerns regarding the reliability of the indices (*CPUEex5yr*). The selectivity of the commercial fisheries was alternatively configured to fully select the older age classes (*BTlogistic*) or be length-based (*SelexLen*) rather than age-based. The 2002 tag release-recovery data sets were incorporated in the model framework (*Tag2002*) rather than using the externally derived estimate of biomass from the tagging programme. The alternative series of recreational catches for 2019–2021 derived from a constant recreational harvest rate (*RecF*) was also included. These model sensitivities yield estimates of current stock status that are very similar to the Base Case.

The range of model sensitivities also retained another option from the preliminary modelling phase (section 4.3). The *TrawlSurveyBiomass* option incorporated the time series of *Kaharoa* trawl survey biomass indices and age compositions rather than the age-specific indices included in the Base Case. The fit to the recent trawl survey biomass indices in the *TrawlSurveyBiomass* model was poor, with the model considerably under-estimating the two most recent (2019/20 and 2020/21) trawl survey biomass indices. The estimate of current stock status from the *TrawlSurveyBiomass* was very similar to the Base Case (Table 11).

The recent higher level of recruitment and the temporal variation in growth rates indicate that the stock is not in an equilibrium state. Hence, equilibrium-based reference points may not be appropriate for the determination of current stock status, particularly given the uncertainty regarding the nature of the SRR. A theoretical, dynamic SB_0 incorporates the temporal variation in recruitment and growth to represent the annual spawning biomass in the absence of fishing (Figure 55). From 1990 onwards, the dynamic SB_0 is estimated to be considerably higher than the initial, unexploited equilibrium biomass. This reflects the higher recruitment from 2000 onwards and higher growth rates during the late 1980s and 1990s. The latter component may not be appropriate for inclusion in the estimate of dynamic SB_0 if growth rates vary as a function of stock abundance. Nonetheless, the comparison between the fished and unfished biomass reveals that since 2010 the fished biomass has increased considerably relative to the dynamic SB_0 and approached the corresponding default reference level in 2021 ($SB_{2021}/SB_{2021,F=0}$ = 0.404) (Figure 55).

Further, average recruitment from the recent period (2005–2017) is estimated to be about 65% higher than the equilibrium recruitment level (*R0*). If that level of recruitment were to persist, the long-term equilibrium, unexploited biomass would be at a correspondingly higher level.

For the base case, the estimate of current yield at a fishing mortality rate of $F_{SB40\%}$ (3951 t) is considerably higher than the equilibrium yield estimate (2449 t) (Table 11). This is consistent with the current fishing mortality rate being less than the $F_{SB40\%}$ level, and current biomass is above the target biomass level (40% of SB_0).

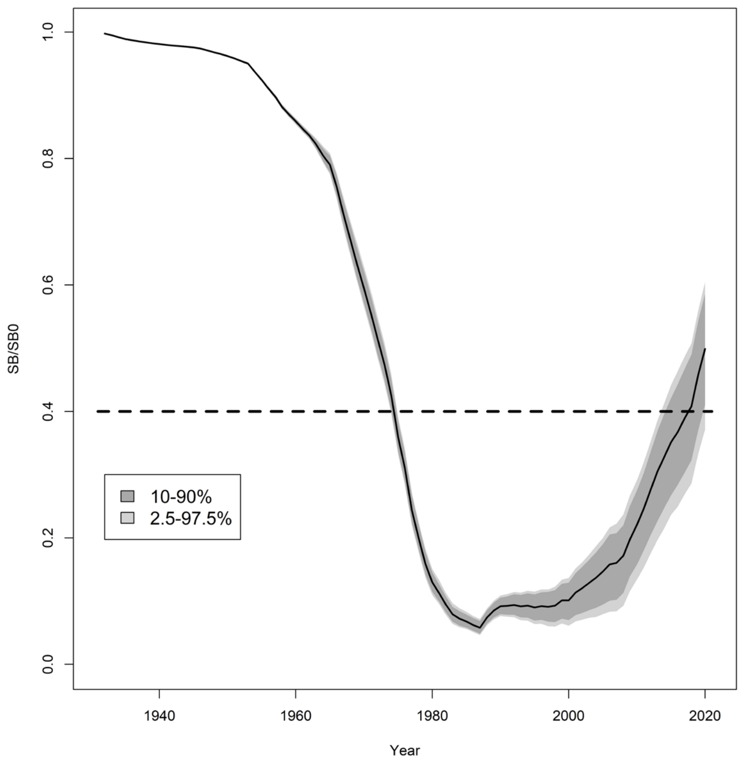

Figure 53: Annual spawning biomass relative to virgin biomass (equilibrium, unexploited) estimated from the Base Case model. The solid line represents the median of the MCMCs and the shaded areas represent the 95% confidence intervals. The horizontal dashed line represents the default target biomass level.

