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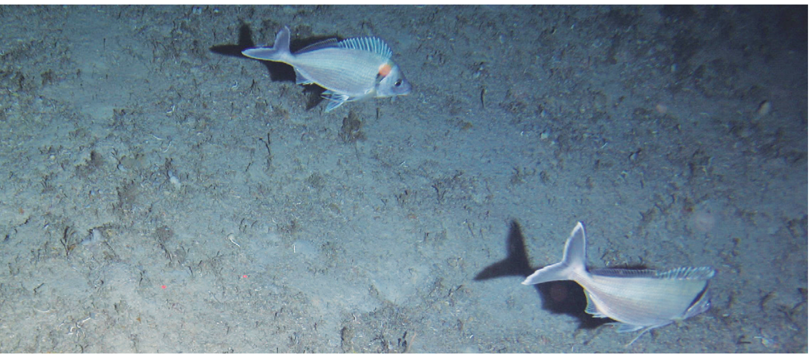
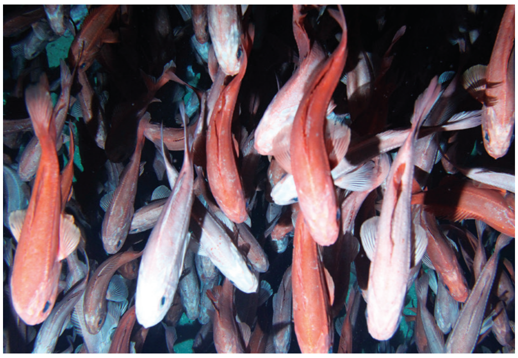
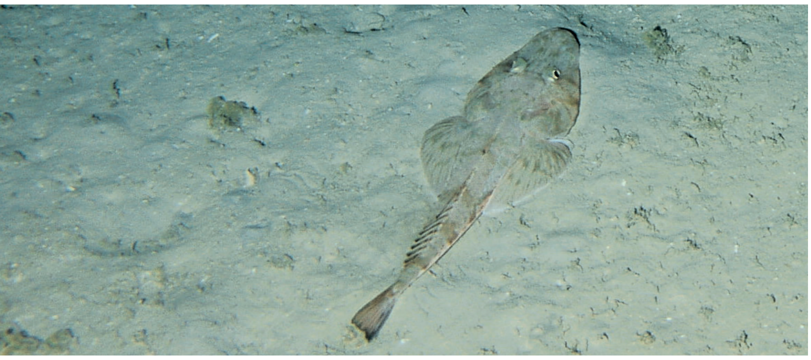
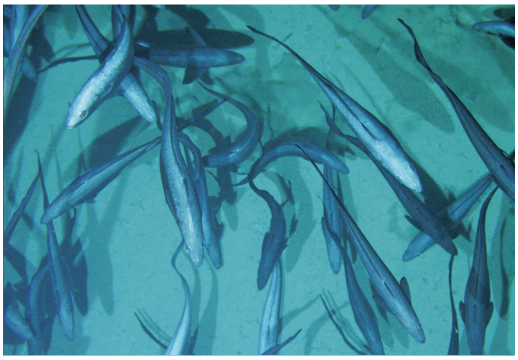
Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery: 2014





PART 1





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Cover photographs

Front cover, jackass morwong, orange roughy, blue grenadier, and flathead.

Report structure

Part 1 of this report describes the Tier 1 assessments of 2014. Part 2 describes the Tier 3 and Tier 4 assessments, catch rate standardisations and other general work contributing to the assessment and management of SESSF stocks in 2014.

Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery: 2014

Part 1: Tier 1 assessments

G.N. Tuck
June 2015
Report 2013/0010

Australian Fisheries Management Authority

Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery: 2014 Part 1

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1. Non-Technical Summary

Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery: 2014

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OBJECTIVE:

- Provide quantitative and qualitative species assessments in support of the five SESSF resource assessment groups.

1.1 Outcomes Achieved

The 2014 assessments of stock status of the key Southern and Eastern Scalefish and Shark fishery (SESSF) species are based on the methods presented in this report. Documented are the latest quantitative assessments for the SESSF quota species. Typical assessment results provide indications of current stock status, in addition to an application of the recently introduced Commonwealth fishery harvest control rules that determine a Recommended Biological Catch (RBC). These assessment outputs are a critical component of the management and Total Allowable Catch (TAC) setting process for these fisheries. The results from these studies are being used by SESSFRAG, industry and management to help manage the fishery in accordance with agreed sustainability objectives.

1.2 General

Examination of catch rate indices to determine whether to break out of a multi-year TAC

An examination was made of whether recent actual CPUE trends are consistent with projected trends from the most recent Tier 1 stock assessments. Only species not planned for assessment in 2014 were examined, to allow RAG judgement of whether as assessment may be warranted. Of the species examined, four showed actual CPUE trends that fell outside of the 95% confidence bounds projected from the stock assessment – tiger flathead, pink ling, jackass morwong and silver warehou. Break out for pink ling and jackass morwong were for only one of the areas/fleets, and were marginal. Silver warehou however, only had one CPUE indicator series, and this had unambiguously broken out for the past two years. This was not unexpected given past RAG deliberations that the assessment shows bad retrospective behaviour. It is of concern that flathead Danish seine CPUE has broken out, but the east coast trawl CPUE for that species has not.

For the GAB, standard CPUE breakout analyses were conducted for deepwater flathead and Bight redfish. Neither species was close to the edge of the projected 95% confidence intervals around the CPUE predicted from the projected Tier 1 assessments from earlier years.

Western gemfish did not exhibit any exceptional deviations in CPUE from the long term average. However, the estimate of high discarding rates for western gemfish in the latest year may imply that the latest CPUE estimate is not a valid representation of current real catch rates. On the other hand, if this is actually the case then it is likely that CPUE should be higher than the records suggest, which again is not a sign of stock decline.

Catch rate standardisations

Catch-per-unit-effort (CPUE) data is an important input to many of the stock assessments conducted within the South East and Southern Shark Fishery (SESSF), where it is used as an index of relative abundance through time. The catch and effort logbook data from the SESSF, which is the source of CPUE data, constitutes shot by shot data derived from a wide range of vessels, areas (zones), months, depths, and fishing gears. Catch rates used in the assessments are standardized to reduce the effects of factors such as which vessel fished, where and when fishing occurred, the gear used, at what depths fishing was conducted, and whether fishing occurred during the day or night. The intent is to focus on any changes in catch rates that occurred between years as a result of changes in stock size rather than changes that occur in any of these other factors. This intent is not always realized when there are unknown influential factors or factors for which we have no data, so interpretation of the catch rate trends should not necessarily be taken at face value. This is especially the case when there have been major management changes, such as the introduction of quotas or the more recent structural adjustment. Such large events can greatly influence fishing behaviour, which in turn influences catch rates. Because these changes affected the whole fleet at the same time it is not possible to standardize for their effects.

Catch rates, generally as kilograms per hour fished (though sometimes as catch per shot *e.g.* Danish Seine, or non-trawl methods), were natural log-transformed to normalize the data and stabilize the variance before standardization. A General Linear Model was used rather than using a Generalized Linear Model with a log-link. This simple analytical approach means that the exact same methods can be applied to all species/stock combinations in a relatively robust manner. The statistical models fitted were of the form: LnCE = Year + Vessel + Month + Depth Category + Zone + DayNight. There were interaction terms which could sometimes be fitted, such as Month:Zone or Month:Depth_Category. Data from all vessels reporting catches of a species were included although a preliminary data selection was made on a given depth range for each species for the zones of interest to focus attention on those depths contributing significantly to the fishery for each assumed stock and to reduce the number of empty categories within the statistical models.

Documented are the statistical standardization of the commercial catch and effort data for 21 species, distributed across 50 different combinations of stocks and fisheries ready for inclusion in the annual round of stock assessments. These include School Whiting, Eastern Gemfish, Jackass Morwong, Flathead, Redfish, Silver Trevally, Royal Red Prawn, Blue Eye, Blue Grenadier, Spotted/Silver Warehou, Blue Warehou, Pink Ling, Western Gemfish, Ocean Perch, John Dory, Mirror Dory, Ribaldo, Ocean Jackets, Deepwater Flathead and Bight Redfish.

Summary graphs are provided across all species as well as more detailed information for each stock. Out of 36 stocks, there were seven whose catch rates have increased over the last 10 years; 17 stocks where catch rates were stable and 12 stocks whose catch rates have declined over the last 10 years. There were eight stocks whose catch rates have increased since the 2007 corresponding to the structural adjustment and introduction of the Harvest Strategy Policy; five stocks whose catch rates were stable and 23 stocks whose catch rates have declined over last seven year period.

Yield, total mortality values and Tier 3 analyses

Yield and total mortality estimates are provided for John dory and Mirror dory caught in the Southern and Eastern Scalefish and Shark Fishery (SESSF) on the shelf and slope. Yield estimates were made using a yield-per-recruit model with the following input: selectivity-at-age, length-at-age, weight-at-age, age-at-maturity, and natural mortality. Total mortality values corresponding to various reference equilibrium biomass depletions were calculated for each species.

Recent average total mortality was estimated from catch curves constructed from length frequency information. Length frequency data were from ISMP port and/or onboard measurements. The method used to estimate total mortality also estimates average fishery selectivity.

For John dory, age data are available from otoliths collected during a 14 month period from mid 2010 to mid 2011.

For Mirror dory, age data are available from a range of years, most recently 242 otoliths collected during 2013 and 111 from 2014, mainly from the east. Length data are only available to 2013. The 2013 and 2014 samples both show relatively large numbers of young fish. The sample for 2013 is reasonably well spread across the months of 2013, but the 2014 sample came from June and July only. For mirror dory, estimated F current (F_{cur}) values are averaged over the east and west. Fits to the age data for the west are poor, possibly indicating that the theoretical relationship for gear selectivity that is used, is not appropriate for that sector. Estimated F_{cur} is much lower in the west (0.01) than in the east (0.88) giving an overall F_{cur} of 0.44.

The calculated RBCs are lower than those of 2013, being 164t for John dory and zero for Mirror dory (due to an estimate that the fishing mortality rate is above that which leads to a stock size of 20% of pristine).

Tier 4 analyses 1986 - 2013

The Tier 4 harvest control rule is applied to species for which there is no reliable information on either current biomass levels or current exploitation rates. Ideally, in line with the notion of being more precautionary in the absence of information, the outcome from these analyses should be more conservative than those available from higher Tier analyses; this is now explicitly implemented by imposing a 15% discount factor on the RBC as a precautionary measure, unless there are good reasons for not imposing such an discount on particular species. The default procedure will now be to apply the discount factor unless RAGs generate advice that alternative and equivalent precautionary measures are in place (such as spatial or temporal closures) or that there is evidence of historical stability of the stock at current catch levels. Tier 4 analyses require, as a minimum, knowledge of the time series of total catches and of catch rates, either standardized or simple geometric mean catch rates.

This year, only standardized catch rates were used except where discards were explicitly included in the analyses.

Five Tier 4 analyses were applied only to John Dory and Mirror Dory in the SESSF. There were spatial data available for Mirror Dory, which led to analyses for the east and west presumed stock regions. Recent discard estimates for Mirror Dory have been relatively high, so a further Tier 4 analyses was conducted where discard estimates were included in the analysis of catch rates. Neither John Dory nor Mirror Dory are recognized as Tier 4 managed species. The estimated RBC for John Dory was zero, while the Mirror Dory RBC varied between 161 t (west) to 392 t (east) and 523 t (east with discards), and 595 t if zones are not considered.

1.3 Slope and Deepwater Species

Orange roughy

The 2014 assessment for Eastern Zone orange roughy (*Hoplostethus atlanticus*) uses an integrated stock assessment model implemented using the platform Stock Synthesis. It assumes a stock structure hypothesis that the Eastern Zone and Pedra Branca from the Southern Zone (all seasons) constitutes a single homogeneous stock. New data inputs since the 2011 preliminary assessment model include recent research catches; total spawning biomass estimates for 2012 and 2013 from acoustic towed surveys at St Helens Hill and St Patricks Head, and revised indices of spawning biomass from towed and hull surveys since 1990.

The acoustic indices are considered to be relative indices in the model in the sense that there are several factors that can lead to the acoustic biomass estimate differing from the biomass available to survey on average. Informative prior distributions were developed for the catchability coefficient for the acoustic surveys, and the Francis data weighting method was applied to select the weights for the age composition data, which led to more weight being assigned to the acoustic survey indices when the model was fitted. The other new data inputs were a revised egg survey estimate, a catchability coefficient for that survey, and an updated ageing error matrix using data from a recent re-ageing experiment. The re-ageing experiment, which was designed to investigate between-year bias in age reads, found no evidence of a major bias in the early age readings for Eastern Zone orange roughy.

The assessment model estimates a pattern of recruitment that oscillates from high to low prior to the start of the fishery, and imply a steep decline in female spawning biomass during the early 1990's (as the commercial fishery developed), followed by a period of gradual further decline, and a recent increase to levels above 20% of the unfished female spawning biomass. The model estimates a recent increasing trend in spawning biomass, whereas the observed acoustic point estimates for 2012 and 2013 are less than the point estimates for the preceding years.

The base case model estimated female spawning biomass in 2015 to be 26% of the unfished level. The estimated RBC under the 20:35:48 harvest control rule is 381t, with a long-term RBC of approximately 1,534 t. This outcome is consistent with those from the 2006 Eastern Zone orange roughy stock assessment. The posterior median estimates from the MCMC simulation were close to the MPD estimates for most of the parameters of interest. The median estimate of female spawning depletion (SB_{2015}/ SB_0) was 0.25 with a 95% Bayesian CI of 0.23 to 0.28, and is close to the MPD estimate of 0.26. The 95% Bayesian CIs are fairly narrow and may indicate that the model is constrained. In particular, the model assumption regarding the degree to which data inform estimates of recruitment in the recent and forecast years could have overly constrained the estimates of recruitment variability for these years, and this should be explored in future assessments. The catchability coefficients for the towed and hull acoustic surveys were estimated by the Final Base-case model to be 1.32 and 1.78 respectively, and these were within the bounds of the priors. Assumptions regarding stock structure are a key uncertainty in the assessment, as the model outcomes differed depending on this assumption. The base-case model was also sensitive to the inclusion of recruitment deviations, higher earlier catches and, to a lesser extent, the data weighting method for the age compositions.

1.4 Shelf Species

Eastern redfish

For the first time, the 2014 assessment of eastern redfish *Centroberyx affinis* in the SESSF uses an age- and size-structured model implemented in the generalized stock assessment software package, Stock Synthesis. The assessment includes data up to the end of the 2013 calendar year. Data include annual landings, catch rates, discard rates, and length/age compositions. Alternative potential base-case models were considered that differed according to assumptions regarding discard and retention practices, as changes occurred in the fishery as it moved from market-based discarding to size-based discarding.

Results from the assessments conclude that the estimated redfish spawning biomass in 2015 will be considerably less than the unexploited spawning stock biomass. For the base-case model, the estimated virgin female biomass is 14,558 t, and the 2015 estimated spawning biomass level is 11% of un-exploited levels. As the estimated stock status is below the limit reference point of 20% assuming the 20:35:48 control rule, the RBCs are consequently zero. All models that have been tuned, including models tuned using the Francis method, similarly led to zero RBCs for 2015.

Evidence in the aging data suggests that there have been two recent years of improved recruitment (in 2011 and 2012). While a small improvement in catch rates may also have occurred as a consequence of these fish moving into the available biomass, the existence and magnitude of these recruitments should be monitored over the ensuing years to verify what may be a positive sign for the stock.

1.5 Shark Species

Shark fishery characterisation

An analysis of shark data, including catches and cpue was conducted. Catches of School shark are as low as they have ever been, however, CPUE from the gillnet fishery can no longer be assumed to constitute an index of relative abundance for the school shark stock. The efforts to avoid school shark appear to be relatively successful. Catches by trawler are not targeted, as evidenced by the large proportion of < 30kg shots present in the data. Nevertheless, the areas in which they are caught has not changed greatly and yet the catch rates have begun to increase significantly. This is a positive sign, which when combined with the observation of increased proportions of smaller school sharks in the ISMP sampling are a first clear evidence of school sharks showing some signs of increasing.

The avoidance of school sharks and an array of closures in South Australia have also led to a reduction in gillnet catches of gummy sharks as well as an apparent reduction in the catch rates for gillnet caught gummy sharks. However, catches by bottom line and trawl are increasing, especially those by bottom line. Catch rate standardizations for both bottom-line and for trawl caught gummy sharks indicate strong and recent increases in catch rates for gummy shark. This counters the appearance of events from the gillnet fishery.

Catches of saws sharks are considered to be a bycatch and this is supported by the high proportion of reported catches being < 30 kg in both gill net and trawl caught fish. The CPUE standardization for gillnets exhibits a steady decline since about 2001, however, the trawl caught saw shark standardization exhibits a noisy but flat trend. To complement this finding, the CPUE of saw sharks by Danish Seine (which has the highest proportion of shots < 30kg among methods) has been flat since 2006 onwards.

Elephant fish also constitute a non-targeted species, again with a large proportion of small shots. The gillnet CPUE is also flat and noisy, which is an analysis conducted in the absence of discard data. In the last few years discard rates for elephant fish have been very high, which would imply that their catch rates would in fact be increasing.

Saw shark and elephant fish Tier 4 analyses

The Tier 4 control rule is used to calculate RBCs for saw sharks (*Pristiophorus* sp.) and elephant fish (*Callorhinchus milii*). Standardized catch rates for both species were estimated using the SESSF logbook data only rather than the earlier data, along with total catches of the respective species in a standard analysis. For saw sharks the reported catches by trawl are now approaching the level of gill net catches so an additional analysis was conducted where the standardized catch rate for trawl saw shark catches was used instead of the gillnet catch rates.

The gillnet catch rates for saw sharks in 2013 were slighter higher than those in 2012 but owing to the initial drop in catch rates in 2012 the tier 4 analysis, which considers the average catch rate over the last four years and that has now declined to about 57% of the target catch rate (down from about 65% in 2012). Whether the decline in the gillnet catch rates constitute a reasonable reflection of the stock status remains questionable due to the level of avoidance that occurs in the fishery (due to low and reducing value of saw sharks in the market). Importantly, when the trawl catch rates for saw sharks are standardized a different trend is apparent. In 2000 the catches by trawl were only 20% of all catches whereas gillnets accounted for 78%, but in 2013 trawls account for 44.7% while gillnets account for 41.7% (most of the remainder is taken by Danish Seine).

The catch rate data used for elephant fish now also only relates to the SESSF database, which means the probability of obtaining a positive shot cannot be well identified. Elephant fish catch rates continued, in 2013, to approximate the long term average through the entire time-series. However, these values do not include discards in their calculations and since 2007 and especially since 2011 the importance of discards has become particularly influential in elephant fish. When discards are included in the calculation of CPUE as well as total catches then the CPUE increased in both 2011 and 2012, implying a rise in RBC. When discards are not stable, as is the case with elephant fish then this latter analysis more closely reflects the fishery dynamics. The analysis including discards makes the important assumption that discards only derive from a portion of each shot that catches elephant fish. If there is a high proportion of discards where the entire catch of elephant fish are discarded then the assumptions behind the analysis are broken and it will become biased high.

In both the saw shark and elephant fish these analyses relate to the target catch rate being a proxy for 48% of unfished biomass. However, neither species are reported as being targeted in the fishery (when using any method) so these calculated RBC are inherently conservative. Alternative estimates based on a target of 40% were therefore also calculated. RBCs varied between 185 t and 600 t for saw shark and 99 t and 357 t for elephant fish.

KEYWORDS: fishery management, southern and eastern scalefish and shark fishery, stock assessment, trawl fishery, non-trawl fishery

2. Background

The Southern and Eastern Scalefish and Shark Fishery (SESSF) is a Commonwealth-managed, multi-species and multi-gear fishery that catches over 80 species of commercial value and is the main provider of fresh fish to the Sydney and Melbourne markets. Precursors of this fishery have been operating for more than 85 years. Catches are taken from both inshore and offshore waters, as well as offshore seamounts, and the fishery extends from Fraser Island in Queensland to south west Western Australia.

Management of the SESSF is based on a mixture of input and output controls, with over 20 commercial species or species groups currently under quota management. For the previous South East Fishery (SEF), there were 17 species or species groups managed using TACs. Five of these species had their own species assessment groups (SAGs) – orange roughy (ORAG), eastern gemfish (EGAG), blue grenadier (BGAG), blue warehou (BWAG), and redfish (RAG). The assessment groups comprise scientists, fishers, managers and (sometimes) conservation members, meeting several times in a year, and producing an annual stock assessment report based on quantitative species assessments. The previous Southern Shark Fishery (SSF), with its own assessment group (SharkRAG), harvested two main species (gummy and school shark), but with significant catches of saw shark and elephantfish.

In 2003, these assessment groups were restructured and their terms of reference redefined. Part of the rationale for the amalgamation of the previous separately managed fisheries was to move towards a more ecosystem-based system of fishery management (EBFM) for this suite of fisheries, which overlap in area and exploit a common set of species. The restructure of the assessment groups was undertaken to better reflect the ecological system on which the fishery rests. To that end, the assessment group structure now comprises:

- SESSFRAG (an umbrella assessment group for the whole SESSF)
- Slope and Deepwater Resource Assessment Group (Slope and Deep RAG)
- Shelf Resource Assessment Group (Shelf RAG)
- Shark Resource Assessment Group (Shark RAG)
- Great Australian Bight Resource Assessment Group (GAB RAG)

Each of the depth-related assessment groups is responsible for undertaking stock assessments for a suite of key species, and for reporting on the status of those species to SESSFRAG. The plan for the resource assessment groups (Slope/Deep, Shelf, GAB and Shark RAGs) is to focus on suites of species, rather than on each species in isolation. This approach has helped to identify common factors affecting these species (such as environmental conditions), as well as consideration of marketing and management factors on key indicators such as catch rates.

The quantitative assessments produced annually by the Resource Assessment Groups are a key component of the TAC setting process for the SESSF. For assessment purposes, stocks of the SESSF currently fall under a Tier system whereby those with better quality data and more robust assessments fall under Tier 1, while those with less reliable available information are in Tiers 3 and 4. To support the assessment work of the five Resource Assessment Groups, the aims of the work conducted in this report were to develop new assessments if necessary (under all Tier levels), and update and improve existing ones for priority species in the SESSF.

3. Need

A stock assessment that includes the most up-to-date information and considers a range of hypotheses about the resource dynamics and the associated fisheries is a key need for the management of a resource. In particular, the information contained in a stock assessment is critical for selecting harvest strategies and setting Total Allowable Catches.

4. Objectives

- Provide quantitative and qualitative species assessments in support of the five SESSFRAG assessment groups, including RBC calculations within the SESSF harvest strategy framework.

5. Orange Roughy (*Hoplostethus atlanticus*) Eastern Zone stock assessment incorporating data up to 2014

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5.1 Summary

A workshop organised by AFMA (including New Zealand participants) was held at CSIRO Hobart in May 2014 to discuss the Eastern Zone orange roughy fishery and stock assessment, including the development of a base-case model specification. The base case model outlined in this document draws largely on the outcomes of that workshop, as well as the 'future work' outlined by Upston & Wayte (2012b). The aim of this document is to report on the Preliminary and Final Base-case assessment models that were considered by the Slope Resource Assessment Group (Slope RAG) at their meetings in September and October 2014, and to report on the additional work that was conducted during November 2014 (out of session).

The current assessment for Eastern Zone orange roughy (*Hoplostethus atlanticus* Collett 1889) uses an integrated stock assessment model implemented using the platform Stock Synthesis 3. It assumes a stock structure hypothesis that the Eastern Zone and Pedra Branca from the Southern Zone (all seasons) constitutes a single homogeneous stock. New data inputs since the 2011 preliminary assessment model (Upston & Wayte 2012a) include recent research catches; total spawning biomass estimates for 2012 and 2013 from acoustic towed surveys at St Helens Hill and St Patricks Head, and revised indices of spawning biomass from towed and hull surveys since 1990.

The acoustic indices are considered to be relative indices in the model in the sense that there are several factors that can lead to the acoustic biomass estimate differing from the biomass available to survey on average. Informative prior distributions were developed for the catchability coefficient for the acoustic surveys, and the Francis (2011) data weighting method was applied to select the weights for the age composition data, which led to more weight being assigned to the acoustic survey indices when the model was fitted. The other new data inputs were a revised egg survey estimate, a catchability coefficient for that survey, and an updated ageing error matrix using data from a recent re-ageing experiment (by Fish Ageing Services). The re-ageing experiment, which was designed to investigate between-year bias in age reads, found no evidence of a major bias in the early age readings for Eastern Zone orange roughy.

A Preliminary Base-case model was presented at the Slope RAG meeting in September 2014, and the Final Base-case Model 0, which included minor updates to recent catches and the ageing error matrix, was presented at the Slope RAG meeting in October 2014. The model outcomes were similar; both models estimate a pattern of recruitment that oscillates from high to low prior to the start of the fishery, and imply a steep decline in female spawning biomass during the early 1990's (as the commercial fishery developed), followed by a period of gradual further decline, and a recent increase to levels above 20% of the unfished female spawning biomass. The model estimates a recent increasing trend in spawning biomass, whereas the observed acoustic point estimates for 2012 and 2013 are less than

the point estimates for the preceding years (Ryan et al. 2014 raise the possibility that the 2013 St Helens acoustic survey may have missed the spawning peak but they cannot be definitive).

The Final Base-case Model 0 estimated female spawning biomass in 2015 to be 26% of the unfished level (maximum posterior density MPD estimate). The estimated RBC under the 20:35:48 harvest control rule is 381t, with a long-term RBC of approximately 1,534 t. The outcome of Model 0 is consistent with those from the 2006 Eastern Zone orange roughy stock assessment, which forecasted that the biomass would reach the limit level of 20% of the unfished level in 2014 (if removals in each future year were based on the 48:48:20 harvest control rule).

The posterior median estimates from the MCMC simulation were close to the MPD estimates for most of the parameters of interest. The median estimate of female spawning depletion (SB_{2015}/ SB_0) was 0.25 with a 95% Bayesian CI of 0.23 to 0.28, and is close to the MPD estimate of 0.26. The 95% Bayesian CIs for the estimated parameters, notably female spawning biomass, are fairly narrow and may indicate that the model is constrained. In particular, the model assumption regarding the degree to which data inform estimates of recruitment in the recent and forecast years could have overly constrained the estimates of recruitment variability for these years, and this should be explored in future assessments.

The catchability coefficients for the towed and hull acoustic surveys were estimated by the Final Base-case model to be 1.32 and 1.78 respectively, and while substantially higher than 1, both were within the bounds of the priors. The selected priors may not have captured all of the uncertainty associated with the difference between estimates from the acoustic surveys and the underlying biomass. Assumptions regarding stock structure and the proportion spawning annually could also have a scaling effect on biomass estimates in the model.

Assumptions regarding stock structure are a key uncertainty in the assessment, as the model outcomes differed depending on this assumption. The base-case model was also sensitive to the inclusion of recruitment deviations, higher earlier catches and, to a lesser extent, the data weighting method for the age compositions.

5.2 Introduction

5.2.1 The fishery

The two most recent stock assessments for Eastern Zone orange roughy (*Hoplostethus atlanticus* Collett 1889) were completed in 2006 (using data up to July 2006 and using an estimate of catch for calendar 2006; Wayte 2007) and in 2011 (using data up to December 2010; Upston & Wayte 2012a, b). Hereafter, these models are referred to as “2006 assessment model” and the “2011 preliminary assessment model” respectively. Historically, the stock assessment has been referred to as the “Eastern Zone orange roughy stock assessment”, distinct from the “Southern Zone stock assessment” (Wayte 2002), and we continue with this naming convention. We describe the stock structure assumptions for the Eastern Zone stock assessment in Section 5.2.2.

A history of the fishery for orange roughy in the Australian Fishing Zone is provided by CSIRO & TDPIF (1996); Bax (2000); Wayte (2007), and in a series of articles in the journal, Australian Fisheries, since the early 1980’s (e.g. May 1989; December 1989; October 1990).

The fishery was closed to commercial fishing at end of 2006 (with the exception of the Cascade Plateau Zone), with orange roughy listed as conservation dependent. A 5-year conservation plan has been in place since 2007 and was due for review in 2011/12. It is currently in the process of review. There is a requirement under the Conservation Program, developed in response to the species being listed as conservation dependent, to collect information on how the stock status for the species is tracking over time. Consequently, recent estimates of biomass from acoustic surveys are available, and age data have also been collected. A research quota of less than 200 t has been allocated and fished in each year to collect this information. A workshop organised by AFMA (including NZ participants) was held at CSIRO Hobart in May 2014 to discuss the fishery and the Eastern Zone orange roughy stock assessment, including development of a base-case model specification. The base case model in this document draws largely on the outcomes of this workshop.

5.2.2 *Stock structure*

Information on stock structure and life history of orange roughy is included in Deriso & Hilborn (1994); CSIRO & TDPIF (1996); Bax (2000); Wayte (2007); and Prince & Hordyk (2011). In a review of Australian orange roughy stock assessments, Stokes (2009) recommended that a comprehensive or “forensic” review of all information relevant to stock structure (e.g. see Dunn & Devine, 2010, for orange roughy in New Zealand) be undertaken to explain and justify existing assumptions and/ or underpin model development for management strategy evaluation.

The stock structure of orange roughy remains uncertain. Stokes (2009) noted that modelling of biomass based on various plausible stock structure hypotheses, as was done in the 2006 assessment (Wayte, 2007), was a reasonable approach in the absence of information on stock structure. The stock structure hypotheses specified in the 2006 assessment are listed in Table 5.1 (from Wayte, 2007). The Australian orange roughy management zones and areas are shown in Figure 5.1.

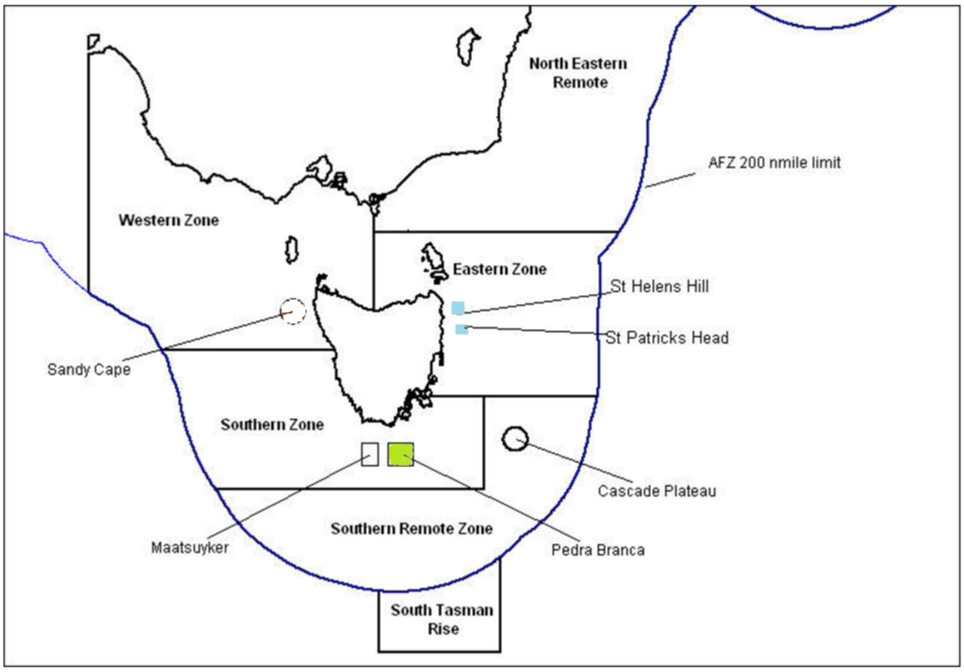


Figure 5.1. Map of Australian orange roughy management zones and areas (adapted from Wayte, 2007).

Table 5.1.The stock structure hypotheses used in the 2006 assessment (Wayte, 2007).

Stock hypothesis	Description	Corresponding catch data
East	All roughy in the Eastern zone (spawning and non-spawning)	Total Eastern zone catch (all months)
2002 Combined	Eastern zone spawning roughy and the Pedra Branca non-spawning roughy	Eastern zone winter catch (June, July, August) and Pedra Branca[1] non-winter catch (all months except June-Aug)
*Combined	Eastern zone roughy and the Pedra Branca roughy	Total Eastern zone catch (all months) and Pedra Branca catches (all months)
East + South	All roughy in the Eastern and Southern zones	Total Eastern zone catch and total Southern zone catch (all months)
East + South + West	All roughy in the Eastern, Southern and Western zones	Total Eastern zone catch, total Southern zone catch and total Western zone catch (all months)

[1] Pedra Branca area : -44.5S < latitude=<-44S; 146.5<=longitude<147.75

*Base-case in the 2006 assessment

The stock structure hypothesis used in the 2014 base-case model is the same as that specified for the 2006 and 2011 base-case models, i.e. the ‘Combined‘ hypothesis in Table 5.1: Eastern Zone and Pedra Branca from the Southern Zone, for all seasons. For the 2014 assessment, we refer to this hypothesis as “East and South (Pedra Branca)”. This stock structure hypothesis is partly based on the prevailing theory that a proportion of Southern Zone orange roughy migrate to the main spawning grounds in the Eastern Zone (St Helens Hill or the nearby St Particks Head) to spawn in winter. It excludes the possibility that orange roughy in other areas of the Southern Zone (e.g. Maatsuyker, near to Pedra Branca), and indeed other Zones, also migrate to spawn in the Eastern Zone. The base-case model includes all seasons so it implies a degree of mixing throughout the year.

The stock structure hypothesis used in the models will influence estimates of unfished biomass and current biomass, but not necessarily depletion estimates. Thus a potential “scaling” issue, stemming from an incorrect stock structure assumption (or some other factor), might become evident if the model consistently over- or under-estimates current spawning biomass when compared with a reliable time series of absolute biomass indices. We explore the sensitivity of the results to alternative stock structure in this assessment.

5.2.3 *2014 Base-case and modifications to the 2011 Eastern Zone preliminary assessment*

The 2014 base-case model was developed following discussions and outcomes of the May 2014 Australian Orange Roughy workshop, as well as reviews of the two most recent stock assessments (Wayte 2007; Upston &Wayte 2012a, b) by Stokes (2009), Cordue (2011) and a CSIRO internal review.

New data inputs since the 2011 preliminary assessment were: research catch for 2011- 2014; total spawning biomass estimates from acoustic towed surveys at St Helens Hill and St Patricks Head, for 2012 and 2013; and revised tow and hull acoustic biomass series - revised paired snapshots are used to calculate an average series (Section 5.3.1.5). Informative prior distributions have also been developed for the acoustic catchability parameter, for the towed and the hull surveys (Appendix A). The egg survey estimate of absolute female spawning biomass was revised, and historical assumptions regarding the survey were made explicit in the formulation of the catchability coefficient. The ageing error matrix was updated using data from a re-ageing experiment that was completed in October 2014 (Appendix B).

A Preliminary Base-case model was presented at the Slope RAG meeting in September 2014, and the Final Base-case Model 0, which included minor updates to recent catches and the ageing error matrix (when the data became available), was presented at the Slope RAG meeting in October 2014. The models were considered broadly similar by the RAG, and the sensitivity analyses for the Preliminary Base-case model were not repeated for the Final Base-case Model 0. We distinguish between the models in the relevant sections.

5.3 Methods

5.3.1 The data and model inputs

The parameters estimated by the model, priors, and pre-specified parameters are shown in Table 5.2

This report uses the available data as they were known before 12 September 2014 (Preliminary Base-case model), and before 18 October 2014 (Final Base-case Model 0). We distinguish between the models only where relevant, given that they have the same parameters, stock assumptions, and data inputs (with only minor adjustments for recent catches and the ageing error matrix for the Final model (Table 5.3 and Appendix B)).

Table 5.2. Number of estimated parameters and values of pre-specified parameters of the model for the Eastern Zone orange roughy base-case assessment. F=female, M=male. N(μ,σ^2) refers to a normal distribution with mean μ and variance σ^2.

Estimated parameters	Number of parameters	Prior	Source
Unexploited recruitment (ln (R_0))	1	N (9.3;10^2)	Chosen to be uninformative
Recruitment deviations 1905 - 1980*	76	N (0; σ_R^2)	See section 5.3.2.1 for rationale
Selectivity logistic inflection	1	N (35.0;99^2)	Chosen to be uninformative
Selectivity logistic width	1	N (3.0;99^2)	Chosen to be uninformative
Catchability coefficients			
q Acoustic towed	1	N (0.95;0.3^2)	Appendix B
q Hull	1	N (0.95;0.9^2)	Appendix B

Pre-specified parameters	Values	Source
Recruitment steepness, *h*	0.75	Annala (1994) cited in CSIRO & TDPIF (1996)
Recruitment variability , σ_R	0.58	
Rate of natural mortality, *M*	0.04 yr^{-1}	Stokes (2009)
Maturity logistic inflection	35.8 cm	Est. selectivity of spawning aggregation.
Maturity logistic slope	-1.3 cm^{-1}	Smith et al. (1995)
Von Bertalanffy growth coefficient, k	0.06 yr^{-1}	
Length at 1 yr F	8.66 cm	
Length at 70 yrs F	38.6 cm	
Length-weight scale, *a*	3.51×10^{-5} (F) 3.83×10^{-5} (M)	Lyle et al. (1991)
Length-weight power, *b*	2.97, 2.942 (F,M)	Lyle et al. (1991)
Plus-group age	80 yr	
Length at age CV for young	0.07	Est. from data
Length at age CV for old	0.07	Exp. offset from young
Catchability coefficient (egg survey); *q*	0.90	Bell et al. (1992); Koslow et. al (1995) & Wayte (2007)

*for 1960 to 1973 the full bias-correction is applied, and for 1950 to 1959 and 1974 to 1980 the amount of bias-correction applied is linearly phased in and out.

5.3.1.1 Biological parameters

The sources for the pre-specified biological parameters used in the sex- and age- structured base-case model are given in previous assessment reports (CSIRO & TDPIF 1996; Bax 2000; Wayte 2007). The pre-specified parameter values (those for recruitment steepness, natural mortality) are broadly consistent with those used in New Zealand orange roughy stock assessments (e.g. Smith et al. 2001; MFSWG 2009; Cordue 2014). Other relevant references for biological parameters include Lyle et al. (1989).

Natural mortality (M) was set to 0.04yr^{-1}, which was a recommendation from the May 2014 Australian Orange Roughy workshop. The basis for this decision was the Stokes (2009) review of orange roughy stock assessments which recommended that “a consistent default assumption of M=0.04 should be made for all Australian orange roughy assessments. Departure from that default on a case by case basis should occur following careful analysis and re-examination of maximum age estimates”. Further, M was estimated to be 0.04yr^{-1} in the 2006 and 2011 base-case models; see Stokes (2009) for discussion of M.

Maturity was modelled as a logistic function of length, with 50% maturity at 35.8 cm. The model was fitted, and the parameters governing maturity as a function of length were set to match estimated selectivity of the spawning aggregations (i.e. “maturity” is assumed to be the same as spawning). The approach of equating orange roughy being present on the spawning grounds with maturity (which will differ from functional maturity) is consistent with how recent assessments of orange roughy have been undertaken (Wayte 2007), including New Zealand assessments by Cordue (2014). Fecundity-at-length was assumed to be proportional to weight-at-length. The pre-specified parameters of the length-weight relationship are given in Table 5.2

The selectivity of the fleet was assumed to be a length-based logistic function, with parameters for inflection and width for 95% selection estimated within the model. Selectivity of the acoustic surveys for male and female spawning roughy was set to mirror that of the trawl fleet. This allowed the selectivity of the spawning aggregations to be estimated, and maturity was fixed at the estimated values.

The “egg survey” (see Section 5.3.1.5) refers to the female spawning biomass estimate from St Helens Hill (main spawning ground), calculated using egg production methods (Koslow et al. 1995). Selectivity for the egg survey was set so that the expected survey abundance was equal to female spawning biomass (selectivity pattern 30 in Stock Synthesis; Methot & Wetzell, 2013).

Recruitment steepness was set to 0.75. However sensitivity of the assessment results to lower steepness (0.4), and a higher steepness (0.8) (Francis 1992) was also explored.

5.3.1.2 Fleets

The assessment assumes a single trawl fleet, which is consistent with the 2006 and 2011 assessments. However, it differs from an earlier assessment that specified two Eastern fleets, St Helens Hill and St Patricks Head (Wayte & Bax, 2002). Wayte (2007) states the rationale for a one fleet model was the principal of parsimony.

The 2014 Australian Orange Roughy workshop resolved to model St Patricks Head and St Helen’s Hill together; given the available data there is no obvious way to resolve the apparent “switching” of spawning fish between the grounds in certain years (see Table 9.4 in Upston & Wayte 2012a).

Consistent with previous models, the current base-case model assumes a single fleet that fishes the East and South (Pedra Branca), throughout the year, and that the selectivity of the fleet can be estimated from the Eastern spawning aggregation. It may be prudent to test this in the future, if relevant data become available. However, the assumption of one fleet seems reasonable as historically the major component of the catch was taken from the Eastern spawning aggregations (during winter), with a lesser component from Pedra Branca (see Table 5.3; Bax 2000, Figure 2).

5.3.1.3 Landed catches

Commonwealth Commercial logbook data for the years 1985 to 1991 and landings for the years 1992 to 2014 provide information on orange roughy retained catch in the SESSF. The respective databases are administered by AFMA and a mirror copy of the databases (current at the date of extract by AFMA) is housed at CSIRO.

Table 5.3 lists reported and agreed catch histories for three of the Management Zones (Eastern, Southern, and Western Zones) and the area, East and PB, which encompasses the East and includes Pedra Branca (PB) in the South. The East and PB catch history is used in the base-case assessment. Wayte (2007) provides details on how catches have been adjusted from the originally reported values. Other key references for the rationale for adjustments to the catch history, including outcomes of the 1994 workshop that determined an “agreed” history are CSIRO & TDPIF 1996 (i.e. the 1994 orange roughy stock assessment report) and stock assessment reports by Bax (for years 1995, 1996 and 1997 – see Bax 1997, Bax 2000a and 2000b) for minor adjustments to the initial “agreed” history.

Table 5.6 (Tables in Section 5.9) lists catches for the sensitivity model I “Higher early catches”, which places a nominal higher bound on agreed catches (see Section 5.3.2.2).

Table 5.3. Total recorded logbook catches (t) 1985 - 1991, recorded landed catches (t) 1992 – 2014 (Reported), and agreed catch history* (Agreed) of orange roughy for East, South and West Management Zones and area Pedra Branca (PB) in the South. All seasons are included. The base-case model uses East and PB Agreed catches. * Agreed catch history (incorporates adjustments for proportion lost due to gear lost and burst bags/ panels etc, and misreporting (CSIRO & TDPIF 1996; Wayte 2007). Highlighted columns refer to catches included in the stock assessments used in the report. The catches for 2014 are estimates based on the landings as at October 2014. For the Preliminary Base-case model the EAST and PB catches for 2011 to 2013 inclusive were 160 t each year and the 2014 catch was not included.

	EAST		EAST and PB	PB only	SOUTH (including PB)		WEST
Year	Reported	Agreed	Agreed	Agreed	Reported	Agreed	Reported
1985	6	6	6	0	58	58	129
1986	33	33	60	27	631	631	3,970
1987	310	310	310	0	353	353	5,128
1988	1,949	1,949	1,949	0	469	469	4,765
1989*	18,365	26,236	28,575	2,339	7,620	10,886	1,386
1990*	16,240	23,200	34,502	11,302	24,801	35,430	802
1991*	9,727	12,159	20,436	8,277	11,541	14,426	628
1992*	7,484	15,119	24,265	9,146	7,947	16,054	1,141
1993*	1,971	5,151	8,798	3,647	7,602	5,486	1,031
1994*	1,682	1,869	4,140	2,271	4,345	4,828	927
1995	1,959	1,959	2,544	585	2,157	2,157	1,055
1996	1,998	1,998	2,231	233	802	802	1,320
1997	2,063	2,063	2,250	187	454	454	352
1998	1,968	1,968	2,087	119	250	250	360
1999	1,952	1,952	2,052	100	174	174	244
2000	1,996	1,996	2,109	113	311	311	192
2001	1,823	1,823	2,027	204	357	357	248
2002	1,584	1,584	1,674	90	167	167	294
2003	772	772	877	105	210	210	243
2004	767	767	797	30	80	80	321
2005	754	754	772	18	99	99	281
2006	614	614	615	1	5	5	159
2007	113	113	129	16	22	22	31
2008	98	98	98	0	0	0	5
2009	193	193	193	0	10	10	16
2010	113	113	113	0	18	18	27
2011	160	160	162	2	17	17	37
2012	163	163	163	0	22	22	20
2013	150	150	150	0	8	8	45
2014	20	20	20	0	20	20	20

5.3.1.4 Discard rates

Discards are not included explicitly in the assessment, although they are included implicitly via adjustment to landed catches that are input into the model for "losses" at sea during the years 1989 to 1994 (Table 5.3). There are no implicit assumptions regarding discards for other years.

5.3.1.5 Indices of abundance

The Eastern Zone orange roughy assessment uses relative indices of abundance (spawning biomass) from independent acoustic towed body (select years between 1991 to 2013) and hull (1990, 1991, 1992) surveys, and an absolute index from an egg survey (1992). The acoustic 38 kHz towed body and hull snapshot estimates of spawning biomass (and associated CVs) at St Helens Hill and St Patricks Head are listed in Table 5.7, Table 5.8 and Table 5.9, with the paired area snapshots over 24 to 48 hrs denoted. The series was revised from that used in the 2011 preliminary assessment model, and the CVs were calculated to include an error estimate for the dead zone component (the dead zone refers to the area extending from the seafloor to the depth threshold for acoustics detection - where orange roughy are presumed to be distributed but not directly observed by acoustics). Based on expert judgement, the few observations of "zero" orange roughy were ignored. The interlaced towed survey used in 2013 was considered broadly comparable to the grid survey 1991 to 2012. Regarding the 2013 acoustic survey observations, Ryan et al. (2014) state that "given the apparent downward trend in biomass observed at St Helens Hill [over the survey period] it is possible that the 2013 surveys did not quantify the spawning stock at its peak". We have included the 2013 estimates in the assessment because the survey was carried out in a manner that was consistent with the other years (see Table 5.7).

The average of the snapshots in each survey year was calculated (assuming a common variance, i.e. a simple average), to form a series that indexes relative male and female spawning biomass for the stock (an outcome from the May 2014 Australian Orange Roughy workshop). A series based on the maximum snapshot values was also calculated for a sensitivity analysis, as the maximum estimates were used in the previous stock assessments. The spawning biomass estimates from each area were combined for a given year by adding the area averages, and the 'Combined areas CVs' (St Helens and St Patricks areas combined) were calculated from the combined distributions. The 'Between snapshots CV'=0.20 (a nominal value but based on the average between snapshot CVs for SH and SP) was a separate component of the total survey CV.

For early years, where there were observations from only one of the areas, the average catch ratio between the grounds over the years 1986 to 1996 (Table 9.4 in Upston & Wayte 2012a) was calculated and the ratio was applied to the observed St Helens acoustic estimates to derive the St Patricks biomass estimates (mean of the proportion StP/ (StH+StP) = 0.29, assuming a Beta distribution). The estimates were assigned a "wide" associated error (Orange Roughy May 2014 workshop) by adding in an additional CV=0.25 (termed "Survey one area CV") as a separate component of the total survey CV. The total survey CV is calculated by combining the three component errors (considered independent) - Combined areas CV, Between snapshots CV, and Survey one area CV.

Priors were developed for the catchability (q) scalar for acoustic towed and hull surveys (Appendix A). The priors were developed using available acoustic data and expert judgement. In setting a prior for the acoustic catchability (q scalar) we essentially have made a statement about how well the acoustic towed or hull series is thought to provide an absolute estimate of biomass of the spawning roughy for the stock that we are assessing, East and South (Pedra Branca) for the base-case.

There is also an absolute estimate of female spawning biomass (15,922 t, CV=0.5) for 1992, based on the egg production method (Bell et al. 1992; Koslow et al. 1995), which includes an adjustment to account for 5% loss of eggs due to advection from the survey area (the Koslow et al. 1995 estimate of 13,785 t was increased to 15,922 t); a recommendation in Deriso & Hilborn 1994. The catchability coefficient (q) for the egg production survey was set to 0.90 (Table 5.2) to account for an estimated 10% of spawning females that did not migrate from the Southern zone to St Helens in 1992 (this assumption was also incorporated into the acoustic survey priors, Appendix A). This is consistent with the assumptions in historical assessments, but is made explicit in the specification of catchability (q) for the absolute index (Bell et al. 1992; Deriso & Hilborn, 1994).

A distinction is made between the (i) percentage of spawning fish that are on the spawning grounds in the East and therefore can be "seen" by the acoustics surveys (recall the base-case stock structure assumption is East and South (Pedra Branca) i.e. it includes migration of fish from Pedra Branca), and (ii) the proportion of mature fish that are spawning in a given year. Historically, the implicit assumption for (i) has been 100%, except for 1992 when it was estimated that there were only 90% of spawning fish available to the surveys, i.e. a small percentage of spawners remained in the South in that year (and the egg survey was adjusted; Deriso & Hilborn 1994; Bell et al. 1992; Koslow et al. 1995). The assumption for (i) (the percentage of spawning fish on the grounds) in the current base-case is approximately 95% (the prior distribution is defined as a Beta(95, 5)). The current assessment models the spawning population and therefore explicitly references (i).

The current assessment does not explicitly include (ii) the proportion of mature fish that are spawning in a given year (this was agreed at the Orange Roughy workshop in May 2014), but assumes that it is constant on average (i.e. we assume that relative abundance of the spawning stock that is indexed by the acoustic surveys is not confounded with the proportion of mature fish that are spawning in a given year). Historically the implicit assumption for (ii) was 70% based on Bell et al. (1992) and the Koslow et al. (1995) proportion spawning surveys. An exception to the assumption of a constant proportion spawning is the acoustic hull series. In previous assessments the proportion spawning was not assumed to be constant over the early years of the fishery, as it developed (an historical assumption - see Deriso & Hilborn 1994). The 1990 hull acoustic estimate was increased by 30%, to account for a lower observed proportion spawning estimate in that year compared to 1991 and 1992 (proportion spawning 54% in 1990, 71% in 1991 and 72% in 1992 (Bell et al. 1992; Koslow et al. 1995)).

A non-constant proportion spawning for the hull index over the early years of the fishery (1990, 1991, and 1992) has also been assumed in this assessment. However no proportion spawning adjustment was made to the towed index as it begins in 1991 (proportion spawning was estimated to be 71% in that year).

5.3.1.6 Age composition data

Male and female age-compositions for years when spawning aggregations were sampled: 1992, 1995, 1999, 2001, 2004, 2010 are included in the assessment and are assumed to be simple random samples of the catch (see Table 5.10) for sample sizes). The age-compositions for St Helens Hill and St Patricks Head have been weighted based on either the relative abundance implied by the acoustic estimates or the relative catch (see method outlined in Wayte, 2007). The age samples for 1992 and 1995 are from St Helens only (but see Appendix C regarding 1995), where the major proportion of the catch was taken (Table 9.4 Upston & Wayte 2012a).

The issue of potential ageing bias, that is, the between-year bias for a given reader(s) - the drift hypothesis (Francis, 2006), was investigated by re-ageing approximately 350 Eastern Zone orange roughy otoliths from each of four years used in the stock assessment (1992, 1995, 2001, 2004; Appendix B). The latest ageing protocols (Tracey et. al 2007) were used for re-ageing (using the same method as for the 2010 ageing in the stock assessment). If notable bias was detected in the early age reads, the age reading bias could be modelled using the outputs of a program developed by Andre Punt (unpublished data).

A recommendation by Francis & Hilborn (2002) was to include an estimate of ageing error as model input so the ageing imprecision is dealt with within the model by including a correction to the likelihood. An estimate of the standard deviation of age reading error was calculated from data supplied by Kyne Krusic-Golub of Fish Ageing Services (Table 5.11). The estimate was updated from that used in the 2011 preliminary assessment, to include data from the re-ageing experiment (the difference between the age error matrices was minor).

Further details of the age samples used in the stock assessment are reported in Appendix C, including the current state of knowledge on provenance of the historical age samples, the sample coverage (Table C1), and the raw age frequencies (Figure C1). We also include information on sampling methods, and a note on the 2012 and 2013 age samples (otoliths are as yet unread) in Appendix C.

5.3.2 *Stock assessment method*

5.3.2.1 Population dynamics model and parameter estimation

The current assessment is based on a two-sex age-structured model incorporating growth and stochastic recruitment to provide a series of annual stock biomasses given the catch history.

The integrated model analysis was conducted using the software package Stock Synthesis (SS, version 3.24Q; Methot & Wetzel, 2013). The population dynamics model and the statistical approach used in the fitting of the model to the various types of data are described in the SS technical description (Methot & Wetzel, 2013). Some key assumptions of the base-case analysis of Eastern Zone orange roughy are:

1. The Eastern Zone and Pedra Branca (from the Southern Zone) constitute a single stock within the area of the fishery;

2. As in previous assessments, the population is assumed to have been at its unfished biomass with the corresponding equilibrium unfished age-structure at the start of 1904. The fishery start year was 1980 (with zero catches for 1980 to 1984, to avoid an unrealistic recruitment spike being estimated by the model (S. Wayte pers. comm. 2014));

3. One trawl fishing fleet is modelled;

4. The natural mortality rate, M, is assumed to be independent of age and time, and not to differ between sexes (M is set to 0.04yr^{-1} in the model);

5. Recruitment is assumed to be distributed about a Beverton-Holt stock-recruitment relationship, with parameters being the average recruitment at unfished equilibrium, R_0, and steepness, h. The standard deviation of the variation about the stock-recruitment relationship (quantified by σ_R) is pre-specified (fixed in the model), along with the extent of how bias-correction changes over time. Recruitment deviations were estimated for 1905 to 1980 (1980 is the fishery start year). For 1960 to 1973 the full bias-correction is applied, and for 1950 to 1959 and 1974 to 1980 the amount of bias-correction to be applied is linearly phased in and out. Recruitment deviations were estimated from 1905, as there are catch data in 1985 and orange roughy aged 80+ years (born in 1905 or earlier) were caught in the early years of the fishery (80+ observed in the age compositions for 1992). The recruitment deviations were estimated to 1980, since orange roughy recruit to the fishery at approximately 35 yrs, thus few of the fish born in 1980 would have recruited to the fishery in 2014 or 2015;

6. The plus- age group was set at 80 years;

7. The Francis (2011) approach is used for weighting the age compositions.

The estimated and pre-specified parameters of the model are shown in Table 5.2 (Section 5.3.1).

5.3.2.2 Sensitivity tests and alternative models

Key sensitivities to the base-case model were identified at the May 2014 Australian Orange Roughy workshop and by Slope RAG. Five of the sensitivities that were defined *a priori* (A to E) were considered for the Preliminary Base-case model at the September 2014 Slope RAG (final recent catches and age error data were unavailable at the time), and these provided information on the effects of some of the main changes between the current assessment model, and previous assessment models (e.g. informative priors for the catchability coefficient (q) for the acoustic biomass estimates, a new weighting method for age compositions, acoustic indices as the average of snapshots rather than the maximum).

The five additional key sensitivities (F to J) that were considered for the Final Base-case Model 0 at the October 2014 Slope RAG included three alternative stock structure assumptions identified in Wayte (2007), sensitivity to a higher agreed catch for the early years, and sensitivity to include a minor age bias for early age compositions. Sequential models for the preliminary and final base-case models were also completed to show the effects of main changes to the data and model settings on the model outcomes. Standard sensitivities to natural mortality, steepness and data weighting for the Final Base-case are also considered.

Model outputs and sensitivity analyses presented for the Preliminary Base-case model and associated sequential models (September RAG) are listed in Table 5.12. The model outputs and sensitivity analyses for the Final Base-case Model 0 and the associated sequential model (October RAG) are listed in Table 5.4 (Results section 5.4.2.3).

