Fisheries New Zealand

Tini a Tangaroa

Stock assessment of snapper in SNA 7

New Zealand Fisheries Assessment Report 2018/25

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ISSN 1179-5352 (online)
ISBN 978-1-77665-914-2 (online)

June 2018

New Zealand Government

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

Annual CPUE indices for snapper in SNA 7 were derived from the catch and effort data from the main TBGB trawl fishery. The CPUE indices are relatively constant during 1989/90 to 2010/11, increase substantially in 2011–12 and remain at the higher level during the subsequent years (to 2016/17).

A stock assessment was conducted for SNA 7 using a statistical age-structured population model integrating annual catch, an estimate of absolute biomass from the 1987 Tasman/Golden Bay tagging programme, recent trawl CPUE indices, length composition data from the recreational fishery and age compositions from the commercial fishery and the 2017 *Kaharoa* trawl survey. The assessment model provides a relatively coherent integration of the main data sets, although there is some deterioration in the fit to the recent CPUE indices and recent (2016/17) commercial age composition data.

Stock biomass is predicted to have declined substantially from 1950 to the mid-1980s due to high levels of catch, particularly during the late 1970s and early 1980s. The assessment estimates that stock biomass had been reduced to approximately 7% of the unexploited (SB_0) level by the mid-1980s, and the stock remained at about this level throughout the 1990s and 2000s. Since 2009, stock biomass has increased rapidly and current (SB_{2016} or 2016/17) biomass is estimated to be at 39% of the SB_0 level.

The stock is characterised by high variability in recruitment with episodic periods of strong recruitment occurring at 7–10 year intervals. The recent increase in stock abundance is attributable to the recruitment of an exceptionally strong 2007 (2007/08) year class and strong 2010 (2010/11) year class, mediated by the large increase in the trawl CPUE indices from 2010/11. The strong 2007 and 2010 year classes are also evident in the recent age composition data from the commercial fishery and *Kaharoa* trawl survey.

The current stock status was assessed relative to the MPI Harvest Strategy Standard. Current (2016/17) biomass is assessed to be well above the soft biomass limit (20% SB_0). There is considerable uncertainty in the magnitude of the recent increase in biomass, although the stock is estimated to be at about the interim target biomass level (40% SB_0). Two model sensitivity runs estimated a current stock status that bracketed the base model estimates; less optimistic current stock status from a model option with a lower level of natural mortality and more optimistic stock status for a model with a lower SigmaR for the stock-recruitment relationship. For all model options, current rates of fishing mortality are estimated to be well below the corresponding fishing mortality threshold ($F_{SB40\%}$).

Stock projections were conducted for a 6 year period (i.e. 2017/18–2022/23) based on status quo catch and TAC levels. The projections indicated that the stock would remain at about the target biomass (40% SB_0) and well above the soft limit (20% SB_0).

The next assessment for SNA 7 is tentatively scheduled for 2022. The assessment would incorporate updated CPUE indices and additional age composition data from the commercial catch and the 2019 *Kaharoa* trawl survey.

1 INTRODUCTION

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

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

The assessment estimated that stock biomass declined substantially from 1950 to the mid-1980s due to high levels of catch, particularly during the late 1970s and early 1980s (Langley 2015a). Stock biomass was estimated to be approximately 7% of the unexploited (SB_0) level in the mid-1980s and the stock remained at about that level throughout the 1990s and 2000s. From 2009, stock biomass increased rapidly and recent (SB_{2014}) biomass was estimated to be at 29% of the SB_0 level. The recent increase in stock abundance was attributable to the recruitment of an exceptionally strong (2007) year class (Langley 2015a).

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

This report summarises recent trends in the SNA 7 fishery, including updated CPUE indices, and presents the results of the 2018 stock assessment for snapper in SNA 7. The study was funded by the Ministry for Primary Industries (Project SNA2017-01). The stock assessment was accepted by the Fisheries Stock Assessment Plenary in May 2018.

2 FISHERY CHARACTERISATION

Trends in catch and effort from the SNA7 fishery have been described in previous reports (Hartill & Sutton 2011, Langley 2013). This section updates previous analyses to include data to the 2016/17 fishing year.

Commercial catch and effort data from the snapper fishery were sourced from the Ministry for Primary Industries (MPI) database *warehou*. The scope of the study encompassed the SNA 7 fishstock area and the data extract included the catch and effort data from any fishing trip that recorded a catch of snapper from the fishstock. The extract was supplemented by data from any additional fishing trips that conducted fishing within the Statistical Areas that constitute the fishstock area (Statistical Areas 017 and 033–039) and targeted the range of inshore species that are caught in association with snapper (i.e., SNA, FLA, RCO, GUR and JDO).

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 2016/17 fishing year.

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

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

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

1) **Daily** aggregated catch and effort data set from 1989/90–2016/17. Snapper catch and effort data were aggregated by vessel fishing day and fishing method to approximate the CELR data format. The predominant Statistical Area and target species recorded during the fishing day were assigned to the Daily aggregate record. For each trip, the landed catch of snapper was apportioned amongst the daily fishing records in proportion to the estimated catches of snapper (when included within the five main species caught in the day). Snapper landed catches from trips without corresponding estimated catches were distributed amongst daily records in proportion to fishing effort (number of trawls).
2) **Trawl** based catch and effort data set from 2007/08–2016/17. TCER format catch and effort records. For each trip, the landed catch of snapper was apportioned amongst the individual trawl records in proportion to the estimated catches of snapper. Snapper landed catches from trips without corresponding estimated catches were distributed equally amongst trawl records.

Total annual catches of SNA 7 under the Quota Management System (QMS) are compiled from Monthly Harvest Returns (MHR) submitted by fishing permit holders (MPI 2017). The total annual estimated and landed catches included in the SNA 7 catch and effort data sets approximated the QMS annual catches (Figure 1).

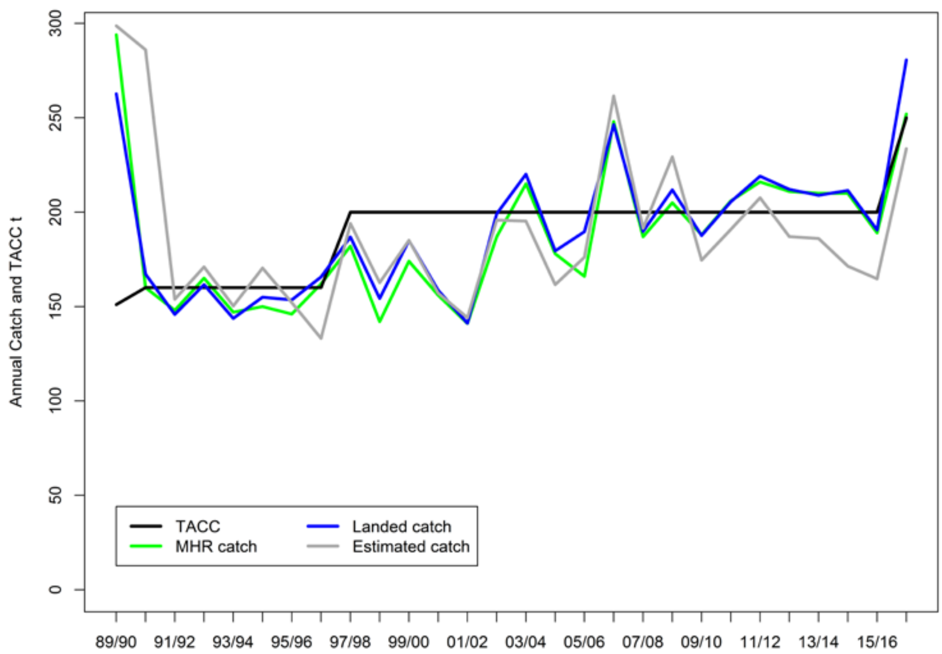

Figure 1: A comparison of total annual SNA 7 estimated and landed catches (t) by fishing year from the catch and effort returns and the total reported landings (t) to the QMS (MHR).

The Daily catch and effort data set was used to characterise the main trends in the catch from SNA 7 during 1989/90–2016/17. Annual catches were dominated by the pair bottom trawls (BPT) targeting snapper and by the single bottom trawls (BT) targeting snapper and other inshore finfish species, primarily flatfish and, to a lesser extent, barracouta, red gurnard and tarakihi (Figure 2). The pair trawl fishery ceased operation in 2011/12. From 2012/13, there was an increase in the proportion of the snapper catch taken by trawls targeting flatfish and red gurnard (Figure 2).

The annual SNA 7 catch were predominantly (65–80%) taken within TBGB (Statistical Area 038) with most of the remainder (25–30%) from off the northern west coast of the South Island (WCSI) (Statistical Areas 035–37) (Figure 3).

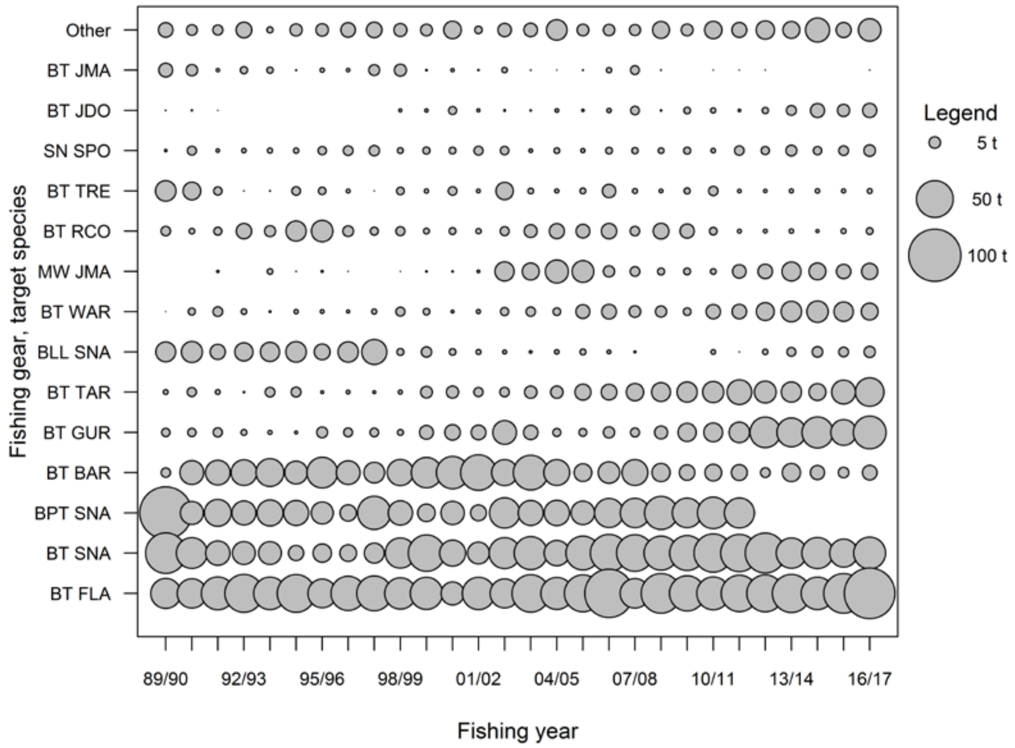

Figure 2: Landed catch of snapper by fishing method/target species and fishing year.

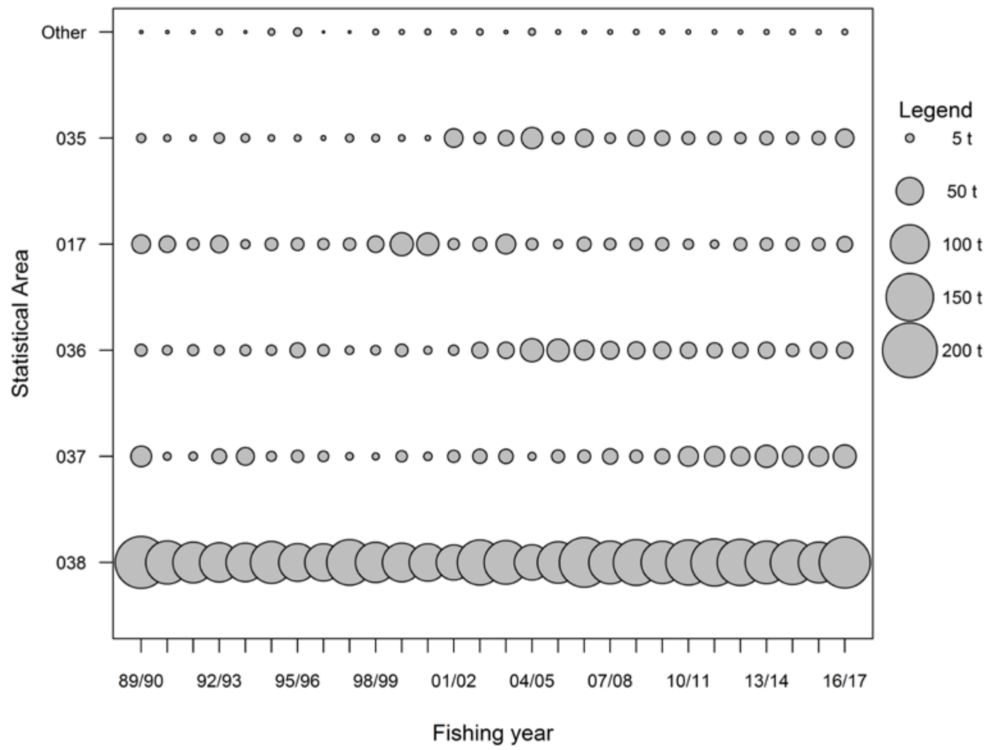

Figure 3: Landed catch of snapper by Statistical Area and fishing year.

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

Catches during November–April were dominated by the fishery within TBGB, while most of the catch from the WCSI was taken during May–September (Figure 5).

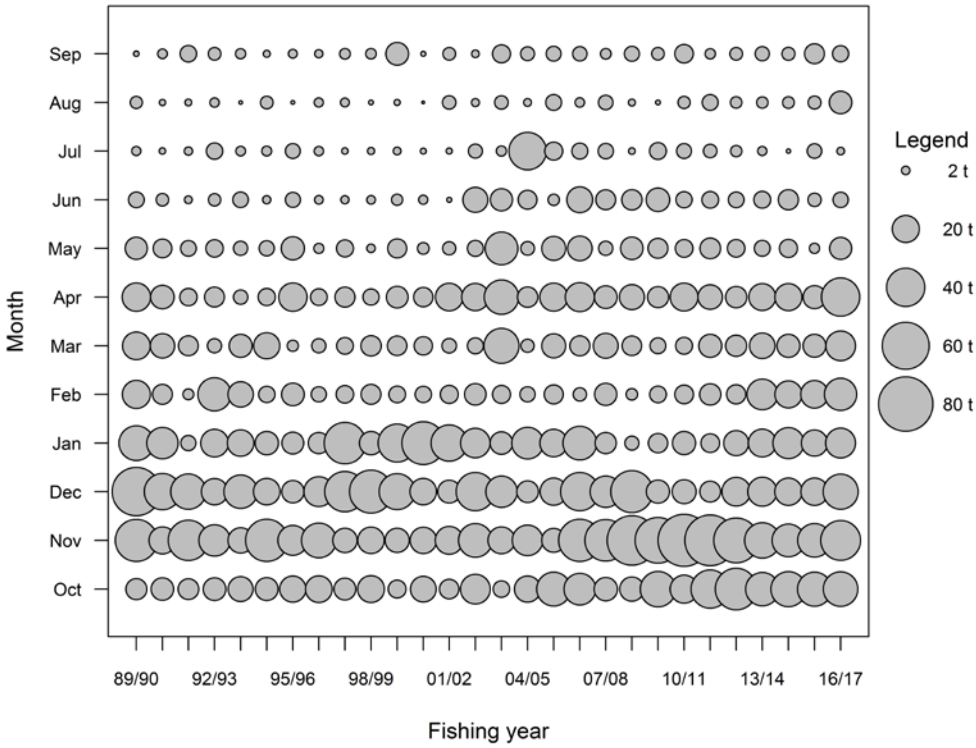

Figure 4: Landed catch of snapper by month and fishing year.

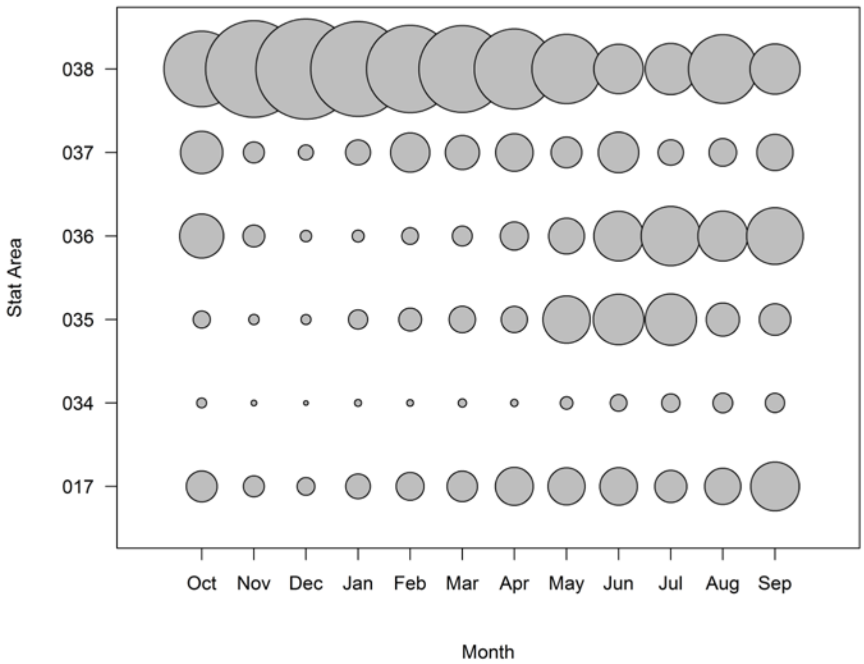

Figure 5: Proportional distribution of landed snapper catch by month and Statistical Area, 1989/90–2016/17 combined.

Within TBGB, snapper catch and snapper catch rates are highest in the inshore areas (within the 10–25 m depth range), although the depth distribution of the snapper catch extends to 50–60 m (Figure 6 and Figure 7). From 2013/14, the snapper catch was taken over a broader depth range (Figure 7).

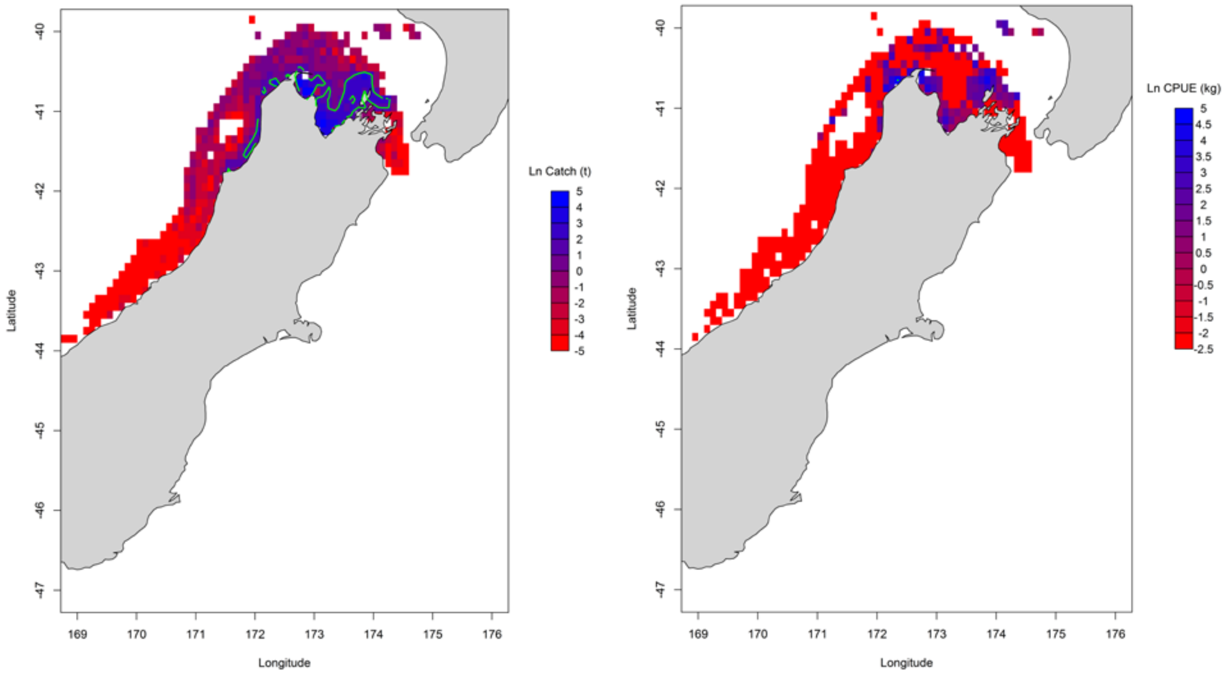

Figure 6: Total snapper single trawl catch (left) and median snapper catch per trawl (right) by 0.1 degree latitude/longitude, aggregated for 2007/08–2016/17 (logarithmic scale). The green contour line corresponds to an aggregate catch of 5 t.

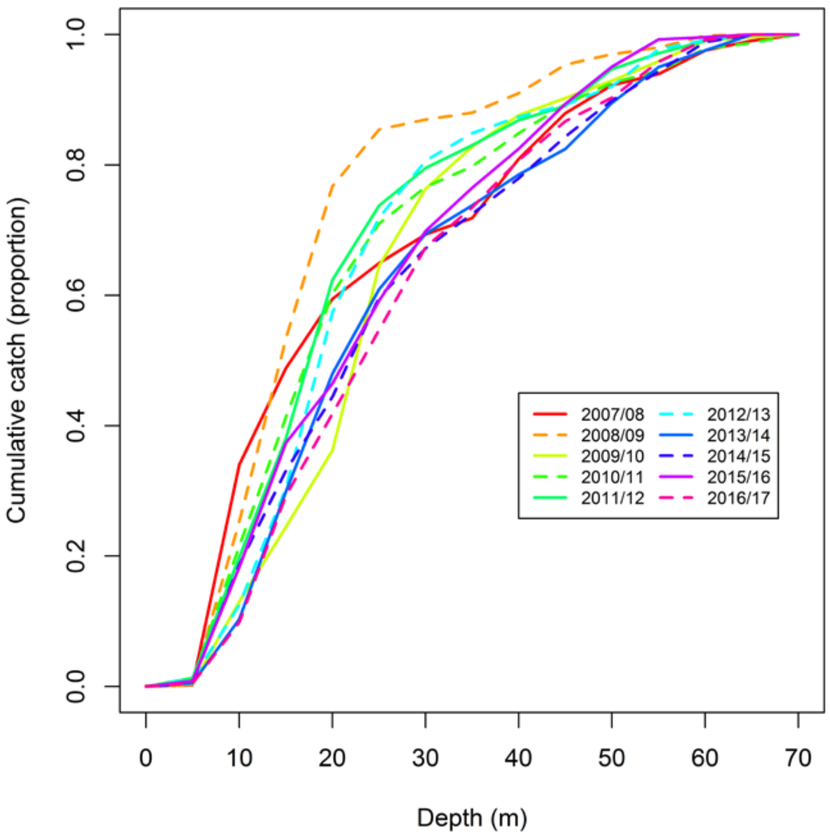

Figure 7: Cumulative distribution of the annual TBGB snapper catch by the single trawl method by 5 m depth intervals from 2007/08 to 2016/17 (Trawl based data set).

3 CPUE ANALYSIS

Standardised CPUE analyses were conducted for the TBGB single trawl fishery, following the previous analyses (Hartill & Sutton 2011, Langley 2013, 2015a) and extending the time-series of CPUE indices to include the 2016/17 fishing year. The primary CPUE analysis was based on the Daily aggregated data set. An additional analysis was conducted using the Trawl based catch and effort data (TCER format) to investigate the potential influence of changes in the spatial distribution (location and depth) of the fishery (during the 2007/08–2016/17 fishing years).

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

A Generalised Linear Modelling (GLM) approach was used to separately model the occurrence of snapper catches (presence/absence) and the magnitude of positive snapper catches. The dependent variable of the catch magnitude CPUE models was the natural logarithm of catch. For the positive catch CPUE models, a lognormal error structure was initially adopted, although alternative distributions (Weibull, Gamma) were also investigated. The presence/absence of snapper catch was modelled based on a binomial distribution.

