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Stock assessment of snapper in SNA 7

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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, and commercial age and size composition data. The assessment model provides a coherent integration of the main data sets.

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_{2014} or 2014/15) biomass is estimated to be at 29% 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 year class, quantified by a large increase in the CPUE indices from the Tasman/Golden Bay trawl fishery during 2010/11–2013/14. The strong 2007 year class is also evident in the recent age composition data from the commercial fishery. There is also some evidence to indicate the presence of a relatively strong 2010 year class.

The current stock status was assessed relative to the MPI Harvest Strategy Standard. Current (2014/15) biomass is assessed to be above the soft biomass limit (20% SB_0) and below the interim target biomass level (40% SB_0). Current rates of fishing mortality are considered likely to be below the corresponding target fishing mortality level ($F_{SB40\%}$). These conclusions were robust to the range of key model assumptions investigated.

Stock projections were conducted for a 4 year period (i.e. 2015/16–2018/19), based on the status quo (2014/2015) commercial catch/TACC (200 t) and two alternative scenarios for recreational catch (status quo or increasing with stock abundance). The stock projections are largely driven by the continued increase in the biomass of the 2007 year class. The spawning biomass is forecast to continue to increase towards the target biomass level ($SB_{40\%}$), although the stock is unlikely to attain the target biomass level by 2018/19.

The current and projected stock status is sensitive to the estimate of the strength of the 2007 year class and the strength of subsequent recruitment, especially the 2010 year class. Further sampling of the age composition of the commercial catch would provide information regarding the relative strength of these year classes. Ideally, sampling would be undertaken once the 2010 year class is fully recruited to the commercial fishery (2015/16 or 2016/17). It is recommended that a full update of the stock assessment is conducted in 2017/18 to confirm that the stock is continuing to rebuild towards the target biomass level.

1 INTRODUCTION

A stock assessment of SNA 7 was undertaken in 2002 (Gilbert & Phillips 2003) following an initial assessment conducted by Harley & Gilbert (2000). These assessments incorporated a long time-series of historical catch and the magnitude of the overall catch produced relatively large estimates of virgin stock biomass. Correspondingly, the productivity of the stock was estimated to be relatively high. The stock was estimated to be in a depleted state during the 1980s, based on lower levels of catches and the 1986–88 estimate of absolute biomass from a tag release/recapture programme (Kirk et al. 1988). Nonetheless, the assessments estimated that the stock had rebuilt to well above the B_{MSY} level by the early 2000s, driven by the assumption that recruitment had fluctuated at about average levels during the 1980s and 1990s (Gilbert & Phillips 2003).

These early stock assessments did not include an index of relative abundance, and the model prediction of increasing stock abundance had not been corroborated by increasing catches, catch rates or other auxiliary information. Following an external review of the SNA 7 assessment in 2006, , the Snapper Working Group concluded that the estimates of stock biomass from the terminal years of the assessment model (early 2000s) were unrealistically high and, hence, the assessment was not providing reliable estimates of stock status and yields. The Working Group also concluded that a further SNA 7 assessment should not be conducted until a reliable index of abundance was available for the stock (MPI 2014a).

The development of a time-series of CPUE indices from the SNA 7 trawl fishery (Hartill & Sutton 2011) has enabled a new stock assessment to be conducted (MPI 2014a). The assessment model was similar in structure to the earlier assessments and many of the historical data sets were sourced directly from Harley & Gilbert (2000). The results were accepted as a preliminary assessment by the Plenary in 2014 (MPI 2014a), although a range of issues were identified that required further investigation and model development. These issues included the incorporation of recent (2013/14) age composition data, an update of the CPUE indices, restructuring of commercial catch history by fishing method, a review of historical age composition data and the estimate of snapper biomass from the 1987 tagging programme (MPI 2014a).

These issues were addressed during 2014–15 and the stock assessment model was refined and updated accordingly. This report documents the completed SNA 7 stock assessment that was accepted by the Fishery Assessment Plenary in May 2015. The development and completion of the assessment was funded by Southern Inshore Fisheries Management Company Ltd and the Ministry for Primary Industries.

2 DATA SETS

Data are available from the SNA 7 fishery from a wide range of sources collected throughout the history of the fishery. This section details the various data sets included in the final stock assessment model. In developing the stock assessment model, a range of additional data sets were reviewed and their suitability for inclusion in the assessment was evaluated. These data sets are briefly summarised in Section 2.7.

2.1 Commercial catch

Commercial catch data are available for the SNA 7 fishery from 1931. The time-series of annual reported commercial catches were derived from MPI (2013). The reported commercial catches prior to 1986 were increased by 20% to account for an assumed level of under-reporting. There was no allowance for under-reporting of the commercial catch in the subsequent years (post 1986). These assumptions are consistent with the formulation of the commercial catch history incorporated in previous SNA 7 assessments.

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.

The current catch and effort reporting regime provides sufficient information to determine the proportion of the total catch taken by each method fishery during 1989–2014. For the period of the catch history prior to 1989, the following rationale was applied to apportion catches to each method fishery.

1. The pair trawl fishery commenced operation in the mid 1970s (Kevin Sullivan, MPI, pers. comm.). Prior to 1974, all commercial catch was allocated to the single trawl fishery (Figure 1).
2. SNA 7 catches peaked in the late 1970s and early 1980s following the introduction of the pair trawl fishing method and the direct targeting of spawning schools of snapper. During this period, it was assumed that only 10% of the catch was taken by single trawl, the remainder being taken by the combined pair trawl and purse seine fishery. There was a transitional period during the mid 1970s when it was assumed the proportion of the single trawl catch declined from 100% (1973) to 10% (1978).
3. The purse seine fishery ceased operating in the early 1980s and, therefore the relative proportion of the catch taken by single trawl is likely to have increased. From 1981 to 1986, it was assumed that single trawl accounted for 20% of the SNA 7 catch. The available data from the Fisheries Statistical Unit (FSU) from 1983–87 are generally consistent with this assumption with the single trawl fishery accounting for 18% of the total catch during the period.
4. Following the introduction of the QMS, the proportion of catch taken by the pair trawl fishery declined, and by 1989/90 this fishery represented about 20% of the total catch. It was assumed that the proportion of the catch taken by single trawl steadily increased from 20% in 1986 to 80% in 1989.

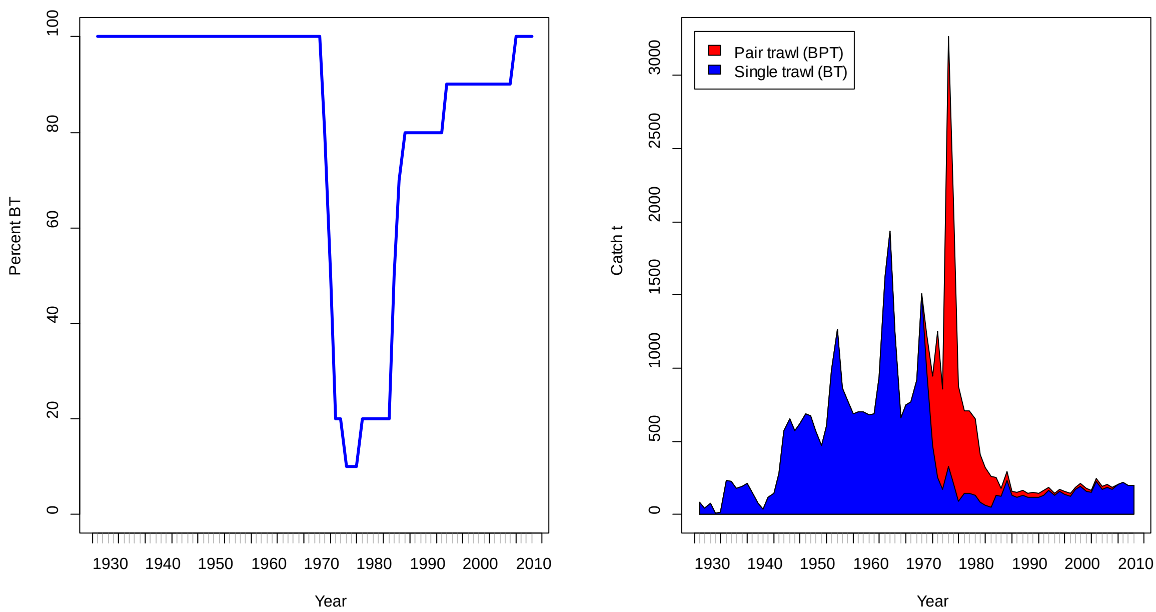

Figure 1: The proportion of the total SNA 7 catch allocated to the BT fishery by year (left panel) and the total annual commercial catch by fishing method (right panel), including an allowance for unreported catch prior to 1986.

The SNA 7 annual catches for 1931–82 documented in the 2014 Plenary Report (MPI 2014a) differs considerably from MPI (2013). This is due to a revision of the catch history by Francis & Paul (2013). The revised annual catches are considerably lower (approximately 25% lower) than the previous reported catches. This is the result of snapper landings in Nelson being reapportioned between FMA 7 (70%) and FMA 8 (30%), compared to the previous catch history that assumed that all of the Nelson landings were from SNA 7 (Francis & Paul 2013). There are some concerns that the assumption of a constant proportional split of the Nelson landed catch may not be appropriate for SNA 7, particularly during the 1970s and early 1980s when snapper were targeted within Tasman Bay and Golden Bay. The apportioning of the landed catch probably results in a substantial underestimation of the SNA 7 catch during that period. On the other hand, the previous catch history probably represents an over-estimate of the catch in the earlier period (1950s and 1960s), although the absolute magnitude of the discrepancy is likely to be relatively minor. On that basis, the previous catch history (MPI 2013) was retained for the current assessment, although further evaluation of the catch history is probably warranted.

2.2 Non-commercial catch

The model included a non-commercial fishery that encompasses catches from the recreational and customary sectors. A catch history for the non-commercial fishery was derived based on three relatively recent estimates of recreational catch. 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 survey (2005/06 42.6 t) and panel survey (2011/12 88 t) were used to determine the annual non-commercial catch in the specific years. Previous telephone/diary estimates of recreational catch are considered unreliable and were disregarded (MPI 2014a) (Figure 2).

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 and 2010) (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 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 in 2011 was slightly higher than the 2005 level. A linear increase in ER was assumed between the two years and the resulting ER was used to determine the recreational catch during the intervening years.

vi. The non-commercial exploitation rates in 2012–2014 were assumed to be equivalent to the 2011 level. The ER was applied to total recruited biomass to determine recreational catch in these years. The relatively large increase in estimated stock biomass (from the assessment model) results in a substantial increase in the assumed recreational catch during the most recent years (Figure 2).

vii. Prior to 1987, the ER is assumed to decrease at 10% per year 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 or the catch determined from ER (vii).

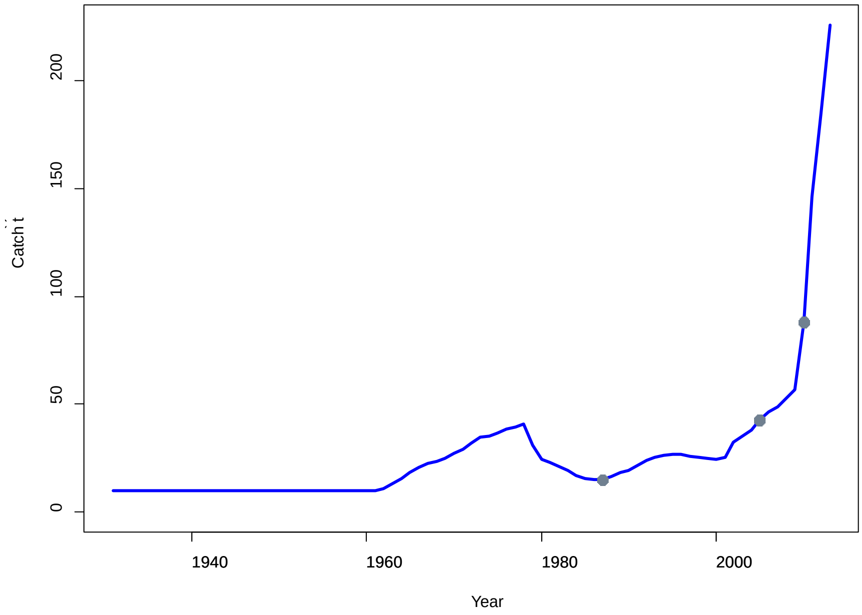

Figure 2: Annual non-commercial catch from SNA 7 included in the stock assessment model. The grey points represent individual estimates of recreational catch for SNA 7 (see text for details).

Some members of the SINS Working Group expressed concern that there was a degree of circularity in the approach used to derive the time-series of non-commercial annual catches using the biomass trajectory derived from a stock assessment model. In response, an alternative approach was applied to determine recent recreational catches, following the methodology used to derive annual recreational catches for the CRA 1 and CRA 3 rock lobster fisheries (MPI 2014b). This approach involved determining the ratio between the three SNA 7 recreational catch estimates and the SNA 7 BT CPUE indices in the corresponding year. The ratio was then applied to the entire BT CPUE time-series to determine annual estimates of recreational catch. The resulting annual catch estimates were very similar to the catch estimates derived from the model biomass trajectory.

2.3 BT CPUE indices

Recent CPUE indices for the BT fishery were derived by Langley (2013), updating the previous analysis by Hartill & Sutton (2011). The current study extended the GLM standardised CPUE analysis to include data from the 2012/13 and 2013/14 fishing years. The current CPUE analysis was based on the equivalent delta-lognormal model structure to the previous analyses (Langley 2013).

The resulting CPUE indices increased considerably from 2009/10 to 2011/12 and remained at the higher level during 2011/12–2013/14 (Figure 3). Additional CPUE modelling identified a significant fishing year, month interaction term that was primarily related to an increase in the catch rate of snapper in February–March during the more recent years (from 2010/11). The increase in the seasonal availability of snapper has been interpreted as adult snapper remaining within the Tasman Bay/Golden Bay area later in the fishing season compared to the preceding years. Such a change in fish behaviour could introduce a positive bias in the resulting abundance indices derived from the CPUE data from the entire fishing period (October–May).

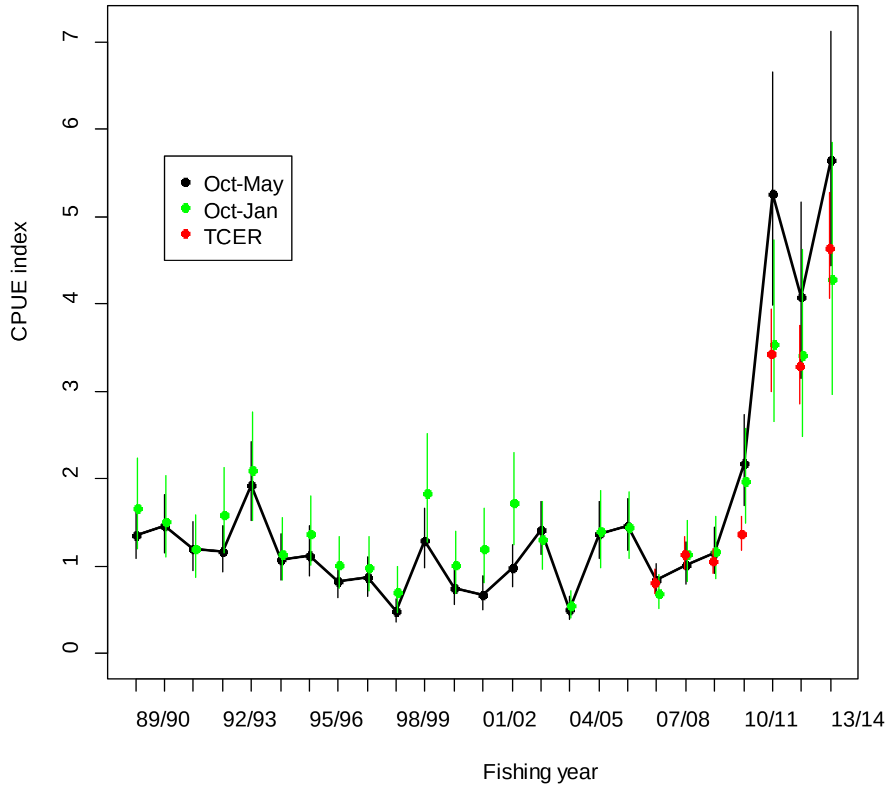

Figure 3: Relative SNA 7 CPUE indices derived from the delta-lognormal model for the combined single trawl fishery (Oct-May). The vertical lines represent the 95% confidence intervals. The confidence intervals were derived using a bootstrapping procedure. For comparison, indices derived from the October–January period and from the TCER data set are also presented.