The sensitivity tests and their rationale are:

A. weight the age-composition data using the McAllister and Ianelli (1997) method used in past assessments. This weighting approach was used in the previous assessment (2011 preliminary base-case models) and is compared to the current base-case model that uses the Francis (2011) approach to weighting the age compositions;
B. set the CV for the priors for *q* for the towed acoustic survey index to a larger value (i.e. diffuse priors CV=99);
C. do not estimate recruitment deviations. A scenario similar was included in the 2006 assessment (the 'no age' model) and the 2011 preliminary assessment (the "No Recruitment Devs" model). This sensitivity test sets recruitment to expected recruitment, determined by the stock-recruitment function;
D. use the maximum acoustic spawning biomass estimates in the model instead of the average estimates. The maxima have been used in the previous stock assessments;
E. assume a lower steepness (*h*=0.4; Francis, 1992). Sensitivity of the model to an alternative stock-recruitment relationship to the Beverton and Holt was not tested (but see Upston & Wayte (2012a) - similar depletion estimates for the 2011 preliminary model assuming a B-H or Ricker stock-recruitment relationship were reported);
F. assume an alternative stock structure (East + South; Stokes 2009). The catches from the Eastern Zone and all of the Southern Zone (all seasons) are included in the model, whereas the base-case includes catches from only Pedra Branca in the Southern Zone. The same indices of relative abundance apply to all the alternative stock structure models, so the assumption is that the observed spawning aggregations in a given year comprise most of the spawning population from the respective Zones/ areas that are included in the stock structure (i.e. the assumption is that the orange roughy from the other Zones/ areas migrate to the Eastern Zone during winter to spawn);
G. assume an alternative stock structure (East + South + West; Stokes 2009). The catches from the Eastern, Southern and Western Zones (all seasons) are included ;
H. assume an alternative stock structure (East; Stokes 2009). The catches from the Eastern Zone only (all seasons) are included;
I. use higher earlier catches. This scenario was suggested as a nominal upper bound on the Agreed catch history (Table 5.6). A lower bound was not tested. However, the scenario "Unadjusted catches" was included in Upston & Wayte (2012a) - estimated a less depleted spawning stock than for Base-case Model A;

J. allow for a minor ageing bias (Appendix B, Table B1). The re-ageing experiment did not find evidence of major bias in the early age readings of Eastern Zone orange roughy; nevertheless we tested the effect of correcting for the minor bias (~1 year) that was detected in the early age readings in some years (see Appendix B).

Additional diagnostic models were completed for the Final Base-case Model 0 (post-October RAG) and are listed in Table 5.4. The diagnostic models tested sensitivity of the Final Base-case model to alternative data weightings, natural mortality, steepness, and a lower bound for the fleet selectivity width (the base-case model lower bound was set at 1.0 based on previous models; Wayte 2007 and Upston & Wayte 2012a).

The following four metrics were used to examine the sensitivity of the results of the base-case models to some of the assumptions and data inputs:

- the average unexploited female spawning biomass, SB_0;
- SB_{2015} - the female spawning biomass at the start of 2015 (SB_{2014} for Preliminary Base-case model);
- SB_{2015}/SB_0 - the depletion level at the start of 2015, i.e. the 2015 spawning biomass expressed as a fraction of the unexploited spawning biomass (SB_{2014}/SB_0 for Preliminary Base-case model);
- *–lnL* - the overall negative of the logarithm of the likelihood function (this is the value minimised when fitting the model, thus a lower value implies a better fit to the data, although this value is not comparable among all of the sensitivity tests);

A qualitative assessment of the model fit to the expected values for each data source was completed and the relative contribution to the likelihood from each source of data fitted in the assessment was considered when gauging model performance.

The 20:35:48 harvest rule is used to calculate the RBC.

5.3.2.3 MCMC analysis for Final Base-case Model 0

The Markov chain Monte Carlo (MCMC) is a method for approximating the posterior distribution for parameters of interest in the Bayesian framework (Gelman et al. 2003). The MCMC simulation should be run long enough so that the model converges in the sense that the parameter vectors are random independent samples from the posterior (i.e. the distribution of draws is close enough to the target posterior distribution $p(\theta \mid y)$) (Gelman et al. 2003).

MCMC simulations of the parameter space were completed for the Final Base-case Model 0 (during November 2014). Diagnostics from an initial run revealed a high correlation for the selectivity parameters (which will degrade the efficiency of MCMC implementation) and the estimate for the selectivity width was drifting towards low values (approaching zero; implying knife-edged selectivity). Therefore the selectivity inflection and width parameters were set at the maximum posterior density (MPD) estimates. Note that maturity was fixed in the base-case model at the estimated values for the selectivity of the spawning aggregations (i.e. selectivity of trawl fleet).

The final MCMC simulation ran for 24 million cycles, every 40,000th iteration was saved (run time for the final model was ~ 6 days using a standard scientific personal computer). This gave 600 samples from the posterior distribution. The first sample was omitted from the chain, which resulted in 599 posterior samples. Model convergence was assessed using the statistics: (i) the extent of batch autocorrelation (examined using trace plots), (ii) whether the posterior distribution was approximately multivariate normal (we examined the plot of the posterior distribution), and whether the distribution of the chain is stationary, as judged by the *p*-value computed from the Geweke statistic (which should be close to 1) and (iii) whether the Heidelberger and Welch test is passed or not (Gelman et al. 2003). The R package, r4ss (Taylor et al., 2014), was used to produce the plots and statistics.

Alternative chains with different starting values for the MCMC simulation can also be used to assess model convergence. The MCMC simulations from alternative chains were not completed at the time of writing. However, they should be possible to do in the future (J. Upston following up on the implementation of this in Stock Synthesis).

5.4 Results and Discussion

5.4.1 Preliminary Base-case Model

The Preliminary Base-case model (September 2014 RAG) results are included in Table 5.12 (Section 5.9). The parameter estimates, fits to the data, and the assessment outcomes are very similar to those for Final Base-case Model 0 (see Table 5.4; female spawning depletion in 2015 is 0.26 for both models), and are therefore not presented in this section. The similarity in model outcomes is not unexpected given the minor differences between the two base-case models. The Final Base-case Model 0 included minor adjustments to recent catches (2011, 2012 and 2013; the 2014 estimated catch was added) and to the age error matrix (Table 5.3 and Table 5.11), otherwise the models are the same. We consider the results from the sensitivity tests and transition models for the Preliminary Base-case model in Section 5.4.3, as the analyses provide information on the effects of some of the main changes to the current assessment model, when compared to the previous Eastern Zone orange roughy assessment models.

5.4.2 Final Base-case Model 0

The Final Base-case Model 0 assumed a stock hypothesis: East and South (Pedra Branca), all seasons; and included relative spawning biomass indices from towed (1991 – 2013, selected years) and hull (1990-1993) acoustic surveys, with priors imposed on catchability (*q*); and an absolute female spawning biomass index for 1992, derived from egg production methods. The ending year expected growth is pre-specified in the model (Figure 5.2).

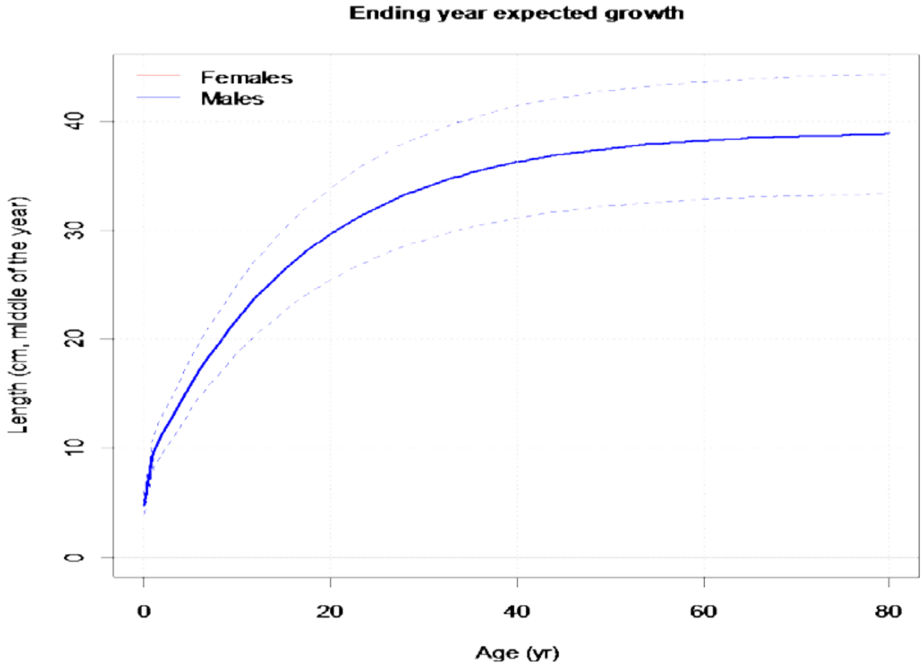


Figure 5.2. The ending year expected growth (one curve for males and females), which is pre-specified in the model.

5.4.2.1 Parameter estimates

The parameter estimates for unexploited recruitment (SR_LN(R0)), selectivity and the catchability coefficients (*q*) are shown in Table 5.4. The Final Base-case model estimate of selectivity inflection was 35.8 cm, and selectivity width was 1.0 cm (Table 5.4) The selectivity width was estimated to be at the lower bound set for this parameter, so we have considered sensitivity where the bound is set lower (see Section 5.4.3).

The Final Base-case model estimate of the catchability scalar (*q*) for the acoustic towed survey was 1.32 (Table 5.4) The estimate of *q* implies that the acoustic towed survey is on average observing more spawning orange roughy (~ 1.3 times) than the available spawning biomass (estimated in the model). For the recent four years of towed surveys we note that the observed point estimates are above the model estimates for 2006 and 2010, however they are below the model estimates for 2012 and 2013 (Figure 5.3). A *q* estimate of 1.32 is within the bounds of the prior, which had approximately 95% of its density between 0.40 to 1.50 (Table 5.7 and Appendix A, Figure A2), thus *q* could moderately deviate from 1, and in either direction. It is noteworthy that the estimates of *q* ranged between 2.6 and 3.3, depending on the model in the 2011 preliminary base-case assessment (Upston & Wayte 2012a). In the 2011 model, the surveys indexed total mature biomass, and the greater *q* is at least in part explained by the multiplying up of the acoustic observations of spawning biomass to total mature biomass. We do not directly compare outcomes from the 2011 model and the base-case model in this document, given the different data inputs and model structure.

The estimate of *q* for the hull survey in the Final Base-case model was 1.78 (Table 5.4). This estimate is within the bounds of the prior, which has a wide CV (0.92) to reflect the greater uncertainty associated with the hull biomass estimates than for those from the towed body acoustic surveys.

The acoustic indices are considered to be relative indices in the model in the sense that there are several factors that can influence the acoustic biomass estimates (e.g. see the note in Table 5.7 on 2013 survey timing). If we have not captured all of the uncertainty in our prior definitions (e.g. the random error component could be much larger than assumed), then the imposed *q* scaling in the model may be too “tight”. Further, there are assumptions regarding stock structure and constant proportion spawning that are embedded in the model, which could have also have a scaling effect on biomass estimates. Hence ongoing review of the prior definitions of *q* for the acoustic surveys based on the latest data and understanding of the system, is suggested.

5.4.2.2 Fits to the data

There were good fits to the abundance indices and the age data for the Final Base-case Model 0 (Figure 5.3 and Figure 5.4). The model estimates of spawning biomass for 2012 and 2013 are above the observed point estimates for the towed body survey, and below the survey estimates in 2006 and 2010 (Figure 5.3). However, the trajectories of spawning biomass intercept all the 95% confidence intervals for the abundance indices. Plots of the Pearson residuals for the age data showed no notable trend in the residuals (Figure 5.5).

The model estimate for the 1992 egg survey absolute index of female spawning biomass was 15,922 t (i.e. the same as the observed estimate). The *q* for the survey was set at 0.9.

Acoustic towed body (1991-2013) Acoustic hull (1990-1993)

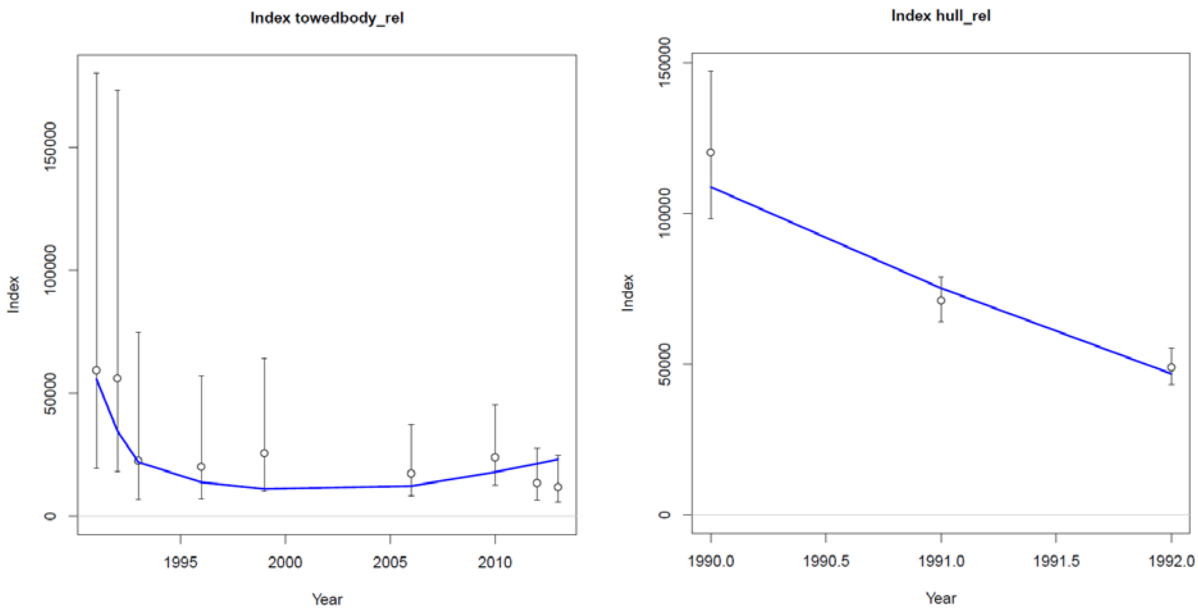


Figure 5.3 Final Base-case Model 0 Observed (circles) and model-estimated (lines) of relative indices of total spawning biomass - Acoustic towed (left plot) and hull (right plot). The vertical lines indicate approximate 95% confidence intervals for the data.

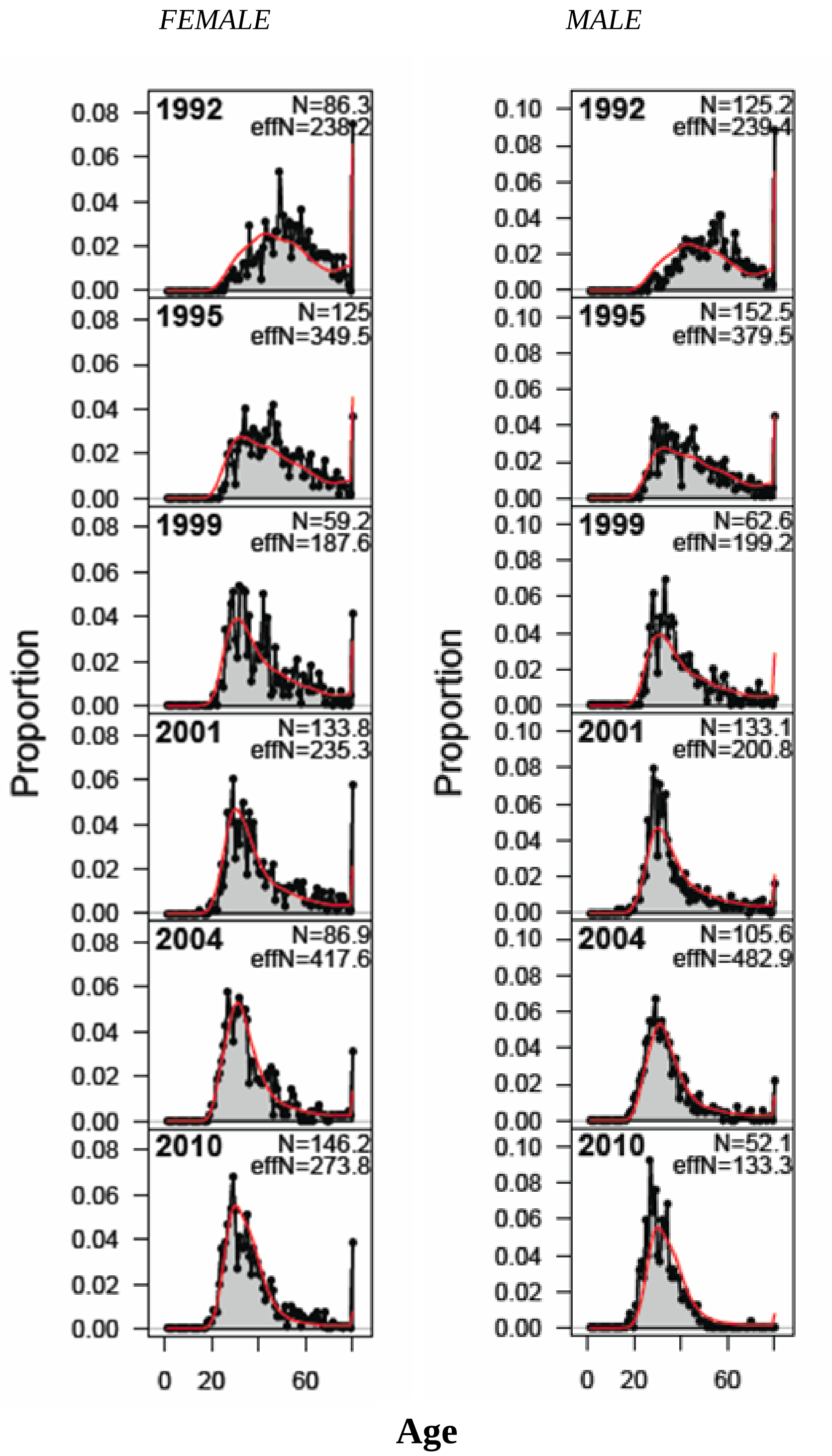
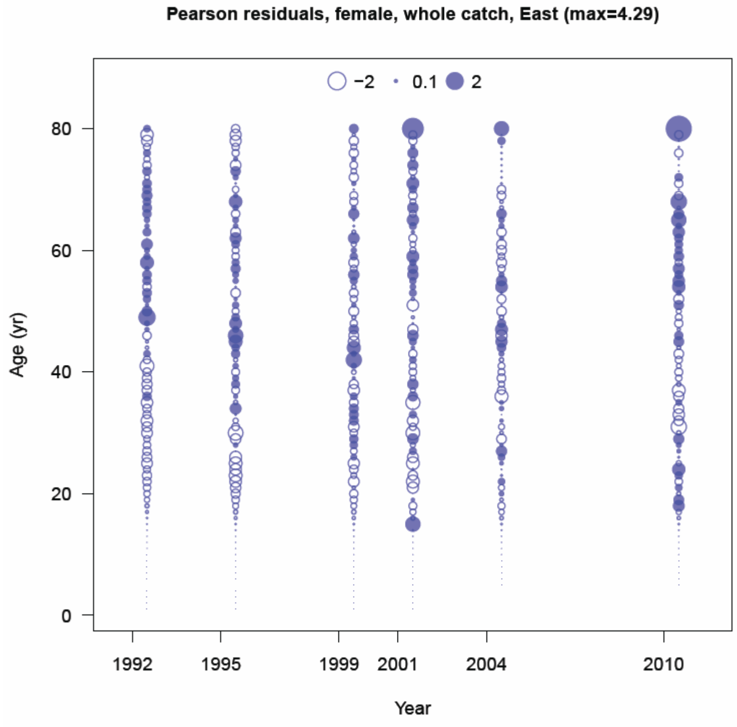


Figure 5.4. Fits to age compositions for the Final Base-case Model 0.



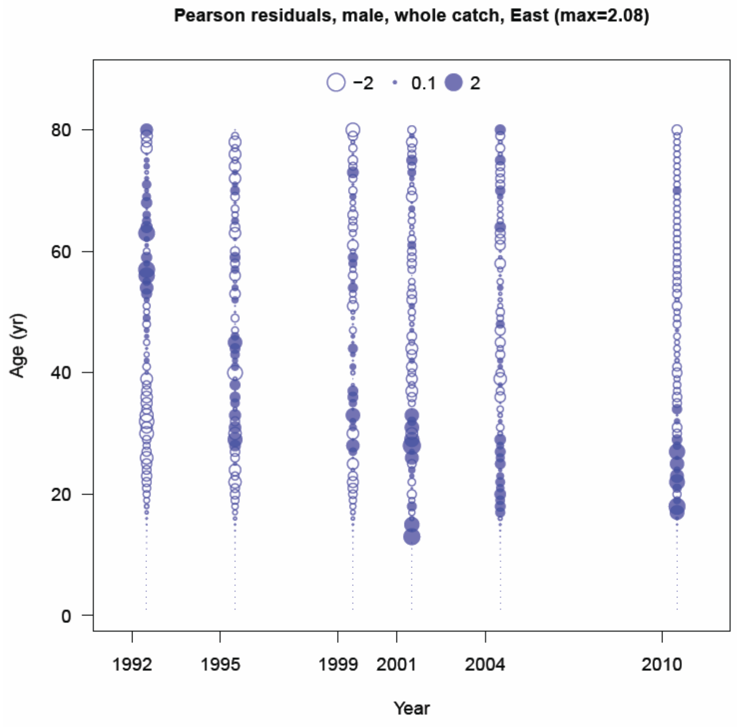


Figure 5.5. Standardized residual plots - age compositions for the Final Base-case Model 0.

5.4.2.3 Assessment outcomes

The Final Base-case Model 0 estimated stock status in 2015 (female spawning biomass at the start of 2015 relative to the unfished female spawning biomass) at 26% (MPD estimate). The estimated RBC under the 20:35:48 harvest control rule is 381t, with a long-term RBC of approximately 1,534t (Table 5.4). The outcome was consistent with the 2006 Eastern Zone orange roughy stock assessment model, which forecasted that the biomass would rebuild to the limit level of 20% of the unfished spawning biomass in 2014 (if catches equalled those from the 48:48:20 harvest control rule each year) (Table5.13, Wayte 2007).

The trajectory of female spawning biomass relative to unfished levels implies a pattern of steep decline in the spawning biomass in the early 1990's (as the commercial fishery developed), followed by a period of gradual further decline between approximately 1995 and 2005, and a recent increase to levels above 20% (Figure 5.6). The forecast over the next 55 years implies a continued increase in the female spawning biomass, at a slower rate beyond 2020 and over the next five decades (estimated mean generation time from the model was ~56 years) (Figure 5.7).

The model estimates a pattern of recruitments that oscillates from high to low prior to the start of the fishery (Figure 5.8). The recruitment deviations are not estimated after 1980 for the base-case model, instead expected recruitment from the spawner recruitment curve is assumed.

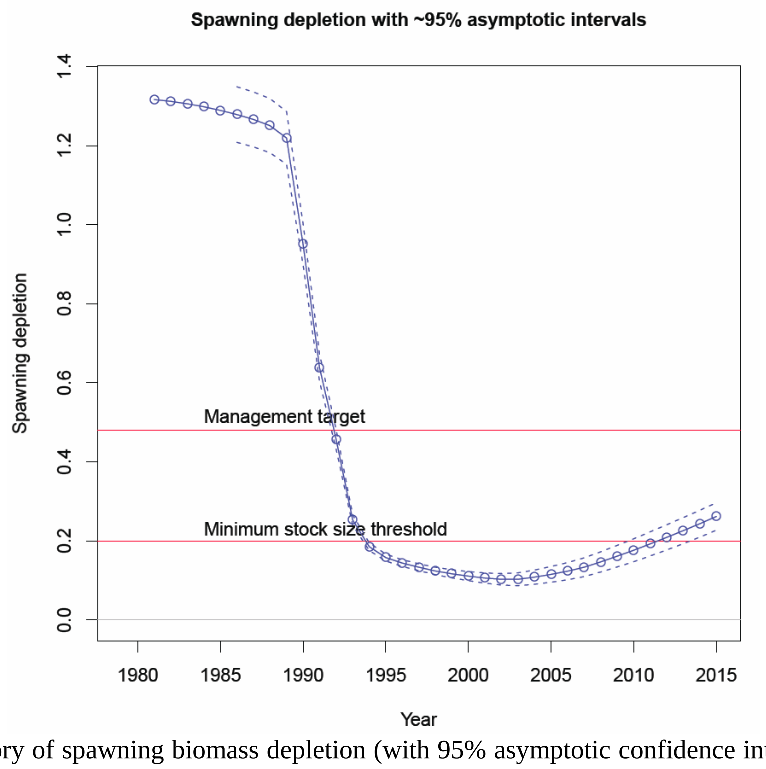


Figure 5.6. Time-trajectory of spawning biomass depletion (with 95% asymptotic confidence intervals) corresponding to the MPD estimates for the Final Base-case model 0.

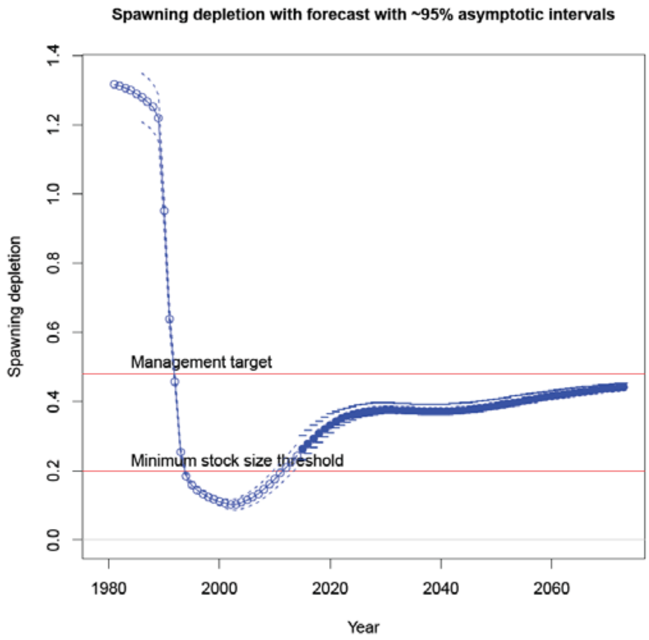


Figure 5.7. Time-trajectory of spawning biomass depletion (with 95% asymptotic confidence intervals) corresponding to the MPD estimates for the Final Base-case Model 0, and including a forecast period (assuming constant recruitment for the forecast period).

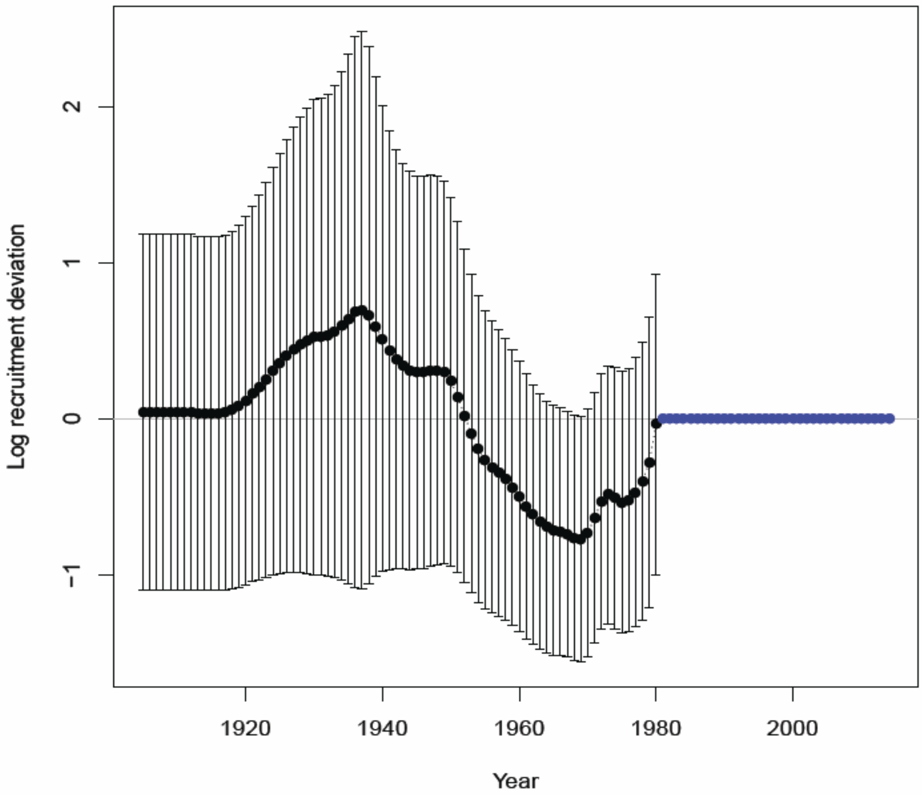


Figure 5.8. Final Base-case Model 0 – Recruitment estimates for the Eastern Zone base case analysis - time trajectory of estimated recruitment deviations. Recruitment deviations are not estimated after 1980, instead expected recruitment (from the spawner recruitment curve) is assumed.

Table 5.4. Summary of results for Final Base-case Model 0 (tuned model) and the associated sensitivity tests (same tuning as Final Base-case), including sequential models to construct the final base model, and additional diagnostic models. Lower total NLL (negative log-likelihood) values indicate a better fit to the data for comparable models. Models with different weighting and data are not comparable (C indicates models that are comparable to Final Base-case). *q* prior for towed: N(0.95, 0.3), hull: N(0.95, 0.92).

Model	**FEMALE SPAWN BIOMASS**							**NLL**	**NLL Main components**			**Estimated Parms**				
	SB0	**SB2014**	**SB2014/B0**	**SB2015**	**SB2015/B0**	**RBC_{2015}**	**RBC_{2070}**	Total	Survey	Age_comp	Recruit	SR_LN(R0)	Selectivity_Infl.	Selectivity_Width	Q3_Towed_rel	Q4_Hull_rel
Final Base-case Model 0	38,931	9,470	0.24	10,185	0.26	381	1,534	210.32	-17.61	134.89	12.67	9.05	35.77	1.00	1.32	1.78
Sensitivity Model F: Stock Structure E + S	47,295	9,398	0.20	10,225	0.22			347.98	-15.67	274.37	9.10	9.25	35.37	1.00	1.27	1.65
Sensitivity Model G: Stock Structure E + S + W	51,325	9,954	0.19	10,832	0.21			434.95	-16.70	364.08	7.78	9.33	34.99	1.00	1.10	1.53
Sensitivity Model H: Stock Structure E	37,560	17,483	0.47	18,200	0.48			249.90	-12.38	180.77	1.23	9.02	35.10	1.00	0.69	1.62
Sensitivity Model I: Higher early catches	43,061	8,937	0.21	9,652	0.22			619.73	-14.49	536.59	18.03	9.15	33.80	1.00	0.91	1.28
Sensitivity Model J: Minor Age bias	38,842	9,528	0.25	10,244	0.26			212.12	-17.65	136.40	12.88	9.05	35.90	1.00	1.36	1.82
Sequential Models associated with Final Base-case Model 0																
Model: Preliminary Base-case model September RAG	38,727	9,223	0.24	9,887	0.26			210.88	-17.70	135.18	13.05	9.05	35.70	1.01	1.32	1.76
Final Base-case Model 0: Update age error & recent catches (as above)	38,931	9,470	0.24	10,185	0.26			210.32	-17.61	134.89	12.67	9.05	35.77	1.00	1.32	1.78

Additional Models (post October RAG)	**FEMALE SPAWN BIOMASS**							**NLL**	**NLL Main components**		
	SB0	**SB2014**	**SB2014/B0**	**SB2015**	**SB2015/B0**			Total	Survey	Age_comp	Recruit
Diagnostic Model i: *h* 0.4 [C]	38,965	9,817	0.25	10,540	0.27			209.67	-17.42	134.29	12.46
Diagnostic Model ii: *h* 0.7 [C]	38,934	9,494	0.24	10,209	0.26			210.27	-17.60	134.84	12.66
Diagnostic Model iii: *h* 0.8 [C]	38,929	9,449	0.24	10,165	0.26			210.37	-17.63	134.94	12.69
Diagnostic Model iv: M 0.035 [C]	39,313	8,436	0.21	9,087	0.23			208.36	-17.88	135.52	10.21
Diagnostic Model v: M 0.045 [C]	38,776	10,440	0.27	11,216	0.29			215.65	-17.32	136.51	16.16
Diagnostic Model vi: selectivity width low bound 0.1 [C]	38,863	9,389	0.24	10,103	0.26			210.21	-17.60	134.75	12.76
Diagnostic Model vii: Double weight on age data	37,515	8,352	0.22	9,036	0.24			341.97	-17.59	259.38	19.37
Diagnostic Model viii: Half weight on age data	40,512	10,818	0.27	11,561	0.29			140.82	-17.52	72.65	5.70
Diagnostic Model ix: Double weight on biomass indices	38,721	9,269	0.24	9,975	0.26			192.59	-35.64	134.84	12.87
Diagnostic Model x: Half weight on biomass indices	39,034	9,574	0.25	10,294	0.26			219.07	-8.65	134.89	12.64

5.4.3 *Sensitivity analysis*

Sensitivity analyses were completed for the Preliminary Base-case model (Table 5.12) and the Final Base-case Model 0 (Table 5.4). The outcomes of the base-case models were similar, and we consider the key sensitivities to each of the models here to investigate various questions. The sensitivity analyses for the Preliminary Base-case model provide information on the effects of some of the main changes in the current assessment model, when compared to the previous Eastern Zone orange roughy assessment models (2006 and 2011). The sensitivity analyses for the Final Base-case model provide information on the effects of different stock structures, a higher agreed catch for the early years, and the effect of a minor age bias for the early age compositions (Appendix B). We also include additional sensitivity tests (post-October RAG) as a diagnostic tool to examine sensitivity of the results from the Final Base-case model to alternative data weightings, natural mortality, steepness, and a lower bound for the fleet selectivity width.

5.4.3.1 Sensitivity analysis for Preliminary Base-case model

Sensitivity of the Preliminary Base-case model to alternative assumptions and different data was investigated (Sensitivity Models A to E and Sequential Models; Table 5.12). The fits for Sensitivity Model C, No Recruitment Deviations, are included below because, of the models tested, this scenario had the greatest impact on the assessment outcomes. The Preliminary Base-case model outcomes were also influenced (to a lesser extent) by the weighting method used for the age compositions. Sensitivity Model A, which used the McAllister and Ianelli (2007) weighting method for age compositions (the method used in the previous stock assessment) was compared to the Preliminary Base-case model, which used the Francis (2011) weighting approach , as was agreed by the Australian Orange Roughy workshop in May 2014. The Preliminary Base-case estimated a less depleted female spawning stock in 2014 than the Sensitivity Model A (Table 5.12).

The Preliminary Base-case model was not overly sensitive to using the maximum acoustic spawning biomass estimates instead of the average estimates (Sensitivity Model D), or to using a broader CV around the priors for q for the towed acoustic survey index (i.e. diffuse priors CV=99) (Sensitivity Model B; Table 5.12).

The effect on the Preliminary Base-case model of adding in recent data since 2010 (i.e. the 2012, 2013 towed acoustic estimates and the catches for 2011, 2012 and 2013) was a slightly lower estimate of B_0 and 2014 spawning biomass, and hence a greater depletion in 2014 (Model #1: Data to end of 2010;Table 5.12). This shows that the base-case model is at least partially sensitive to the recent data.

Fits to the data - Sensitivity Model C (no recruitment deviations)

Fits to relative abundance (biomass) towed body index (Figure 5.9) and age compositions (Figure 5.10) for sensitivity Model C: No Recruitment Deviations show an obviously degraded fit to the early age data (Figure 5.10). There are fewer older-age fish in 1992 and 1995 implied by the model, and a different implied trend for spawning biomass, which is considered implausible given the large early catches and the population dynamics (Figure 5.9; Table 5.3). The total negative log-likelihood for the Preliminary Base-case model was substantially lower than that for sensitivity Model C (Table 5.12), indicating a better overall fit to the data for the Preliminary Base-case model, which estimated recruitment deviations.

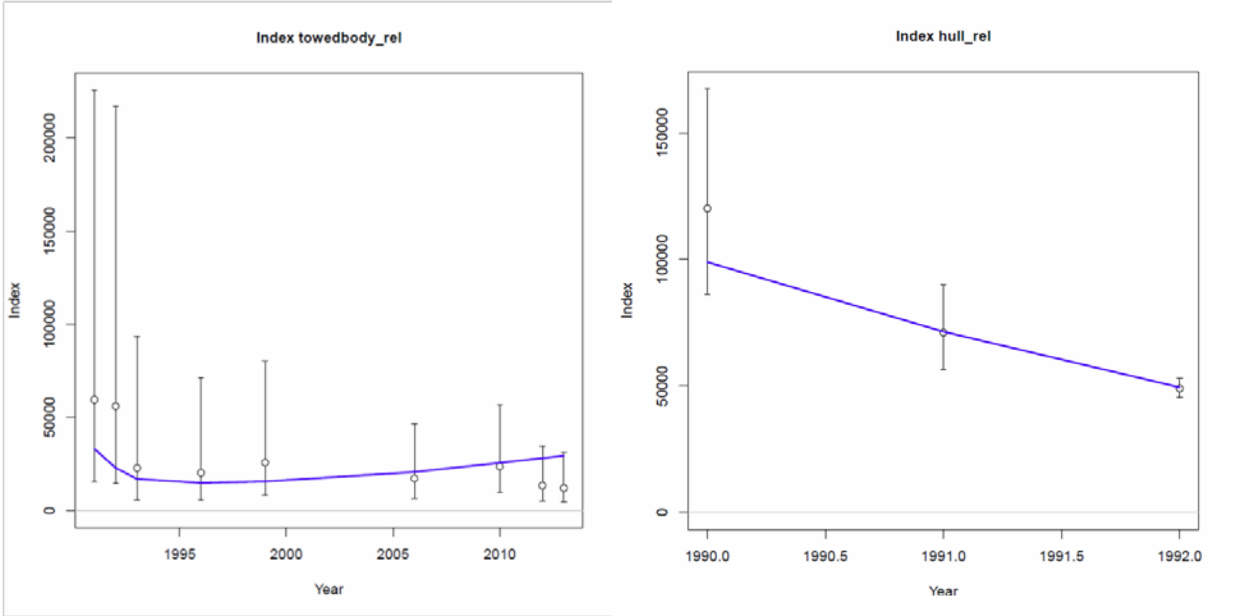
The fits for the acoustic towed and hull relative index do not improve on that of the Preliminary Base-case Model as both model fits go through the confidence intervals for the data (the variance for the sensitivity model has been re-tuned; however, the estimates for 1990, 1991 and 1992 have a wide associated CV in both models).

The Preliminary Base-case model sensitivity C provides insight into the dynamics in the model (demonstrates the influence of assuming constant recruitment, described by the spawner-recruitment curve, on the model survey biomass estimates). If we consider the 1999, 2006 and 2010 model point estimates for the towed body index in Figure 5.9(a), they are closer to the observed point estimates than that of the Preliminary Base-case model in Figure 5.9(b) and are coincident with lower model biomass estimates for the early years in the no recruitment deviations model.

Following from above, other inputs into the model that will influence how rapidly a stock can recover include the biology of orange roughy – the species are long-lived and have low fecundity; one generation time for orange roughy is estimated to be around 56 years (model estimate).

(a) Sensitivity Model C (No Recruitment Deviations)

Acoustic towed body (1991-2013) Acoustic hull (1990-1993)



(b) Preliminary Base Model – Acoustic towed body and hull (for reference)

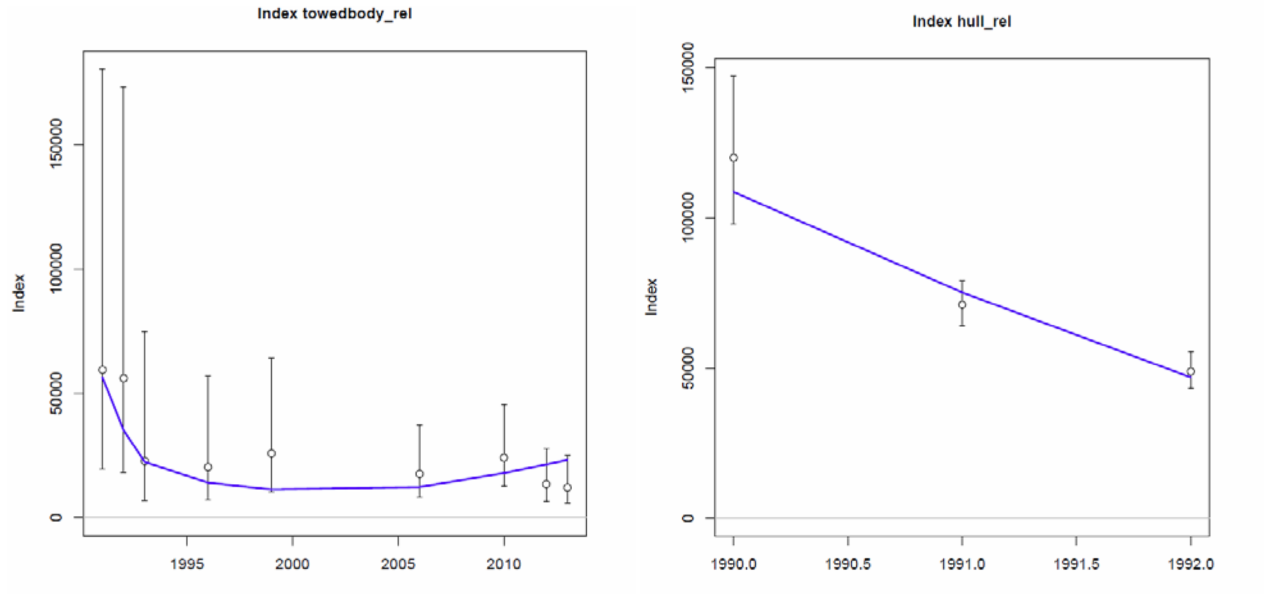


Figure 5.9. (a) Sensitivity Model C Observed (circles) and model-estimates (lines) of relative indices of total spawning biomass - Acoustic towed and hull, against year. (b) Preliminary Base Model - towed survey towed and hull survey fits (left and right plots respectively) for reference. The vertical lines indicate approximate 95% confidence intervals for the data.

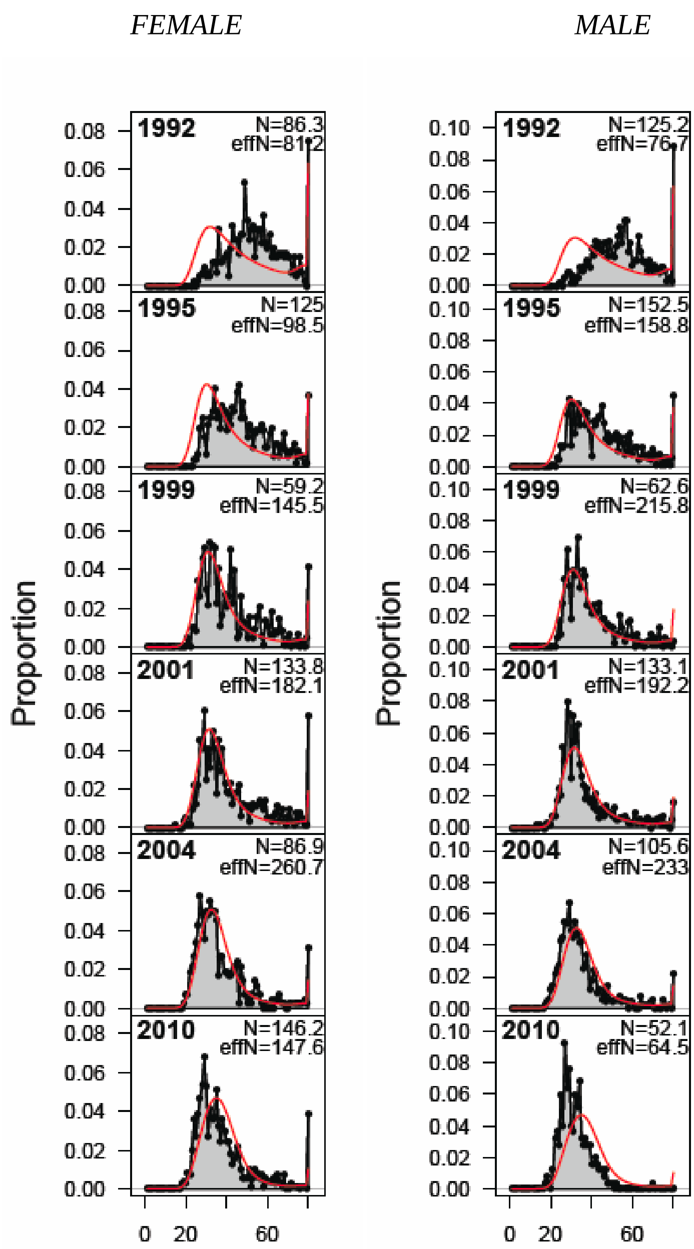


Figure 5.10 Fits to age compositions for Sensitivity Model C.

Fits to the data - Sensitivity Model A (McAllister & Ianelli weighting)

Fits to relative abundance (biomass) index (Figure 5.11) and age compositions (Figure 5.12) for sensitivity Model A: McAllister and Ianelli (2007) weighting are comparable with those of the Preliminary Base-case model, with only minor differences for the early years.

Acoustic towed body (1991-2013)

Sensitivity Model A Preliminary Base Model

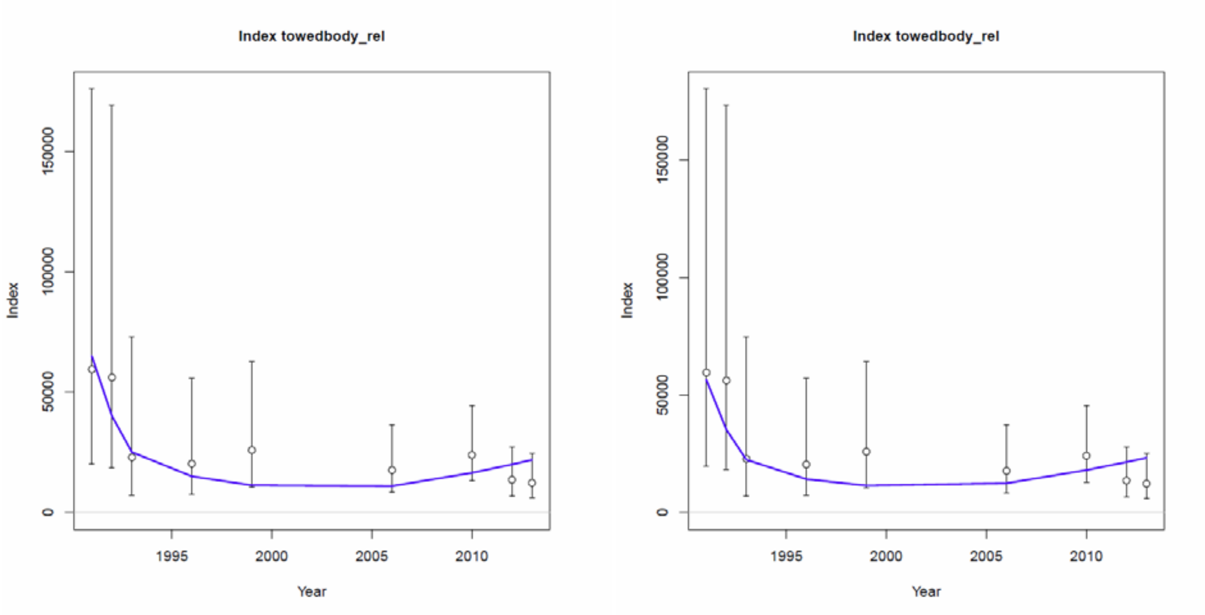


Figure 5.11. Comparison of fits to acoustic towed surveys for Sensitivity Model A (M&I weighting; left plot) and Preliminary Base Model (Francis weighting; right plot). Observed (circles) and model-estimates (lines) of relative indices of total spawning biomass, against year. The vertical lines indicate approximate 95% confidence intervals for the data.

Sensitivity Model A *Preliminary Base Model*

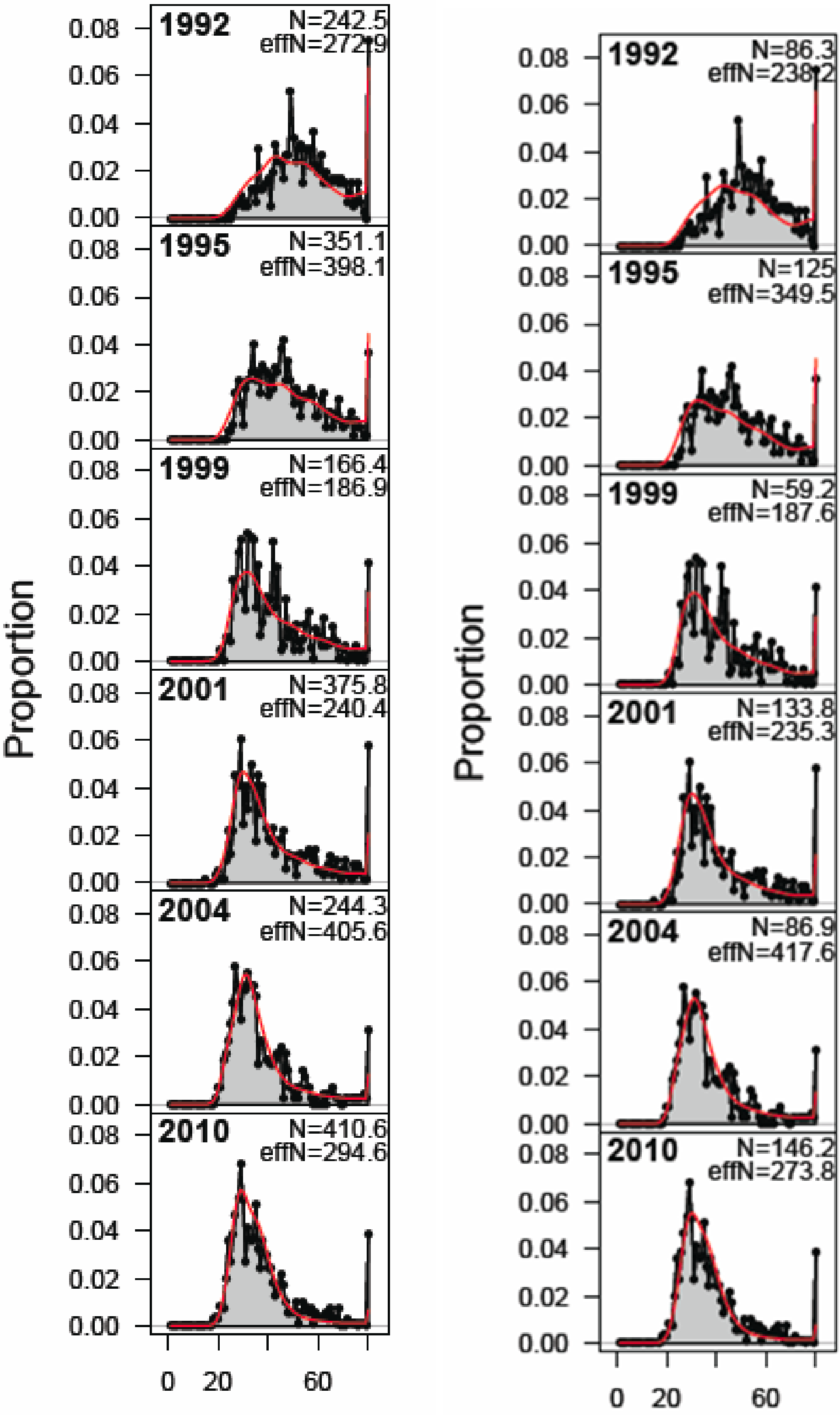


Figure 5.12. Comparison of fits to FEMALE age compositions for Sensitivity Model A -M&I weighting (left plot) and Preliminary Base Model -Francis weighting (right plot).

5.4.3.2 Sensitivity analysis for Final Base-case Model 0

Sensitivity of the results of the base-case model to alternative assumptions and different data was tested (Sensitivity Models F to I and additional Diagnostic Models (i) to (x); Table 5.4). The fits for Sensitivity Model G: Alternative stock structure East + South + West, and for Sensitivity Model H: Alternative stock structure: East, are provided below (Figure 5.13 to Figure 5.16).

Apart from Sensitivity Model J, which examined the effect on the model outcomes of a minor age bias in the early age compositions, the results of the Final Base-case Model 0 outcomes differed notably from those of the key sensitivity tests (Table 5.4). The base-case model was sensitive to the Stock Structure assumption (Sensitivity Models F, G, and H) and to the Higher earlier catches (Sensitivity Model I) (Table 5.4). The scenario that had the greatest impact on the assessment outcomes was the assumption of a stock structure comprising only the Eastern Zone (Sensitivity Model H). Assuming this stock structure, the model estimated a much greater female spawning biomass in 2015 and a lower level of spawning depletion relative to unfished (Table 5.4; Figure 5.15). Sensitivity Model G assumed a broader stock structure, East + South + West, and estimated a larger initial female spawning biomass and a greater level of spawning depletion relative to unfished compared to the Final Base-case model (Table 5.4). The catch history provides some insights (Table 5.3); total catch between 1985 and 2014 for the E+S+W is approximately twice that of East only, and 68% of the agreed catch in one of the peak years, 1989, comes from East only. Further, the model estimates an increase in recruitment for the period since approximately 1965 to 1980 for the East only model, whereas for the E+S+W model estimated recruitment decreases over that period (Figure 5.16).

Examining the estimated q for the acoustic towed and hull surveys for each of the stock structure sensitivity models, and the model fits to the surveys and age compositions, provides some insight into the underlying dynamics in the model. For example, for the towed survey, the estimate of q is 0.69 for the stock structure East, compared with 1.32 for the base-case model and 1.10 for East, South and West (E+S+W) stock structure (Table 5.4). The lower towed survey q for the East stock structure is coincident with an implied biomass trend from the model that is "flat" across the series, with less of a decline in the early years (Figure 5.15), however the fit to the age compositions was not degraded. Whilst for the broader E+S+W stock structure, with q estimated at 1.10, the fit to the early age compositions was notably degraded, and there were only subtle differences in the fit to the towed survey for the early and the recent years (Table 5.13, Figure 5.14 and Figure 5.15).

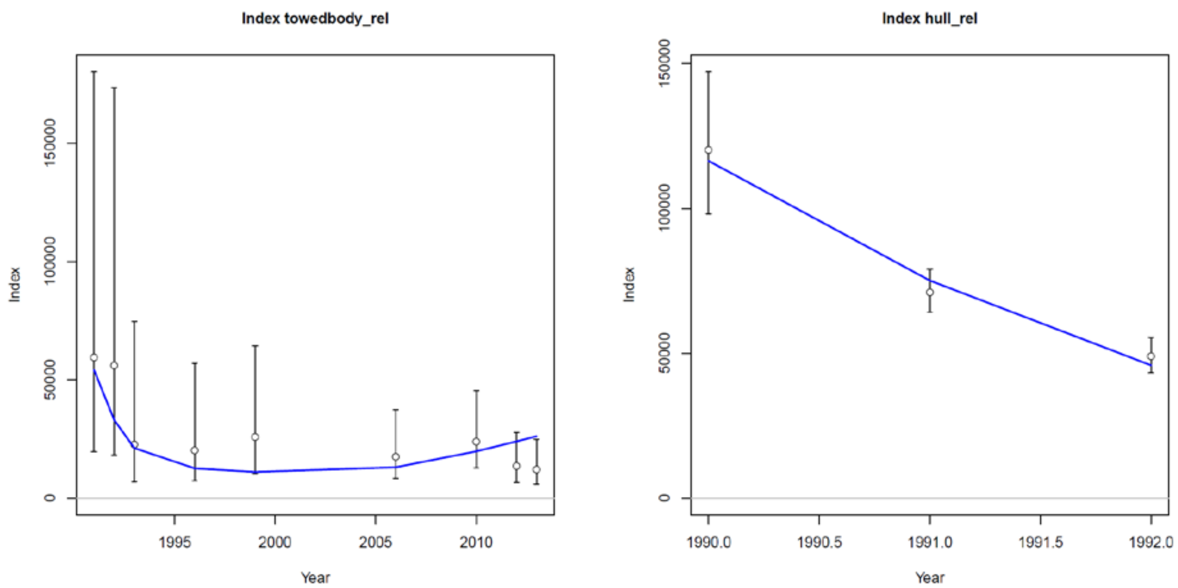
The additional diagnostic models showed that the Final Base-case model was not overly sensitive to the values for steepness tested (including a low steepness of 0.4), or a lower bound on the selectivity width (0.1 instead of 1.0 in the base-case) (Table 5.4). However the Final Base-case model was moderately sensitive to alternative data weightings, and natural mortality (Table 5.4).