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

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

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

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

Variable	Definition	Data type
Vessel	Fishing vessel category	Categoric
FishingYear	Fishing year	Categoric
Month	Month	Categoric (12)
Loc	Start location of trawl categorised by 0.1 degree latitude/longitude cell.	Categoric
TargetSpecies	Declared target species for trawl.	Categoric
Duration	Natural logarithm of trawl duration (hours)	Continuous
Depth	Fishing depth (m)	Continuous
StartTime	Hour at the start of trawl.	Continuous
Speed	Trawl speed (knots)	Continuous
GearWidth	Wingspread of trawl gear (m)	Continuous
GearHeight	Headline height of trawl gear (m)	Continuous
SNAcatch	Scaled estimated SNA trawl catch (kg).	Continuous
SNAbin	Presence (1) or absence (0) of SNA catch in trawl.	Categoric

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

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

The final (combined) indices were determined from the product of the positive catch CPUE indices and the binomial indices following the approach of Stefansson (1996). A recent local study highlighted the importance of incorporating both components in the derivation of the final indices, particularly for bycatch fisheries where the reporting of smaller catches may be variable (particularly over time) (Langley 2015b). The confidence intervals associated with the combined indices were determined using a bootstrapping approach.

The primary CPUE analysis was based on the Daily catch and effort data. The core fleet accounted for 87% of the snapper catch included within the defined fishery. The criteria resulted in the selection of 55 unique vessels including eight vessels that operated in the fishery for at least 20 years (Figure 8). Approximately half of the snapper catch included in the data set was taken by eight vessels.

The annual catch included in the Daily core vessel CPUE data set increased from the mid-2000s, while the proportion of effort records with no associated snapper catch declined (Figure 9, Appendix 1 Table A1). Almost all of the snapper catch was allocated to the daily aggregated fishing effort records based on the distribution of the estimated catches within individual fishing trips (Figure 9), although a considerable proportion (30–40% by number) of the positive catch records were allocated based on the distribution of fishing events amongst trips (i.e. those trips with no estimated catches of snapper). These records were dominated by flatfish target trawl records and the associated snapper catches were generally small (median catch of 4.3 kg). Overall, the average daily catch of snapper increased considerably between 2010/11 and 2011/12 and remained at the higher level during the subsequent years (to 2016/17) (Figure 10).

The number of trawls conducted per fishing day remained relatively stable throughout the study period, while there was an increase in the average trawl duration during the early 1990s (Figure 10). There was no appreciable change in either of the main fishing effort metrics corresponding with the introduction of the TCER reporting form in 2007/08.

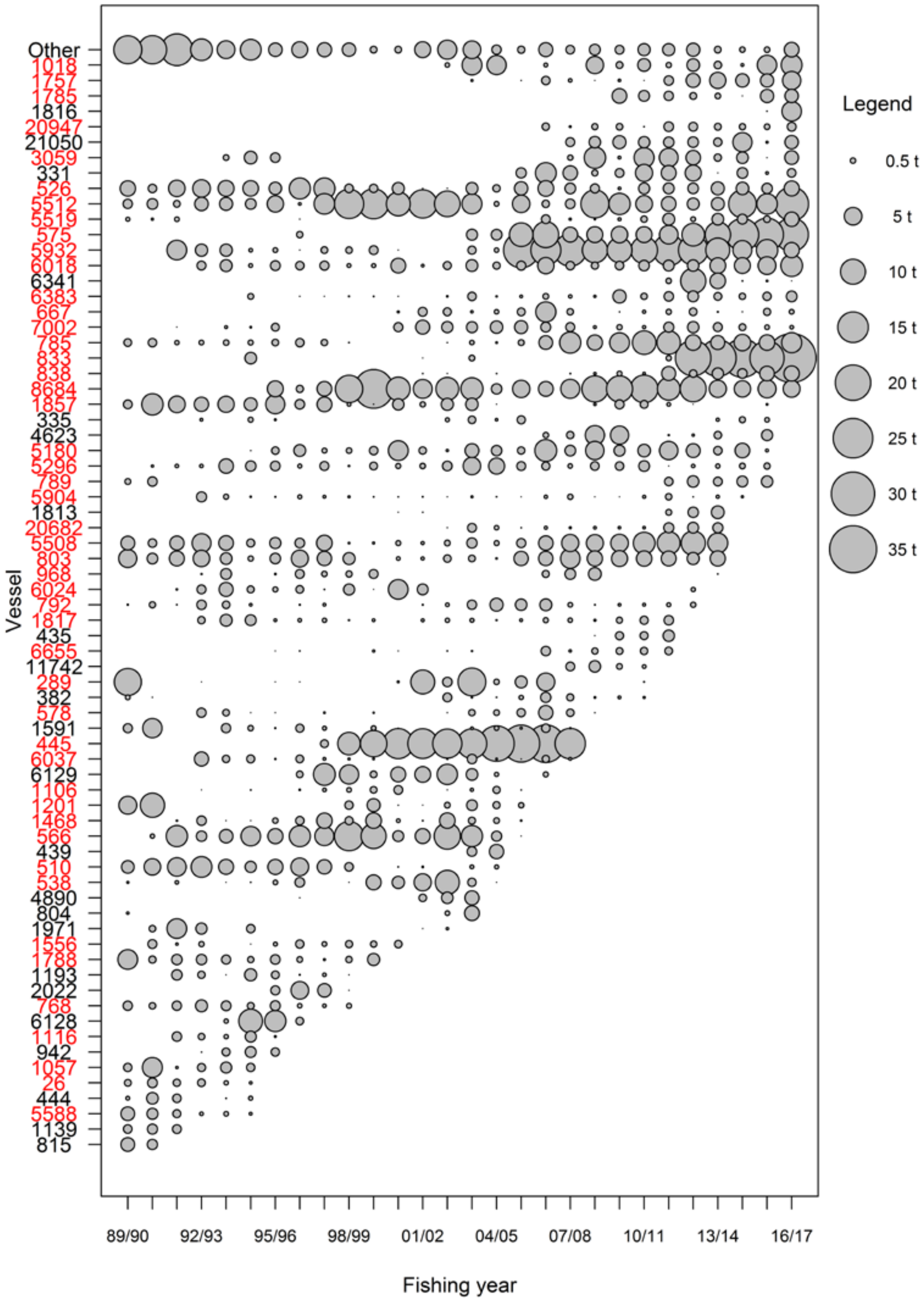

Figure 8: Distribution of TBGB snapper trawl catch by year and fishing vessel. The vessels comprising the core fleet included in the final Daily CPUE data set are highlighted in red.

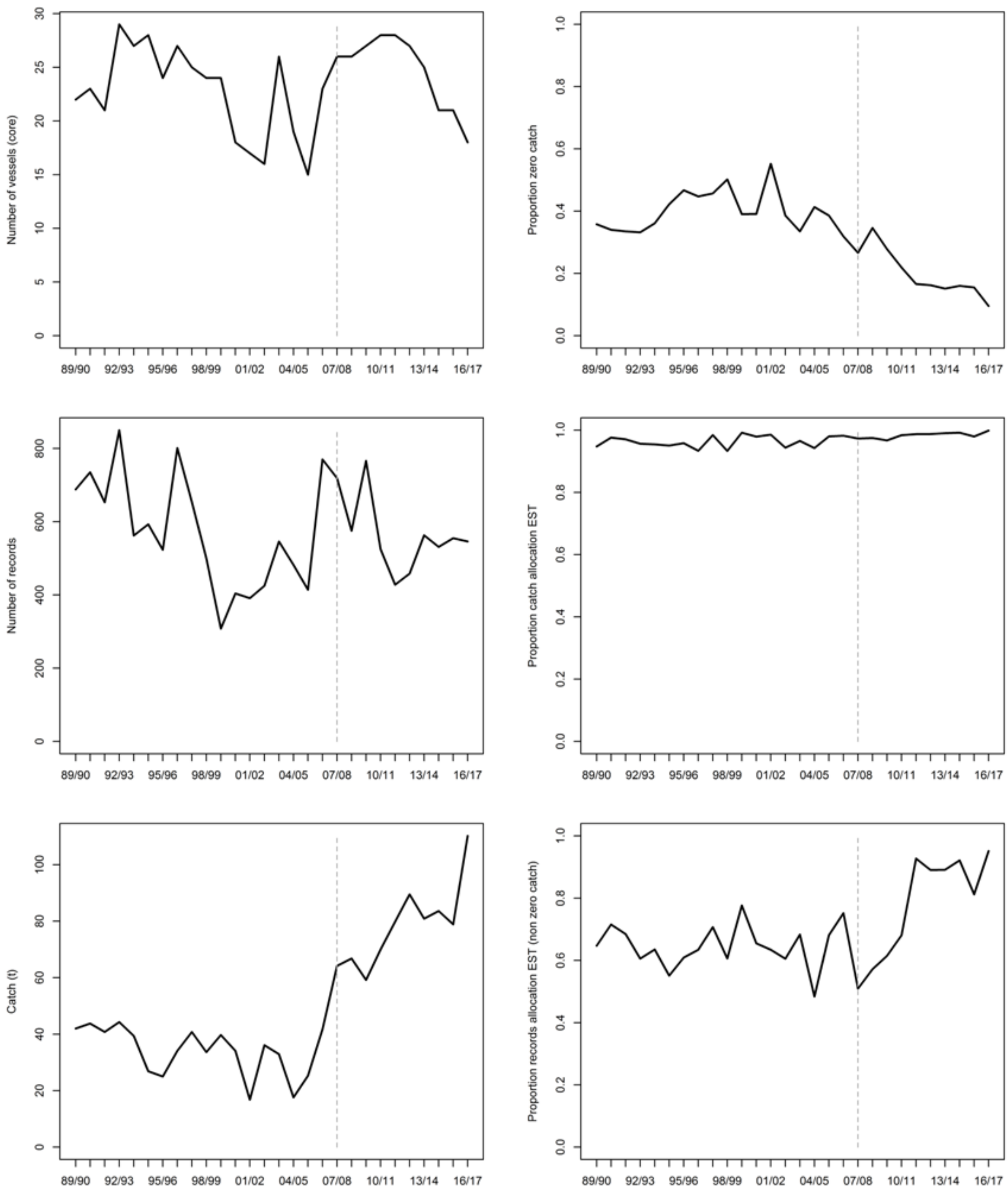

Figure 9: A summary of the data included in the core vessel data set by fishing year, including the proportion of the catch and effort records with snapper catches allocated based on the distribution of estimated snapper catch (rather than fishing effort). The dashed vertical line represents the year the TCER reporting form was introduced.

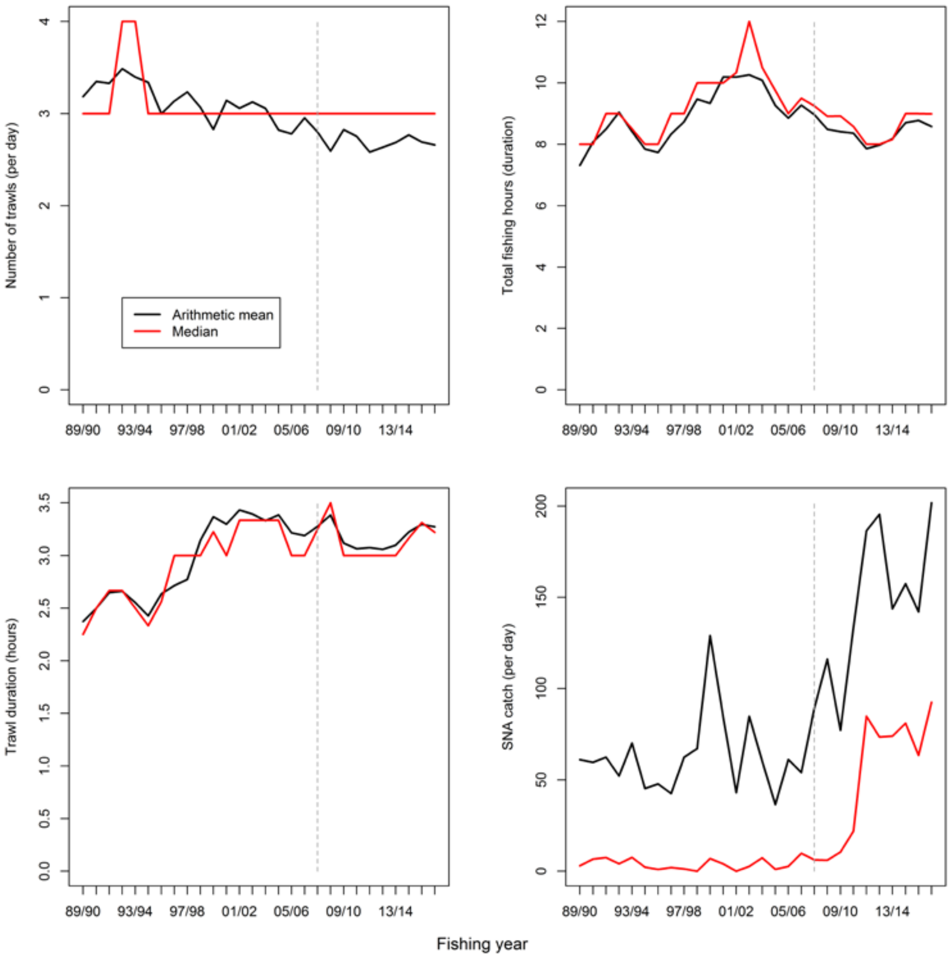

Figure 10: Annual trends in the main fishing effort and snapper catch rates (average and median) for the core vessel data set. The dashed vertical line represents the year the TCER reporting form was introduced.

For the analysis of the Daily data set, the dependant variable of the positive catch CPUE model was the natural logarithm of the snapper catch. The final model included the predictor variables *FishingYear*, *Vessel*, *TargetSpecies*, natural logarithm of *Duration*, *GearHeight* and the *Month:TargetSpecies* interaction term (Table 3). Overall, the model explained 40.1% of the variation in the positive catch of snapper (Nagelkerke pseudo-R^2), with the *FishingYear* variable accounting for 10.1% of the total variation. The distribution of the CPUE model residuals is generally consistent with the assumption of normality (Figure 11).

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

Term	DF	Log likelihood	AIC	Nagelkerke pseudo-R^2 (% Improvement)
FishingYear	27	-21 768	43 594	0.101 *
Vessel	54	-20 792	41 750	0.253 *
TargetSpecies	3	-20 154	40 479	0.338 *
Duration	3	-19 913	40 005	0.368 *
GearHeight	3	-19 869	39 923	0.373 *
GearWidth	3	-19 853	39 897	0.375
Month:TargetSpecies	24	-19 574	39 386	0.408 *

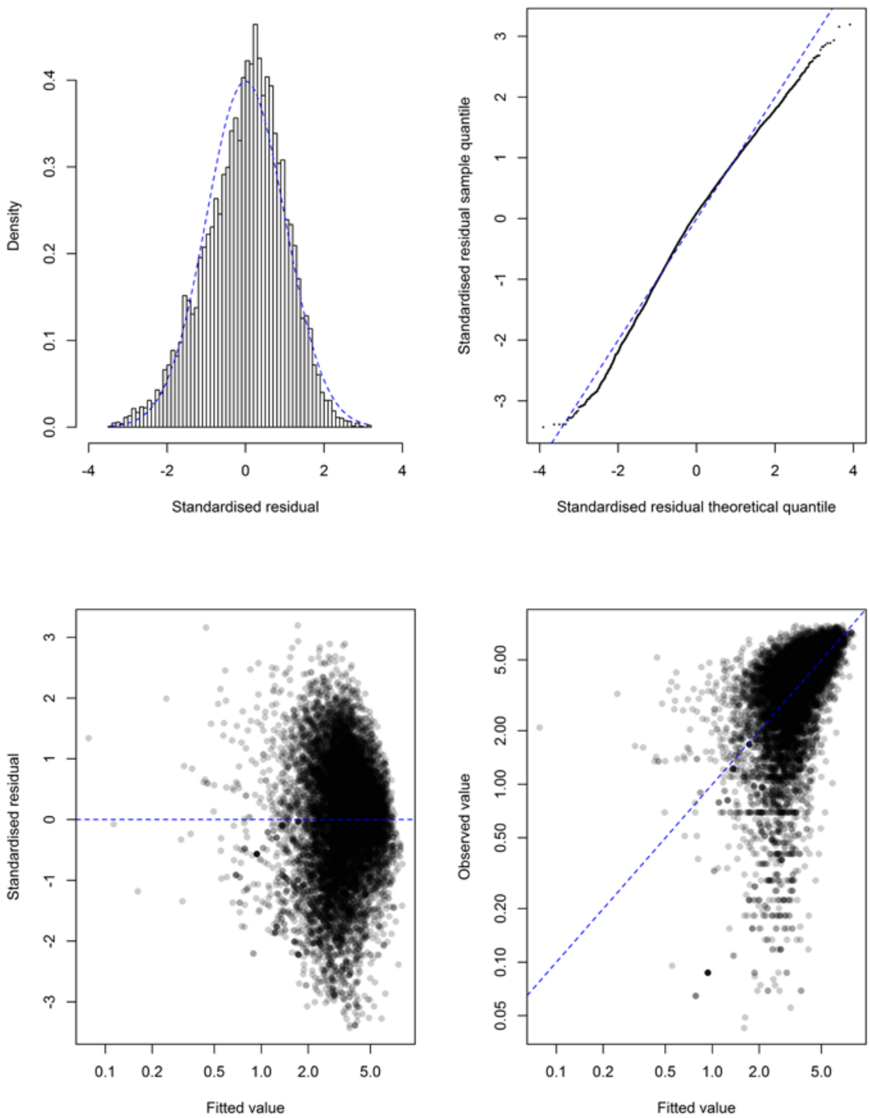

Figure 11: Residual diagnostics for the positive catch CPUE model for the Daily data set. Top left: histogram of standardised residuals compared to standard normal distribution. Bottom left: quantile-quantile plot of standardised residuals. Top right: fitted values versus standardised residuals. Bottom right: observed values versus fitted values.

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

The lognormal CPUE indices are relatively constant during 1989/90 to 2010/11, increase considerably in 2011/12 (by 382%) and remain at the higher level during the subsequent years (Figure 12). The trend in the lognormal CPUE is comparable to the unstandardised (nominal) CPUE from the fishery, although the increase in the recent CPUE indices is more pronounced, primarily due to the inclusion of the *Vessel* and *EffortHeight* variables in the model. From 2011/12, there was an increase in the relative proportion of fishing effort by individual vessels with a lower overall catch rate of snapper (Figure 13, Appendix 1 Figure A1). During the same period, there was an increase in the proportion of effort records from trawls with a lower headline height (*EffortHeight*) which are predicted to yield lower catch rates of snapper (Figure 13, Appendix 1 Figure A4).

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

Term	DF	Log likelihood	AIC	Nagelkerke pseudo-R^2 (% Improvement)
FishingYear	27	-9 614	19 283.4	0.081 *
Vessel	54	-9 359	18 881.6	0.122 *
Duration	3	-9 351	18 871.1	0.123
GearHeight	3	-9 334	18 843.0	0.126
Month:TargetSpecies	28	-8 918	18 066.3	0.190 *

An examination of the residuals from the Daily lognormal CPUE model revealed that the annual CPUE trends are comparable amongst the individual *Target Species*, *Month* and the main *Vessel* categories (Appendix 1 Figures A5–A7).

The annual indices derived from the Daily binomial model were generally comparable to the annual proportion of positive catch records. The binomial indices declined during the 1990s and increased steadily from the early 2000s (Figure 12).

The final (combined) CPUE indices were comparable to the trend in the lognormal CPUE indices, although the increase in the indices from 2010–11 was more pronounced due to the influence of the recent binomial indices (Figure 12).

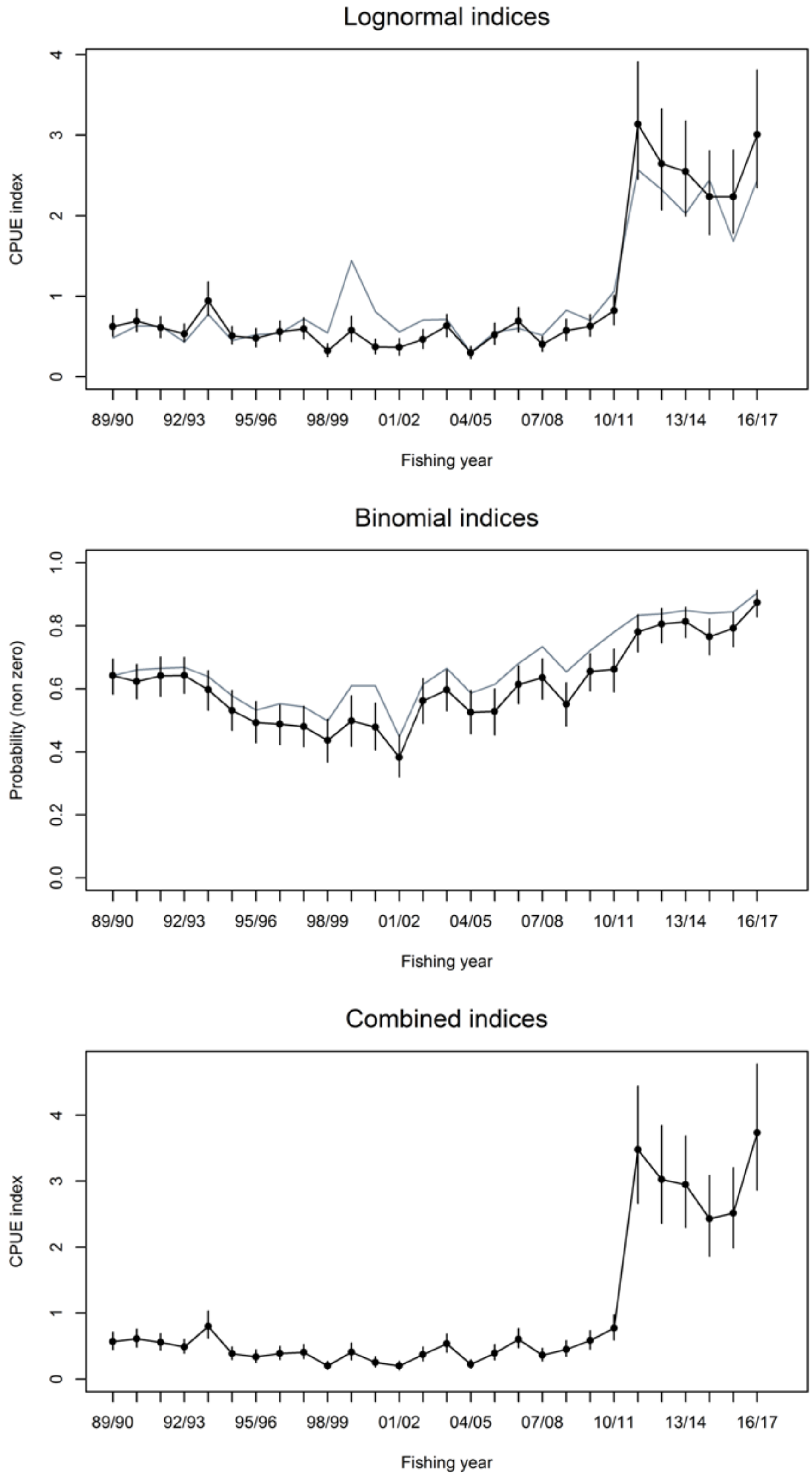

Figure 12: A comparison of the standardised CPUE indices and the geometric mean of the annual catch per day (grey line) (top panel), a comparison of the binomial indices and the annual proportion of positive catch records (grey line) in the data set (middle panel) and the combined index (bottom panel) . The error bars represent the 95% confidence intervals associated with each index. The annual indices are provided in Table A2 (Appendix 1).