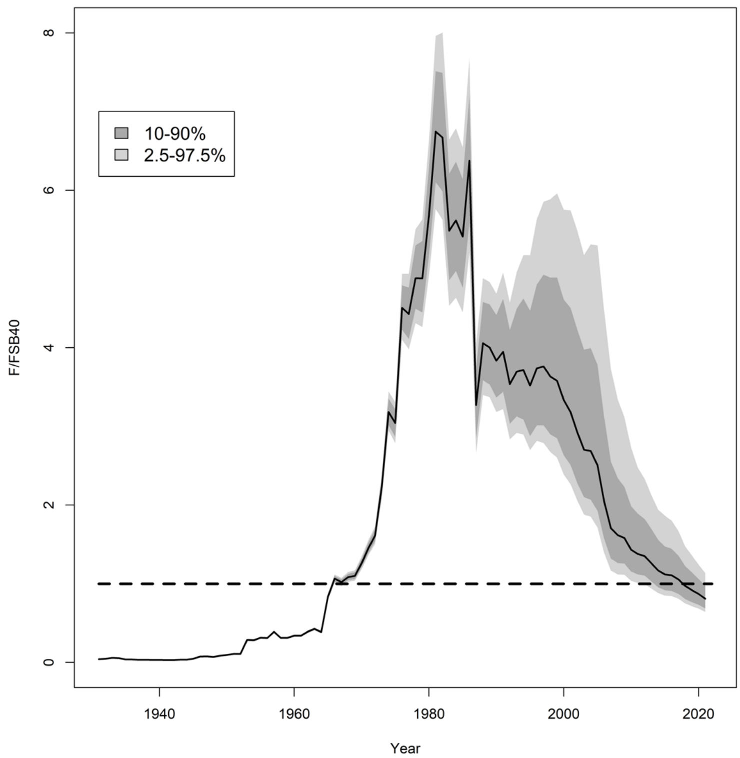

Figure 54: Annual fishing mortality relative to the reference ($F_{SB40\%}$) fishing mortality level. The black line represents the median of the MCMCs and the shaded areas represent the 90 and 95% confidence intervals. The horizontal dashed line represents the reference level.