Fits to the data - Sensitivity Model G (EAST+SOUTH+WEST)

Fits to the relative abundance (biomass) indices (Figure 5.13) and age compositions (Figure 5.14) or Sensitivity Model G: Stock structure E+S+W are compared to the Final Base-case Model 0. There is a subtle difference in the fits for the acoustic towed body – the sensitivity model estimate for the first year (1991) is less than that for the Final Base-case model, and for recent years since 2006 the implied biomass upwards trajectory in marginally steeper (Figure 5.13). However the fits to the early age compositions are notably degraded in the sensitivity model (Figure 5.14).

(a) Sensitivity Model G (Stock structure EAST+SOUTH+WEST)

Acoustic towed body (1991-2013) Acoustic hull (1990-1993)



(b) Final Base Model 0 – Acoustic towed body and hull (for reference)

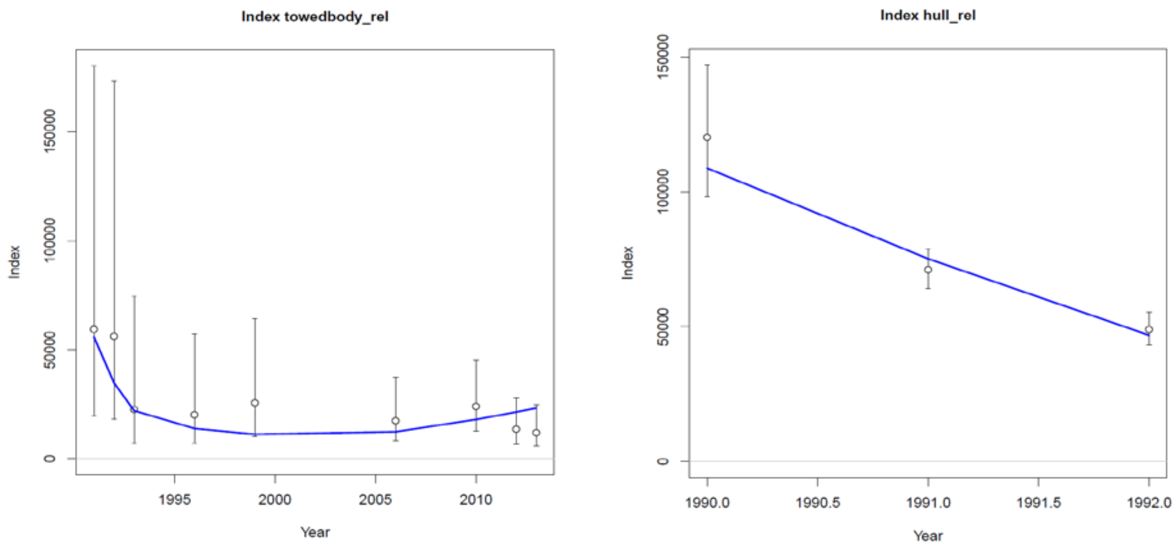


Figure 5.13. (a) Sensitivity Model G Observed (circles) and model-estimated (lines) of relative indices of total spawning biomass - Acoustic towed and hull, against year. (b) Final Base Model 0 towed and hull survey its (left and right plots respectively) for reference. The vertical lines indicate approximate 95% confidence intervals for the data.

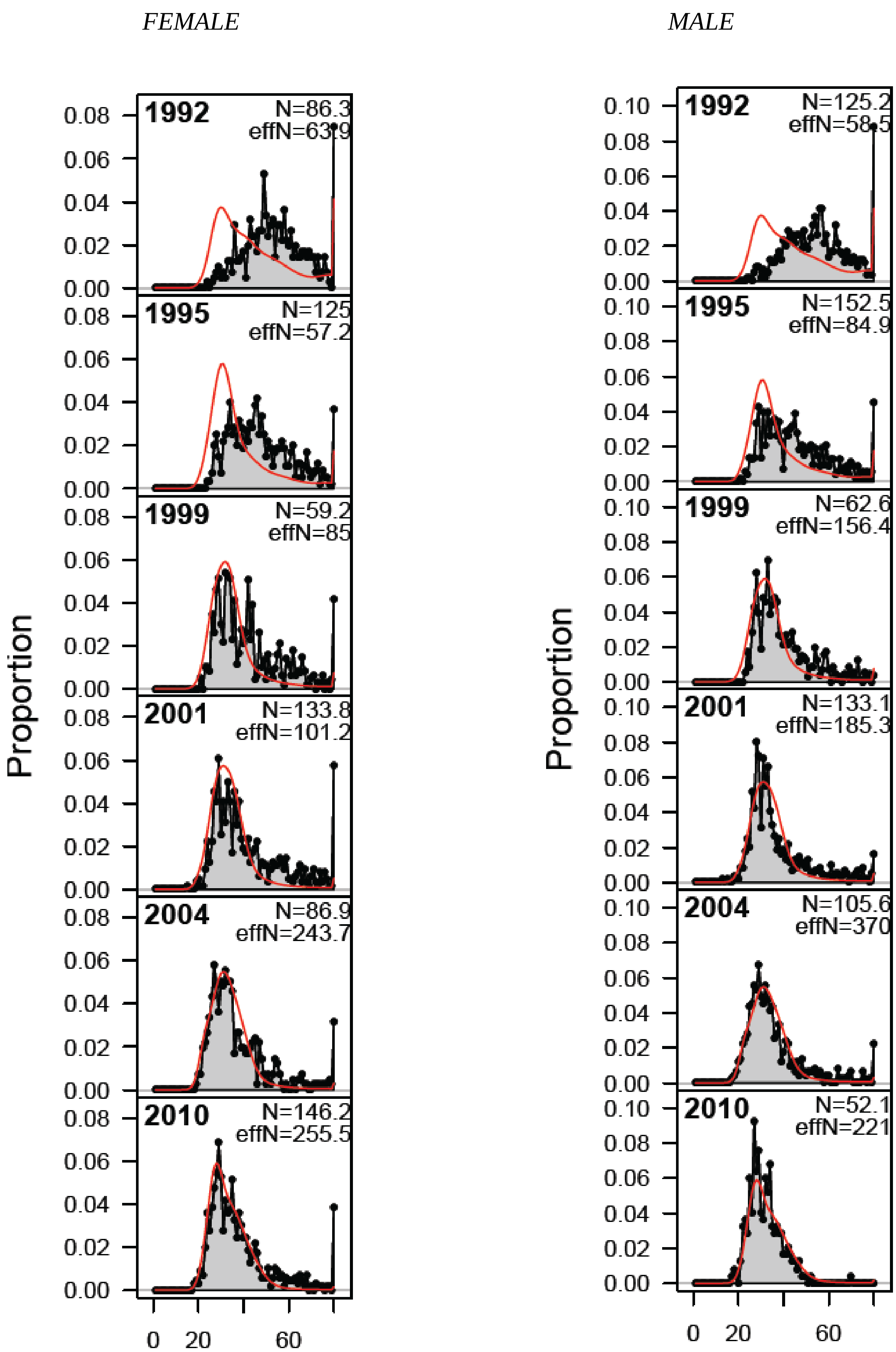


Figure 5.14. Fits to age compositions for Sensitivity Model G.

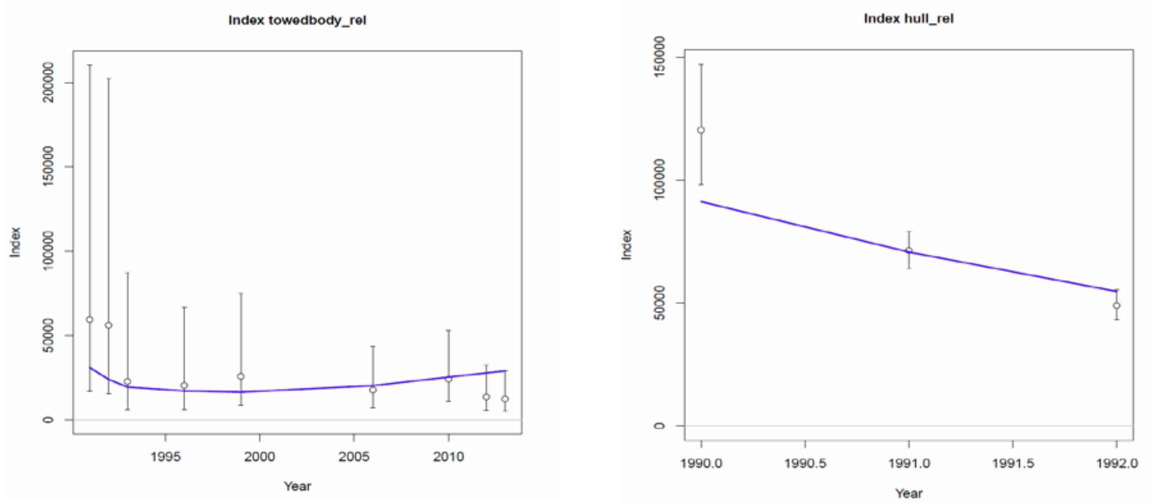
Fits to the data - Sensitivity Model H (EAST ONLY)

Fits to relative abundance (biomass) indices (Figure 5.15) for Sensitivity Model H: Stock structure: EAST are compared to the Final Base-case Model 0. The fits to the age compositions were comparable with those for the Final Base-case model and are not shown here. However, similar to Sensitivity Model C, with No Recruitment Deviations, there is a different implied trend for spawning biomass for the towed body, the trend being “flat” across the series (Figure 5.15).

The fits for the acoustic towed relative index do not improve on that of the Preliminary Base-case Model as both model fits go through the confidence intervals for the data. The fits for the acoustic hull relative index are degraded in Sensitivity Model H compared to the Final Base-case model (Figure 5.15).

(a) Sensitivity Model H (Stock structure EAST)

Acoustic towed body (1991-2013) Acoustic hull (1990-1993)



(b) Final Base Model 0 – Acoustic towed body and hull (for reference)

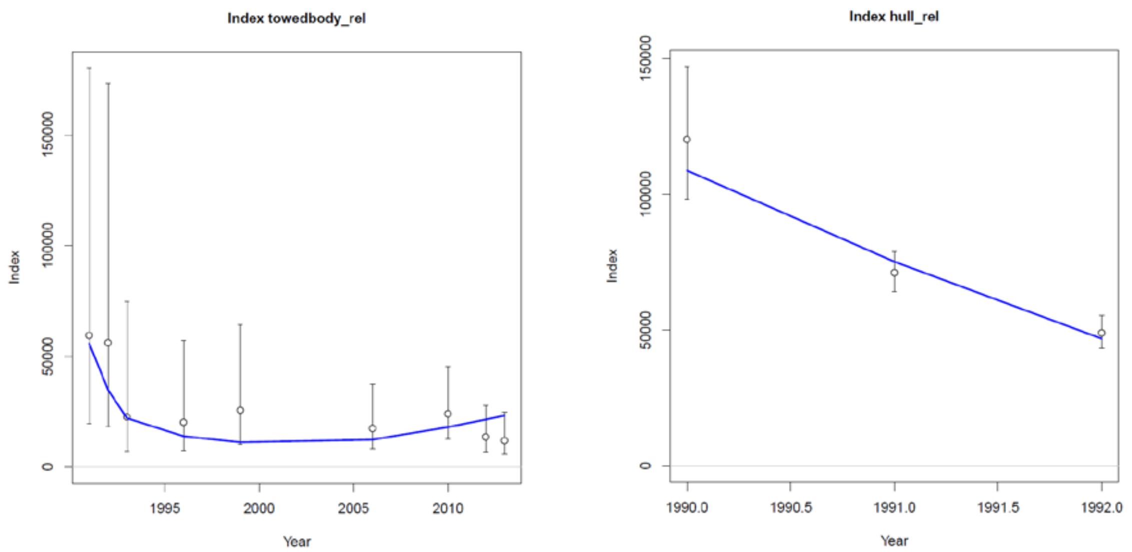
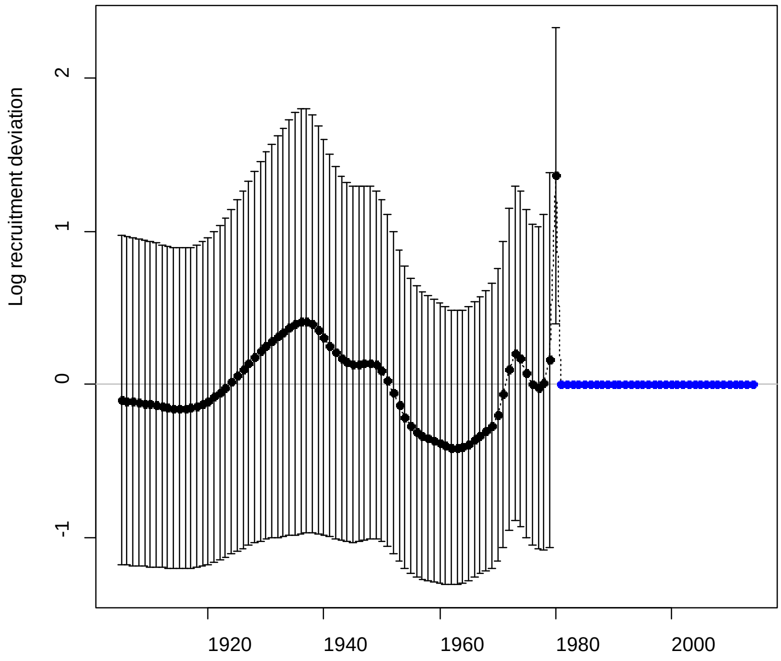


Figure 5.15. (a) Sensitivity Model H Observed (circles) and model-estimated (lines) of relative indices of total spawning biomass - Acoustic towed and hull, against year. (b) Final Base Model 0 towed and hull survey fits (left and right plots respectively) for reference. The vertical lines indicate approximate 95% confidence intervals for the data.

The model estimates an increase in recruitment for the period since approximately 1965 to 1980 for the East only model, whereas for the E+S+W model estimated recruitment decreases over that period (Figure 5.16).

(a) Sensitivity Model H (Stock structure EAST)



(b) Sensitivity Model G (Stock structure EAST+SOUTH+WEST)

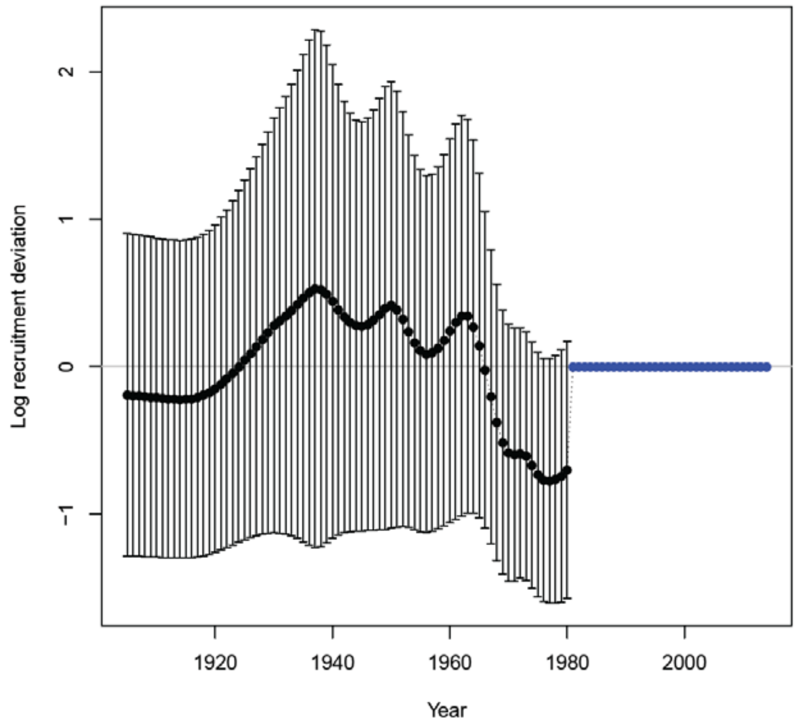


Figure 5.16. Time trajectory of estimated recruitment deviations for Sensitivity Model H (a) and Sensitivity Model G (b). Recruitment deviations are not estimated after 1980, instead expected recruitment (from the spawner recruitment curve) is assumed.

5.4.4 *MCMC simulations for the Final Base-case Model 0*

The MCMC simulation approached convergence. However, the chain was not yet fully converged even with 24 million cycles and a thinning interval of 40,000 (see Appendix D – diagnostic plots). Nevertheless, we consider the results of the MCMC analysis as adequate for the purposes of this report, i.e. to draw broad inferences about the variability in the parameter estimates from the base-case model.

The female spawning biomass trajectory with 95% Bayesian credible intervals are given in Figure 5.17, the posterior distribution for estimated female spawning depletion is given in Figure 5.18, and the estimated probability density function for the RBC is shown in Figure 5.19.

The posterior median estimates from the MCMC simulations were close to the maximum posterior density (MPD) estimates for most of the parameters of interest (Table 5.5). The MPD estimates for initial female spawning biomass (B_0) and initial recruitment (SR_LN(R0)) are outside of the 95% Bayesian CIs (Table 5.5). This is in part explained by recruitment for the era ~ 1930 to 1950, which is estimated by the MCMC to be greater than that estimated by MPD, and with more precision (Figure 5.20). However, the median estimate of female spawning depletion (SB_{2015}/ SB_0) was 0.25 with a 95% Bayesian CI of 0.23 to 0.28, which is similar to the MPD estimate of 0.26 (Table 5.5). The median estimates for the catchability parameter *q* for the towed body and the hull were close to the MPD estimates (Table 5.5).

The 95% Bayesian CIs for the estimated parameters, notably female spawning biomass (Figure 5.17), are fairly narrow and may indicate that the model parameter space is constrained. Further work should consider this in more detail. In particular, there are assumptions embedded in the model regarding the degree to which the data inform estimates of recruitment in the recent (1981 to 2013) and forecast years that should be explored in future assessments. Briefly, the issue is that for the base-case model MPD estimate of SB_{2015} the recruitment deviations are not estimated beyond 1980 (given orange roughy do not recruit until ~35 years, very few fish post-1980 will have recruited in 2015), instead average recruitment (from the spawner recruitment curve) is assumed. However, for the MCMC simulations for the Final Base-case model we enable stochastic recruitment and this extends into the recent and forecast periods (beyond 1980), but we apply a penalty function for the recent and forecast years when there is sparse, noisy data. It is possible that recruitment variability has been overly constrained for these recent years.

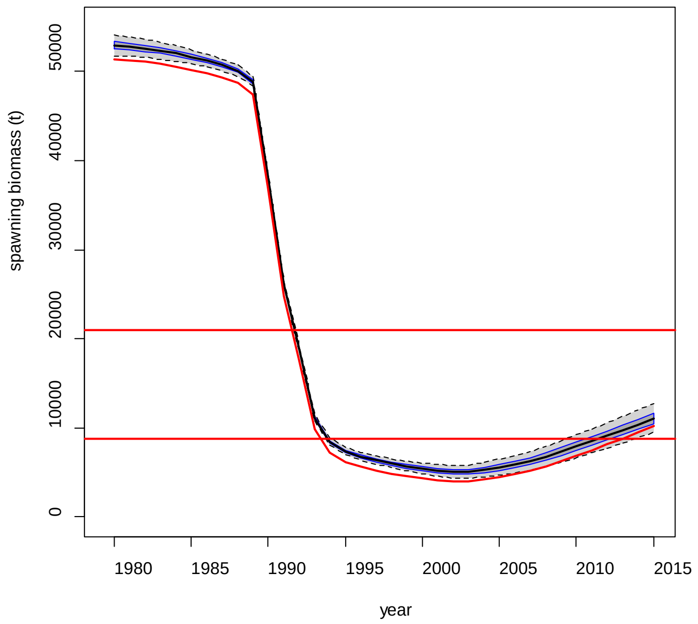


Figure 5.17. Female spawning biomass trajectory to 2015 (50% and 95% Bayesian credible intervals: blue and dotted black lines respectively). The horizontal red lines denote the 20% minimum stock size threshold and the 48% management target. The estimate of initial spawning biomass (not shown) is less than the 1980 estimate. The MPD female spawning biomass trajectory is shown by the red line.

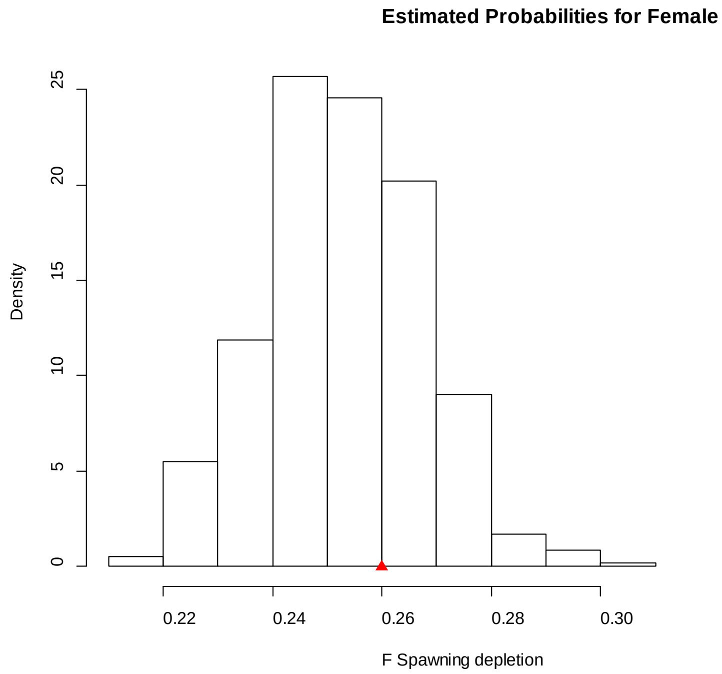


Figure 5.18. Estimated probabilities for female spawning depletion in 2015 for Final Base-case Model 0. The MPD estimate is shown by the red point on the x-axis.

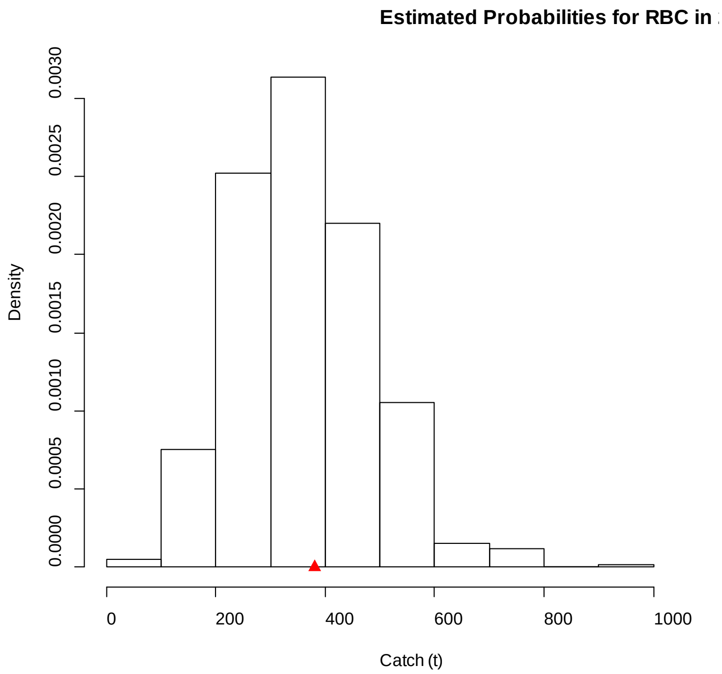


Figure 5.19. Estimated probabilities for RBC in 2015 for Final Base-case Model 0. The MPD estimate is shown by the red point on the x-axis.

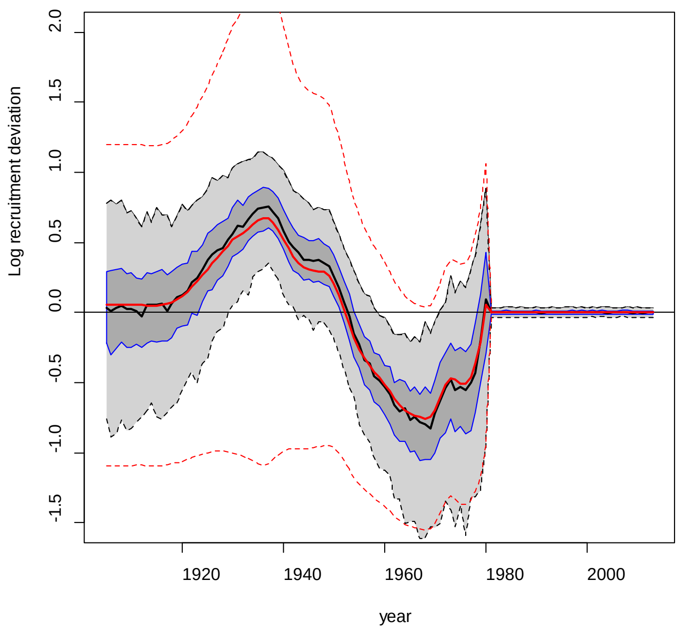


Figure 5.20. Time trajectory of estimated recruitment deviations for Final Base-case Model 0 (50% and 95% Bayesian credible intervals: blue and dotted black lines respectively). The MPD estimate is shown by the red line (with 95% asymptotic confidence intervals: red dotted line).

SUMMARY OF MCMC RESULTS FOR FINAL BASE CASE MODEL 0

Table 5.5. Summary statistics for key parameters estimated from MCMC simulations of the Final Base-case Model 0.

Key parameters	MPD esimtate	MCMC Median	(95% Bayesian CI)	1%	99%
SR_LN(RO)	9.05	9.16	(9.13 - 9.20)	9.12	9.21
Q3_Towed_rel	1.32	1.31	(1.03 - 1.66)	0.92	1.80
Q4_Hull_rel	1.78	1.79	(1.65 - 1.93)	1.62	1.95
SB0	38,931	43,591	(41,863 - 45,282)	41,641	45,707
SB2015	10,185	11,020	(9,586 - 12,620)	9,320	13,165
SB2015/B0	0.26	0.25	(0.23 - 0.28)	0.22	0.29
RBC2015	381	351	(151 - 622)	120	718

5.5 Summary

The Final Base-case Model 0 maximum posterior density (MPD) estimate of female spawning biomass in 2015 was 26% of unfished female spawning biomass, which was close to the median Bayesian estimate of 25% with 95% Bayesian CI of 23% to 28%. The estimated RBC under the 20:35:48 harvest control rule is 381t, with a long-term RBC of approximately 1,534 t.

The model estimates a steep decline in female spawning biomass in the early 1990's (as the commercial fishery developed), followed by a period of gradual further decline, and a recent increase to levels above 20% of unfished level. The forecast over the next 55 years implies a continued increase in the female spawning biomass, at a slower rate beyond 2020 and over the next five decades if catches equal RBCs (estimated mean generation time from model was ~56 years).

The model estimates a spawning biomass trend that is recently increasing, whereas the observed acoustic point estimates for 2012 and 2013 are less than estimates for preceding years (but see Ryan et al. 2014). In this assessment we have adopted a weighting scheme for the data that places more importance on fitting the acoustic indices as a direct measure of spawning biomass. Hence, the acoustic indices are influential in the model. Thus, a continued series for the acoustic towed index (that uses a consistent survey design) could be particularly important. Given the observed year-to-year variability in recent acoustic estimates, making observations over a few consecutive years would provide some context for the observations.

The catchability coefficients for the towed and hull acoustic surveys were estimated by the Final Base-case model to be 1.32 and 1.78 respectively, and these were within the bounds of the priors.

The stock structure assumption is a key uncertainty in the assessment, as the model outcomes differed depending on this assumption. The base-case model was also sensitive to the inclusion of recruitment deviations (which concurs with Cordue's 2014 finding for NZ orange roughy model), higher earlier catches and, to a lesser extent, the data weighting method for the age compositions (Francis 2011 or McAllister and Ianelli 2007).

5.6 Future work

In addition to the any remaining future work outlined in Upston & Wayte (2012b), further work to investigate some of the uncertainty and improve on the base-case model could include:

- Stock structure is a key uncertainty in the assessment, as the model outcomes differed depending on the assumption regarding stock structure. The next step for modelling could be management strategy evaluation (MSE) testing of the assessment outcomes when different stock structures are assumed (see Stokes 2009);

- Continue to investigate uncertainty in the stock assessment. The MCMC simulations would benefit from further work in terms of running the chain for longer (and get closer to model convergence), and running alternative chains (another check for model convergence). Also, the model has embedded assumptions regarding how well the observed data inform estimates of recruitment in the recent and forecast years (1981 onwards), and testing of the model sensitivity to those assumptions would be useful;

- Further investigation of the data weighting method used in the assessment could be important, since the base-case model is sensitive to the method used. Whilst the Francis (2011) method for weighting the age compositions is the currently accepted method, this is an evolving field of study;

- Some minor technical issues were identified during internal review and these should be reviewed for the next assessment: source the data for the young length at age CV; revise the years for which recruitment deviations are estimated (this becomes increasingly important beyond 2015, as the fishery moves into an era where recruitment is estimated from the spawning stock that was fished (commencing in the mid-1980’s).

5.7 Acknowledgements

The members of the SESSF stock assessment group at O&A –Malcolm Haddon, Geoff Tuck, and Robin Thomson– are thanked for their reviews. Rudy Kloser and Tim Ryan provided the acoustic data and discussions on the acoustics methods. Tim Ryan assisted with compiling the acoustic snapshot series. The ageing data were provided by Kyne Krusic Golub (Fish Ageing Services). Kyne is thanked for his efforts in the re-ageing of Roughy otoliths. Caroline Sutton (O&A) and Kyne reviewed the historical ageing data for Eastern Zone orange roughy. Neil Klaer and Mike Fuller (O&A) provided data for the stock assessment. Thanks to all members of the RAG and the participants in the May 2014 Australian Orange Roughy workshop for helpful discussions and advice. Patrick Cordue and Geoff Tingley from NZ are thanked for their time and for providing insights on the New Zealand Roughy experience. Matt Dunn and Murdoch McAllister are also thanked for their helpful discussions. Thanks to Nic Bax for providing insights into the history of the fishery and the stock assessments. AFMA provided support for J. Upston to attend the 2014 Fisheries Assessment Plenary (Orange roughy session) at the Ministry for Primary Industries in NZ.

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5.9 Tables

Table 5.6. Catches (t) for Sensitivity Model I "Higher earlier catches" for the Eastern Zone (East) and the area Pedra Branca (PB). The "Higher agreed catch" values were suggested by AFMA (May 2014) as a nominal higher bound on the agreed catches in the base-case model.

	BASE CASE		HIGHER AGREED CATCH	
Year	**EAST and PB MX1**	**Catch_EAST and PB Agreed MX1*Reported catch**	**EAST and PB_HigherCatch MX2**	**EAST and PB _HigherCatch MX2*Catch_EAST and PB Agreed**
1988		1949	1.5	2924
1989	1.3	28575	1.5	42863
1990	1.3	34502	1.5	51753
1991	1.2	20436	1.5	30654
1992	1.55+	24265	2	48530
1993	2.1*	8798	1.5	13197
1994	1.1			
TOTAL Catch (t) 1988-1993		118525		189920

"MX" is multipler
MX1 rationale is outlined below:
1989, 1990: 30% losses assumed; 1991: 20% losses assumed
1992+ reported catches increased by 45% for est. misreporting + 10% losses assumed
1993*: 2665 t transferred from South zone reported catch to East zone catch for est. misreporting + 10% losses assumed
1994: 10% losses assumed
Sources: Wayte (2007) Eastern Roughy Assessment (description of adjustments);
Upston & Wayte (2012a) Table 9.6 catches used in the 2011 prelim assessment for base-case (highlighted column 2)
Note: A "low catch" scenario (at the extreme end) is given by Sensitivity Model A - Unadjusted catch in Table 9.9 of Upston & Wayte (2012a), which includes the reported catch with no upwards adjustments

Table 5.7. Acoustic TOWED spawning biomass estimates and associated CVs by snapshot, area and year. Snapshot refers to one observation for an acoustic survey. The average survey estimates, associated CVs and priors are tabulated. The “Bias” column is a flag to check that the calculated total survey CV for early years is not too “narrow” – expert judgement was that in early years the acoustic estimates were generally less precise than for recent years. Key: Area SH =St Helens, SP=St Patricks; Pair –flag for snapshot pair within 24-48 h; Max Biomass –maximum snapshot biomass; snapshot CVs were obtained from acoustic reports (for acoustics CV2 e.g. see Table 3.10 in Ryan et al. 2013); Bias-flag to impose a “wide” CV. Total survey CV is calculated by adding the three component errors (considered independent) - Combined areas CV, Between snapshots CV, Survey one area CV.

											SNAPSHOT BIOMASS				**SNAPSHOT CV**				
Year	System	Fleet	Date	Op	Transects	Area	Pair	Target strength (original)	Target strength (revised)	Simrad TVG error factor	Biomass above DZ (t)	Deadzone %	**Biomass total (t)**	Max Biomass	snapshot CV	snapshot CV1 incl. deadzone	acoustics CV2	**total snapshot CV (CV1 & CV2)**	Bias
1991	S	3	30/07/1991	SS291	?	SH		-50.0	-51.8	1.10	34,526	25.1	46,109	1	0.28	0.31	0.2	0.37	1
1991	S	3	-	-	-	SP		-	-		-	-	-						
1992	S	3	19/07/1992	SS392	?	SH		-50.0	-51.8	0.93	27,394	37	43,493	1	0.28	0.33	0.2	0.39	1
1992	S	3	-	-	-	SP		-	-		-	-	-						
1993	S	3	25/07/1993	SS593	?	SH		-50.0	-51.8	1.12	13,851	21.7	17,683	1	0.35	0.37	0.2	0.42	1
1993	S	3	-	-	-	SP		-	-		-	-	-						
1996	M1	3	17/07/1996	SS496_1	?	SH		-50.0	-51.8	1.12	12,320	14.6	14,429		0.28	0.29	0.2	0.35	
1996	M1	3	20/07/1996	SS496_2	?	SH		-50.0	-51.8	1.12	13,733	20	17,156	1	0.28	0.30	0.2	0.36	
1996	M1	3	-	-	-	SP		-	-		-	-	-						
1999	M1	3	18/07/1999	SP6	6	SP	1	-50.3	-52.0	1	-	-	21,366		0.63	-	0.2	-	1
1999	M1	3	19/07/1999	SH6	5	SH	1	-50.0	-51.7	1	0	0	0		-	-	-	-	1
1999	M1	3	30/07/1999	SP18	3	SP	2	-50.3	-52.0	1	17,178	15.8	20,399	1	0.63	0.64	0.2	0.67	1
1999	M1	3	31/07/1999	SH22	5	SH	2	-50.0	-51.7	1	3,815	23	4,955	1	0.28	0.3	0.2	0.36	
2006	M2	3	15/07/2006	1_2	10	SH		-50.3	-52.2	1	10,723	23.8	14,065		0.12	0.17	0.23	0.29	
2006	M2	3	16/07/2006	6_7	10	SH	1	-50.3	-52.2	1	12,464	23.6	16,307		0.14	0.18	0.23	0.29	
2006	M2	3	18/07/2006	10	12	SP	1	-50.1	-52.1	1	1,659	23	2,156		0.15	0.19	0.23	0.30	
2006	M2	3	18/07/2006	11_12	10	SH	1	-50.3	-52.2	1	10,581	31.5	15,438		0.09	0.18	0.23	0.29	
2006	M2	3	19/07/2006	13_14	10	SH	1	-50.3	-52.2	1	9,699	24.8	12,895		0.1	0.16	0.23	0.28	
2006	M2	3	20/07/2006	15	12	SP	2	-50.1	-52.1	1	1,973	13.7	2,286	1	0.15	0.16	0.23	0.28	
2006	M2	3	20/07/2006	16_17	10	SH	2	-50.3	-52.2	1	12,586	21.5	16,037	1	0.11	0.15	0.23	0.28	
2006	M2	3	22/07/2006	26_27	10	SH	3	-50.3	-52.2	1	11,656	15.8	13,847		0.13	0.15	0.23	0.28	
2006	M2	3	23/07/2006	30	12	SP	3	-50.1	-52.1	1	2,162	6.9	2,322		0.15	0.16	0.23	0.28	
2006	M2	3	25/07/2006	40	12	SP	4	-50.1	-52.1	1	4,507	4.6	4,727		0.17	0.17	0.23	0.29	
2006	M2	3	25/07/2006	42_43	10	SH	4	-50.3	-52.2	1	10,575	21.6	13,486		0.09	0.14	0.23	0.27	

	AVERAGE BIOMASS			**SURVEY CV**						**PRIORS**			
Year	SH Biomass_average (t)	SP Biomass_average (t)	**SH+SP Biomass_average (t)**	SH average total snapshot CV	SP average total snapshot CV	Combined areas CV	Between snapshots CV	survey one area CV	**total survey CV_average**	target strength ratio (ts_ true/ts) A	%SB popn surveyed (prop) B	Random error C	**Catchability Q (A*B*C)**
1991	46,109	-	59,481	0.37	-	0.37	0.20	0.25	0.49	LN(1,0.15)	Beta(95,5)	LN(1, 0.25)	N(0.95, 0.30)
1992	43,493	-	56,106	0.39	-	0.39	0.20	0.25	0.5	LN(1,0.15)	Beta(95,5)	LN(1, 0.25)	N(0.95, 0.30)
1993	17,683	-	22,811	0.42	-	0.42	0.20	0.25	0.53	LN(1,0.15)	Beta(95,5)	LN(1, 0.25)	N(0.95, 0.30)
1996	15,793	-	20,372	0.31	-	0.31	0.20	0.25	0.45	LN(1,0.15)	Beta(95,5)	LN(1, 0.25)	N(0.95, 0.30)
1999	4,955	20,883	25,838	0.36	0.67	0.33	0.20		0.39	LN(1,0.15)	Beta(95,5)	LN(1, 0.25)	N(0.95, 0.30)
2006	14,668	2,873	17,541	0.28	0.29	0.24	0.20		0.31	LN(1,0.15)	Beta(95,5)	LN(1, 0.25)	N(0.95, 0.30)

Table 5.7 continued. Acoustic TOWED spawning biomass estimates and associated CVs. Regarding the 2013 acoustic survey observations, Ryan et al. (2014) state that “given the apparent downward trend in biomass observed at St Helens Hill [over the survey period] it is possible that the 2013 surveys did not quantify the spawning stock at its peak”. We have included the 2013 estimates in the assessment because the survey was carried out in a manner that was consistent with the other years (despite vessel equipment issues the AOS survey was conducted within the historical time-frame), and there was no *a priori* reason to exclude the observations (given the potential for large shot-to-shot variability in spawning condition of orange roughy a single trawl observation was not definitive enough to conclude that the survey had missed the main spawning event).

											SNAPSHOT BIOMASS				SNAPSHOT CV				
Year	System	Fleet	Date	Op	Transects	Area	Pair	Target strength (original)	Target strength (revised)	Simrad TVG error factor	Biomass above DZ (t)	Deadzone %	**Biomass total (t)**	Max Biomass	snapshot CV	snapshot CV1 incl. deadzone	acoustics CV2	**total snapshot CV (CV1 & CV2)**	Bias
2010	AOS	3	18/07/2010	18	10	SH	1	-52.0	-52.0	1	14,200	26	19,200	1	0.08	0.15	0.1	0.18	
2010	AOS	3	19/07/2010	21	12	SP	1	-52.0	-52.0	1	6,000	3.2	6,200	1	0.13	0.13	0.1	0.16	
2010	AOS	3	22/07/2010	27	12	SP	2	-52.0	-52.0	1	2,600	16.1	3,100		0.17	0.19	0.1	0.21	
2010	AOS	3	22/07/2010	30	10	SH	2	-52.0	-52.0	1	14,600	25.1	19,500		0.08	0.15	0.1	0.18	
2012	AOS	3	16/07/2012	2	10	SH	1	-52.0	-52.0	1	7,085	41.2	12,058	1	0.18	0.26	0.1	0.28	
2012	AOS	3	17/07/2012	5	6	SP	1	-52.0	-52.0	1	2,328	34.7	3,564	1	0.16	0.23	0.1	0.25	
2012	AOS	3	18/07/2012	11	10	SH	2	-52.0	-52.0	1	4,582	25	6,107		0.26	0.29	0.1	0.31	
2012	AOS	3	19/07/2012	15	6	SP	2	-52.0	-52.0	1	6,973	2.3	7,136		0.17	0.17	0.1	0.20	
2012	AOS	3	21/07/2012	24	6	SP	3	-52.0	-52.0	1	2,152	10.5	2,405		0.22	0.23	0.1	0.25	
2012	AOS	3	20/07/2013	12_13	9	SH	3	-52.0	-52.0	1	7,707	19.3	9,547		0.23	0.25	0.1	0.27	
2013	AOS	3	21/07/2013	14	9	SP	1	-52.0	-52.0	1	4,863	11.9	5,519	1	0.37	0.37	0.1	0.38	
2013	AOS	3	21/07/2013	17_18	9	SH	1	-52.0	-52.0	1	6,560	23.5	8,572	1	0.23	0.26	0.1	0.28	
2013	AOS	3	22/07/2013	19_20	9	SP	1	-52.0	-52.0	1	4,932	13.5	5,700		0.13	0.15	0.1	0.18	
2013	AOS	3	24/07/2013	23_24	9	SH	2	-52.0	-52.0	1	2,887	27.7	3,995		0.24	0.27	0.1	0.29	
2013	AOS	3	25/07/2013	27a	9	SP	2	-52.0	-52.0	1	6,025	6.7	6,458		0.24	0.24	0.1	0.26	

AVERAGE BIOMASS				SURVEY CV						PRIORS			
Year	SH Biomass_average (t)	SP Biomass_average (t)	**SH+SP Biomass_average (t)**	SH average total snapshot CV	SP average total snapshot CV	Combined areas CV	Between snapshots CV	survey one area CV	**total survey CV_average**	target strength ratio (ts_ true/ts) A	%SB popn surveyed (prop) B	Random error C	**Catchability Q (A*B*C)**
2010	19,350	4,650	24,000	0.18	0.18	0.15	0.20		0.25	LN(1,0.15)	Beta(95,5)	LN(1, 0.25)	N(0.95, 0.30)
2012	9,237	4,368	13,605	0.29	0.24	0.21	0.20		0.29	LN(1,0.15)	Beta(95,5)	LN(1, 0.25)	N(0.95, 0.30)
2013	6,284	5,892	12,176	0.30	0.28	0.21	0.20		0.29	LN(1,0.15)	Beta(95,5)	LN(1, 0.25)	N(0.95, 0.30)

Table 5.8. Acoustic TOWED spawning biomass estimates and associated CVs - average survey estimates, associated CVs and priors. Regarding the 2013 acoustic survey observations, Ryan et al. (2014) state that “given the apparent downward trend in biomass observed at St Helens Hill [over the survey period] it is possible that the 2013 surveys did not quantify the spawning stock at its peak”. We have included the 2013 estimates here because the survey was carried out in a manner that was consistent with the other years.

	AVERAGE BIOMASS			**SURVEY CV**						**PRIORS**			
Year	SH Biomass_average (t)	SP Biomass_average (t)	**SH+SP Biomass_average (t)**	SH average total snapshot CV	SP average total snapshot CV	Combined areas CV	Between snapshots CV	survey one area CV	**total survey CV_average**	target strength ratio (ts_ true/ts) A	%SB popn surveyed (prop) B	Random error C	**Catchability Q (A*B*C)**
1991	46,109	-	59,481	0.00	-	0.37	0.20	0.25	0.49	LN(1,0.15)	Beta(95,5)	LN(1, 0.25)	N(0.95, 0.30)
1992	43,493	-	56,106	0.00	-	0.39	0.20	0.25	0.5	LN(1,0.15)	Beta(95,5)	LN(1, 0.25)	N(0.95, 0.30)
1993	17,683	-	22,811	0.00	-	0.42	0.20	0.25	0.53	LN(1,0.15)	Beta(95,5)	LN(1, 0.25)	N(0.95, 0.30)
1996	15,793	-	20,372	0.31	-	0.31	0.20	0.25	0.45	LN(1,0.15)	Beta(95,5)	LN(1, 0.25)	N(0.95, 0.30)
1999	4,955	20,883	25,838	0.36	0.67	0.33	0.20		0.39	LN(1,0.15)	Beta(95,5)	LN(1, 0.25)	N(0.95, 0.30)
2006	14,668	2,873	17,541	0.28	0.29	0.24	0.20		0.31	LN(1,0.15)	Beta(95,5)	LN(1, 0.25)	N(0.95, 0.30)
2010	19,350	4,650	24,000	0.18	0.18	0.15	0.20		0.25	LN(1,0.15)	Beta(95,5)	LN(1, 0.25)	N(0.95, 0.30)
2012	9,237	4,368	13,605	0.29	0.24	0.21	0.20		0.29	LN(1,0.15)	Beta(95,5)	LN(1, 0.25)	N(0.95, 0.30)
2013	6,284	5,892	12,176	0.30	0.28	0.21	0.20		0.29	LN(1,0.15)	Beta(95,5)	LN(1, 0.25)	N(0.95, 0.30)

Table 5.9. Acoustic HULL spawning biomass estimates and associated CVs by snapshot, area and year. A snapshot refers to one observation for an acoustic survey. The average survey estimates, associated CVs and priors are tabulated. Key: Area SH =St Helens, SP=St Patricks; Max Biomass –maximum snapshot biomass; snapshot CVs were obtained from acoustic reports (for acoustics CV2 e.g. see Table 3.10 in Ryan et al. 2013). Total survey CV is calculated by adding the three component errors (considered independent) - Combined areas CV, Between snapshots CV, Survey one area CV.

											SNAPSHOT BIOMASS				**SNAPSHOT CV**				
Year	System	Fleet	Date	Op	Transects	Area	Pair	Target strength (original)	Target strength (revised)	Simrad TVG error factor	Biomass above DZ (t)	Deadzone %	**Biomass total (t)**	Max Biomass	snapshot CV	snapshot CV1 incl. deadzone	acoustics CV2	**total snapshot CV (CV1 & CV2)**	Bias
1990	Hull	4	16/07/1990	SH190	5	SH		-50.0	-51.8	1.23	48,227	33	71,699	1	0.49	0.51	0.2	0.55	
1990	Hull	4	-	-	-	SP		-	-		-	-	-						
1991	Hull	4	26/07/1991	SS291	5	SH		-50.0	-51.8	1.24	36,680	34	55,204	1	0.41	0.44	0.2	0.48	
1991	Hull	4	-	-	-	SP		-	-		-	-	-						
1992	Hull	4	17/07/1992	SS392	5	SH		-50.0	-51.8	1.25	23,405	38	37,973	1	0.41	0.45	0.2	0.49	
1992	Hull	4	-	-	-	SP		-	-		-	-	-						

	AVERAGE BIOMASS			**SURVEY CV**						**PRIORS**			
Year	SH Biomass_average (t)	SP Biomass_average (t)	**SH+SP Biomass_average (t)**	SH average total snapshot CV	SP average total snapshot CV	Combined areas CV	Between snapshots CV	survey one area CV	**total survey CV_average**	target strength ratio (ts_ true/ts) A	%SB popn surveyed (prop) B	Random error C	**Catchability Q (A*B*C)**
1990	71,699	-	120,239	0.55	-	0.55	0.20	0.25	0.63	LN(1,0.15)	Beta(95,5)	LN(1, 0.8)	N(0.95, 0.92)
1991	55,204	-	71,213	0.48	-	0.48	0.20	0.25	0.58	LN(1,0.15)	Beta(95,5)	LN(1, 0.8)	N(0.95, 0.92)
1992	37,973	-	48,985	0.49	-	0.49	0.20	0.25	0.59	LN(1,0.15)	Beta(95,5)	LN(1, 0.8)	N(0.95, 0.92)

Table 5.10. Number of age samples by sex and area, used to construct age compositions that are input into the stock assessment model (areas combined). Note that the model is subsequently tuned to account for variance in the age compositions relative to the quality of the fit to these data (i.e. tuned to down-weight the importance of variable age-composition samples). The weighting factors applied when combining the areas SP and SH are given, and we outline the rationale. *For 1992 SP was not sampled - most of the catch was taken from SH (~90%; Table 9.4 Upston & Wayte 2012a) and it was assumed that most of the spawning fish were at SH in these years (Wayte 2007). Similarly, the 1995 catch was mostly taken from SH (84%) where the sampling occurred. The logbook data indicate that some of the 1995 samples may have been taken be from SP, and if so, we consider whether a 'combined' age distribution (with area sample weighting = 1) is appropriate, since this is the 'weighting' in the current assessment with all samples designated as SH (see also Appendix C).

Year	St Helens (SH)			St Patricks (SP)			Combined area		Combined area sample weighting	
	F	M	Tot	F	M	Tot	F	M	SP : SH	Rationale
1992*	410	596	1006	-	-		410	596	-	
1995*	595	726	1321	?	?		595	726	-	? some of the SH samples could be from SP. If so, age compositions by logbook area SP SH were broadly similar (Appendix C); an unweighted 'combined' distribution seems appropriate
1999	117	94	211	165	204	369	282	298	1.08	sample ratio SP: SH = 1.75 (Wayte 2007) & estimate 85% of spawning fish at SP (towed body acoustics; Kloser et al 2008)
2001	305	175	480	332	460	792	637	635	1	sample ratio SP: SH = 1.65, in proportion to commercial catches (no towed body acoustic estimates; Wayte 2007)
2004	228	234	462	186	270	456	414	504	1	age compositionns for SP SH were similar (Wayte 2007)
2010	474	121	595	218	130	348	692	251	1	age compositionns for SP SH were broadly similar (Appendix C); combined areas age frequency without sample weighting was similar to that with a combined area weighting SP: SH of 0.4 (sample ratio SP: SH=0.59 & estimate 24% of spawning fish at SP (towed body acoustics; Kloser et al 2011)

Table 5.11. Standard deviations of age reading error, based on 1,856 otolith readings by CAF, FAS & affiliates.

Age	StDev	Age	StDev
1	0.001	41	3.242
2	0.173	42	3.312
3	0.259	43	3.383
4	0.345	44	3.453
5	0.430	45	3.523
6	0.515	46	3.592
7	0.600	47	3.661
8	0.684	48	3.730
9	0.767	49	3.798
10	0.851	50	3.866
11	0.934	51	3.933
12	1.016	52	4.000
13	1.098	53	4.067
14	1.180	54	4.133
15	1.262	55	4.199
16	1.343	56	4.264
17	1.423	57	4.330
18	1.503	58	4.394
19	1.583	59	4.459
20	1.663	60	4.523
21	1.742	61	4.586
22	1.821	62	4.649
23	1.899	63	4.712
24	1.977	64	4.774
25	2.054	65	4.836
26	2.131	66	4.898
27	2.208	67	4.959
28	2.284	68	5.020
29	2.360	69	5.080
30	2.436	70	5.140
31	2.511	71	5.200
32	2.586	72	5.259
33	2.660	73	5.318
34	2.734	74	5.377
35	2.808	75	5.435
36	2.881	76	5.493
37	2.954	77	5.550
38	3.027	78	5.607
39	3.099	79	5.663
40	3.170	80	5.719

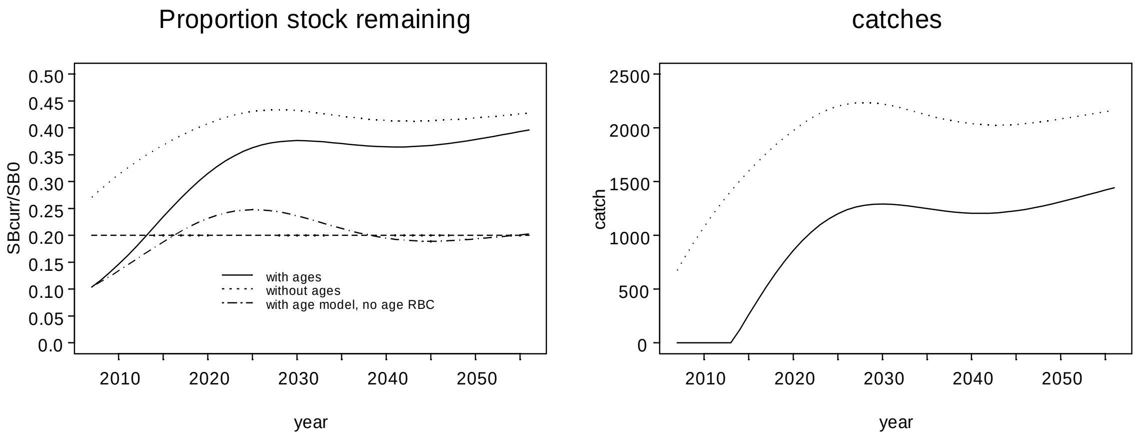
Table 5.12. Summary of results for Preliminary Base-case model and sensitivity tests (tuned models), including sequential models for the base case model specification and data inputs. Lower total NLL (negative log-likelihood) values indicate a better fit to the data for comparable models. Models with different weighting and data are not comparable (C indicate models comparable to Preliminary Base-case). *q* prior for towed: N(0.95, 0.3), Hull: N(0.95, 0.92). Sequential Models #1 and #2 have acoustic survey (towed and hull), age and catch data to 2010 (Tables 5.3, 5.8, 5.9 and 5.10). Preliminary Base-case model with data to end of 2013 has the same data inputs, model structure and data weighting approach as Model #1 but includes the acoustic towed survey data for 2012 and 2013 (Table 5.8, and thus shows the influence of the new data on the model outcomes. *2011 Preliminary Base-case A model used the same weighting approach as Model #2 but the data inputs and model structure are different (e.g. the 2011 model used a maximum acoustic index without priors for *q*; acoustic survey observations of spawning biomass were multiplied up to index total mature biomass). In a broad sense, comparison of outcomes for the latter two models shows the impact of revising the data inputs and model structure.

Model	**FEMALE SPAWN BIOMASS**			**NLL**	**NLL Main components**			**Estimated Parms**				
	SB0	**SB2014**	**SB2014/B0**	Total	Survey	Age_comp	Recruit	SR_LN(R0)	Selectivity_Infl.	Selectivity_Width	Q3_Towed_rel	Q4_Hull_rel
Preliminary Base-case model	38,727	9,223	0.24	210.88	-17.70	135.18	13.05	9.05	35.70	1.01	1.32	1.76
Sensitivity Model A: M&I Weighting	36,693	7,726	0.21	448.08	-17.57	361.19	22.89	8.99	35.76	1.00	1.53	1.77
Sensitivity Model B: Diffuse priors	38,579	9,095	0.24	206.16	-21.60	134.48	13.75	9.04	35.76	1.13	1.46	1.86
Sensitivity Model C: No Recruitment Devs (degrade age fit)	44,479	18,237	0.41	328.49	-15.95	264.51	0.00	9.18	35.58	2.17	0.79	1.69
Sensitivity Model D: Maximum acoustic SB estimate	38,767	9,269	0.24	206.39	-22.49	135.56	12.71	9.05	35.69	1.01	1.40	1.83
Sensitivity Model E: Steepness 0.40 [C]	38,770	9,587	0.25	206.39	-21.40	134.71	12.73	9.05	35.73	1.01	1.31	1.85
Sequential Models associated with Preliminary Base-case model												
Model #1: Data to end of 2010 (Francis weighting)	39,012	9,562	0.25	203.79	-26.35	136.63	11.77	9.05	35.67	1.00	1.72	1.83
Model #2: Data to end of 2010 (McAllister & Ianelli weighting)*	36,973	8,055	0.22	441.88	-25.50	362.76	21.45	9.00	35.75	1.00	2.07	1.86
Model: 2011 Preliminary Base-case A (Upston & Wayte 2012a)*	41,128	9,326	0.23	347.28	-3.96	346.67	4.56	9.28	36.23	2.06	3.26	n/a
Preliminary Base-case model: Data to end of 2013 (as above)	38,727	9,223	0.24	210.88	-17.70	135.18	13.05	9.05	35.7	1.01	1.32	1.76

Table 5.13. Excerpt from Wayte (2007; p 445). The future projection, applying the 48:48:20 harvest control rule each year, indicates that the biomass will reach the limit level of 20% unfished in 2014 (bottom panel – left).

Proportion of stock remaining in ten years and catch over ten years using different future catch regimes.

Model	Future catches	Prop. remaining in 2016	Total catch 2007-2016
One fleet with age	RBC 48:48:20	0.25	777
One fleet with age	RBC 48:48:20 from no age model	0.19	12,199
One fleet, no age data	RBC 48:48:20	0.38	12,199



RBC calculations for the 48:48:20 HCR for the scenarios with and without fitting to age, and the estimates of proportion of stock remaining if the ‘no age’ RBCs are applied to the ‘with age’ scenario.