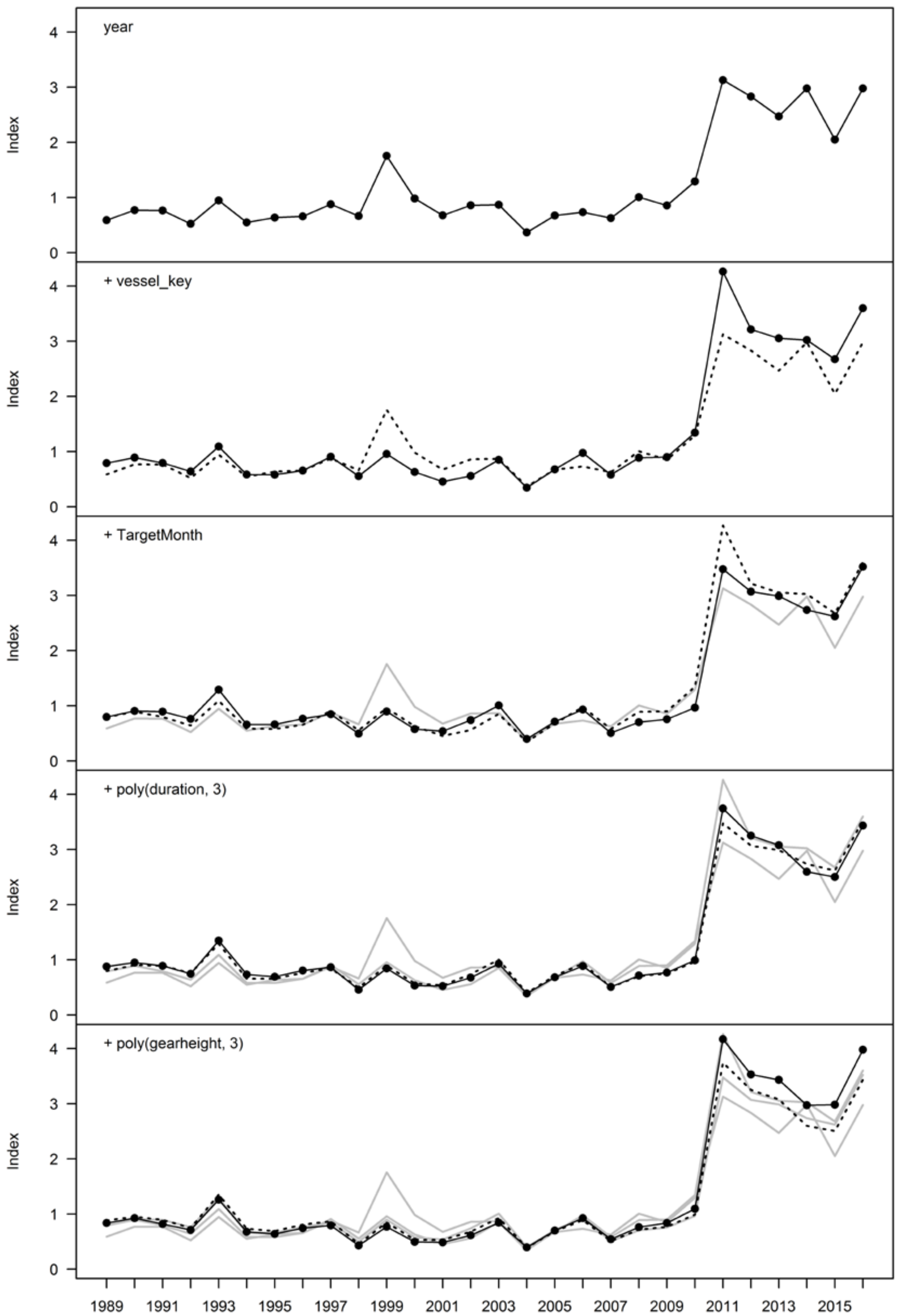

Figure 13: The change in the annual coefficients with the step-wise inclusion of each of the significant variables in the positive catch CPUE model for the Daily data set (from top to bottom panel). The solid line and points represent the annual coefficients at each stage. The fishing year is denoted by the calendar year at the beginning of the fishing year (e.g. 1989 denotes the 1989/90 fishing year).

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

The resulting combined (delta-lognormal) CPUE indices were similar to the combined Daily CPUE indices for the corresponding period (2007/08–2016/17) (Figure 14), although the magnitude of the increase in CPUE indices between 2010/11 and 2011/12 was slightly lower for the Trawl based indices.

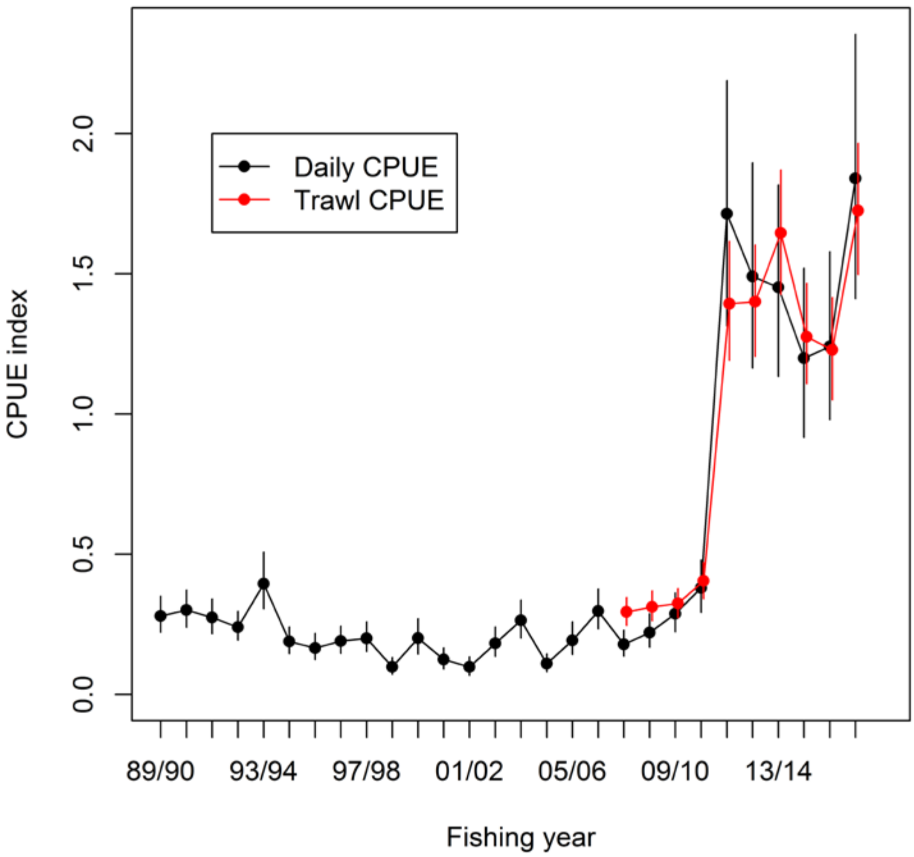

Figure 14: A comparison of the combined Daily and combined Trawl based CPUE indices (and associated 95% confidence intervals).

The residuals from the Trawl based lognormal CPUE indices revealed differential trends in relative CPUE amongst areas of TBGB partitioned by depth (10 m depth categories). The CPUE data set is dominated by trawls in the 10–19 m and 20–29 m depth categories and the overall CPUE indices are consistent with the trends in relative CPUE from these two areas (Figure 15). By comparison, the shallower areas (0–9 m depth) revealed a somewhat larger increase in relative CPUE during 2010/11–2011/12 and a decline in CPUE over the more recent years. In contrast, the snapper CPUE from the deepest area of TBGB remained at a lower level throughout 2007/08–2012/13 and then increased considerably during 2013/14–2016/17 (Figure 15). The relative increase in CPUE in the deeper area was greater than the increase in the overall CPUE indices, although absolute catch rates of snapper in the area remained lower than for the core area of the fishery. These results suggest a seaward expansion of the SNA 7 population as the strong year class grew older, perhaps resulting in a disproportionate increase in CPUE (relative to biomass) in water deeper than 40 m.

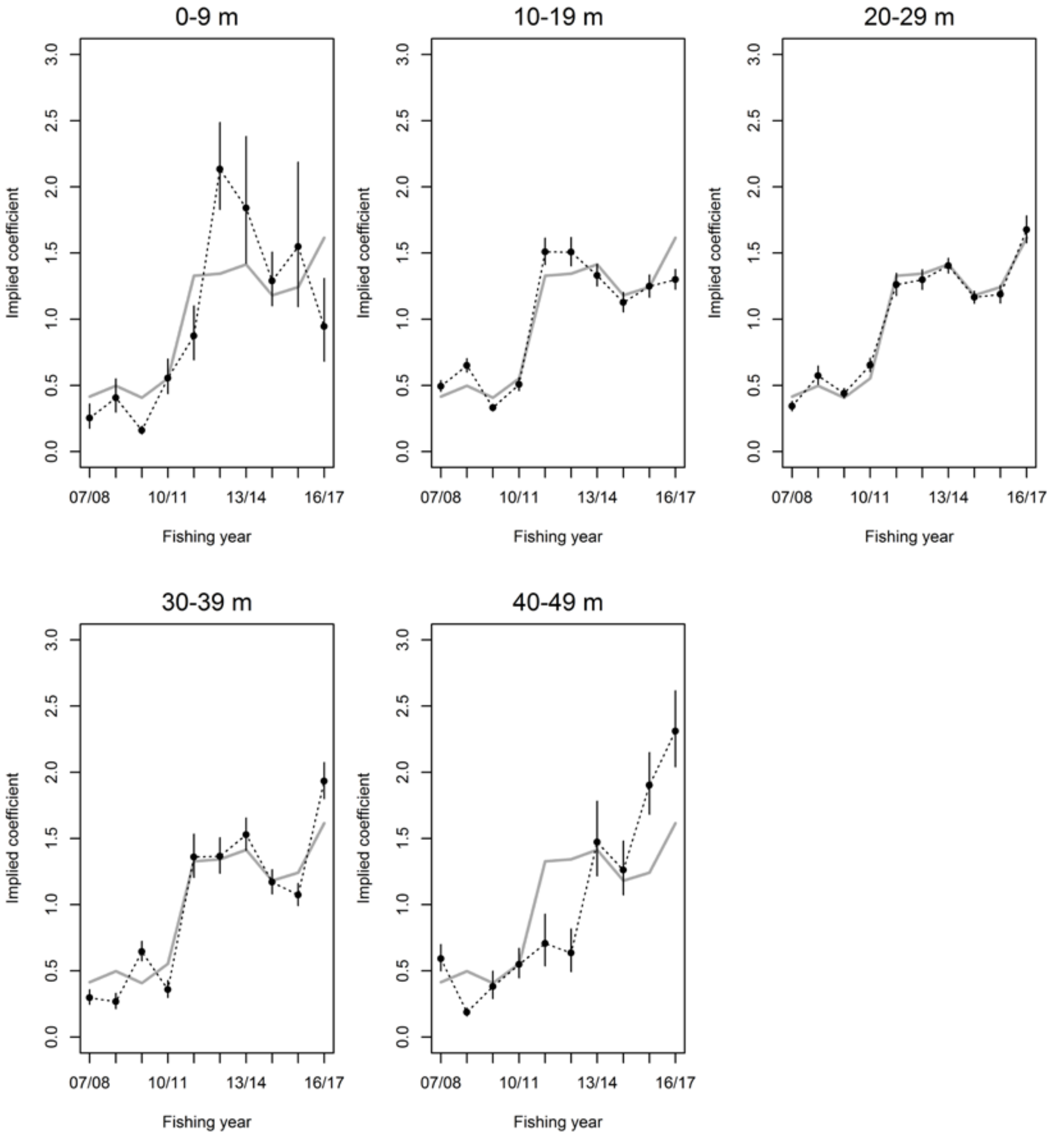

Figure 15: A comparison of the Trawl based lognormal CPUE indices (grey line) and the annual implied coefficients for each 10 m depth category derived from the residuals of the CPUE model (points). Each series is normalised to the average of the series.

4 STOCK ASSESSMENT

The 2018 stock assessment modelling was based on the configuration of the 2015 stock assessment model (Langley 2015a) and updated to include additional data from 2015/16 and 2016/17 fishing years. The assessment model integrates annual catch, an estimate of absolute biomass from the 1987 TBGB tagging programme, trawl CPUE indices, and age and size composition data.

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

Additional data, apart from catch and CPUE, available for inclusion in the current assessment include the 2016/17 commercial age composition, length compositions from the recreational catch and an age composition from the 2017 *Kaharoa* trawl survey.

4.1 Commercial catch

Commercial catch data are available for the SNA 7 fishery from 1931 to the 2016/17 fishing year. The time-series of annual reported commercial catches were derived from MPI (2017).

The model data set was configured to include two main commercial fisheries: a single trawl fishery (BT) and a pair trawl fishery (BPT). The SNA 7 catch taken by the purse-seine method during the late 1970s and early 1980s was assigned to the pair trawl fishery, as both methods are considered to harvest the full range of adult age classes in the population (Figure 16).

The reported commercial catches from 1931–1986 were increased by 20% to account for an assumed level of under-reporting. Since the introduction of the Quota Management System (QMS), the accuracy of the reporting of commercial catches has improved considerably, although a degree of under-reporting may persist. For 1987–2016, reported catches were increased by 10% to account for the assumed level of under-reporting in the more recent period. These assumptions are consistent with the formulation of the commercial catch histories incorporated in other inshore finfish stock assessments (based on assumptions for SNA 1 made according to quota appeals when the QMS was first introduced).

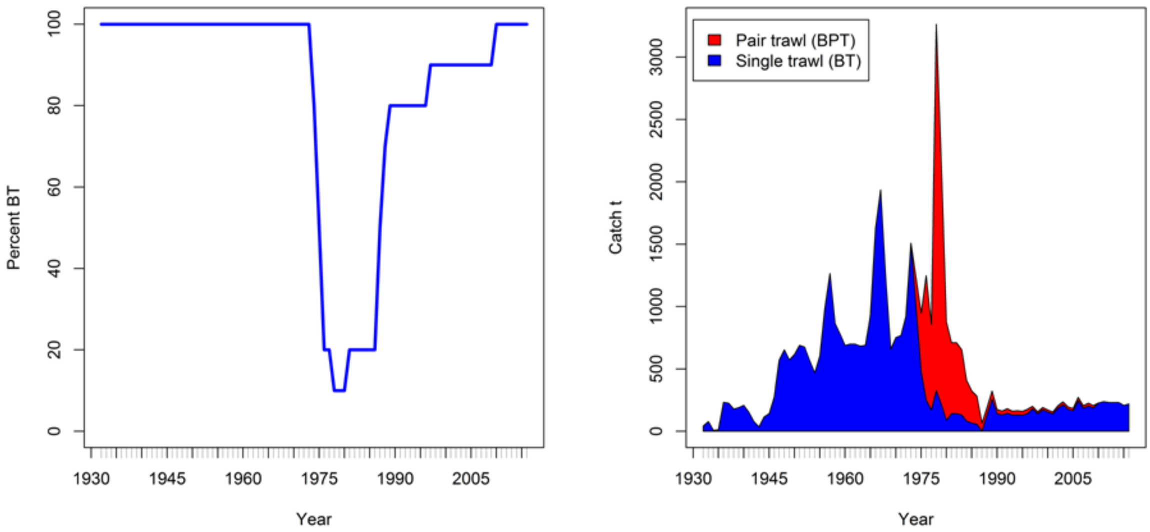

Figure 16: The proportion of the total SNA 7 catch allocated to the BT fishery by year (left panel) and the total annual commercial catch by fishing method (right panel), including an allowance for unreported catches.

4.2 Non-commercial catch

The model included a non-commercial fishery that encompasses catches from the recreational and customary sectors. The catch history for the non-commercial fishery was derived following the approach used in Langley (2015a) updated to include an additional estimate of recreational catch from 2015/16 (Hartill et al. 2017). The approach is detailed in the following steps:

i. Recreational catch (point) estimates from the SNA 7 tagging programme (1987 15 t), aerial over flight (2005/06 42.6 t), panel (2011/12 88 t), and aerial access (2015/16 83.1 t) surveys were used to determine the annual non-commercial catch in specific years. Previous telephone/diary estimates of recreational catch are considered unreliable and were disregarded (MPI 2017) (Figure 17).

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

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

iv. The non-commercial exploitation rate (from iii) for 2005 was considerably higher than 1987. It was assumed that there was a linear increase in the annual exploitation rate from 1987 to 2005.

The annual recreational catch in those intervening years was determined by multiplying the annual ER by the annual estimate of recruited biomass from the preliminary assessment model (ii. above).

v. Similarly, the recreational exploitation rate was interpolated between the successive recreational catch estimates in 2005 and 2011 and between 2011 and 2015 to derive the annual recreational catches for the intervening years.

vi. The non-commercial exploitation rate in 2016 was assumed to be equivalent to the 2015 level, yielding a similar estimate of recreational catch for the two years (Figure 17).

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

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

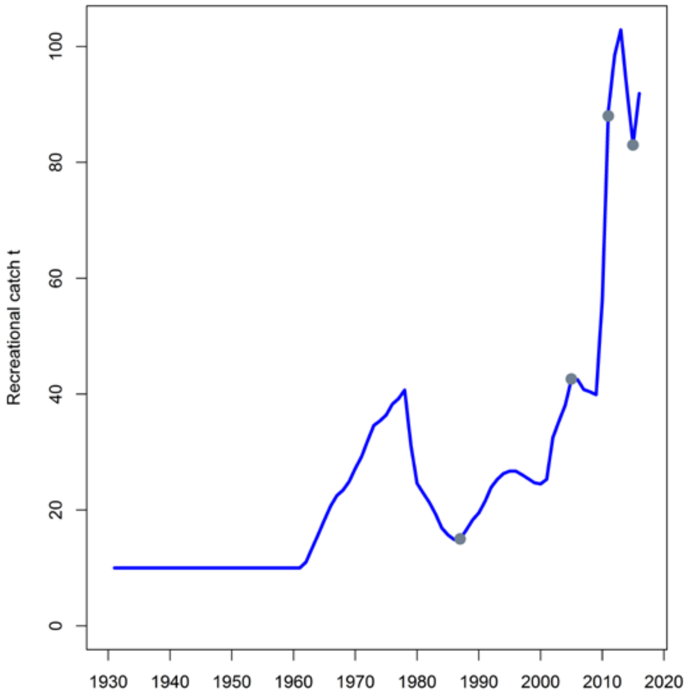

Figure 17: Annual non-commercial catch from SNA 7 included in the stock assessment model. The grey points represent individual estimates of recreational catch for SNA 7 (see text for details).

4.3 Tagging programme data

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

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

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

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

4.4 Age composition data

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

The age composition from the 2016/17 trawl fishery was dominated by 6 and 9 year old fish, corresponding to the 2010 and 2007 year classes, respectively (Figure 18).

Table 5: A summary of the age composition data from the SNA 7 commercial fishery.

Fishing season	Model year	No. Otoliths	No. landings	Comments, source	Fishery assignment
1974/75	1974	85	1	Additional landings sampled during Apr-Jun, not included.	BPT
1978/79	1978	295	4	Otoliths collected from 4 landings. Additional length sampling of BPT and PS landings.	BPT
1979/80	1979	84	1	Otoliths collected from 1 BPT trip. Additional length sampling of 19 landings, mostly BPT.	BPT
1980/81	1980	348	4	Otoliths collected from BPT (2), PS (1) and BT (1). Additional (19) landings sampled for length.	BPT
1983/84	1983	265	2	Otoliths collected from two BPT landings. Six landings sampled for length.	BPT
1992/93	1992	364	NA	Harley & Gilbert (2000)	BT
1997/98	1997	1 439	47	Blackwell et al. (1999)	BT
1998/99	1998	913	34	Blackwell et al. (2000)	BT
1999/00	1999	1 004	56	Blackwell & Gilbert (2001).	BT
2000/01	2000	1 035	60	Blackwell & Gilbert (2002).	BT
2003/04	2003	1 007	59	Blackwell & Gilbert (2005).	BT
2006/07	2006	1 007	60	Blackwell & Gilbert (2008).	BT
2013/14	2013	848	21	Parker et al. (2015).	BT
2016/17	2016	1440	27	Parsons et al. (2018).	BT

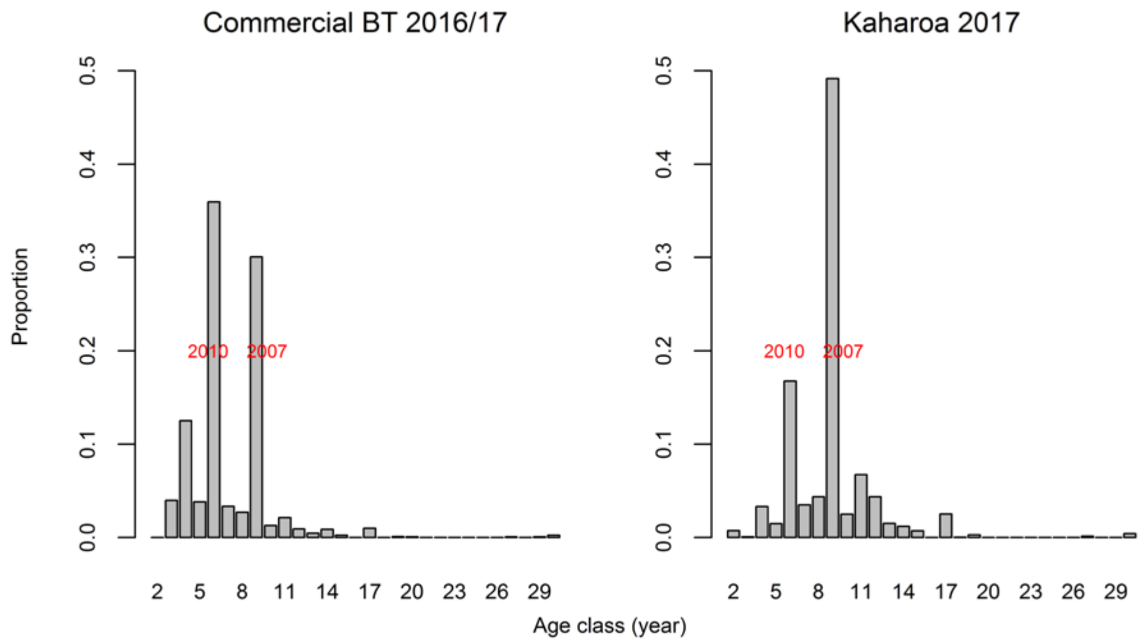

Figure 18: A comparison of the snapper age compositions from the 2016/17 bottom trawl fishery (left) and the 2017 *Kaharoa* trawl survey (right). The age classes corresponding to the strong 2007 and 2010 year classes are labelled.

4.5 Commercial size grading data

A large proportion of the total annual commercial catch from SNA 7 is processed by Talley Group Ltd in Motueka. A considerable proportion (45–70%) of this component of the landed catch is graded by fish size and packed in 10 kg cartons. The five grading categories are based on the number of fish packed in each carton (2–5 fish, 6–7 fish, 8–15 fish, 16–25 fish and 26+ fish). The minimum average fish weight in each size grade was determined based on the maximum number of fish packed in the grade; e.g. for the 8–15 count grade a minimum fish weight of 0.67 kg was assumed.

Commercial grading data were available from 2004/05–2016/17. The proportion of the annual graded catch (in weight) in each size grade was determined to generate a weight frequency distribution (i.e. proportion of the catch by weight in each of the five fish weight grades).

Previous analysis of the commercial grading data revealed strong trends in the composition of the catch (Langley 2013, 2015a). These trends were generally consistent with the corresponding age composition data derived from the catch sampling programmes. On that basis, it was considered that the commercial grading data provided information regarding the general size composition of the stock, albeit in a relatively coarse format. The commercial size grading data were assumed to be representative of the size composition of the catch from the BT fishery as the method dominated the total landed catch during the data period.

4.6 Recreational length compositions

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

The samples collected during 2005/06 and 2011/12 were dominated by fish caught by rod-and-line (approx. 95%) and catches were predominantly comprised of 27–35 cm (F.L.) fish (Figure 19). A broader length range of fish was caught in 2015/16 and 2016/17. This corresponded to an increase in the proportion of the sampled fish being taken by longline (41% in 2015/16 and 52% in 2016/17). In each year, the longline caught fish were generally larger than fish caught by rod-and-line (Hartill et al. 2017).

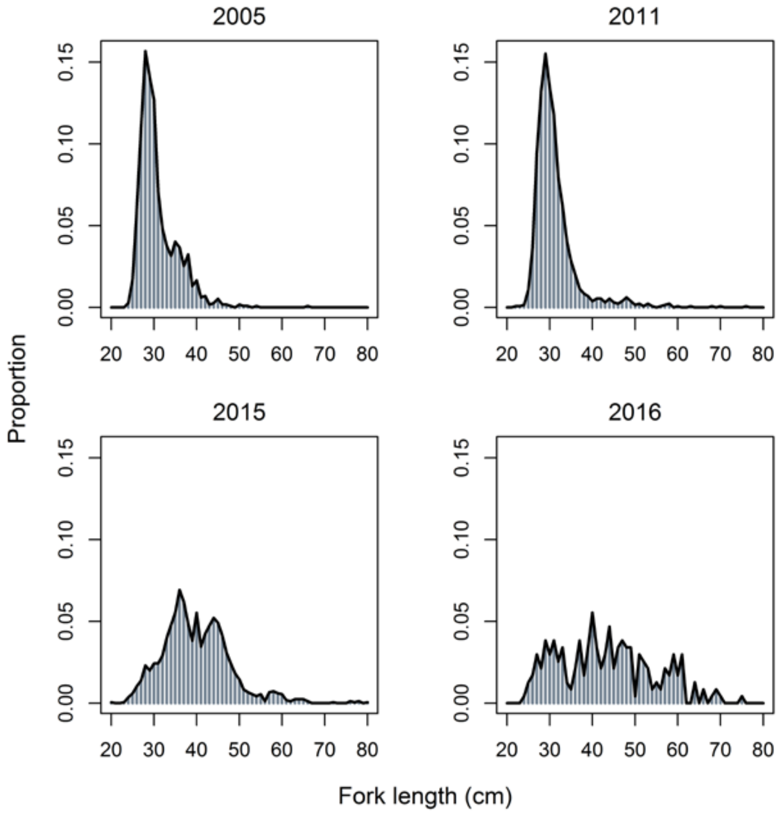

Figure 19. Length compositions of SNA 7 recreational catches by model year (e.g. 2005 represents the 2005/06 fishing year).