An alternative set of CPUE indices was derived from a more restricted fishing period (October–January). The alternative CPUE indices were derived from a delta-lognormal model with the equivalent formulation (lognormal and binomial components) to the CPUE models incorporating the entire fishing period. The resulting indices exhibited a similar annual trend, although the recent increase was less pronounced than the CPUE model for the entire period (an increase of about 300% compared to 450%) (Figure 3). Both sets of indices have relatively large confidence intervals associated with the more recent CPUE indices.

A third set of CPUE indices were derived from the individual trawl records reported using the Trawl Catch and Effort Return (TCER) from 2007/08 to 2013/14. Data definition was similar to that used for the other CPUE analyses; with the data set limited to single bottom trawl records that targeted snapper, flatfish, barracouta or red gurnard within Statistical Area 038 during the October–March. The data set was limited to vessels that operated in the fishery for at least three of the seven years.

The final TCER data set of 9134 trawls was dominated by trawls targeting flatfish species (70% of records) and included a declining number of snapper target trawls from 2010/11 onwards. The final data set included a total snapper catch of 55–70 t per annum, representing 60–80% of the total qualifying snapper catch. The reduction in the catch and the associated number of trawl records is primarily attributable to the criteria applied to select the main vessels in the final data set.

The TCER data set included a range of variables detailing the operation of the trawl fishery. Variables included in the CPUE analysis included fishing year, month, vessel identifier, fishing location, target species, trawl start depth, trawl headline height, trawl speed and trawl duration. Fishing location was defined based on a grid of 0.2 degree latitude and longitude cells. An interaction term between month and depth was also included to account for seasonal trends in the depth distribution of snapper.

A standardised CPUE analysis was conducted using a step-wise GLM procedure to model the positive catch component assuming a lognormal error structure, and the presence/absence of snapper in the catch (binomial error structure). The resulting annual indices from the two models were combined to derive a set of delta-lognormal CPUE indices. The resulting indices were similar to the corresponding CPUE indices from the October–January CPUE model, although there was a higher level of precision for the indices derived from the TCER data (Figure 3).

2.4 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). The programme released a total of 4657 tagged fish during summer 1986/87. The tag recovery period was limited to October 1987 to January 1988 and a total of 390 tags were recovered from the commercial catch of 190 t that was taken during that period. The tag reporting rate for the commercial fishery was assumed to be 100%.

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). For the purpose of the current assessment, the stock biomass is assumed to represent the total biomass of snapper that had recruited to the commercial BPT fishery.

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).

For the current assessment, the base model included the tag biomass estimate from the previous assessment and assumed the equivalent level of uncertainty (CV 30%).

An examination of the tagging data set was conducted to investigate the potential magnitude of the bias that could be attributable to spatial heterogeneity in the distribution of tags in the population. The data set includes details of the tag recovery locations and an indication of the nett displacement of tagged fish from the release location. The displacement of tagged fish recovered during the main recovery period revealed that a high proportion of the tagged fish moved a relatively short distance from the release site (less than 5 nautical miles). Further, many of the recoveries were from fish that were released from a relatively small number of the research trawls, primarily within shallow waters (less than 3 fathoms) between Ruby Bay and Rabbit Island and from a few trawls in the shallow waters off Pohara (Golden Bay).

Most (approximately 90%) of the tags recovered in Golden Bay or Tasman Bay were recovered in the respective area of release. This indicates that the tagged fish had not mixed at the scale of the SNA 7 stock. There was clearly substantial variation in the recovery of tags from individual release locations; for some of the research trawls, 30–40% of all the released tags were recaptured during the recovery phase, while recovery rates were very low for a substantial proportion of the release events (trawls). These results indicate a limited amount of mixing of fish in some areas and/or differential exploitation rates amongst areas. No data are available to investigate the distribution of total fishing effort and catch during the recovery phase.

The clumped distribution of some of the tag releases has the potential to result in a negative bias in the tag biomass estimate, especially if fishing effort was concentrated in these areas. To investigate the sensitivity of the stock assessment to the magnitude of the tagging biomass estimate an alternative tagging biomass estimate was derived that excluded localised tag recoveries. Tag recoveries were excluded where at least five tags were recovered from within 5 nautical miles of the individual release event. All other tags recovered from the release events (i.e. beyond 5 n. mile) were included in the recovery data set. These criteria reduced the number of tag recoveries by about 50% (from 390 to 197). The total number of tag releases was also corrected to account for the tags excluded from the recovery data set.

The reduction in tag recoveries resulted in a proportionate increase in the tag biomass estimate and was approximated by doubling the actual biomass estimate (from 1 548 t to 3 098 t). The alternative tag biomass estimate is not intended to represent a credible estimate of stock biomass, rather the intention is to determine the scale of the likely negative bias and investigate the sensitivity of the model results to higher estimates of tag biomass.

2.5 Age composition data

Age composition data are available from the commercial catch of the SNA 7 fishery from two periods demarcated by the introduction of the QMS (1986/87). All age sampling data have been aggregated by sex on the basis that there is no variation in growth between the sexes.

The previous SNA 7 stock assessments included nine age compositions from the commercial catch from the 1970s and early 1980s (Harley & Gilbert 2000, Gilbert & Phillips 2003). Harley & Gilbert (2000) provide limited information to explain the derivation of these data, except to state that the samples were "assumed to have been collected as simple random samples". The fit to the individual age compositions was quite variable indicating a lack of coherence in the time series of age samples (figure 3 from Harley & Gilbert 2000).

These data were incorporated in the preliminary SNA 7 assessment presented to Plenary in 2014. The model runs also highlighted inconsistencies in the time series of age composition data from the 1970s and early 1980s. The 2014 Plenary recommended that further examination of these data was required to evaluate the reliability/representativeness of the individual age compositions and the appropriate model configuration for the inclusion of these data (MPI 2014a).

A subset of five of the nine years of sampling data were available for review (Dr Kevin Sullivan MPI, unpublished data) (Table 1). Each year of sampling included a limited number of landings (1–4) sampled for otoliths and in some of the years sampling was also conducted of the length composition of additional landings. Most of the age samples were obtained from catches by the pair trawl fishery with some samples also taken from purse-seine and single trawl landings. Some years also included additional sampling from catches taken outside the main fishing season (October–March).

Annual age compositions were recomputed for the five years with available data. The age samples were limited to the data collected during the main fishing season, primarily from the pair trawl fishery. Data collected from the small number of landings from the purse-seine fishery were also included on the basis that the selectivity of the pair trawl and purse seine fisheries was likely to be similar, i.e. both methods are considered to exploit the full range of the recruited age classes. Two approaches were applied to determine the annual age compositions from these data: 1) a simple aggregation of the aged otoliths from all qualifying landings and 2) determining an age-length key (ALK) from the annual otolith collection and applying the ALK to an annual combined length composition derived from all sampled landings. The two approaches produced very similar annual age compositions and for simplicity, age compositions derived from the former approach were used in the final assessment model. These age compositions were very similar to those presented in Harley & Gilbert (2000). The five annual age compositions were assigned to the pair trawl fishery in the assessment model (Table 1).

It was not possible to evaluate the reliability of the age composition data from the four years without the associated source data. The three earliest years (1969, 1972 and 1973) predate the introduction of the pair trawl fishing method and it may be assumed that the data were collected from the single trawl fishery. However, no information is available regarding the seasonality of the sampling and there was considerable variability in the age compositions. On that basis, it was decided to exclude these data from the final assessment model (Table 1). Similarly, the 1977 age composition was also excluded due to the lack of supporting information.

Table 1: A summary of the age composition data available 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
	1969			No additional information/data available.	Not included
	1972			No additional information/data available.	Not included
	1973			No additional information/data available.	Not included
	1977			No additional information/data available.	Not included
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	Scaled age composition, October–March. Parker (2015).	BT

For the post QMS period, age compositions are available for eight years during 1992/93–2013/14. The details of the individual sampling programmes are provided in the corresponding reference documents (Table 1). The age compositions are representative of the commercial catch from SNA 7 and are dominated by the catches from the spring–summer period. For most years, there was no stratification of the sampling by trawl method (BT or BPT) and the age compositions represent an amalgam of the catch from the two fishing gears. However, during the post QMS period, the commercial catch has been dominated by the single bottom trawl method and, on that basis, the age compositions were assigned to the BT fishery in the assessment model (Table 1).

2.6 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 2004/05–2013/14. 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). 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.

2.7 Other data sets

A range of other data sets from SNA 7 were evaluated for inclusion in the current stock assessment modelling. The data sets were not included in the final assessment models for the reasons summarised in the following paragraphs.

Age compositions of the snapper sampled by trawl surveys in 1969, 1971 and 1972 were included in previous assessments (Harley & Gilbert 2000, Gilbert & Phillips 2003). The age compositions are highly variable among the surveys, particularly the proportion of juvenile (age 1 and 2 year) and older (20 years or more) fish in the individual age compositions. Preliminary models that included these data were unable to provide a coherent fit to the individual age compositions and it was considered that these data were not providing a reliable indication of the age structure of the population.

The tagging programme provided an estimate of the population age structure in 1988 (Kirk et al. 1988, Harley & Gilbert 2000). However, the resulting age composition is dominated by a relatively narrow range of age classes and the age composition was not consistent with the age structure of the BPT catch from the preceding years. On this basis, it was concluded that the tagging programme had not adequately sampled the older age classes in the population and, consequently the resulting estimate of the age structure was not representative of the entire population (see Section 4.1.2).

Commercial catch and effort data from the Tasman/Golden Bay snapper fishery from 1983–1987 were evaluated to determine the potential to derived annual CPUE indices for the period. During the period, most (70–85%) of the annual snapper catch was taken by the pair trawl method. The reporting of catches by this method appears to be problematic for the period when data were collected by the Fisheries Statistic Unit (FSU) and it was not possible to reconcile the total snapper catch with the overall landed catches reported for SNA 7 (MPI 2013). Insufficient time and resources were available to fully interrogate the catch and effort data set to identify the extent of duplication of reported catch and effort from individual vessel pairs operating in the fishery.

Three trawl surveys of juvenile snapper were conducted in Tasman/Golden Bay during 1983–86 (Drummond & Kirk 1986). The length compositions derived from these surveys provide some indication of the relative year class strength of snapper from 1980–1985. However, the surveys were not designed to quantify the relative abundance of the individual year classes and, consequently, the data are unlikely to be informative in the framework of an assessment model. It appears that the 1980–1985 year classes corresponded to a period of low overall recruitment (see Section 4.1.1).

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). Trawl surveys are conducted during March–April and the most recent survey was conducted in 2015. Snapper are not a specified target species for the survey and the catch rates of juvenile and adult snapper have been low for most surveys. The shallower areas of Tasman/Golden Bay represent the prime habitat for juvenile snapper and these areas are not included within the survey area. Consequently, it is considered that the surveys are unlikely to provide reliable indices of relative year class strength. The trawl surveys are conducted during autumn and the availability of adult snapper to the trawl survey may vary considerably amongst years, depending on the prevailing environmental conditions. The utility of the current trawl survey for monitoring snapper is further discussed in Section 5.

Trawl surveys specifically targeting juvenile snapper in Tasman/Golden Bays were conducted in 1995 and 1996 (Stevenson 1996, Blackwell & Stevenson 1997). These surveys do not provide a sufficient time-series for the monitoring of juvenile snapper. Very few juvenile snapper were caught during either survey. This result is consistent with the results of the stock assessment modelling that estimated very low recruitment during 1990–1994 (see Section 4.1.1).

3 MODEL CONFIGURATION

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

The assessment model includes the entire SNA 7 catch history (from 1931) and assumes that the initial population age structure was in an equilibrium, unexploited state. The population is structured by sex and includes 30 age classes, the oldest age class representing an aggregated "plus" group (30 years or more). The model data period extends to the 2014 year (2014/15 fishing year).

The key biological parameters for the SNA 7 stock assessment are presented in Table 2. Following previous assessments, natural mortality (M) was assumed to be 0.075 for the base model options. Growth parameters for SNA 7 are provided in MPI (2014a). There is no evidence of sexual dimorphism in snapper growth and the growth parameters have been determined for both sexes combined. Variation of length-at-age was assumed to be equivalent to a CV of 5% of the mean length at age based on a cursory examination of SNA 7 ageing data. 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 (1950–2008) 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 using an earlier iteration of the assessment model.

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) (Table 3). For all age compositions there was assumed to be no error associated with the age determination. Each fishery was associated with an age-specific, sex invariant selectivity function. The BT fishery selectivity was parameterised using a double normal function, enabling considerable flexibility in the estimation of the selectivity function (see Methot 2013) (Table 2). The BPT fishing method can potentially catch larger snapper than the single BT fishing method and a separate logistic selectivity function was estimated for the BPT fishery. No age or size composition data are available from the non-commercial fishery and the fishery was assumed to have a selectivity equivalent to the BT fishery.

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 2.4). The single trawl CPUE indices (October–May) are assumed to have a lognormal distribution and represent the relative abundance of the biomass of snapper vulnerable to the BT fishery.

Table 2. 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	0.05	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 (1950–2008)	Estimated (59)
Selectivity			
BT fishery	Double normal parameterisation		Estimated (4)
	p1 – *peak*: beginning age for the plateau	Norm(5,1)	
	p2 – *top*: width of plateau	Norm(-4,1.5)	
	p3 – *asc-width*	1.5 (fixed)	
	p4 – *desc-width*	Norm(3,0.5)	
	p5 – *init*: selectivity at first bin	0 (fixed)	
	p6 – *final*: selectivity at last bin	Norm(2,1.5)	
BPT fishery	Logistic parameterisation		Estimated (2)
	p1 – age at inflection	Norm(3,0.5)	
	p2 – width for 95% selection	Norm(1,0.5)	
Non comm fishery			Equivalent to BT
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 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 3).

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.

Table 3. 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.

Data set	Model years	Nobs	Relative weighting
BT CPUE indices (Oct-May)	1989–2013	25	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	8	ESS 10
Tag biomass	1987	1	CV 30%
Commercial size grade	2004–2013	10	ESS 8

There are six 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. Tag biomass estimate. The fit to the 1987 tag biomass estimate, assuming a lognormal error structure.
iv. Size composition data. The fit to the commercial size grade data assuming a multinomial error structure.
v. Recruitment deviations. The likelihood is formulated to constrain recruitment deviations relative to the (assumed) standard deviation (sigmaR).
vi. 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.

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 2014 model year (2014/15 fishing year) ($SB_{current}$ or SB_{2014}).

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 also implies a default target biomass level of 40% SB_0 for stocks where SB_{MSY} has not been fully evaluated. 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 (2014). Estimates of equilibrium yield are determined from the level of fishing mortality that produces the target biomass level ($F_{SB40\%}$).

4 RESULTS

During model development, a wide range of model options were investigated to examine key structural assumptions, including parameterisation of model priors (especially fishery selectivity), the relative weighting of different data sets and the estimation period for recruitment deviates. Overall, the stock assessment model was relatively insensitive to these assumptions. A base assessment model was chosen that provided a reasonable fit to all the main data inputs and the 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 number of model sensitivity analyses were formulated to encompass the main sources of uncertainty in the stock assessment.

4.1 Model results

4.1.1 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 (double-normal) and BPT fishery (logistic) (Figure 4).

The double-normal selectivity function (Methot 2013) for the BT fishery has four estimated parameters (p1, p2, p4, p6) and one fixed parameter (p3) (Table 2). The initial (starting) parameter values corresponded to a selectivity function that had a relatively high selectivity for the oldest age classes. The model data are relatively informative regarding the parameters that determine the age at recruitment to the fishery (p1) (Figure 4). However, the data appear relatively uninformative regarding the parameterisation of the right-hand limb of the selectivity function (p2, p4 and p6), although there is some tendency towards relatively high selectivity of the oldest age class (p6 parameter) (Figure 4). The model estimates of BT fishery selectivity result in full selectivity at age 5 years and high selectivity for the older age classes (Figure 5).

For the BPT fishery, the data are relatively informative regarding the age at 50% selection (p1) but uninformative regarding the steepness of the selectivity function (p2) (Figure 4). The estimated selectivity function has full recruitment at age 6 years (Figure 5). The selectivity function appears to be quite tightly constrained and the assumed prior distributions may be overly influential. The sensitivity of the model results to the BT and BPT selectivity parameterisations is investigated in Section 4.1.3.