5.10 Appendices

Appendix A – Priors for acoustic surveys

The priors for catchability coefficients (*q*) for the acoustic towed and hull biomass estimates used in the base-case assessment are listed in Table 5.7, Table 5.8 and Table 5.9. The priors were developed using the methods of Cordue (presentation to the Australian Orange Roughy workshop, 15 -16 May 2014; Cordue 2014) for the NZ orange roughy assessments as a starting point, and modified for the Australian Eastern orange roughy situation using the available acoustic data (see below) and expert judgement (informal orange roughy acoustics working group in Hobart included J. Upston, T. Ryan, R. Kloser, and A. Punt). An outline of the methods is provided here.

In brief, the methods for calculating acoustic priors were:

Determine the sampling distribution, mean and CV associated with each of three components that we considered for the acoustic priors: (i) uncertainty in acoustic target strength (TS), i.e. the ratio of true target strength to assumed target strength – lognormal distribution centred at 1 with CV=0.15 (after Cordue presentation 2014): a) calculate the mean and standard deviation of two independent mean estimates of acoustic TS, -52.0 and -51.1 dB (ignores sampling variability), and assume TS ~ N(-51.6, sd=0.64), b) convert TS from log scale to linear scale via $\log_e(10^{ts/10})$ where ts is random normal TS, to get $\log_e(10^{ts/10})$ ~ N(-11.88, 0.1476), c) calculate mean and standard deviation of lognormal distribution centred on 1 (including bias correction); (ii) percentage of the spawning stock on the Eastern grounds that acoustics is “seeing” – historically the assessment has assumed 100% and the current assessment assumes “most” (Beta distribution centred on 95%) but allows for the possibility that some spawning stock do not migrate to the Eastern grounds in some years (e.g. an estimated 10% of spawning fish from the South did not migrate to the East in 1992; Bell et al. 1992). Thus a Beta(95, 5) distribution, centred on 95% and with reasonably high values of α and β for an approximately normal shape, was chosen for this prior component. The distribution shape, with less probability mass towards the left-hand tail of the distribution (less probability of only 90% or fewer spawning fish migrating to the spawning grounds and being observed), seemed appropriate based on expert judgement, however other Beta distributions could also have been used (e.g. Beta(950, 50); (iii) random error component capturing other uncertainty (e.g. estimated density of fish in an area; species ID issues; sampling variability in target strength since (i) is an average of the mean estimates). The random error has a lognormal distribution centred on 1, with a nominal “low” CV for towed body surveys, and a wider CV for the hull surveys, given the uncertainty with species ID and other issues (Kloser & Ryan et al. 2001).

The next step was to combine the independent component distributions to get an overall distribution. The CVs associated with each of the three components (and hence the overall prior) were determined by data and expert judgement – in combining the three components and setting a prior on acoustic catchability (*q* scalar) we essentially have made a statement about how well the acoustic towed or hull series is thought to provide an absolute estimate of biomass of the spawning roughy for the stock East and South (Pedra Branca) i.e. the stock we are assessing. We have assumed on average a constant percentage of fish migrating to the eastern grounds and spawning each year. The priors will undoubtedly be further developed as more information becomes available, thus the random error component (lognormal with CV=0.25 for the towed body and 0.8 for the hull) was explicitly included to accommodate this.

Distributions for each of the independent components, and the combined overall distribution for the acoustic *q* prior- are shown below (Figures A1 to A3). The series of acoustics reports are also listed immediately below.

Years	**Index**	**Reference**
1990	Hull	Kloser & Ryan (2002)
1991	Hull /Towed	Kloser & Ryan (2002)
1992	Hull /Towed	Kloser & Ryan (2002)
1993	Towed	Kloser & Ryan (2002)
1996	Towed	Kloser & Ryan (2002)
1999	Towed	Kloser, R. J., T. E. Ryan, et al. (2001)
2006	Towed	Kloser, R. J., T. E. Ryan, et al. (2008)
2010	Towed	Kloser, R. J., I. A. Knuckey, et al. (2011); Kloser et al 2012
2012	Towed	Ryan.T.E, Sutton.C, et al. (2013)
2013	Towed	Ryan, T. E., C. Sutton, et al. (2014)

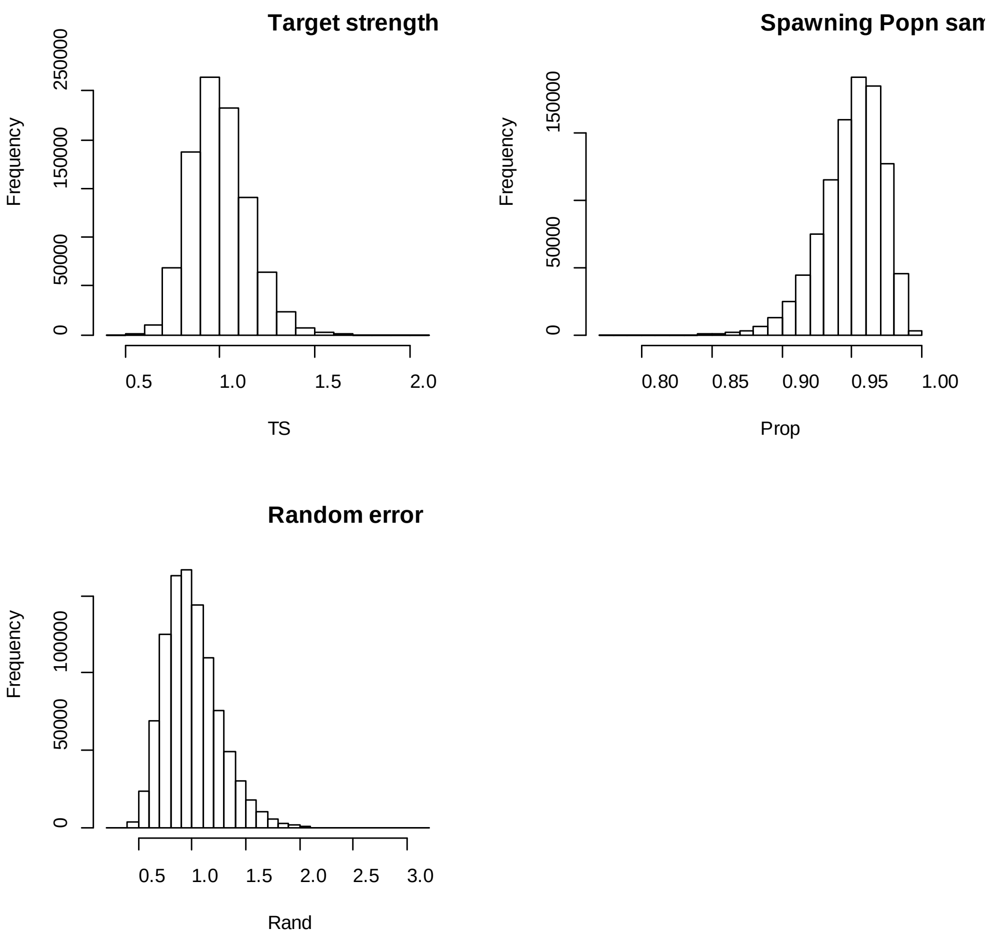


Figure A1. Prior component distributions for target strength, spawning population sampled, and random error for acoustics towed.

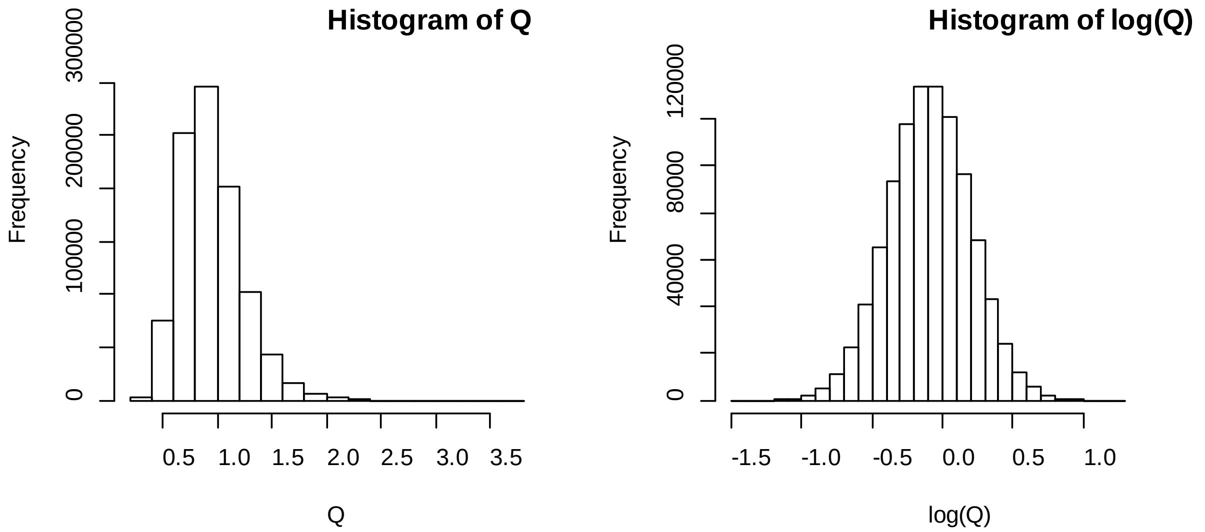


Figure A2. Priors for q and $\log_e(\boldsymbol{q})$ for acoustics towed

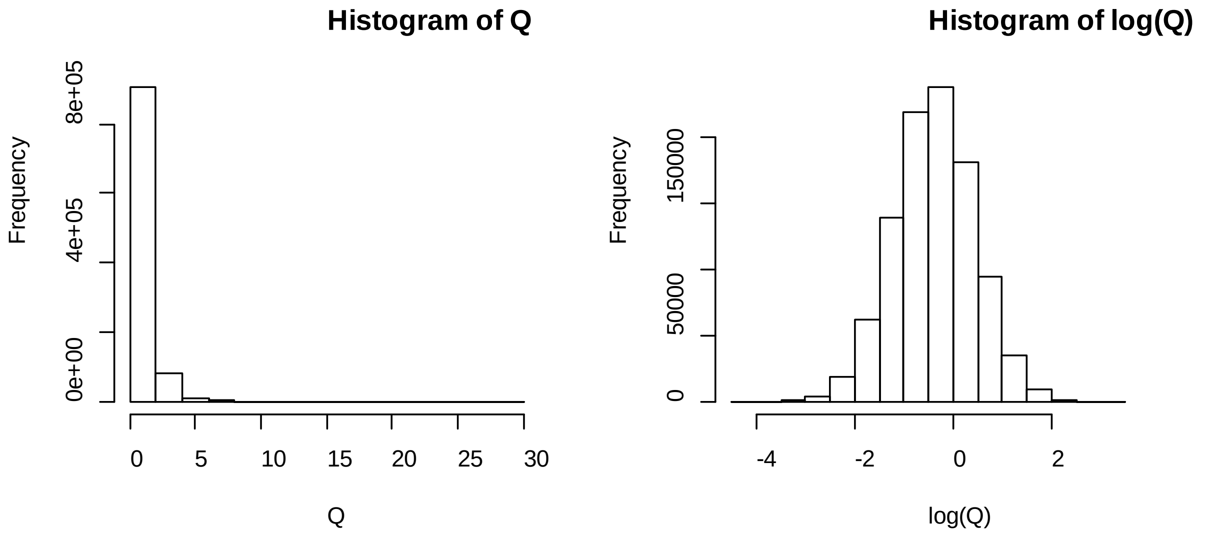


Figure A3. Priors for q and $\log_e(q)$ hull. The random error component is greater than that for towed body.

Appendix B – Re-ageing of Eastern roughy otoliths to test for bias in age reads (J. Upston, K. Krusic Golub & A.E. Punt)

Re- ageing of Eastern Zone orange roughy samples used in the stock assessment was completed by Kyne Krusic Golub (KKG, Fish Ageing Services). Approximately 350 otoliths from each of four years were re-aged: 1992, 1995, 2001, and 2004. Simulations by Punt (pers comm) indicated that a 10% linear bias in age reads could be detected in a sample size of 350.

The otolith samples from each year were selected at random within batches (proxy for vessel) and spread across dates/areas approximately in proportion to sampling, and including the range of ages in the sample. Approximately even numbers of females and males were selected randomly (as per the assessment – separate sex model). J. Upston did the random sample selections from the CSIRO historical data files for the stock assessment (with reference to 2011 version of FAS database), and KKG cross matched the selections with the current FAS database and the otolith slides. The re-ageing was done "blind" i.e. KKG did not have reference to the original ages when re-reading the otoliths, and the ageing methods followed those described by Tracey et al. (2007). For each sample the number of zones from the primordia to the transition zone (TZ) and the number of zones from the TZ to the edge of the otolith was counted and recorded. The final age was the sum of these two counts. The TZ age was also recorded along with readability scores for pre TZ and post TZ counts. For the purpose of this assessment, only the total ages were compared.

The age error program AGEMAT by Punt (2014) was used to model ageing error and bias, to estimate ageing error/bias matrices for each year, which can be incorporated into the stock assessment model. There was no evidence of major bias from the results of the re-reads of the otoliths (QQ plots in Figure B1, noting that the plus age group in the model is 80), and therefore no imperative to include ageing bias in the ageing error matrix for the base-case model. However a minor bias (~1 yr) was evident in the 60-80 age range for some years (e.g. 1995, 2001), and therefore the inclusion of a minor ageing bias (matrix in Table B1) in the model was explored as a sensitivity test. The model estimates of female spawning biomass and depletion were similar to those of the base-case model (a more parsimonious model). The result was as expected given the minor age bias (in the context of the estimated ageing error) and the down-weighting of the age-data in the current assessment (Francis 2011 weighting approach for age compositions).

The results of the re-ageing experiment are included below (Figure B1 and Table B1).

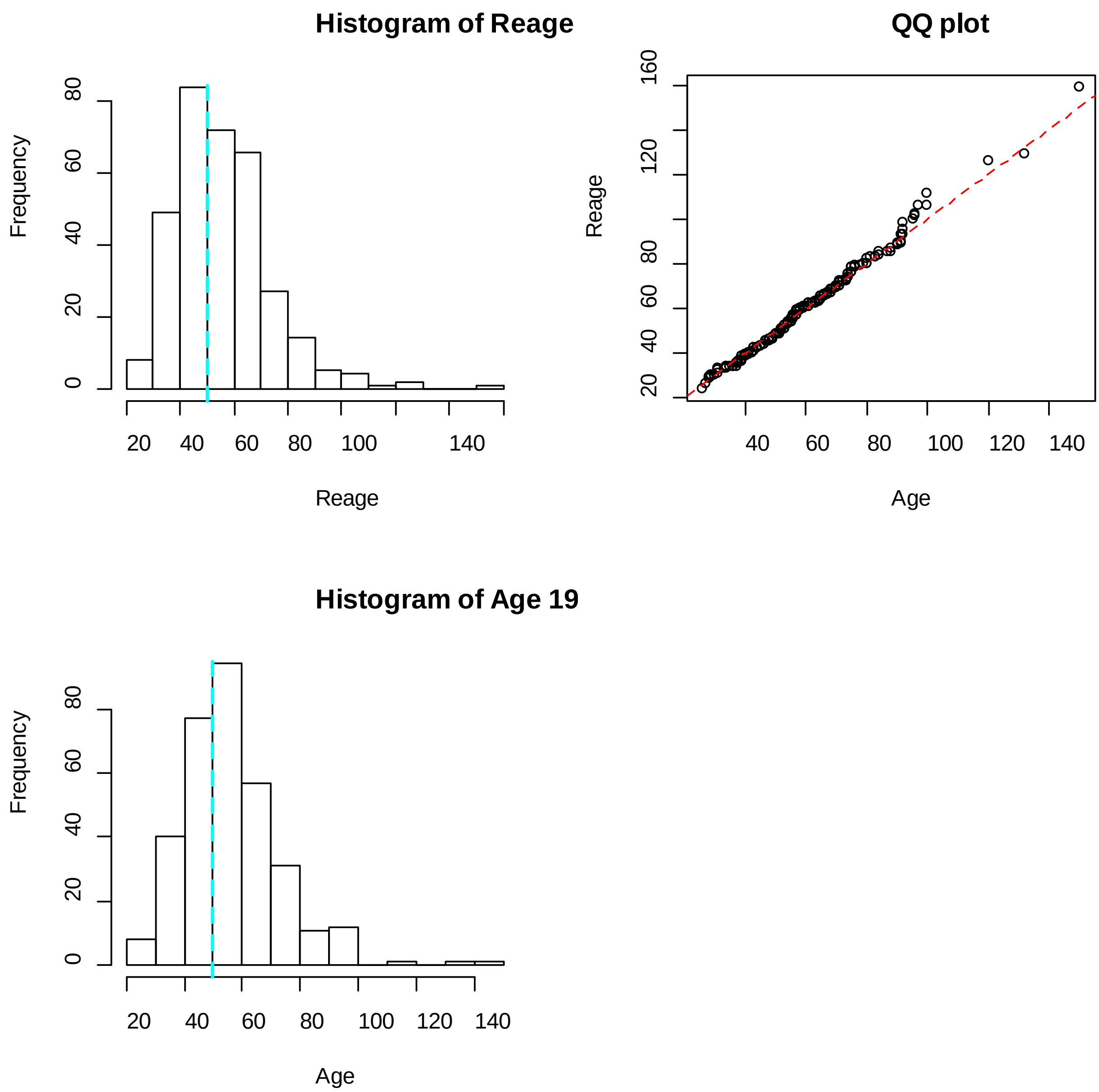


Figure B1. Histograms and QQ plots for re-ageing experiment for 1992; n = 330.

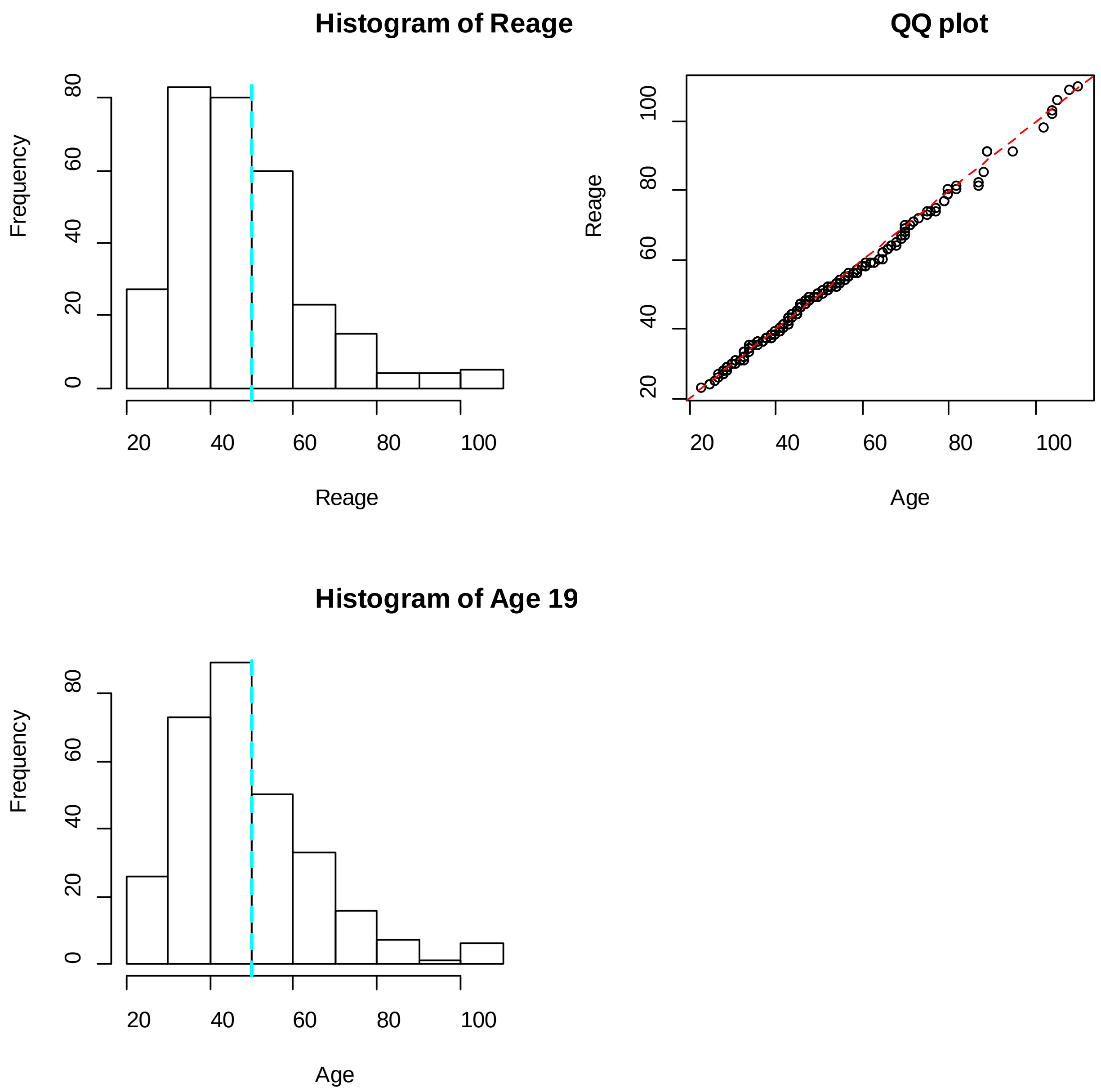


Figure B1. Histograms and QQ plots for re-ageing experiment for 1995; n = 304.

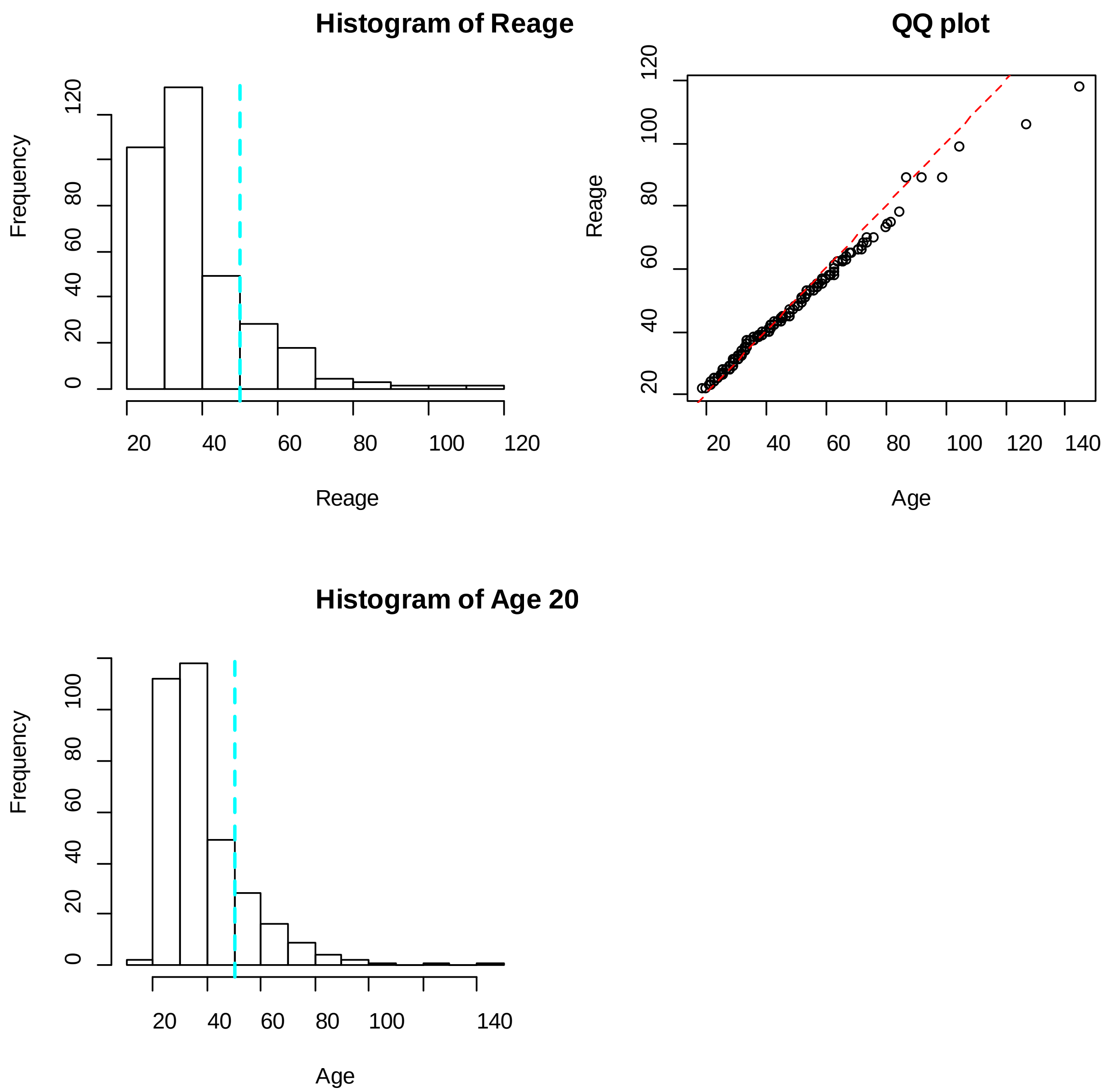


Figure B1. Histograms and QQ plots for re-ageing experiment for 2001; n = 343.

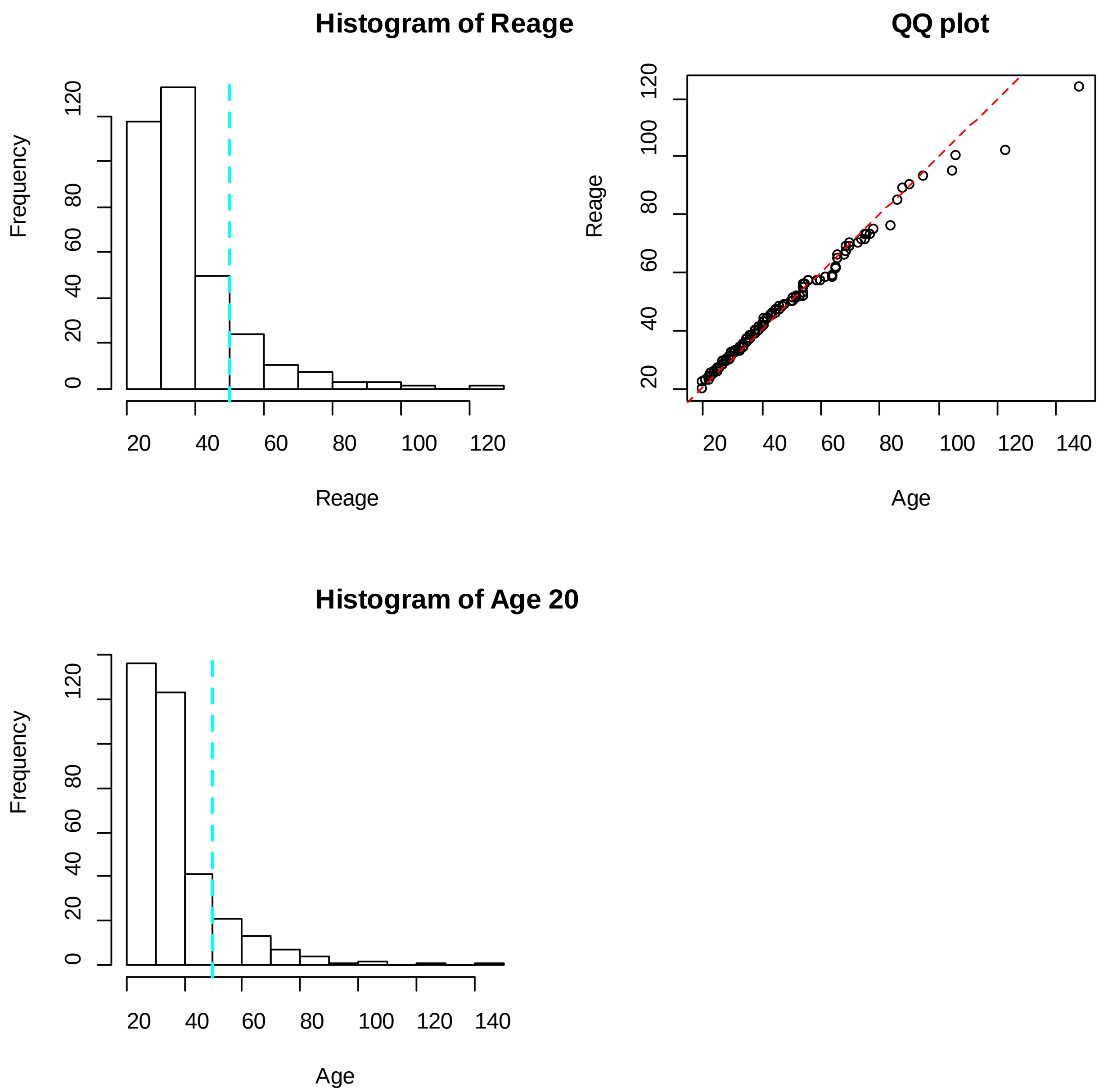


Figure B1. Histograms and QQ plots for re-ageing experiment for 2004; n = 350.

Table B1. Estimated age error and minor age reading bias for “old” age reading method, applied to 1995, 1999, 2001 and 2004 (sensitivity “Minor age reading bias”; note that for 1992 there no evidence of a minor bias (Figure B1), hence it was not included for this analysis). E.g. Expected Age would be 60.5 for Age 60 if the reader was unbiased (ignoring error).

Age	StDev	Expected Age	Age	StDev	Expected Age
1	0.001	0.5	41	3.242	41.4
2	0.173	1.5	42	3.312	42.5
3	0.259	2.5	43	3.383	43.5
4	0.345	3.6	44	3.453	44.5
5	0.430	4.6	45	3.523	45.5
6	0.515	5.6	46	3.592	46.6
7	0.600	6.6	47	3.661	47.6
8	0.684	7.7	48	3.730	48.6
9	0.767	8.7	49	3.798	49.6
10	0.851	9.7	50	3.866	50.7
11	0.934	10.7	51	3.933	51.7
12	1.016	11.8	52	4.000	52.7
13	1.098	12.8	53	4.067	53.7
14	1.180	13.8	54	4.133	54.7
15	1.262	14.8	55	4.199	55.8
16	1.343	15.9	56	4.264	56.8
17	1.423	16.9	57	4.330	57.8
18	1.503	17.9	58	4.394	58.8
19	1.583	18.9	59	4.459	59.9
20	1.663	19.9	60	4.523	60.9
21	1.742	21.0	61	4.586	61.9
22	1.821	22.0	62	4.649	62.9
23	1.899	23.0	63	4.712	64.0
24	1.977	24.0	64	4.774	65.0
25	2.054	25.1	65	4.836	66.0
26	2.131	26.1	66	4.898	67.0
27	2.208	27.1	67	4.959	68.1
28	2.284	28.1	68	5.020	69.1
29	2.360	29.2	69	5.080	70.1
30	2.436	30.2	70	5.140	71.1
31	2.511	31.2	71	5.200	72.2
32	2.586	32.2	72	5.259	73.2
33	2.660	33.3	73	5.318	74.2
34	2.734	34.3	74	5.377	75.2
35	2.808	35.3	75	5.435	76.2
36	2.881	36.3	76	5.493	77.3
37	2.954	37.3	77	5.550	78.3
38	3.027	38.4	78	5.607	79.3
39	3.099	39.4	79	5.663	80.3
40	3.170	40.4	80	5.719	81.4

Appendix C – Eastern Zone orange roughy age samples from winter spawning aggregations

Further details of the historical age samples in the stock assessment – from Eastern spawning aggregations (exception 1999 St Patricks also included non-aggregated fish; Bax 2000 and references therein; Wayte 2007) - were annotated (future work that was identified in Upston & Wayte 2012b). Kloser et al. (2012) list sources for Eastern Zone orange roughy age samples. However these samples were for July only and spawning aggregations were presumed (there was no identifier in the FAS database for an aggregation). The Eastern Zone stock assessment includes historical age samples selected from spawning aggregations in July, and in other months during the spawning season (the data were kept in an historical data base held by CSIRO). Table C1 includes the current state of knowledge on the provenance of the historical age samples used in the stock assessment. It was not possible to directly match the historical age samples to individual shots for the early years; however from the commercial logbook data we were able to derive the total number of possible shots that were sampled for a given date, area of operation and vessel (Table C1).

During the 1999 spawning season, otoliths from orange roughy at St Helens and St Patricks in 'aggregated' and 'backscatter' samples were collected and aged (see Table C1 Comments). According to Kloser et al. (2001) 'aggregation' samples were taken from regions where distinct and large fish marks were seen with the deep towed acoustic body and the resulting catch was large enough (> 1 tonne) to confirm that the mark was sampled. 'Backscatter' samples were taken from diffuse fish marks on areas of flat bottom adjacent to the seamount and canyon, and adjacent deep areas. The age profiles for St Helens orange roughy differed between the 'aggregated' and 'backscatter' samples and only the aggregated age samples were included in the stock assessment (Bax 2000; Figure C1). The age profiles for St Patricks did not differ between the sample types and all of the samples were included in the stock assessment (Bax 2000; Figure C1).

The age data in the stock assessment are assumed to be simple random samples from orange roughy spawning aggregations at St Helens Hill or St Patricks Head, taken from survey shots (surveys utilised commercial vessels) or from commercial fishing operations (Table C1). The assumption of random sampling from shots is broadly consistent with the findings of Kloser et al. 2012 (Figure 4.5 in their report); who found the CAF (now FAS) dataset to be a random sub-set of the CSIRO length dataset for most years (exception 2004, St Patricks females were on average 1 cm smaller in the age sub-set c.f. csiro dataset). For 1992, there was no direct test (the sampling periods differed), although we know that age samples in the early years were taken from unsorted large commercial catches (J. Lyle 2014 pers. comm.), either at port or onboard.

As a gauge of sample coverage (whether the coverage is sufficient for a representative sample), we report the number of vessels, days and shots from which age samples were collected in Table C1. We also report the average KG per shot in July, as a proxy for orange roughy aggregations (catches > ~ 1 tonne) at the time of sampling, although it can only be a broad indicator as it is inferred from logbook records for most years. Regarding sample coverage, there is a tendency to sample ages over fewer days and shots in recent years. Given the potential for large shot-to-shot and day-to-day variability in ages of orange roughy on the spawning grounds (Kloser et al. 2012) it could be important to revise the strategy for future age sampling.

We note that there are age samples, as yet unread, for 2012 and 2013 (sampling was coincident with acoustic surveys), and the 2012 age sample may provide some important insights given that the observed spawning biomass point estimate at St Helens approximately half of the 2010 estimate (Table 5.8). The 2013 age sampling method was different from that for other years – smaller shot weights were sampled, possibly around edges of the spawning aggregation (see Ryan et al. 2014) – thus the 2013 age samples may not be representative of the spawning aggregation or comparable with previous years (e.g. different selectivity of trawl shots), and if so, are therefore unlikely to be useful for stock assessment purposes.

In addition to Table C1, histograms of the Eastern orange roughy raw age frequency data from the historical assessment files (now crossed-referenced with the FAS data), and for 2010, are included below. The graphs were produced using Stata Vers 10.1.

Table C1. Sample coverage and provenance of the age samples used in the Eastern Zone orange roughy stock assessment. All Vessels were commercial fishing vessels, and for select years research surveys (see Comments - "survey" or "commercial fishing"). Key: Area "SH" St Helens Hill; "SP" St Patricks Head. The age data in the latest Fish Ageing Services (FAS) database were available at the shot level for 1999, 2001, and 2010 but catch per shot was not available. The latter data were sourced from reports for 2004 and 2010 and from the logbook data for the other years (see Reference). *from logbook records and based on all possible July shots spanning the sampling period for a given vessel(s) and area. The number of shots for 1992 and 1995 are the total shots from logbooks based on the otolith sample dates (sampling period for 1995). [L] The minimum for SH 1999 is an under-estimate as the age samples are only from the fish aggregations that were identified during the survey. [SP?] Possibly includes samples from St Patricks. A note that the 1987 Eastern Zone age samples were from non-aggregated fish and are not included in the assessment (Bax 2000).

Year, sampling period	Area	JulyAvKG.shot^{-1}	Vessels	Days	Shots	FAS Batch no.	Comments	Reference
1992 21 June to 06 July	SH	25750* (25,000 - 26,500)	3	5	21*	91, 92, 94, 95, 98	commercial fishing	Anon (1995) cited in Smith et al (1998); Bax (2000); no shot info in FAS dbase
1995 06 to 13 July	SH (& SP?)	7459* (775 - 20,000)	5	15	55*	24[SP?],26[SP?],27,28,30,31	commercial fishing logbooks indicate also SP area?	Smith et al (1998); Bax (2000); Fig C1 this report no shot info in FAS dbase
1999 11 to 26 July	SH	4490* (10[L] - 36,000)	1	4	5	78, 82, 83, 85	survey; incl. only aggreg. fish	Kloser et al (2001) see Fig. 3.1; Bax 2000; shot info in FAS database
1999 09 July to 10 Aug	SP	9483* (5 - 55,000)	1	7	10	77, 80, 81, 84, 86, 88, 89	survey; incl. aggreg. & non-aggreg. fish	as above for 1999
2001 05 July to 02 Aug	SH	2873* (50 - 7,000)	2	11	22	115	commercial fishing	Kloser et al (2001) see Fig. 8.8; shot info in FAS database
2001 06 to 29 July	SP	5260* (301 - 26,500)	2	15	26	114	commercial fishing	as above for 2001
2004 19 to 22 July	SH	4,750 1,500 - 7,000)	1	4	6	166	industry survey; assume age sample was random across shots	Diver (2004) Tables 2 & 5 no shot info in FAS dbase
2004 20 to 23 July	SP	12,333 (4,000 - 28,000)	1	3	3	167	industry survey; assume age sample was random across shots	as above for 2004
2010 15 to 22 July	SH	7,677 (60 - 14,000)	1	5	6	233, 234, 238, 239, 242 to 247 inclusive	survey; revised 2010 data	Kloser et al (2011) Table A-2 shot info in FAS database
2010 17 to 22 July	SP	1,500 (1,500 - 1,500)	1	2	2	231, 232, 235, 236, 237, 240, 241	survey; revised 2010 data	as above for 2010

Figure C1 Histograms of raw age frequency data (prior to weighting) in the assessment model for historical years – 1992 to 2004 inclusive - and for 2010.

Figure C1 continued – raw age frequencies

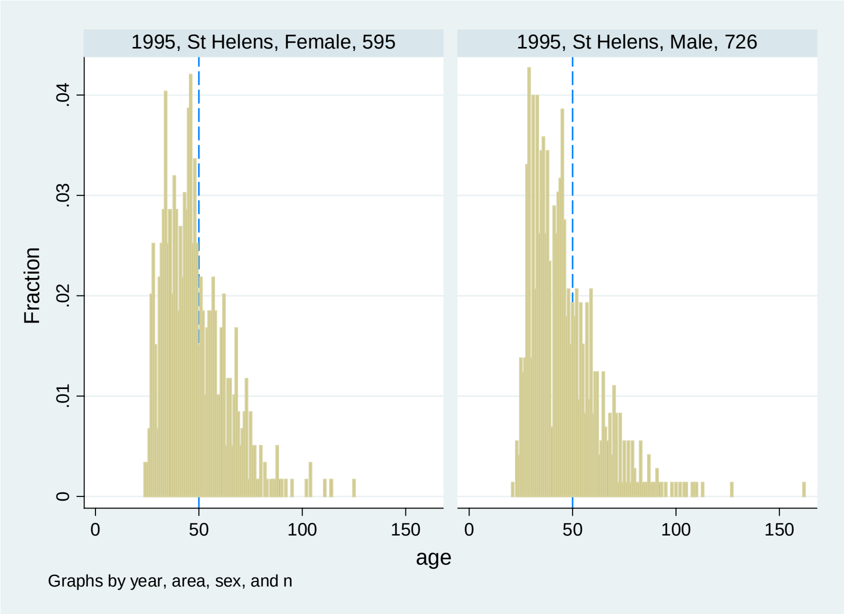
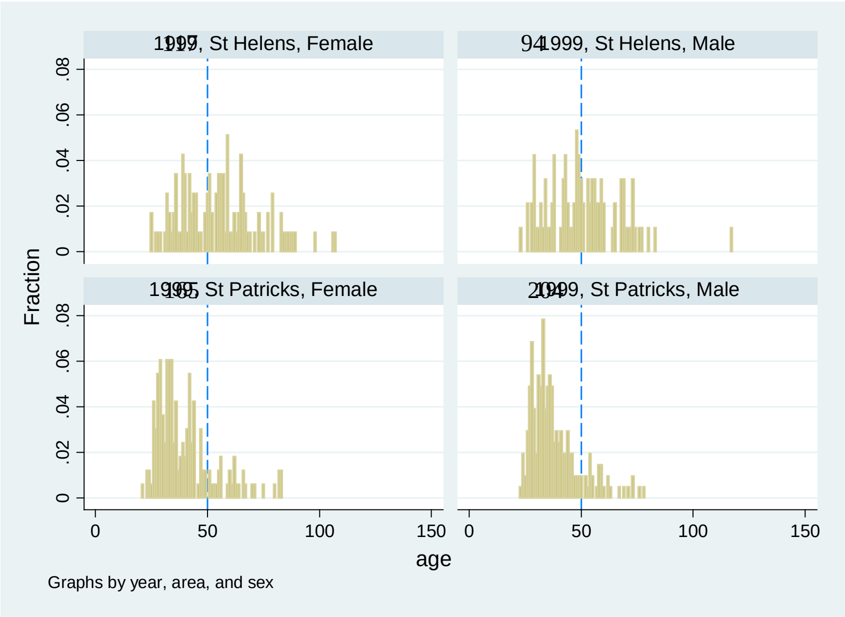
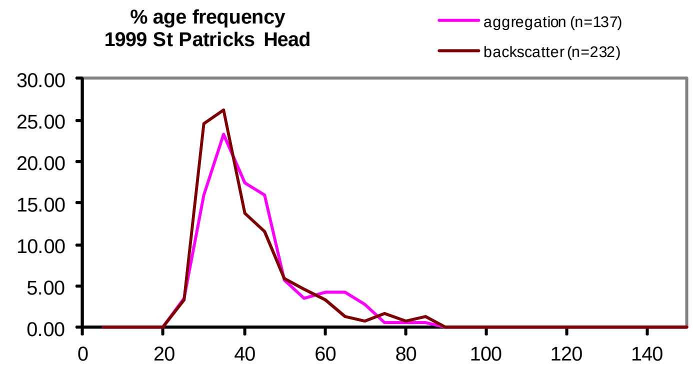


Figure bottom panel 1995 - age frequency by area from logbook records (derived from the latitude). The age frequencies for logbook areas are broadly similar, therefore a 'combined' distribution without weighting by area (top panel - historically denoted as St Helens area) seems appropriate. However, if it is necessary to follow-up further then the area for age samples would need to be verified with reference to the original raw data sheets (not held by CSIRO; see Table C1), given that both Bax (2000) and Wayte & Bax (2002) refer to the 1995 age samples as from St Helens spawning aggregations and the historical CAF data (held by FAS) lists the samples as East Coast - St Helens, Tasmania area. Note - the difference in total sample sizes for the top and bottom plots is explained by the former samples being sourced from historical files and the latter from the recent FAS database, which seems to be missing some of the age samples. This was not considered an issue as the age frequencies derived from the different sources were similar (investigated by J. Upston).

Figure C1 continued – raw age frequencies





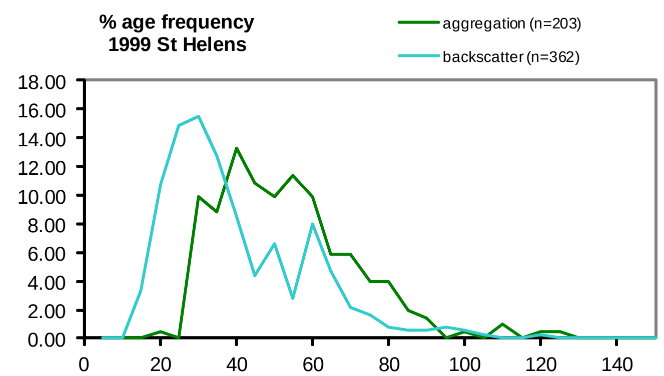


Figure bottom panels 1999 - Bax (2000) Figure 6 adapted. The plots show similar age frequency distributions for 'aggregation' and 'backscatter' samples for St Patricks in 1999, and different age frequency distributions for corresponding samples from St Helens. Hence the rationale, in addition to presumably boosting the otherwise low sample size, for historically including St Patricks 'backscatter' age samples in the stock assessment (which has a focus on spawning aggregations).

Figure C1 continued – raw age frequencies

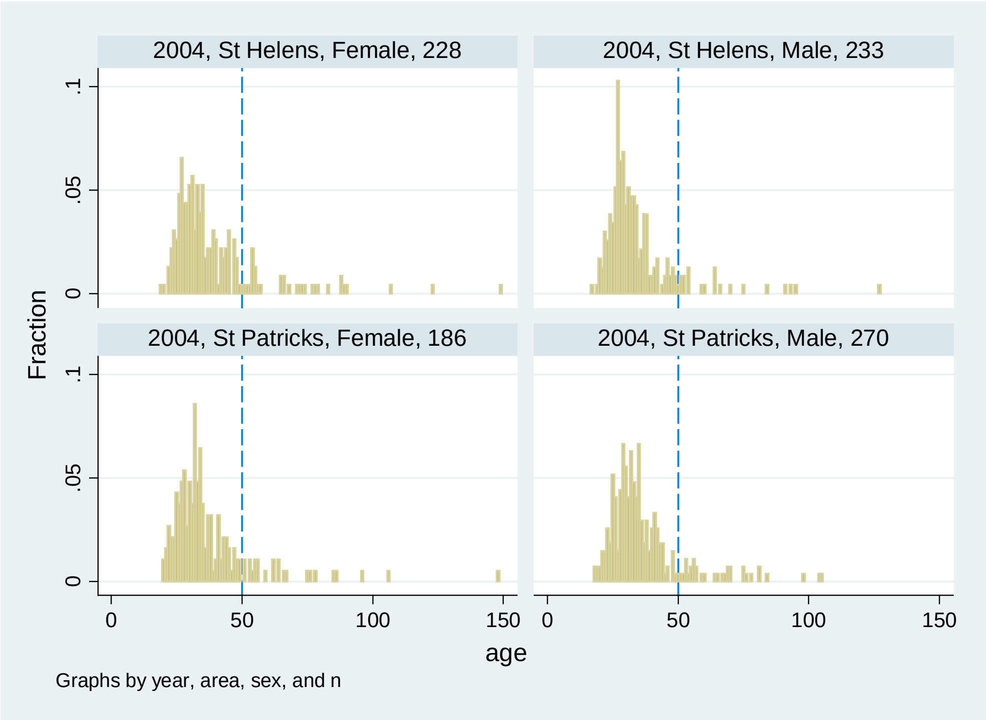
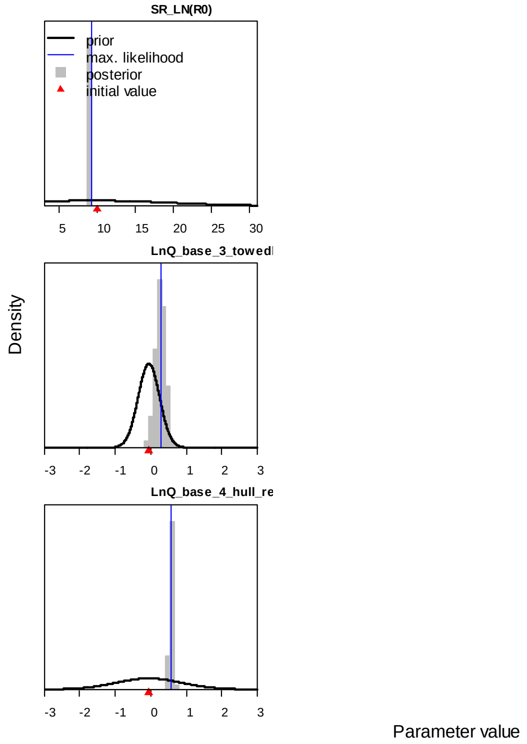


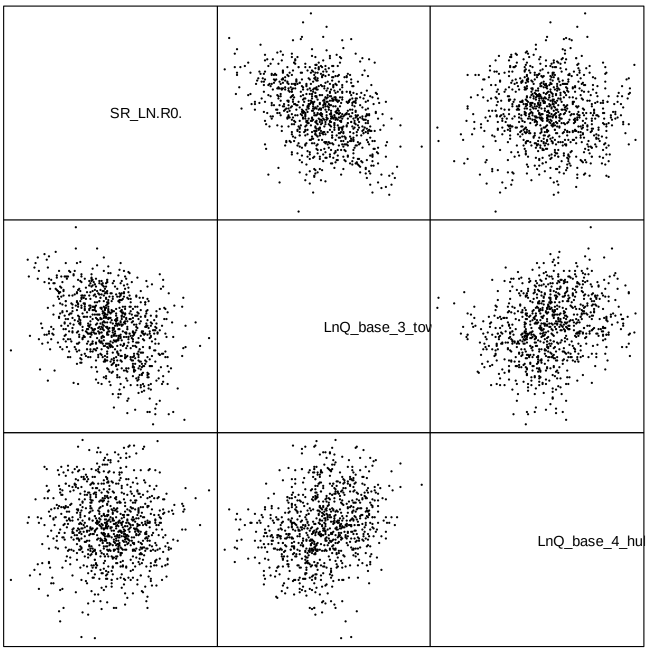
Figure C1 continued – raw age frequencies

Appendix D – MCMC Diagnostics for Final Base-case Model 0

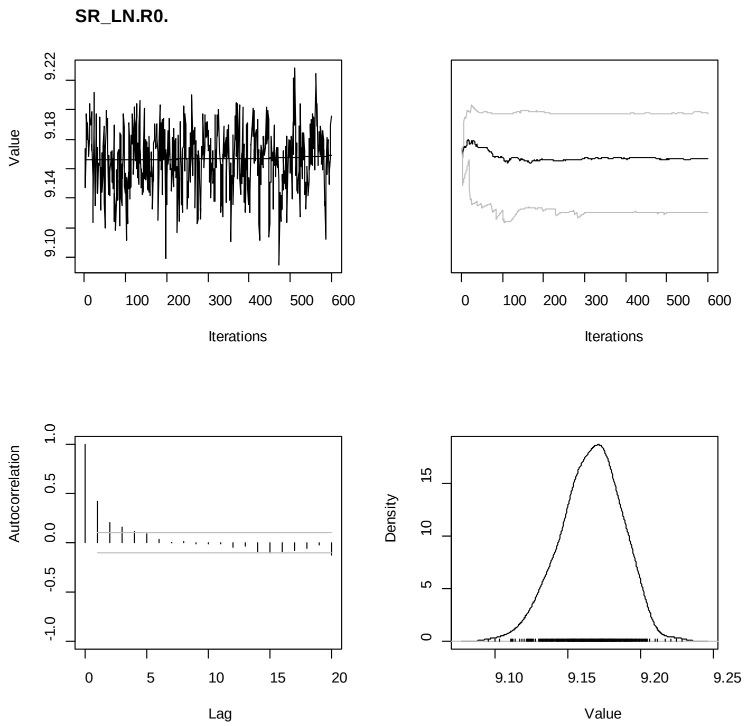
The diagnostic plots from the MCMC simulations for the Final Base-case Model 0 -24 million cycles, a 40,000 thinning interval, and omitting the first sample in the chain - are included below. Note that the final MCMC sample did not pass the convergence statistics (Geweke statistic and the Heidelberger and Welch test). With a heavy thinning interval the sample size was only 599, so there was less power to detect violations of convergence, however the trace plots suggested that the model was near convergence.

(a) Plot of prior and posterior distributions (b) Pairwise correlation plot for main parameters

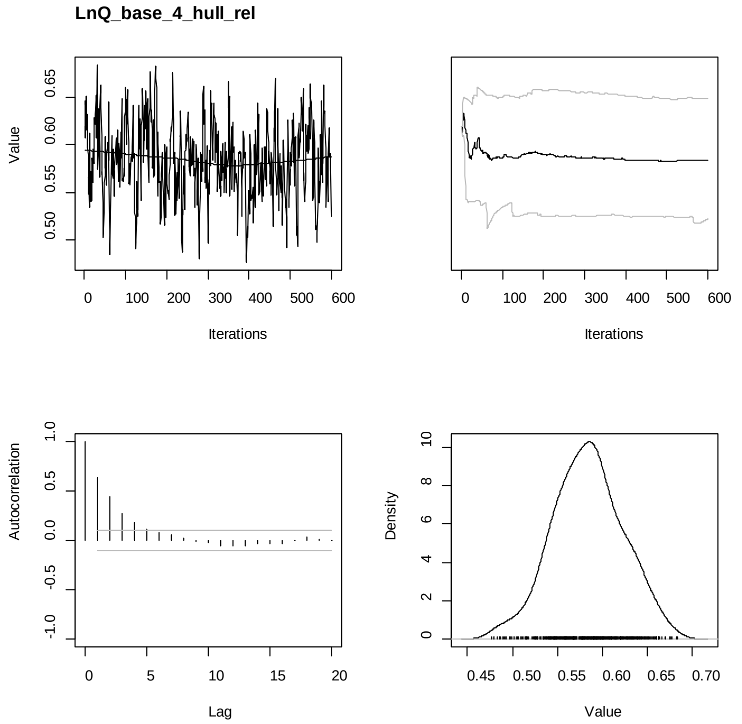


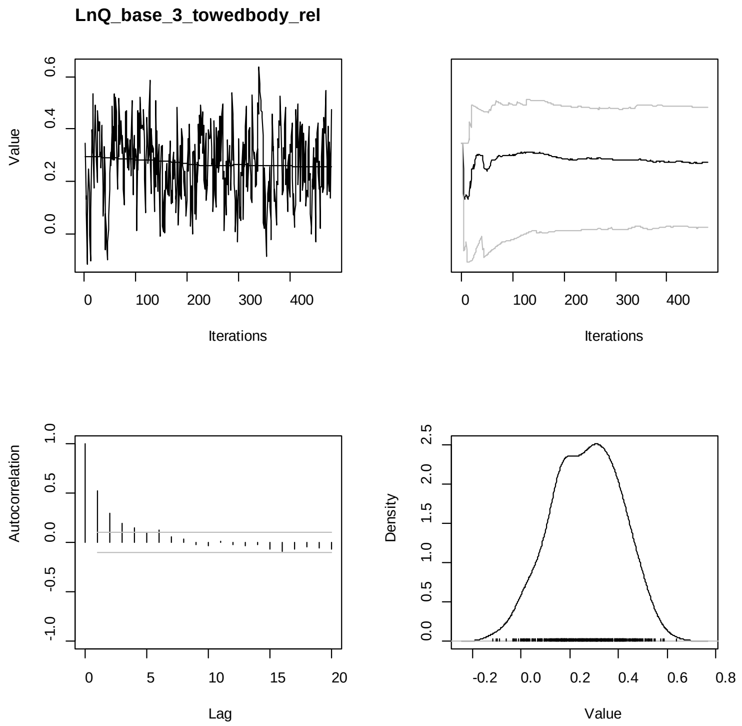


(c) Four panel plot for unexploited recruitment (SR_LN(R0)): trace plot and moving average (top panel), autocorrelation plot (bottom panel – left), and probability density plot for parameter (a check for approximate multivariate normal shape; bottom panel - right)



d) Four panel plot for the log of the catchability parameter, *q*, for acoustic hull and towed body surveys : trace plot and moving average (top panel), autocorrelation plot (bottom panel – left), and probability density plot for parameter (a check for approximate multivariate normal shape; bottom panel - right)





6. Development of a base-case Tier 1 assessment of redfish *Centroberyx affinis* based on data up to 2013

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6.1 Summary

This paper presents the data and results from a preliminary assessment developed to assist the establishment of a 2014 base-case assessment of eastern redfish *Centroberyx affinis* in the Southern and Eastern Scalefish and Shark Fishery (SESSF). For the first time, the assessment uses an age- and size-structured model implemented in the generalized stock assessment software package, Stock Synthesis (SS). The assessment includes data up to the end of the 2013 calendar year. Data include annual landings, catch rates, discard rates, and length/age compositions. The main purpose of this document is to initiate discussion regarding the data to be used and the assumptions to be included in the base-case model structure. This is especially pertinent to the catch time-series, and assumptions regarding discard rates and discarding behaviour.