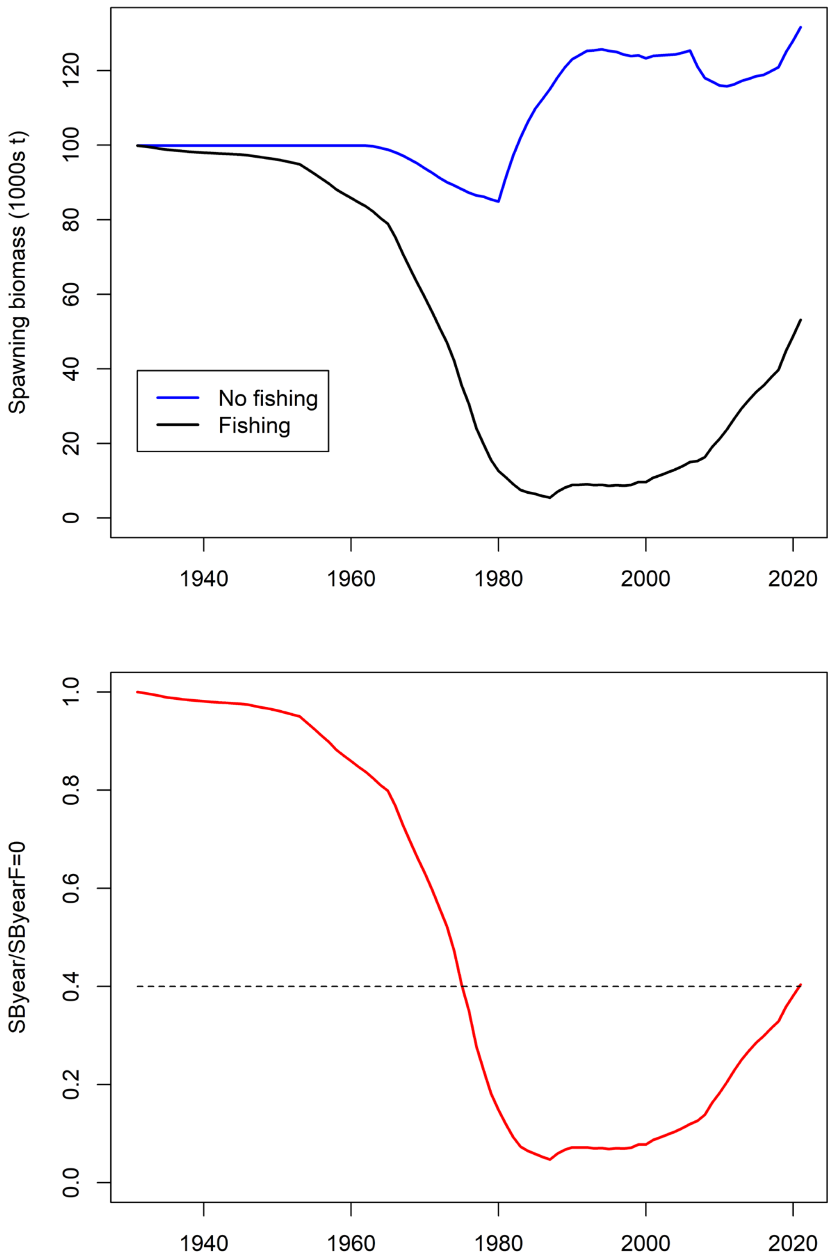

Figure 55: A comparison of the spawning biomass trajectory and the theoretical biomass trajectory in the absence of fishing (top panel) and the ratio of spawning biomass with and without fishing (lower panel) (MPD Base Case model). The dashed horizontal line represents the level of depletion corresponding to the default target biomass level.

Table 11: Stock status summary for the Base Case model (*TSurveyAgeIndices*) and model sensitivity options. The results represent the medians of the MCMC samples and the associated 95% confidence intervals for all options, except for *Steep085*, where results are MPD values. Yield 2021 represents the potential yield in 2021 corresponding to the $F_{SB40\%}$ fishing mortality rate. (Continued on next page)

							Pr ($SB_{2021} > X\%SB_0$)		
Model option	SB_0	SB_{2021}	$SB_{40\%}$	$SB_{40\%}$ *Yield*	$SB_{2021}/SB_{40\%}$	SB_{2021}/SB_0	40%	20%	10%
TSurveyAgeIndices	99 319	53 689	39 728	2 449	1.353	0.541	0.967	1.000	1.000
	(95 129–104 419)	(37 876–68 059)	(38 052–41 768)	(2 361–2 542)	(0.975–1.657)	(0.390–0.663)			
BTlogistic	93 724	46 153	37 490	2 443	1.232	0.493	0.845	0.991	1.000
	(90 592–96 961)	(25 223–58 218)	(36 237–38 784)	(2 362–2 522)	(0.687–1.524)	(0.275–0.610)			
CPUEex5yr	99 063	52 097	39 625	2 444	1.32	0.528	0.942	0.999	1.000
	(94 668–103 793)	(34 866–67 410)	(37 867–41 517)	(2 351–2 537)	(0.896–1.644)	(0.358–0.658)			
NatMort06	111 315	47 244	44 526	2 255	1.058	0.423	0.664	0.990	0.998
	(106 790–116 147)	(29 475–60 641)	(42 716–46 459)	(2 194–2 324)	(0.666–1.326)	(0.267–0.530)			
RecF	99 497	53 656	39 799	2 447	1.349	0.54	0.959	0.998	1.000
	(94 786–104 014)	(35 840–67 824)	(37 914–41 606)	(2 355–2 544)	(0.900–1.653)	(0.36–0.661)			
SelexLen	98 811	47 806	39 524	2 404	1.215	0.486	0.897	0.998	1.000
	(94 034–103 961)	(32 679–61 569)	(37 614–41 584)	(2 310–2 503)	(0.846–1.504)	(0.338–0.602)			
SigmaR08	108 408	54 727	43 363	2 661	1.265	0.506	0.931	0.999	1.000
	(103 154–114 876)	(38 059–70 148)	(41 262–45 950)	(2 553–2 783)	(0.902–1.554)	(0.361–0.622)			
Steep085	110 364	51 671	49 313	2 515	Na	0.468	Na	Na	Na
	(105 732–114 996)	(40 296–63 047)	(47 131–51 496)	(2 429–2 600)		(0.377–0.559)			
Tag2002	101 199	52 636	40 480	2 489	1.302	0.521	0.917	0.974	0.976
	(97 124–105 648)	(17 672–65 123)	(38 850–42 259)	(2 399–2 576)	(0.442–1.566)	(0.177–0.626)			
TSurveyBiomass	100 290	59 838	40 116	2 476	1.492	0.597	0.986	1.000	1.000
	(95 679–105 128)	(41 761–76 491)	(38 271–42 051)	(2 386–2 580)	(1.064–1.862)	(0.426–0.745)			