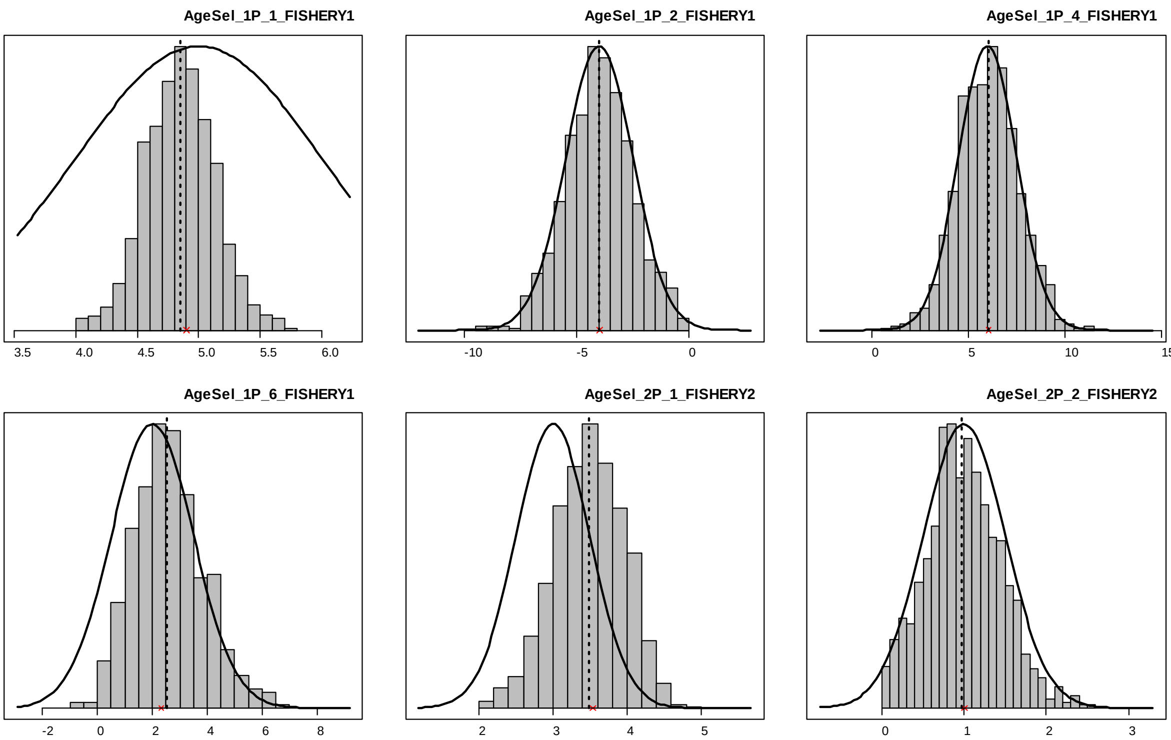

Figure 4: Prior distributions (solid line) and estimated probability distributions derived from McMC (histograms) for the estimated selectivity parameters of the base model (Fishery1, BT; Fishery2, BPT). The median of the McMCs (dashed vertical lines) and MPD estimates (red crosses) are also presented.

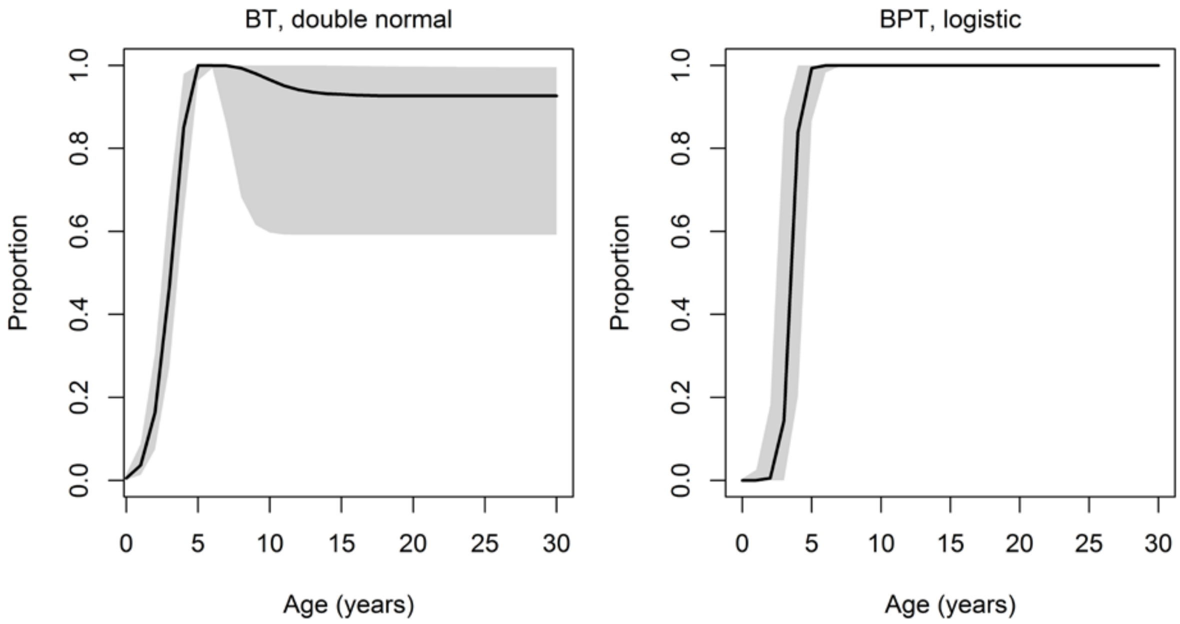

Figure 5: Age specific selectivity functions estimated for the BT (left) and BPT (right) fisheries from the base assessment model. The lines represent the median of the McMC samples and the grey shaded area represents the 95% confidence interval.

Diagnostic plots of the McMC traces for key parameters are presented in Appendix 1. The diagnostics of the R_0 parameter reveal that there is considerable autocorrelation amongst successive McMC draws (Figure A1). The estimates of the R_0 parameter are negatively correlated with the estimates of some of the early year classes (especially 1960 and 1969). 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 2 million and 5 million). The resulting spawning biomass trajectories and confidence intervals were very similar for the three options (Figure A6) 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 exceptionally strong recruitment in 2007 (Figure 6). The variation in the estimated recruitment deviates (std. dev = 0.93) is somewhat less than the assumed variation (*SigmaR* 1.5).

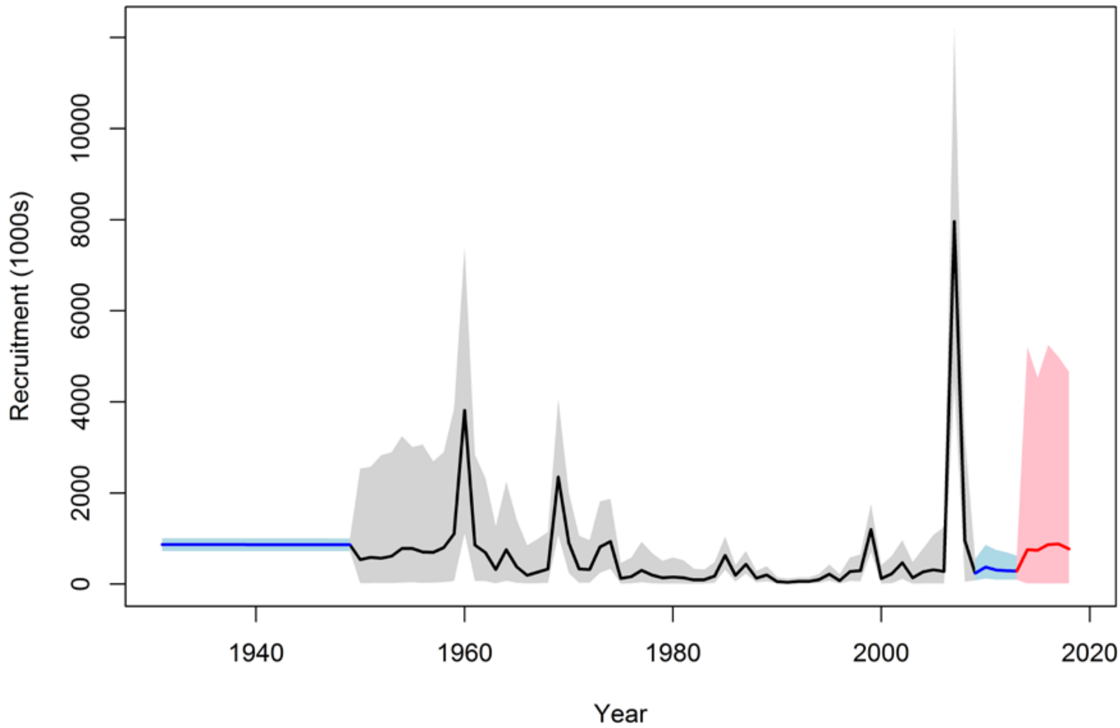

Figure 6: Estimates of annual recruitment (numbers of fish) from the base assessment model. The line represents the median of the McMC samples and the shaded area represents the 95% confidence interval. The grey time block represents the period for which recruitment deviates are estimated. The blue time blocks correspond to years within the model period for which recruitment deviates were not estimated. The red time block represents the 4-year forecast (projection) period.

Recruitment in the most recent period (2009–2014) was not estimated in the base model and recruitment in this period was constrained at a level below the long-term average (Figure 6). This is due to the recruitment estimation procedure implemented in Stock Synthesis, whereby a bias correction factor is applied to the estimated recruitments to ensure that the long-term average recruitment level is consistent with the R_0 level (Methot & Wetzel 2013). In this case the bias correction factor is due to the high value for *SigmaR* (1.5) and the constraint applied to ensure that the 2009–2014 recruitment deviates approximate zero. The constraint was necessary to reduce the influence of the recent data included in the model (primarily the increasing CPUE indices) that indicate that recruitment was above average in the recent period (2009–2014).

4.1.2 Fit to observational data

The base model provides a reasonable fit to the time-series of BT CPUE indices (Figure 7). 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 positive trend in the model residuals during 2008–2011, with a large positive residual in 2011 (Figure 7).

The estimate of vulnerable biomass in 1987 from the base model is consistent with the biomass estimate from the tag release/recovery programme (Figure 8). Kirk et al. (1988) also used the results of the tagging programme to derive an estimate of the population age structure at release. This observation was not included in the base assessment model as there was concern that the tagging programme had not adequately sampled the older age classes in the population. This assumption is supported by the results of the current base model which estimates a broader age structure of the recruited population in 1987 than had been determined from the tag release/recovery programme (Figure 9).

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 10). The base model provides 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) and the aggregate 30+ age class (Figure 10). 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 age compositions from the BT fishery during 1992–2000 are dominated by the progression of the relatively strong 1985, 1987 and 1989 year classes (Figure 11). Fish older than 10 years have represented a minor proportion of the age composition of the sampled catch during 2003–2013 as the model age structure has become dominated by recruitment from 1997 onwards, with particularly higher recruitment estimated for 1997–99, 2002, and 2007–08 (Figure 11). Overall, the model provides a good fit to the time-series of recent BT age samples, although the fit to the youngest age classes (3–4 years) is variable among years (Figure 11). For the 2013 age composition, the model under-estimates the proportion of fish in the 3 year age class, representing the 2010 year class. For the base model, recruitment deviates were not estimated from 2009 onwards and, hence, the proportion of 3 year old fish is not informed by the recent age frequency data. There is some indication that the 2010 year class is reasonably strong and a further model sensitivity run was conducted that extended the recruitment estimation period to include the 2009 and 2010 years.

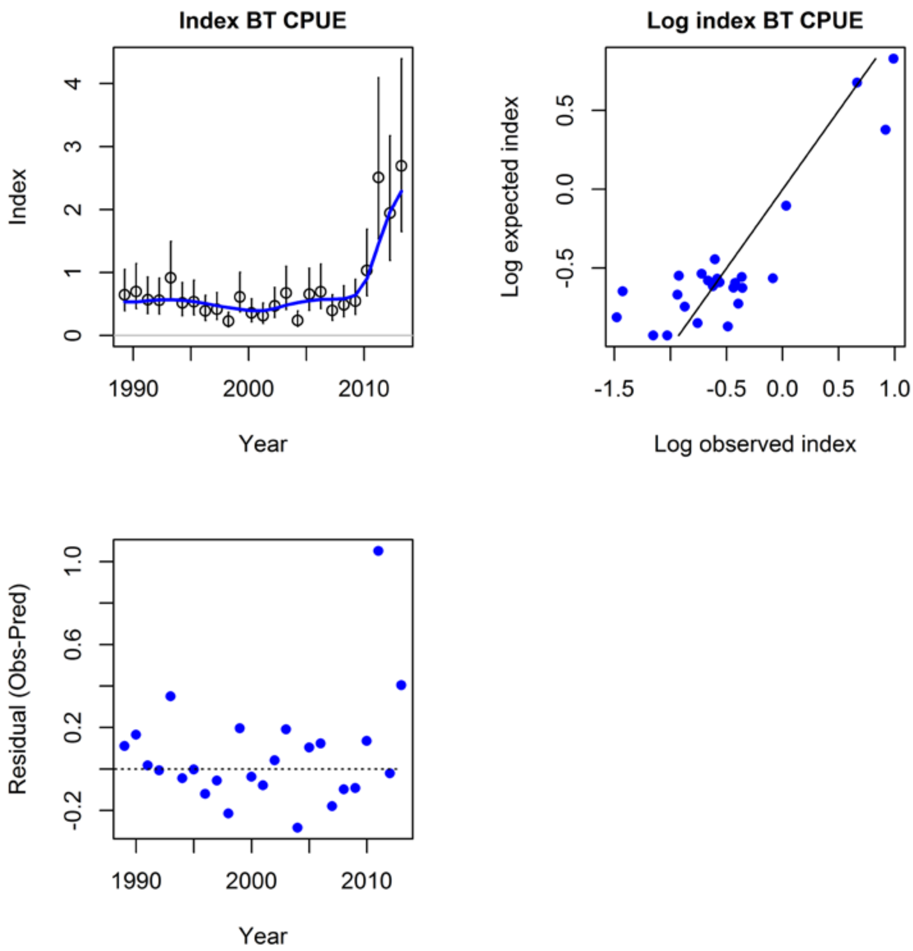

Figure 7: Fit to the CPUE indices and associated diagnostics for the base model. The year represents the model year denoted by the start of the fishing year (e.g. 1995 denotes the 1995/96 fishing year).

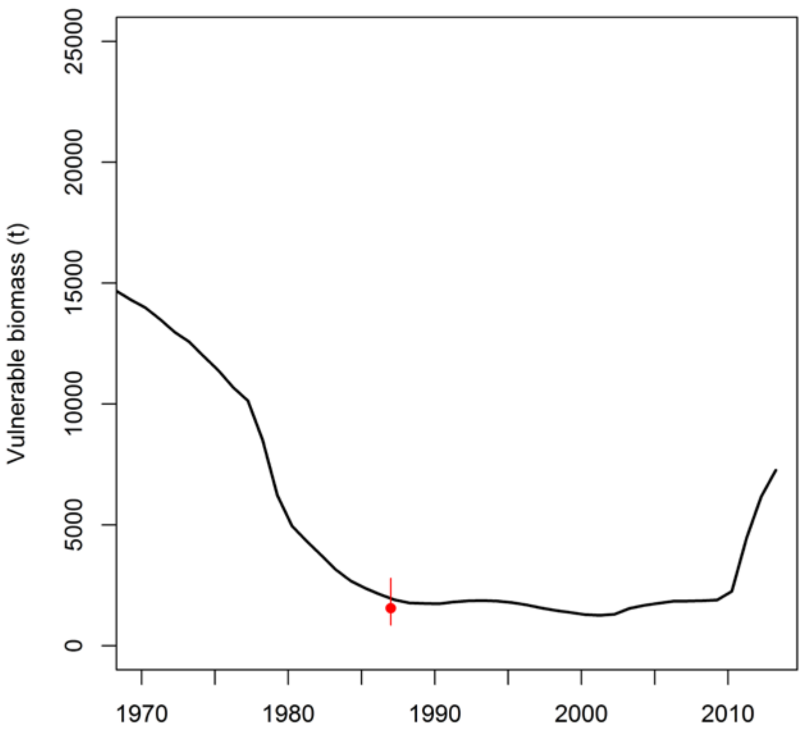

Figure 8: Base model fit to the tagging biomass estimate (red point) and associated confidence interval. The vulnerable biomass is determined based on the estimated selectivity function for the BPT fishery.