4.7 Trawl survey age composition (2017)

Since 1992, a time-series of inshore trawl surveys has been conducted off the west coast South Island and in Tasman/Golden Bay within the 20–70 m depth range (Stevenson & Hanchet 2000, MacGibbon & Stevenson 2013, Stevenson & MacGibbon 2015). Trawl surveys are conducted during March–April and the most recent survey was conducted in 2017 (i.e. the 2016 model year) (Stevenson & MacGibbon 2018).

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

The 2017 trawl survey estimated a relatively high biomass of snapper within TBGB with a moderate level of precision (CV 17%). The corresponding length composition was dominated by fish in the 35–55 cm length range and was comparable to the length composition sampled from the trawl fishery during 2016/17 (Parsons et al. 2018), indicating that the trawl survey had sampled the recruited component of the snapper population within TBGB. The randomised design of the survey means that the resulting length composition data are likely to be more representative of the overall population size composition than the sampling from the commercial fishery (i.e., less likely to be biased by the non-random distribution of fishing by the commercial fishery, especially when targeting other species, e.g. flatfish).

An age composition was derived from the scaled trawl survey length composition by applying an age-length-key obtained from the otoliths collected during sampling of the 2016/17 commercial catch. The resulting trawl survey age composition was similar to the age composition from the commercial catch, although the 2007 year class was more dominant in the trawl survey age composition (Figure 18).

4.8 Assessment Model Configuration

The assessment modelling was conducted using the Stock Synthesis (SS) software (version 3.24Z), a flexible platform for implementing statistical, age structured population models (Methot 2013, Methot & Wetzell 2013).

Overall, the structure of the 2018 assessment model is similar to the previous (2015) assessment. The assessment model included the entire SNA 7 catch history (from 1931) and assumed that the initial population age structure was in an equilibrium, unexploited state. The population was structured by sex and included 30 age classes, the oldest age class representing an aggregated “plus” group (30 years and older). The model data period extended to the 2016 year (2016/17 fishing year).

The key biological parameters for the SNA 7 stock assessment are presented in Table 6. Following previous assessments, natural mortality (*M*) was assumed to be 0.075 for the base model options. Von Bertalanffy growth parameters for SNA 7 are provided in MPI (2017). There is no evidence of sexual dimorphism in snapper growth and the growth parameters have been determined for both sexes combined. Growth parameters were assumed to be temporally invariant. An examination of length-at-age from six otolith collections (1978, 1979, 1980, 1983, 2006 and 2016) did not reveal an appreciable difference in growth rates between the samples. These otolith collections were also used to determine the variation in length-at-age; approximated by a constant CV of 7.5% of the mean length at age. Maturity was assumed to be age-specific with all fish reaching sexual maturity at age 3 years.

The model was structured with an annual time-step comprised of two seasons (October–January and February–September). The seasonal structure partitions the main spawning period and commercial catch (season 1). Spawning is assumed to occur instantaneously at the start of the year and recruitment is a function of the spawning biomass at the start of the year. A Beverton-Holt spawning stock-recruitment relationship (SRR) was assumed with steepness (*h*) fixed at 0.90 for the base assessment model. Recruitment deviates (1950–2012) from the SRR were estimated assuming a standard deviation of the natural logarithm of recruitment (σ_R) of 1.5. This represents a high level of recruitment variability that is consistent with the high variation in the strength of individual year classes in the SNA 7 age composition data sets. The value of σ_R was informed from the results of a likelihood profile of this parameter in the 2015 assessment (Langley 2015a).

The model was configured to encompass three fisheries: single trawl (BT), pair trawl (BPT) and non-commercial. Age composition data are available from the single trawl fishery (9 observations), pair trawl fishery (5 observations) and 2016/17 *Kaharoa* trawl survey (Table 7). For all age compositions there was assumed to be no error associated with the age determination.

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

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

The age composition from the 2016/17 *Kaharoa* trawl survey was fitted in the model using a separate age-specific, logistic selectivity function (Table 6).

The commercial grading data are assumed to be representative of the weight composition of the catch from the BT fishery. The predicted weight frequency distribution is derived from the fishery age-specific selectivity converted to a length composition based on the VB growth parameters and variation of length-at-age composition and converted to a weight composition (based on the length-weight relationship) (Methot & Wetzell 2013).

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

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

Component	Parameters	Value, Priors	
Biology	*M*	0.075	Fixed
	VB Growth	*k* = 0.122, *Lmax* = 69.6 cm	Fixed
	CV length-at-age	0.075	Fixed
	Length-wt	*a* = 4.4467e-005, *b* = 2.793	Fixed
	Maturity	0.0 ≤2 yr, 1.0 ≥3 yr	Fixed
Recruitment	Ln*R0*	Uniform[0-10]	Estimated (1)
	B-H SRR steepness *h*	0.90	Fixed
	SigmaR *σR*	1.5	Fixed
	Recruitment deviates	Lognormal deviates (1950–2012)	Estimated (63)
Selectivity			
BT fishery	Logistic parameterisation		Estimated (2)
	p1 – age at inflection	Norm(4,2.0)	
	p2 – width for 95% selection	Norm(1,0.5)	
BPT fishery	Logistic parameterisation		Estimated (2)
	p1 – age at inflection	Norm(4,2.0)	
	p2 – width for 95% selection	Norm(1,0.5)	
Trawl survey	Logistic parameterisation		Estimated (2)
	p1 – age at inflection	Norm(4,2.0)	
	p2 – width for 95% selection	Norm(1,0.5)	
Non comm fishery	Double Normal		Estimated (5)
	p1 – length at peak	Norm(30,5)	
	p2 – width of peak	Fixed (-3)	
	p3 – width of ascending limb	Norm(2,2)	
	p4 – width of descending limb	Norm(4.5,3)	
	p6 – selectivity at max length	Norm(-5,5)	
	p4 – dev time block 2	No prior	
Abundance			
CPUE indices	*CPUEq*	Nuisance parameter	Estimated (1)
Tag biomass	Catchability *TAGq*	1.0 (fixed)	Fixed (1)

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

The main data inputs were assigned relative weightings based on the approach of Francis (2011). This followed a two-step procedure: the first step was to fit the single trawl CPUE indices in the assessment model with all the age composition data down-weighted (Effective Sample Size ESS of 1). The SDNR from the fit to the CPUE indices was used to determine the CV for all the individual CPUE observations (CV 25%) (Table 7).

The second step of the fitting procedure was to rerun the model with the revised CPUE CV and determine the fleet/fishery specific ESS for the age composition data sets. The approach used Method TA1.8 of Francis (2011) to provide an indicative overall ESS for each fleet. The fleet specific ESSs were approximately 10 and 8.5 for the BT and BPT age composition data sets, respectively, and an ESS of 8 for the BT commercial size grade data. The single trawl survey age composition was assigned an ESS of 10.

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

Table 7. Summary of input data sets for assessment model. The relative weighting includes the Effective Sample Size (ESS) of age/size composition data and the coefficient of variation (CV) associated with the abundance data. The Commercial size grade data were excluded from the final model options.

Data set	Model year(s)	Nobs	Relative weighting
BT CPUE indices (Oct-May)	1989–2016	28	CV 25%
BPT age comp	1974, 1978, 1979, 1980, 1983	5	ESS 8.5
BT age comp	1992, 1997, 1998, 1999, 2000, 2003, 2006, 2013, 2016	9	ESS 10
Tag biomass	1987	1	CV 30%
Commercial size grade	2004–2016	13	ESS 8
Trawl survey age comp	2016	1	ESS 10
Recreational length comp	2005, 2011, 2015, 2016	4	ESS 1

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

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

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

During the development of the 2018 assessment model, a range of model options were investigated that varied the relative weighting of the recent data sets (BT age composition, grade data, and CPUE indices). The recent trends in biomass were relatively insensitive to the treatment of the individual data sets, although increasing the weighting of the BT age and grade composition data relative to the CPUE indices resulted in a slightly more optimistic estimate of current stock status (and vice versa). The inclusion of both the BT age and grade composition data was effectively duplicating the composition data from the BT fishery and, on that basis, the grade composition data were excluded from the model likelihood, effectively removing the influence of these data from the model estimation procedure.

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

Stock status was determined relative to the equilibrium, unexploited spawning (mature) biomass of female fish (SB_0). Current biomass was defined as the biomass in the 2016 model year (2016/17 fishing year) ($SB_{current}$ or SB_{2016}).

Following the MPI Harvest Strategy Standard (HSS), current biomass was assessed relative to the default soft limit of 20% SB_0 and hard limit of 10% SB_0 (Ministry of Fisheries 2008). The HSS includes a default target biomass level of 40% SB_0 for stocks with low productivity where an operational ("real world") SB_{MSY} has not been fully evaluated. The Inshore Fishery Assessment Working Group accepted 40% SB_0 as an appropriate SB_{MSY} proxy for SNA 7. Current stock biomass is reported relative to the default target biomass level ($SB_{40\%}$) and current levels of fishing mortality are reported relative to the level of fishing mortality that result in $SB_{40\%}$ under equilibrium conditions (i.e. $F_{SB40\%}$). The reference level of age specific fishing mortality is determined from the composite age specific fishing mortality from the last year of the model data period (2016/17). Estimates of equilibrium yield are determined from the level of fishing mortality that produces the target biomass level ($F_{SB40\%}$).

4.9 Model results

A base assessment model was selected that provided a reasonable fit to all the main data inputs and estimated key parameters that were consistent with the general understanding of the operation and performance of the fishery. The following sections primarily report the results from the base model. In addition, a limited number of model sensitivity runs were conducted to encompass the main sources of uncertainty in the stock assessment.

4.9.1 Parameter estimation

Priors were formulated for fishery selectivity parameters based on a qualitative examination of the age composition data (i.e. age at recruitment and the proportion of older fish in the samples). Relatively uninformative, normally distributed priors were adopted for the selectivity parameters for the BT fishery (logistic), BPT fishery (logistic) and *Kaharoa* trawl survey (logistic) (Figure 20).

For the BT and BPT fisheries, the data are relatively informative regarding the age at 50% selection (p1), while the data are less informative regarding the steepness of the selectivity function (p2), particularly for the BPT fishery (Figure 20). Fish are estimated to be fully selected at age 4 years for BT and 6 years for BPT (Figure 21).

For the *Kaharoa* trawl survey selectivity function, the single age composition is relatively uninformative regarding the estimation of the two parameters of the logistic function (Figure 20) and the selectivity of the youngest age classes was poorly determined (Figure 21). The model estimated full selectivity at about 4–6 years.

The selectivity of the recreational fishery increases sharply from the Minimum Legal Size (MLS) of 25 cm (FL) and full selectivity is reached at 28 cm (Figure 22). For the period prior to 2013, the fishery is estimated to predominantly select fish from a relatively small length range of 28–35 cm. In the subsequent period (2013–2016), a broader selectivity function is estimated, with the descending limb of the function extending to include fish up to 60–80 cm (Figure 22).

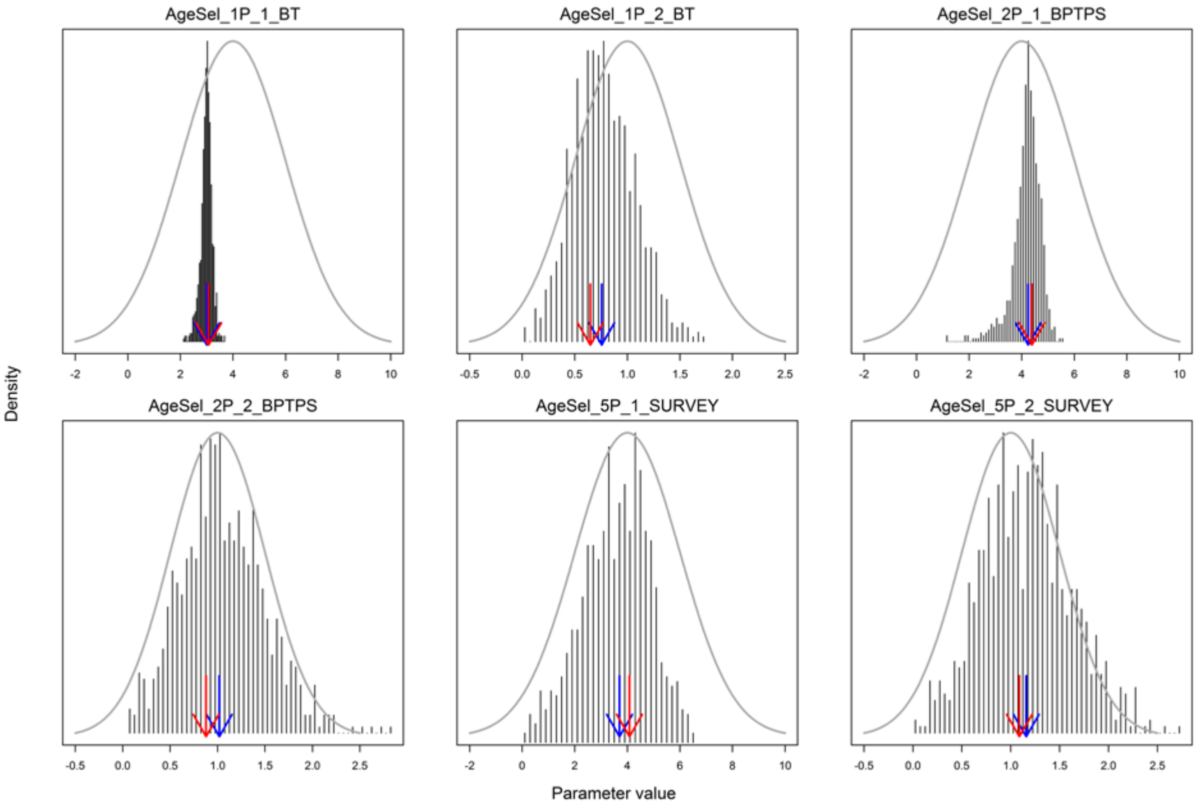

Figure 20: Prior distributions (solid line) and estimated probability distributions derived from McMC (histograms) for the estimated age based selectivity parameters of the base model (bottom trawl, BT; bottom pair trawl, BPTPS; trawl survey, SURVEY). The median of the McMCs (blue arrows) and MPD estimates (red arrows) are also presented.

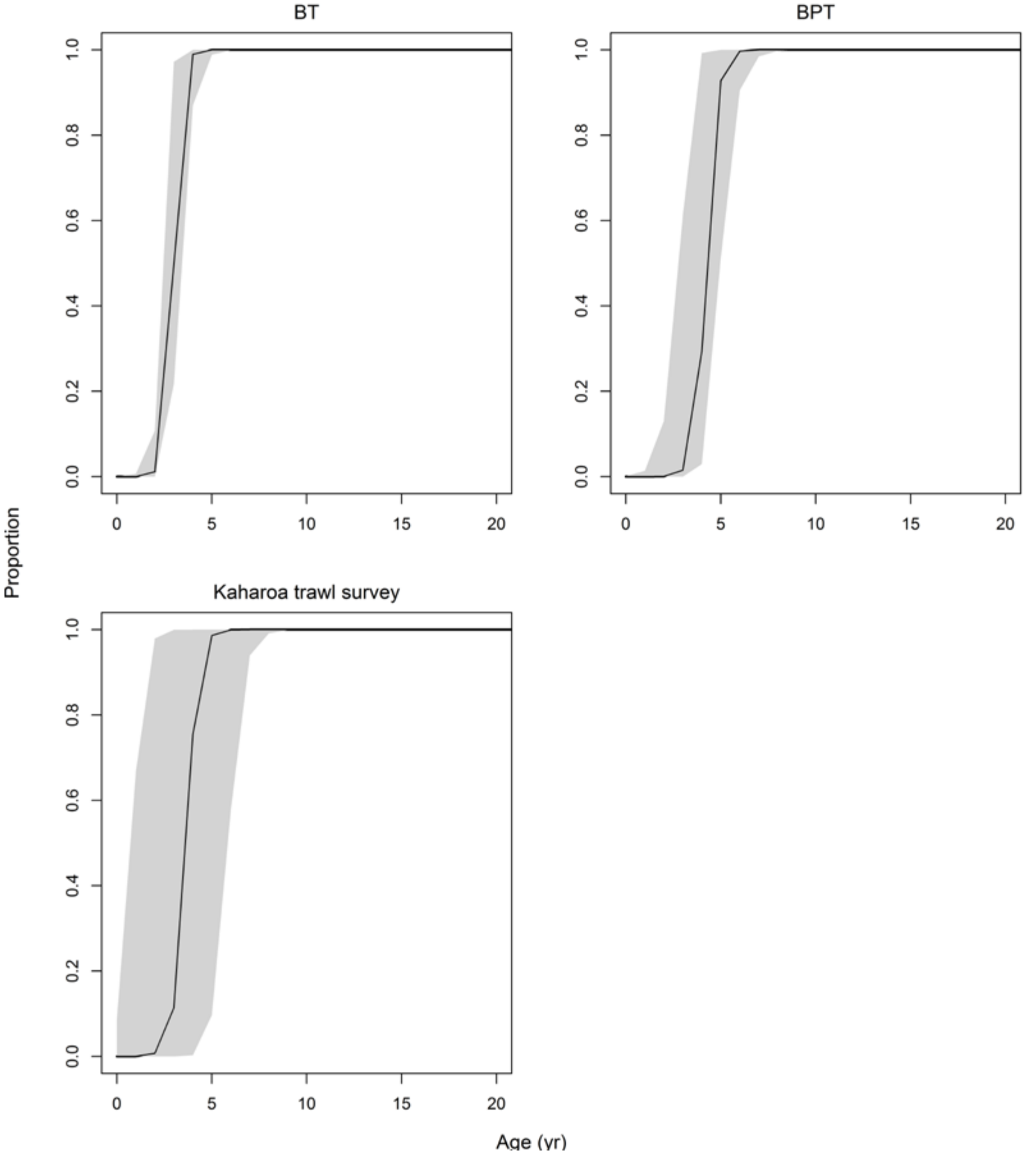

Figure 21: Age specific selectivity functions estimated for the BT (top left), BPT (top right) fisheries and *Kaharoa* trawl survey (bottom) from the base assessment model. The lines represent the median of the McMC samples and the grey shaded area represents the 95% confidence interval.

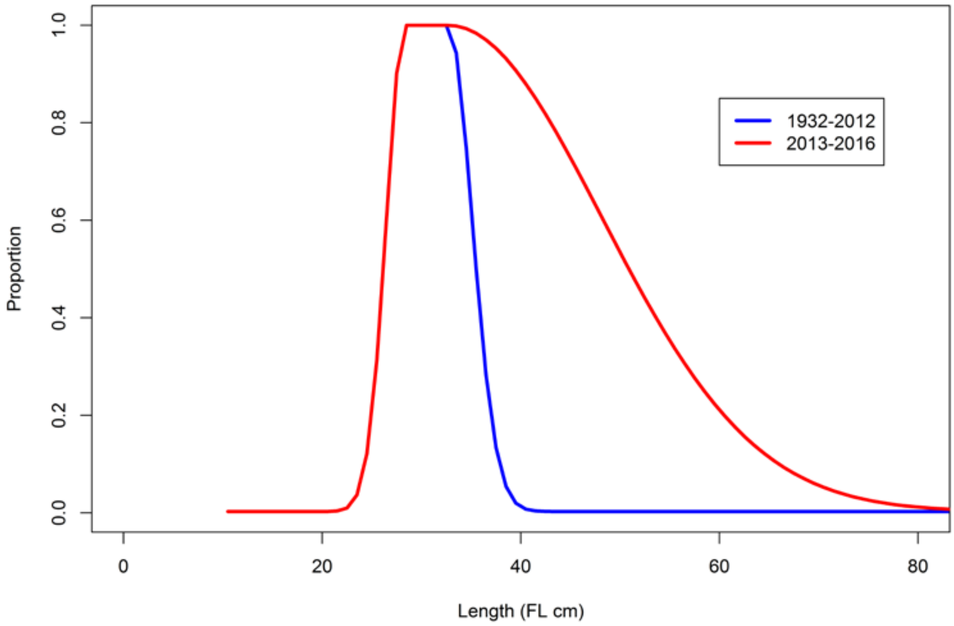

Figure 22: Estimates (MPDs) of length based selectivity of the Recreational fishery for the two time periods (blocks).

Diagnostic plots of the McMC traces for key parameters are presented in Appendix 3. The diagnostics of the R_0 parameter reveal that there is considerable autocorrelation amongst successive McMC draws (Figure A8). The estimates of the R_0 parameter are negatively correlated with the estimates of some of the early year classes (especially 1960). To determine whether the McMC samples were adequately sampling the parameter error structure, the derived parameters were compared with the results of sampling from longer McMC chains (chain lengths of 5 million). The resulting spawning biomass trajectories and confidence intervals were very similar for the two options (Figure A11) and on that basis it was concluded that McMC chains of 1 million were adequate for the estimation of model uncertainty.

The base case model estimates episodic recruitment during the 1950–2008 period with strong recruitment occurring in 1960, 1969, 1974, 1985–87, 1999 and 2010 and exceptionally strong recruitment in 2007 (Figure 23 and Figure 24). The variation in the estimated recruitment deviates (std. dev = 0.95) is somewhat less than the assumed variation (*SigmaR* 1.5).

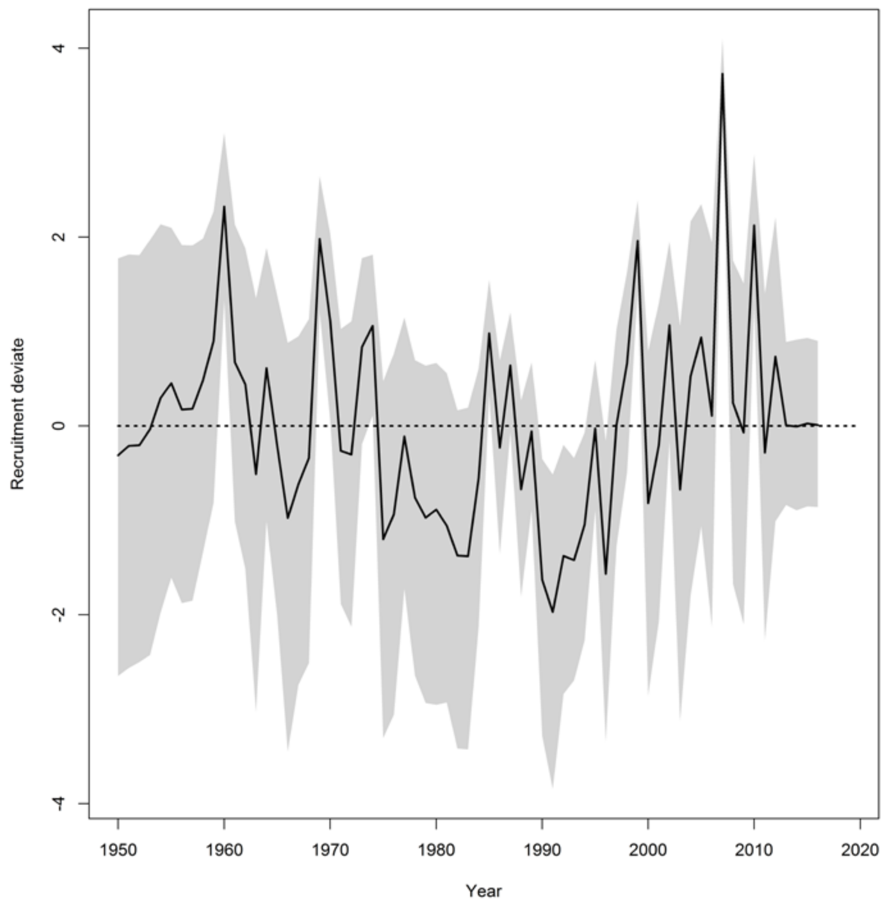

Figure 23: Estimates of annual recruitment deviates from the base assessment model. The line represents the median of the McMC samples and the shaded area represents the 95% confidence interval.