Table 11 (continued)

Model option	$F_{SB40\%}$	$F_{2021}/F_{SB40\%}$	$Pr(F_{2021}<F_{SB40\%})$	Yield 2021
TSurveyAgeIndices	0.054	0.810	0.916	3 951
	(0.052–0.056)	(0.643–1.136)		(2 977–4 881)
BTlogistic	0.058	0.882	0.761	3 367
	(0.057–0.059)	(0.705–1.557)		(2 039–4 144)
CPUEex5yr	0.054	0.831	0.873	3 876
	(0.052–0.056)	(0.647–1.226)		(2 818–4 813)
NatMort06	0.043	1.167	0.121	3 046
	(0.041–0.045)	(0.909–1.843)		(2 112–3 714)
RecF	0.054	0.901	0.787	3 922
	(0.053–0.056)	(0.721–1.336)		(2 871–4 793)
SelexLen	0.053	0.932	0.702	3 668
	(0.051–0.054)	(0.731–1.348)		(2 738–4 545)
SigmaR08	0.054	0.801	0.913	4 032
	(0.052–0.056)	(0.63–1.131)		(2 978–5 028)
Steep085	0.050	0.911	NA	3 627
	(0.048–0.052)	(0.718–1.103)		(2 917–4 337)
Tag2002	0.056	0.803	0.891	3 810
	(0.055–0.054)	(0.656–2.296)		(1 582–4 638)
TSurveyBiomass	0.0546	0.729	0.963	4 133
	(0.053–0.057)	(0.573–1.028)		(3 044–5 406)

Five-year stock projections (to the 2025/26 fishing year) were conducted using the Base Case model assuming annual commercial catches equivalent to the 2021 catch; i.e., a commercial catch of 1346 t (approximating the current TACC of 1300 t) and an allowance of 10% for unreported catches (total 1481 t). Annual recreational catches were either assumed to be constant at 935 t (the 2019 catch level, representing a total annual catch of 2416 t) or were projected forward based on the recreational fishery mortality rate from the terminal year of the *RecF* model (2021), resulting in a general increase in recreational catch during the projection period. Fish growth in the projection period was maintained at the slower rate observed in recent years. Annual recruitment deviates for the 5-year projection period were resampled from the long-term average level with the standard deviation equivalent in *sigmaR* (0.6). The level of recruitment in the projection period has a minor influence on the projected (spawning) stock biomass due to the delay in maturity of the recent recruitments.

Both projections indicate that the stock biomass will continue to increase during the 5-year projection period, with the biomass at the end of the period (2025/26) projected to be about 20% larger than the current (2020/21) biomass (Table 12). The increase in spawning biomass during the projection period is partly attributable to the contribution of the exceptionally large 2016 year class. For the *RecF* model, the recreational catch is predicted to remain relatively stable during the 5-year projection period (at about 1250 t), under the assumption of a constant fishing mortality rate and the composite selectivity of the two components of the fishery (inside and outside harbours) (Table 12).

Table 12: Annual commercial (including an additional 10% unreported) and recreational catches (assumed or predicted) for the last three years of the model period and the five-year projection period (shaded) from the Base Case and *RecF* models. The annual stock status ($SB_{year}/SB0$) for the projection period is also presented for both model options (and the associated 95% confidence intervals).

Year	Commercial catch (t)	Recreational catch (t)		$SB_{year}/SB0$	
		Base	*RecF*	*Base*	*RecF*
2018/19	1 421	935	1 005		
2019/20	1 481	935	1 095		
2020/21	1 481	935	1 192	0.541	0.540
				(0.390–0.663)	(0.360–0.661)
2021/22	1 481	935	1 206	0.579	0.575
			(867–1 483)	(0.427–0.701)	(0.398–0.696)
2022/23	1 481	935	1 251	0.607	0.599
			(930–1 539)	(0.451–0.731)	(0.426–0.721)
2023/24	1 481	935	1 267	0.627	0.616
			(942–1 550)	(0.472–0.754)	(0.448–0.737)
2024/25	1 481	935	1 256	0.643	0.627
			(949–1 532)	(0.483–0.776)	(0.465–0.751)
2025/26	1 481	935	1 241	0.653	0.635
			(942–1 510)	(0.493–0.789)	(0.478–0.759)

An additional 5-year projection was conducted assuming total annual catches in the projection period at the level equivalent to the current (2021) potential yield at $F_{SB40\%}$ (3951 t, commercial and recreational catch combined) (Table 11). The projection estimated that biomass would increase slightly in 2022 and stabilise at that level for the remainder of the projection period (at about 59% SB_0), at a slightly lower level than the two other projection scenarios (Table 13).