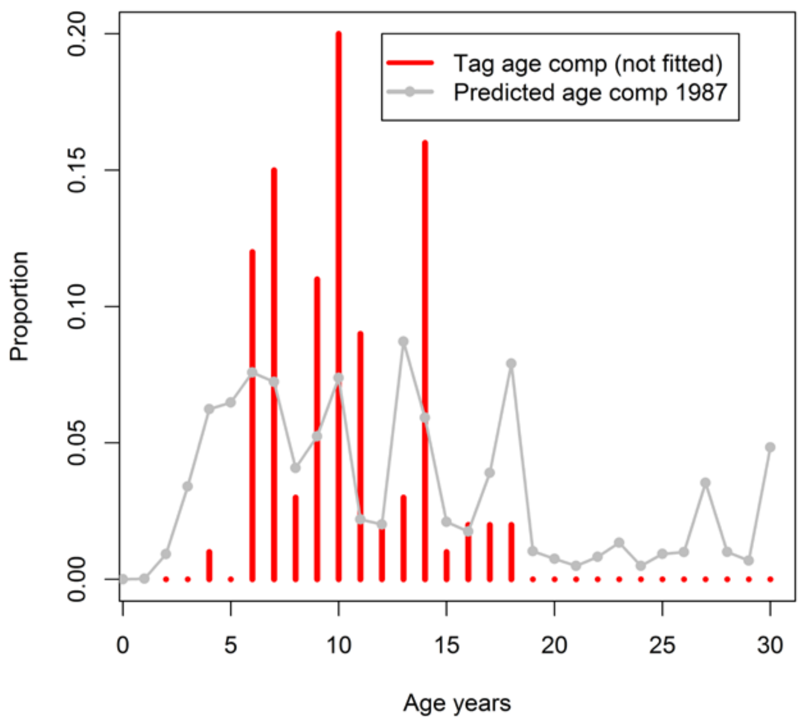

Figure 9: A comparison between the predicted age composition of the BPT vulnerable component of the population in 1987 and the estimate of the age composition of the population determined from the tagging programme (Kirk et al. 1988). The tagging age composition data were not included in the final assessment model.

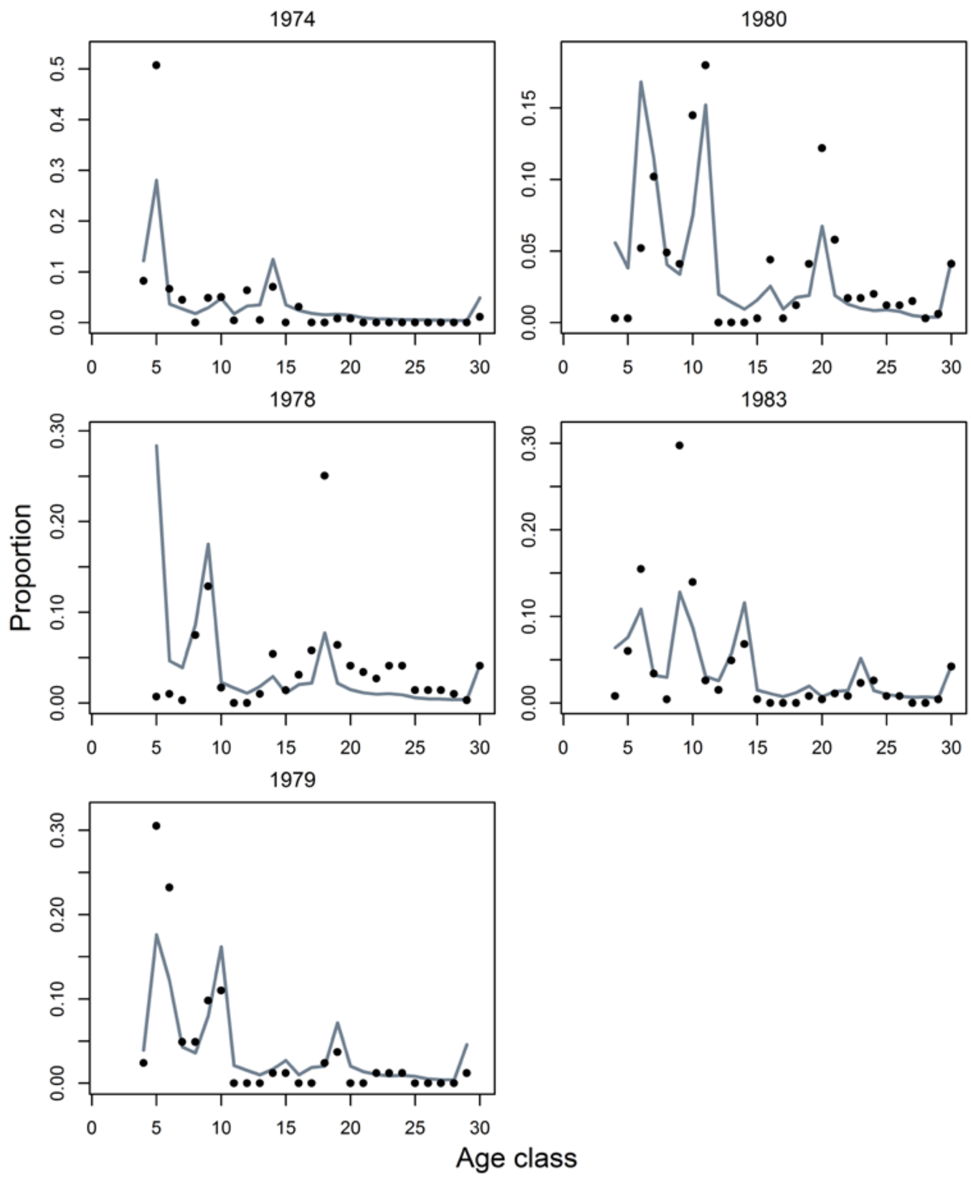

Figure 10: Observed (points) and predicted (line) proportions at age for the bottom pair trawl (BPT) catch-at-age data included in the base model.

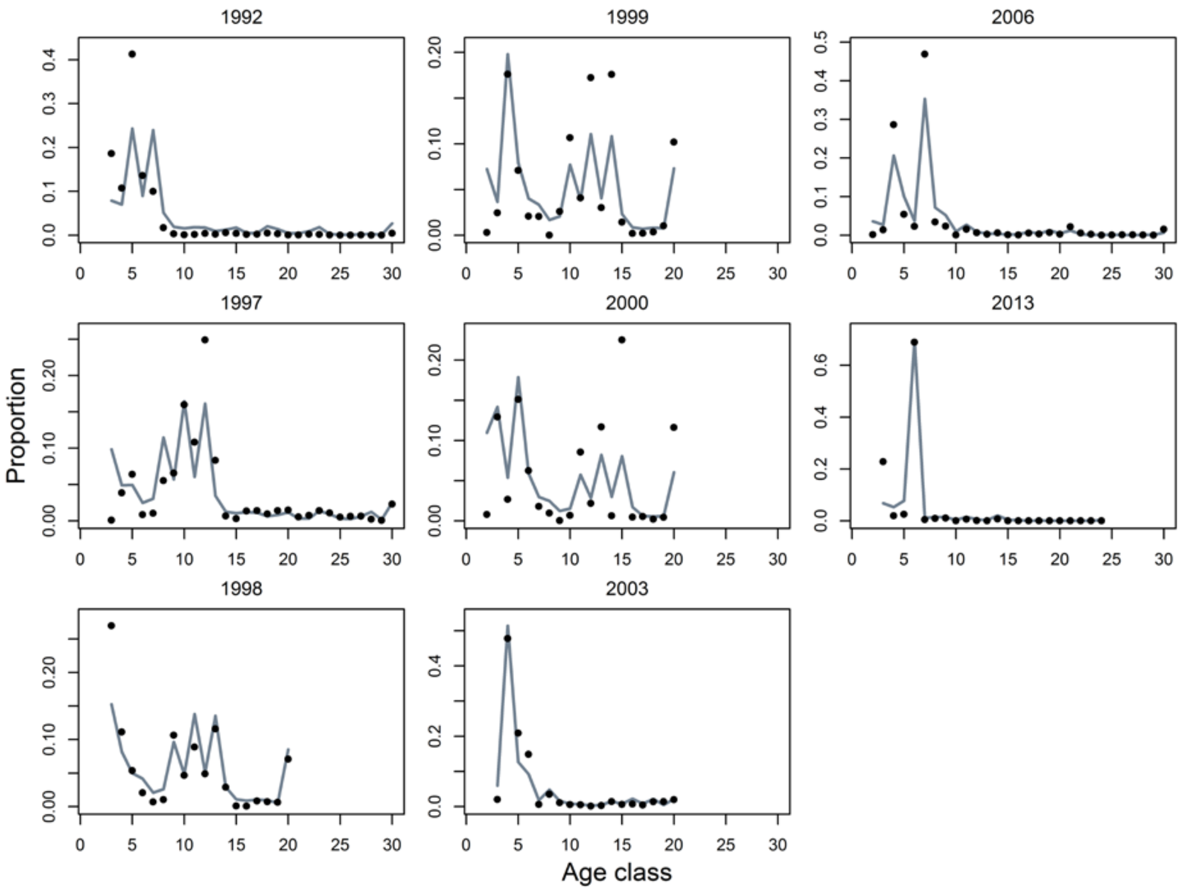

Figure 11: Observed (points) and predicted (line) proportions at age for the bottom single trawl (BT) catch-at-age data included in the base model.

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. There was a marked shift in the size composition of fish in the commercial grading data during 2004–2013 (Figure 12). 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 BT age composition data. Since 2011, there was a marked increase in the proportion of smaller fish in the commercial grading data that is consistent with the recent (2007) strong recruitment (Figure 12).

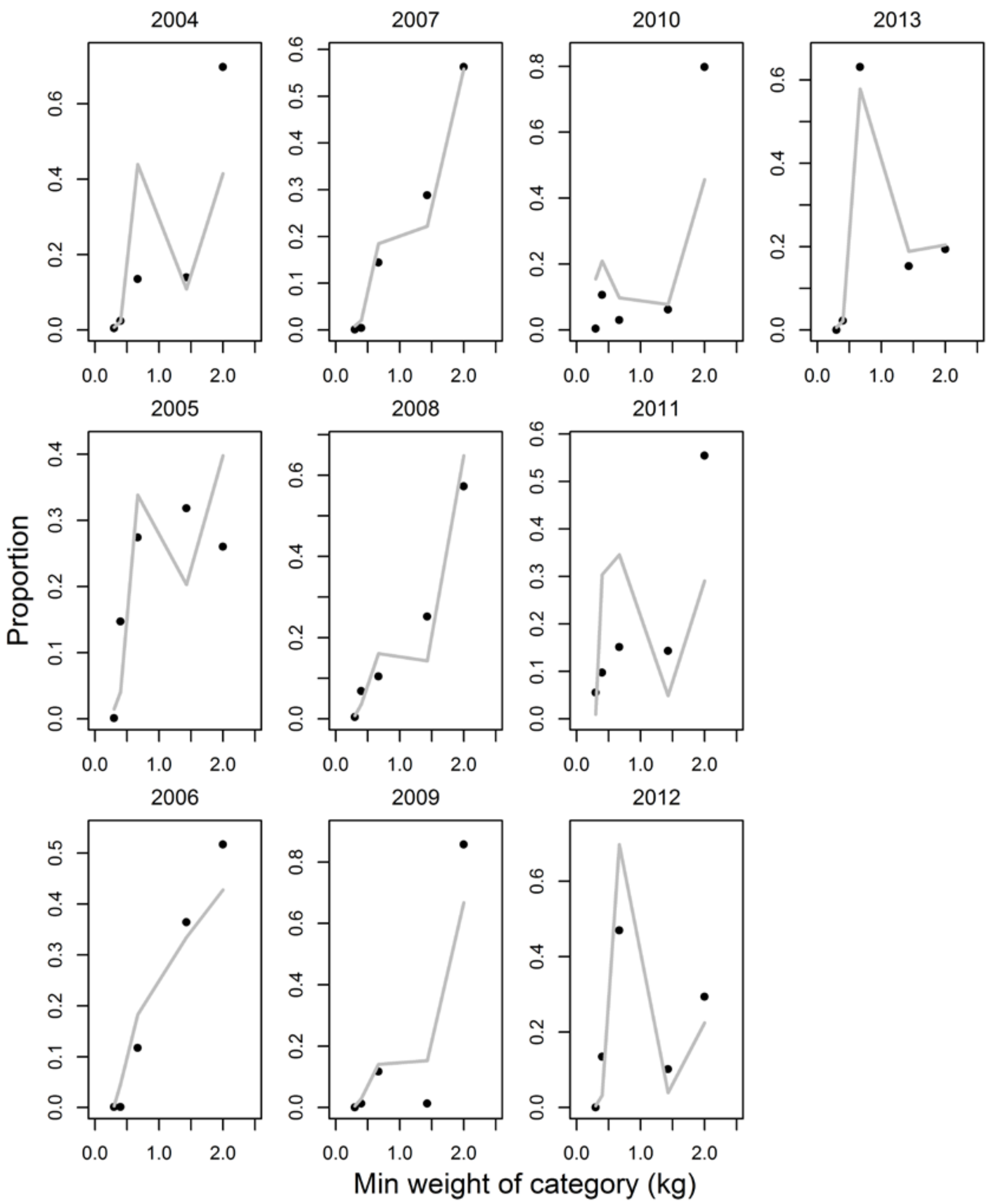

Figure 12: Observed (points) and predicted (line) proportions by fish weight grade for the bottom trawl (BT) fishery.

4.1.3 Model sensitivity analyses

A suite of model runs were conducted to investigate the sensitivity of the base model to key model parameters and assumptions (Table 4).

Compared to the base model, the sensitivity runs with a lower value of natural mortality (*LowM*) and lower steepness of the SRR (*Steep075*) estimated slightly higher levels of virgin biomass (SB_0) and, in the case of the *Steep075* sensitivity run, higher uncertainty associated with the initial conditions (Figure 13). For both model sensitivity runs there was a slight increase in the overall model likelihoods, indicating a slight deterioration in model fit relative to the base model (Table 5).

Table 4: Description of model sensitivity runs.

Sensitivity Run	**Description**
LowM	M = 0.06
Steep075	SRR h = 0.75
RecDev2010	Recruitment deviates estimated for 1950–2010
SelectAll	Parameterisation of BT selectivity exponential-logistic function, uninformative priors for three parameters. Relaxed prior assumptions for BPT selectivity parameters
TagBiomass	Arbitrarily double the 1987 tag biomass estimate.

Table 5: Model log likelihoods for the base model and selected sensitivity runs.

Model						Likelihood component
	Total	CPUE indices	Tag	BT Age comp	BPT age comp	Size grade
base	56.25	-15.32	-0.95	14.21	14.89	12.83
lowM	57.22	-15.30	-1.06	14.05	15.55	12.82
steep075	58.17	-15.33	-0.77	13.62	15.26	13.05
RecDev2010	55.44	-15.32	-0.92	12.96	14.87	12.84
SelectAll	57.56	-14.19	-1.04	17.46	13.48	11.51

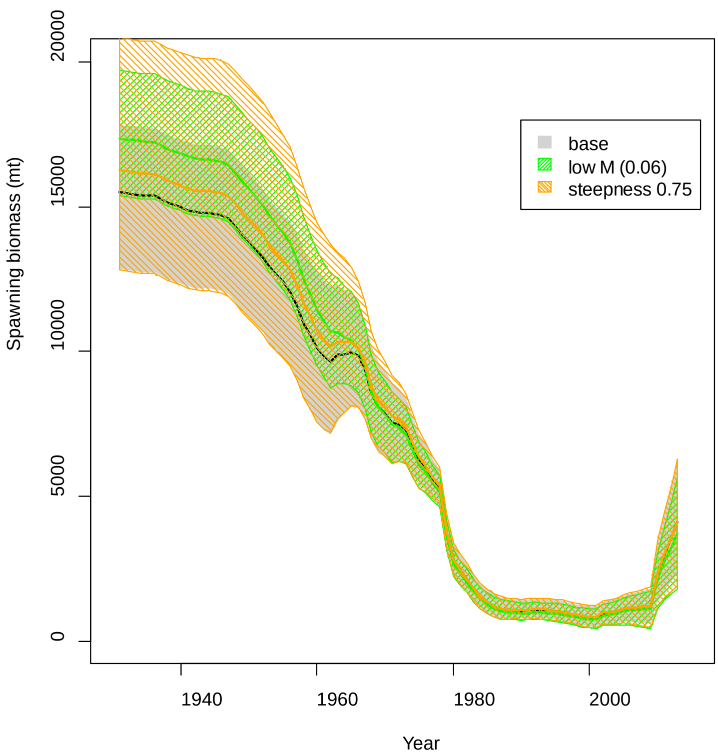

Figure 13: A comparison of the spawning biomass trajectory (and 95% confidence interval) of the base model and model sensitivity runs related to natural mortality (*LowM*) and SRR steepness (*Steep075*). The lines represent the median and the shaded area represents the 95% confidence interval (McMC results).