Tentative results from the preliminary assessment conclude that the redfish spawning biomass in 2014 is considerably less than the unexploited spawning stock biomass. However, at this point, focus should be on obtaining an agreed set of data and model structures for the base-case model, which currently has many strong and influential assumptions, especially about early catches and discard rates.

6.2 Introduction

An integrated analysis model, implemented in the generalized stock assessment software package, Stock Synthesis (SS) (Methot, 2011; Methot and Wetzel, 2013. V3.24f), was applied to the eastern redfish stock of the SESSF, with data from 1975 to the 2013 calendar year (length and age data; age-error, catch rate series; landings and discard rates). The model fits directly to length frequencies (by sex where possible) and conditional age-at-length data.

Previous assessment models for eastern redfish are those of Chesson (1995), Thomson (2002) and Klaer (2005). The first comprehensive assessment of redfish was carried out in 1993 (Chesson, 1995). This assessment concluded that stock biomass was low in the late 1980s (less than 20% of that in 1969) but increases in catch and CPUE from 1990 to 1993, especially of small fish, suggested an increase in recruitment. A yield per recruit analysis based on growth and mortality rates indicated that better yields and value could be obtained if fish were caught at a greater size and age (Redfish FAR, 2002). No further comprehensive assessments of redfish were undertaken until April 1997 when a workshop (Rowling, 1997) was held in Cronulla to discuss the research findings for redfish which had accumulated since 1993. This led to the formation of the Redfish Assessment Group (RAG) in November 1997. The RAG was charged with developing an authoritative stock assessment for redfish, which first required the development of acceptable data sets to describe the true catch level and size composition throughout the history of the fishery (to account for the significant discarding which had always been a characteristic of this fishery) (Redfish FAR, 2002).

Thomson (2002) used an integrated assessment (ADMB) to assess stock status of redfish using data up 2001. The model of Thomson (2002) showed a considerable decline in stock biomass for both northern and southern regions (~25% of initial biomass in 2001). However, there were concerns regarding fits to catch at length data; namely a consistent tendency to over-estimate the proportion of large fishes in the catches since 1995 and to under-estimate them prior to 1995. Klaer (2005) focussed on the effect of changes in mesh selectivity on the future stock status of redfish, using the assessment platform Coleraine (Hilborn et al. 2000). Klaer (2005) largely used the biological parameters, catch and discard rate information provided by Thomson (2002), with updates of recent catch rate, catch and discard estimates to 2004. Results for the northern and southern regions, under the nominated base-case parameter set, showed stock status of less than 20% of initial biomass.

This paper presents the first assessment for redfish to be implemented using SS. The use of SS allows the implementation of a model very similar to that used in previous assessments, but additionally presents an opportunity to improve the estimation of length-based selectivity. SS can be fitted simultaneously to several data sources and types of information available for redfish. The population dynamics model, and the statistical approach used in the fitting of the model to the various types of data, is outlined fully in the SS user manual (Methot, 2005; 2011) and is not reproduced here.

6.3 The fishery

The history of the redfish fishery is well documented in previous reports (eg Rowling 1999; Wise and Thomson, 2002). Redfish (also known as nannygai) occur throughout southern Australia and in New Zealand (Rowling, 1994). It is well established that redfish are a slow growing species which may live more than 35 years (Kalish, 1995; Wise and Thomson, 2002). Tagging studies (Rowling, 1990) suggested a single unit stock of redfish off NSW, however studies of mean length at age suggest differences in growth rates between the ‘northern’ and ‘southern’ sectors of the fishery off eastern Australia (Morison and Rowling, 2001). The redfish assessments of Thomson (2002) and Klaer (2005) have assumed that the fishery exploits two separate populations, with the boundary between these ‘stocks’ being 36ºS (just north of Montague Island). The assessments presented in this paper also assume northern and southern stocks, split at 36ºS.

The 2002 redfish fishery assessment report (Redfish FAR, 2002) states that the breeding biology of redfish remains poorly documented. They are reported to mature between five and seven years of age, with spawning thought to occur on continental shelf grounds in late summer and autumn throughout much of the range of the species. Juveniles commonly occur in the larger coastal bays and nearshore reefs, while adults have historically been more abundant in deeper continental shelf and upper slope waters.

The following text is taken from Wise and Thomson (2002) and provides a brief summary of the fishery to 2002.

> The earliest catches of redfish were made by the steam trawler fleet which began operating in 1915, however most redfish were discarded at sea as these boats principally targeted tiger flathead (Houston 1955). Expansion of the steam trawl fishery continued until 1929. The late 1950s and early 1960s were characterised by small, incidental redfish catches as steam trawlers were displaced by Danish seiners as the main units in the fishery. During the 1960s the Danish seine fleet began converting to otter trawling. Modern diesel powered trawlers were predominant in many ports by the mid 1970s, and Danish seiners had all but disappeared from the fishery by the early 1980’s. During the 1970s trawling extended to the upper continental slope (to depths of 600 m), mainly targeting gemfish (*Rexea solandri*). Large incidental catches of redfish were taken on upper slope grounds while targeting gemfish. These fish were generally larger than those taken on continental shelf grounds and had a higher market acceptance.

> Some large targeted catches of redfish were taken by fishers returning from unsuccessful gemfish targeting, and in the periods either side of the main gemfish catching season. However, a very significant proportion of the redfish catch continued to be discarded at sea due to oversupply of the market. Redfish consignments to the Sydney Fish Markets increased to 2400 t in 1980 as effort levels increased and markets gradually improved. Landings fluctuated between 1500 t and 2000 t per year until 1985. Despite continuing high effort levels, recorded landings of redfish declined to less than 1000 t in 1989. Landings increased again in the early 1990s reaching a peak of just over 2000 t in 1993.
>
> Individual transferable quotas (ITQs) were introduced in 1992 with the total allowable catch (TAC) for redfish of 600 t reflecting concern over the decline in catches in the late 1980s and the indications from early stock assessments (Rowling, 1993). However, the implementation of quota management coincided with a substantial increase in the availability of redfish, which resulted in calls for the TAC to be increased. Enforcement of the TAC was compromised as some redfish caught in Commonwealth waters were reported as coming from State waters to avoid being counted against quota (in fact in 1993 when the TAC was 600 t the actual landings of redfish were around 2000 t). In recognition of the increased availability of redfish, the TAC was increased to 1000 t in 1994 and to 1700 t in 1995. The "state waters" loophole was reduced in 1994 with the imposition by NSW of a 100 kg trip limit for redfish caught in waters south of Barranjoey Point.
>
> Discarding and high-grading have been features of the fishery for redfish since its inception. The rate of discarding is known to have varied over time but only since 1993 have actual data been available from observers participating in Scientific Monitoring Programs and the NSW Bycatch Study (Liggins, 1996). Between 1993 and 1995 overall discard rates were estimated to be around 50% by weight, but this rate declined to less than 10% during 1997.

Discard practices seem also to be influenced by the availability of surimi markets, with discarding generally lower during the periods the processors operated. Discard rates may have been as high as 80% in some years, but unfortunately no estimates of the quantities, size or age composition of the discarded fish exist prior to 1993 (Rowling, 1999). As stated by Hall (2001), the lack of these data will result in considerable imprecision in estimates of the pristine biomass prior to 1993.

Rowling (1999) documents historical estimates of discard rates and catches since 1960. Rowling (1999; Appendix 2) also describes the factors considered when determining the rate of discarding and the size composition of the catch. These factors were used to determine periods of operational change that influenced discarding practices when structuring the current SS assessment's retention function. Thomson (2002) provides updated catch and discard values for the northern and southern regions, as determined and agreed by the redfish RAG and more precisely in recent years from AFMA data. Discard rates prior to 1998 (north) and 1992 (south) are those estimated by the RAG and after these dates from ISMP observer data. Catch, discard, catch rate and length/age composition data have all been updated to the end of 2013 in this assessment. These data are described in the sections that follow.

Several authors have expressed concerns regarding growth over-fishing of redfish (Rowling, 1999, 2001; Wise, 2002; Knuckey, 2010). As stated by Knuckey (2010) "If we track the biomass of a cohort of fish as they grow, we find that it reaches a maximum at a certain age when the improved yield from growth is matched by the reduced yield from mortality. Growth overfishing occurs when large numbers of small fish are taken at a size or age before this maximum is reached". Knuckey finds that growth overfishing of redfish is occurring in the trawl fishery using current codend configurations. Analyses showed that the optimum yield per recruit is obtained when redfish are between 18 to 22 cm fork length. Due to the selectivity of standard 90mm diamond codends (50% selectivity at ~13cm), a large proportion of redfish are captured below the size of optimum yield.

6.4 Data

The data inputs to the assessment come from multiple sources: length and age-at-length data from the trawl fishery, updated cpue series (Sporcic and Haddon, 2014), the annual total mass landed and discard rates, and age-reading error. Data were formulated by calendar year (i.e. 1 Jan to 31 Dec) and data sources were split at 36˚S (and east of 147˚E) to delineate the northern and southern regions.

6.4.1 *Catch and discard rates*

The catch tonnage for redfish has been estimated in the past based on a combination of sources, including Sydney Fish Market (SFM) data (to 1986), NSW and Victorian landings and the SEF logbook data (Table 28 of Rowling (1994); Appendix 1 of Rowling (1999); Table 1 of Thomson (2002); Table 1 of Klaer (2005)). The estimated annual tonnages of landings, discard rates and cpue are provided in Table 6.1. The landings from the SEF1 logbook data (over years available) were used to apportion catches to the northern and southern regions (Table 6.2). These proportions were then applied to the landings (CDRs) for the corresponding year to give the total tonnage caught in each region. For years in which the logbook was greater than the landings, the logbook data were used (1992-1994). For years in which there were no CDRs but logbook data did exist, the average of years 1992 to 1996 was used for the ratio of landings to logbook catches.

State data exist for years 1984 to 2012 for NSW and 1978 to 2005 for Vic (zero catch from 2006 in Victoria). For NSW, it appears that the state data have been recorded in the logbook until perhaps 1997 (Figure 6.1). Therefore, for the northern region, state data were only added into the Commonwealth catch after 1997 (Table 6.2).

Discard rates prior to 1998 in the north and 1992 in the south are those estimated by the redfish RAG (Thomson, 2002). Discard rates after these dates were estimated from on-board data which gives the weight of the retained and discarded component of those shots that were monitored (Thomson and Klaer, 2011). Rowling (1999) provides considerable detail on how the historical discard rates were estimated and the factors that influenced discard practices. Redfish discarding was discussed at a redfish workshop held in Cronulla in April 1997 and at various open redfish assessment group meetings during late 1997 and early 1998. The resulting discard rates are documented in Rowling (1999) and also listed in the last redfish assessment group (Thomson, 2002) and Shelf RAG (Klaer, 2005) assessments of redfish. Here we update the discard estimates by the addition of on-board estimates through to 2013 (Table 6.1).

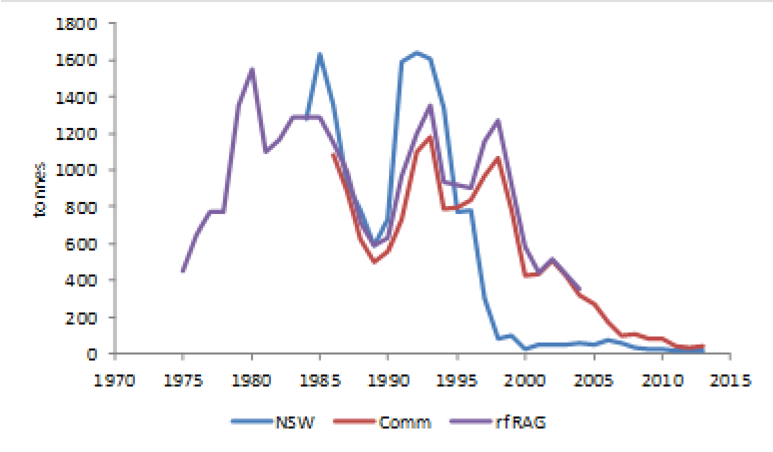

Figure 6.1.The time series of catches for the north from NSW, Commonwealth and that estimated by the various redfish assessment groups (rf RAG) and supplemented by AFMA data (Klaer, 2005).

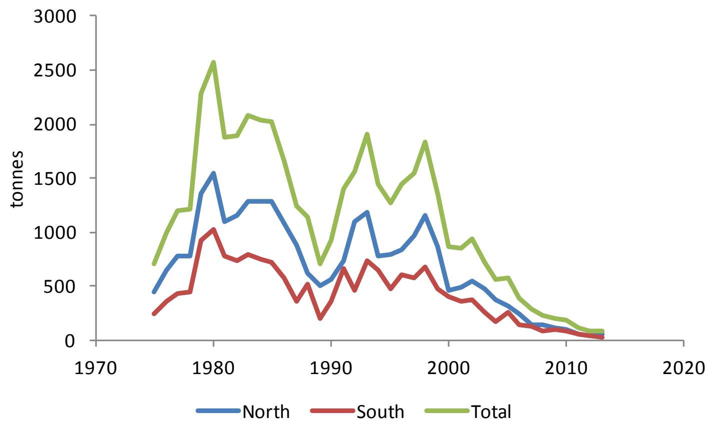

Figure 6.2 The annual catch series (tonnes) for the northern and southern redfish regions and the combined total catch.

The SS assessment model allows an estimation of the probably of retention (which is 1 – P(discard)) as a function of length in order to estimate the annual discard rate and any information on discard length composition. It is apparent that the redfish fishery has undergone numerous changes that may have influenced the behaviour of discarding; these changes are documented in Rowling (1999; Appendix 2). In consultation with K. Rowling (pers. comm.), the following discarding periods have been identified:

1975 – 1985. Market driven discarding

1975 – 1985. Discards largely across all size ranges, but with more small fish discarded

1986 – 2000. Surimi markets period

1986 – 1992. Surimi market. Discarding rates lower, mainly small fish.

1993 – 1995. Quantity of fish sent to surimi market declined, Geelong surimi market closes; consequent increase in discarding.

1996 – 2000. Discarding declined ‘as redfish became less available’. Close of Hacker surimi processor in 2000.

2001 – 2013. Size based discarding period

2001 – 2013. Assume mostly small fish discarded

These changes in discarding behaviour have influenced the large variations in discard rates observed (Table 6.1), as well as the catches, catch rates and discard length composition. The model retention function has been allowed to vary according to each of these identified discard periods.

6.4.2 *Catch rates*

Sporcic and Haddon (2014) provides the updated catch rate series for redfish (Table 6.1; Figure 6.3). After substantial increases in catch rate in the early and late 1990s, the catch rate has continued to decline since then, and is now less than 15% of levels in 1986. The most recent year in the series has shown a small increase, which may correspond to the apparent large influx of young fish noticeable in the 2013 age data.

Note that since 2010, the redfish Tier 4 assessment, which is based upon catch rates, has used a split reference period, covering the years 1986 to 1990 and 1999 to 2003. The intervening period is not considered representative of the fishery because it involved large trawlers catching large quantities of redfish for surimi markets.

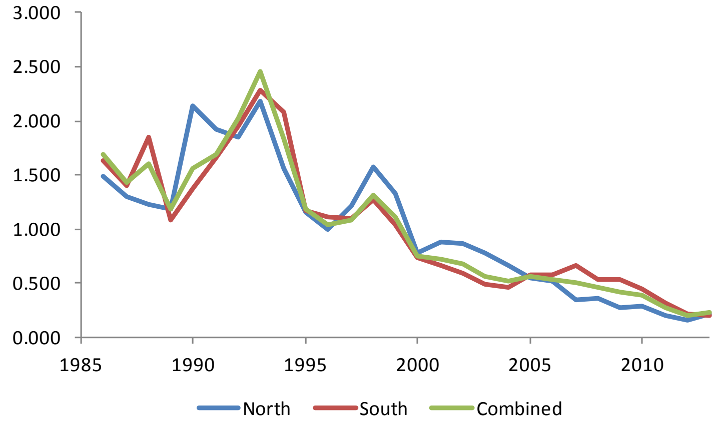

Figure 6.3. The annual catch rate series for the northern and southern redfish regions and the combined region.

Table 6.1. Estimated landings, discard rates and cpue (Sporcic and Haddon, 2014) for the northern and southern redfish regions by calendar year.

Year	Landings		Discard Rates		CPUE	
	North	South	North	South	North	South
1975	452	249	0.4	0.4		
1976	645	355	0.4	0.4		
1977	774	426	0.4	0.4		
1978	774	446	0.4	0.4		
1979	1355	920	0.4	0.4		
1980	1548	1030	0.3	0.3		
1981	1097	787	0.2	0.2		
1982	1161	731	0.2	0.2		
1983	1290	794	0.2	0.2		
1984	1290	750	0.2	0.2		
1985	1290	727	0.2	0.2		
1986	1079	584	0.2	0.2	1.495	1.638
1987	885	360	0.1	0.2	1.293	1.407
1988	624	521	0.1	0.2	1.231	1.854
1989	499	205	0.1	0.2	1.186	1.079
1990	560	364	0.1	0.1	2.141	1.371
1991	732	662	0.1	0.1	1.921	1.656
1992	1096	466	0.1	0.1	1.846	1.945
1993	1179	730	0.14	0.580	2.177	2.283
1994	785	657	0.44	0.540	1.561	2.080
1995	795	473	0.40	0.758	1.159	1.174
1996	839	606	0.25	0.279	0.994	1.114
1997	969	576	0.02	0.062	1.206	1.091
1998	1150	685	0.054	0.432	1.581	1.266
1999	872	480	0.001	0.101	1.330	1.039
2000	457	406	0.030	0.212	0.780	0.730
2001	490	357	0.233	0.539	0.876	0.668
2002	553	378	0.483	0.684	0.869	0.592
2003	472	254	0.242	0.440	0.780	0.486
2004	378	178	0.448	0.291	0.667	0.459
2005	320	259	0.221	0.216	0.554	0.579
2006	248	149	0.012	0.059	0.516	0.575
2007	151	133	0.405		0.341	0.658
2008	138	93	0.034		0.358	0.538
2009	109	98	0.198	0.496	0.271	0.540
2010	102	86	0.198	0.041	0.283	0.450
2011	55	61	0.179	0.123	0.205	0.312
2012	47	39	0.086	0.023	0.164	0.213
2013	52	28	0.224	0.282	0.215	0.204

Table 6.2. Logbook and CDR landings for the northern and southern redfish regions by calendar year and adjustments made to account for logbooks being less than landings and State data. Shaded values for the North explain the origin of values used in the catch series for the assessment. [1] estimated value taken as the tonnage from 2012.

Year	Logbook		CDR	Multiplier	Adjusted Comm Catch		State Catch		RAG agreed values (<2005)		Catch for assessment	
	North	South		CDR/Log bk	North	South	NSW	Vic	North	South	North	South
1975									452	249	452	249
1976									645	355	645	355
1977									774	426	774	426
1978								20	774	426	774	446
1979								175	1355	745	1355	920
1980								178	1548	852	1548	1030
1981								184	1097	603	1097	787
1982								92	1161	639	1161	731
1983								84	1290	710	1290	794
1984							1277	40	1290	710	1290	750
1985	90	39		1.019	91	40	1628	17	1290	710	1290	727
1986	1059	568		1.019	1079	578	1350	6	1145	555	1079	584
1987	869	346		1.019	885	352	923	8	993	407	885	360
1988	612	485		1.019	624	494	779	26	713	487	624	521
1989	490	194		1.019	499	198	589	7	589	211	499	205
1990	550	354		1.019	560	360	728	4	631	369	560	364
1991	719	629		1.019	732	640	1592	22	970	630	732	662
1992	1096	463	829	1.000	1096	463	1636	2	1193	607	1096	466
1993	1179	705	538	1.000	1179	705	1606	25	1351	749	1179	730
1994	785	645	699	1.000	785	645	1332	12	938	662	785	657
1995	783	445	1246	1.014	795	451	767	22	921	479	795	473
1996	774	551	1436	1.084	839	597	776	8	903	597	839	606
1997	864	513	1544	1.120	969	575	304	<1	1155	581	969	576
1998	939	603	1752	1.136	1067	685	83	<1	1266	638	1150	685
1999	684	422	1258	1.137	778	480	95	<1	920	486	872	480
2000	385	364	836	1.117	430	406	27	<1	582	253	457	406
2001	403	329	795	1.085	438	357	52	<1	440	354	490	357
2002	457	341	885	1.109	507	378	47	<1	520	360	553	378
2003	364	218	678	1.165	424	254	49	<1	436	241	472	254
2004	297	165	498	1.079	320	178	58	<1	352	186	378	178
2005	241	229	532	1.134	273	259	47	<1			320	259
2006	166	145	321	1.033	172	149	76				248	149
2007	89	123	230	1.087	97	133	54				151	133
2008	98	84	201	1.103	108	93	29				138	93
2009	73	86	182	1.149	84	98	25				109	98
2010	73	78	166	1.098	80	86	22				102	86

2011	33	52	99	1.156	38	61	16	55	61
2012	30	34	73	1.139	34	39	14	47	39
2013	36	26	66	1.078	39	28	14[1]	52	28

6.4.3 *Length frequencies and age data*

Length and age data have been included in the model as length frequency data and conditional age-at-length data by year and sex (when available). Age composition data is included in diagnostic plots but is not used directly within the fitting procedure. Catch length frequency data were obtained from NSW records of fish measured at the Sydney Fish Markets to 1998 in the north and 1991 in the south. After these dates length frequencies were obtained from ISMP on-board measurements. Figures of the observed length and age data are shown in later figures with the corresponding model predicted values.

6.4.4 *Age-reading error*

Standard deviations for aging error by reader have been estimated, producing the age-reading error matrix of Table 6.4 (A.E. Punt, pers. comm.).

Table 6.3.The standard deviation of age reading error.

Age	St Dev	Age	St Dev
0	0.167	20	0.98
1	0.167	21	1.00
2	0.237	22	1.02
3	0.304	23	1.04
4	0.366	24	1.06
5	0.424	25	1.07
6	0.479	26	1.09
7	0.531	27	1.10
8	0.579	28	1.12
9	0.625	29	1.13
10	0.668	30	1.14
11	0.708	31	1.15
12	0.746	32	1.17
13	0.781	33	1.18
14	0.815	34	1.19
15	0.846	35	1.19
16	0.876	36	1.20
17	0.903	37	1.21
18	0.930	38	1.22
19	0.954	39	1.23
		40	1.23

6.4.5 *Fishery independent survey (FIS) estimates*

Abundance indices for redfish over surveys in 2008, 2010 and 2012 are provided in Knuckey et al. (2013) and summarised in Table 6.4. Indices from the FIS were not used in the preliminary assessments.

Table 6.4. Abundance indices of redfish in the summer and winter surveys with corresponding cv.

	2008	2010	2012
Summer	3.43	10.35	3.76
c.v.	0.79	0.64	0.5
Winter	14.37	26.89	1.14
c.v.	0.23	0.23	0.31

6.4.6 *Kapala data*

Abundance indices from the Kapala research cruises for redfish provide estimates of 115 for 1976/77 and 4.8 for 1996/97, a decline of 24:1. Previous modelling attempted to include these abundance indices but the model was unsuccssful in providing reasonable fits (Thomson, 2002). Length frequncy of redfish from the Kapala research cruises are provided in Figure 6.3. These length frequencies have not been included in any previous assessment models. Sample sizes for the south are small (n=1548 for 1977 and n=210 for 1997) compared to the north (n=54526 for 1977 and n=4991 for 1997). Data from the Kapala have not been included in the preliminary model presented here.

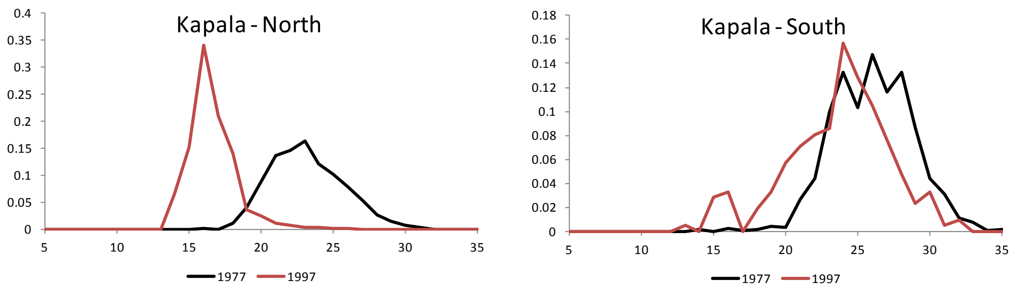

Figure 6.4. The Kapala length frequencies for the northern and southern redfish regions.

6.4.7 *Biological parameters*

The preliminary assessment assumes that length at 50% maturity of 19cm for females in the north and 18cm in the south (Thomson, 2002). Natural mortality is assumed to be 0.10y^{-1}. Redfish natural mortality is generally assumed to be in the 0.05 and 0.15 y^{-1} range (SEFAG, 2000). Morison and Rowling (2001) calculated natural mortality values between 0.07 and 0.11 y^{-1}. Steepness is assumed to be 0.75. Parameters for the length weight relationship were taken from Klaer (2005; also used by Thomson, 2002). The Redfish FAR (2002) states that studies of mean length at age suggest differences in growth rates between the northern and southern regions of the fishery off eastern Australia (Morison and Rowling, 2001). As a consequence two assessments are considered here: a northern assessment and a southern assessment, split at 36˚S. The von Bertalanffy growth parameter *k* for the north is 0.24 while for the south it is 0.2 (Thomson, 2002). These values are fixed in the preliminary assessment; other growth parameters, including those by sex, are estimated.

6.5 Analytic approach

6.5.1 The population dynamics model

The 2014 assessment of eastern redfish uses an age- and size-structured model implemented in the generalized stock assessment software package, Stock Synthesis (SS) (Version 3.24f, NOAA 2011). The methods utilised in SS are based on the integrated analysis paradigm. SS can allow for multiple seasons, areas and fleets, but most applications are based on a single season and area. Recruitment is governed by a stochastic Beverton-Holt stock-recruitment relationship, parameterized in terms of the steepness of the stock-recruitment function (h), the expected average recruitment in an unfished population (R_0), and the degree of variability about the stock-recruitment relationship (σ_r). SS allows the user to choose among a large number of age- and length-specific selectivity patterns. The values for the parameters of SS are estimated by fitting to data on catches, catch-rates, discard rates, discard and retained catch length-frequencies, and conditional age-at-length data. The population dynamics model and the statistical approach used in fitting the model to the various data types are given in the SS technical documentation (Methot, 2005).

The base–case model includes the following key features:

(a) Two regions are considered separately: north and south, split at 36˚S and east of 147˚E.

(b) The selectivity pattern for the trawl fleet was assumed to be length-specific and logistic. The parameters of the selectivity function for each fleet were estimated within the assessment. A trend in selectivity centred on 1995 was considered to account for the shift in mean length from larger to smaller fish.

(c) Redfish within each region consist of a single stock within the area of the fishery.

(d) The model accounts for males and females separately.

(e) The initial and final years are 1975 and 2013. Previous modelling (Thomson, 2002; Klaer, 2005) has begun models in 1975 due to the generally perceived poorer quality of data prior to this year. Allowing pre-1975 exploitation of the stock will be considered in future iterations of the model.

(f) The CVs of the CPUE indices for the non-spawning fleet were initially set at a low value to encourage a fit to the abundance data, before being re-tuned to the model-estimated standard errors after tuning to length and age data. The Francis method (Francis, 2011) has not been used here but will be in future iterations of the model.

(g) Discard tonnage was estimated through the assignment of a retention function. This was defined as a logistic function of length, and the inflection and slope of this function were estimated where discard information was available. A retention function was estimated for each 'block' period: namely 1975-1985; 1986-1992; 1993 -1996; 1997 – 2000; 2001 – 2013. This attempts to account for the changing discarding behaviour throughout the fishery (Rowling, 1999).

(h) The rate of natural mortality, M, is assumed to be constant with age, and also time-invariant. The value for M is 0.1 y^{-1}.

(i) Recruitment to the stock is assumed to follow a Beverton-Holt type stock-recruitment relationship, parameterised by the average recruitment at unexploited spawning biomass, R_0, and the steepness parameter, *h*. Steepness for the base-case analysis is set to 0.75.

(j) The value of the parameter determining the magnitude of the process error in annual recruitment, σ_r, is initially set to 0.6 and re-tuned in the preliminary model.

(k) The population plus-group is modelled at age 40 years, as is the maximum age for observations.

(l) Growth is assumed to follow a von Bertalanffy type length-at-age relationship, with the parameters of the growth function being estimated separately for females and males inside the assessment model, except for the k parameter which is fixed at 0.24 (north) and 0.2 (south).

(m) Retained and discard length sample sizes were capped at 200 and required to have a minimum of 100 samples to be included. Reducing the sample size to a maximum of 200 is because the appropriate sample size for length frequency data is probably more related to the number of shots sampled, rather than the number of fish measured. The length frequency data is given too much weight relative to other data sources if the number of fish measured were used. Length, age, σ_r, and cpue data were tuned.

The values assumed for some of the (non-estimated) parameters of the base case models are shown in Table 6.5.

Table 6.5. Parameter values assumed for some of the non-estimated parameters of the base-case model.

Parameter	Description	Value
M	Natural mortality	0.1
σ_r	Initial c.v. for the recruitment residuals	0.6
h	“steepness” of the Beverton-Holt stock-recruit curve	0.75
x	age observation plus group	40 years
a	allometric length-weight equations	0.0577 g^{-1}.cm
b	allometric length-weight equations	2.77
l_m	Female length at 50% maturity	19cm
k	Von Bertalanffy growth parameter	0.24 (n) 0.2 (s)

6.5.2 *Alternative models*

A key uncertainty in the assessment of redfish relates to the early catch and discarding practices (Rowling, 1999; Hall, 2001). Years from 1975 - 1985 are generally assumed to be a period of large discarding due to a lack of markets, with the discard size composition matching that of the landed catch (Rowling, 1999; Appendix 2). However, as has been stated by Thomson (2002), it is unlikely that that when skippers did choose to land redfish that they landed small fish as well as large fish. After 1985 discarding is assumed to have changed from being market-driven to being size based, and influenced by the surimi markets. In order to model the situation where the size of the discard and retained catch are similar, but with a larger proportion of small fish discarded, two methods are considered here:

1) Scenario 1 (S1). Use model derived discard rates to fit to estimates over the period 1975-1985. Include a logistic retention function with a cap less than 1.0 (i.e. larger fish do not reach full retention and can be discarded).

2) Scenario 2 (S2). Add the estimated mass of discards into the retained mass (see new landings values in Table 6.2). Retention is 1.0 across all lengths for 1975-1985. Do not allow selection of small fish through the selectivity function. In this case, model derived discard rates over 1975 – 1985 are not fit to the corresponding estimates in Table 6.1. This is the method that was adopted by Thomson (2002).

Table 6.6. Landings (tonnes) assumed under scenario (S2) where the estimated discard mass is added into the estimated retained mass for years 1975 - 1985. Discard rates used to calculate the discard mass are in Table 6.1.

Year	Landings	
	North	South
1975	753	415
1976	1075	592
1977	1290	710
1978	1290	744
1979	2258	1534
1980	2211	1471
1981	1371	983
1982	1451	914
1983	1613	993
1984	1613	937
1985	1613	909

6.6 Results and discussion

6.6.1 The base case stock assessment

6.6.1.1 Parameter estimates

The weight-length relationships, maturity-at-length and growth are shown in the Appendices pages 1-3 for each of the regions and model scenarios. Selectivity and the retention functions are shown on pages 4-8 (Figure 6.5). Selectivity is allowed to vary with time and is logistic for the trawl fleet. Retention has multiple ‘time-blocks’ to account for the varying discarding behaviours documented. Retention during the years of the surimi markets (1986 – 2000) can be seen to have been much higher than at other times (less discarding), as a much broader range of size classes are retained and sold to surimi processors. Selectivity tends to move from larger sized fish to much smaller fish. This pattern of decreasing mean length has been noted in previous assessments (Rowling, 1999; Thomson, 2002) and may be related to a gradual movement away from deeper waters where larger fish were caught, to more shallow depths (K. Rowling, pers. comm.).

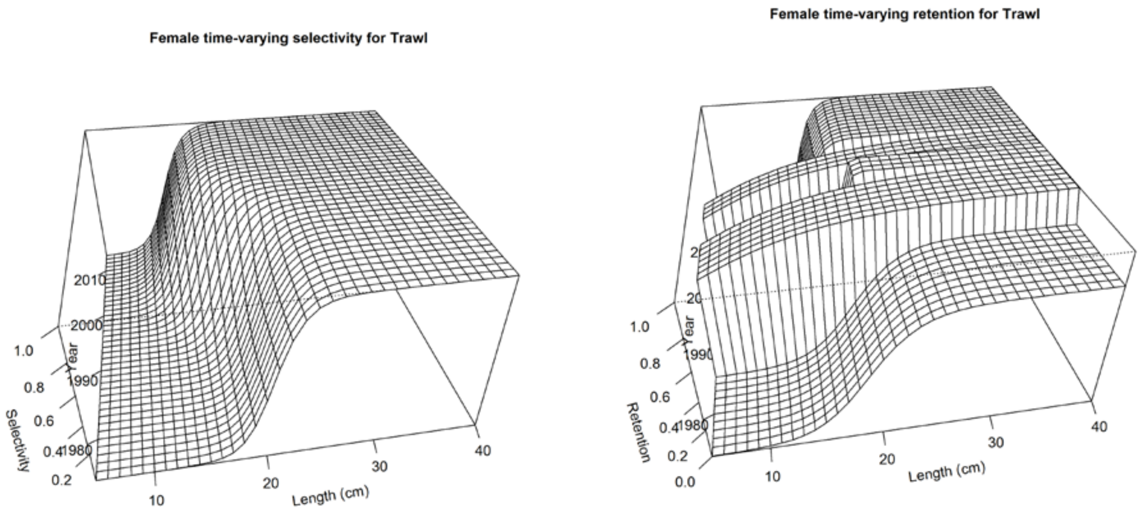

Figure 6.5.The estimated selectivity (left) and retention (right) functions for the northern redfish regions under scenario 1 where discarding over 1975 – 1985 is estimated.

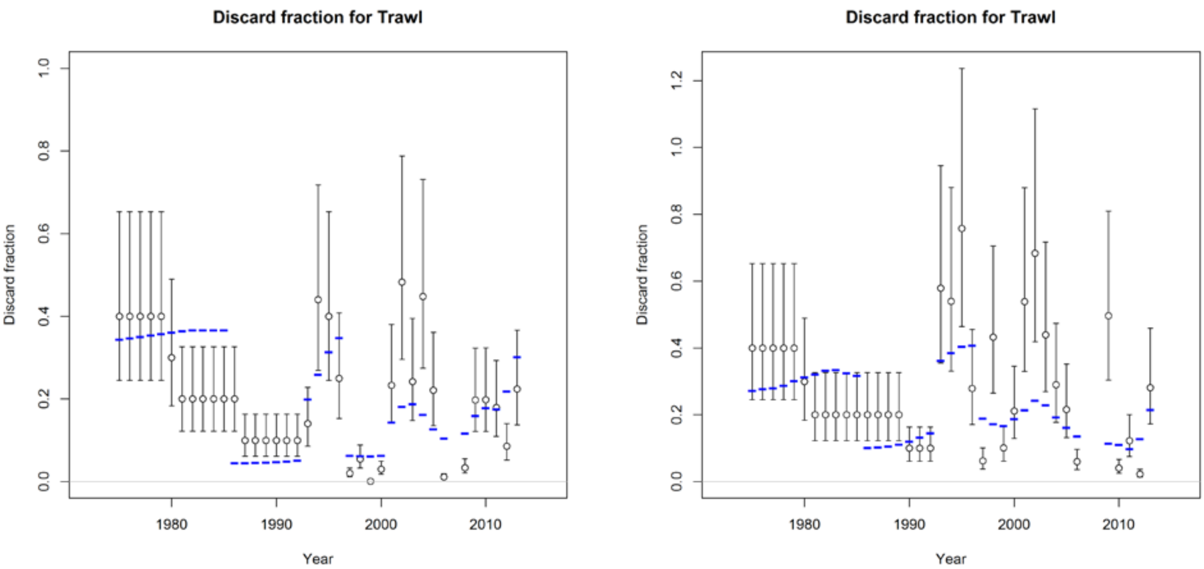

Figure 6.6. The fit to the discard rate data for the northern region (left) and southern region (right) under scenario 1 where discarding over 1975 – 1985 is estimated; blue dashes are the model fitted estimates.

6.6.2 *Fits to the data*

The fit of the model to the discard rates shows some correspondence as the model attempts to fit to the various changes in discarding over time, however, discard rates are highly variable and predicted discard rates appear biased low in many years (Appendices). Figure 6.7 shows the model fit to the catch rate series showing little difference between the model scenarios with both providing acceptable fits, especially after 1995. Appendix p17 show that the model fits intersect most of the 95% confidence intervals for the catch rate data.

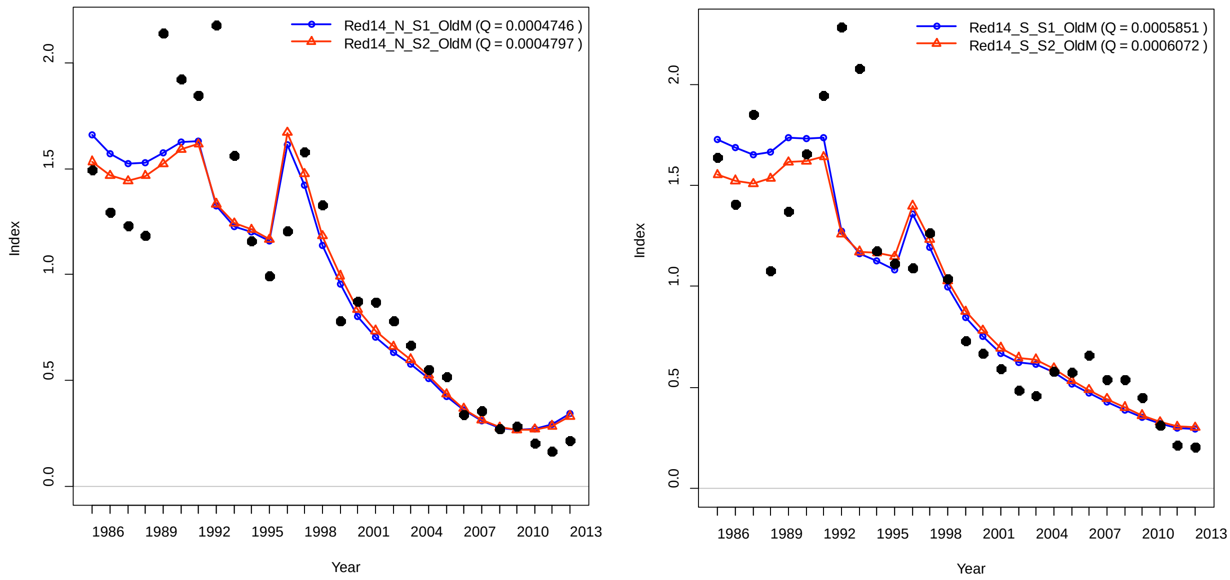

Figure 6.7. The fit to the annual catch rate series for the northern region (left) and southern region (right). Blue = scenario 1, Red = scenario 2.

The model is able to replicate the implied age-composition data reasonably well, particularly where the samples were from the separate sexes in the retained catch (Appendices p24-32). Age compositions from 2012 and 2013 seem to suggest that a relatively large recruitment may have moved into the available stock. This is also evident in the model estimates of recruitment for both regions. Length composition data are not as well estimated by the model, with early years showing an over-estimation of small fish, and later years showing a much narrower distribution of observed lengths compared to the model estimates (Appendices p18-19). Length fits for the southern region are particularly poor from 1988 onward. The length composition data for this stock appear to vary markedly from one year to the next; making model fitting difficult (e.g. 1997, 1998).

6.6.3 *Assessment outcomes*

The estimated time series of recruitment under the preliminary assessment models S1 and S2 for both regions show periods of strong recruitment, amongst a general declining trend (Appendices p11; Figure 6.8). The model estimates a recent large recruitment for both northern and southern regions, which is also evident in the age composition data for 2013.

The trajectories of spawning biomass (Figure 6.8) and spawning biomass relative to the un-exploited level (Appendices p9-10) show a general declining trend of stock status since 1975. Models for both regions show stock status moving below the limit reference point of 20% in 1999, with current stock status well below the limit (Appendices p10).

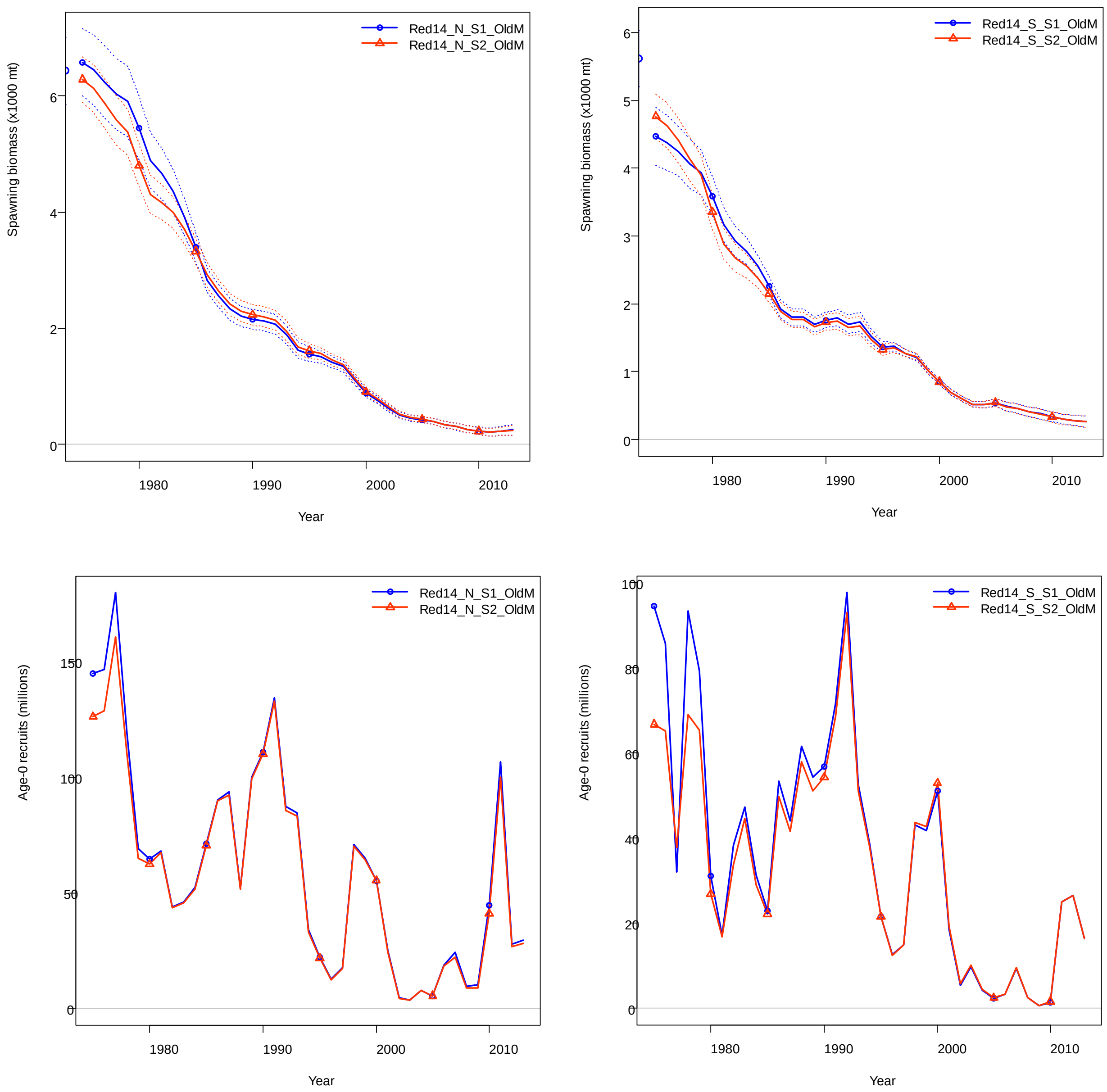

Figure 6.8.The annual time-series of female spawning biomass (top) and recruitment (bottom) for the northern (left) and southern (right) redfish regions. Blue = scenario 1, Red = scenario 2.

6.6.4 *Development towards the 2014 base-case*

1) Are the assumptions behind the catch time-series appropriate?
2) Are the time-block set-ups appropriate for retention and selectivity? Which of scenario S1 or S2 is favoured for years 1975 - 1985?
3) How should selectivity be refined to deal with the residual pattern in length fits?
4) Ensure composition data are included where appropriate and available
5) Consider Francis (2011) tuning method
6) Are assumptions about growth appropriate with respect to the different regions?
7) Should any of the current fixed parameters be estimated? M, growth
8) What sensitivities should be considered, e.g. with respect to historical discard rates, tuning methods, alternative parameters?
9) Should Kapala data be included?
10) What, if any, attention should be provided to FIS abundance indices?
11) Should the composition data from 2007 – 2009 be included?
12) Should a ‘combined regions’ model be considered?

6.7 Acknowledgements

Many thanks are due to the CSIRO SESSF-WG: Sally Wayte, Neil Klaer, Robin Thomson, Judy Upston, Malcolm Haddon and André Punt for their assistance with model discussions and development. Malcolm Haddon is thanked for providing catch rate indices, Mike Fuller, Robin Thomson and Neil Klaer for their advice on data matters. Kyne Krusic-Golub (Fish Aging Services) and the AFMA observer section are thanked for providing the aging data and length frequency data respectively. Kevin Rowling, Ian Knuckey and Tony Lavalle provided invaluable advice on historical catch and discarding practices.

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7. Stock assessment of redfish *Centroberyx affinis* based on data up to 2013

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7.1 Summary

This chapter presents the data and results from the 2014 base-case assessment of eastern redfish *Centroberyx affinis* in the Southern and Eastern Scalefish and Shark Fishery (SESSF). For the first time, the assessment uses an age- and size-structured model implemented in the generalized stock assessment software package, Stock Synthesis (SS). The assessment includes data up to the end of the 2013 calendar year. Data include annual landings, catch rates, discard rates, and length/age compositions.

Two potential base-case models are presented. BC1 includes the ability to have multiple changes in the discard function to account for changes in discarding practices, whereas BC3 allows only a single change in the discard function (in 1985), as the fishery moved from market-based discarding to size-based discarding.

Results from the assessments conclude that the estimated redfish spawning biomass in 2015 will be considerably less than the unexploited spawning stock biomass. For the base-case model BC1, the estimated virgin female biomass is 15,047 tonnes, and the 2015 estimated spawning biomass level is 9% of un-exploited levels. Under the base-case 3 (BC3) assessment, the estimated virgin spawning biomass is 14,615 tonnes, with estimated 2015 stock status of 12% of unexploited levels. As the estimated stock status is below the limit reference point of 20% for both base-case models BC1 and BC3, assuming the 20:35:48 control rule, the RBCs are consequently zero. All models that have been tuned, including models tuned using the Francis method, similarly led to zero RBCs for 2015.

Evidence in the aging data suggests that there have been two recent years of improved recruitment (in 2011 and 2012). While a small improvement in catch rates may also have occurred as a consequence of these fish moving into the available biomass, the existence and magnitude of these recruitments should be monitored over the ensuing years to verify what may be a positive sign for the stock.

7.2 Introduction

An integrated analysis model, implemented in the generalized stock assessment software package, Stock Synthesis (SS) (Methot, 2011; Methot and Wetzel, 2013. V3.24f), was applied to the eastern redfish stock of the SESSF, with data from 1975 to the 2013 calendar year (length and age data; age-error, catch rate series; landings and discard rates). The model fits directly to catch rates, discard rates, length frequencies (by sex where possible) and conditional age-at-length data.

Previous assessment models for eastern redfish are those of Chesson (1995), Thomson (2002) and Klaer (2005). The first comprehensive assessment of redfish was carried out in 1993 (Chesson, 1995).

This assessment concluded that stock biomass was low in the late 1980s (less than 20% of that in 1969) but increases in catch and CPUE from 1990 to 1993, especially of small fish, suggested an increase in recruitment. A yield per recruit analysis based on growth and mortality rates indicated that better yields and value could be obtained if fish were caught at a greater size and age (Redfish FAR, 2002). No further comprehensive assessments of redfish were undertaken until April 1997 when a workshop (Rowling, 1997) was held in Cronulla to discuss the research findings for redfish which had accumulated since 1993. This led to the formation of the Redfish Assessment Group (RAG) in November 1997. The RAG was charged with developing an authoritative stock assessment for redfish, which first required the development of acceptable data sets to describe the true catch level and size composition throughout the history of the fishery (to account for the significant discarding which had always been a characteristic of this fishery) (Redfish FAR, 2002).

Thomson (2002) used an integrated assessment (ADMB) to assess stock status of redfish using data up 2001. The model of Thomson (2002) showed a considerable decline in stock biomass for both northern and southern regions (~25% of initial biomass in 2001). However, there were concerns regarding fits to catch at length data; namely a consistent tendency to over-estimate the proportion of large fishes in the catches since 1995 and to under-estimate them prior to 1995. Klaer (2005) focused on the effect of changes in mesh selectivity on the future stock status of redfish, using the assessment platform Coleraine (Hilborn et al. 2000). Klaer (2005) largely used the biological parameters, catch and discard rate information provided by Thomson (2002), with updates of recent catch rate, catch and discard estimates to 2004. Results for the northern and southern regions, under the nominated base-case parameter set, showed stock status of less than 20% of initial biomass.

This paper presents the first full assessment for redfish to be implemented using Stock Synthesis (SS). The use of SS allows the implementation of a model very similar to that used in previous assessments, but additionally presents an opportunity to improve the estimation of length-based selectivity. SS can be fitted simultaneously to several data sources and types of information available for redfish. The population dynamics model, and the statistical approach used in the fitting of the model to the various types of data, is outlined fully in the SS user manual (Methot, 2005; 2011) and is not reproduced here. This paper uses the agreed base-case model structure from the Shelf RAG (September, 2014), in addition to sensitivities to this base-case. The preliminary models to assist the establishment of a base-case were presented at Shelf RAG and can be found in Tuck and Day (2014).

7.3 The fishery

The history of the redfish fishery is well documented in previous reports (eg Rowling 1999; Wise and Thomson, 2002). Redfish (also known as nannygai) occur throughout southern Australia and in New Zealand (Rowling, 1994). It is well established that redfish are a slow growing species which may live more than 35 years (Kalish, 1995; Wise and Thomson, 2002). Tagging studies (Rowling, 1990) suggested a single unit stock of redfish off NSW, however studies of mean length at age suggest differences in growth rates between the ‘northern’ and ‘southern’ sectors of the fishery off eastern Australia (Morison and Rowling, 2001). The redfish assessments of Thomson (2002) and Klaer (2005) have assumed that the fishery exploits two separate populations, with the boundary between these ‘stocks’ being 36ºS (just north of Montague Island). The assessment presented in this paper no longer assumes northern and southern stocks, split at 36ºS, but rather a single stock combined across regions.

The 2002 redfish fishery assessment report (Redfish FAR, 2002) states that the breeding biology of redfish remains poorly documented. They are reported to mature between five and seven years of age, with spawning thought to occur on continental shelf grounds in late summer and autumn throughout much of the range of the species. Juveniles commonly occur in the larger coastal bays and nearshore reefs, while adults have historically been more abundant in deeper continental shelf and upper slope waters.

The following text is taken from Wise and Thomson (2002) and provides a brief summary of the fishery to 2002.

> The earliest catches of redfish were made by the steam trawler fleet which began operating in 1915, however most redfish were discarded at sea as these boats principally targeted tiger flathead (Houston 1955). Expansion of the steam trawl fishery continued until 1929. The late 1950s and early 1960s were characterised by small, incidental redfish catches as steam trawlers were displaced by Danish seiners as the main units in the fishery. During the 1960s the Danish seine fleet began converting to otter trawling. Modern diesel powered trawlers were predominant in many ports by the mid 1970s, and Danish seiners had all but disappeared from the fishery by the early 1980's. During the 1970s trawling extended to the upper continental slope (to depths of 600 m), mainly targeting gemfish (*Rexea solandri*). Large incidental catches of redfish were taken on upper slope grounds while targeting gemfish. These fish were generally larger than those taken on continental shelf grounds and had a higher market acceptance. Some large targeted catches of redfish were taken by fishers returning from unsuccessful gemfish targeting, and in the periods either side of the main gemfish catching season. However, a very significant proportion of the redfish catch continued to be discarded at sea due to oversupply of the market. Redfish consignments to the Sydney Fish Markets increased to 2400 t in 1980 as effort levels increased and markets gradually improved. Landings fluctuated between 1500 t and 2000 t per year until 1985. Despite continuing high effort levels, recorded landings of redfish declined to less than 1000 t in 1989. Landings increased again in the early 1990s reaching a peak of just over 2000 t in 1993.
>
> Individual transferable quotas (ITQs) were introduced in 1992 with the total allowable catch (TAC) for redfish of 600 t reflecting concern over the decline in catches in the late 1980s and the indications from early stock assessments (Rowling, 1993). However, the implementation of quota management coincided with a substantial increase in the availability of redfish, which resulted in calls for the TAC to be increased. Enforcement of the TAC was compromised as some redfish caught in Commonwealth waters were reported as coming from State waters to avoid being counted against quota (in fact in 1993 when the TAC was 600 t the actual landings of redfish were around 2000 t). In recognition of the increased availability of redfish, the TAC was increased to 1000 t in 1994 and to 1700 t in 1995. The "state waters" loophole was reduced in 1994 with the imposition by NSW of a 100 kg trip limit for redfish caught in waters south of Barranjoey Point.
>
> Discarding and high-grading have been features of the fishery for redfish since its inception. The rate of discarding is known to have varied over time but only since 1993 have actual data been available from observers participating in Scientific Monitoring Programs and the NSW Bycatch Study (Liggins, 1996). Between 1993 and 1995 overall discard rates were estimated to be around 50% by weight, but this rate declined to less than 10% during 1997.

Discard practices seem also to be influenced by the availability of surimi markets, with discarding generally lower during the periods the processors operated. Discard rates may have been as high as 80% in some years, but unfortunately no estimates of the quantities, size or age composition of the discarded fish exist prior to 1993 (Rowling, 1999). As stated by Hall (2001), the lack of these data will result in considerable imprecision in estimates of the pristine biomass prior to 1993.

Rowling (1999) documents historical estimates of discard rates and catches since 1960. Rowling (1999; Appendix 2) also describes the factors considered when determining the rate of discarding and the size composition of the catch. These factors were used to determine periods of operational change that influenced discarding practices when structuring the current SS assessment's retention function. Catch, discard, catch rate and length/age composition data have all been updated to the end of 2013 in this assessment. These data are described in the sections that follow.

Several authors have expressed concerns regarding growth over-fishing of redfish (Rowling, 1999, 2001; Wise, 2002; Knuckey, 2010). As stated by Knuckey (2010) "If we track the biomass of a cohort of fish as they grow, we find that it reaches a maximum at a certain age when the improved yield from growth is matched by the reduced yield from mortality. Growth overfishing occurs when large numbers of small fish are taken at a size or age before this maximum is reached". Knuckey finds that growth overfishing of redfish is occurring in the trawl fishery using current codend configurations. Analyses showed that the optimum yield per recruit is obtained when redfish are between 18 to 22 cm fork length. Due to the selectivity of standard 90mm diamond codends (50% selectivity at ~13cm), a large proportion of redfish are captured below the size of optimum yield.

7.4 Data

The data inputs to the assessment come from multiple sources: length and age-at-length data from the trawl fishery, updated cpue series (Sporcic and Haddon, 2014), the annual total mass landed and discard rates, and age-reading error. Data were formulated by calendar year (i.e. 1 Jan to 31 Dec) and were aggregated across all eastern zones (Zones 10, 20 and 30), as sufficiently strong evidence to suggest a north-south split did not exist (Shelf RAG agreement, September 2014; Haddon, 2014).

7.4.1 Catch and discard rates

The catch tonnage for redfish has been estimated in the past based on a combination of sources, including Sydney Fish Market (SFM) data (to 1986), NSW and Victorian landings and the SEF logbook data (Table 28 of Rowling (1994); Appendix 1 of Rowling (1999); Table 1 of Thomson (2002); Table 1 of Klaer (2005)). The estimated annual tonnages of landings, discard rates and cpue are provided in Table 7.1. Where available, previously agreed catch tonnages from RAGs were used (Rowling, 1999; Klaer, 2005), and CDR records are used from 2005.