Table 13: Summary of the results of 5-year stock projections.

			Pr ($SB_{2026} > X\%SB0$)		
Model option	Projected catch (t)	SB_{2026}/SB_0	10%	20%	40%
Base Case	2 356	0.653 (0.493–0.789)	1.00	1.00	1.00
	3 951	0.587 (0.421–0.723)	1.00	1.00	0.98
RecF	1 481+Rec	0.635 (0.478–0.759)	1.00	1.00	1.00

5. DISCUSSION

This assessment represents the completion of the first stock assessment of SNA 8 since 2004/05 and incorporates a considerable amount of additional data collected from multiple sources over the intervening period. These data provide a coherent signal that abundance has increased following a period of relatively strong recruitment, while commercial catches have been constrained by the TACC. There has been an increase in the catch from the recreational fishery, although the total removals from the stock were considerably less than the levels of surplus production over the last 10 years. Consequently, estimates of stock status have improved considerably since the previous assessment, from about 10% of SB_0 in 2003/04 (Davies et al. 2016) to about 54% SB_0 in 2020/21. The current assessment indicates stock biomass will continue to increase over the next five years, remaining well above the default target biomass level at the current level of catch.

The current assessment was finalised following the completion of the third consecutive WCNI trawl survey. The biomass indices from the three recent trawl surveys (2018–2020) are considerably greater than the indices from the earlier trawl surveys (1989–1999), corroborating the recent increase in stock abundance. However, the variability in the catchability of adult snapper for the three recent trawl surveys has limited the utility of these data in the assessment modelling. The variability in catchability of snapper is likely to have been influenced by the timing of the individual surveys relative to the main spawning period compounded by the restriction from trawl sampling within the Māui dolphin trawl exclusion zone. Further, the distribution of adult snapper appears to have expanded (into deeper water) as the abundance of snapper increased in recent years, potentially increasing the overall availability of snapper to the trawl surveys. A longer time series of trawl surveys may enable a more thorough evaluation of the factors influencing the variability in catchability and, thereby, increase the utility of the trawl surveys to monitor stock abundance. In the interim, subsequent trawl surveys would continue to provide additional estimates of the abundance of recent year classes (surveyed as 2–5 year-old fish).

The age compositions derived from the recent inshore trawl surveys could also be used to further investigate stock relationships between SNA 8 and SNA 7 and spatial structure of the snapper population within sub-areas of SNA 8.

The trawl CPUE indices represent an important index of abundance within the current assessment model. However, there have been considerable changes in the operation of the inshore trawl fishery to minimise snapper catches. These changes in fishing operation are not fully accounted for in the standardised CPUE analysis and, consequently, the CPUE indices are likely to under-estimate the extent of the increase in snapper abundance, especially in recent (3–5) years. This limits the utility of the CPUE indices to monitor current and future trends in stock abundance. Future monitoring of SNA 8 may require more direct estimation of stock abundance via mark-recapture using conventional tags or genetic techniques, although such programmes will be expensive due to the relatively large current stock size (Bravington et al. 2016, McKenzie et al. 2015).

During the development of the 2020 assessment, a range of recommendations were identified for consideration in the 2021 assessment (Langley 2020). In general, these recommendations were considered to represent refinements to the assessment rather than substantive issues that were likely to result in an appreciable change in the outcome of the stock assessment. Progress was made on implementing many of those recommendations in the current assessment, and a number of additional issues have been identified, specifically:

i. An extension of the range of age classes included in the age compositions from the sampling of the trawl fisheries in the 1970s beyond the current ‘plus group’ of 20 years. This would require the re-ageing of sampled otoliths from fish included in these older age classes using the current snapper ageing protocol (Walsh et al. 2014a). The extension of the range of age classes would enable recruitment deviations to be estimated for the earlier years (prior to 1960), providing more information regarding the dynamics of the stock during the earlier period of the model. In the interim, progress was made in the re-ageing of the historical otolith sets; however, the results were not available for inclusion in the current assessment. These data will be included in the next iteration of the stock assessment model.
ii. The refinement of the estimation of temporal variation in growth parameters (in length and body weight), including alternative growth functions (other than von Bertalanffy) and a stock specific length-weight relationship. The latter was investigated during the current assessment using fish length/weight observations collected during the time series of WCNI *Kaharoa* trawl surveys. These data were consistent with the established generic length-weight relationship for snapper.
iii. The current assessment assumes all fish reach maturity at age 3 years. There has been no comprehensive evaluation of this assumption. The biological data collected from snapper sampled during the WCNI *Kaharoa* trawl surveys should be analysed to derive a length (and age) maturity OGIVE for SNA 8. An exploratory model investigated the sensitivity of the current maturity assumption by increasing the age at maturity to 5 years. This model estimated a somewhat lower point estimate of current stock status (SB_{2026}/SB_0) compared with the Base Case, although the overall stock status was similar.
iv. Determination of multinomial sample sizes for individual age compositions based on estimates of precision of the proportions-at-age (CVs). This will require the collation of the CVs for each of the catch-at-age observations.
v. Accounting for the potential shift in the selectivity of the trawl fisheries that occurred following the change in the minimum codend mesh size from 100 mm to 125 mm in October 1995. This was investigated in a model trial which allowed the width of the ascending limb of the selectivity function to vary between the two time periods (pre and post 1995). This resulted in a steepening of the selectivity for the latter period, as would be anticipated from the increase in mesh size. There was a corresponding improvement in the overall fit to the trawl age compositions, although there was no appreciable change in the estimate of current stock status.
vi. Further, it may be appropriate to account for the temporal variation in growth within the selectivity function of the trawl fishery, which is currently assumed to be age based and temporally invariant. Growth rates appear more variable for fish older than about 7 years than for younger fish and, consequently, the length/age of fish recruiting to the fishery may not have varied substantially over time. This presumption was supported by the results of the *SelexLen* model sensitivity which yielded very similar results to the Base Case model.
vii. During the current assessment, model trials were conducted to integrate the 2002 tag release/recovery data within the framework of the model. These trials yielded results that were very similar to the biomass estimate derived from the external modelling of those data.

Some of the potential sources of uncertainty identified above will be investigated through a current study (SNA2019-03b) that will apply a simulation approach to evaluate current model assumptions. That analysis will focus on the potential biases associated with key structural assumptions of the assessment, particularly related to the spatial structure of the snapper population within SNA 8 and non-stationarity in recruitment and growth (potentially related to stock abundance). It is anticipated that the results of the simulation study will be available in late 2021.

The current assessment highlights the utility of regular sampling of the age composition of the commercial catch, particularly to provide information regarding the relative strength of recruited year classes. The current assessment estimates an exceptionally strong 2016 year class based on observations of the year class from the three recent trawl surveys (at ages 3, 4, and 5 years). This year class will have been recruiting to the commercial fishery over the last few years and age composition data from the fishery will refine model estimates of the relative strength of the year class. The next catch sampling programme for the SNA 8 fishery is scheduled for 2021/22. A review of the frequency of future sampling should be conducted following an evaluation of the efficacy of the trawl survey sampling of the snapper population (scheduled for 2021).

The trawl surveys provide estimates of relative strength of individual year classes for 1985–1998 and 2014–2019. Recruitment is considerably higher from the latter period, and the assessment also estimates higher recruitment during 2005–2013, informed by commercial age compositions and trawl CPUE indices. Limited information is available to externally corroborate the recruitment during the intervening period. Limited sampling has been intermittently conducted of juvenile (0+) snapper habitat within the Kaipara Harbour from three surveys (Morrison et al. 2014). The relative abundance of juvenile snapper strength from these surveys is broadly consistent with the model recruitment estimates for 2003 (low), 2010 (high), and 2014 (high) (Mark Morrison, NIWA, pers. comm.), although the (3) comparative observations are too few for these data to be considered corroboratory support for the model recruitment estimates.

Recruitment of snapper in the Hauraki Gulf has been correlated with sea surface temperature (SST) during the summer months following spawning (Francis et al. 1995). There are limited *in situ* environmental observations from the central area of the SNA 8 fishery; the longest time series of SST data is available from a site at the entrance of the Manukau Harbour. Monthly observations were available from January 2009 (source: Auckland Council Environmental Data Portal). There was a weak correlation (corr = 0.47, nobs = 11) between the estimates of annual recruitment (natural logarithm of numbers of fish) from the assessment model and the SST in January (following the November spawning period). The estimate of exceptional strong recruitment in 2016 corresponded to a sustained period of above average SST during January-March 2016. The potential relationship between SST and recruitment in SNA 8 should be re-evaluated once a longer time series of comparative data is available.