Another model sensitivity run was conducted to extend the full recruitment estimation period to include 1950–2010 (*RecDev2010*). This run estimated a relatively strong 2010 year class (Figure 14) and improved the fit to the 2013/14 age composition without appreciably changing the fit to the CPUE indices. These results indicate a degree of conflict between the timing and extent of the increase in the CPUE indices and the recent age/size composition data. An improvement in the fit to the recent CPUE indices could only be achieved by a substantial reduction in the ESS of the recent age/size composition data, resulting in a corresponding increase in the strength of the 2007 year class (by about 20%).

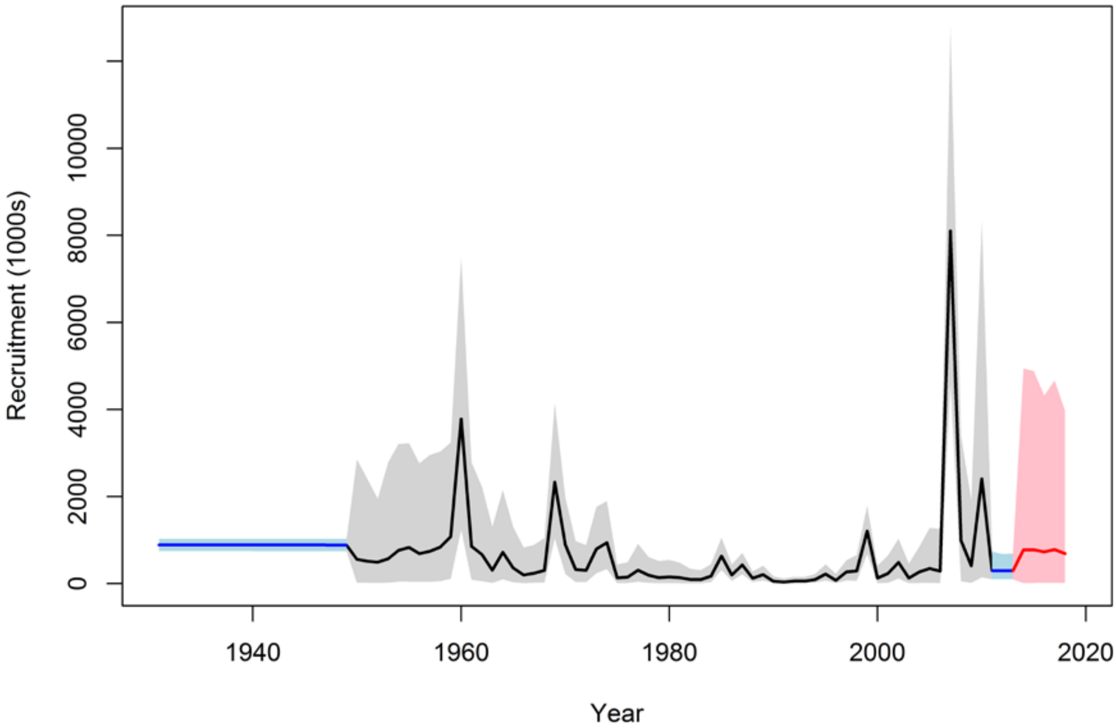

Figure 14: Estimates of annual recruitment (numbers of fish) from the *Recdev2010* assessment model. The line represents the median of the McMC samples and the shaded area represents the 95% confidence interval. The grey time block represents the period for which recruitment deviates are estimated. The blue time blocks correspond to years within the model period for which recruitment deviates were not estimated. The red time block represents the 4-year forecast (projection) period.

Another model run investigated the sensitivity to the parameterisation of the fishery selectivity functions for the BT and BPT fisheries (*SelectAll*). The selectivity for the BT fishery was reparameterised using an exponential-logistic selectivity function (Methot 2013) with uninformative priors for each of the three parameters and the BPT selectivity priors were relaxed.

The fishery selectivity functions estimated for the model sensitivity run were similar to the base model, although the age at recruitment to the BPT fishery was increased by approximately one year (Figure 15). The *SelectAll* model estimated a BT selectivity that approximated full selection for all the recruited age classes. The change in selectivitity parameterisation resulted in an increase in the overall model likelihoods relating to a deterioration in the fit to the BT age composition data and, to a lesser extent, the CPUE indices, athough there was a small improvement in the fit to the BPT age composition data (Table 5). The overall effect of the changes in the selectivity assumptions on the stock biomass trajectory was trivial (Figure 16).

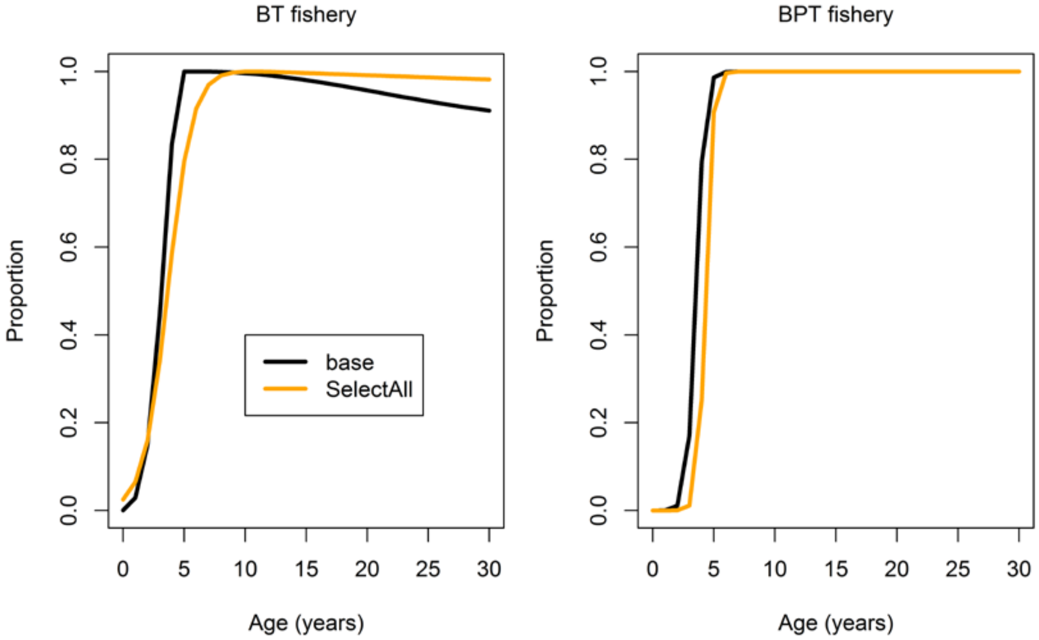

Figure 15: A comparison of the age specific fishery selectivity for the BT (left) and BPT (right) fisheries from the base assessment model and the *SelectAll* model sensitivity run (MPD fits).

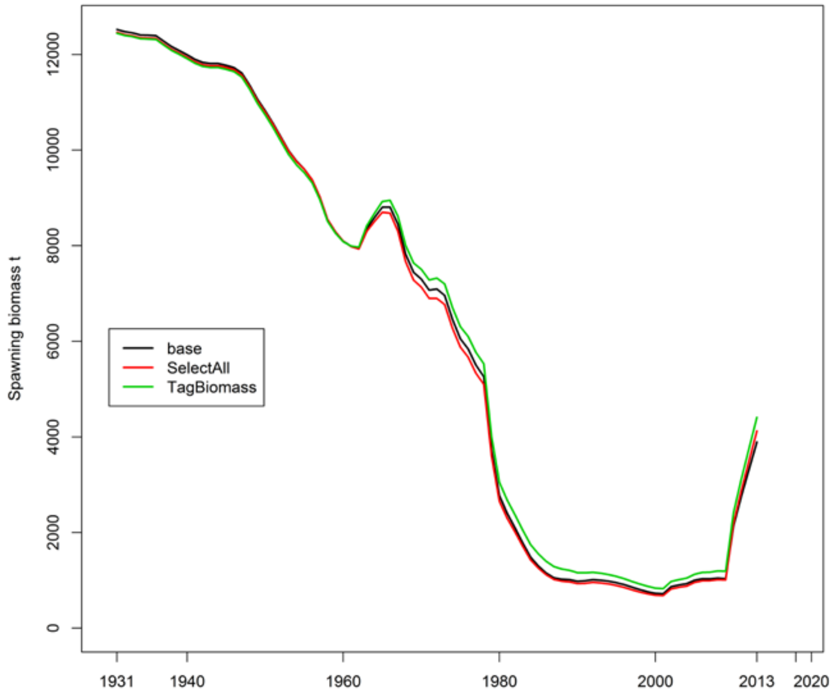

Figure 16: Spawning biomass trajectories for the base model and runs showing sensitivity to fishery selectivity parameterisations and the estimate of biomass from the tagging programme (MPD fits).

An additional model run was conducted to evaluate the influence of the tagging biomass estimate (*TagBiomass*). There is some indication that the 1987 tagging biomass estimate may be negatively biased, although the extent of the bias is unknown. The tagging biomass estimate may have considerable influence on the assessment model as it is the earliest source of direct abundance information available and, consequently, is likely to influence the estimation of stock depletion that occurred during the period of high catches (late 1970s–early 1980s). The influence of the tagging biomass estimate was investigated by doubling the reported value while maintaining the assumed CV of 30%. This resulted in a 30% increase in the stock biomass in 1987 and an elevated biomass level throughout the subsequent period (17% in 2014) without a corresponding increase in SB_0 (Figure 16). This indicates that the extent of any potential bias introduced by the 1987 tag biomass is relatively small. This conclusion is supported by an additional model run that excluded the 1987 tag biomass estimate altogether which produced results that were virtually identical to the base model.

4.2 Stock status

The base assessment model estimated that the spawning biomass declined considerably from 1950 to the mid 1980s when the stock biomass is estimated to have been approximately 7% of the virgin (SB_0) level (Figure 17). The stock biomass is estimated to have remained at this level throughout the 1990s and 2000s and then increased rapidly from 2009 to reach 29% of the SB_0 level in 2014 (SB_{2014}).

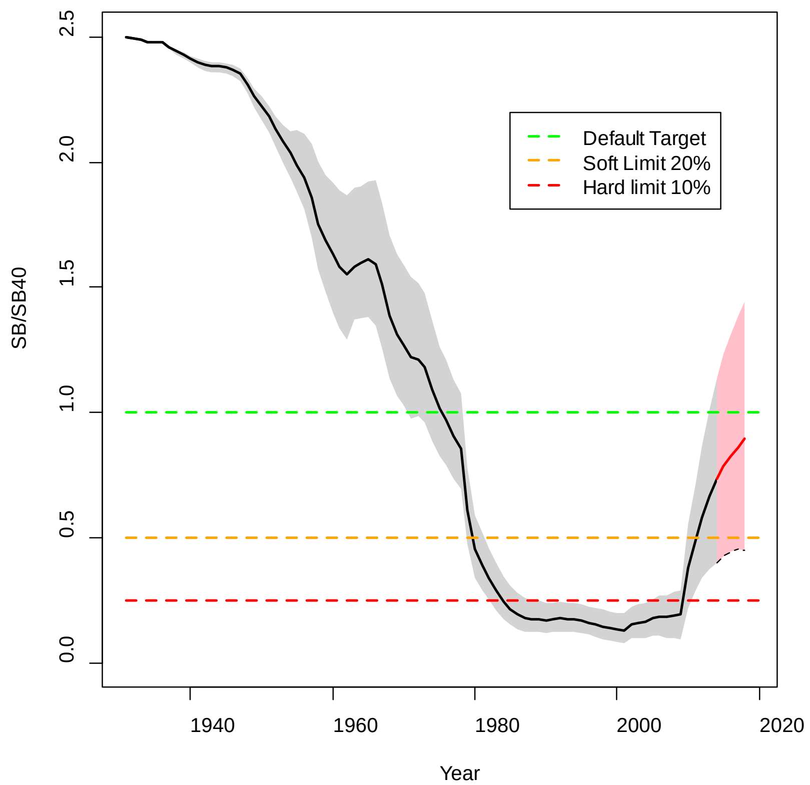

Figure 17: Spawning biomass relative to the default target spawning biomass reference point from the base assessment model. The solid line represents the median of the McMC samples and the shaded area represents the 95% confidence interval. The red time block represents the 4-year forecast (projection) period..

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 2014 and forecast to 2018) for spawning biomass is reported relative to the default hard and soft limits and the target biomass level. Fishing mortality (in 2014 and 2018) is reported relative to the corresponding interim target biomass level (i.e. $F_{SB40\%}$) based on the 2014 age-specific exploitation pattern.

Current (2014) biomass is estimated to be above the soft limit (20% SB_0) for the base model and all model sensitivity runs (Figure 17) (Table 6). Current biomass is very likely to be below the interim target biomass level (40% SB_0) for all model options. For the base model, current rates of fishing mortality are Likely (more than 60%) to be below the corresponding target fishing mortality level ($F_{SB40\%}$) (Table 6 and Figure 18). The *LowM* model is the least optimistic of the range of model sensitivity runs, primarily due to the higher level of reference biomass (SB_0) (Table 6). Nonetheless, the current stock status relative to the hard and soft limits does not differ markedly from the base model run.

The equilibrium yields corresponding to $F_{SB40\%}$ at the current biomass level and the $SB_{40\%}$ target biomass level were also determined. Equilibrium yields at the target biomass level are estimated to be about 600–800 t per annum. The $F_{SB40\%}$ yields at current (2014/15) biomass levels are broadly comparable to the level of current catch (425 t), approximately 25% less than the yields at $SB_{40\%}$ (Table 7).

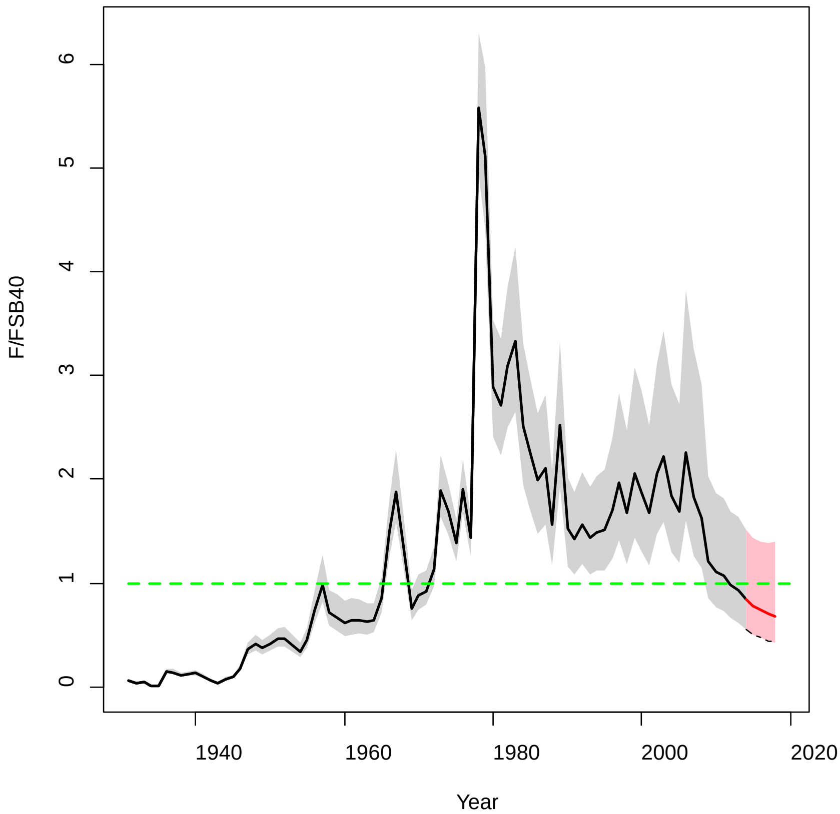

Figure 18: Annual fishing mortality relative to the level of fishing mortality that corresponds to the default target spawning biomass from the base assessment model. The line represents the median of the McMC samples and the shaded area represents the 95% confidence interval. The red time block represents the 4-year forecast (projection) period.