Discard rates prior to 1992 are those estimated by the redfish RAG (Rowling, 1999; Thomson, 2002). Discard rates after 1992 were estimated from on-board data which gives the weight of the retained and discarded component of those shots that were monitored (Thomson and Klaer, 2011). Rowling (1999) provides considerable detail on how the historical discard rates were estimated and the factors that influenced discard practices. Redfish discarding was discussed at a redfish workshop held in Cronulla in April 1997 and at various open redfish assessment group meetings during late 1997 and early 1998. The resulting discard rates are documented in Rowling (1999) and also listed in the last redfish assessment group (Thomson, 2002) and Shelf RAG (Klaer, 2005) assessments of redfish. Here we update the discard estimates by the addition of on-board estimates through to 2013 (Table 7.1).

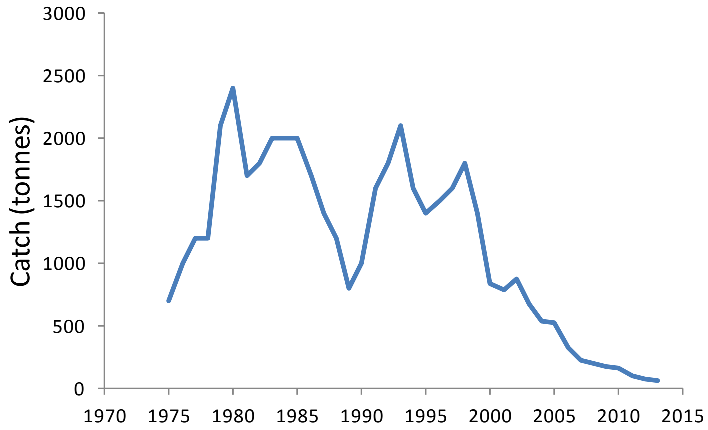


Figure 7.1. The time series of catches for redfish estimated by the various redfish assessment groups and supplemented by AFMA data.

The SS assessment model allows an estimation of the probably of retention (which is 1 – P(discard)) as a function of length in order to estimate the annual discard rate and any information on discard length composition. It is apparent that the redfish fishery has undergone numerous changes that may have influenced the behaviour of discarding; these changes are documented in Rowling (1999; Appendix 2). In consultation with K. Rowling (pers. comm.), the following discarding periods have been identified:

1975 – 1985. Market driven discarding

1975 – 1985. Discards largely across all size ranges, but with more small fish discarded

1986 – 2000. Surimi markets period

1986 – 1992. Surimi market. Discarding rates lower, mainly small fish.

1993 – 1995. Quantity of fish sent to surimi market declined, Geelong surimi market closes; consequent increase in discarding.

1996 – 2000. Discarding declined ‘as redfish became less available’. Close of Hacker surimi processor in 2000.

2001 – 2013. Size based discarding period

2001 – 2013. Assume mostly small fish discarded

These changes in discarding behaviour have influenced the large variations in discard rates observed (Table 6.1), as well as the catches, catch rates and discard length composition. The model retention function has been allowed to vary according to each of these identified discard periods.

7.4.2 *Catch rates*

Sporcic and Haddon (2014) provides the updated catch rate series for redfish (Table 7.1, Figure 7.2). After substantial increases in catch rate in the early and late 1990s, the catch rate has continued to decline since then, and is now less than 15% of levels in 1986. The most recent year in the series has shown a small increase, which may correspond to the apparent large influx of young fish noticeable in the 2013 age data.

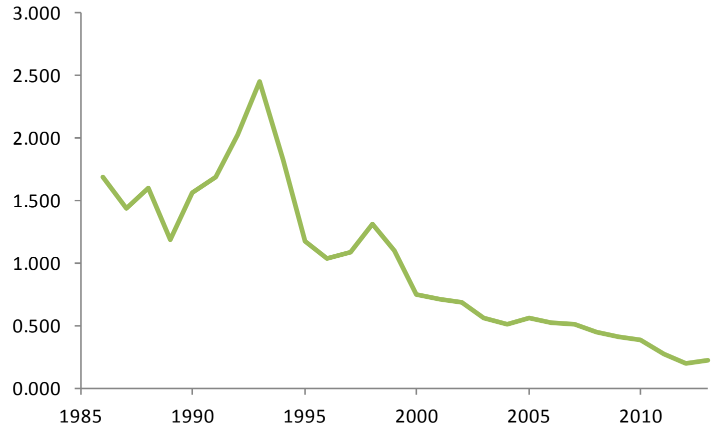


Figure 7.2.The annual catch rate series for redfish (Sporcic and Haddon, 2014).

Table 7.1. Estimated landings (t), discard rates and cpue (Sporcic and Haddon, 2014) for redfish by calendar year. Catch for years 1975 to 2004 were taken from previously agreed catch estimates from RAG meetings (Rowling, 1999, Appendix 1; Klaer, 2005) and from CDR records for 2005 onwards.

Year	Landings	Discard Rates	CPUE
1975	700	0.40	
1976	1000	0.40	
1977	1200	0.40	
1978	1200	0.40	
1979	2100	0.40	
1980	2400	0.30	
1981	1700	0.20	
1982	1800	0.20	
1983	2000	0.20	
1984	2000	0.20	
1985	2000	0.20	
1986	1700	0.20	1.696
1987	1400	0.15	1.435
1988	1200	0.15	1.598
1989	800	0.15	1.184
1990	1000	0.10	1.562
1991	1600	0.10	1.691
1992	1800	0.25	2.024
1993	2100	0.580	2.457
1994	1600	0.540	1.830
1995	1400	0.758	1.182
1996	1500	0.279	1.044
1997	1600	0.062	1.090
1998	1800	0.202	1.318
1999	1406	0.039	1.106
2000	835	0.118	0.746
2001	794	0.370	0.716
2002	880	0.568	0.685
2003	677	0.316	0.568
2004	538	0.392	0.516
2005	532	0.219	0.563
2006	321	0.034	0.528
2007	230	0.159	0.509
2008	201	0.018	0.458
2009	182	0.357	0.412
2010	166	0.117	0.388
2011	99	0.143	0.273
2012	73	0.038	0.198
2013	66	0.259	0.225

7.4.3 *Length frequencies and age data*

Length and age data have been included in the model as length frequency data and conditional age-at-length data by year and sex (when available). Age composition data is included in diagnostic plots but is not used directly within the fitting procedure. Catch length frequency data were obtained from NSW records of fish measured at the Sydney Fish Markets to 1991. After 1991 length frequencies were obtained from ISMP on-board and port measurements. The observed length and age data are shown in later figures with the corresponding model predicted values.

7.4.4 *Age-reading error*

Standard deviations for aging error by reader have been estimated, producing the age-reading error matrix of Table 7.2 (A.E. Punt, pers. comm.).

Table 7.2. The standard deviation of age reading error.

Age	St Dev	Age	St Dev
0	0.167	20	0.98
1	0.167	21	1.00
2	0.237	22	1.02
3	0.304	23	1.04
4	0.366	24	1.06
5	0.424	25	1.07
6	0.479	26	1.09
7	0.531	27	1.10
8	0.579	28	1.12
9	0.625	29	1.13
10	0.668	30	1.14
11	0.708	31	1.15
12	0.746	32	1.17
13	0.781	33	1.18
14	0.815	34	1.19
15	0.846	35	1.19
16	0.876	36	1.20
17	0.903	37	1.21
18	0.930	38	1.22
19	0.954	39	1.23
		40	1.23

7.4.5 *Biological parameters*

The assessment assumes that length at 50% maturity is 19cm for females (Thomson, 2002). Natural mortality is assumed to be $0.10y^{-1}$. Redfish natural mortality is generally assumed to be in the 0.05 and 0.15 y^{-1} range (SEFAG, 2000). Morison and Rowling (2001) calculated natural mortality values between 0.07 and 0.11 y^{-1}. Steepness is assumed to be 0.75. Parameters for the length weight relationship were taken from Klaer (2005; also used by Thomson, 2002). Growth parameters, including the von Bertalanffy growth parameter *k*, are estimated (Thomson, 2002).

7.5 Analytic approach

7.5.1 The population dynamics model

The 2014 assessment of eastern redfish uses an age- and size-structured model implemented in the generalized stock assessment software package, Stock Synthesis (SS) (Version 3.24f, NOAA 2011). The methods utilised in SS are based on the integrated analysis paradigm. SS can allow for multiple seasons, areas and fleets, but most applications are based on a single season and area. Recruitment is governed by a stochastic Beverton-Holt stock-recruitment relationship, parameterized in terms of the steepness of the stock-recruitment function (h), the expected average recruitment in an unfished population (R_0), and the degree of variability about the stock-recruitment relationship (σ_r). SS allows the user to choose among a large number of age- and length-specific selectivity patterns. The values for the parameters of SS are estimated by fitting to data on catches, catch-rates, discard rates, discard and retained catch length-frequencies, and conditional age-at-length data. The population dynamics model and the statistical approach used in fitting the model to the various data types are given in the SS technical documentation (Methot, 2005).

The base–case model includes the following key features:

(n) A single region, single stock model is considered, aggregated across zones 10, 20 and 30.
(o) The selectivity pattern for the trawl fleet was assumed to be length-specific and logistic. The parameters of the selectivity function for each fleet were estimated within the assessment.
(p) The model accounts for males and females separately.
(q) The initial and final years are 1975 and 2013. Previous models (Thomson, 2002; Klaer, 2005) used 1975 as the initial year due to the generally perceived poorer quality of data prior to this year. An initial fishing mortality is estimated to account for catches prior to the starting year. A beginning year of 1960 is also considered in the sensitivities.
(r) The CVs of the CPUE indices for the non-spawning fleet were initially set at a low value to encourage a fit to the abundance data, before being re-tuned to the model-estimated standard errors after tuning to length and age data. The Francis method (Francis, 2011) has been applied as a sensitivity.
(s) Discard tonnage was estimated through the assignment of a retention function. This was defined as a logistic function of length, and the inflection and slope of this function were estimated where discard information was available. A retention function was estimated for each ‘block’ period: namely 1975 – 1985; 1986 – 1992; 1993 – 1996; 1997 – 2000; 2001 – 2013. This attempts to account for the changing discarding behaviour throughout the fishery (Rowling, 1999). This model is termed base-case 1 (BC1). An alternative model was considered with blocks only covering the periods 1975 – 1985 and 1986 – 2013. This model is termed base-case 3 (BC3).
(t) Use model derived discard rates to fit to estimates over the period 1975-1985. Include a logistic retention function with a cap less than 1.0 (i.e. larger fish do not reach full retention and can be discarded; fixed at 0.8). This is model Scenario S1 in Tuck and Day (2014).
(u) The rate of natural mortality, M, is assumed to be constant with age, and also time-invariant. The value for M is 0.1 y^{-1}. Alternative values, including estimating natural mortality, are considered as sensitivities.
(v) Recruitment to the stock is assumed to follow a Beverton-Holt type stock-recruitment relationship, parameterised by the average recruitment at unexploited spawning biomass, R_0, and the steepness parameter, h. Steepness for the base-case analysis is set to 0.75.

(w) The value of the parameter determining the magnitude of the process error in annual recruitment, σ_r, is set to 0.6.
(x) The population plus-group is modelled at age 40 years, as is the maximum age for observations.
(y) Growth is assumed to follow a von Bertalanffy type length-at-age relationship, with the parameters of the growth function being estimated separately for females and males inside the assessment model.
(z) Retained and discard length sample sizes were capped at 200 and required to have a minimum of 100 samples to be included. The sample size is reduced to a maximum of 200 because the appropriate sample size for length frequency data is probably more closely related to the number of shots sampled, rather than the number of fish measured. The length frequency data is given too much weight relative to other data sources if the number of fish measured were used. Length, age, and cpue data were tuned.

The values assumed for some of the (non-estimated) parameters of the base case models are shown in Table 7.3.

Table 7.3. Parameter values assumed for some of the non-estimated parameters of the base-case model.

Parameter	Description	Value
M	Natural mortality	0.1
σ_r	c.v. for the recruitment residuals	0.6
h	“steepness” of the Beverton-Holt stock-recruit curve	0.75
x	age observation plus group	40 years
a	allometric length-weight equations	0.0577 g^{-1}.cm
b	allometric length-weight equations	2.77
l_m	Female length at 50% maturity	19cm

7.6 Sensitivities considered

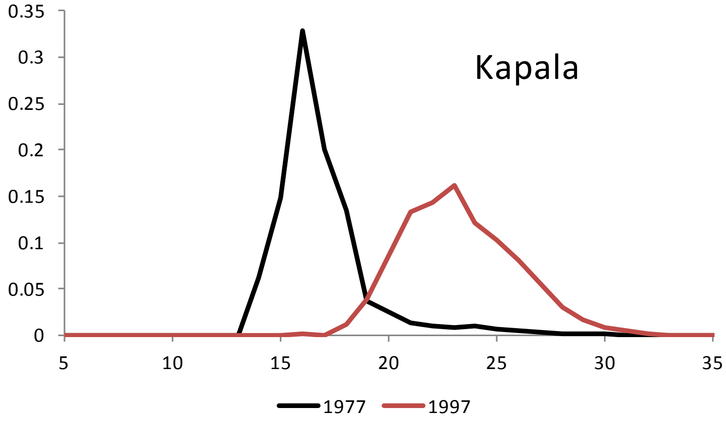
7.6.1 Alternative natural mortality, steepness and data weightings

Standard sensitivities to alternative natural mortality values (M=0.08, 0.12, and M estimated), steepness (h=0.65, 0.85, and h estimated), length at maturity (18cm, 20cm), and doubling and halving weights on cpue, ages and lengths were considered.

7.6.2 Kapala data

Length frequncy of redfish from the Kapala research cruises are provided in Figure 7.3. These length frequencies have not been included in any previous assessment models. Sample sizes are n=56,073 for 1977 and n=5,200 for 1997.

Figure 7.3.The Kapala length frequencies for redfish.



7.6.3 *Alternative weighting scheme (Francis, 2011)*

The model data were also weighted according to the methods suggested in Francis (2011).

7.6.4 *Alternative discard rates from 1975 to 1978*

Rowling (1999; Appendix 1) provides alternative discard rate estimates from 1975 to 1978, being 80%, 70%, 60%, and 50%. These replace the 40% discard rates for the corresponding years for this sensitivity.

7.6.5 *Model start year is 1960*

Rowling (1999; Appendix 1) provides catch and discard rate estimates to 1960. Considerable uncertainty exists for these data, and in particular the discard estimates which are either 40% or 80% between 1960 and 1974. For this sensitivity, a 40% discard rate is assumed for this period.

Table 7.4. Estimated landings (t) and discard rates for redfish by calendar year as estimated by the Redfish Assessment Group (Rowling, 1999).

Year	Landings	Discard Rates
1960	200	0.40
1961	200	0.40
1962	200	0.40
1963	200	0.40
1964	200	0.40
1965	200	0.40
1966	200	0.40
1967	200	0.40
1968	300	0.40
1969	400	0.40
1970	500	0.40
1971	700	0.40
1972	500	0.40
1973	500	0.40
1974	500	0.40

7.6.6 *No retention blocks*

The base-case 1 (BC1) model includes a number of “blocks” in the retention function in an attempt to account for the varying discarding practices of the fleet. This sensitivity removes all blocks and has a single retention function from 1975 to 2013 to account for discarding. This sensitivity was taken through to full tuning as a second potential base-case (BC2).

7.6.7 *Only block 1975-1985 in the retention function*

The base-case 1 (BC1) model includes a number of “blocks” in the retention function in an attempt to account for the varying discarding practices of the fleet. This sensitivity maintains the block from 1975-1985, which accounts for market based discarding. From 1986 to 2013 a single retention function accounts for size-based discarding. This is akin to the models of Thomson (2002). This sensitivity was taken through to full tuning as a third potential base-case (BC3).

7.7 Results and discussion

7.7.1 The base case stock assessment (BC1)

7.7.1.1 Parameter estimates

The weight-length relationships, maturity-at-length and growth are shown in Figure 7.4 and Figure 7.5. The von Bertalanffy growth parameter k was estimated to be 0.235, with a cv on growth of 0.146. The initial fishing mortality was estimated to be F_{init} = 0.015.

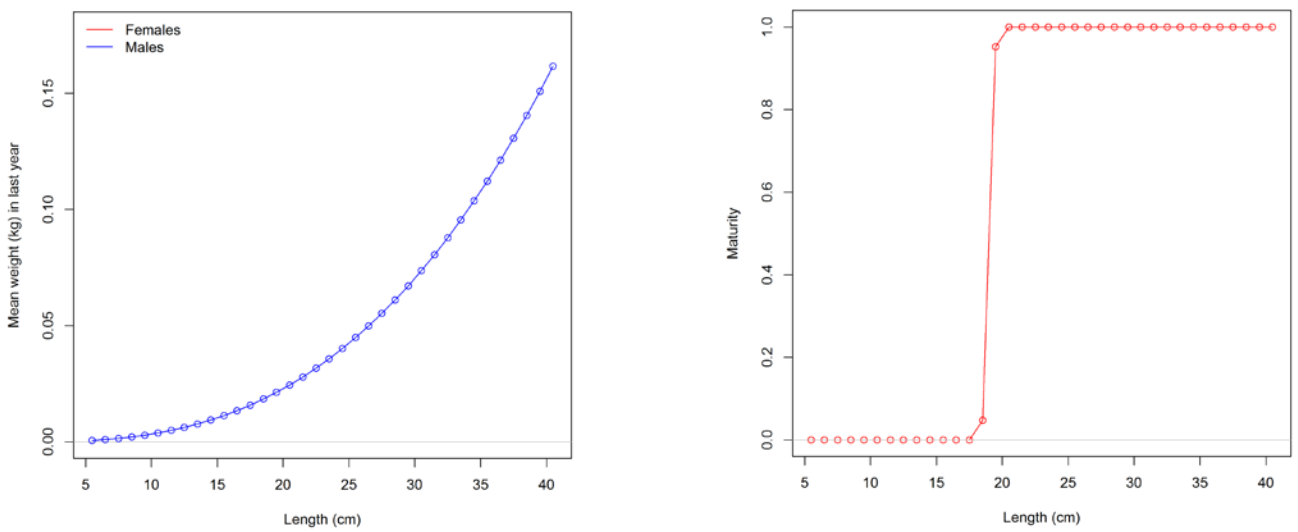


Figure 7.4.The length-weight relationship (left) and maturity (right) functions for eastern redfish.

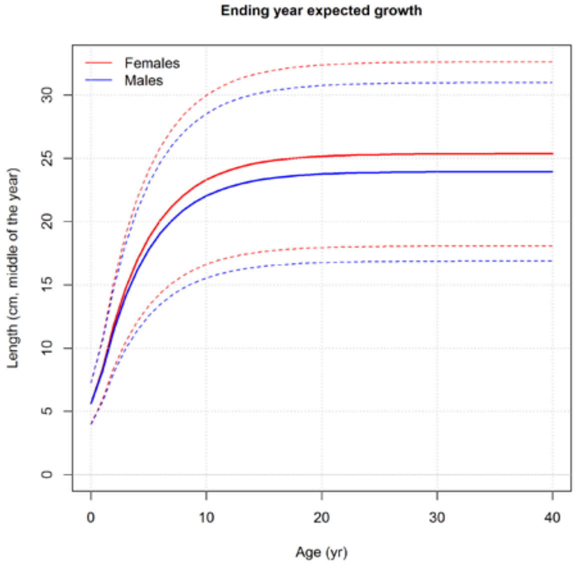


Figure 7.5.The estimated length-at-age relationship for males (blue) and females (red) under BC1.

Selectivity and the retention functions are shown in Figure 7.6. A single logistic selectivity function is estimated for the trawl fleet. Retention has multiple 'time-blocks' to account for the varying discarding behaviours documented. Retention during the years of the surimi markets (1986 – 2000) can be seen to have been much higher than at other times (less discarding), as a much broader range of size classes are retained and sold to surimi processors.

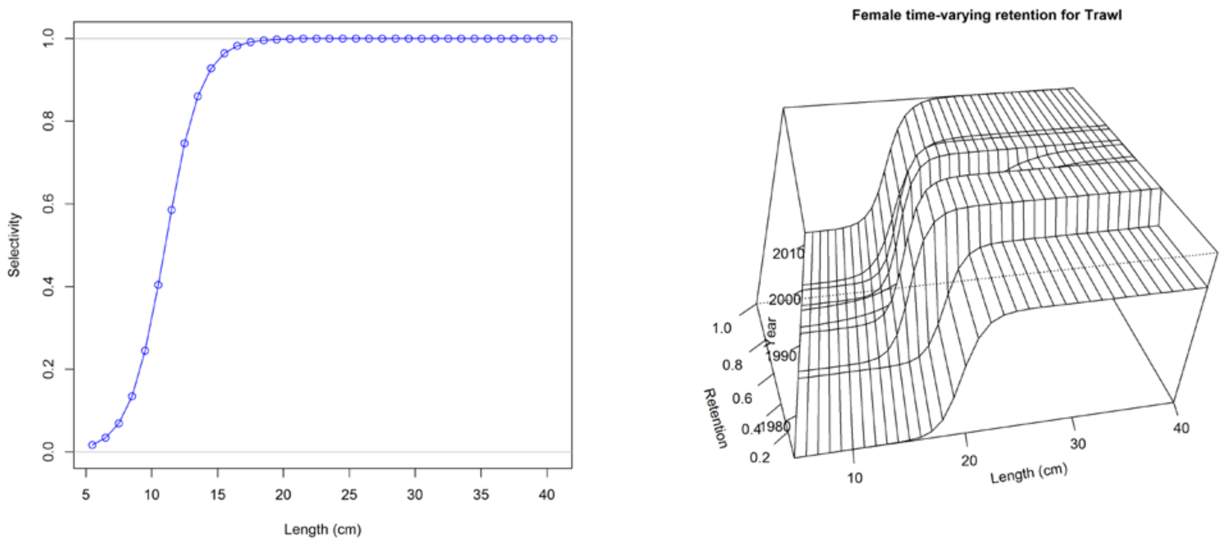


Figure 7.6.The estimated selectivity (left) and retention (right) functions for eastern redfish under BC1.

7.7.1.2 Fits to the data

The fit of the model to the discard rates shows some correspondence as the model attempts to fit to the various changes in discarding over time (Figure 7.7). Figure 7.7 also shows the model fit to the catch rate series showing an over-estimation from years 1985 to 1992, followed by under-estimation from 1993 to 1996. Standard iterative re-weighting procedures did not improve the model fit; the catch rate model fits consistently fell outside the 95% confidence intervals even if the cv's were broadened under re-weighting. As such, catch rates were not tuned in BC1. However, the Francis (2011) weighting substantially down-weighted the length and age data and led to better fits to the catch rate data (see sensitivity results). Likewise, base-case 3 (BC3; only a single retention block from 1975-1985) did not have this catch rate weighting issue.

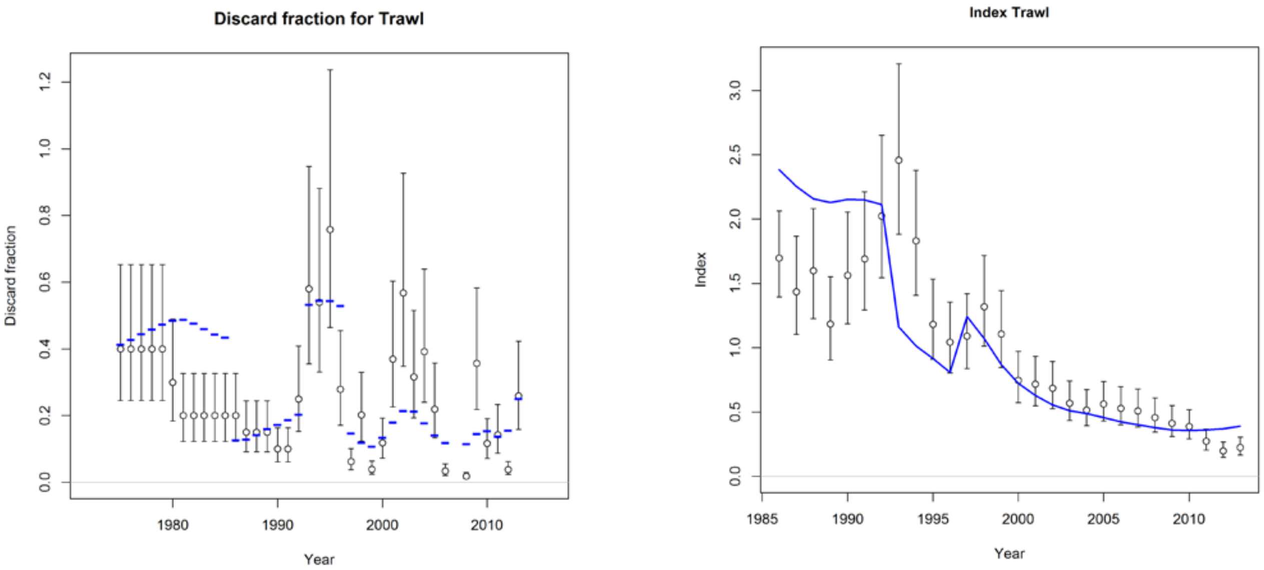


Figure 7.7. The fit to the discard rate data (left) and the catch rate data (right) under BC1; blue dashes/lines are the model fitted estimates.

The model is able to replicate the implied age-composition data reasonably well, particularly where the samples were from the separate sexes in the retained catch (Appendix 1). Age compositions from 2012 and 2013 seem to suggest that a recent relatively large recruitment may have moved into the available stock. This is also evident in the model estimates of recruitment. Length composition data are not as well estimated by the model, with early years showing an over-estimation of small fish, and later years showing a much narrower distribution of observed lengths compared to the model estimates. The length composition data for this stock vary markedly from one year to the next; making model fitting difficult (e.g. 1991 and 1993; 1997 and 1998).

7.7.1.3 Assessment outcomes for BC1

The estimated time series of recruitment under the base-case assessment model BC1 shows periods of strong recruitment, amongst a general declining trend (Figure 7.8; Appendix 1). The model estimates a recent large recruitment, which is also evident in the age composition data for 2013 (Appendix 1).

The trajectories of spawning biomass (Figure 7.8) and spawning biomass relative to the un-exploited level show a general declining trend of stock status since 1975. The model shows stock status moving below the limit reference point of 20% in 1999, with current stock status well below the limit.

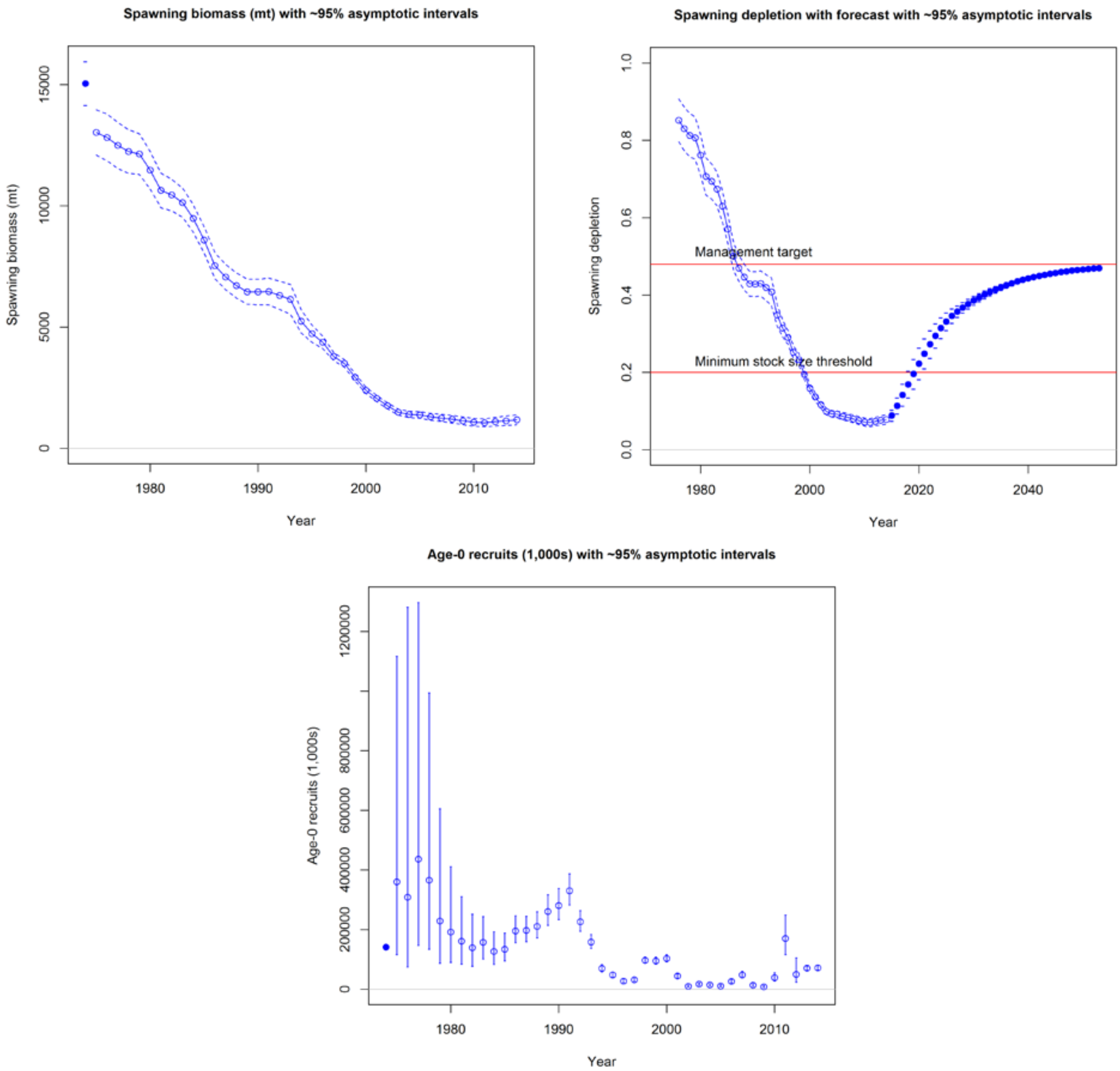


Figure 7.8. The annual time-series of female spawning biomass (absolute left and relative right) and recruitment (bottom) under BC1.

7.7.2 *Alternative Base-Case 3 (BC3)*

As the base-case model that had been identified by the Shelf RAG (BC1) was not able to fit the catch rate data well using the standard iterative re-weighting procedure, various alternative model structures were considered to address this issue (including varying parameters, reducing the number of years of recruitment estimation, increasing weights on discards and other data). As part of the sensitivity testing, it was found that removing or reducing the number of time-blocks on the retention function led to a model that can be tuned to the catch rate data. As such, this model, without the complication of numerous time blocks on retention, was identified as a potential base-case model (BC3). This model has only two blocks in the retention function, namely from 1975 to1985 and 1986 to 2013. This is akin to the retention model structure utilized by Thomson (2002) where market-driven discarding was assumed for the years 1975 to 1985 and size-related discarding occurred for years thereafter.

The selectivity and retention functions for BC3 are show in Figure 7.9. Base-case 3 does not have the flexibility to deal with the variations in observed discard rates, but nevertheless is able to produce reasonable fits to discard rates and catch rates (Figure 7.7). In addition, model estimates of catch rates fit through the 95% confidence intervals, and BC3 catch rates show a comparatively better fit relative to BC1. Stock status and trends in biomass do not differ greatly between the two base-case models (Figure 7.8). Additional diagnostics and fits to ages and lengths for BC3 are in Appendix 2. The von Bertalanffy growth parameter k was estimated to be 0.236, with a cv on growth of 0.146. The initial fishing mortality was estimated to be F_{init} = 0.016.

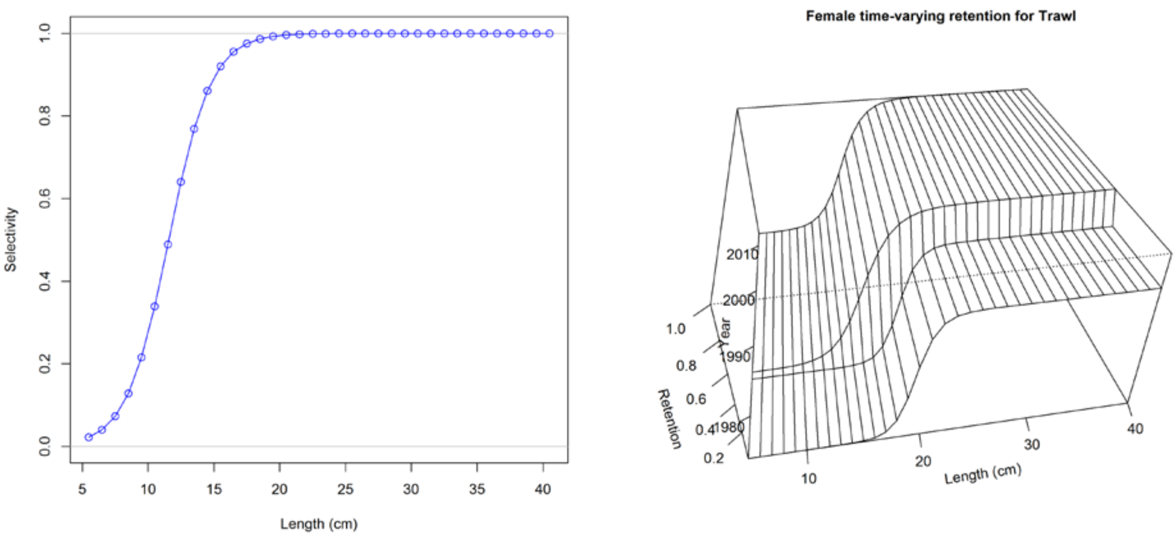


Figure 7.9.The estimated selectivity (left) and retention (right) functions for eastern redfish under BC3.

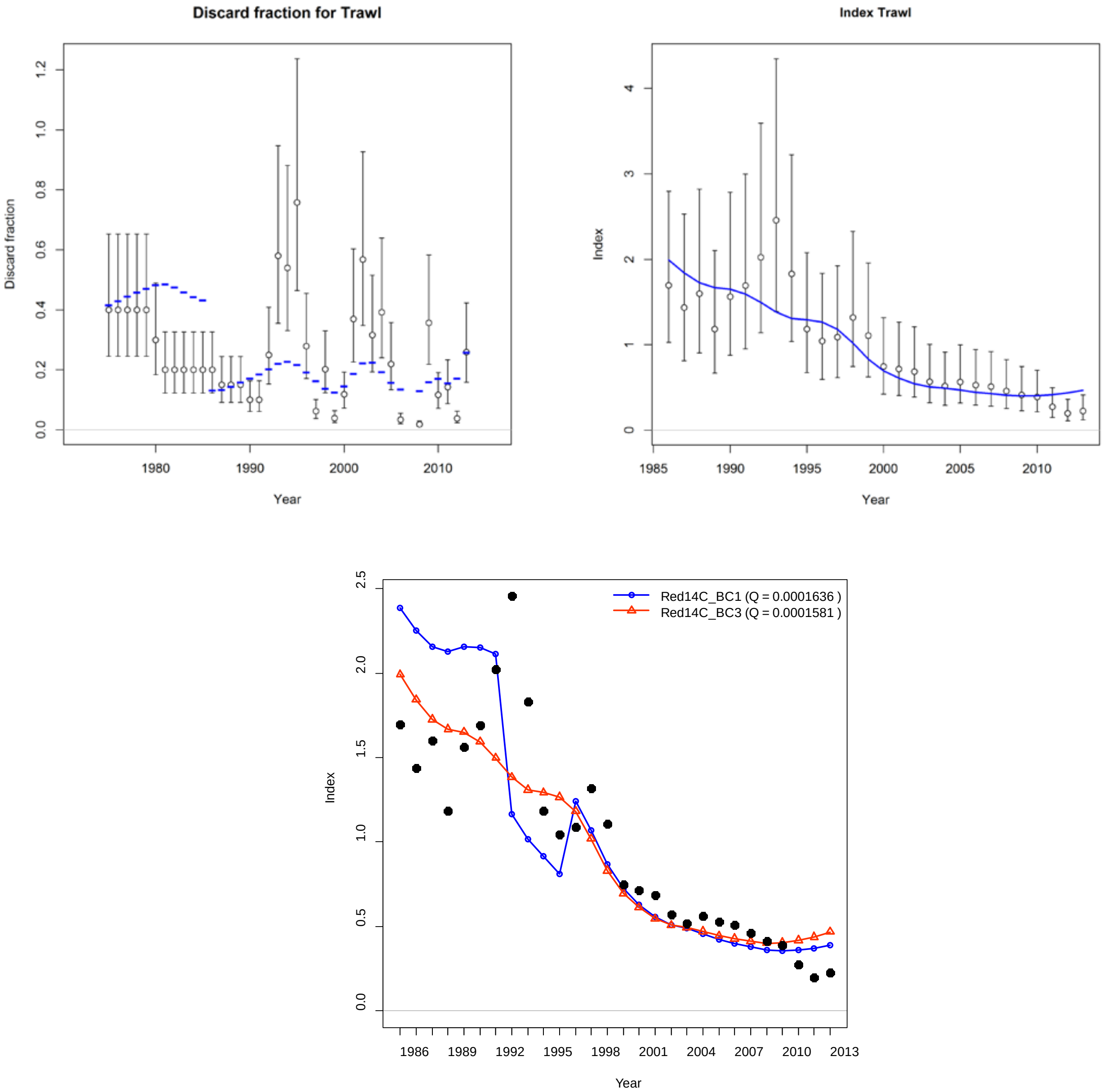


Figure 7.10. The fit to the discard rate data (top-left) and the catch rate data (top-right) under BC3; blue dashes/lines are the model fitted estimates, and a comparison of catch rate fits between BC1 (blue) and BC3 (red) (bottom).

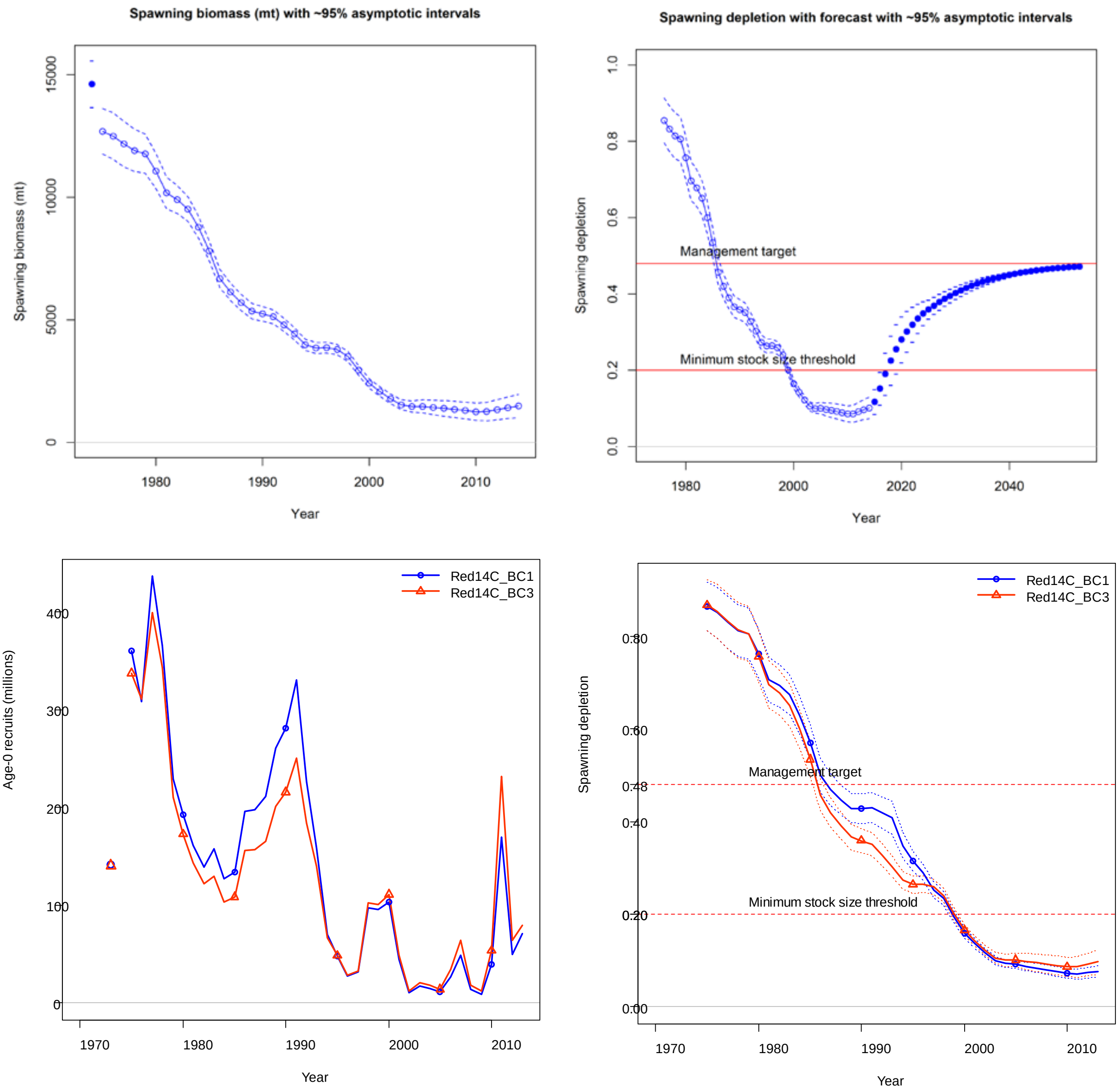


Figure 7.11. The annual time-series of female spawning biomass (absolute biomass, top left, and relative biomass, top right) and recruitment and spawning biomass for BC3 (red) in comparison to BC1 (blue) (bottom).

7.7.3 *Management outcomes for the base-case models*

For the base-case model BC1, the estimated virgin female biomass is 15,047 tonnes, and the 2015 estimated spawning biomass level is 9% of un-exploited levels (Table 7.5). Under the base-case 3 (BC3) assessment (that has only a single break in the retention function), the estimated virgin spawning biomass is 14,615 tonnes, with estimated 2015 stock status of 12% of unexploited levels (Table 7.7). As the estimated stock status is below the limit reference point of 20% for both base-case models BC1 and BC3, assuming the 20:35:48 control rule, the RBCs are consequently zero. All models that have been tuned, including models tuned using the Francis method, similarly led to zero RBCs for 2015. Long-term RBCs, assuming a return to a 48% stock status, are in the range of 750 to 850 tonnes.

7.7.4 *Sensitivities*

Results of the various sensitivity tests are shown in Table 7.5 and Table 7.6 for BC1 and Table 7.7 and Table 7.8 for BC3. The base-case models and sensitivities all have stock status less than the limit reference point of 20% of virgin spawning biomass, and generally vary between 7% and 15%. The largest variation in stock status occurs with larger fixed values of natural mortality and steepness. However, estimating these parameters led to M≈0.1 (approximately the base-case value used), and a steepness of h≈0.59 (lower than the base-case assumed value of 0.75).

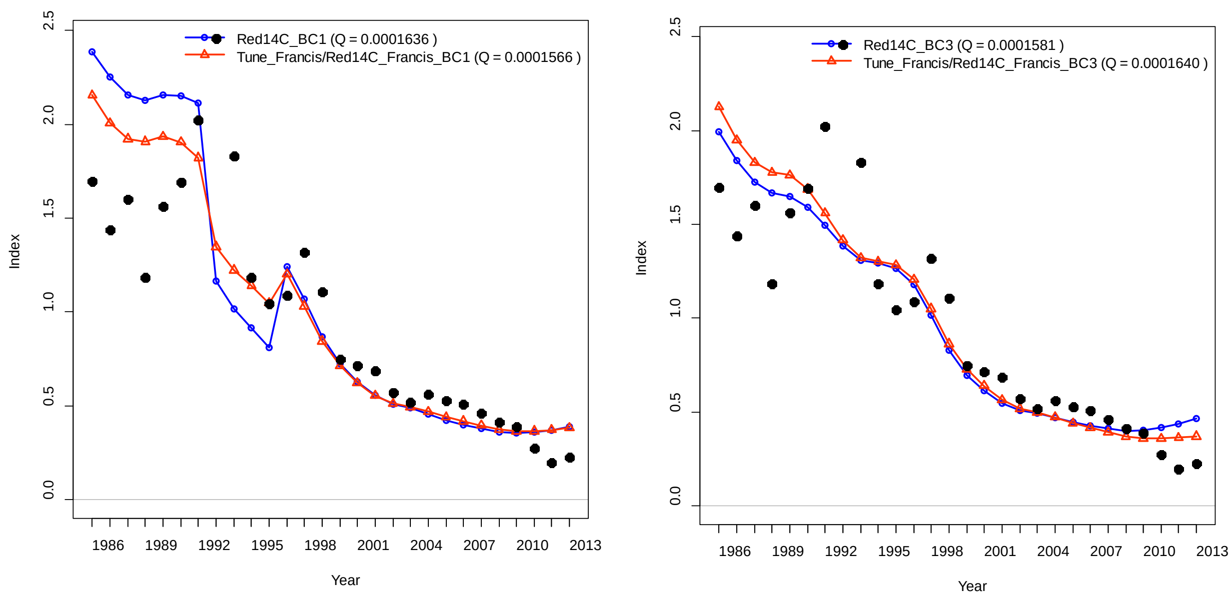


Figure 7.12. A comparison of catch rate fits using the standard method (blue) and the Francis method (red) for base-case models BC1 (left) and BC3 (right).

Using the Francis (2011) weighting procedure led to considerable down-weighting of the length and age data. In general, fits to ages remained reasonable (Appendix 3, for BC3) and fits to the catch rate series were good (Figure 7.9). Overall model outcomes were similar, in terms of stock trajectories and estimated stock status.

Table 7.5. Summary of sensitivity results for the base-case model structure BC1. Long-term RBCs are only provided for models that have been tuned.

Case		SSB_0	SSB_{2015}	SSB_{2015}/SSB_0	RBC_{2015}	$RBC_{longterm}$
0	base case 20:35:48 M=0.10 h=0.75	15,047	1,337	0.09	0	845
1	M=0.08	16,425	1,109	0.07	0	
2	M=0.12	13,345	1,575	0.12	0	
3	estimate M (0.100), h=0.75	15,088	1,331	0.09	0	
4	steepness, h =0.65	16,349	1,244	0.08	0	
5	steepness, h=0.85	14,005	1,435	0.10	0	
6	estimate h (0.593), M=0.10	17,194	1,195	0.07	0	
7	50% maturity at 18cm	15,548	1,502	0.10	0	
8	50% maturity at 20cm	14,393	1,187	0.08	0	
9	σ_R = 0.8	15,894	1,221	0.08	0	
10	begin model in 1960	15,772	1,357	0.09	0	
11	alternative discards	15,047	1,318	0.09	0	
12	Kapala lengths	15,023	1,329	0.09	0	
13	no retention blocks	13,501	1,368	0.10	0	
14	wt x 2 length comp	16,864	1,371	0.08	0	
15	wt x 0.5 length comp	14,077	1,299	0.09	0	
16	wt x 2 age comp	14,875	1,304	0.09	0	
17	wt x 0.5 age comp	15,098	1,330	0.09	0	
18	wt x 2 CPUE	14,092	1,215	0.09	0	
19	wt x 0.5 CPUE	16,519	1,526	0.09	0	
20	cap retention at 0.6 (1975-85)	16,878	1,373	0.08	0	
21	Francis weighting	13,669	1,294	0.09	0	752
22	Base case 2 (no retention blocks)	13,360	1,455	0.11	0	740

Table 7.6. Summary of likelihood components for the base-case model structure BC1 and sensitivity tests. Sensitivities from the BC1 are shown as differences from the base case. A negative value indicates a better fit, a positive value a worse fit. Note that tuned models are not comparable.

Case		Likelihood						
		TOTAL	CPUE	Discard	Length comp	Age comp	Recruitment	Parm priors
0	base case 20:35:48 M=0.10 h=0.75	7694.49	82.93	141.53	1574.67	5847.19	47.64	0.51
1	M=0.08	12.60	-5.84	-5.81	2.88	21.25	0.14	0.00
2	M=0.12	7.68	2.74	4.48	3.97	-8.05	4.54	0.00
3	estimate M (0.100), h=0.75	0.02	-0.11	-0.13	-0.01	0.34	-0.09	0.03
4	steepness, h =0.65	-6.31	-2.24	-2.29	0.38	5.22	-7.37	0.00
5	steepness, h=0.85	8.77	1.70	1.31	0.91	-3.03	7.89	0.00
6	estimate h (0.593), M=0.10	-7.38	-3.74	-3.98	1.26	9.53	-10.75	0.31
7	50% maturity at 18cm	0.50	0.11	0.10	0.03	-0.27	0.54	0.00
8	50% maturity at 20cm	-0.57	-0.13	-0.12	-0.02	0.33	-0.62	0.00
9	σ_R = 0.8	-22.21	-1.85	-2.03	-0.67	2.80	-20.46	0.00
10	begin model in 1960	36.10	1.17	7.34	27.34	-1.79	2.06	0.00
11	alternative discards	5.38	-0.58	7.07	-0.58	-1.18	0.66	0.00
12	Kapala lengths	71.85	0.82	-0.46	73.90	-1.77	-0.63	0.00
13	no retention blocks	296.95	-32.37	41.13	295.95	1.01	-8.53	-0.22
14	wt x 2 length comp	42.00	63.78	16.04	-95.41	54.12	3.49	-0.02
15	wt x 0.5 length comp	15.55	-23.44	-4.41	62.60	-17.90	-1.30	0.01
16	wt x 2 age comp	8.56	-0.14	5.02	23.97	-22.94	2.64	0.00
17	wt x 0.5 age comp	19.79	-1.24	-2.70	-35.56	61.63	-2.33	0.00
18	wt x 2 CPUE	9.75	27.42	0.80	33.95	1.44	1.32	0.01
19	wt x 0.5 CPUE	16.16	-13.15	4.48	-45.36	0.15	0.27	-0.01
20	cap retention at 0.6 (1975-85)	30.55	2.69	29.66	-2.90	-2.20	3.31	0.00
21	Francis weighting	-6097.14	-27.80	-23.33	-1300.62	-4736.01	-9.41	0.03
22	Base case 2 (no retention blocks)	-277.09	-68.93	35.39	-304.97	70.17	-8.51	-0.22

Table 7.7.Summary of sensitivity results for the base-case model structure BC3. Long-term RBCs are only provided for models that have been tuned.

Case		SSB_0	SSB_{2015}	SSB_{2015}/SSB_0	RBC_{2015}	$RBC_{longterm}$
0	base case 20:35:48 M=0.10 h=0.75	14,615	1,714	0.12	0	840
1	M=0.08	15,849	1,084	0.07	0	
2	M=0.12	13,565	2,519	0.19	0	
3	estimate M (0.100), h=0.75	14,585	1,731	0.12	0	
4	steepness, h =0.65	15,686	1,379	0.09	0	
5	steepness, h=0.85	13,907	2,089	0.15	0	
6	estimate h (0.589), M=0.10	16,538	1,199	0.07	0	
7	50% maturity at 18cm	15,135	1,958	0.13	0	
8	50% maturity at 20cm	13,939	1,494	0.11	0	
9	σ_R = 0.8	15,189	1,302	0.09	0	
10	begin model in 1960	15,412	1,788	0.12	0	
11	alternate discards	14,599	1,644	0.11	0	
12	Kapala lengths	14,612	1,681	0.12	0	
13	wt x 2 length comp	14,852	1,723	0.12	0	
14	wt x 0.5 length comp	14,276	1,648	0.12	0	
15	wt x 2 age comp	14,201	1,506	0.11	0	
16	wt x 0.5 age comp	14,902	1,811	0.12	0	
17	wt x 2 CPUE	14,275	1,444	0.10	0	
18	wt x 0.5 CPUE	15,133	2,196	0.15	0	
19	cap retention at 0.6 (1975-85)	16,510	1,883	0.11	0	
20	Francis weighting	13,281	1,185	0.09	0	727

Table 7.8. Summary of likelihood components for the base-case model structure BC3 and sensitivity tests. Sensitivities from the BC3 are shown as differences from the base case. A negative value indicates a better fit, a positive value a worse fit. Note that tuned models are not comparable.

Case		Likelihood						
		TOTAL	CPUE	Discard	Length comp	Age comp	Recruitment	Parm priors
0	base case 20:35:48 M=0.10 h=0.75	7581.97	13.95	171.80	1594.37	5762.65	38.85	0.34
1	M=0.08	10.62	-1.79	-3.68	-3.69	17.97	1.82	0.00
2	M=0.12	4.71	4.69	3.02	4.25	-7.70	0.45	0.00
3	estimate M (0.100), h=0.75	0.03	0.08	0.09	0.10	-0.28	0.01	0.03
4	steepness, h =0.65	-5.44	-1.80	-1.45	-1.56	3.91	-4.53	0.00
5	steepness, h=0.85	6.54	2.85	0.59	1.43	-2.11	3.79	0.00
6	estimate h (0.589), M=0.10	-6.55	-2.29	-2.80	-2.42	7.74	-7.10	0.32
7	50% maturity at 18cm	0.48	0.14	0.06	0.15	-0.25	0.38	0.00
8	50% maturity at 20cm	-0.55	-0.16	-0.07	-0.17	0.29	-0.44	0.00
9	σ_R = 0.8	-19.25	-2.19	-1.28	-0.81	0.79	-15.76	0.00
10	begin model in 1960	35.04	0.46	7.21	26.93	-1.18	1.61	0.00
11	alternate discards	5.20	-0.46	7.01	-0.92	-1.42	0.99	0.00
12	Kapala lengths	60.62	0.03	1.10	59.87	-0.21	-0.16	0.00
13	wt x 2 length comp	23.29	0.81	8.32	-48.34	63.04	-0.52	-0.01
14	wt x 0.5 length comp	9.42	-0.65	-7.09	34.57	-18.17	0.75	0.01
15	wt x 2 age comp	8.68	-1.52	3.02	25.85	-23.30	4.63	0.00
16	wt x 0.5 age comp	20.07	1.55	0.12	-40.07	62.49	-4.02	-0.01
17	wt x 2 CPUE	0.63	10.57	0.11	0.98	-1.42	2.65	0.00
18	wt x 0.5 CPUE	1.26	-4.95	-0.71	-0.53	1.79	-3.34	0.00
19	cap retention at 0.6 (1975-85)	31.14	1.21	29.01	0.09	-1.88	2.72	0.00
20	Francis weighting	-6061.26	34.39	-37.53	-1401.81	-4656.37	0.02	0.03

7.7.5 *Further development*

- Further refinement of the Francis (2011) method, in particular for assessments with age-at-length data.
- Agree to a model structure, with regard to discard function.
- Explore what may be leading to the variations in year-to-year length data.