The recent increase in the catch from the recreational fishery highlights the importance of this component of the fishery, which currently accounts for approximately 40% of the total catch. The increase in the magnitude of the estimates of recreational catch from 2006/07 to 2017/18 (892/260 = 343%) is broadly consistent with the magnitude of the corresponding increase stock biomass from the stock assessment model (260%). Given the magnitude of the catch from the recreational fishery, it is important to routinely monitor the level of recreational catch to determine total removals from the stock. The next National Panel Survey to estimate recreational catch is scheduled for 2022/23. Indices of recreational fishing activity have also been developed from web cam observations at key boat ramps within SNA 8. These observations should be evaluated in conjunction with the overall recreational harvest survey data. There is potential for the web cam indices to provide more regular monitoring of recreational fishing activity and catch.

Estimates of stock status have been provided principally based on the assumption of long-term, equilibrium conditions. Productivity of the SNA 8 stock appears to have varied considerably over the history of the fishery, with variable levels of recruitment and variation in growth rates (that appear to be related to stock abundance). Recent recruitment is estimated to be at an historically high level with recruitment considerably higher than the equilibrium level (from the stock-recruitment relationship). Further consideration is required to develop stock status indicators that are robust to the variation in the productivity of the SNA 8 stock.

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APPENDIX 1: CPUE DATA SET

Table A1: Summary of the SNA 8 catch and effort data from the January-April 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
1996/97	570	7	59	131.0	570	1 757	23.2
1997/98	621	9	60	128.4	621	1 769	26.4
1998/99	875	8	72	140.8	875	2 400	9.9
1999/2000	1 136	9	82	195.1	1 136	3 538	11.4
2000/01	881	10	78	158.2	881	2 900	21.2
2001/02	752	9	91	201.0	752	2 537	7.7
2002/03	792	7	79	204.1	792	2 713	8.1
2003/04	629	8	71	131.6	629	2 232	14.3
2004/05	666	9	73	153.1	666	2 302	21.5
2005/06	436	8	50	108.0	436	1 484	23.9
2006/07	699	6	64	133.0	699	2 335	21.9
2007/08	814	6	71	247.8	814	2 679	11.3
2008/09	802	7	73	278.8	802	2 728	10.7
2009/10	634	4	63	251.5	634	1 924	8.2
2010/11	670	6	72	291.6	670	2 097	7.9
2011/12	744	5	72	355.7	744	2 283	3.0
2012/13	938	6	86	384.0	938	2 980	3.2
2013/14	630	6	70	341.3	630	2 013	3.3
2014/15	523	6	56	287.8	523	1 620	2.3
2015/16	563	5	52	324.0	563	1 764	1.8
2016/17	328	4	37	181.2	328	1 000	2.7
2017/18	252	2	27	148.9	252	782	10.7
2018/19	281	2	31	175.7	281	875	20.3
2019/20	300	2	35	165.4	300	1 008	13.3

APPENDIX 2: TABULATED CPUE INDICES

Table A2: Annual SNA 8 trawl CPUE indices and the lower (LCI) and upper (UCI) bounds of the 95% confidence intervals.

Fishing	Combined			Binomial			Lognormal		
year	Index	LCI	UCI	Index	LCI	UCI	Index	LCI	UCI
96/97	0.769	0.669	0.882	0.768	0.713	0.814	1.000	0.893	1.124
97/98	0.701	0.611	0.798	0.730	0.672	0.785	0.960	0.851	1.070
98/99	0.788	0.694	0.881	0.865	0.828	0.898	0.912	0.811	1.013
99/00	0.957	0.861	1.071	0.917	0.892	0.938	1.044	0.946	1.170
00/01	0.690	0.607	0.784	0.769	0.714	0.819	0.898	0.799	1.004
01/02	1.017	0.908	1.134	0.930	0.904	0.951	1.094	0.979	1.212
02/03	0.961	0.853	1.075	0.910	0.877	0.936	1.056	0.939	1.176
03/04	0.728	0.638	0.825	0.836	0.788	0.875	0.871	0.774	0.969
04/05	0.998	0.883	1.121	0.849	0.808	0.883	1.175	1.054	1.308
05/06	1.247	1.070	1.438	0.837	0.789	0.878	1.489	1.294	1.696
06/07	0.844	0.739	0.956	0.794	0.743	0.838	1.064	0.948	1.194
07/08	1.443	1.272	1.617	0.906	0.875	0.930	1.593	1.420	1.782
08/09	1.293	1.150	1.439	0.908	0.878	0.932	1.424	1.271	1.581
09/10	1.738	1.545	1.962	0.931	0.905	0.953	1.867	1.667	2.103
10/11	2.445	2.148	2.748	0.916	0.882	0.942	2.670	2.359	2.992
11/12	2.565	2.275	2.868	0.967	0.948	0.980	2.653	2.361	2.968
12/13	2.516	2.237	2.815	0.979	0.969	0.986	2.571	2.292	2.880
13/14	3.075	2.753	3.431	0.975	0.962	0.985	3.152	2.818	3.525
14/15	3.540	3.139	3.978	0.983	0.972	0.991	3.600	3.187	4.041
15/16	3.449	3.038	3.865	0.987	0.976	0.994	3.494	3.076	3.913
16/17	3.078	2.678	3.514	0.983	0.967	0.992	3.131	2.730	3.578
17/18	3.432	2.916	4.021	0.963	0.941	0.978	3.565	3.035	4.173
18/19	3.890	3.306	4.545	0.934	0.906	0.955	4.166	3.559	4.851
19/20	2.633	2.276	3.040	0.945	0.922	0.964	2.786	2.419	3.214