Table 6: Stock status in 2014 (2014/15 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_{2014}	SB_{2014}/SB_0	$SB_{2014}/SB_{40\%}$	Pr(SB_{2014} > $X\%SB_0$)			$F_{SB40\%}$	$F_{2014}/F_{SB40\%}$	Pr(F_{2014} < $F_{SB40\%}$)
					40%	20%	10%			
Base	15 497	4 522	0.293	0.663	0.086	0.912	0.994	0.056	0.836	0.761
	(12 865–17 843)	(2 493–6 919)	(0.16–0.454)	(0.374–1.011)				(0.053–0.058)	(0.546-1.51)	
lowM	17 365	4 124	0.237	0.537	0.012	0.726	0.983	0.047	1.008	0.369
	(15 391–19 721)	(1 897–6 376)	(0.11–0.373)	(0.264–0.824)				(0.045–0.049)	(0.712–2.357)	
steep075	16 250	4 535	0.281	0.637	0.051	0.858	0.986	0.054	0.858	0.717
	(12 809–20 844)	(2 014–7 047)	(0.117–0.438)	(0.275–0.969)				(0.047–0.059)	(0.555–1.929)	
RecDev2010	15 820	5 121	0.328	0.729	0.201	0.944	0.997	0.056	0.741	0.864
	(13 270–18 303)	(2 635–8 245)	(0.162–0.518)	(0.365–1.115)				(0.053–0.058)	(0.458–1.443)	
SelectAll	14 869	4 753	0.322	0.725	0.189	0.924	0.985	0.058	0.767	0.811
	(12 124–17 516)	(2 099–7 412)	(0.144–0.503)	(0.333–1.129)				(0.055–0.060)	(0.485–1.666)	
*TagBiomass**	15 540	5 333	0.345	0.78	0.256	0.973	1.000	0.056	0.717	0.910
	(12 863–18 239)	(3 019–8 440)	(0.198–0.547)	(0.455–1.227)				(0.051–0.058)	(0.453–1.254)	

*Not intended for management advice

Table 7: Estimates of annual yield (t) at $F_{SB40\%}$ at the SB_{2014} (2014/15) 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_{2014}
Base	699 (585–808)	504 (275–772)
lowM	660 (582–751)	388 (178–596)
steep075	713 (595–862)	492 (209–757)
RecDev2010	716 (607–832)	570 (292–926)
SelectAll	694 (564–813)	549 (246–865)

For all model options (base model and sensitivity runs), stock projections were conducted for the 4 year period following the terminal year of the model (i.e. 2015–2018) based on the status quo (2014) commercial catch/TACC (200 t) and recreational catches (225 t) (Table 8). During the projection period, recruitments were resampled from the lognormal distribution around the geometric mean.

Two additional projections were undertaken as sensitivity runs to the base model: 1) recreational catch during 2015–18 increasing in proportion to projected stock abundance (increasing to 354 t in 2018) (*ProjRecCatch*) (Table 8) and 2) annual recruitment set to zero during 2014–2018 (*ProjRecruitZero*). The latter option was conducted to investigate the relative influence of future recruitments on the stock status at the end of the projection period.

Table 8: Annual catches (t) assumed for the projection period.

Fishing year	Model year	Commercial catch (t)	Recreational catch(t)	
			Base	*ProjRecCatch*
2015/16	2015	200	225	275
2016/17	2016	200	225	305
2017/18	2017	200	225	331
2018/19	2018	200	225	354

The model projections are largely driven by the continued increase in the biomass of the 2007 year class resulting in an increase in total biomass during the projection period (see Figure 17). For all model runs considered, spawning biomass in 2018 is forecast to be well above the soft limit (20% SB_0), increasing towards the target biomass level ($SB_{40\%}$), although for most model runs the stock is Unlikely to attain the target biomass level by 2018 (probability less than 40%) (Table 9). The most optimistic sensitivity run is the model that extends the main period of recruitment estimation to include the 2010 year class (*RecDev2010*).

Table 9: Stock status in the terminal year 2018 (2018/19 fishing year) of the four year forecast period for the base model and model sensitivity runs.

Model	*Pr (SB2018 > X% SB0)*			SB_{2018}/SB_{2014}
	10%	20%	40%	
Base	0.997	0.959	0.345	1.328 (1.146–1.661)
lowM	0.987	0.870	0.128	1.373 (1.122–1.697)
steep075	0.989	0.911	0.298	1.324 (1.093–1.639)
RecDev2010	0.998	0.973	0.586	1.459 (1.222–1.892)
SelectAll	0.994	0.971	0.490	1.355 (1.171–1.742)
ProjRecCatch	0.996	0.949	0.318	1.295 (1.087–1.612)
ProjRecruitZero	0.990	0.937	0.246	1.259 (1.052–1.381)

5 ADDITIONAL INFORMATION

Recent stock trends, current stock status and projected stock status are all highly dependent on the estimates of recent recruitment, in particular that of the 2007 year class. The stock assessment estimates that the 2007 year class is exceptionally strong, although there are limited observations of it and there is a degree of conflict amongst the model data sets. Consequently, there is considerable uncertainty associated with the actual magnitude of the 2007 recruitment estimate. Therefore, other sources of information were reviewed to provide some corroboration of the strength of the recent recruitment and the resulting trends in stock biomass.

The time-series of trawl survey biomass estimates of recruited (25+ cm F.L.) snapper from Tasman/Golden Bay reveal a large increase in relative abundance from 2010/11, that is broadly consistent with the trend in stock abundance from the stock assessment model (Figure 19) (MacGibbon, NIWA, unpublished data). The length composition of the snapper sampled by the trawl survey in

2014/15 is also consistent with the length and age structure of the commercial catch from the preceding year (Figure 20). Based on the growth rates for snapper in SNA 7 and the age composition of the 2013/14 commercial catch, it is assumed that the main mode in the trawl survey length composition is predominantly comprised of the 2007 year class. There is also an indication of the presence of the 2010 year class in the 2013/14 commercial age composition (Figure 20). The *Kaharoa* trawl surveys conducted in 2009, 2011 and 2013 also caught reasonable numbers of snapper from the 2007 year class (Figure 21).

The trawl survey data have not been incorporated in the stock assessment as it has previously been considered that the survey is unlikely to adequately monitor juvenile and adult snapper abundance (Stevenson & Hanchet 2000); the survey does not sample the shallower areas of Tasman/Golden Bay and catch rates of snapper are variable, resulting in broad confidence intervals associated with the biomass estimates. Nonetheless, the correspondence between the results from the trawl survey and the assessment modelling indicate that the survey may be useful in the ongoing monitoring of SNA 7.

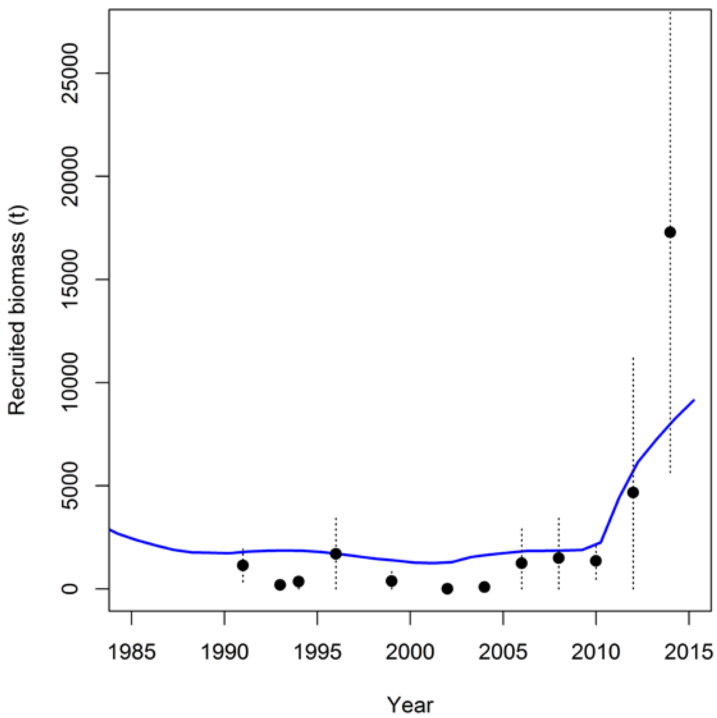

Figure 19: A comparison of the trend in recruited biomass derived from the SNA 7 stock assessment (blue line) and Kaharoa WCSI trawl survey biomass estimates of recruited (25+ cm F.L.) snapper from the Tasman/Golden Bay area (points) (MacGibbon, NIWA, unpublished data). For comparability, the trawl survey biomass estimates were scaled by the ratio of average of the two series from 1992-2014. The last trawl survey biomass index included in the series is for the March–April 2015 survey.

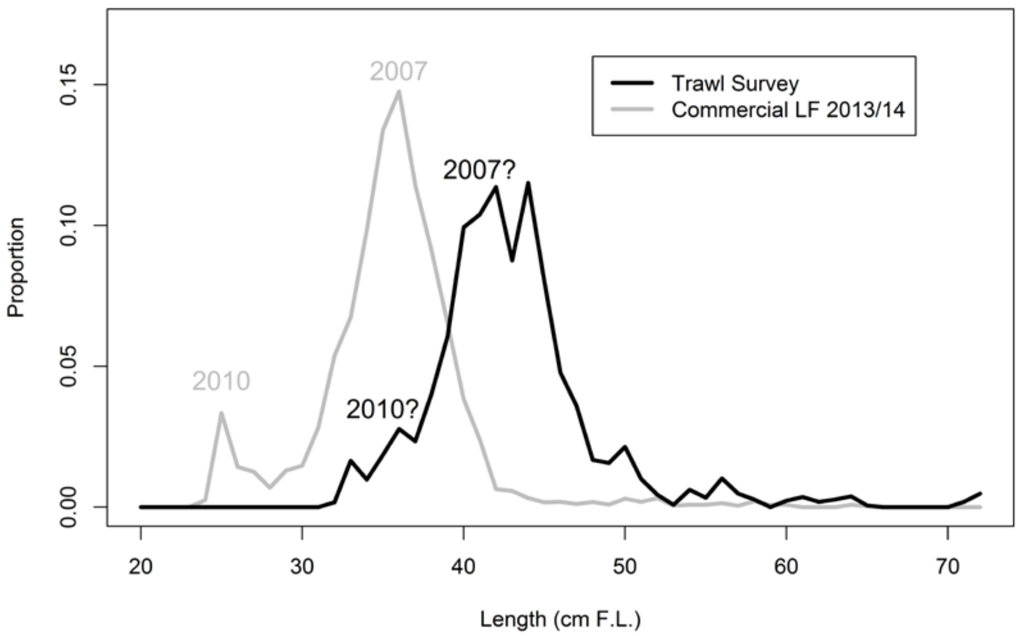

Figure 20: The scaled length composition of snapper from Tasman/Golden Bay derived from the March-April 2015 Kaharoa WCSI trawl survey (Dan MacGibbon, NIWA unpublished data). For comparison the length composition of the commercial snapper catch from 2013/14 is also presented. The labels represent the predominant year class of the length modes as determined from the corresponding age composition of the 2013/14 commercial catch and inferred for the trawl survey length composition.

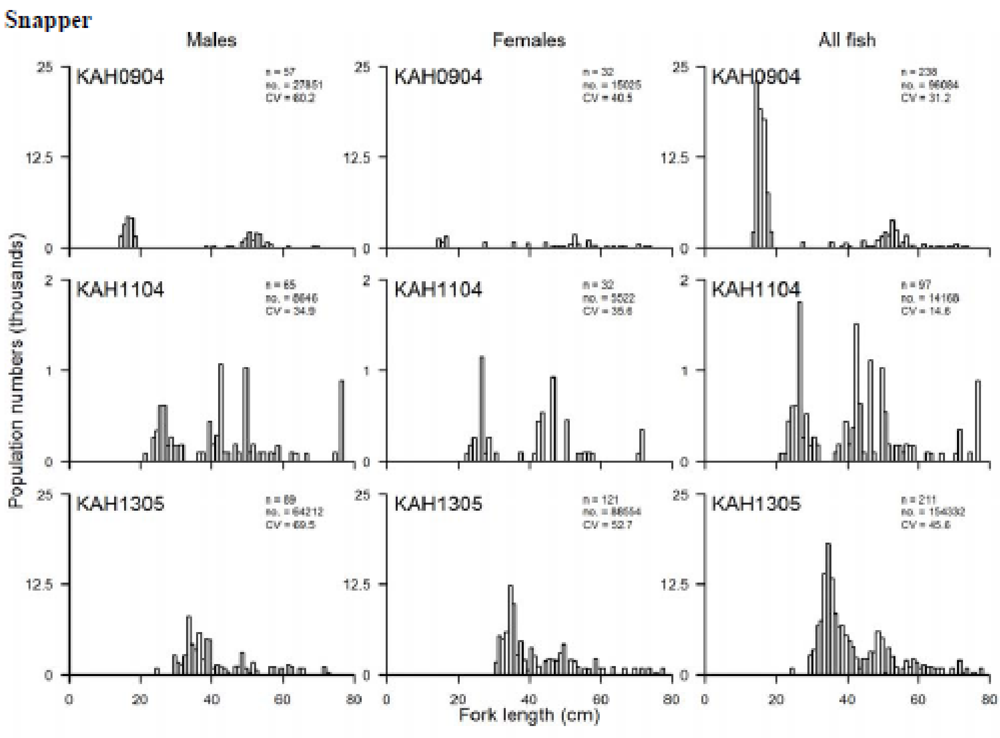

Figure 21: Length composition of snapper sampled by the 2009, 2011 and 2013 WCSI *Kaharoa* trawl surveys (source: MacGibbon & Stevenson 2013). The 2007 year class corresponds to the length modes at 18 cm, 25 cm, 35 cm (F.L.) from the successive surveys.

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, Harley & Gilbert (2000) estimated a positive relationship between air temperature and recruitment deviates in the assessment model. Limited in situ water temperature data are available from the Tasman/Golden Bay area (Langley 2013). The Southern Oscillation Index (SOI) was examined as a potential covariate for recruitment in SNA 7. In general, there is reasonable correspondence between strong year class estimates and positive SOI conditions, while weak year class estimates tend to correspond to negative SOI conditions, particularly from 1980 onwards which represents the period when the year classes are monitored by the CPUE indices (Figure 22). The strong 2007 year class coincided with a period of positive SOI conditions (October 2007–February 2009 average monthly SOI 3.5), although the magnitude of the estimate of the strength of the 2007 year class is not proportional to the corresponding SOI conditions. There was a subsequent period of positive SOI conditions during April 2010–April 2011 (average monthly SOI 5.8) (Figure 22) which may provide some corroboration of the presence of a relatively strong 2010 year class (spawned during the 2010/11 summer).

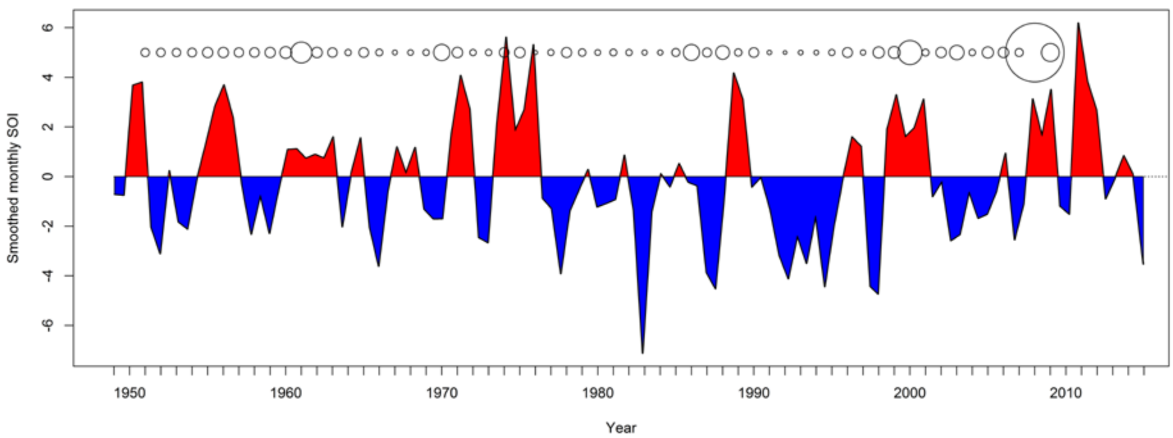

Figure 22: Lowess smoothed monthly Southern Oscillation Indices for 1950-2014 (source: National Centre for Atmospheric Research http://www2.cgd.ucar.edu/). The circle are proportional to the estimated annual recruitment deviates (1950–2008) from the SNA 7 base model. The lowess function determines the smoothed SOI value from a 12 month period.

6 DISCUSSION

The SNA 7 stock assessment model provides a coherent integration of the main data available from the fishery. The stock is characterised by high variability in recruitment and the fishery is dependent on episodic periods of strong recruitment that tend to occur at 7–10 year intervals. There is some information to indicate that the variation in recruitment corresponds to the prevailing environmental conditions during the spring/summer of spawning. The strong, episodic recruitment provides a strong signal in the various fishery data sets.