Full recruitment deviates were not estimated for the most recent period (2013–2016) and recruitment deviates in this period were constrained to approximate zero (Figure 23). Realized recruitments in this period were estimated to be below the long-term average recruitment level due to the effect of the bias correction factor (scaled by the high value for *SigmaR* of 1.5) included within the stock-recruitment relationship (see equation A.1.7 in Methot & Wetzel 2013) (Figure 24).

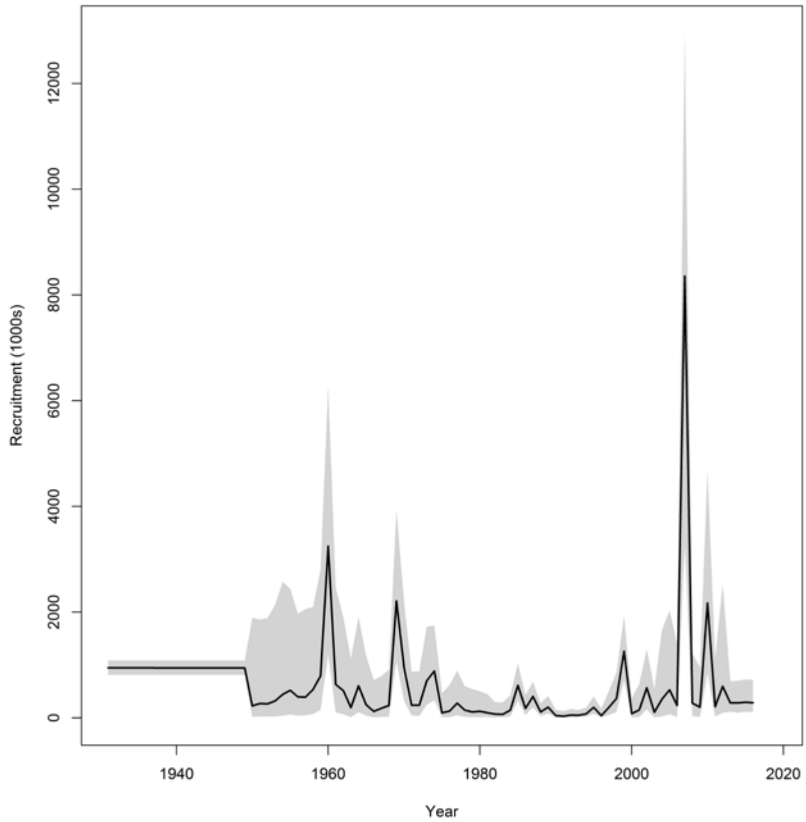

Figure 24: Estimates of annual recruitment (numbers of fish) from the base assessment model. The line represents the median of the McMC samples and the shaded area represents the 95% confidence interval.

4.9.2 Fit to observational data

The base model provides a reasonable fit to the overall trend in the time-series of BT CPUE indices (Figure 25). The main signal in the CPUE indices is the large increase from 2009 to 2011. The base model estimates a strong increase in stock abundance during this period, although the extent of the increase is less than the increase in CPUE, and hence there is a large positive residual for the 2011 index The model also does not adequately fit the inter-annual variation in the CPUE indices during 2011–2016 (Figure 25). The degree of fit to the CPUE indices is reflected in the CV associated with the time series (based on the initial RMSE).

The estimate of vulnerable biomass in 1987 from the base model approximated the biomass estimate from the tag release/recovery programme (Figure 26). There are concerns regarding the reliability of the tag biomass estimate; however, a model option that excluded the biomass estimate did not appreciably change the overall biomass trajectory indicating that the tag biomass estimate is not particularly influential.

The model age structure in 1987 is primarily informed by the age composition data from the sampling of the BPT fishery in the preceding years (Figure 27). The base model provided a reasonable fit to these data, particularly the presence of the strong year classes (e.g. 1960, 1969 and 1974) in the older age range (8–25 years) (Figure 27). However, the fit to the proportions in the youngest age classes (4–5 years) is poor and variable among years. This may indicate that the selectivity of the younger age classes in the BPT fishery was variable among years and/or that there was considerable variability in the proportion of young fish amongst the sampled landings.

The model also consistently over-estimated the proportion of fish in the BPT aggregate 30+ age class (Figure 27). A model option that substantially increased the weighting of the BPT age composition data (from ESS 8.5 to 85) resulted in a considerable improvement in the overall fit to these data, including the plus group, and estimated a somewhat lower biomass level for the period prior to 1965 (including SB_0). However, the absolute biomass trajectories were very similar for the remainder of the model period (1966–2016).

The age compositions from the BT fishery during 1992–2000 are dominated by the progression of the relatively strong 1985 and 1987 year classes (Figure 28). Fish older than 10 years represented a minor proportion of the age composition of the sampled catch during 2003–2016 as the model age structure became dominated by recruitment from 1998 onwards, with higher recruitment estimated for the 1999, 2002, 2005, 2007 and 2010 year classes (Figure 28).

Overall, the model provided a reasonable fit to the time-series of recent BT age samples. However, the proportion of older fish in the sampled catch is under-estimated for 1999 and 2000 and the fit to the youngest age classes (3–4 years) is variable among years (Figure 28).

The model fitted the dominant 6 year old age class in the 2013 age composition (representing the 2007 year class), although the 3 year old age class, representing the 2010 year class, is under-estimated by the model (Figure 28 and Figure 29). The 2010 year class is also under-estimated for the 2016 age composition (age 6 years), while the model over-estimates the proportion at age 9 years (2007 year class).

The model provided a considerably better fit to age composition from the recent *Kaharoa* trawl survey, including the relative proportions of the 2007 and 2010 year classes (Figure 30).

The 2005 and 2011 length compositions from the recreational fishery are approximated by the model, reflecting the relatively narrow selectivity function estimated for the earlier period of the fishery (pre 2013) (Figure 31). The model also approximates the broader length range of fish sampled in 2015 and 2016, although the fit to the 2016 length composition is poor. The 2016 length composition was derived from a relatively small sample (235 fish) and may not adequately define the length composition of the recreational catch.

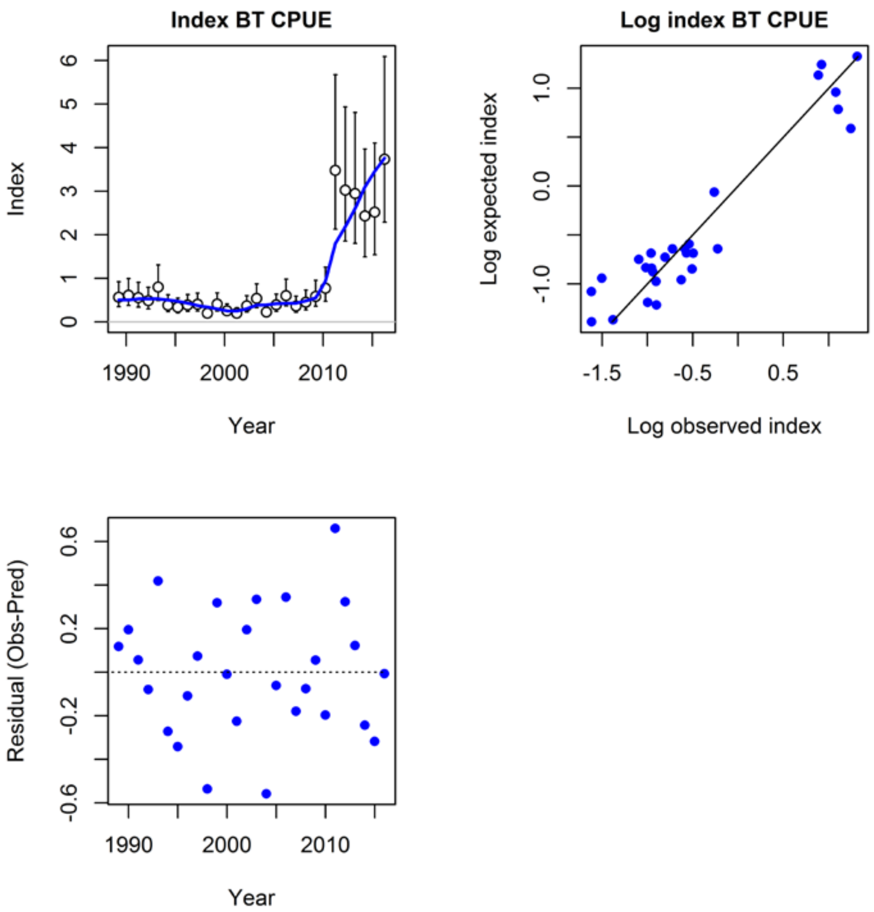

Figure 25: Fit to the CPUE indices and associated diagnostics for the base model. The year represents the model year denoted by the start of the fishing year (e.g. 1995 denotes the 1995/96 fishing year).

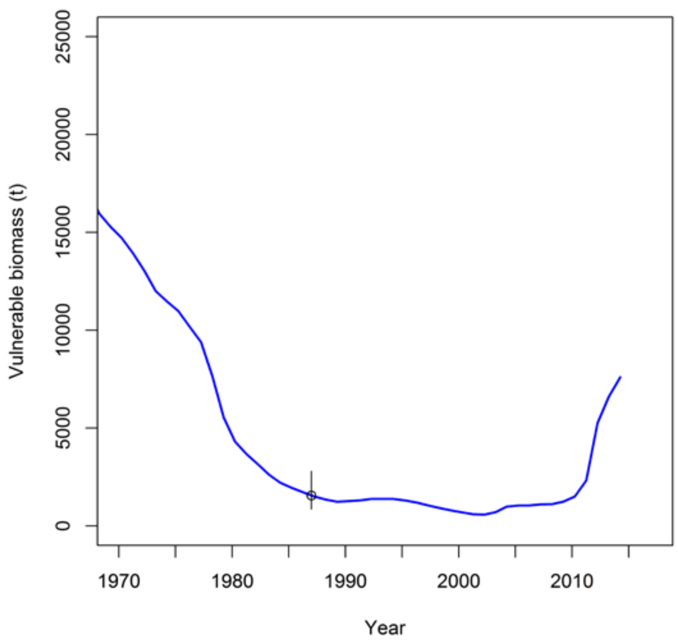

Figure 26: Base model fit to the tagging biomass estimate (point) and associated confidence interval. The vulnerable biomass is determined based on the estimated selectivity function for the BPT fishery.

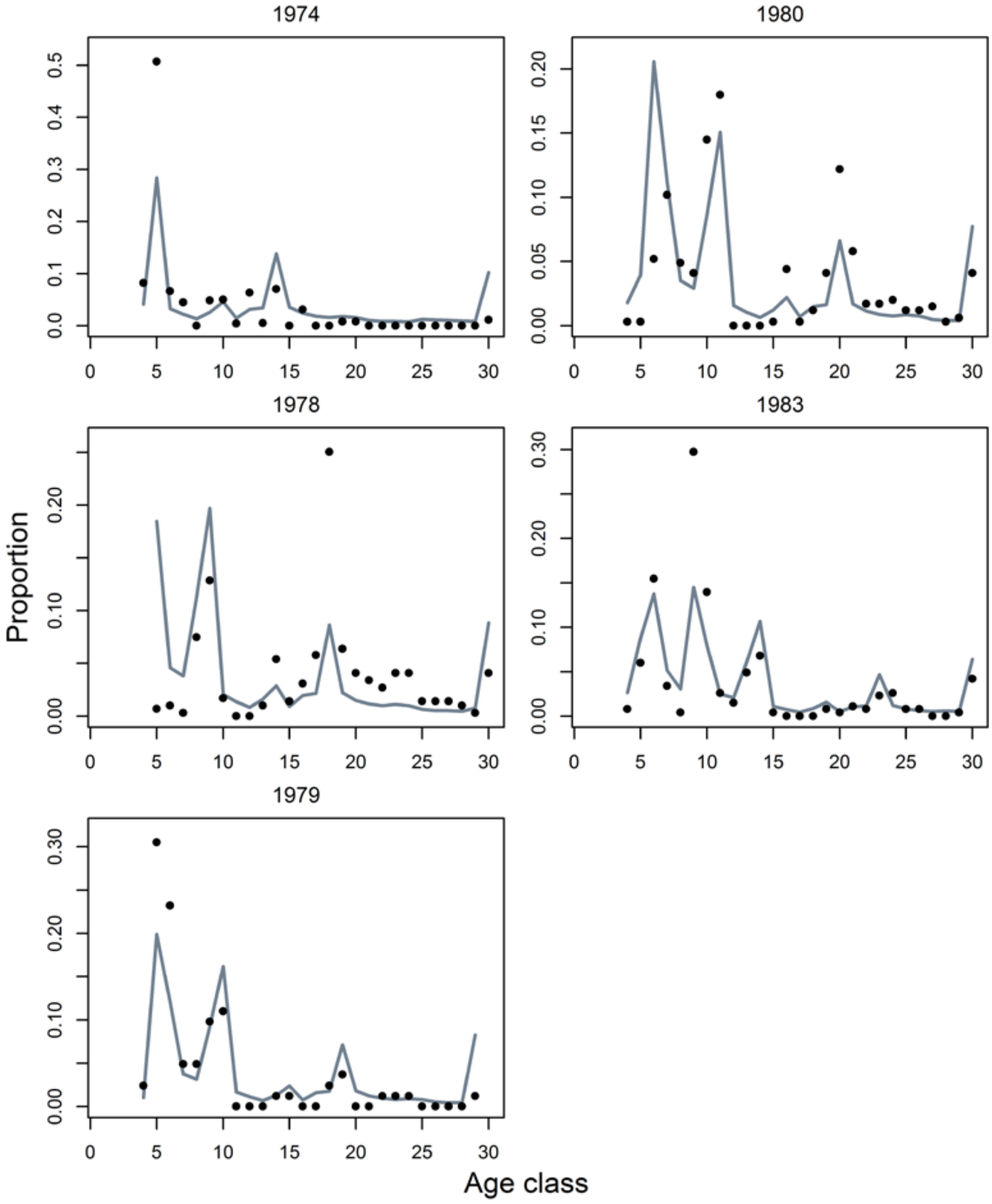

Figure 27: Observed (points) and predicted (line) proportions at age for the bottom pair trawl (BPT) catch-at-age data included in the base model.

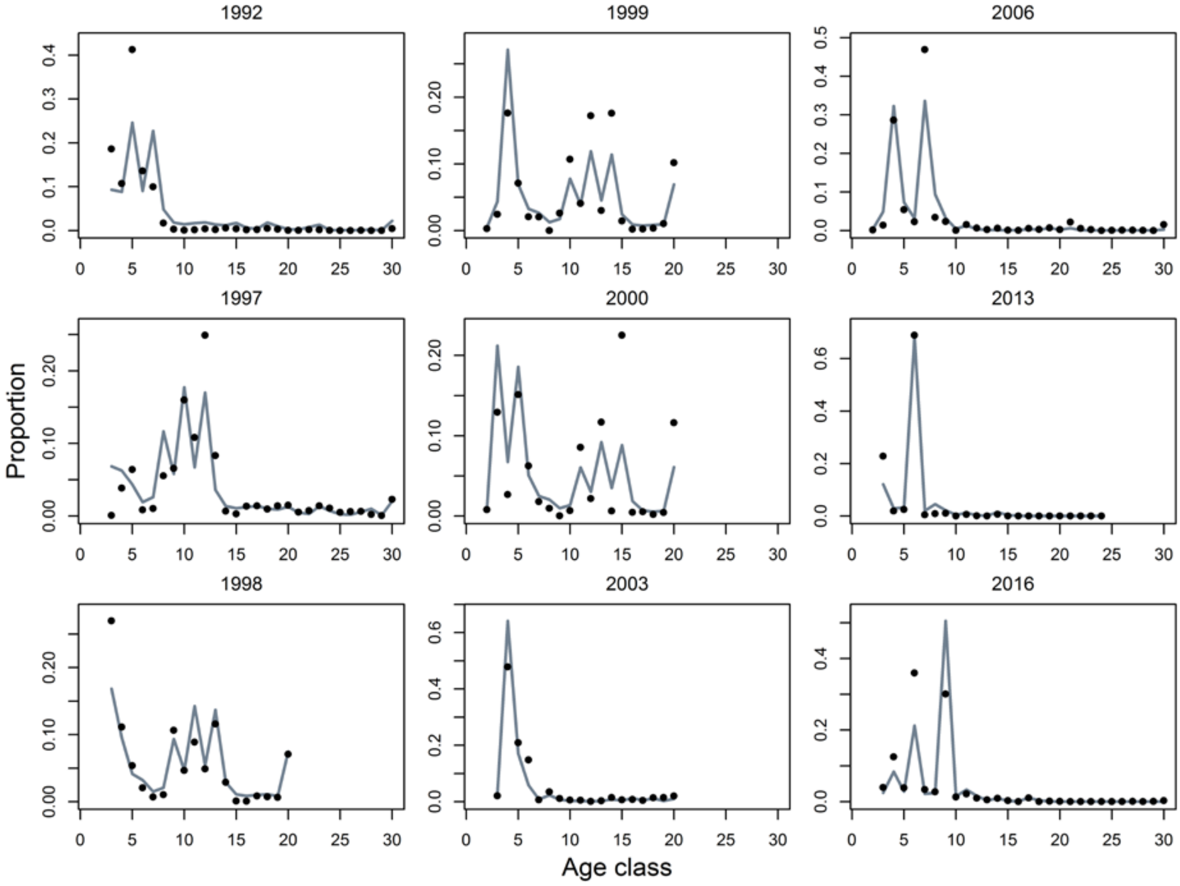

Figure 28: Observed (points) and predicted (line) proportions at age for the bottom single trawl (BT) catch-at-age data included in the base model.

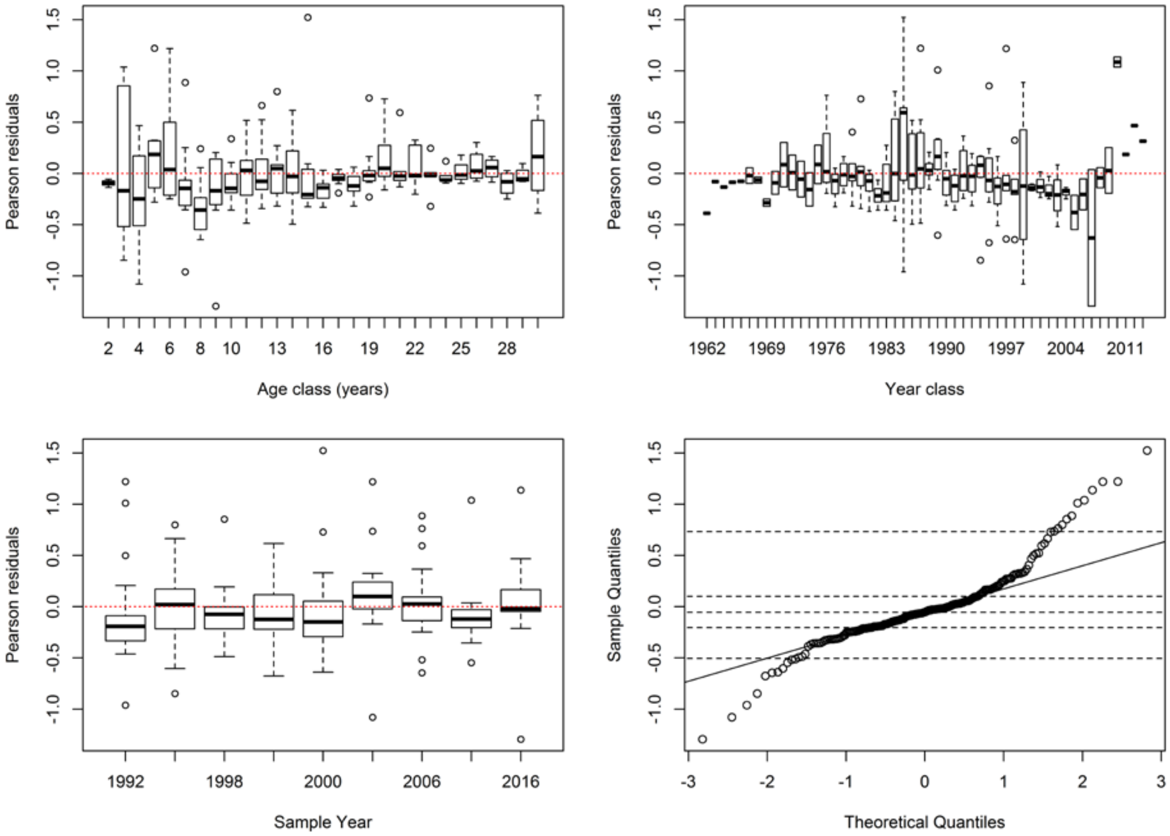

Figure 29: Boxplots of the standardised residuals from the fits of the BT age compositions aggregated by age class (top left panel), year class (top right panel) and year of sample (bottom left panel) and the QQ plot of the residuals (bottom right panel).

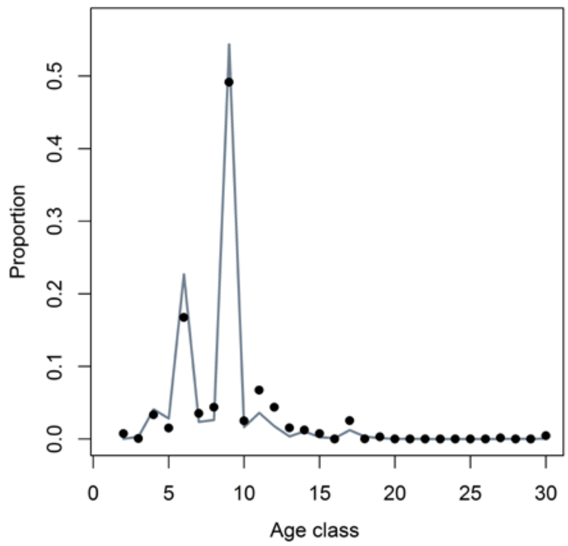

Figure 30: Observed (points) and predicted (line) proportions at age for the *Kaharoa* trawl survey age composition from the base model.

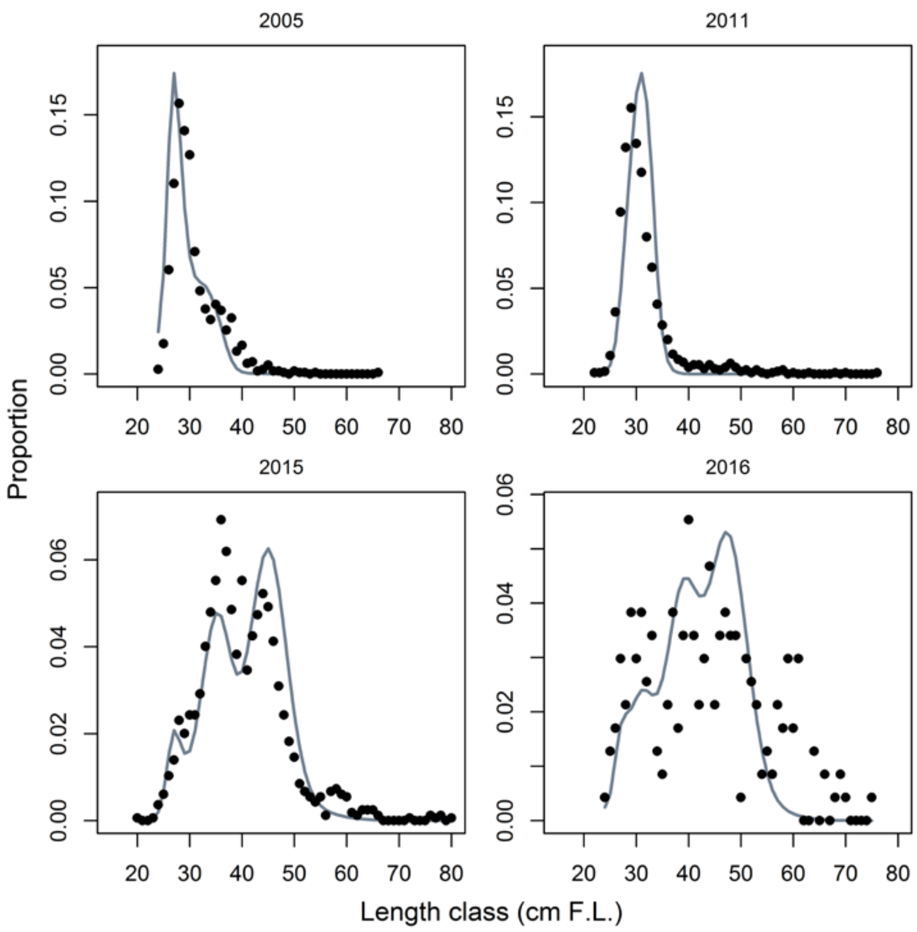

Figure 31. Observed (points) and predicted (line) proportions at length for the Recreational fishery length composition from the base model.