APPENDIX 3: MODEL CATCH HISTORY

Table A3: Catch history included in the Base Case model, by fishery (BT, single trawl; BPT, pair trawl; JPLL, Japanese longline; Rec1, Recreational fishery outside harbours; Rec2, Recreational fishery inside harbours).

Year	Fishery				
	BT	BPT	JPLL	Rec1	Rec2
1931	168	0	0	45	15
1932	191	0	0	47	16
1933	256	0	0	50	17
1934	228	0	0	52	17
1935	130	0	0	54	18
1936	124	0	0	56	19
1937	102	0	0	59	20
1938	107	0	0	61	20
1939	85	0	0	63	21
1940	91	0	0	65	22
1941	74	0	0	68	23
1942	68	0	0	70	23
1943	90	0	0	72	24
1944	83	0	0	75	25
1945	149	0	0	77	26
1946	293	0	0	79	26
1947	301	0	0	81	27
1948	258	0	0	84	28
1949	332	0	0	86	29
1950	382	0	0	88	29
1951	437	0	0	91	30
1952	433	0	0	93	31
1953	1 349	0	0	95	32
1954	1 312	0	0	97	32
1955	1 442	0	0	100	33
1956	1 396	0	0	102	34
1957	1 766	0	0	104	35
1958	1 354	0	0	106	35
1959	1 337	0	0	109	36
1960	1 442	0	0	111	37
1961	1 414	0	0	113	38
1962	1 622	0	0	116	39
1963	1 747	0	0	118	39
1964	1 531	0	0	120	40
1965	1 418	0	2 000	122	41
1966	2 197	0	2 000	125	42
1967	1 772	0	2 000	127	42
1968	1 789	0	2 000	129	43
1969	1 613	0	2 000	131	44
1970	1 906	0	2 000	134	45
1971	2 222	0	2 000	136	45
1972	1 177	1 177	2 000	138	46
1973	1 823	1 823	2 000	141	47
1974	2 604	2 604	2 000	143	48
1975	2 530	2 530	749	145	48
1976	2 557	3 835	1 127	147	49
1977	1 419	3 310	1 104	150	50
1978	1 042	4 166	0	152	51
1979	831	3 325	0	154	51
1980	794	3 177	0	156	52
1981	757	3 027	0	159	53
1982	633	2 531	0	161	54
1983	435	1 741	0	163	54
1984	414	1 656	0	166	55
1985	371	1 484	0	168	56
1986	439	1 755	0	170	57
1987	295	688	0	172	57
1988	616	925	0	175	58
1989	840	840	0	177	59
1990	1 010	696	0	179	60
1991	1 091	734	0	179	60
1992	1 101	504	0	179	60
1993	1 382	315	0	179	60
1994	1 163	534	0	179	60
1995	971	609	0	179	60
1996	1 128	586	0	179	60
1997	1 485	290	0	173	58
1998	1 505	243	0	173	58
1999	1 315	485	0	181	60
2000	1 241	523	0	178	59
2001	1 235	559	0	186	62
2002	1 389	346	0	188	63
2003	1 414	300	0	190	63
2004	1 592	242	0	191	64
2005	1 255	574	0	191	64
2006	1 155	423	0	191	64
2007	1 295	165	0	195	65
2008	1 231	204	0	227	76
2009	1 332	148	0	281	94
2010	1 223	185	0	336	112
2011	1 289	155	0	400	133
2012	1 488	8	0	473	158
2013	1 464	0	0	518	173
2014	1 403	0	0	556	185
2015	1 399	0	0	591	197
2016	1 461	0	0	620	207
2017	1 467	0	0	647	216
2018	1 416	0	0	669	223
2019	1 421	0	0	701	234
2020	1 481	0	0	701	234
2021	1 481	0	0	701	234