7.8 Acknowledgements

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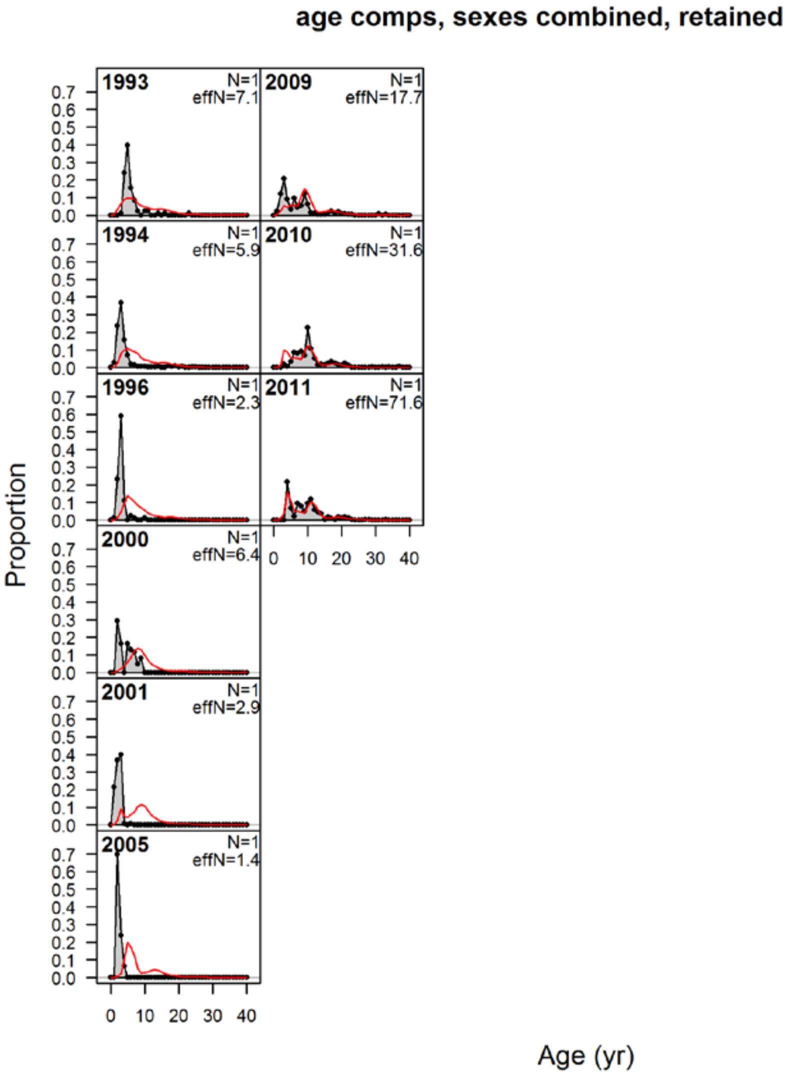
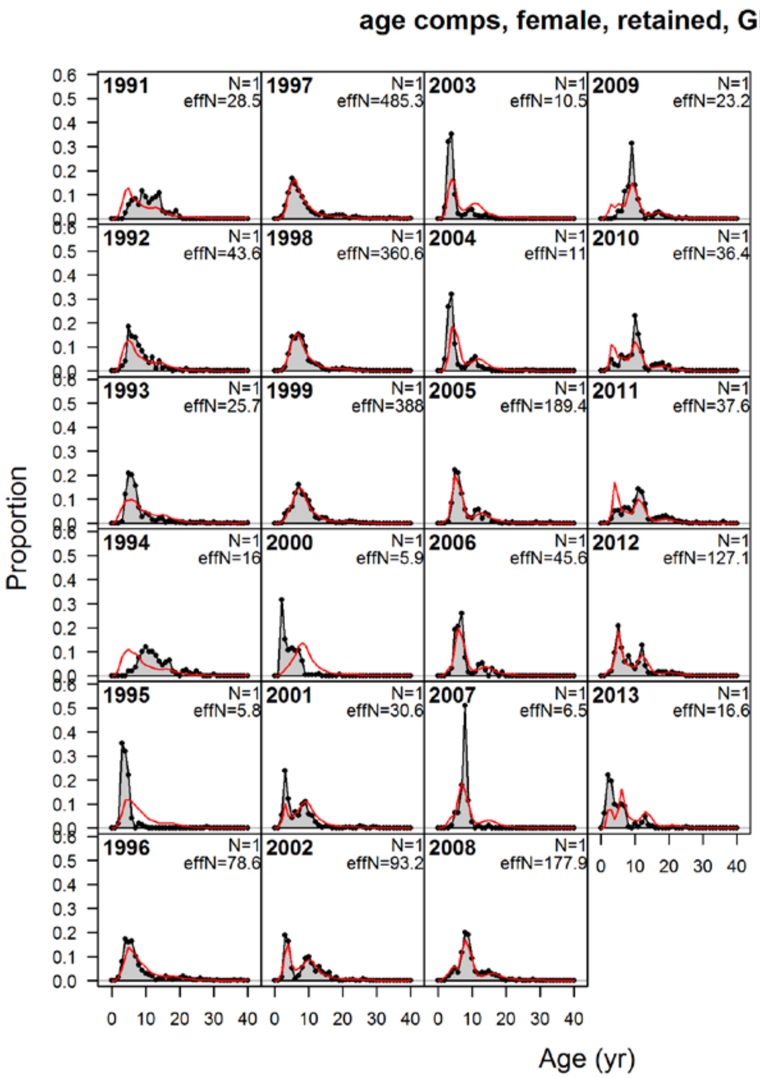
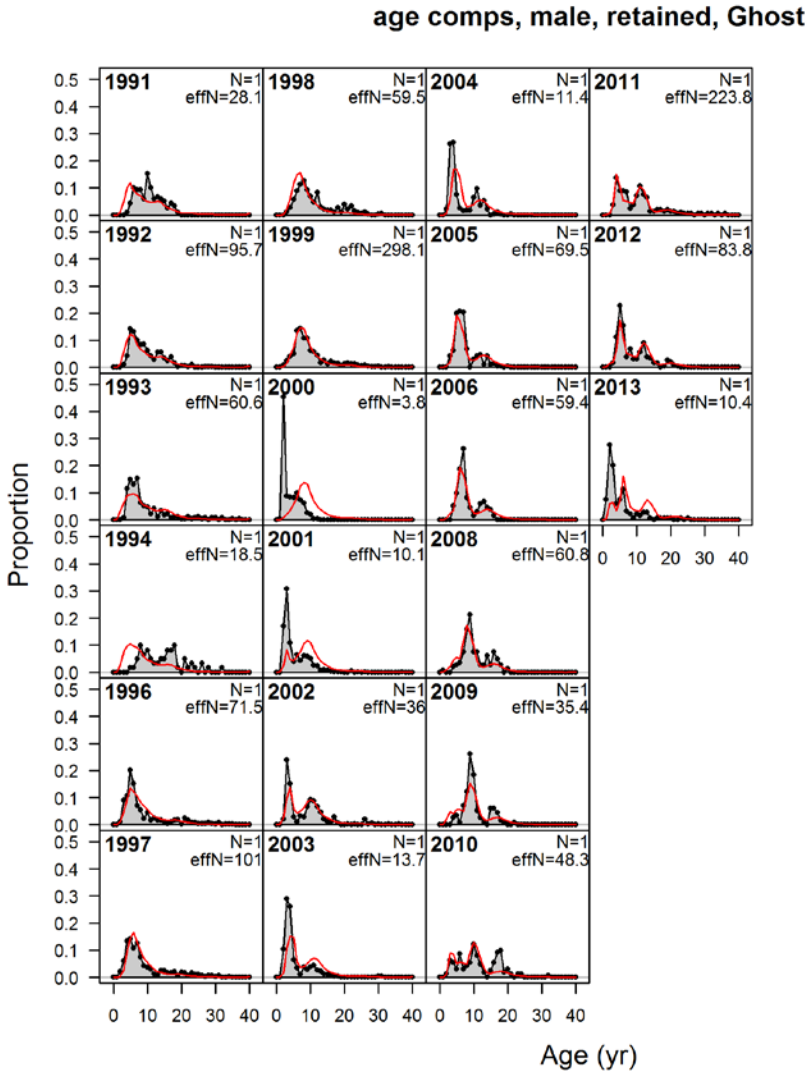
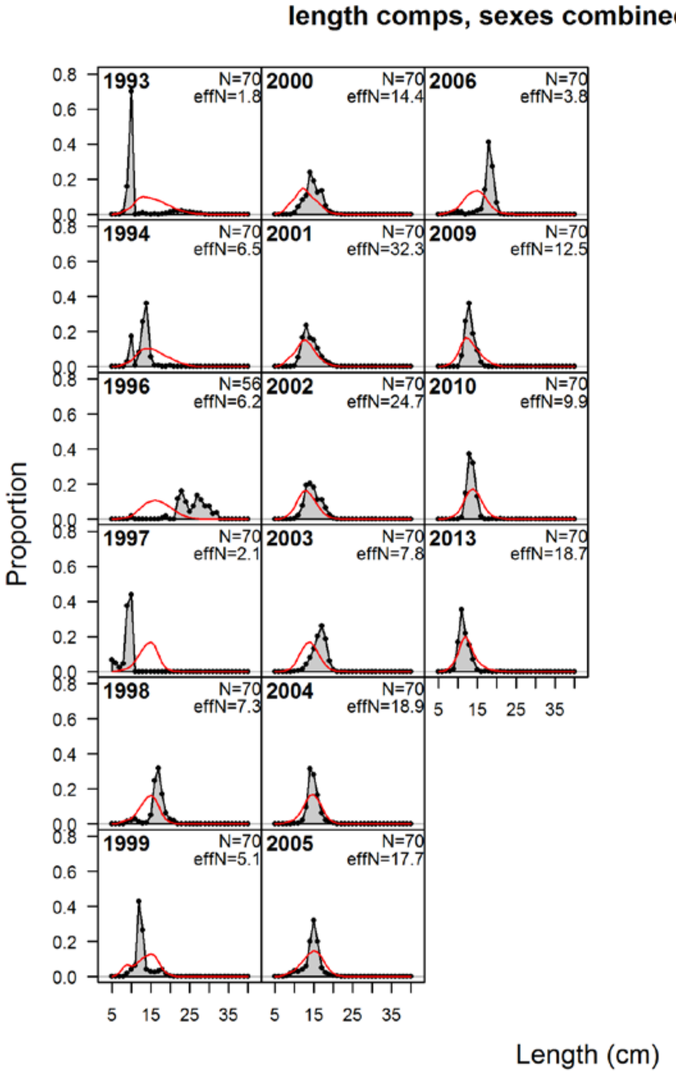
Wise, B. 2002. Redfish and growth overfishing. Report to redfish assessment group. 2p.

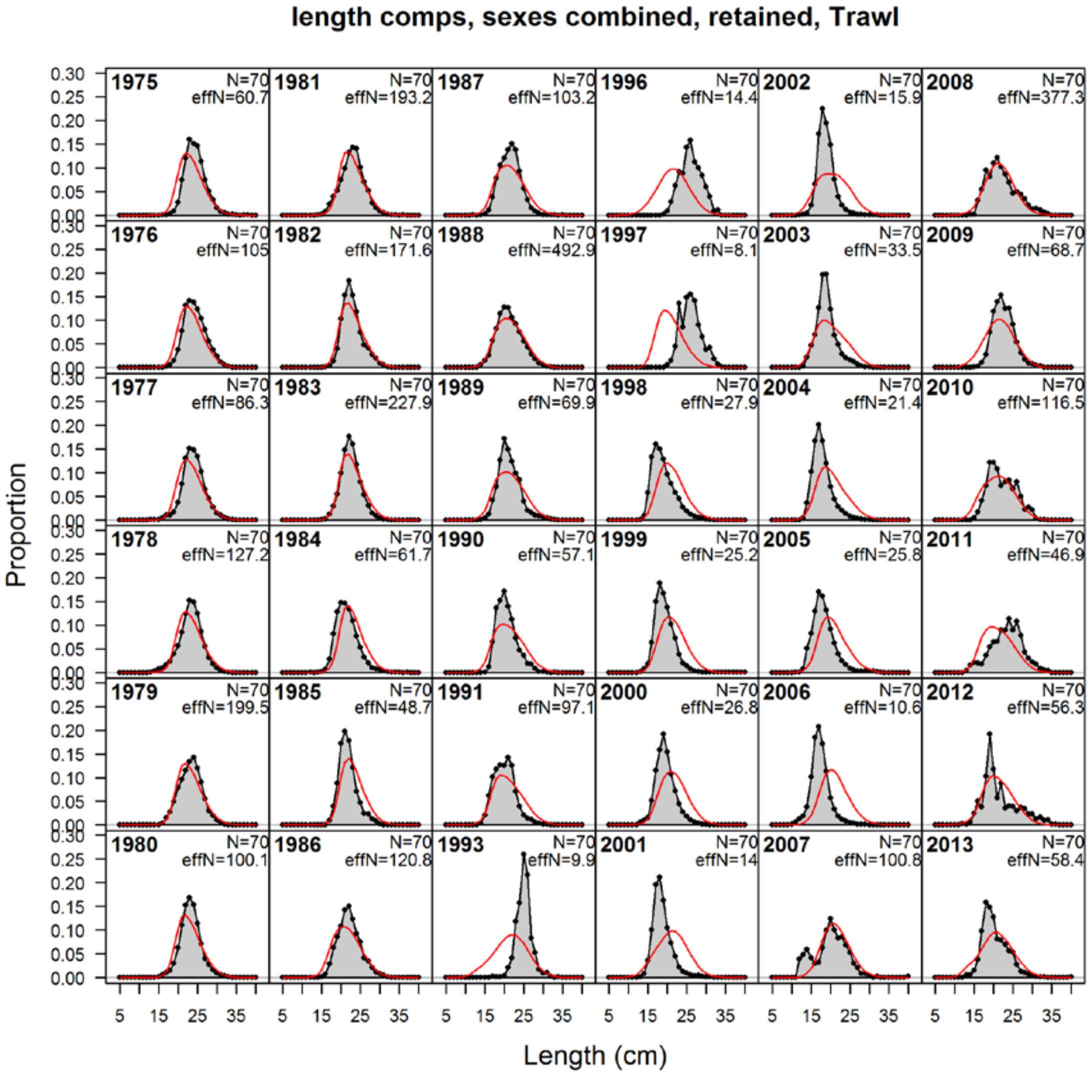
7.10 Appendix 1: Base case 1 (BC1)



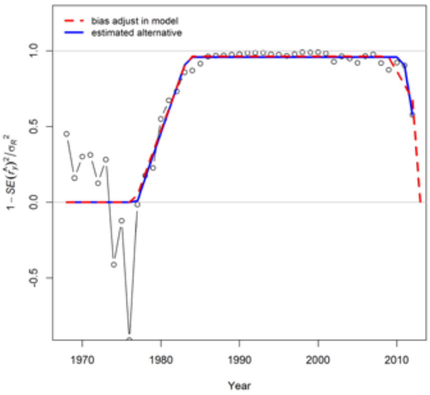

age comps, female, retained, Ghost
Proportion
Age (yr)
1991 N=1 effN=28.5
1997 N=1 effN=485.3
2003 N=1 effN=10.5
2009 N=1 effN=23.2
1992 N=1 effN=43.6
1998 N=1 effN=360.6
2004 N=1 effN=11
2010 N=1 effN=36.4
1993 N=1 effN=25.7
1999 N=1 effN=388
2005 N=1 effN=189.4
2011 N=1 effN=37.6
1994 N=1 effN=16
2000 N=1 effN=5.9
2006 N=1 effN=45.6
2012 N=1 effN=127.1
1995 N=1 effN=5.8
2001 N=1 effN=30.6
2007 N=1 effN=6.5
2013 N=1 effN=16.6
1996 N=1 effN=78.6
2002 N=1 effN=93.2
2008 N=1 effN=177.9

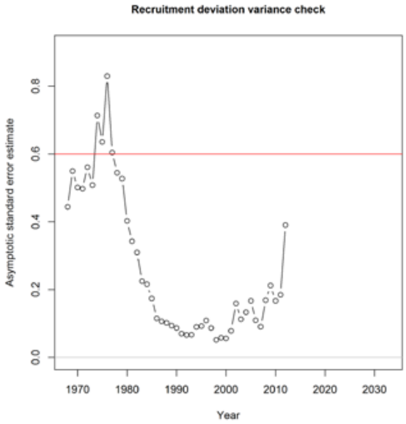

age comps, male, retained, Ghost
1991 N=1 effN=28.1
1998 N=1 effN=59.5
2004 N=1 effN=11.4
2011 N=1 effN=223.8
1992 N=1 effN=95.7
1999 N=1 effN=298.1
2005 N=1 effN=69.5
2012 N=1 effN=83.8
1993 N=1 effN=60.6
2000 N=1 effN=3.8
2006 N=1 effN=59.4
2013 N=1 effN=10.4
1994 N=1 effN=18.5
2001 N=1 effN=10.1
2008 N=1 effN=60.8
1996 N=1 effN=71.5
2002 N=1 effN=36
2009 N=1 effN=35.4
1997 N=1 effN=101
2003 N=1 effN=13.7
2010 N=1 effN=48.3
Proportion
Age (yr)

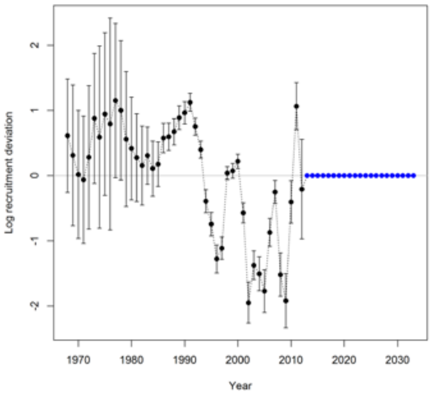

length comps, sexes combined, discard, Trawl
Proportion
Length (cm)
1993 N=70 effN=1.8
2000 N=70 effN=14.4
2006 N=70 effN=3.8
1994 N=70 effN=6.5
2001 N=70 effN=32.3
2009 N=70 effN=12.5
1996 N=56 effN=6.2
2002 N=70 effN=24.7
2010 N=70 effN=9.9
1997 N=70 effN=2.1
2003 N=70 effN=7.8
2013 N=70 effN=18.7
1998 N=70 effN=7.3
2004 N=70 effN=18.9
1999 N=70 effN=5.1
2005 N=70 effN=17.7

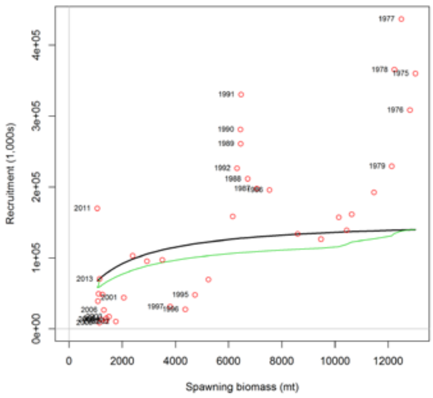


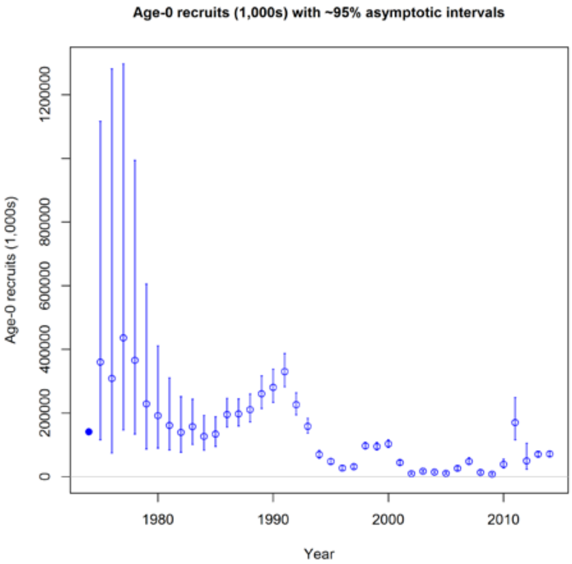
length comps, sexes combined, retained, Trawl
Proportion
Length (cm)
1975 N=70 effN=60.7
1981 N=70 effN=193.2
1987 N=70 effN=103.2
1996 N=70 effN=14.4
2002 N=70 effN=15.9
2008 N=70 effN=377.3
1976 N=70 effN=105
1982 N=70 effN=171.6
1988 N=70 effN=492.9
1997 N=70 effN=8.1
2003 N=70 effN=33.5
2009 N=70 effN=68.7
1977 N=70 effN=86.3
1983 N=70 effN=227.9
1989 N=70 effN=69.9
1998 N=70 effN=27.9
2004 N=70 effN=21.4
2010 N=70 effN=116.5
1978 N=70 effN=127.2
1984 N=70 effN=61.7
1990 N=70 effN=57.1
1999 N=70 effN=25.2
2005 N=70 effN=25.8
2011 N=70 effN=46.9
1979 N=70 effN=199.5
1985 N=70 effN=48.7
1991 N=70 effN=97.1
2000 N=70 effN=26.8
2006 N=70 effN=10.6
2012 N=70 effN=56.3
1980 N=70 effN=100.1
1986 N=70 effN=120.8
1993 N=70 effN=9.9
2001 N=70 effN=14
2007 N=70 effN=100.8
2013 N=70 effN=58.4


bias adjust in model
estimated alternative
Year

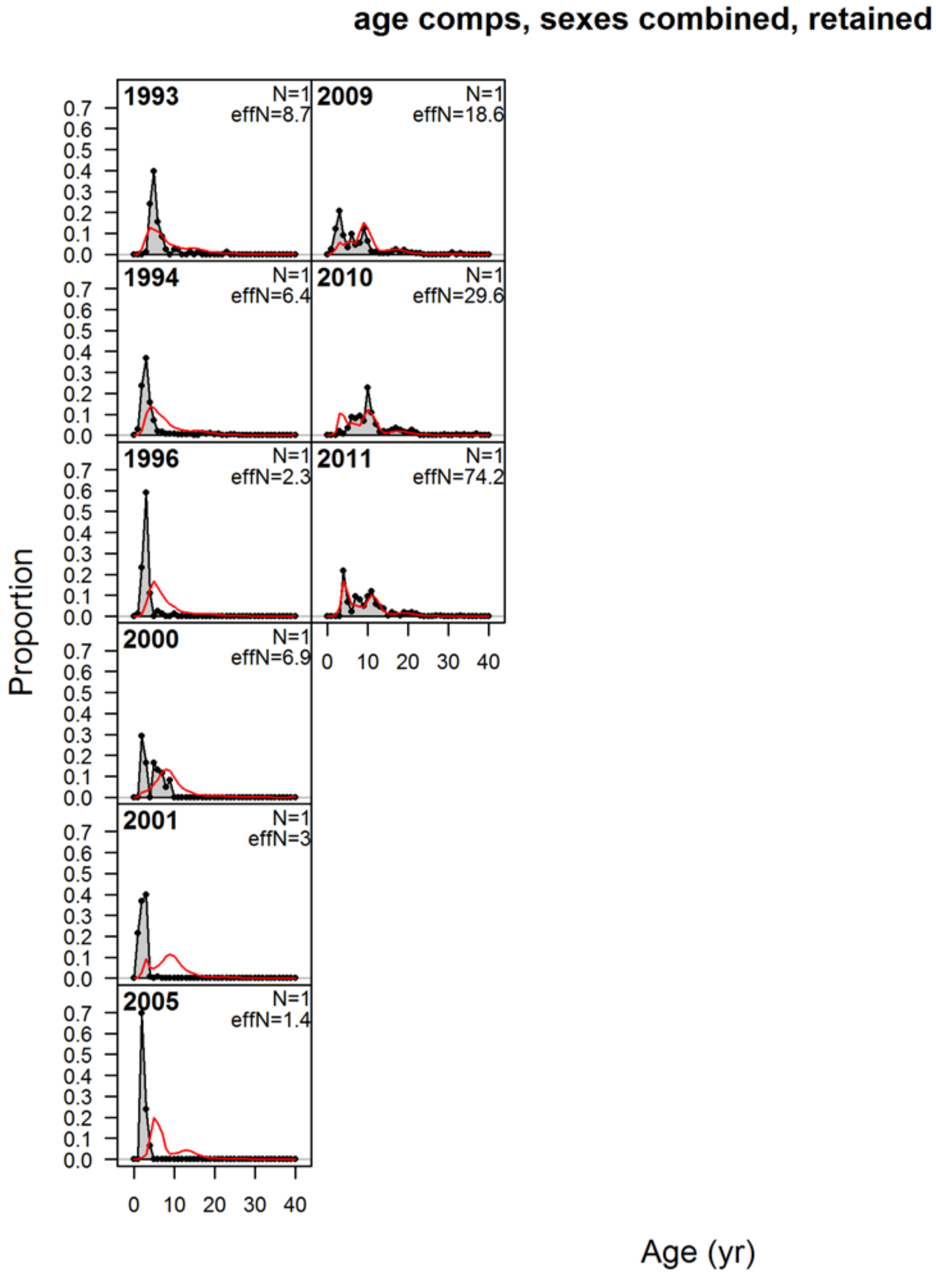

Recruitment deviation variance check
Asymptotic standard error estimate
Year

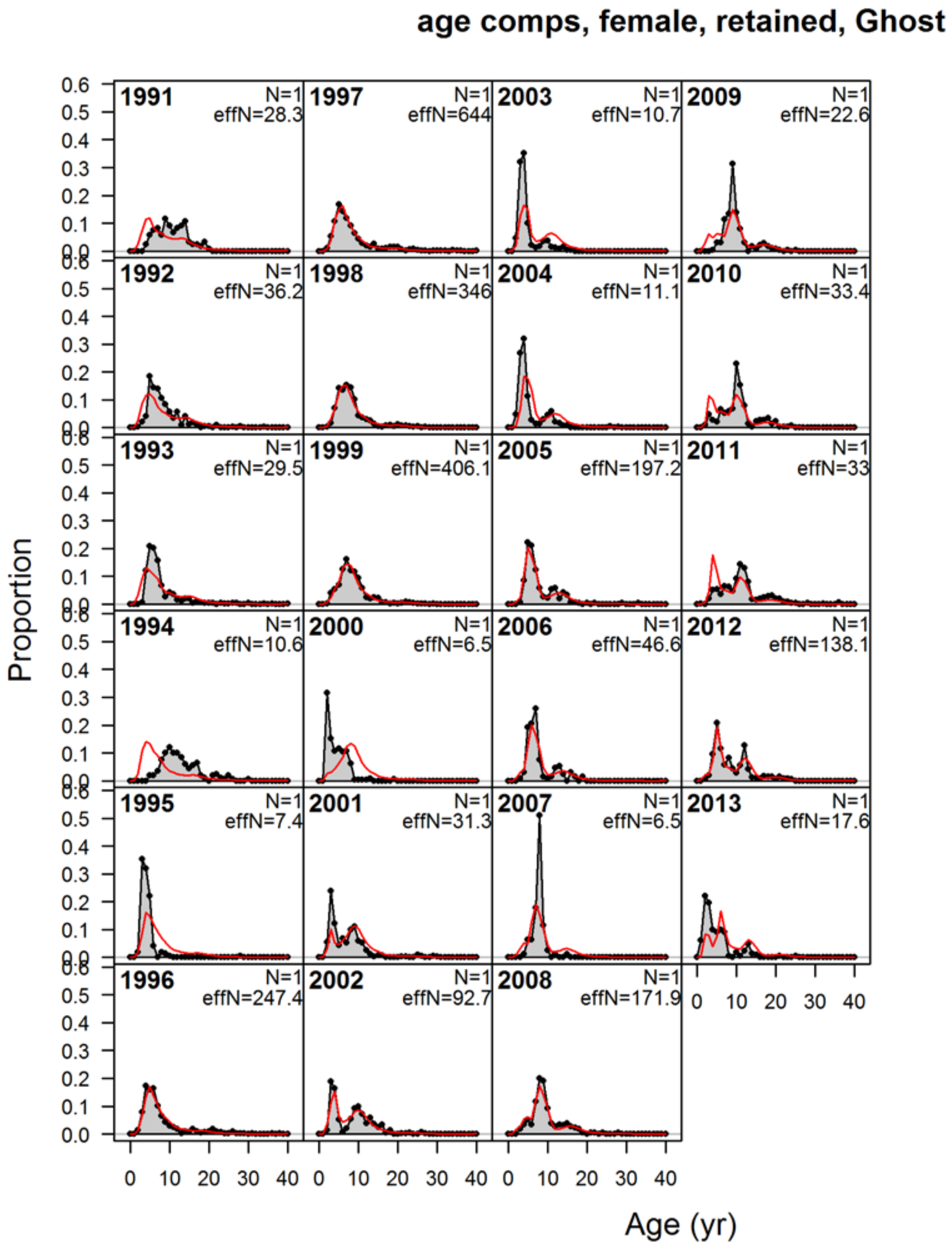

Log recruitment deviation
Year

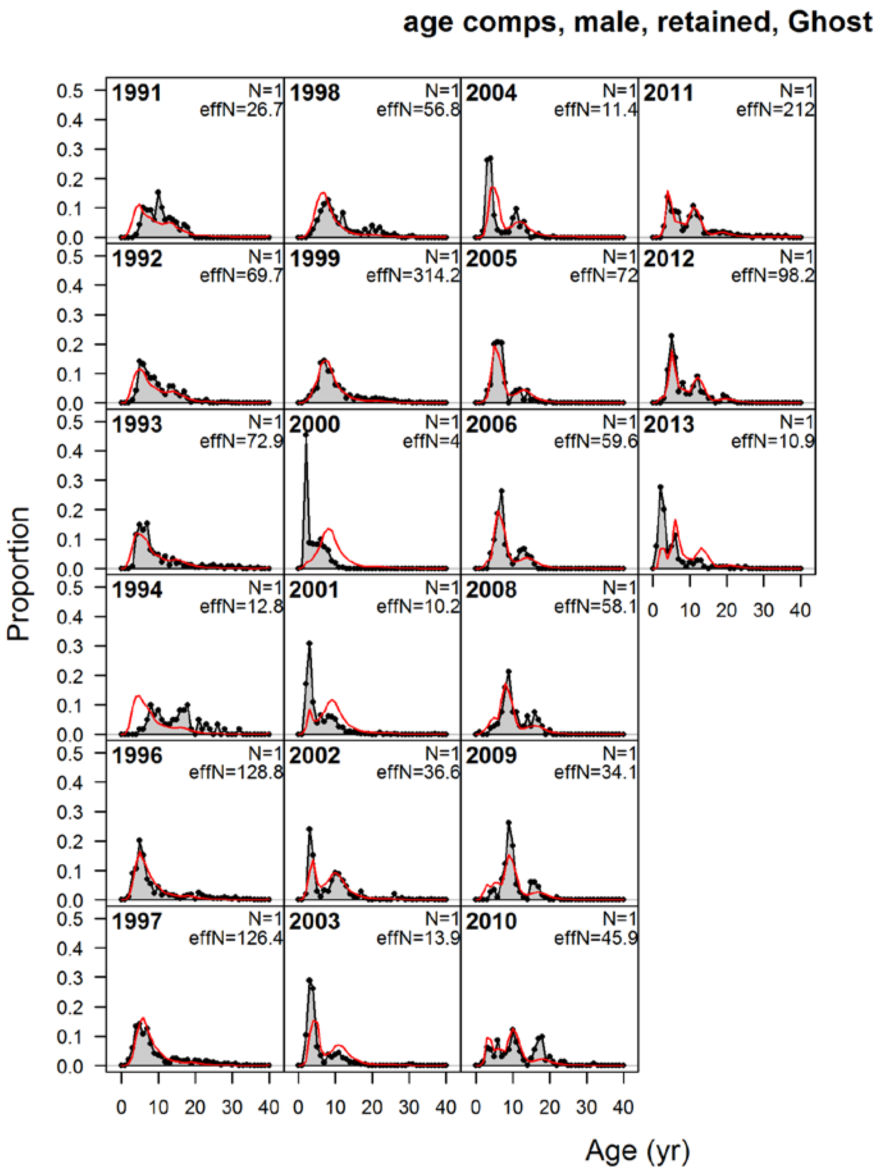

Recruitment (1,000s)
Spawning biomass (mt)


Age-0 recruits (1,000s) with ~95% asymptotic intervals
Age-0 recruits (1,000s)
Year

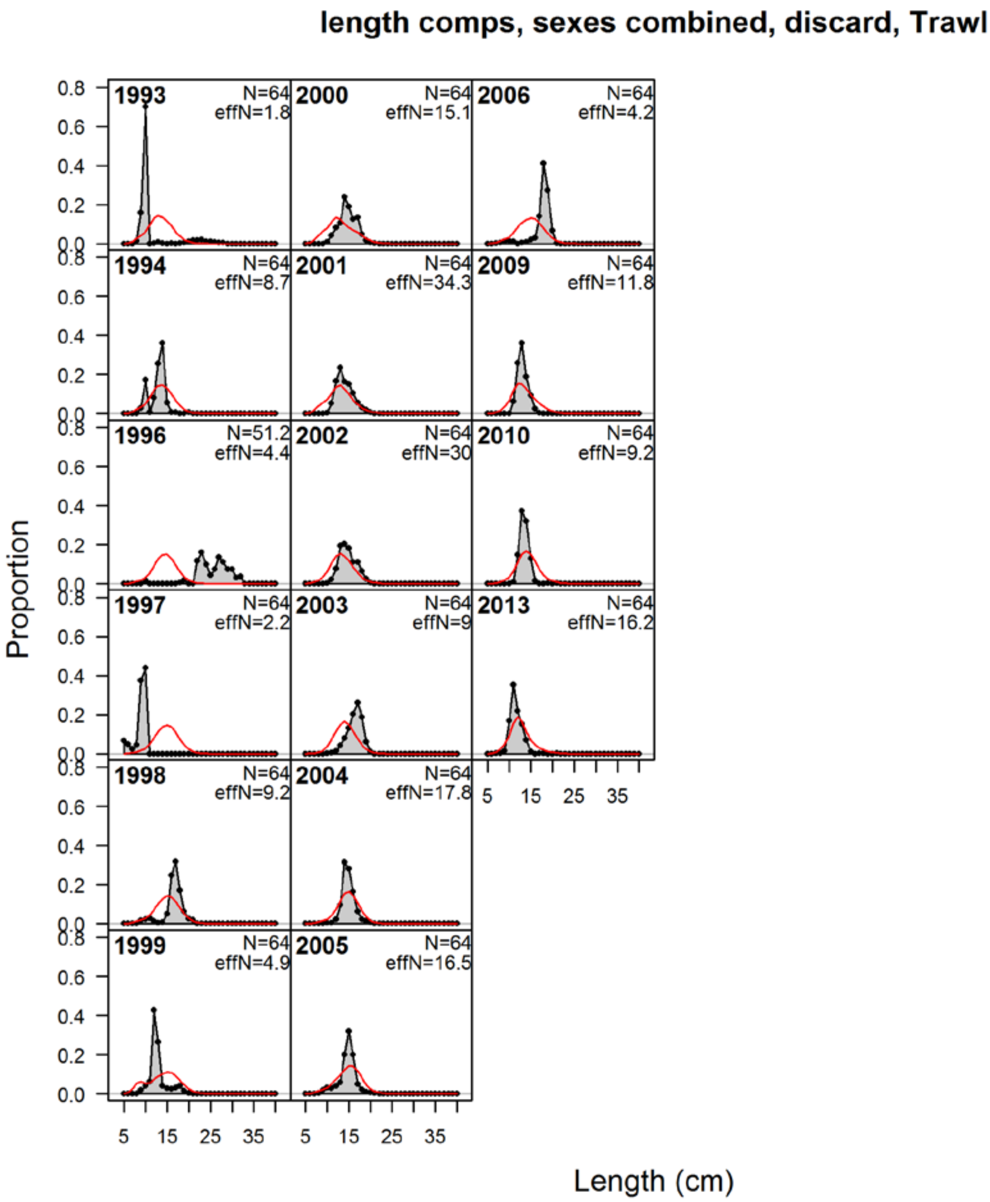
7.11 Appendix 2: Base case 3 (BC3)

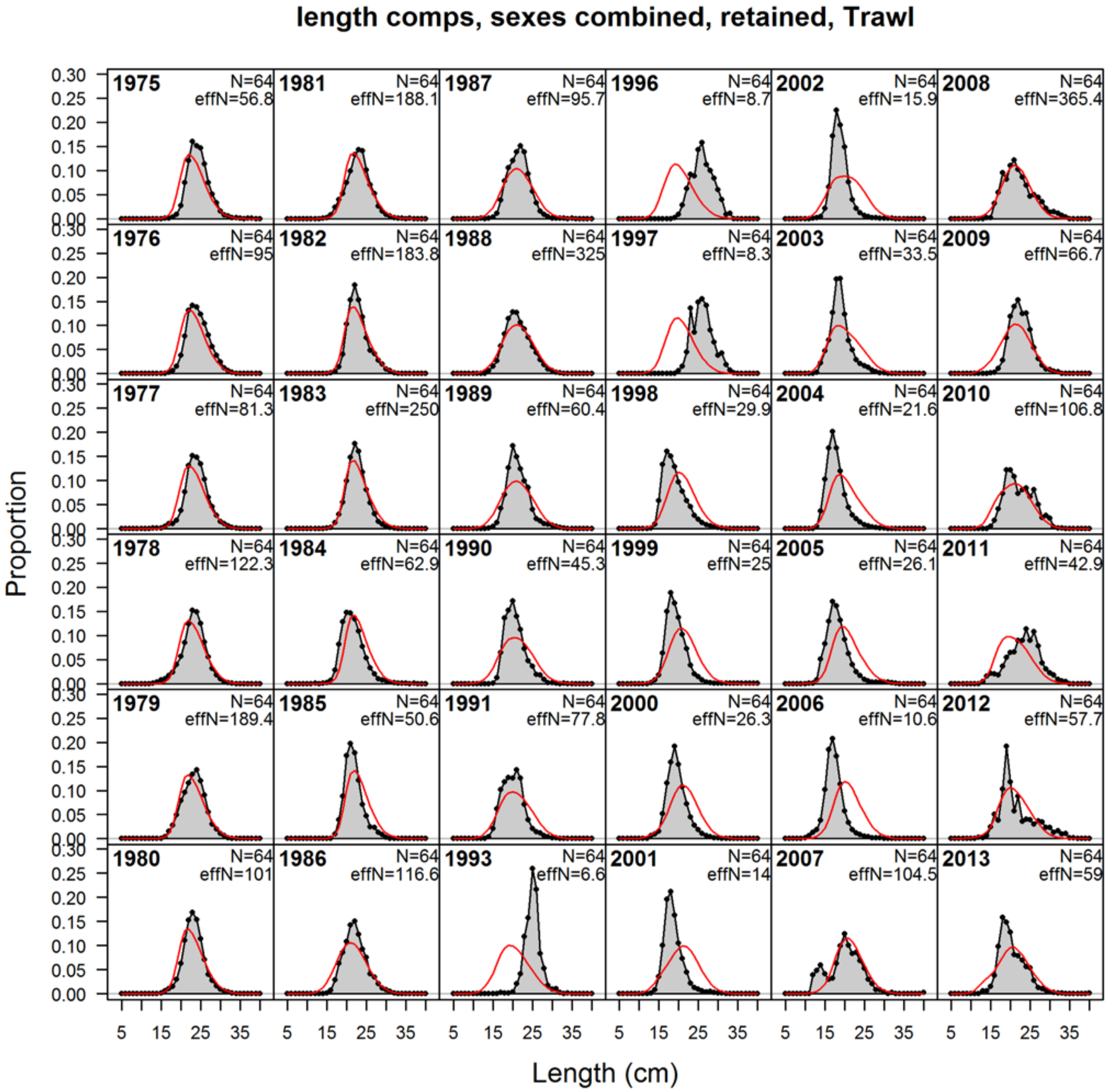



age comps, female, retained, Ghost
Proportion
Age (yr)
1991 N=1 effN=28.3
1997 N=1 effN=644
2003 N=1 effN=10.7
2009 N=1 effN=22.6
1992 N=1 effN=36.2
1998 N=1 effN=346
2004 N=1 effN=11.1
2010 N=1 effN=33.4
1993 N=1 effN=29.5
1999 N=1 effN=406.1
2005 N=1 effN=197.2
2011 N=1 effN=33
1994 N=1 effN=10.6
2000 N=1 effN=6.5
2006 N=1 effN=46.6
2012 N=1 effN=138.1
1995 N=1 effN=7.4
2001 N=1 effN=31.3
2007 N=1 effN=6.5
2013 N=1 effN=17.6
1996 N=1 effN=247.4
2002 N=1 effN=92.7
2008 N=1 effN=171.9



age comps, male, retained, Ghost
1991 N=1 effN=26.7
1998 N=1 effN=56.8
2004 N=1 effN=11.4
2011 N=1 effN=212
1992 N=1 effN=69.7
1999 N=1 effN=314.2
2005 N=1 effN=72
2012 N=1 effN=98.2
1993 N=1 effN=72.9
2000 N=1 effN=4
2006 N=1 effN=59.6
2013 N=1 effN=10.9
1994 N=1 effN=12.8
2001 N=1 effN=10.2
2008 N=1 effN=58.1
1996 N=1 effN=128.8
2002 N=1 effN=36.6
2009 N=1 effN=34.1
1997 N=1 effN=126.4
2003 N=1 effN=13.9
2010 N=1 effN=45.9
Proportion
Age (yr)


length comps, sexes combined, discard, Trawl
Proportion
Length (cm)
1993 N=64 effN=1.8
2000 N=64 effN=15.1
2006 N=64 effN=4.2
1994 N=64 effN=8.7
2001 N=64 effN=34.3
2009 N=64 effN=11.8
1996 N=51.2 effN=4.4
2002 N=64 effN=30
2010 N=64 effN=9.2
1997 N=64 effN=2.2
2003 N=64 effN=9
2013 N=64 effN=16.2
1998 N=64 effN=9.2
2004 N=64 effN=17.8
1999 N=64 effN=4.9
2005 N=64 effN=16.5


length comps, sexes combined, retained, Trawl
Proportion
Length (cm)
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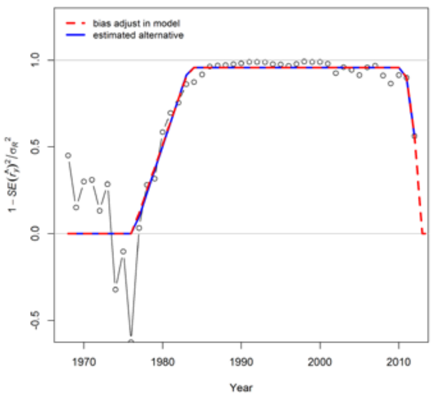
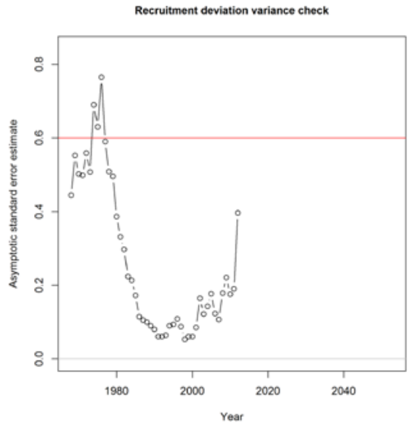
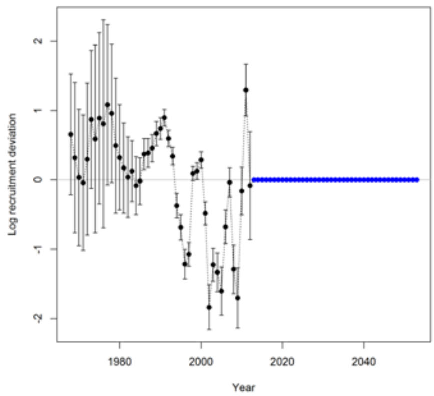
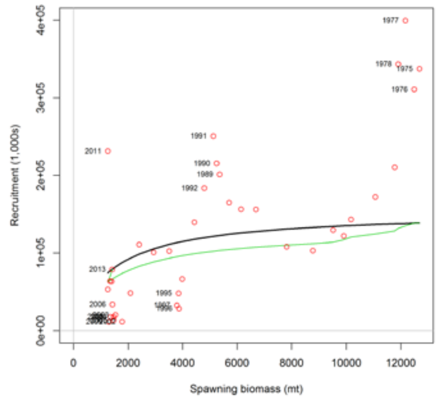
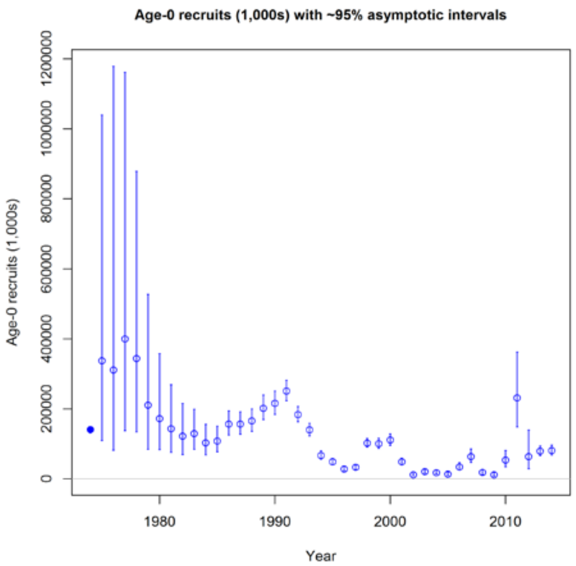
1981 N=64 effN=188.1
1987 N=64 effN=95.7
1996 N=64 effN=8.7
2002 N=64 effN=15.9
2008 N=64 effN=365.4
1976 N=64 effN=95
1982 N=64 effN=183.8
1988 N=64 effN=325
1997 N=64 effN=8.3
2003 N=64 effN=33.5
2009 N=64 effN=66.7
1977 N=64 effN=81.3
1983 N=64 effN=250
1989 N=64 effN=60.4
1998 N=64 effN=29.9
2004 N=64 effN=21.6
2010 N=64 effN=106.8
1978 N=64 effN=122.3
1984 N=64 effN=62.9
1990 N=64 effN=45.3
1999 N=64 effN=25
2005 N=64 effN=26.1
2011 N=64 effN=42.9
1979 N=64 effN=189.4
1985 N=64 effN=50.6
1991 N=64 effN=77.8
2000 N=64 effN=26.3
2006 N=64 effN=10.6
2012 N=64 effN=57.7
1980 N=64 effN=101
1986 N=64 effN=116.6
1993 N=64 effN=6.6
2001 N=64 effN=14
2007 N=64 effN=104.5
2013 N=64 effN=59


bias adjust in model
estimated alternative
Year

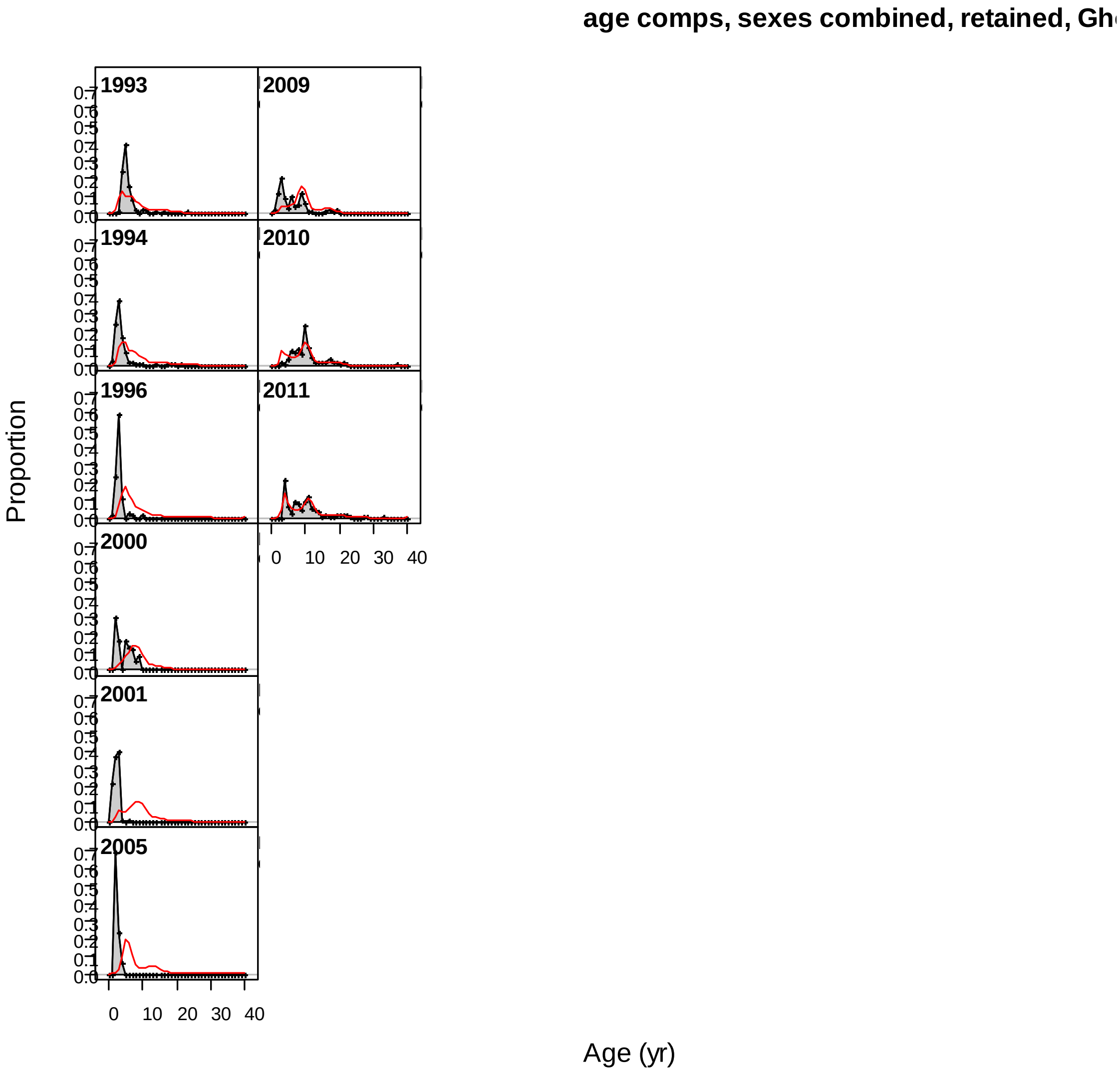

Recruitment deviation variance check
Asymptotic standard error estimate
Year

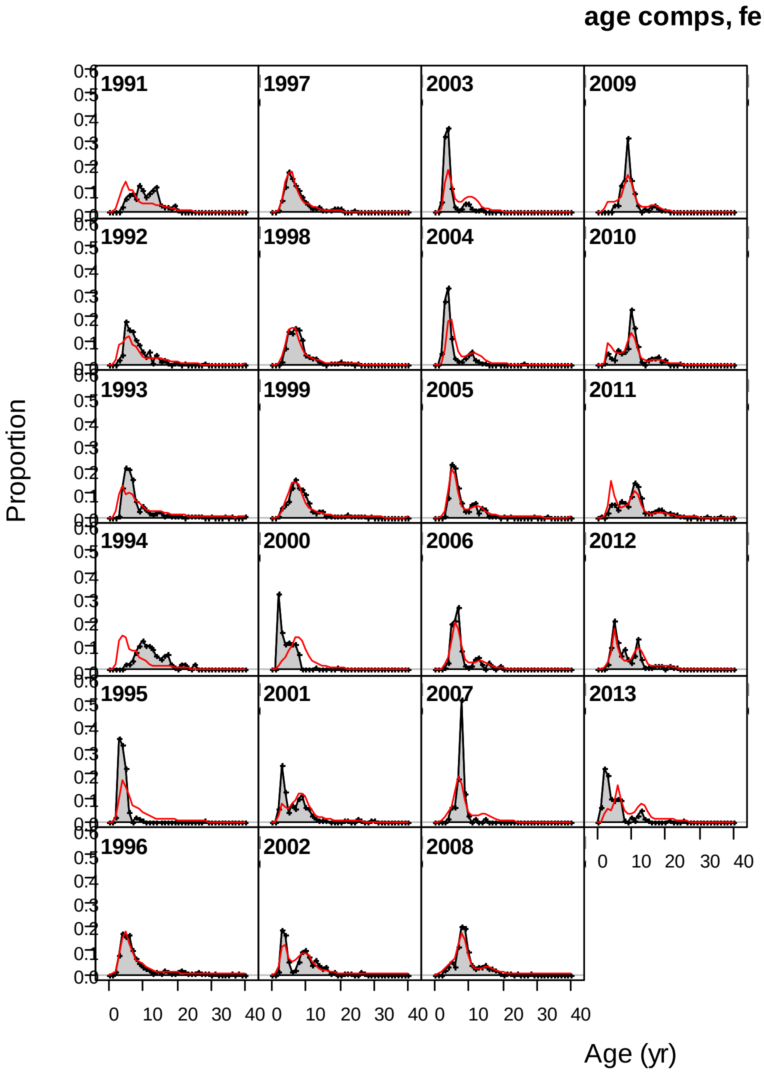

Log recruitment deviation
Year

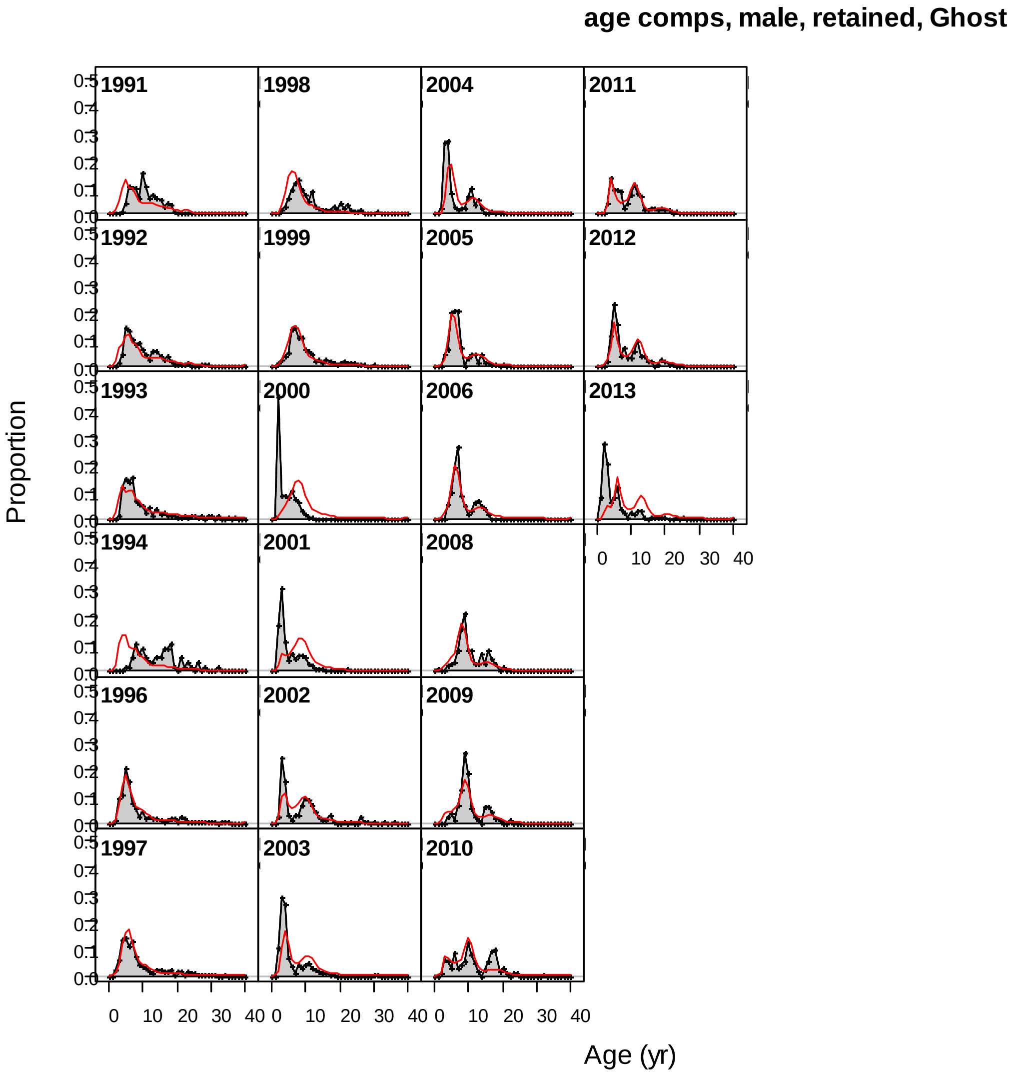

Recruitment (1,000s)
Spawning biomass (mt)