Recent trends in stock abundance, and the associated estimate of the strength of the 2007 year class, are dependent on the large increase in the CPUE indices, especially between 2010/11 and 2011/12, which corresponded to the recruitment of the 2007 year class to the commercial fishery (at age 4 years). The CPUE indices are assumed to be directly proportional to stock abundance. This assumption cannot be thoroughly evaluated in the absence of other reliable indicators of stock abundance. The biomass estimates derived from the *Kaharoa* trawl survey are not sufficiently precise; however, the magnitude of the recent increase in these indices is consistent with the trend in the CPUE indices. The available length and age data from the fishery are also entirely consistent with the presence of a (very) strong 2007 year class.

It has been suggested that the availability of snapper to the fishery (and the trawl survey) may have increased in recent years, with snapper remaining in the Tasman/Golden Bay area during autumn (March–April) as a result of favourable conditions. An analysis of catch and effort data from the commercial fishery does indicate that the seasonal period that snapper are available to the trawl fishery has increased in recent years (Langley 2013). However, the CPUE indices derived from the October–January period do not substantially differ from the base CPUE indices, which include the extended fishing season (October–May). In addition, an analysis of location based TCER catch and effort data did not reveal any appreciable change in spatial distribution of fishing effort, or the relative catch rates of snapper that would have resulted in an increase in the vulnerability of snapper to the trawl fishery (Langley 2013).

Conversely, the increase in the abundance of snapper within Tasman/Golden Bay has meant that the operation of the inshore trawl fishery, particularly the flatfish fishery, is being constrained by the availability of SNA 7 Annual Catch Entitlement (ACE). This may have resulted in a degree of avoidance of snapper that could have negatively biased the recent CPUE indices. As noted above, previous analyses of catch and effort data from the fishery have not revealed any marked shift in the area and depth range fished. However, a more thorough analysis of the catch and effort data should be undertaken to investigate the extent of any localised avoidance behaviour by individual fishing vessels.

The stock assessment results indicate that there is likely to be some inter-annual variability in the selectivity of the younger age classes in the fishery (3–5 years). The variation in selectivity may partly relate to the degree of snapper targeting, as opposed to being caught as a by-catch in the flatfish targeted tows. The flatfish fishery tends to operate in shallower water and uses a smaller trawl net with a lower headline height towed at a relatively slow speed (less than 3 knots). Thus, the fishery can be expected to catch a higher proportion of smaller/younger snapper than the target snapper fishery.

The 2007 year class is likely to have been fully recruited to the commercial fishery towards the end of the CPUE time-series (2012/13 and 2013/14). Therefore, the estimation of the strength of the 2007 year class is likely to be relatively insensitive to variation in the selectivity of the younger age classes in the fishery. Nonetheless, the current model estimate of the magnitude of the 2007 year class is relatively imprecise. The precision of the estimate of the 2007 year class will improve with the accumulation of catch, CPUE and size composition data over the coming years.

The assessment indicates that the stock is currently recovering 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.

7 ADDITIONAL RESEARCH

The current and projected stock status is sensitive to the estimate of the strength of the 2007 year class and the strength of subsequent recruitment, especially the 2010 year class. Further sampling of the age composition of the commercial catch would provide information regarding the relative strength of these year classes. Ideally, sampling would be undertaken once the 2010 year class is fully recruited to the commercial fishery (2015/16 or 2016/17). In the interim, the commercial size grade data may provide some indication of the strength of the 2010 year class. It is recommended that a full update of the stock assessment is conducted in 2017/18 to confirm that the stock is continuing to rebuild towards the target biomass level.

In recent years, the annual catch from the recreational fishery is predicted to have increased with increasing stock biomass and current levels of recreational catch are assumed to be at a similar level to the catch from the commercial fishery. Quantification of the current level 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 size composition data from the recreational fishery. These data would enable an evaluation of the current assumptions regarding the age-based selectivity of the recreational fishery.

Previously, the *Kaharoa* trawl survey encompassing the Tasman/Golden Bay area had not been considered appropriate for the monitoring of snapper within SNA 7. The results from recent surveys suggest that there is potential for the survey to monitor stock abundance trends although the precision of the resulting indices has been low. Changes to the survey design, particularly increasing the density of trawl stations within the Tasman/Golden Bay area and extending the survey area to include shallower areas within Tasman/Golden Bay (10–20 m), may increase the precision of the snapper biomass indices and increase the overall utility of the trawl survey.

The stock assessment was accepted by the Fisheries Stock Assessment Plenary in May 2015.

8 ACKNOWLEDGMENTS

The development and completion of the SNA 7 stock assessment was funded by the Southern Inshore Fisheries Management Company Ltd and the Ministry for Primary Industries (under project SEA2014-13). The commercial size grade data were provided by Doug Loder and Dion Iorns (Talleys Ltd, Motueka). Kevin Sullivan (MPI) provided the historical age composition data from the commercial fishery and Steve Parker (NIWA) provided the recent (2013/14) length and age composition data from the commercial fishery. The data from the 1987 tagging programme were retrieved from storage by Ian Doonan (NIWA). The assessment was developed during 2013–2014 and finalised in 2015. Members of the Southern Inshore Fishery Working Group provided constructive review of each iteration of the assessment, in particular Marc Griffiths (MPI), Paul Starr and Kevin Sullivan.

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APPENDIX 1. MCMC DIAGNOSTICS

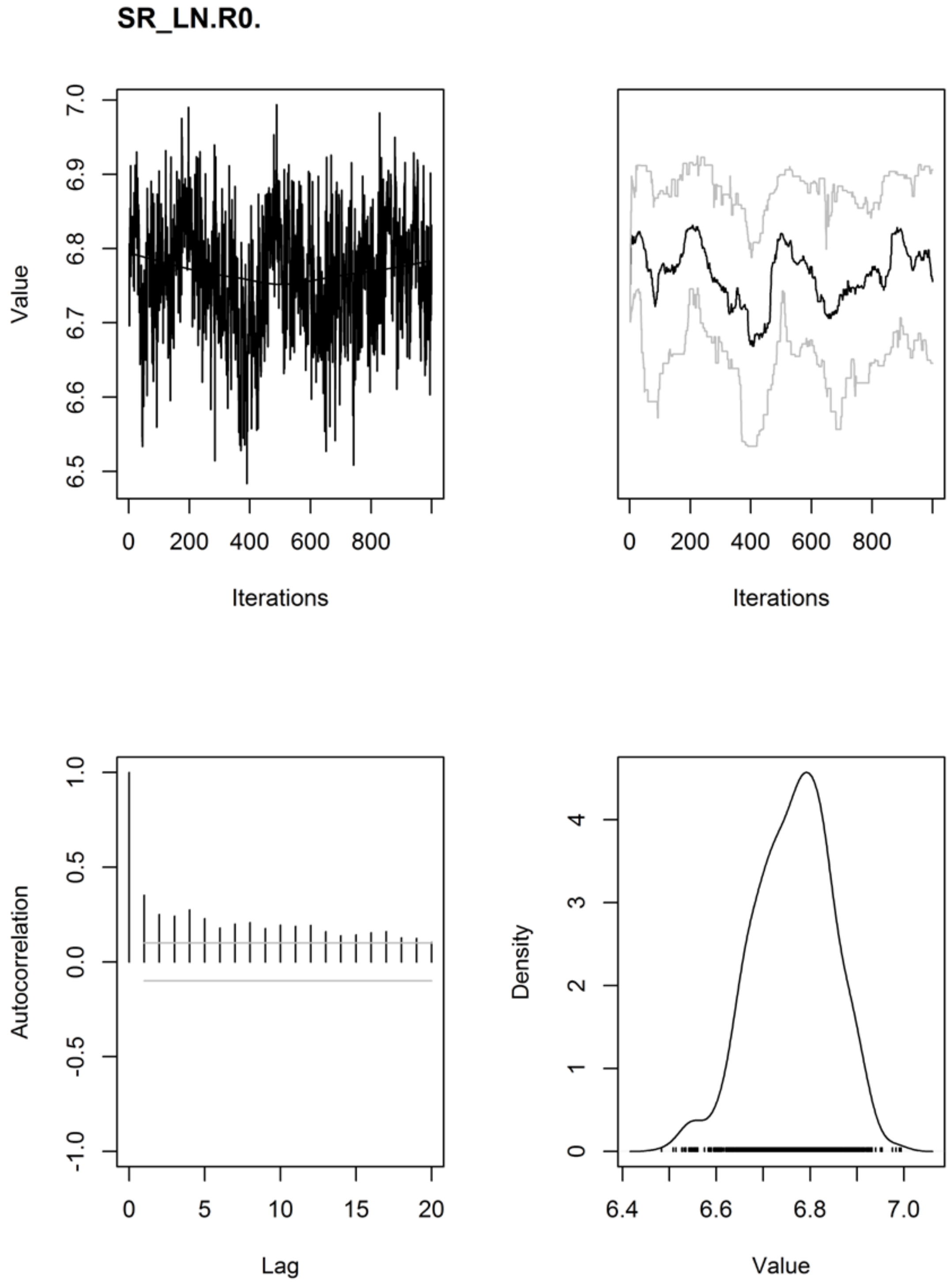

Figure A1: Diagnostic plots for the McMC draws for the *LnR0* parameter of the base assessment model.

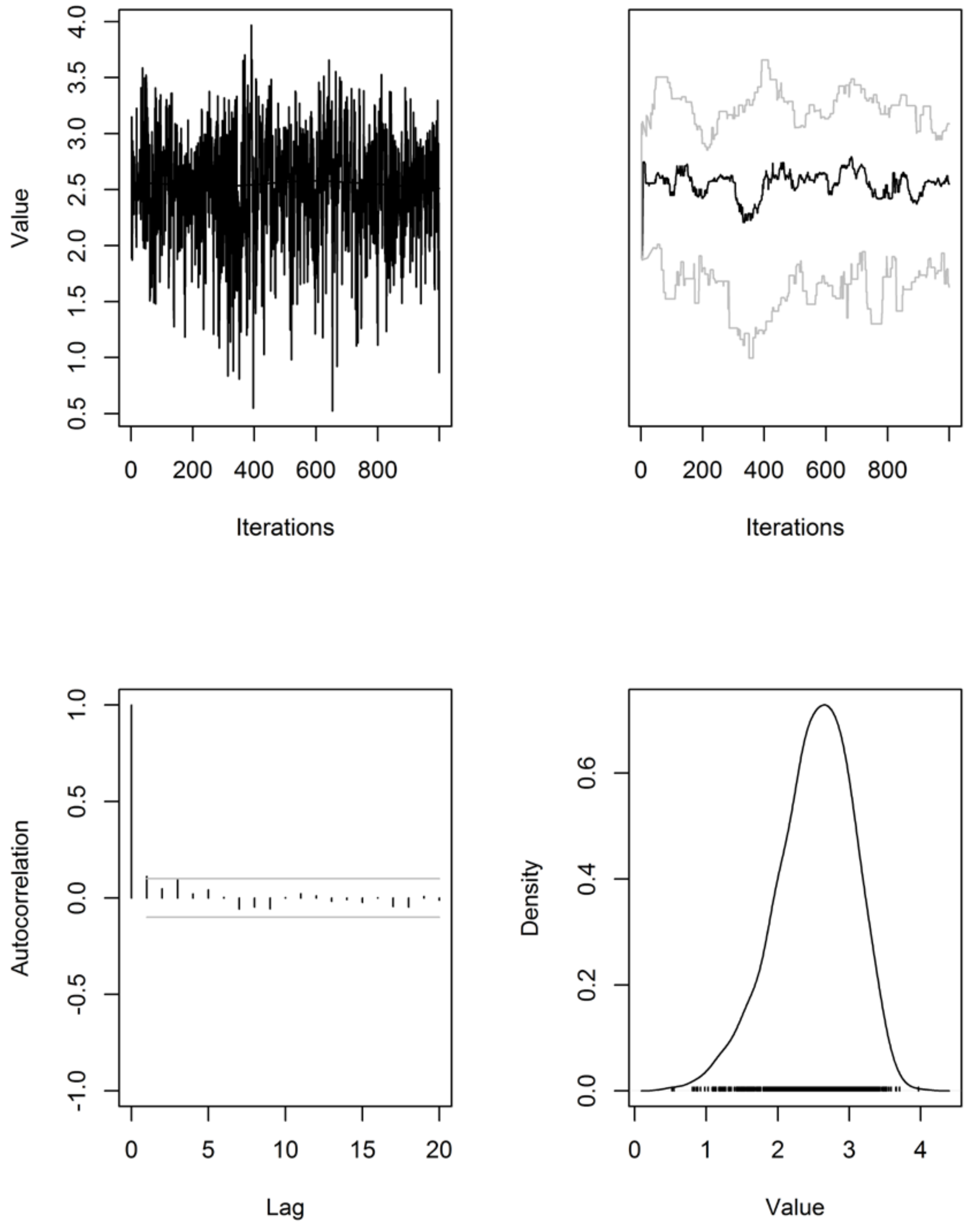

Figure A2: Diagnostic plots for the McMC draws for the *RecDev_1960* parameter of the base assessment model.

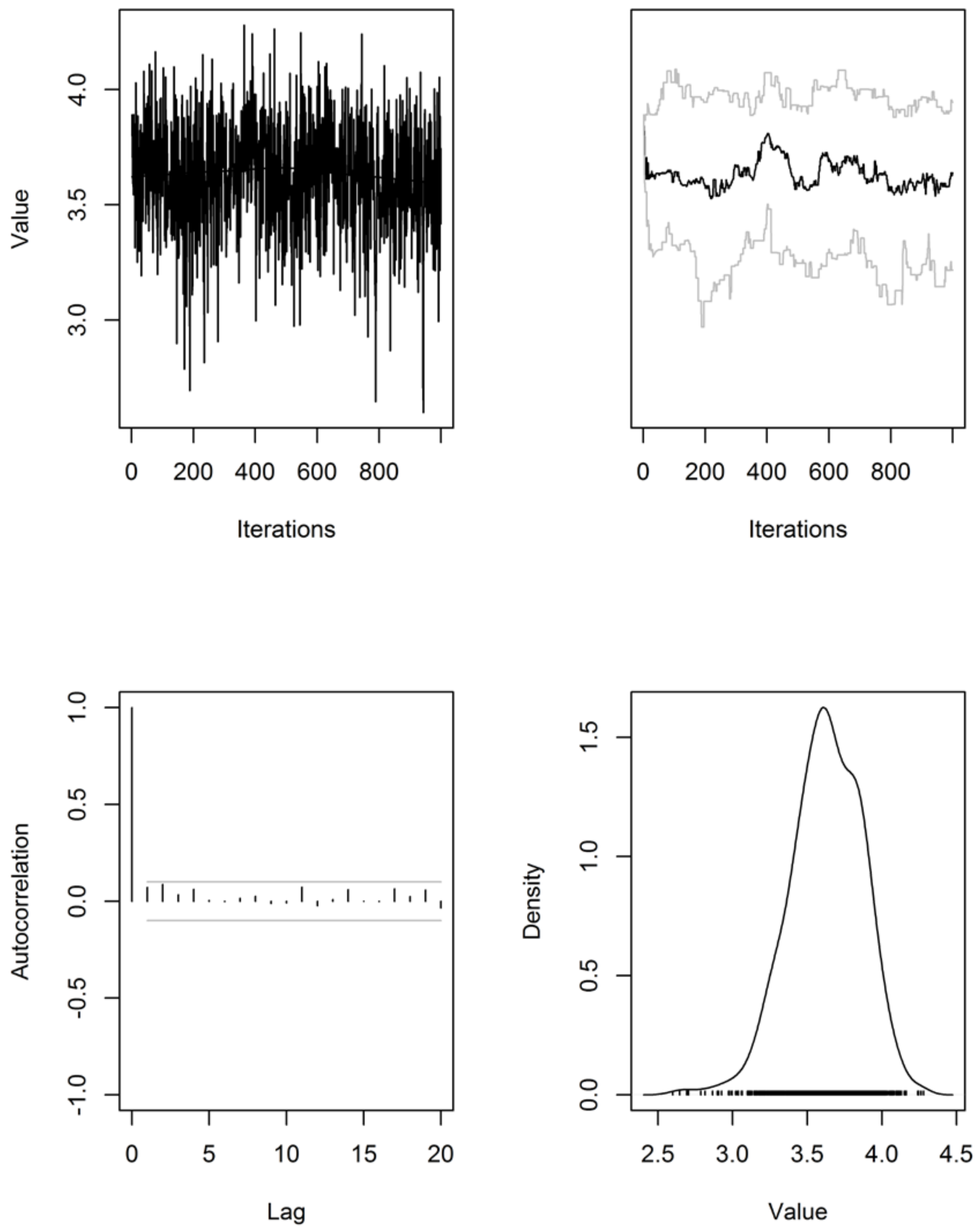

Figure A3: Diagnostic plots for the McMC draws for the *RecDev_2007* parameter of the base assessment model.