Additional information regarding the size structure of the recent BT catches is provided by the inclusion of the commercial grading data in the base model. These data were not included in the likelihood function for the base model and, hence, do not influence the parameter estimates. Nonetheless, the model provided a reasonable approximation of the annual proportions of the catch in each size grade during 2004–2016 (Figure 32). While these data are of considerably lower resolution than the age frequency data, the model fits to these data indicate that the trends in the commercial grading data are generally consistent with the selectivity estimated for the BT fishery (informed by the age composition data. Since 2013, there was an increased proportion of the catch in the largest size grade which is consistent with the dominance of recruitment from the strong 2007 year class (Figure 32).

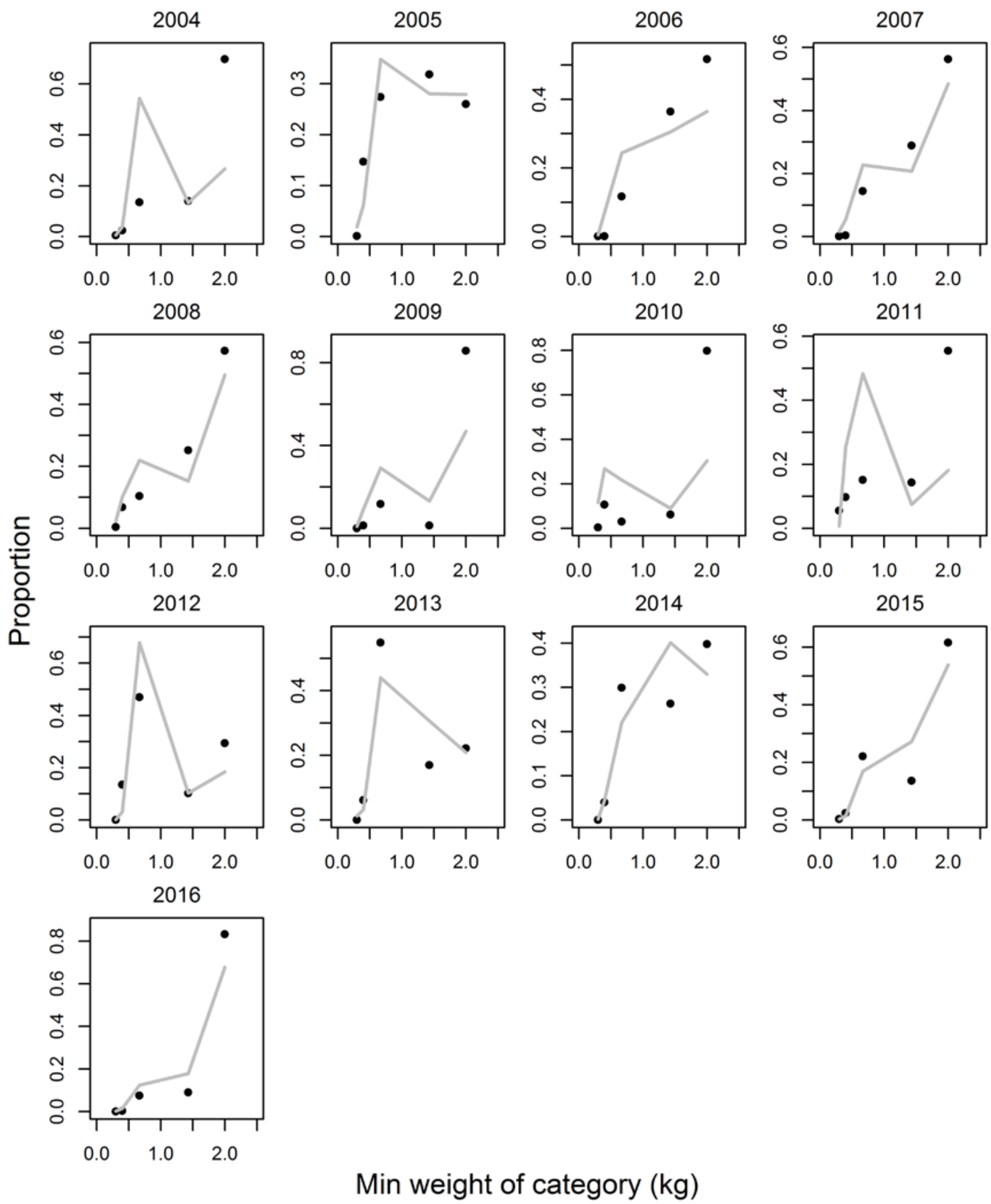

Figure 32: Observed (points) and predicted (line) proportions by fish weight grade for the bottom trawl (BT) fishery.

4.9.3 Model sensitivity analyses

During the development of the base model, a wide range of model options were investigated, including differential weightings on the various age composition data sets and the CPUE indices and varying key (fixed) parameters. Most of the alternative options did not result in an appreciable difference in the estimate of current stock status. It was considered that the relatively broad confidence intervals associated with the base model adequately represented the uncertainty associated with most of the additional model options. On that basis, the final set of model sensitivity analyses was limited to two model options that yielded substantially different results from the base model: 1) a less optimistic scenario with a lower natural mortality (M = 0.06 compared to 0.075 for the base model) (*LowM*) and

2) a more optimistic scenario with a lower value of *SigmaR* (1.0 compared to 1.5 for the base model) (*SigmaR 1.0)*.

Overall, the two model sensitivity runs resulted in a deterioration in the fit to the main age composition data sets (BT and/or BPT) (Table 8). Most of the difference in the total likelihoods was attributable to the contribution from the recruitment deviations component of the likelihood. Reducing the *SigmaR* parameter from 1.5 to 1.0 reduced this component of the likelihood from 31.8 to 19.5.

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

Model						Likelihood component
	Total	CPUE indices	Tag	BT Age comp	BPT age comp	Survey age comp
base	39.1	-20.7	-1.2	12.1	14.3	1.0
lowM	58.5	-20.4	-1.2	12.0	19.2	1.2
SigmaR 1.0	35.7	-20.1	-0.8	16.2	17.8	0.9

4.10 Stock status

The base assessment model estimated that the spawning biomass declined substantially from 1950 to the mid-1980s when the stock biomass is estimated to have been approximately 7% of the virgin (SB_0) level (Figure 33). The stock biomass is estimated to have remained at about that level throughout the 1990s and 2000s and then increased rapidly from 2009 to reach 39% of the SB_0 level in 2016 (SB_{2016}).

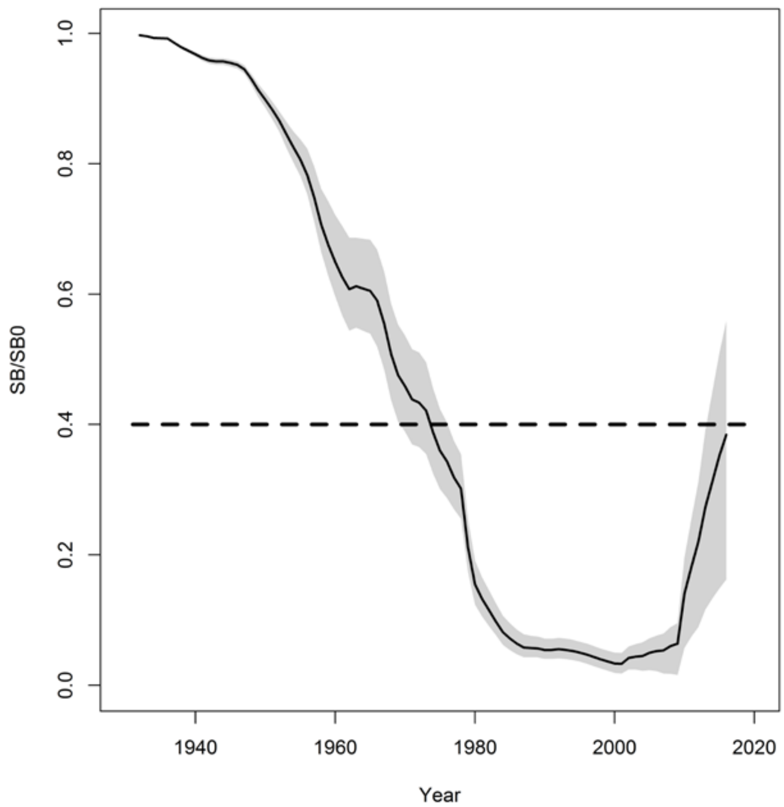

Figure 33: Spawning biomass relative to the default target spawning biomass reference point from the base assessment model. The solid line represents the median of the McMC samples and the shaded area represents the 90% confidence interval. The horizontal line represents the default target biomass level.

The stock status of SNA 7 is currently assessed relative to a default target biomass level of 40% SB_0 ($SB_{40\%}$) and associated soft limit and hard limit of 20% and 10% of SB_0, respectively (Ministry of Fisheries 2008). Stock status (current 2016 and forecast to 2022) for spawning biomass is reported relative to the default hard and soft limits and the target biomass level. Fishing mortality (in 2016 and 2022) is reported relative to the corresponding interim target biomass level (i.e. $F_{SB40\%}$) based on the 2016 age-specific exploitation pattern.

For the base model, biomass is estimated to have increased considerably from 2010 and current (2016) biomass is well above the soft limit (20% SB_0). There is considerable uncertainty in the magnitude of the recent increase in biomass, although the stock is estimated to be at about the interim target biomass level (40% SB_0) (Figure 33 and Table 9). The two model sensitivity runs estimated current stock status that bracketed the base model estimates; less optimistic current stock status from the lower natural mortality sensitivity run and more optimistic stock status from the lower SigmaR sensitivity run.

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

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

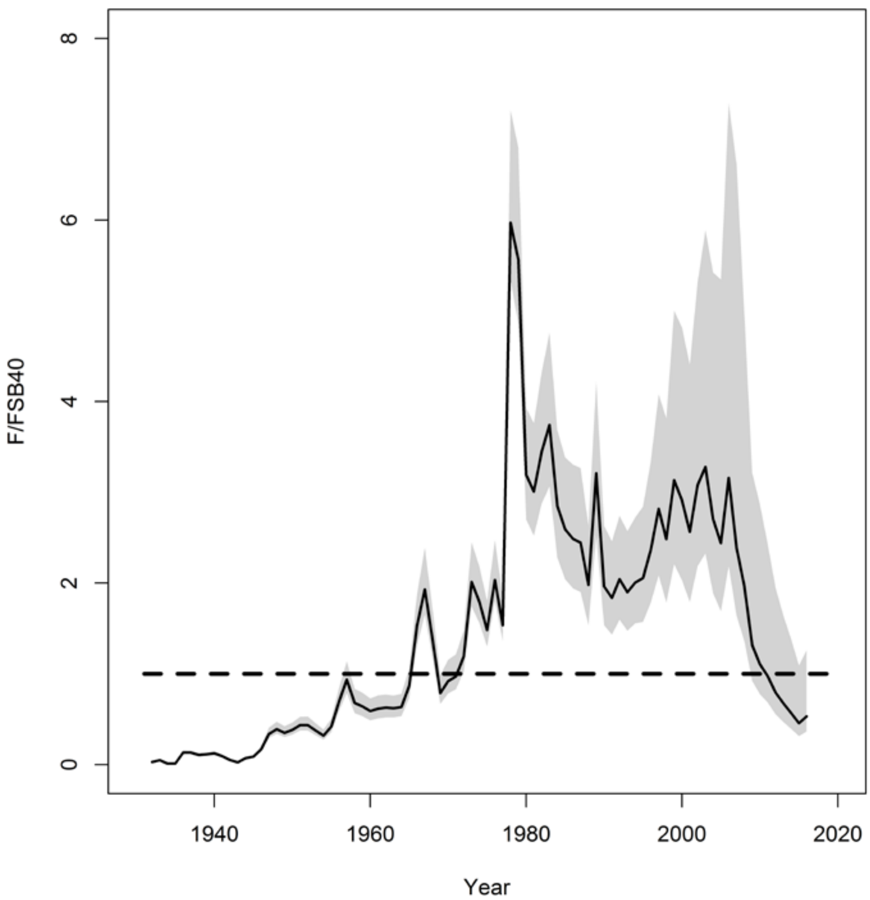

Figure 34: Annual fishing mortality relative to the level of fishing mortality that corresponds to the default target spawning biomass from the base assessment model. The line represents the median of the McMC samples and the shaded area represents the 90% confidence interval. The horizontal line represents the FSB40 fishing mortality.

Estimates of current and equilibrium yield were derived for the stock based on the fishing mortality rate that corresponds to the interim target biomass level (Table 10). Equilibrium yields at the interim target biomass level (40% B_0) are estimated to be about 500–750 t per annum. $F_{SB40\%}$ yields at 2016–17 biomass levels are comparable to the yields at 40% B_0. Current $F_{SB40\%}$ yields are higher than the level of current catch (the 2016/17 model catch is 369 t).

Table 9: Stock status in 2016 (2016/17 fishing year) relative to default target (*SB40%*) biomass and corresponding fishing mortality level ($F_{SB40\%}$) for the base model and main model sensitivity runs. The probability of current biomass being above default limit biomass reference levels and below the level of fishing mortality associated with the interim target biomass level is also presented.

Model	SB_0	SB_{2016}	SB_{2016}/SB_0	$SB_{2016}/SB_{40\%}$	Pr(SB_{2016} > $X\%SB_0$)			$F_{SB40\%}$	$F_{2016}/F_{SB40\%}$	Pr(F_{2016} < $F_{SB40\%}$)
					40%	20%	10%			
Base	16 931	6 542	0.384	0.961	0.453	0.923	0.970	0.054	0.531	0.922
	(14 544–19 474)	(1 313–10 055)	(0.077–0.611)	(0.193–1.526)				(0.042–0.057)	(0.343–2.40)	
lowM	18 761	6 411	0.342	0.856	0.243	0.896	0.949	0.047	0.617	0.889
	(16 554–20 956)	(130–9 592)	(0.007–0.517)	(0.017–1.292)				(0.039–0.056)	(0.407–11.841)	
SigmaR 1.0	12 381	6 122	0.494	1.235	0.734	0.909	0.944	0.052	0.599	0.863
	(10 896–20 956)	(142–9 244)	(0.012–0.740)	(0.030–1.849)				(0.038–0.056)	(0.387–9.192)	

Table 10: Estimates of annual yield (t) at $F_{SB40\%}$ at the SB_{2016} (2016/17) biomass levels and at $SB_{40\%}$, for the base model and the model sensitivity runs. The values represent the median and the 95% confidence interval from the McMCs.

Model option	Annual yield	
	$SB_{40\%}$	SB_{2016}
Base	737 (590–857)	691 (148–1 072)
lowM	707 (611–789)	596 (12–904)
SigmaR 1.0	515 (391–597)	610 (14–949)

For base model option, stock projections were conducted for the 6 year period following the terminal year of the model (i.e. 2017–2022) with the catches in the first year (2017 = 2017/18 fishing year) set at the level of the 2016 catches. During the projection period, recruitments were resampled from the lognormal distribution around the geometric mean. Two scenarios were evaluated for 2018–2022, specifically:

1. All annual catches were set at the current allocations (TACC 250 t, Recreational catch 250 t, Customary 20 t and Other mortality 25 t) representing a total catch of 545 t (*Baseline*).
2. Annual catches for commercial, customary and other mortality were set at the current allocations (TACC 250 t, Customary 20 t and Other mortality 25 t). Recreational catch was calculated from the level of recreational fishing mortality derived from the most recent estimate of recreational catch (2015) (*TACCandRecF*). Total annual catches in the projection period approximated 465 t per annum.

The projections are largely driven by the continued increase in the biomass of the 2007 and 2010 year classes, resulting in an increase in total biomass during the projection period. For the two scenarios, spawning biomass in 2022 is forecast to be at about the target biomass (SB40% level) and well above the soft limit (20% SB_0) (Table 11).

Table 11: Stock status in the terminal year 2022 (2022/23 fishing year) of the six year forecast period for the two projection scenarios.

Scenario	*Pr (SB2022 > X% SB0)*		
	10%	20%	40%
Baseline	0.961	0.921	0.600
lowM	0.959	0.924	0.612

5 DISCUSSION

The results of the current assessment are very consistent with the previous (2015) stock assessment. The current assessment estimates that biomass has increased from 2015 and is at or about the default target biomass level. Recent stock trends, current stock status and projected stock status are all highly dependent on the estimates of the magnitude of recruitment, in particular that of the 2007 year class.

The estimates of recent recruitment are primarily informed by the trawl CPUE indices (from 2008/09) and the BT age composition data. However, the stock assessment model reveals a relatively poor fit to recent observations from both data sets, indicating lower precision of these observations and/or deviation from the structural assumptions of the model. For example, trends in the CPUE indices from 2012/13 have not followed the continued increase in the biomass estimated by the assessment model. A possible explanation is that the snapper catch rates and CPUE indices increased disproportionately as a result of targeting the initial increase in abundance, but were then moderated through avoidance of snapper due to the limited availability of SNA 7 ACE in recent years.

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

The deterioration of the model fit to the recent CPUE indices and commercial age composition data is reflected in the relatively high level of uncertainty associated with the current biomass level (corresponding to high uncertainty associated with the estimate of the strength of the 2007 year class).

The current assessment model incorporated the snapper age composition derived from the 2017 *Kaharoa* trawl survey. This age composition was more consistent with the predicted age structure of the population model (compared to the 2016/17 BT age composition) and was dominated by the 2007 year class. Most of the snapper catch from the TBGB trawl survey was taken in the 20–40 m depth range, whereas the 2016/17 commercial age composition is likely to have been derived from catches taken in 15–30 m depth (see Figure 7). From the 2017 trawl survey, the length of snapper sampled from the 10–20 m depth range was generally smaller than from the 20–40 m depth range, with the 2007 year class representing a smaller proportion of the sampled catch in the 10–20 m depth range (Dan MacGibbon, NIWA unpublished data).

These limited observations may indicate that larger, older (greater than about 6 years) snapper may occupy a deeper habitat range within TBGB compared to younger snapper. Such a morphogenic difference in the spatial distribution of snapper could account for the lower proportion of the 2007 year class (9 years) observed in the catch from the BT fishery in 2016/17 compared to the predicted model age composition, given the assumption of logistic selectivity for the fishery.

These trends are also consistent with the variation in TBGB trawl CPUE indices by depth interval. The increase in snapper catch rates from the deeper areas of TBGB occurred several years after the initial increase in CPUE in the shallower areas, while the scale of the overall increase in relative CPUE in the deeper areas was greater than from the shallower areas.

A morphogenic difference in the spatial distribution of snapper may also explain the magnitude of the increase in the time-series of trawl survey biomass estimates of recruited (25+ cm FL) snapper from the core survey area (20–40 m depth range). The trawl survey biomass estimates increased markedly in 2015, several years after the initial large increase in the CPUE indices (in 2011/12). The increase in trawl survey biomass in 2015 survey was dominated by the 2007 year class at age 8 years (Langley 2015a).

The relative increase in the trawl survey biomass indices is more pronounced than the increase in the recruited biomass (greater than 25 cm) predicted by the stock assessment model (Figure 35). This may indicate that the trawl survey biomass estimates are dominated by older age classes and that recent recruits (25–35 cm; 3–5 year old) were not adequately sampled by the survey. This supports the current rationale for not including the core-area time-series of trawl survey biomass estimates in the stock assessment; i.e., the survey was considered unlikely to adequately monitor juvenile and adult snapper abundance as the surveys did not sample the shallower areas of Tasman/Golden Bay and catch rates of snapper were variable, resulting in broad confidence intervals associated with the biomass estimates. Recent modifications of the trawl survey design (in 2017) to include the shallower areas of Tasman/Golden Bay are likely to improve the utility of the survey for monitoring of SNA 7. It may also be possible to accommodate the existing time series of trawl survey biomass estimates by reconsidering the age (or length) based selectivity of the survey.

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

Limited information is available regarding the magnitude of recent recruitments (2012–2016). There is some indication from the 2016–17 age composition that the 2012 year class may be of moderate strength although insufficient data were available to reliably estimate the magnitude of this year class in the assessment model.

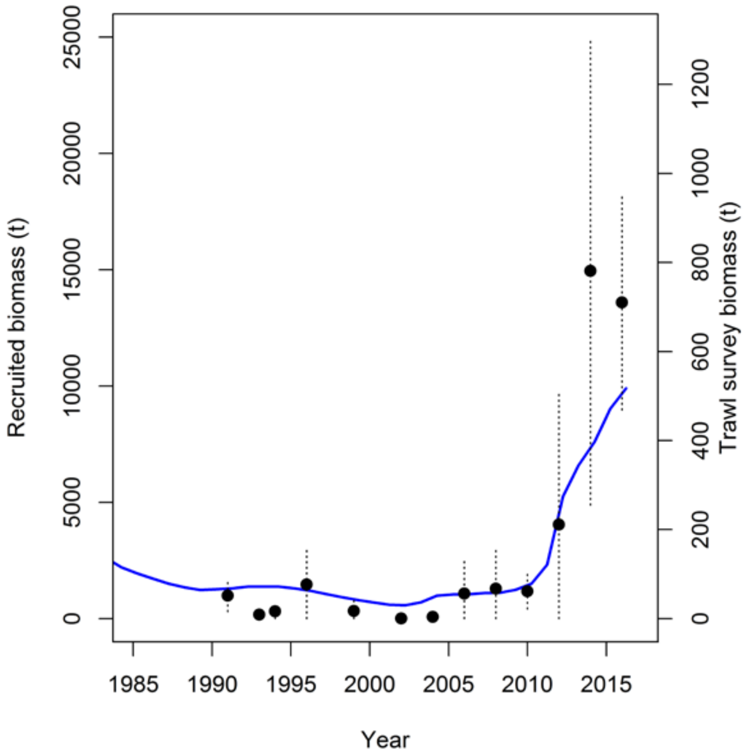

Figure 35: A comparison of the trend in recruited biomass derived from the SNA 7 stock assessment (blue line) and *Kaharoa* WCSI trawl survey biomass estimates of recruited (25+ cm F.L.) snapper from the Tasman/Golden Bay area (points) (MacGibbon, NIWA, unpublished data). The last trawl survey biomass index included in the series is for the March–April 2017 survey.

6 FURTHER RESEARCH

Estimates of current (and projected) stock status are relatively uncertain due to the low precision of the recent CPUE indices and, correspondingly, the uncertainty in the estimation of the strength of recent year classes (particularly the 2007 and 2010 year classes). The *RV Kaharoa* trawl survey was modified in 2017 to encompass the shallower areas of Tasman/Golden Bay to improve the monitoring of snapper abundance. The results of the 2017 survey were encouraging and the modified trawl survey may enable snapper abundance to be monitored more accurately, thus improving future estimates of stock biomass.

Further sampling of the snapper age composition would provide additional information regarding the relative strength of the dominant year classes. Additional age composition data will be available from the next (2019) *Kaharoa* trawl survey and sampling of the commercial fishery should be conducted in advance of the next stock assessment. In addition, the collection of more spatially resolved samples of the snapper catches will enable further investigation of morphological (size) based differences in the distribution of snapper within TBGB.

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

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

7 ACKNOWLEDGMENTS

This project was funded by the Ministry for Primary Industries (under project SNA2017-01). The commercial size grade data were provided by Doug Loder and Dion Iorns (Talleys Ltd, Motueka). Dan MacGibbon (NIWA) provided data from the *Kaharoa* trawl surveys. Members of the Southern Inshore Fishery Working Group provided constructive review of the assessment.

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APPENDIX 1. DETAILED RESULTS FROM CPUE ANALYSIS

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

Fishing year	Number records	Number vessels	Number trips	Catch (t)	Number trawls	Duration (hrs)	Percent zero catch
1989/90	688	22	367	42.0	2 191	5 031	35.8
1990/91	735	23	335	43.8	2 461	5 936	34.0
1991/92	653	21	297	40.8	2 174	5 546	33.5
1992/93	850	29	400	44.3	2 964	7 688	33.2
1993/94	562	27	264	39.4	1 909	4 728	36.1
1994/95	593	28	329	26.9	1 980	4 650	42.2
1995/96	523	24	252	25.0	1 568	4 045	46.7
1996/97	801	27	349	34.1	2 512	6 674	44.7
1997/98	654	25	260	40.8	2 116	5 714	45.7
1998/99	500	24	190	33.6	1 534	4 736	50.2
1999/2000	308	24	128	39.7	871	2 875	39.0
2000/01	404	18	163	34.1	1 270	4 118	39.1
2001/02	391	17	176	16.8	1 196	3 985	55.2
2002/03	425	16	181	36.1	1 328	4 362	38.6
2003/04	546	26	229	32.9	1 669	5 504	33.5
2004/05	482	19	186	17.6	1 360	4 464	41.3
2005/06	414	15	151	25.3	1 151	3 666	38.6
2006/07	770	23	298	41.7	2 274	7 140	31.9
2007/08	719	26	266	64.2	2 013	6 445	26.6
2008/09	575	26	219	66.8	1 491	4 880	34.6
2009/10	766	27	294	59.2	2 164	6 442	27.8
2010/11	525	28	211	70.0	1 445	4 390	21.9
2011/12	428	28	177	79.8	1 105	3 363	16.6
2012/13	458	27	232	89.5	1 206	3 652	16.2
2013/14	563	25	241	80.9	1 512	4 605	15.1
2014/15	531	21	229	83.6	1 470	4 621	16.0
2015/16	555	21	222	78.9	1 494	4 871	15.5
2016/17	546	18	251	110.2	1 452	4 683	9.5

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

Fish year	Model year	Combined			Binomial			Lognormal		
		Index	LCI	UCI	Index	LCI	UCI	Index	LCI	UCI
89/90	1989	0.640	0.508	0.803	0.642	0.584	0.695	1.000	0.810	1.220
90/91	1990	0.691	0.549	0.854	0.623	0.568	0.677	1.109	0.902	1.349
91/92	1991	0.629	0.497	0.779	0.641	0.577	0.702	0.981	0.781	1.197
92/93	1992	0.549	0.444	0.679	0.643	0.586	0.700	0.854	0.700	1.052
93/94	1993	0.904	0.702	1.164	0.597	0.532	0.658	1.514	1.220	1.888
94/95	1994	0.433	0.335	0.550	0.531	0.468	0.595	0.815	0.657	1.003
95/96	1995	0.379	0.286	0.499	0.493	0.429	0.560	0.769	0.597	0.963
96/97	1996	0.437	0.336	0.558	0.488	0.424	0.549	0.895	0.710	1.112
97/98	1997	0.459	0.352	0.593	0.480	0.417	0.545	0.955	0.750	1.179
98/99	1998	0.224	0.165	0.303	0.437	0.368	0.504	0.514	0.396	0.659
99/00	1999	0.461	0.331	0.619	0.499	0.417	0.579	0.925	0.704	1.204
00/01	2000	0.285	0.210	0.381	0.478	0.407	0.555	0.596	0.457	0.750
01/02	2001	0.225	0.157	0.307	0.383	0.320	0.453	0.588	0.432	0.762
02/03	2002	0.418	0.312	0.550	0.562	0.491	0.633	0.743	0.564	0.942
03/04	2003	0.605	0.462	0.771	0.596	0.531	0.660	1.015	0.796	1.243
04/05	2004	0.252	0.186	0.331	0.526	0.458	0.595	0.479	0.365	0.605
05/06	2005	0.442	0.328	0.593	0.529	0.454	0.600	0.836	0.644	1.068
06/07	2006	0.681	0.538	0.863	0.614	0.553	0.674	1.110	0.895	1.380
07/08	2007	0.410	0.315	0.526	0.635	0.567	0.695	0.645	0.505	0.802
08/09	2008	0.506	0.387	0.659	0.552	0.483	0.620	0.918	0.723	1.148
09/10	2009	0.660	0.512	0.830	0.656	0.594	0.711	1.006	0.810	1.240
10/11	2010	0.872	0.672	1.099	0.662	0.591	0.726	1.318	1.038	1.625
11/12	2011	3.931	3.013	5.020	0.781	0.718	0.835	5.034	3.940	6.281
12/13	2012	3.419	2.672	4.349	0.806	0.746	0.856	4.245	3.329	5.343
13/14	2013	3.330	2.601	4.166	0.813	0.763	0.859	4.093	3.207	5.101
14/15	2014	2.750	2.102	3.487	0.766	0.708	0.822	3.591	2.837	4.510
15/16	2015	2.845	2.248	3.621	0.792	0.735	0.843	3.590	2.865	4.524
16/17	2016	4.221	3.238	5.400	0.874	0.829	0.913	4.828	3.766	6.114

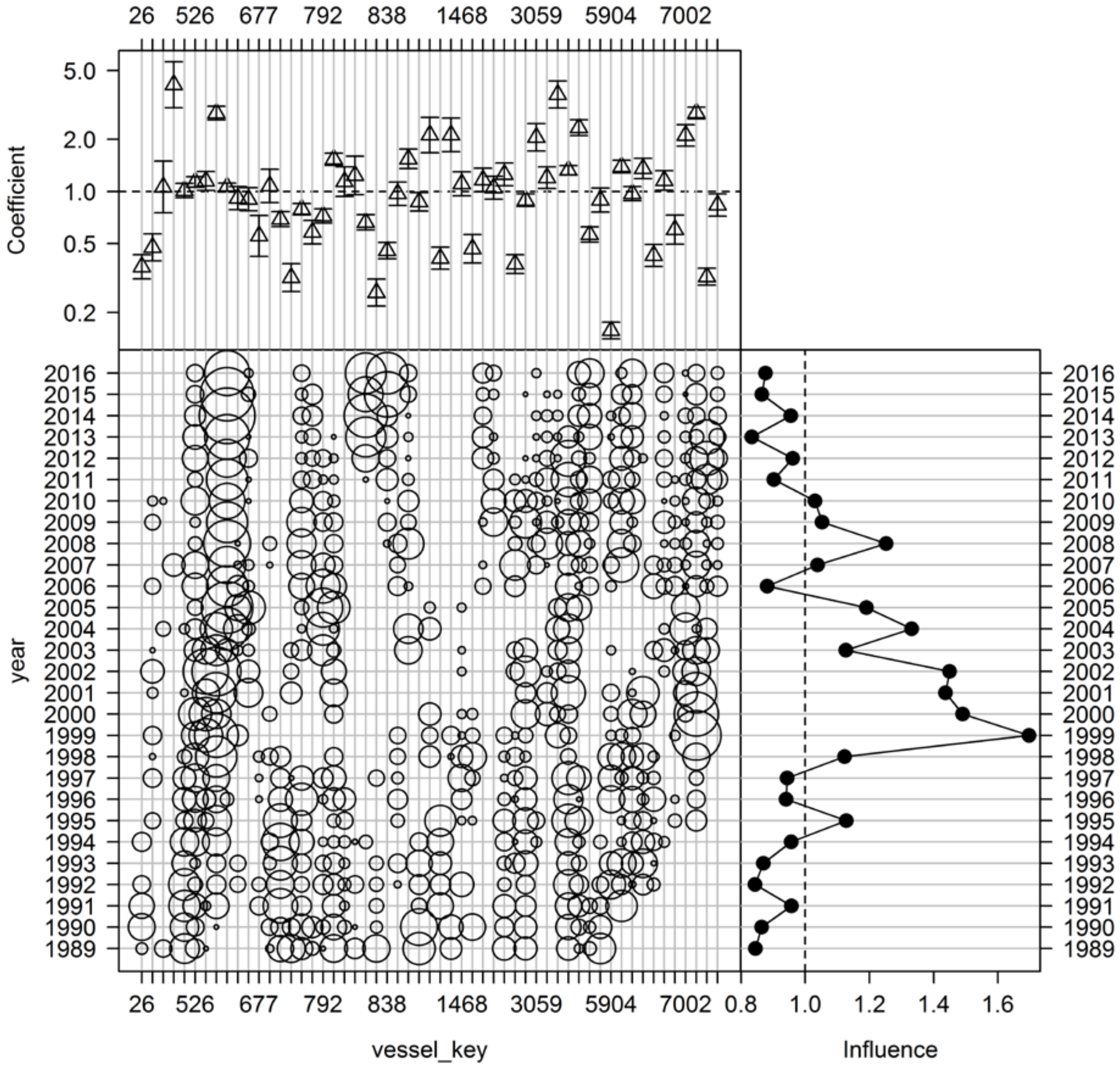

Figure A1: Influence plot for the *Vessel* variable from the Daily lognormal CPUE model.

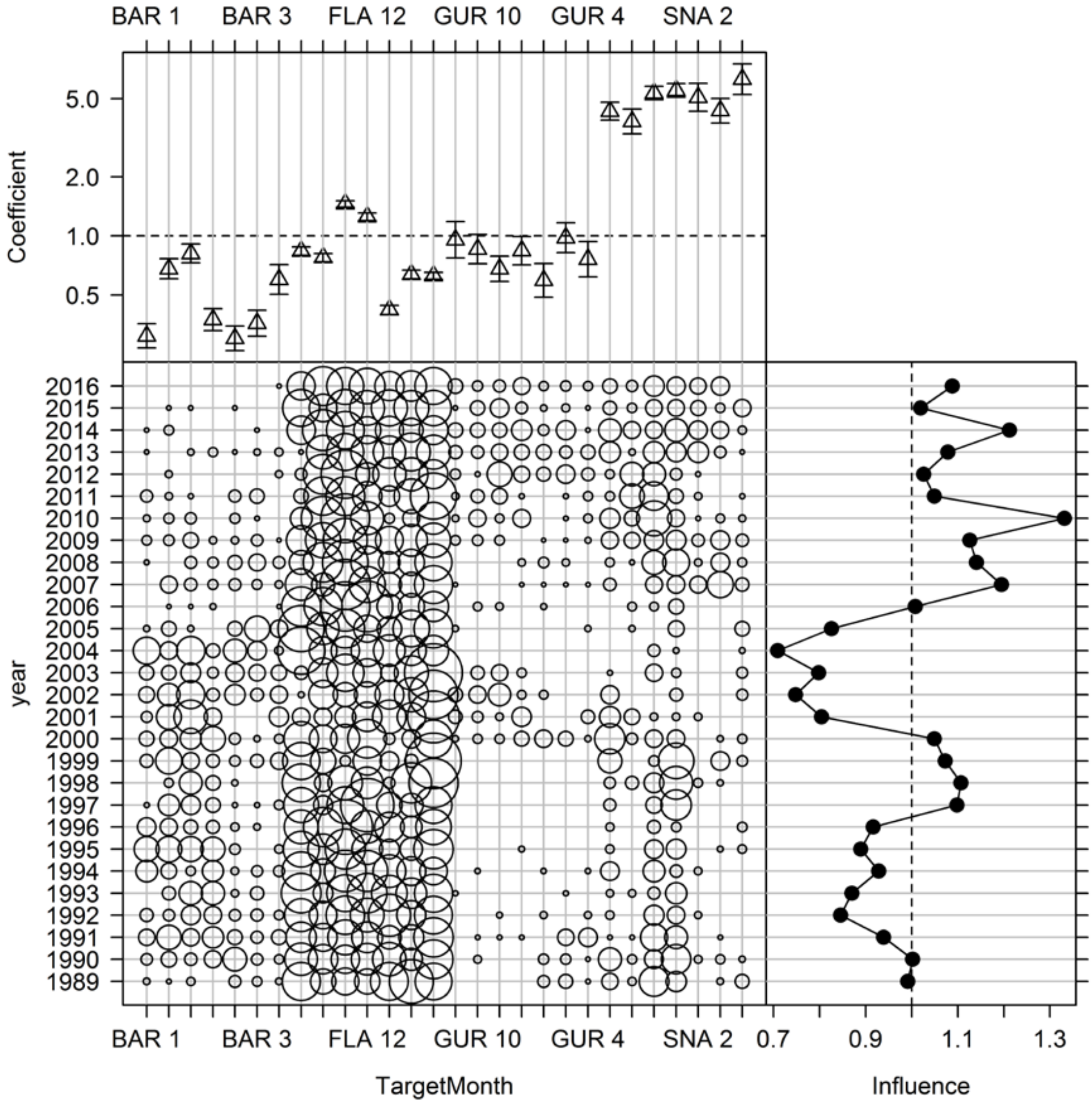

Figure A2: Influence plot for the *TargetSpecies:Month* interactions from the Daily lognormal CPUE model.

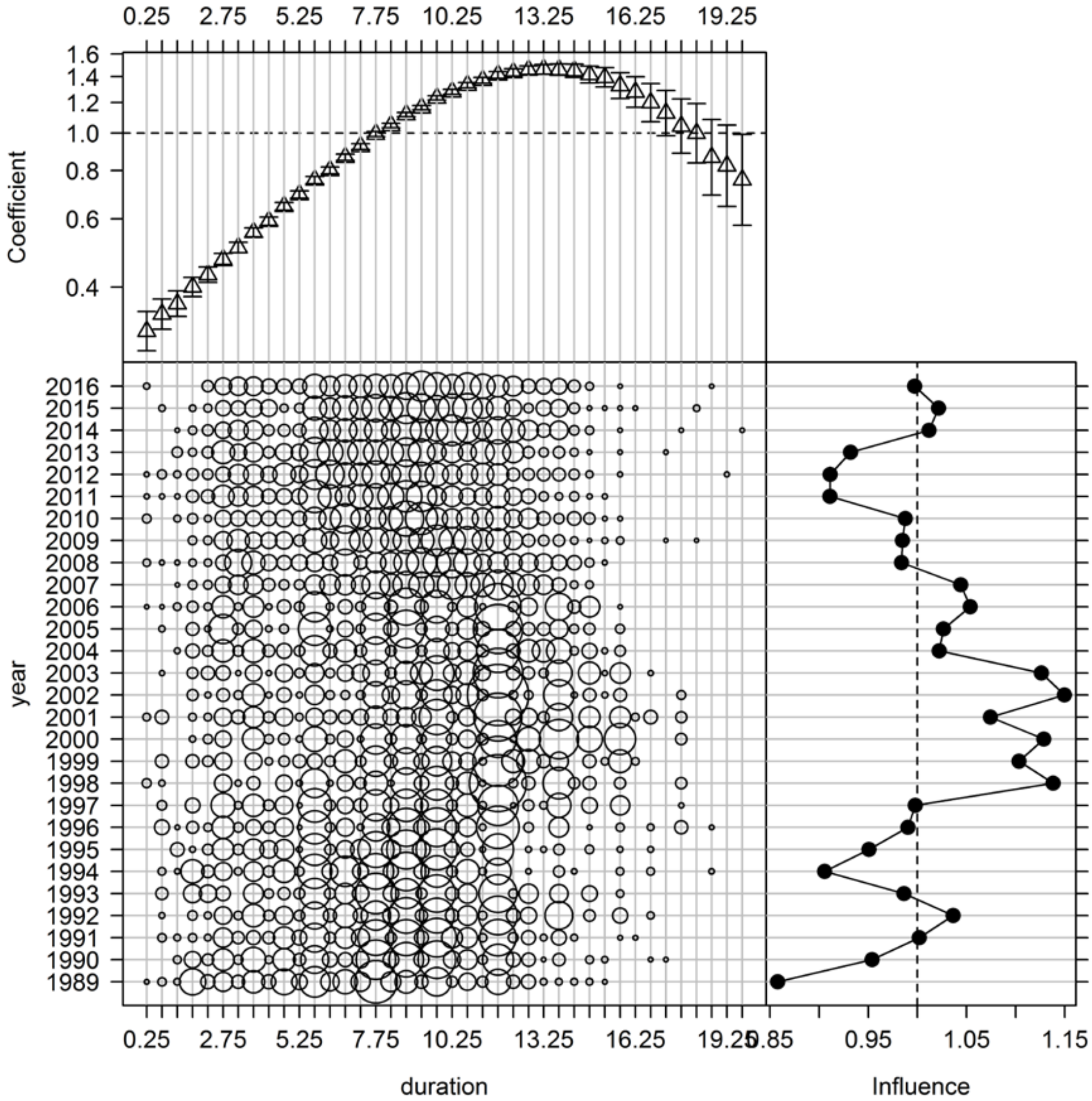

Figure A3: Influence plot for the *Duration* variable from the Daily lognormal CPUE model.

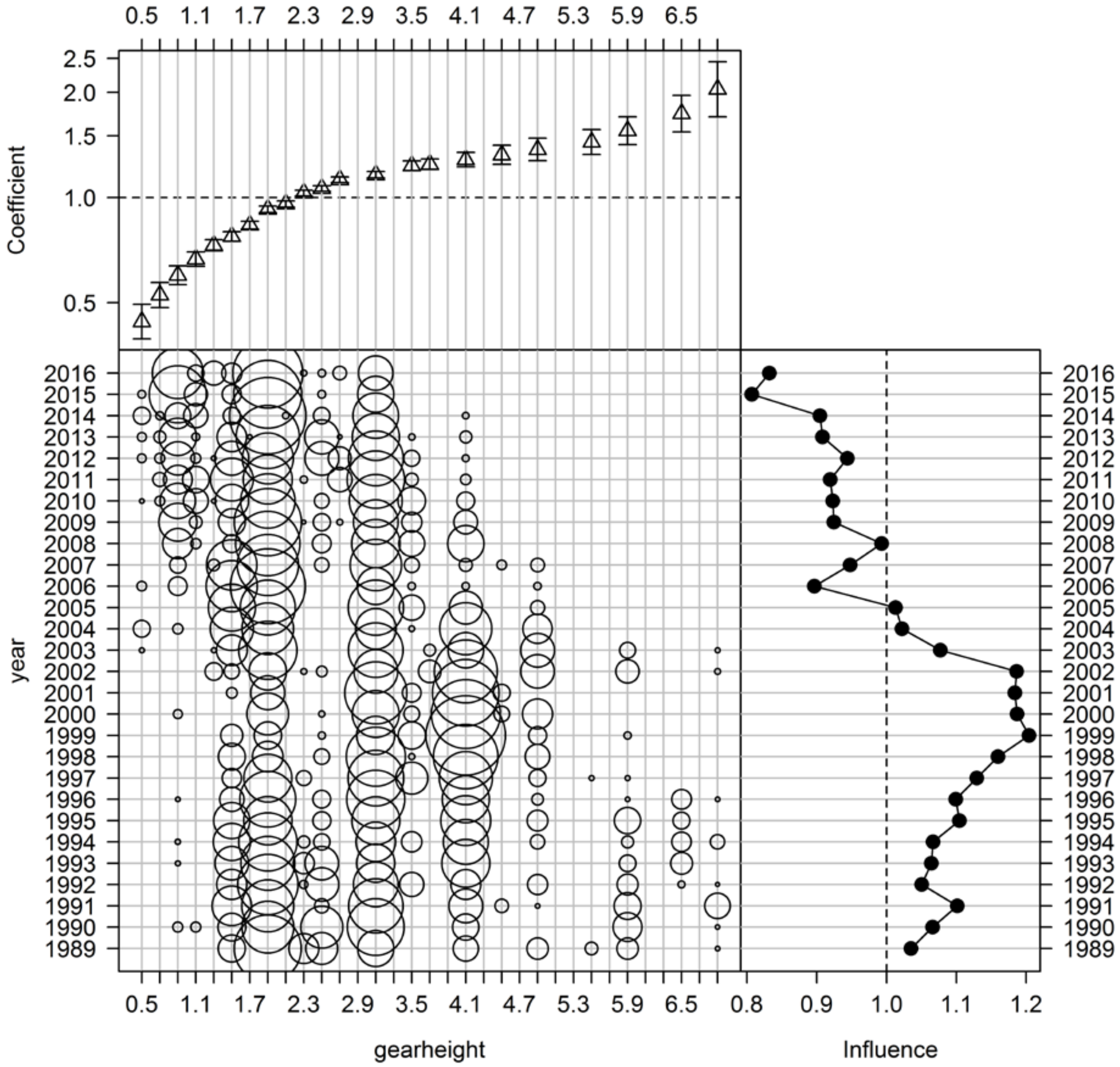

Figure A4: Influence plot for the *GearHeight* variable from the Daily lognormal CPUE model.

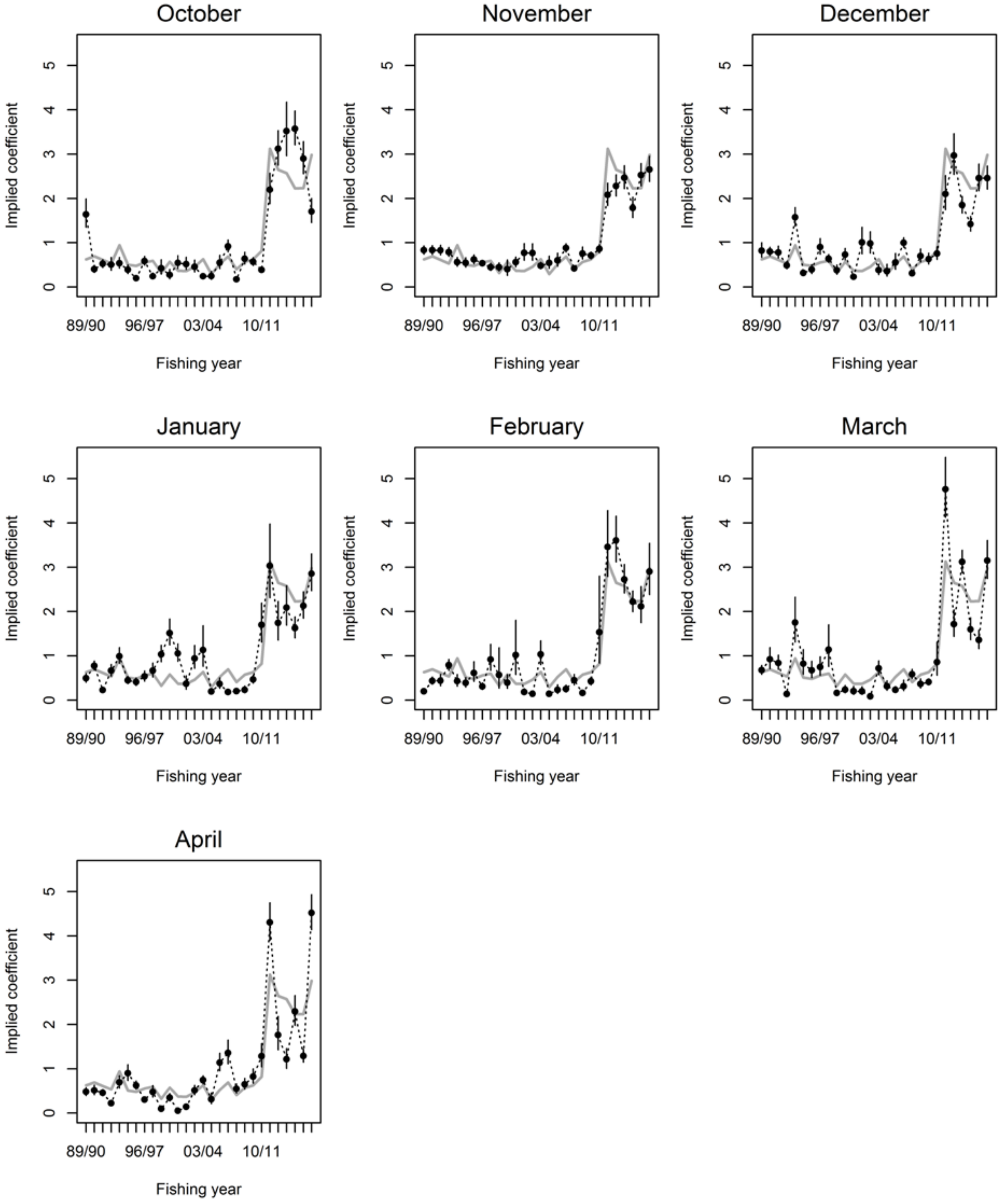

Figure A5: Annual implied coefficients (points) for the individual *Months* included in the Daily lognormal CPUE model. The grey line represents the annual CPUE indices derived from the positive catch CPUE model. The confidence intervals represent the standard error of the annual residuals.