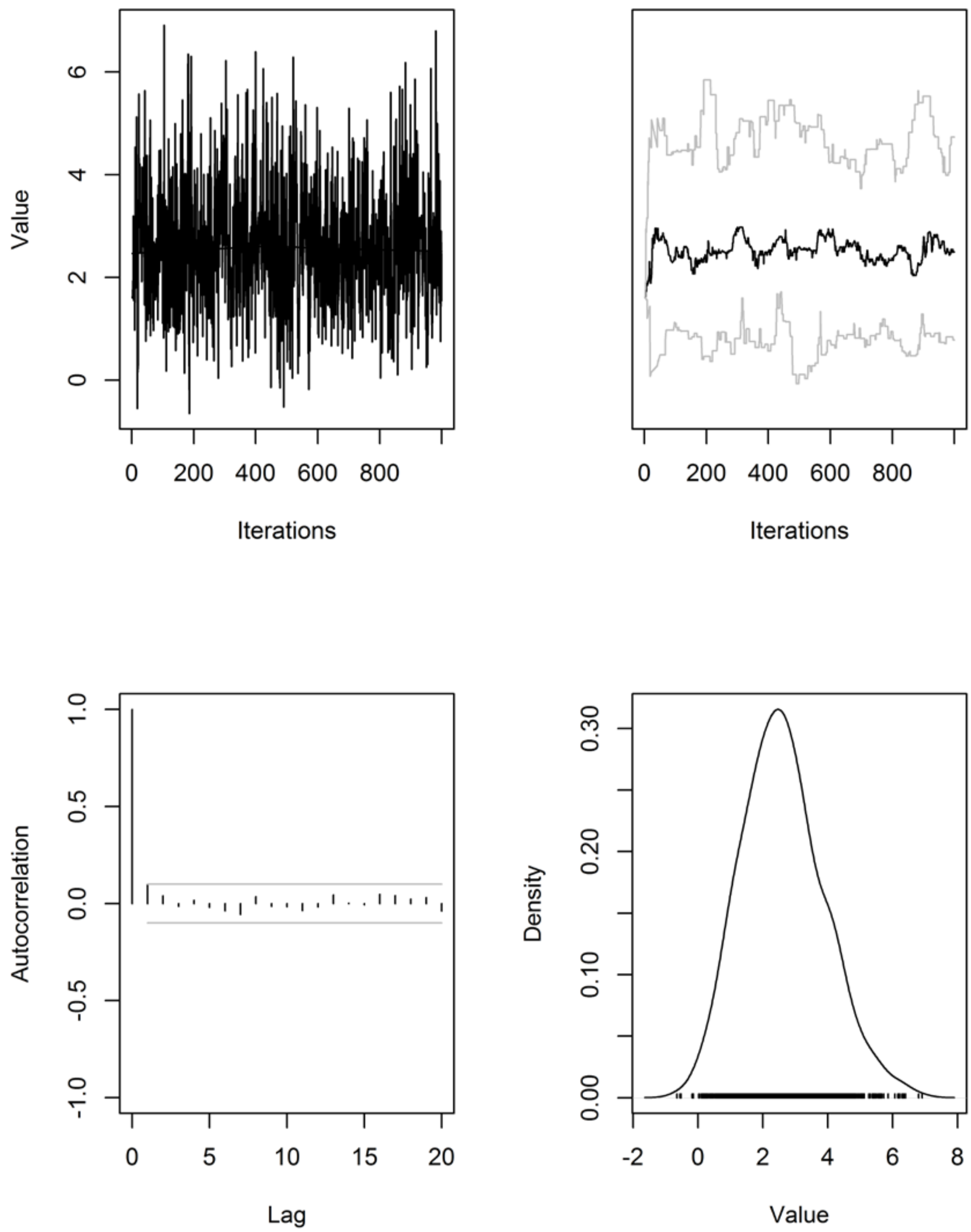

Figure A4: Diagnostic plots for the McMC draws for the BT selectivity parameter 6 of the base assessment model.

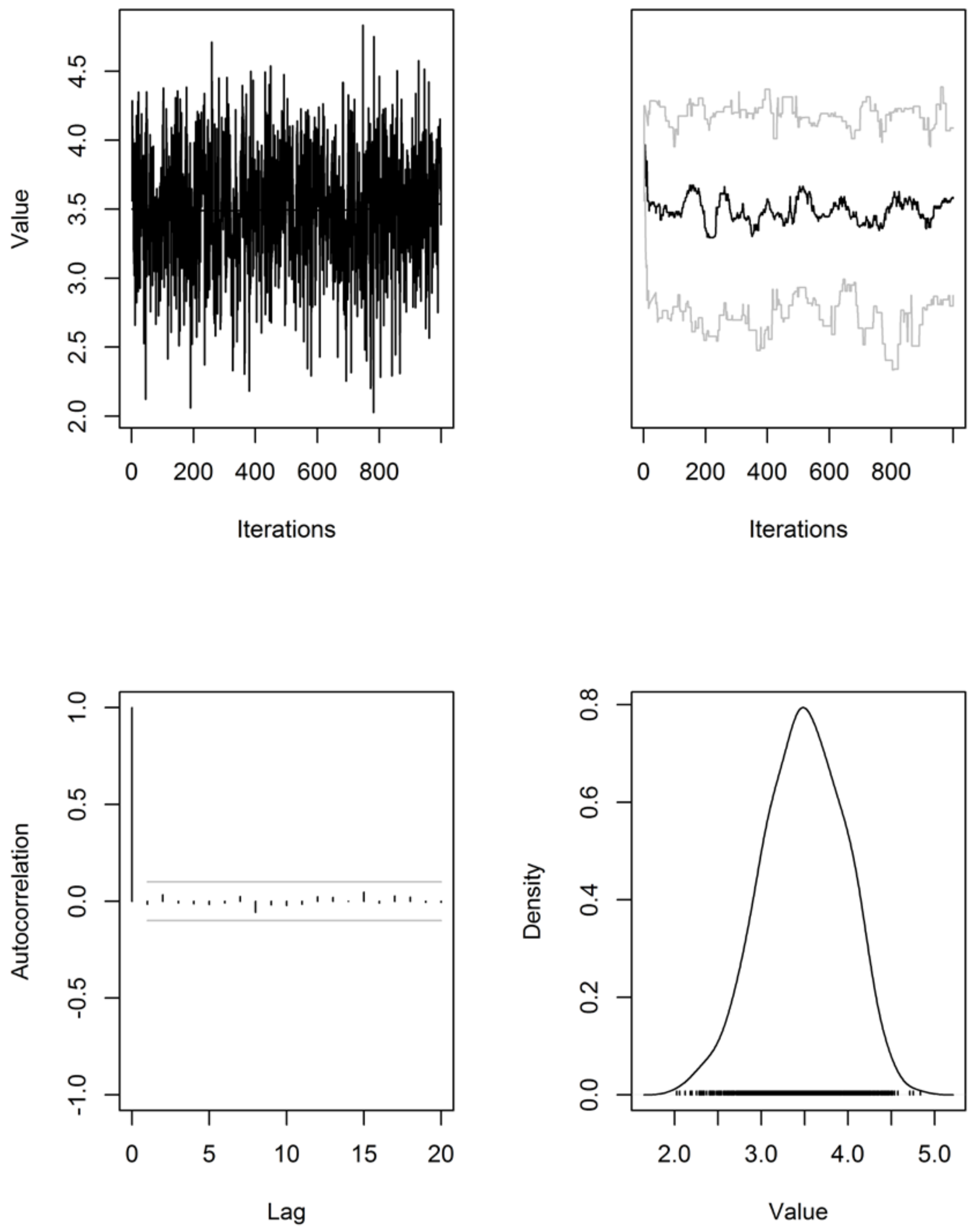

Figure A5: Diagnostic plots for the McMC draws for the BPT selectivity parameter 1 of the base assessment model.

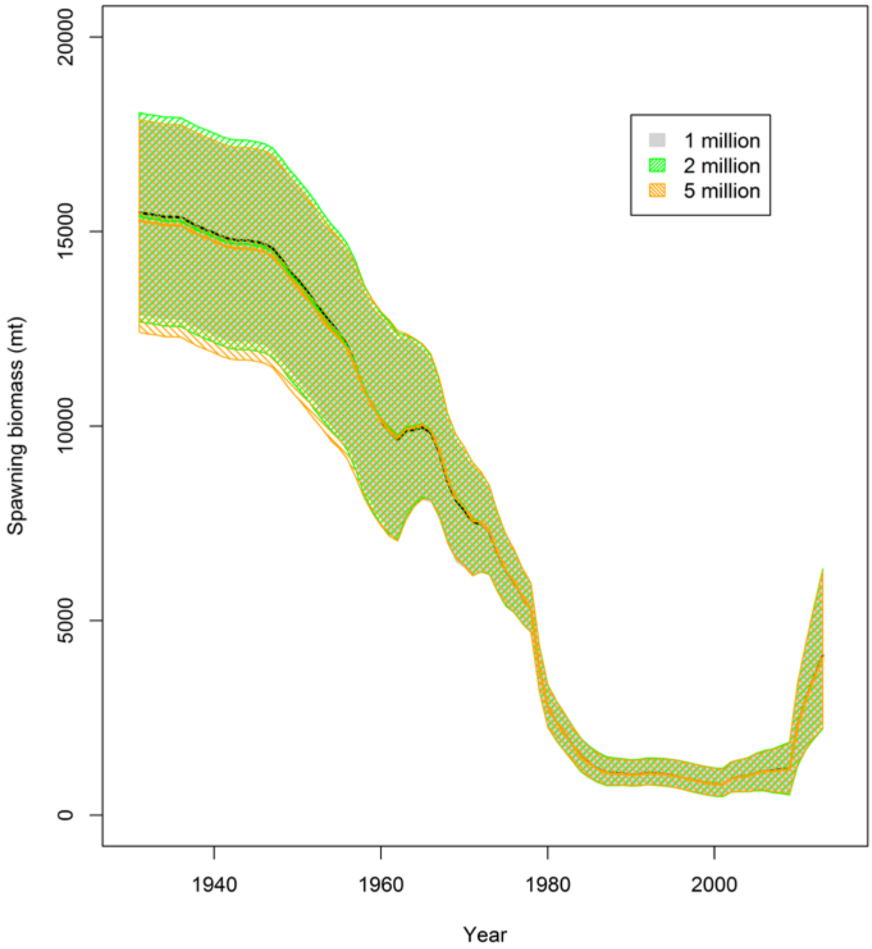

Figure A6: A comparison of the spawning biomass trajectories and 95% confidence intervals derived from McMC chains of different lengths sampled from the base assessment model. In each case, McMCs were sampled at each 1000 interval.

APPENDIX 2. MODEL INPUT DATA SETS

Table A1: Annual snapper catch (t) by fishery (BT, bottom trawl; BPT pair trawl; Rec, recreational) included in the assessment model, including an allowance for under-reporting of the commercial catch prior to 1986. 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	51	206	15
1943	35	0	10	1987	51	205	15
1944	115	0	10	1988	123	53	17
1945	142	0	10	1989	235	59	18
1946	278	0	10	1990	128	32	19
1947	570	0	10	1991	118	30	22
1948	653	0	10	1992	132	33	24
1949	572	0	10	1993	118	29	25
1950	617	0	10	1994	120	30	26
1951	689	0	10	1995	117	29	27
1952	676	0	10	1996	130	32	27
1953	569	0	10	1997	164	18	26
1954	469	0	10	1998	128	14	25
1955	605	0	10	1999	157	17	25
1956	986	0	10	2000	140	16	24
1957	1 266	0	10	2001	127	14	25
1958	865	0	10	2002	168	19	33
1959	780	0	10	2003	194	22	35
1960	688	0	10	2004	160	18	38
1961	700	0	10	2005	149	17	43
1962	698	0	11	2006	223	25	47
1963	683	0	13	2007	170	19	49
1964	689	0	16	2008	184	20	53
1965	936	0	18	2009	169	19	57
1966	1 627	0	21	2010	208	0	88
1967	1 936	0	22	2011	216	0	146
1968	1 244	0	23	2012	211	0	185
1969	659	0	25	2013	200	0	226
1970	751	0	27				
1971	768	0	29				
1972	920	0	32				
1973	1 510	0	35				
1974	985	246	35				

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

Fishing year	Model year	Index	LCI	UCI
89/90	1989	0.646	0.517	0.793
90/91	1990	0.700	0.550	0.863
91/92	1991	0.570	0.451	0.716
92/93	1992	0.559	0.448	0.698
93/94	1993	0.917	0.725	1.156
94/95	1994	0.515	0.404	0.650
95/96	1995	0.537	0.420	0.696
96/97	1996	0.391	0.306	0.489
97/98	1997	0.418	0.315	0.530
98/99	1998	0.228	0.170	0.299
99/00	1999	0.614	0.466	0.791
00/01	2000	0.357	0.268	0.466
01/02	2001	0.316	0.236	0.420
02/03	2002	0.469	0.365	0.593
03/04	2003	0.674	0.543	0.829
04/05	2004	0.240	0.185	0.308
05/06	2005	0.655	0.522	0.832
06/07	2006	0.695	0.563	0.845
07/08	2007	0.397	0.318	0.492
08/09	2008	0.485	0.382	0.607
09/10	2009	0.548	0.440	0.686
10/11	2010	1.034	0.810	1.299
11/12	2011	2.509	1.904	3.173
12/13	2012	1.944	1.499	2.464
13/14	2013	2.693	2.112	3.397

Table A3: 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 A4: 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
1	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
3	0.1861	0.0008	0.2694	0.0244	0.1292	0.0202	0.0139	0.2282
4	0.1071	0.0385	0.1111	0.1760	0.0268	0.4780	0.2860	0.0191
5	0.4125	0.0640	0.0536	0.0709	0.1512	0.2090	0.0536	0.0253
6	0.1358	0.0084	0.0204	0.0207	0.0625	0.1482	0.0229	0.6891
7	0.0999	0.0103	0.0068	0.0204	0.0179	0.0062	0.4685	0.0045
8	0.0169	0.0553	0.0102	0.0000	0.0097	0.0349	0.0343	0.0092
9	0.0031	0.0656	0.1064	0.0259	0.0003	0.0108	0.0231	0.0103
10	0.0009	0.1598	0.0465	0.1067	0.0067	0.0052	0.0005	0.0000
11	0.0017	0.1083	0.0886	0.0407	0.0854	0.0048	0.0153	0.0059
12	0.0040	0.2489	0.0486	0.1722	0.0217	0.0010	0.0064	0.0008
13	0.0021	0.0832	0.1157	0.0301	0.1169	0.0028	0.0025	0.0000
14	0.0055	0.0067	0.0289	0.1758	0.0062	0.0141	0.0060	0.0070
15	0.0039	0.0029	0.0008	0.0142	0.2251	0.0058	0.0011	0.0000
16	0.0016	0.0136	0.0005	0.0019	0.0046	0.0073	0.0002	0.0000
17	0.0019	0.0141	0.0082	0.0021	0.0053	0.0044	0.0053	0.0000
18	0.0048	0.0095	0.0072	0.0034	0.0021	0.0137	0.0027	0.0000
19	0.0028	0.0140	0.0063	0.0102	0.0043	0.0140	0.0067	0.0000
20	0.0003	0.0148	0.0705	0.1017	0.1162	0.0194	0.0023	0.0000
21	0.0005	0.0053					0.0217	0.0000
22	0.0021	0.0076					0.0052	0.0000
23	0.0018	0.0140					0.0023	0.0000
24	0.0003	0.0108					0.0000	0.0006
25	0.0000	0.0051					0.0004	0.0000
26	0.0000	0.0062					0.0011	0.0000
27	0.0002	0.0063					0.0010	0.0000
28	0.0001	0.0022					0.0005	0.0000
29	0.0000	0.0007					0.0000	0.0000
30	0.0042	0.0231					0.0153	0.0000

Table A5: 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	0.022
0.667	0.091	0.274	0.117	0.144	0.104	0.117	0.030	0.151	0.470	0.631
1.428	0.094	0.318	0.364	0.288	0.252	0.013	0.062	0.143	0.102	0.153
2.000	0.470	0.260	0.517	0.562	0.573	0.858	0.798	0.554	0.294	0.194