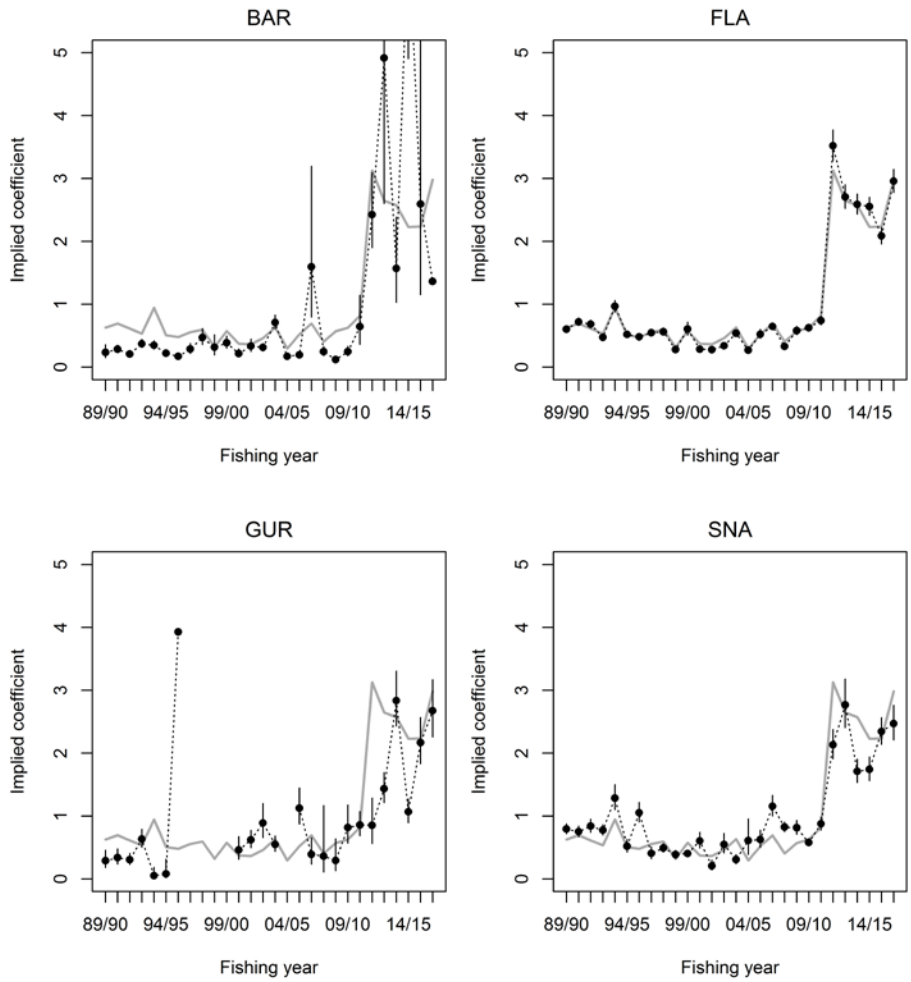

Figure A6: Annual implied coefficients (points) for the individual *TargetSpecies* included in the Daily lognormal CPUE model. The grey line represents the annual CPUE indices derived from the positive catch CPUE model. The confidence intervals represent the standard error of the annual residuals.

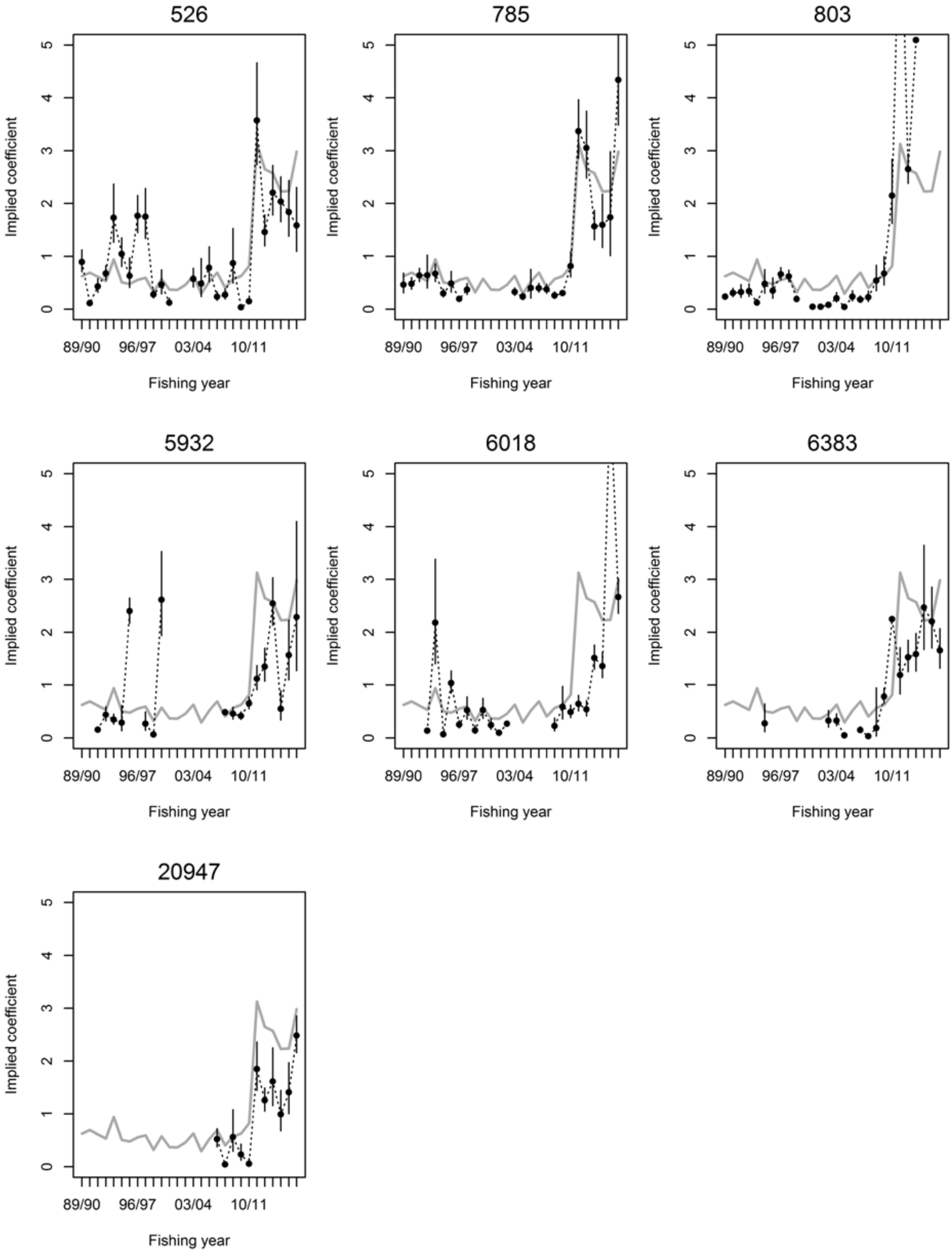

Figure A7: Annual implied coefficients (points) for the main *Vessels* included in the Daily lognormal CPUE model. The grey line represents the annual CPUE indices derived from the positive catch CPUE model. The confidence intervals represent the standard error of the annual residuals.

APPENDIX 2. MODEL INPUT DATA SETS

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

Year	Fishery catch (t)			Year	Fishery catch (t)		
	BT	BPT	Rec		BT	BPT	Rec
1931	83	0	10	1975	473	473	36
1932	43	0	10	1976	250	998	38
1933	78	0	10	1977	171	685	39
1934	8	0	10	1978	326	2 938	41
1935	12	0	10	1979	213	1 918	31
1936	233	0	10	1980	88	791	25
1937	226	0	10	1981	142	568	23
1938	179	0	10	1982	142	567	21
1939	190	0	10	1983	131	522	19
1940	209	0	10	1984	82	326	17
1941	154	0	10	1985	65	259	16
1942	78	0	10	1986	57	226	15
1943	35	0	10	1987	57	199	15
1944	115	0	10	1988	136	58	17
1945	142	0	10	1989	259	65	18
1946	278	0	10	1990	141	35	20
1947	570	0	10	1991	130	33	22
1948	653	0	10	1992	145	36	24
1949	572	0	10	1993	129	32	25
1950	617	0	10	1994	132	33	26
1951	689	0	10	1995	128	32	27
1952	676	0	10	1996	143	36	27
1953	569	0	10	1997	180	20	26
1954	469	0	10	1998	141	16	25
1955	605	0	10	1999	172	19	25
1956	986	0	10	2000	154	17	25
1957	1 266	0	10	2001	140	16	25
1958	865	0	10	2002	185	21	33
1959	780	0	10	2003	213	24	35
1960	688	0	10	2004	176	20	38
1961	700	0	10	2005	164	18	43
1962	698	0	11	2006	246	27	43
1963	683	0	13	2007	185	21	41
1964	689	0	16	2008	203	23	40
1965	936	0	18	2009	186	21	40
1966	1 627	0	21	2010	190	37	57
1967	1 936	0	22	2011	205	33	89
1968	1 244	0	23	2012	232	0	99
1969	659	0	25	2013	231	0	103
1970	751	0	27	2014	231	0	92
1971	768	0	29	2015	208	0	83
1972	920	0	32	2016	277	0	92
1973	1 510	0	35				
1974	985	246	35				

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

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

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

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

Table A6: Proportional age composition for the 2017 *Kaharoa* trawl survey (2016 model year). The oldest age class represents an accumulated age class (plus group).

Age (yr)	Proportion
1	0.0000
2	0.0075
3	0.0007
4	0.0333
5	0.0151
6	0.1675
7	0.0352
8	0.0437
9	0.4915
10	0.0251
11	0.0673
12	0.0438
13	0.0152
14	0.0122
15	0.0074
16	0.0000
17	0.0253
18	0.0002
19	0.0030
20	0.0000
21	0.0000
22	0.0000
23	0.0000
24	0.0000
25	0.0000
26	0.0000
27	0.0014
28	0.0000
29	0.0000
30	0.0044

Table A7: Commercial size grade data for the bottom trawl (BT) fishery. The data are tabulated as the proportion of the annual graded catch, by weight, in each grade category. The grade categories are denoted by the minimum fish weight (kg) in each grade. Model years are denoted by the year at the start of the fishing year (e.g. 1992 is the 1992/93 fishing year).

Grade										Model year
category	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
0.300	0.003	0.001	0.001	0.001	0.004	0.000	0.004	0.055	0.000	0.000
0.400	0.016	0.147	0.001	0.004	0.068	0.013	0.106	0.097	0.135	0.061
0.667	0.091	0.274	0.117	0.144	0.104	0.117	0.030	0.151	0.470	0.548
1.428	0.094	0.318	0.364	0.288	0.252	0.013	0.062	0.143	0.102	0.169
2.000	0.470	0.260	0.517	0.562	0.573	0.858	0.798	0.554	0.294	0.221

Grade			Model year
category	2014	2015	2016
0.300	0.000	0.003	0.000
0.400	0.040	0.024	0.003
0.667	0.299	0.221	0.075
1.428	0.263	0.136	0.090
2.000	0.398	0.617	0.832

Table A8: Length frequency distributions from the snapper sampled from the recreational fishery. Model years are denoted by the year at the start of the fishing year (e.g. 1992 is the 1992/93 fishing year).

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

APPENDIX 3. MCMC DIAGNOSTICS

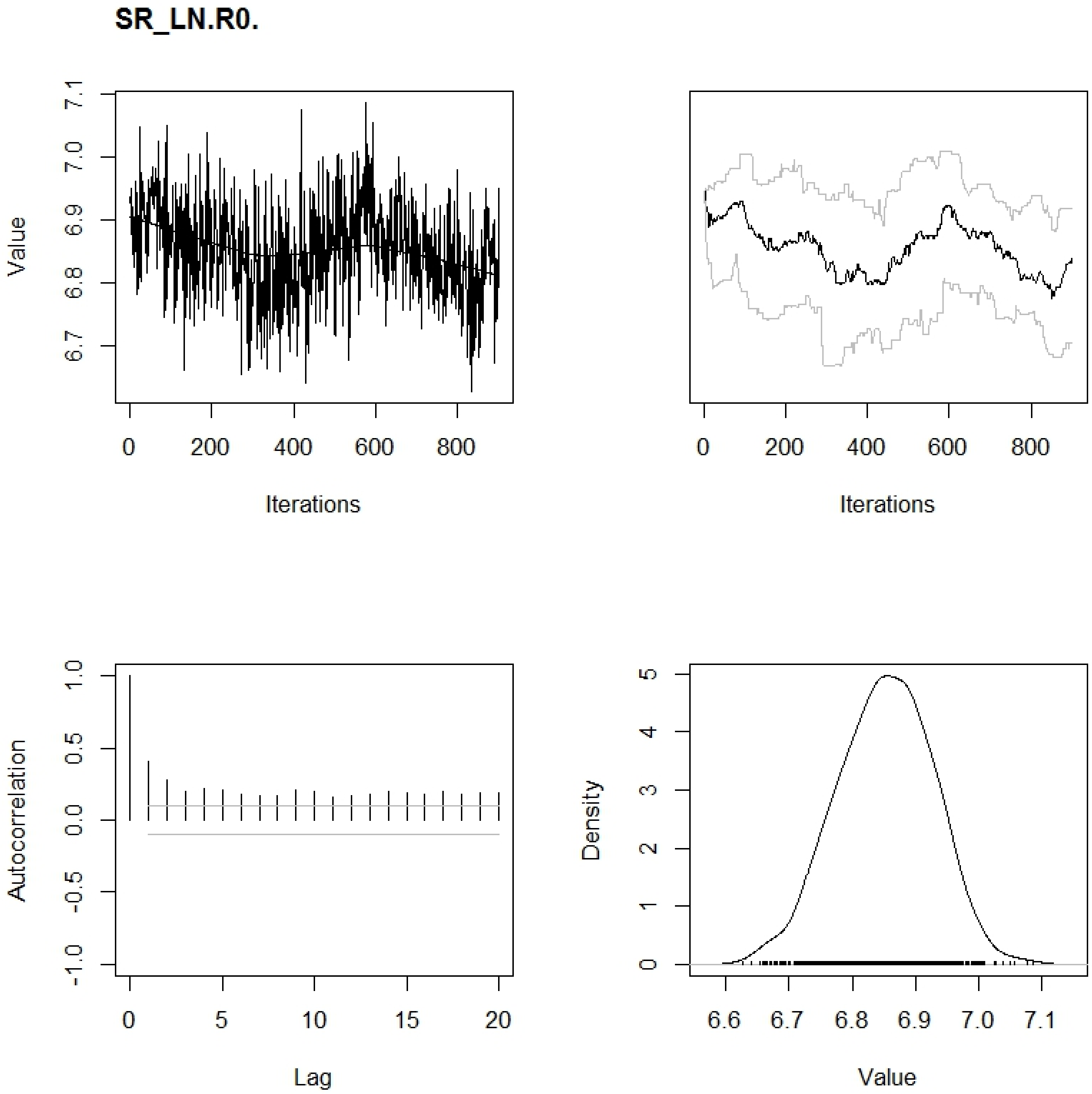

Figure A8: Diagnostic plots for the McMC draws for the *LnR0* parameter of the base assessment model.

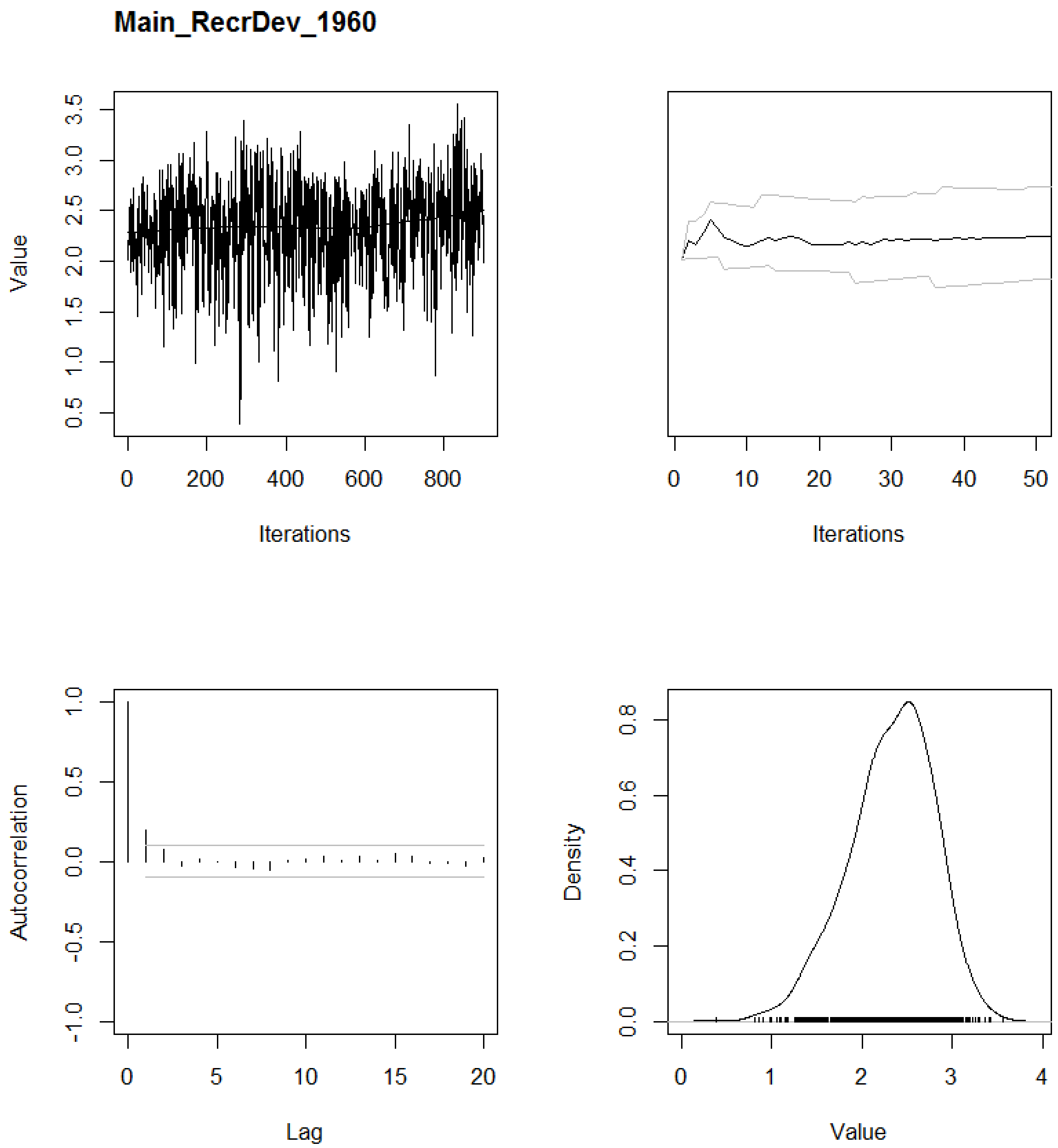

Figure A9: Diagnostic plots for the McMC draws for the *RecDev_1960* parameter of the base assessment model.

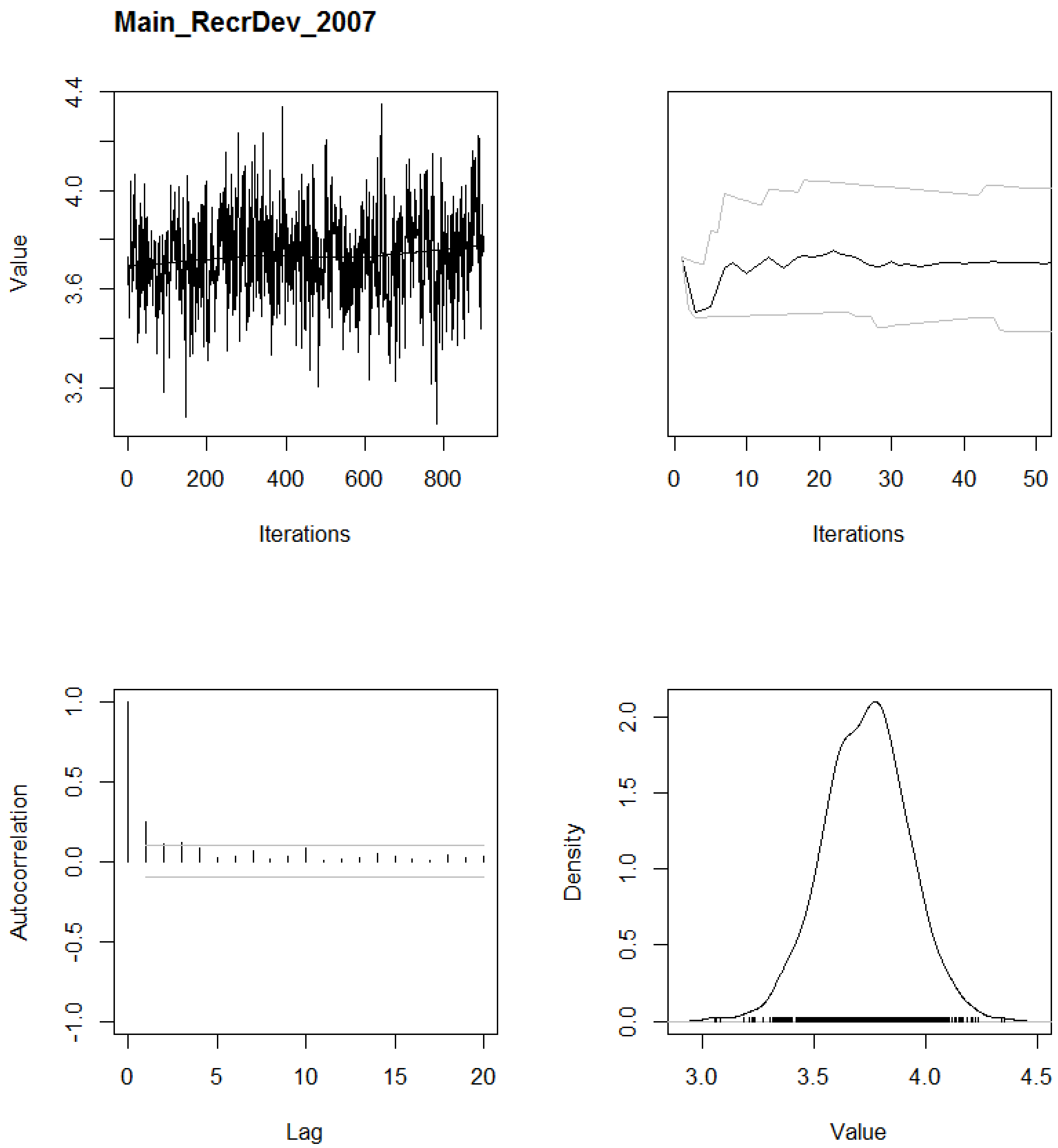

Figure A10: Diagnostic plots for the McMC draws for the *RecDev_2007* parameter of the base assessment model.

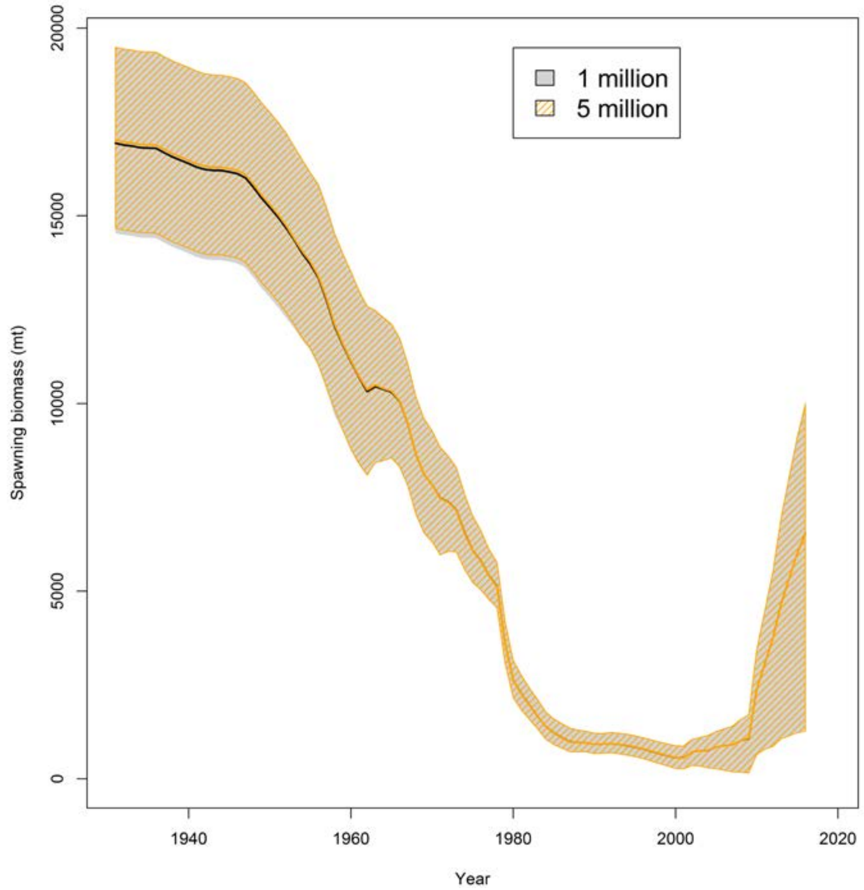

Figure A11: A comparison of the spawning biomass trajectories and 95% confidence intervals derived from McMC chains of different lengths sampled from the base assessment model. In each case, McMCs were sampled at each 1000 interval.