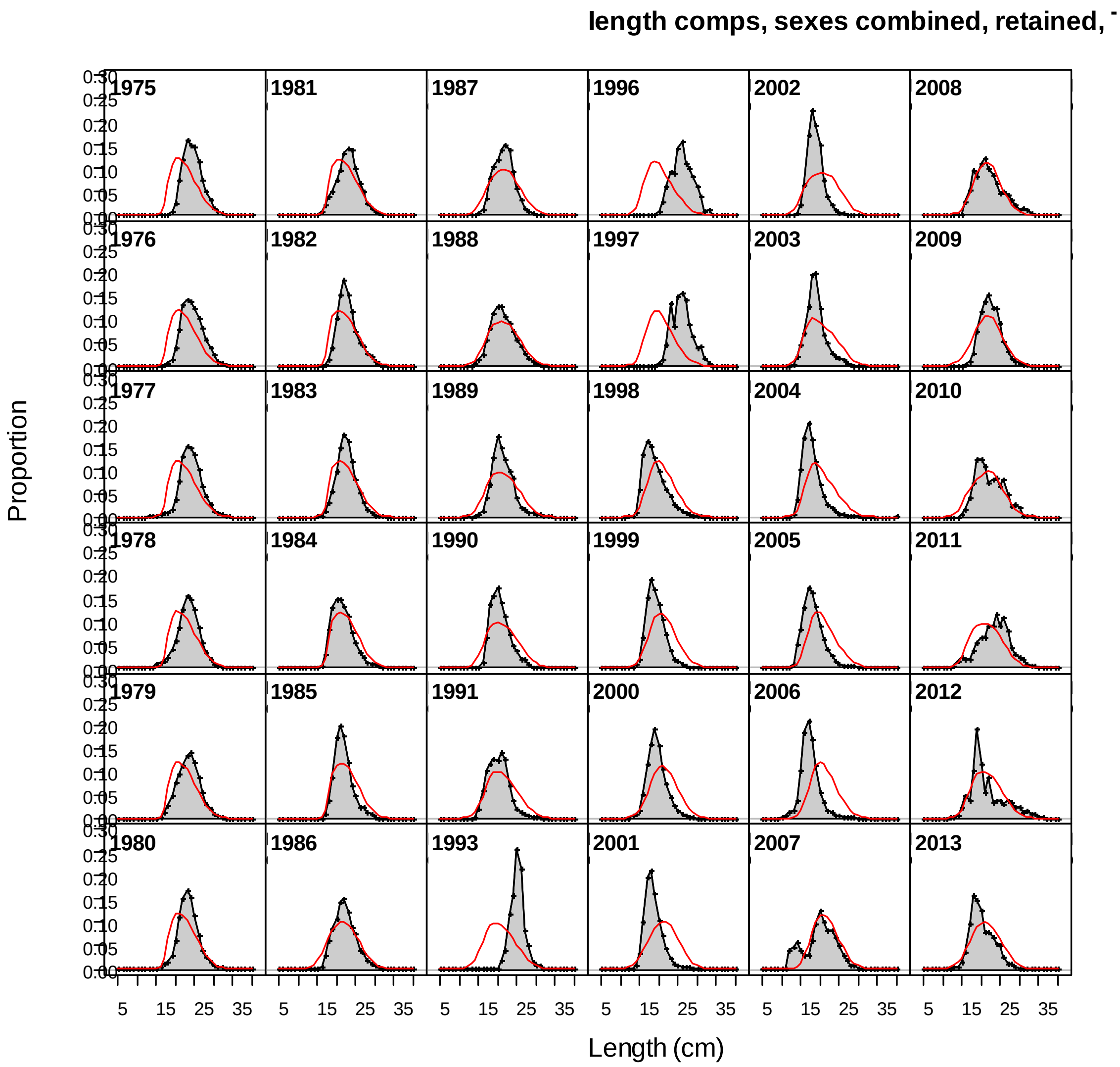

Age-0 recruits (1,000s) with ~95% asymptotic intervals
Age-0 recruits (1,000s)
Year

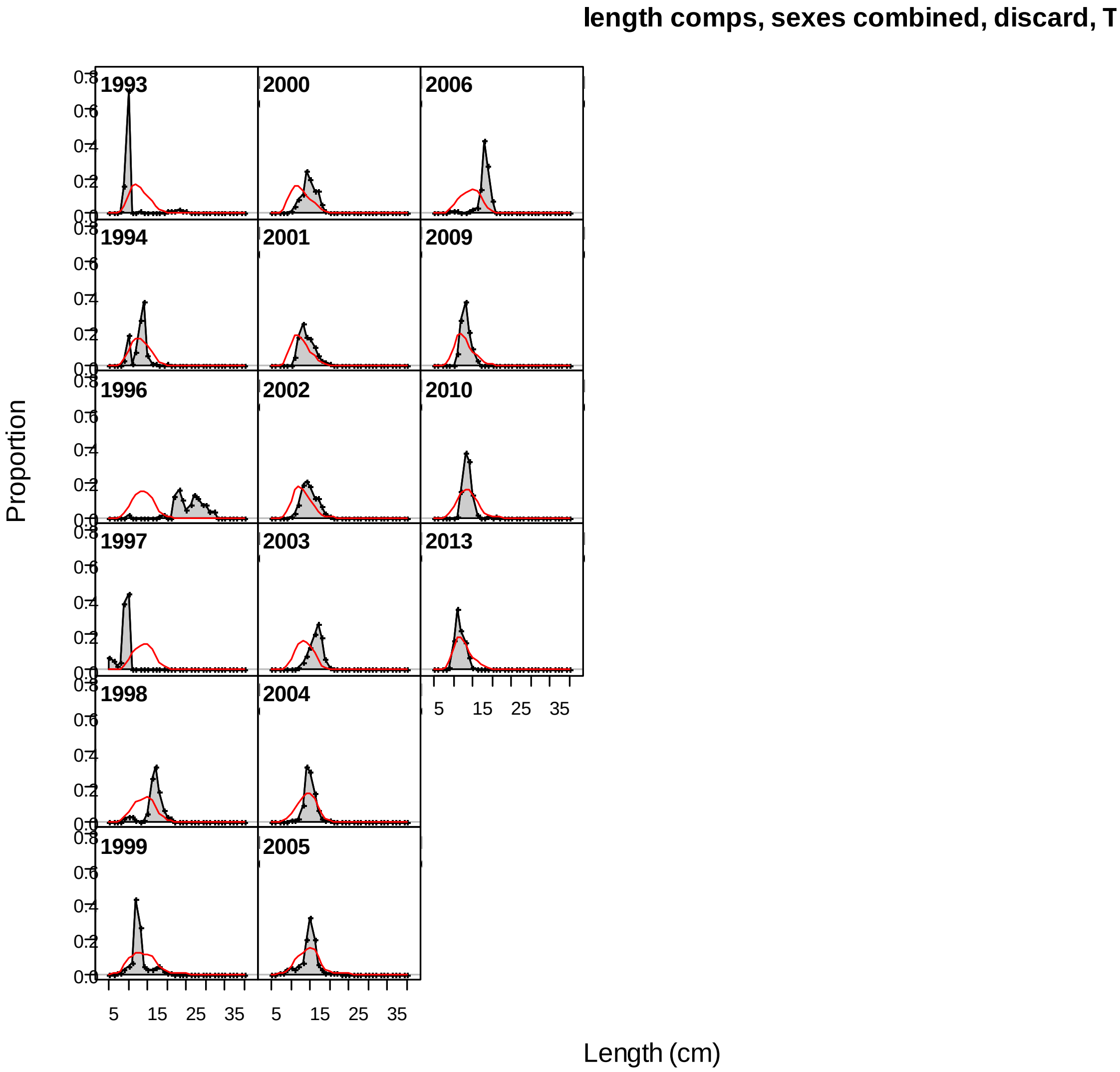
7.12 Appendix 3: Base case 3 (BC3) with francis weighting

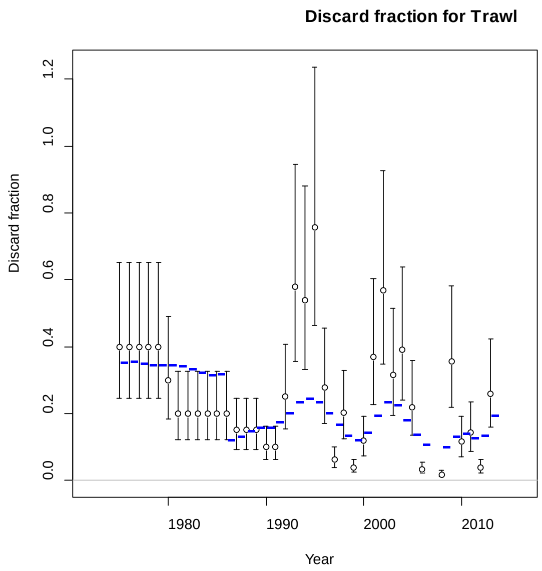


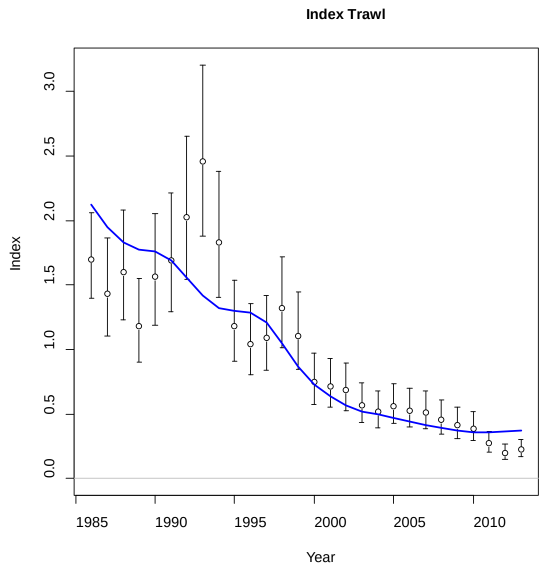

age comps, female, retained, Ghost
Proportion
Age (yr)
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
10
20
30
40

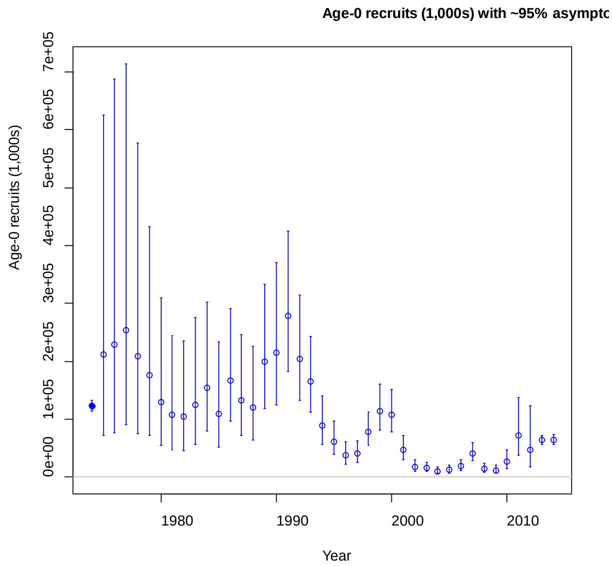

age comps, male, retained, Ghost
Proportion
Age (yr)
1991
1992
1993
1994
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2008
2009
2010
2011
2012
2013
0.5
0.4
0.3
0.2
0.1
0.0
0
10
20
30
40

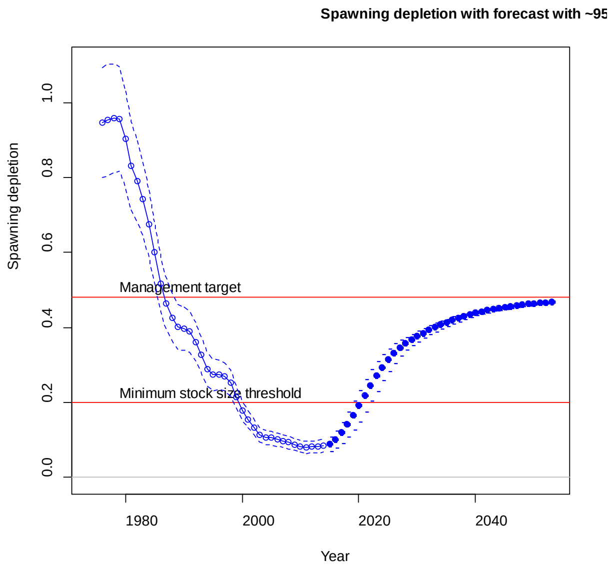

length comps, sexes combined, retained,
Proportion
Length (cm)
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1993
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
0.00
0.05
0.10
0.15
0.20
0.25
0.30
5
15
25
35


length comps, sexes combined, discard, T
1993
2000
2006
1994
2001
2009
1996
2002
2010
1997
2003
2013
1998
2004
1999
2005
Proportion
Length (cm)
0.0
0.2
0.4
0.6
0.8
5
15
25
35


Discard fraction for Trawl
Discard fraction
Year


Index Trawl
Index
Year


Age-0 recruits (1,000s) with ~95% asymptc
Age-0 recruits (1,000s)
Year


Spawning depletion with forecast with ~95
Spawning depletion
Management target
Minimum stock size threshold
Year

8. Stock assessment of redfish *Centroberyx affinis* based on data up to 2013: Supplement to the October 2014 Shelf RAG paper

G.N. Tuck[1]

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8.1 Summary

This report supplements the previous eastern redfish (*Centroberyx affinis*) stock assessments presented in Tuck and Day (2014) by the inclusion of NSW state catch data from 2005 to 2013 inclusive. The catch data of Tuck and Day (2014) were those RAG agreed catch records from previous redfish assessment group meetings that included state and Commonwealth catches (see Rowling 1999; Klaer 2005) and Commonwealth CDR data from 2005. The NSW (state) recorded catch data from 2005 to 2013 in total were 297 t, compared to 2167 t in total from Commonwealth catch records over the same period. This supplementary report provides a comparison of assessment results between the BC3 redfish stock assessment (the RAG agreed base case from October 2014) and the BC3 model with the addition of NSW catch data (hereafter referred to as BC4).

A comparison of BC3 and BC4 showed only minor differences in outcomes across all metrics. The estimated virgin female spawning biomass was 14,615 t under BC3 compared to 14,558 t under BC4. The estimated stock status in 2015 for BC3 was 11.7%, compared to 10.8% for BC4. The estimated stock status is below the limit reference point of 20% for both base-case models BC3 and BC4 assuming the 20:35:48 harvest control rule, and the RBCs are consequently zero.

As described in Tuck and Day (2014), empirical evidence in the aging data suggests that there have been two recent years of improved recruitment (i.e. in 2011 and 2012). While a small improvement in catch rates may also have occurred as a consequence of these fish moving into the available biomass, the existence and magnitude of these recruitments should be monitored over the ensuing years to verify what may be a positive sign for the stock.

8.2 Introduction

An integrated analysis model, implemented in the generalized stock assessment software package, Stock Synthesis (SS) (Methot, 2011; Methot and Wetzel, 2013. V3.24f), was applied to the eastern redfish stock of the SESSF, with data from 1975 to the 2013 calendar year (length and age data; age-error, catch rate series; landings and discard rates). The model fits directly to catch rates, discard rates, length frequencies (by sex where possible) and conditional age-at-length data.

This paper supplements Tuck and Day (2014) by considering an alternative base-case model with the inclusion of NSW state data from 2005 to 2013.

8.3 Data

The data inputs to the assessment come from multiple sources: length and age-at-length data from the trawl fishery, updated standardized CPUE series (Sporcic and Haddon, 2014), the annual total mass landed and discard rates, and age-reading error. Data were formulated by calendar year (i.e. 1 Jan to

31 Dec) and were aggregated across all eastern zones (Zones 10, 20 and 30), as sufficiently strong evidence to suggest a north-south split did not exist (Shelf RAG agreement, September 2014; Haddon, 2014). Data here are the same as that described in Tuck and Day (2014) except for the inclusion of catch data from NSW from 2005 to 2013. As such, descriptions of the other data sources are not repeated (see Tuck and Day (2014)).

8.3.1 *Catch data*

Total annual catches (t) for redfish has been estimated in the past based on a combination of sources, including Sydney Fish Market (SFM) data (to 1986), NSW and Victorian landings and the SEF logbook data (Table 28 of Rowling (1994); Appendix 1 of Rowling (1999); Table 1 of Thomson (2002); Table 1 of Klaer (2005)). The estimated annual tonnages of landings, discard rates and CPUE are provided in Table 8.1. Where available, previously agreed catch tonnages from RAGs were used (Rowling, 1999; Klaer, 2005), and CDR records and NSW state catch data are used from 2005 for base-case model BC4. Figure 8.1 shows the consequence of the inclusion of NSW state catch data on the total catch time-series. Table 8.1 shows the annual catch values used in the assessment.

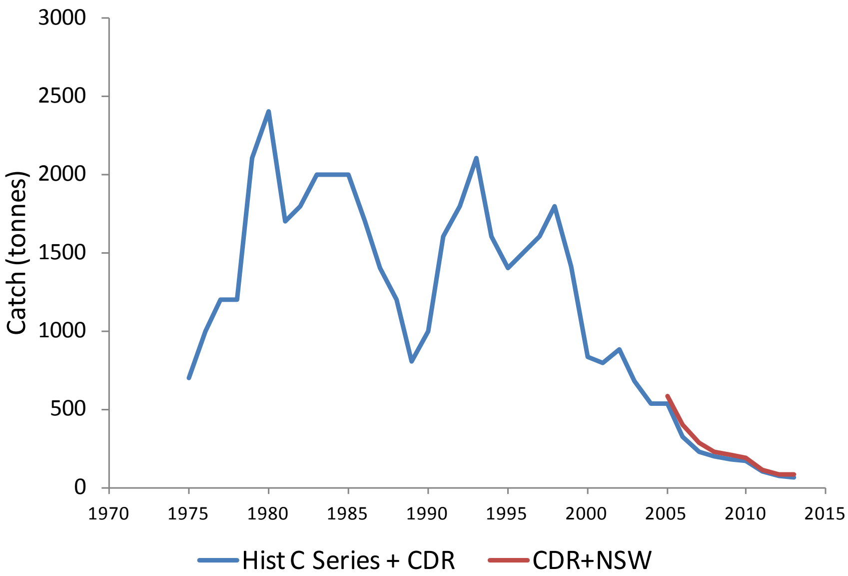


Figure 8.1. The time series of catches for redfish estimated by the various redfish assessment groups and supplemented by AFMA CDR data (blue) and with the addition of NSW state catch data (red).

Table 8.1. Estimated landings (t), discard rates and standardized CPUE (Sporcic and Haddon, 2014) for redfish by calendar year. Total catch (Commonwealth and state) for years 1975 to 2004 were taken from previously agreed catch estimates from redfish assessment group meetings (Rowling, 1999, Appendix 1; Klaer, 2005) and from CDR records for 2005 onwards. Also shown are the NSW state catches from 2005 onwards. Sate catches exist prior to 2005 but are included in the redfish assessment group agreed catches (Landings column) until 2004.

Year	Landings (t)	NSW	Total Landings (t)	Discard Rates	CPUE
1975	700		700	0.40	
1976	1000		1000	0.40	
1977	1200		1200	0.40	
1978	1200		1200	0.40	
1979	2100		2100	0.40	
1980	2400		2400	0.30	
1981	1700		1700	0.20	
1982	1800		1800	0.20	
1983	2000		2000	0.20	
1984	2000		2000	0.20	
1985	2000		2000	0.20	
1986	1700		1700	0.20	1.696
1987	1400		1400	0.15	1.435
1988	1200		1200	0.15	1.598
1989	800		800	0.15	1.184
1990	1000		1000	0.10	1.562
1991	1600		1600	0.10	1.691
1992	1800		1800	0.25	2.024
1993	2100		2100	0.580	2.457
1994	1600		1600	0.540	1.830
1995	1400		1400	0.758	1.182
1996	1500		1500	0.279	1.044
1997	1600		1600	0.062	1.090
1998	1800		1800	0.202	1.318
1999	1406		1406	0.039	1.106
2000	835		835	0.118	0.746
2001	794		794	0.370	0.716
2002	880		880	0.568	0.685
2003	677		677	0.316	0.568
2004	538		538	0.392	0.516
2005	532	47	579	0.219	0.563
2006	321	76	397	0.034	0.528
2007	230	54	284	0.159	0.509
2008	201	29	230	0.018	0.458
2009	182	25	207	0.357	0.412
2010	166	22	188	0.117	0.388
2011	99	16	115	0.143	0.273
2012	73	14	87	0.038	0.198
2013	66	14	80	0.259	0.225

8.4 Analytic approach

8.4.1 The population dynamics model

For completeness, the analytical approach described in Tuck and Day (2014) has been included here. The approach has not changed from this previous work. The 2014 assessment of eastern redfish used an age- and size-structured model implemented in the generalized stock assessment software package, Stock Synthesis (SS) (Version 3.24f, NOAA 2011). The methods utilised in SS are based on the integrated analysis paradigm. SS can allow for multiple seasons, areas and fleets, but most applications are based on a single season and area. Recruitment is governed by a stochastic Beverton-Holt stock-recruitment relationship, parameterized in terms of the steepness of the stock-recruitment function (h), the expected average recruitment in an unfished population (R_0), and the degree of variability about the stock-recruitment relationship (σ_r). SS allows the user to choose among a large number of age- and length-specific selectivity patterns. The values for these and other parameters of SS are estimated by fitting to data on catches, catch-rates, discard rates, discard and retained catch length-frequencies, and conditional age-at-length data. The population dynamics model and the statistical approach used in fitting the model to the various data types are given in the SS technical documentation (Methot, 2005).

The base–case models (BC3 and BC4) include the following key assumptions:

(a) A single region, single stock model is considered, aggregated across zones 10, 20 and 30.

(b) The selectivity pattern for the trawl fleet was assumed to be length-specific and logistic. The parameters of the selectivity function for each fleet were estimated within the assessment.

(c) The model accounts for males and females separately.

(d) Initial and final years are 1975 and 2013 respectively. Previous models (Thomson, 2002; Klaer, 2005) used 1975 as the initial year due to the generally perceived poorer quality of data prior to this year. An initial fishing mortality is estimated to account for catches prior to the starting year. A beginning year of 1960 is also considered in the sensitivities.

(e) The CVs of CPUE indices for the non-spawning fleet were initially set at a low value to encourage a fit to the abundance data, before being re-tuned to the model-estimated standard errors after tuning to length and age data. The Francis method (Francis, 2011) has been applied as a sensitivity.

(f) Discard tonnage was estimated through the assignment of a retention function. This was defined as a logistic function of length, and the inflection and slope of this function were estimated where discard information was available. A retention function was estimated for each ‘block’ period: 1975 – 1985 and 1986 – 2013. This model is termed base-case 3 (BC3).

(g) Use model derived discard rates to fit to estimates over the period 1975-1985. Include a logistic retention function with a cap less than 1.0 (i.e. larger fish do not reach full retention and can be discarded; fixed at 0.8). This is model Scenario S1 in Tuck and Day (2014).

(h) The natural mortality rate, M, is assumed to be constant with age, and also time-invariant. The value for M is 0.1 y^{-1}. Alternative values, including estimating natural mortality, are considered as sensitivities.

(i) Recruitment to the stock is assumed to follow a Beverton-Holt stock-recruitment relationship. Steepness (h) for the base-case analysis is set to 0.75.

(j) The value of the parameter determining the magnitude of the process error in annual recruitment, σ_r, is set to 0.6.

(k) The population plus-group is modelled at age 40 years, as is the maximum age for observations.

(l) Growth is assumed to follow a von Bertalanffy length-at-age relationship, with the parameters of the growth function being estimated separately for females and males inside the assessment model.

(m) Retained and discard length sample sizes were capped at 200 and required to have a minimum of 100 samples to be included. The sample size is reduced to a maximum of 200 because the appropriate sample size for length frequency data is probably more closely related to the number of shots sampled, rather than the number of fish measured. The length frequency data is given too much weight relative to other data sources if the number of fish measured were used. Length, age, and CPUE data were tuned.

Assumed values for some of the (non-estimated) parameters of the base case models (BC3 and BC4) are shown in Table 8.2.

Table 8.2. Parameter values assumed for some of the non-estimated parameters of the base-case models.

Parameter	Description	Value
M	Natural mortality	0.1
σ_r	CV for the recruitment residuals	0.6
h	"steepness" of the Beverton-Holt stock-recruit curve	0.75
x	age observation plus group	40 years
a	allometric length-weight equations	0.0577 g^{-1}cm
b	allometric length-weight equations	2.77
l_m	Female length at 50% maturity	19 cm

8.5 Results and discussion

8.5.1 Base-case stock assessment BC4

8.5.1.1 Parameter estimates

The length-weight relationships, maturity-at-length and growth are shown in Figure 8.2 and Figure 8.3. Note that these figures are indistinguishable to those of BC3 (see previous analysis of Tuck and Day, 2014) and so BC3 results are not repeated here. The von Bertalanffy growth parameter *k* was estimated to be 0.236, with a CV on growth of 0.146. The initial fishing mortality (F_{init}) was estimated to be 0.016.

A single logistic selectivity function is estimated for the trawl fleet (Figure 8.4). Retention has two ‘time-blocks’ to account for the varying discarding behaviours documented (Figure 8.4; Tuck and Day, 2014).

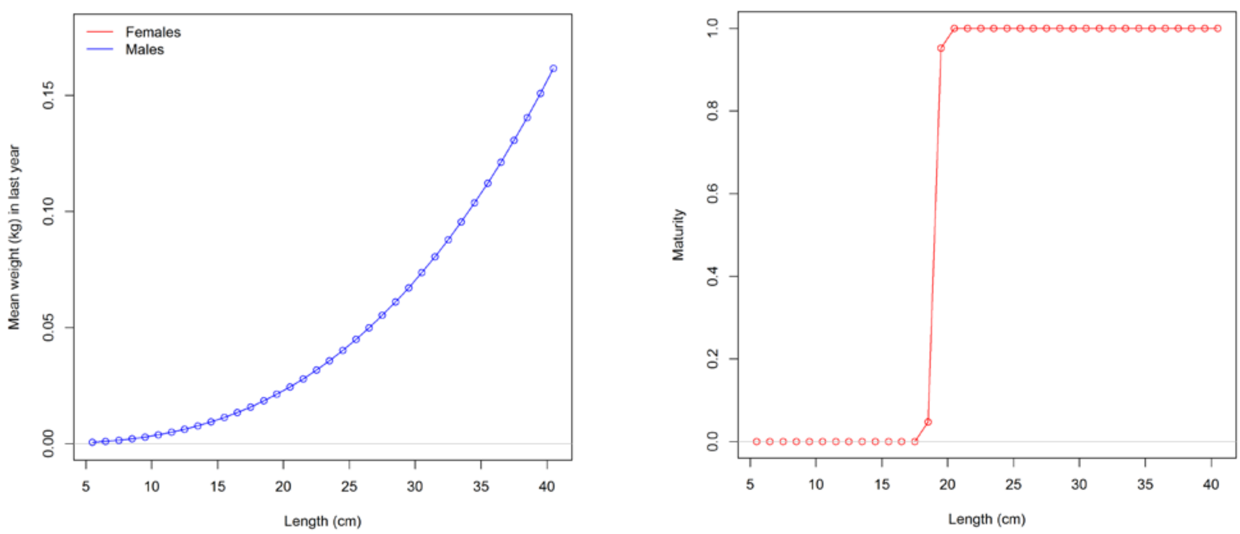


Figure 8.2. The length-weight relationship (left) and maturity (right) functions for eastern redfish.

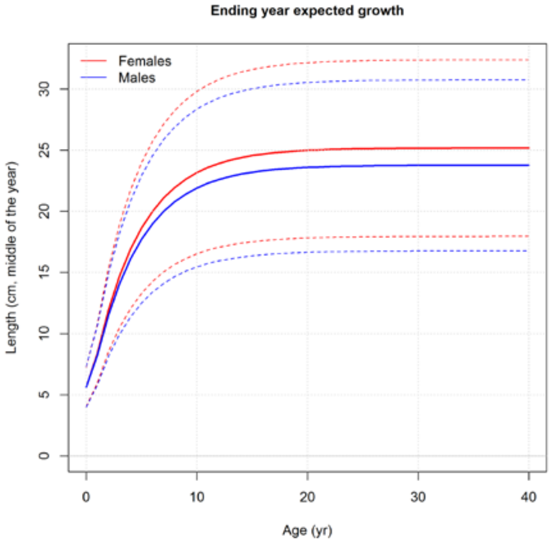


Figure 8.3. Estimated length-at-age relationship for males (blue) and females (red) under BC4 and corresponding 95% confidence intervals (dashed lines).

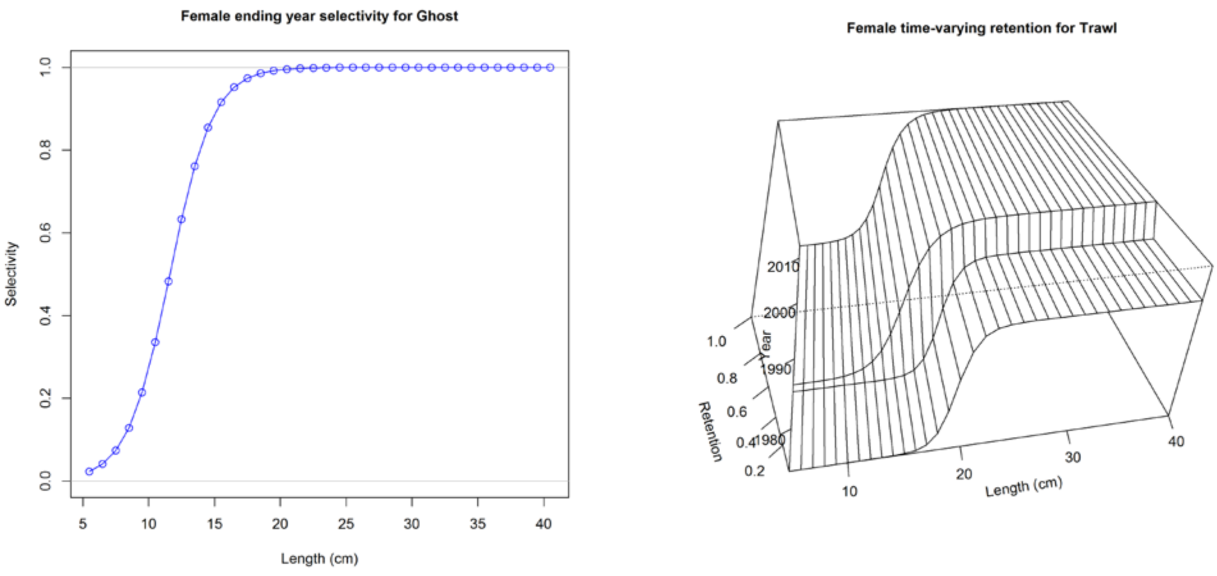


Figure 8.4. The estimated selectivity (left) and retention (right) functions for eastern redfish under BC4.

8.5.1.2 Fits to the data

The model fit to discard rates shows some correspondence as the model attempts to fit to the various changes in discarding over time (Figure 8.5), and the model fit to the catch rate series shows good correspondence to the observations.

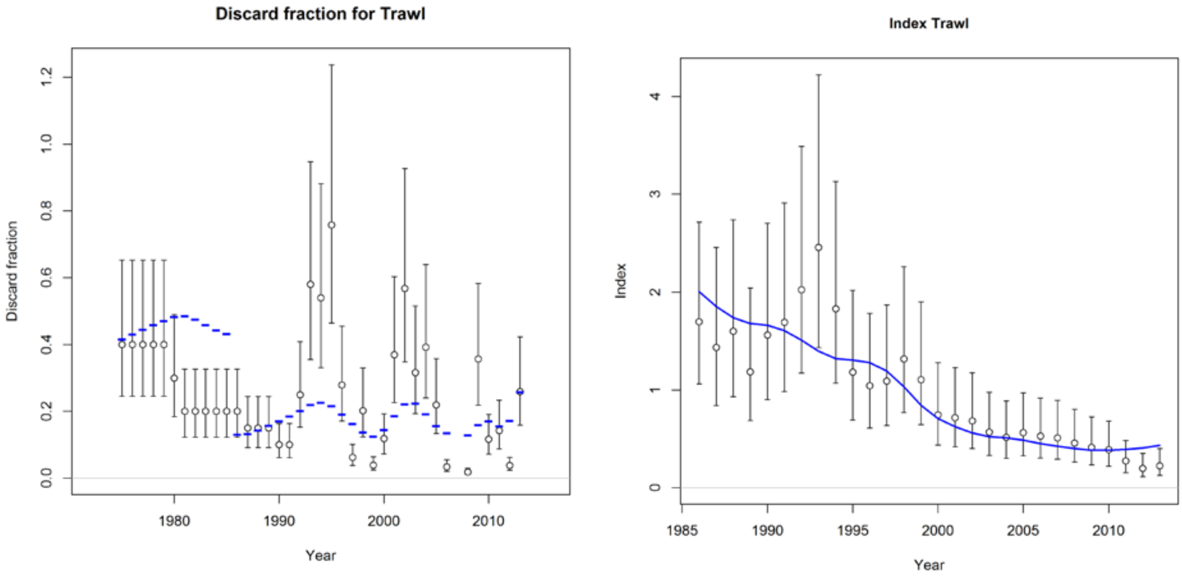


Figure 8.5.The fit to the discard rate data (left) and the catch rate data (right) under BC4; blue dashes/lines are the model fitted estimates.

The model is able to replicate the implied age-composition data reasonably well, particularly where the samples were from the separate sexes in the retained catch (Appendix 1). A comparison between BC3 and BC4 is not made as the fits are essentially indistinguishable. Age compositions from 2012 and 2013 seem to suggest that a recent relatively large recruitment may have moved into the available stock. This is also evident in the model estimates of recruitment. Length composition data are not as well estimated by the model, with early years showing an over-estimation of small fish, and later years showing a much narrower distribution of observed lengths compared to the model estimates (Appendix 1). Length composition data for this stock vary markedly from one year to the next; making model fitting difficult (e.g. 1991 and 1993; 1997 and 1998).

8.5.2 *A comparison of the base case stock assessments BC3 and BC4*

Figure 8.6 to Figure 8.8 show a comparison between model outcomes of BC3 and BC4 for the fit to catch rate data, annual recruitments and spawning biomass trajectories. In general, only minor differences are noticeable during the last 3 to 4 years.

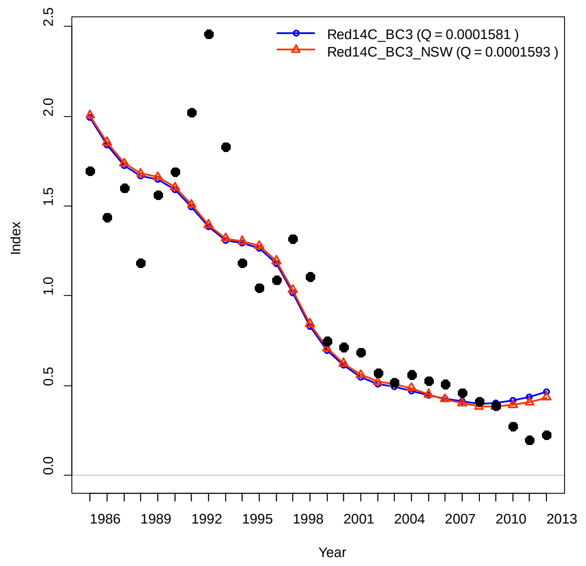


Figure 8.6. A comparison of the fit to the catch rate series for base-case models BC3 (blue) and BC4 (Red14C_BC3_NSW; red).

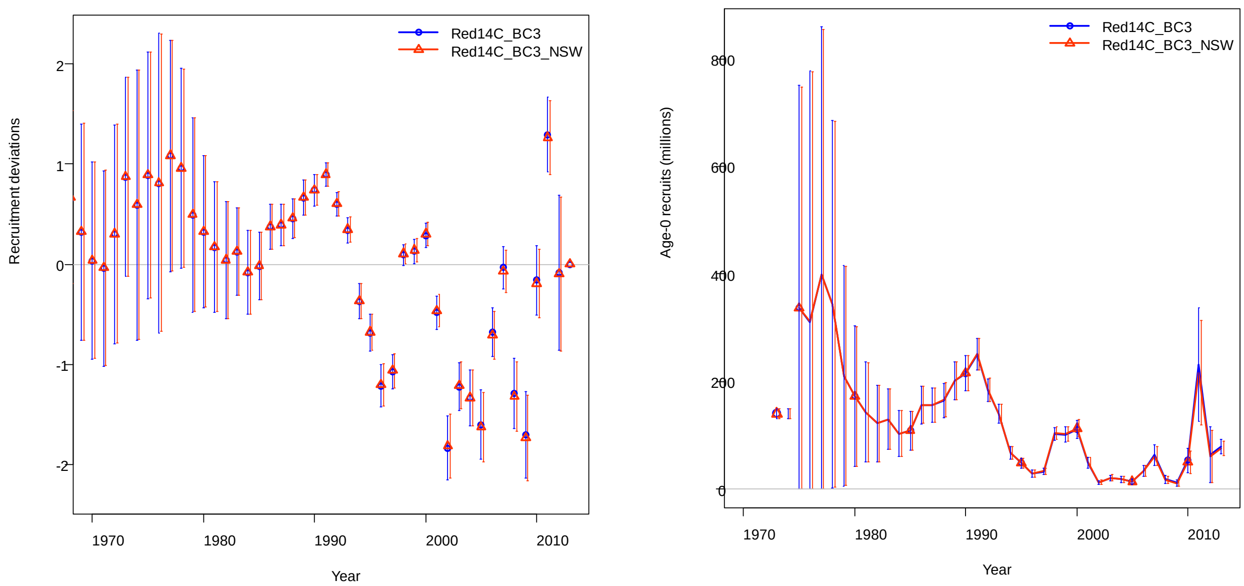
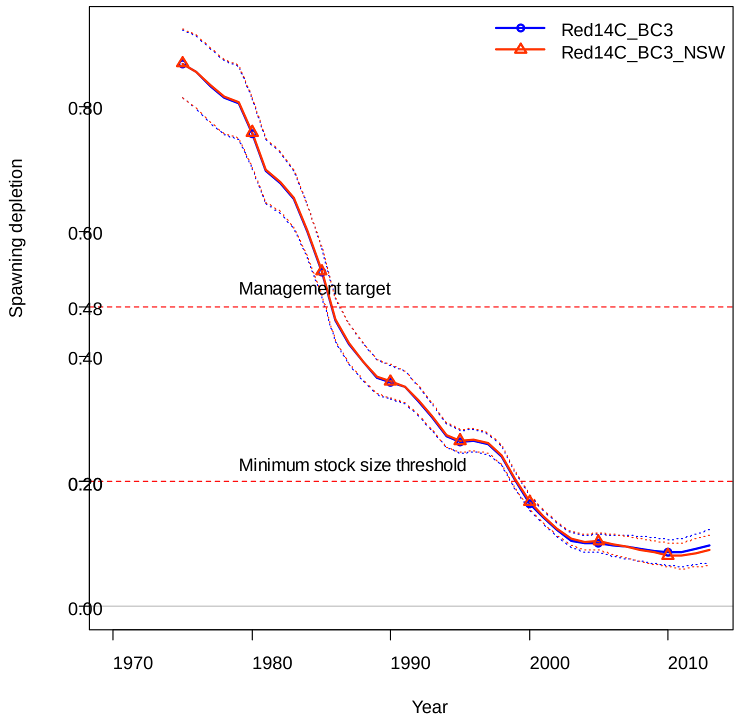


Figure 8.7. A comparison of the annual estimated recruitment series with corresponding approximate 95% asymptotic intervals (vertical lines) (deviations, LHS; age-0 recruits, RHS) for base-case models BC3 (blue) and BC4 (Red14C_BC3_NSW; red).



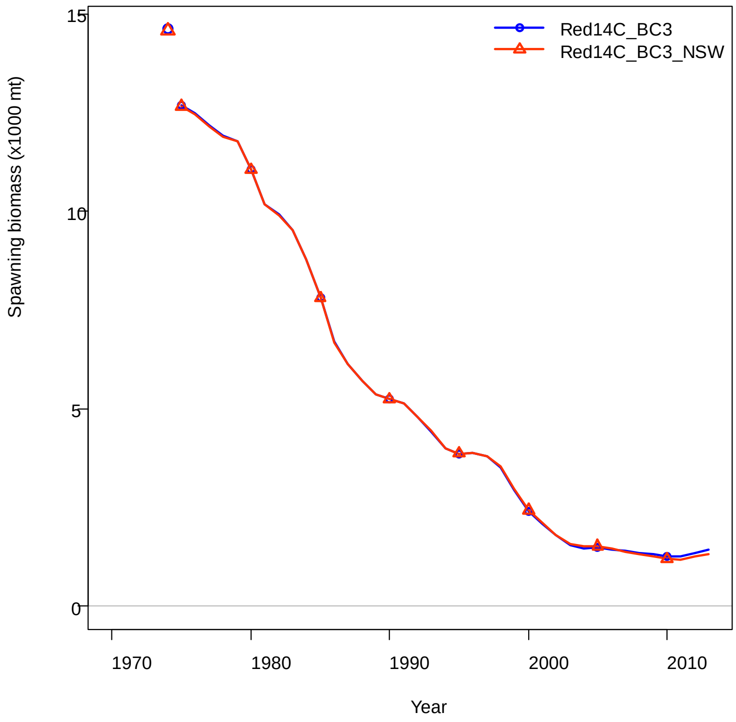


Figure 8.8.A comparison of the annual estimated spawning biomass trajectories (relative, top; absolute, bottom) for base-case models BC3 (blue) and BC4 (Red14C_BC3_NSW; red). Top: dashed blue and red lines correspond to approximate 95% asymptotic intervals for models BC3 and BC4 respectively. Red dashed lines at 0.2 and 0.48 correspond to limit and target reference points respectively.

8.5.3 *Assessment outcomes for BC4*

Estimated annual recruitment under the base-case assessment model BC4 shows periods of strong recruitment, amongst a general declining trend (Figure 8.9; Appendix 1). The model estimates a recent large recruitment, which is also evident in the age composition data for 2013 (Appendix 1).

The spawning biomass trajectories (Figure 8.9 and spawning biomass relative to the un-exploited level show a general declining trend of stock status since 1975. The model shows stock status moving below the limit reference point of 20% in 1999, with current stock status well below the limit.

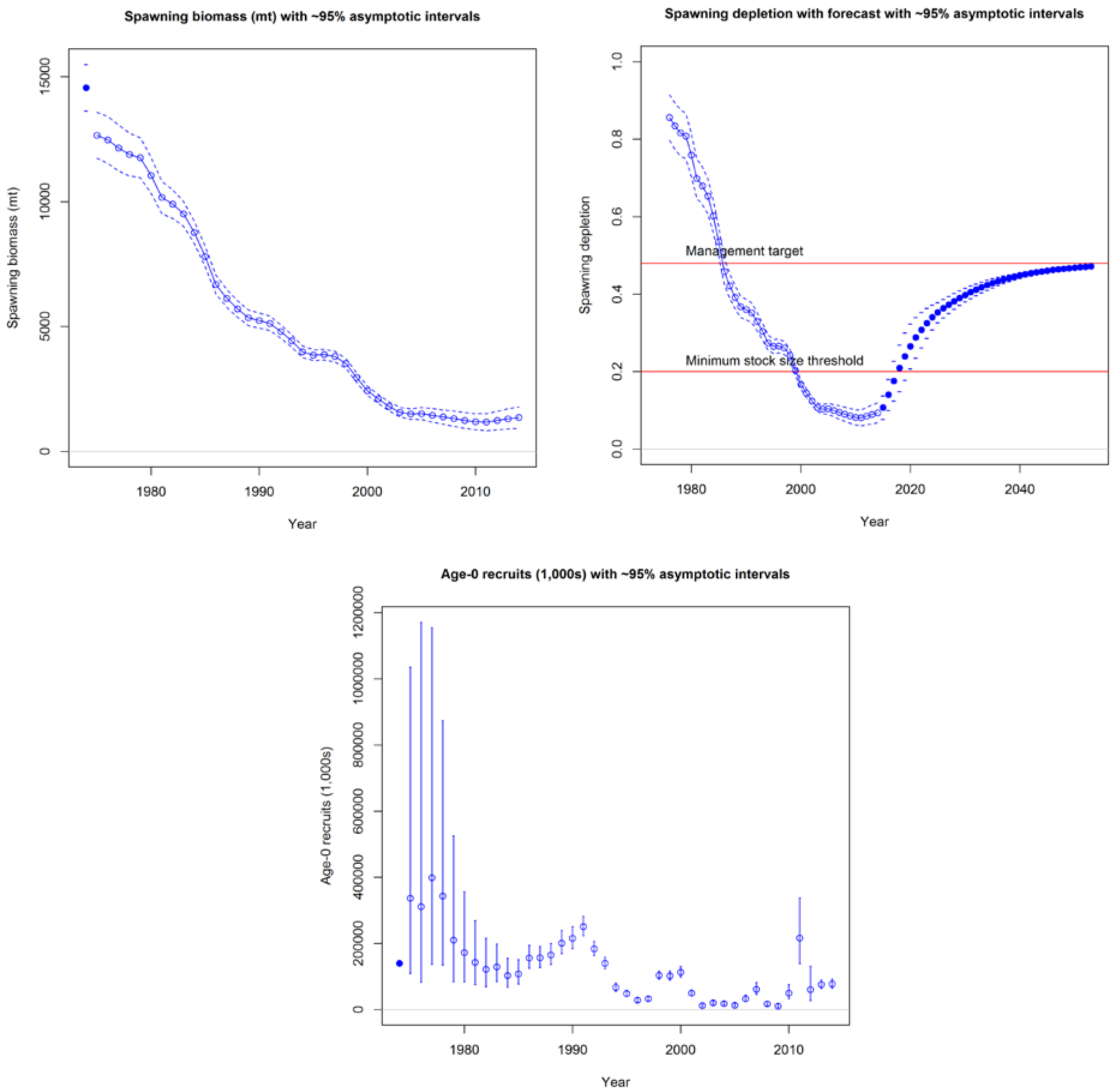


Figure 8.9.The annual time-series of female spawning biomass (absolute left and relative right) and recruitment (bottom) under BC4. Vertical bars correspond to approximate 95% asymptotic intervals.

The estimated time-series of fishing mortality, F, is shown in Figure 8.10. This shows that estimated fishing mortality has been below target levels since 2011. The mean generation time is defined as the mean age of the female mature unfished stock,

$$T_{gen} = \sum_a a f_a N_a / \sum_a f_a N_a$$

where f_a is fecundity at age and N_a are numbers at age for the unfished population. The mean generation time for redfish is T_{gen} = 16.7 years.

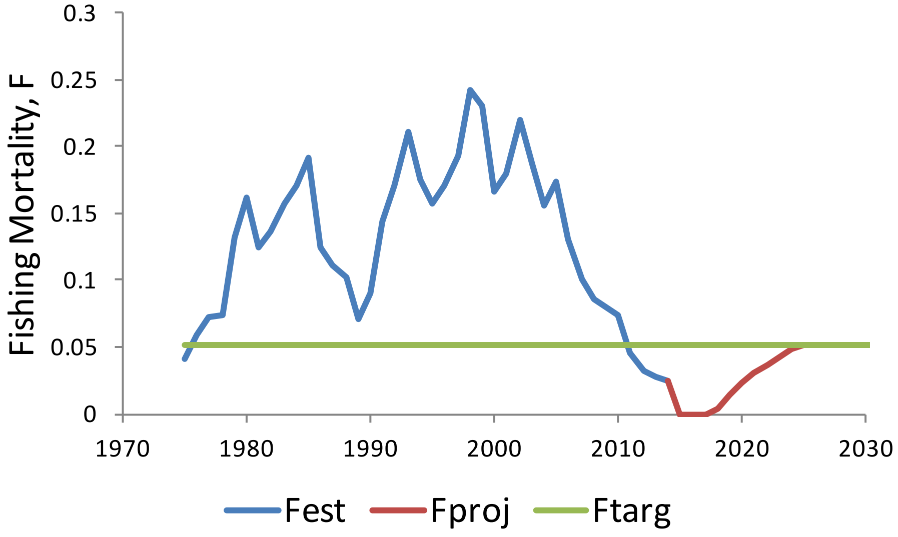


Figure 8.10. The annual estimated fishing mortality for redfish under base-case model BC4. The estimated fishing mortality is shown in blue, and the projected fishing mortality under the 20:35:48 harvest control rule is shown in red. The target fishing mortality (for B48) is shown in green.

8.5.4 *Management outcomes for the base-case model BC4*

The estimated virgin female biomass is 14,558 t, and the 2015 estimated spawning biomass level is 10.8% of un-exploited levels for the base-case model BC4. Under the previous base-case 3 (BC3) assessment (Tuck and Day, 2014), the estimated virgin spawning biomass is 14,615 t, with estimated 2015 stock status of 11.7% of unexploited levels. As the estimated stock status is below the limit reference point of 20% for both base-case models BC3 and BC4, assuming the 20:35:48 control rule, the RBCs are consequently zero. All models that have been tuned, including models tuned using the Francis method, similarly led to zero RBCs for 2015. The long-term RBC, assuming a return to a 48% stock status, for the BC4 model is 836 t.

8.5.5 *Fixed catch projections for the base-case model BC4*

Figure 8.11, Figure 8.12 and Table 8.3 show the time-series of female spawning biomass assuming mean future recruitment and under three deterministic fixed catch projections: 50t, 100t and 150t. In each instance, the stock is projected to move above 20% of unexploited levels by year 2018 or 2019.

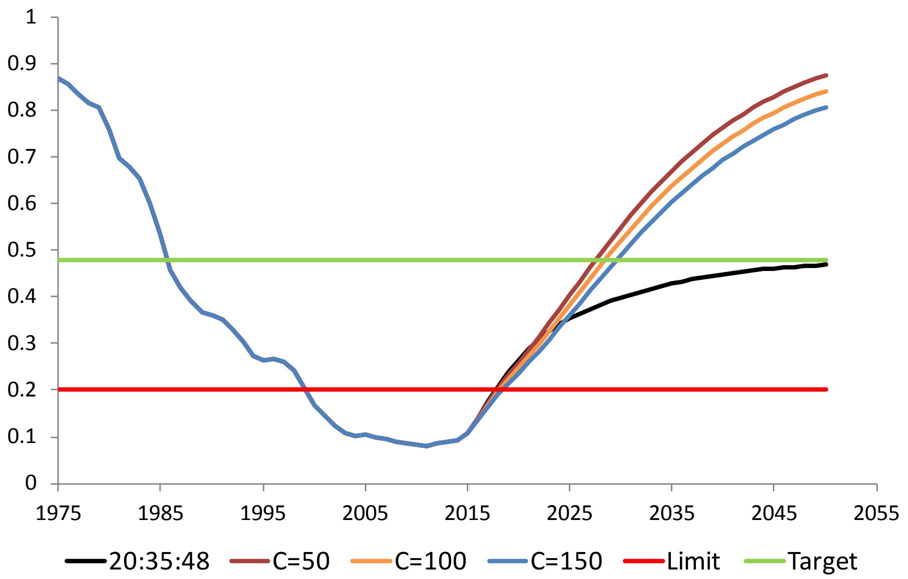


Figure 8.11.Annual relative female spawning biomass for base case BC4 under the 20:35:48 harvest control rule and fixed catch projections of 50, 100, and 150 t. Red line (20% limit reference); green line (48% target reference).

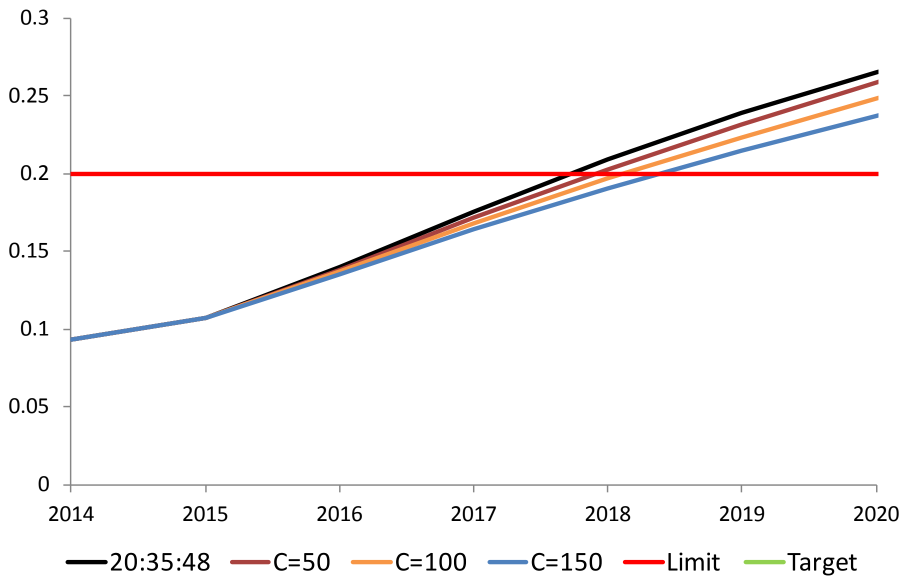


Figure 8.12.Annual projected relative female spawning biomass for base case BC4 under the 20:35:48 harvest control rule and fixed catch projections of 50, 100, and 150 t (between 2014 and 2020). Red line (20% limit reference).

Table 8.3 The annual projected female spawning biomass under the 20:35:48 Tier 1 harvest control rule, and fixed catch (C) projections of 50, 100, 150 t. Shaded values are above the 20% unexploited biomass limit reference point.

Year	20:35:48	C=50	C=100	C=150
2015	0.108	0.108	0.108	0.108
2016	0.140	0.138	0.137	0.135
2017	0.176	0.172	0.168	0.164
2018	0.209	0.203	0.197	0.191
2019	0.239	0.232	0.223	0.215
2020	0.265	0.259	0.248	0.237

8.5.6 *Sensitivities*

Results of the various sensitivity tests are shown in Table 8.4 for BC4. The definitions of each sensitivity test can be found in Tuck and Day (2014). The base-case models and sensitivities all have stock status less than the limit reference point of 20% of virgin spawning biomass, and generally vary between 6% and 16%. The largest variation in stock status occurs with larger fixed values of natural mortality and steepness. However, estimating these parameters led to $M\approx0.1$ (approximately the base-case value used), and a steepness of $h\approx0.59$ (lower than the base-case assumed value of 0.75). Using the Francis (2011) weighting procedure led to considerable down-weighting of the length and age data, a lower long-term RBC and slightly lower estimated stock status.

Table 8.4. Summary of sensitivity results (i.e. Case 2-22) for the base-case model structure BC4 (Case 0). Long-term RBCs are only provided for models that have been tuned.

Case	Model and/or sensitivity description	SSB_0	SSB_{2015}	SSB_{2015}/SSB_0	RBC_{2015}	$RBC_{longterm}$
0	BC4 (20:35:48 M=0.10 h=0.75)	14,558	1,567	0.11	0	836
1	BC3	14,615	1,714	0.12	0	840
2	M=0.08	15,803	1,009	0.06	0	
3	M=0.12	13,409	2,267	0.17	0	
4	estimate M (0.100), h=0.75	14,586	1,554	0.11	0	
5	steepness, h =0.65	15,662	1,277	0.08	0	
6	steepness, h=0.85	13,806	1,891	0.14	0	
7	estimate h (0.589), M=0.10	16,525	1,120	0.07	0	
8	50% maturity at 18 cm	15,073	1,791	0.12	0	
9	50% maturity at 20 cm	13,887	1,365	0.10	0	
10	σ_R = 0.8	15,181	1,209	0.08	0	
11	begin model in 1960	15,562	2,469	0.16	0	
12	alternative discards	14,552	1,506	0.10	0	
13	Kapala lengths	14,558	1,535	0.11	0	
15	wt x 2 length composition	14,794	1,576	0.11	0	
16	wt x 0.5 length composition	14,224	1,509	0.11	0	
17	wt x 2 age composition	14,136	1,378	0.10	0	
18	wt x 0.5 age composition	14,844	1,654	0.11	0	
19	wt x 2 CPUE	14,262	1,339	0.09	0	
20	wt x 0.5 CPUE	15,023	1,983	0.13	0	
21	cap retention at 0.6 (1975-85)	16,419	1,709	0.10	0	
22	Francis weighting	13,724	1,125	0.08	0	751

8.5.7 *Further development*

- Further refinement of the Francis (2011) method, in particular for assessments with age-at-length data.
- Agree to a model structure, with regard to discard function.
- Explore what may be causing the variations in year-to-year length data.

8.5.8 *Conclusion*

This report supplements the previous eastern redfish (*Centroberyx affinis*) stock assessments presented in Tuck and Day (2014) by the inclusion of NSW state catch data from 2005 to 2013 inclusive. The catch data of Tuck and Day (2014) were those RAG agreed catch records from previous redfish assessment group meetings (that included Commonwealth and state data; see Rowling 1999; Klaer 2005) and Commonwealth CDR data from 2005. The NSW (state) recorded catch data from 2005 to 2013, in total were 297 t, compared to 2167 t in total from Commonwealth catch records. This supplementary report provides a comparison of assessment results between the BC3 redfish stock assessment (the RAG agreed base case from October 2014) and the BC3 model with the addition of NSW catch data (hereafter referred to as BC4).

A comparison of BC3 and BC4 showed only minor differences in outcomes across all metrics. The estimated virgin female spawning biomass was 14,615 t under BC3 compared to 14,558 t under BC4. The estimated stock status in 2015 for BC3 was 11.7%, compared to 10.8% for BC4. The estimated stock status is below the limit reference point of 20% for both base-case models BC3 and BC4 assuming the 20:35:48 harvest control rule, and the RBCs are consequently zero.

8.6 Acknowledgements

Many thanks are due to the CSIRO SESSF-WG: Jemery Day, Sally Wayte, Neil Klaer, Robin Thomson, Judy Upston, Malcolm Haddon and André Punt for their assistance with model discussions and development. Miriana Sporcic and Malcolm Haddon are thanked for providing catch rate indices, Mike Fuller, Robin Thomson and Neil Klaer for their advice on data matters. Kyne Krusic-Golub (Fish Aging Services) and the AFMA observer section are thanked for providing the aging data and length frequency data respectively. Kevin Rowling, Ian Knuckey and Tony Lavalle provided invaluable advice on historical catch and discarding practices. Miriana Sporcic is also thanked for her review of this report.

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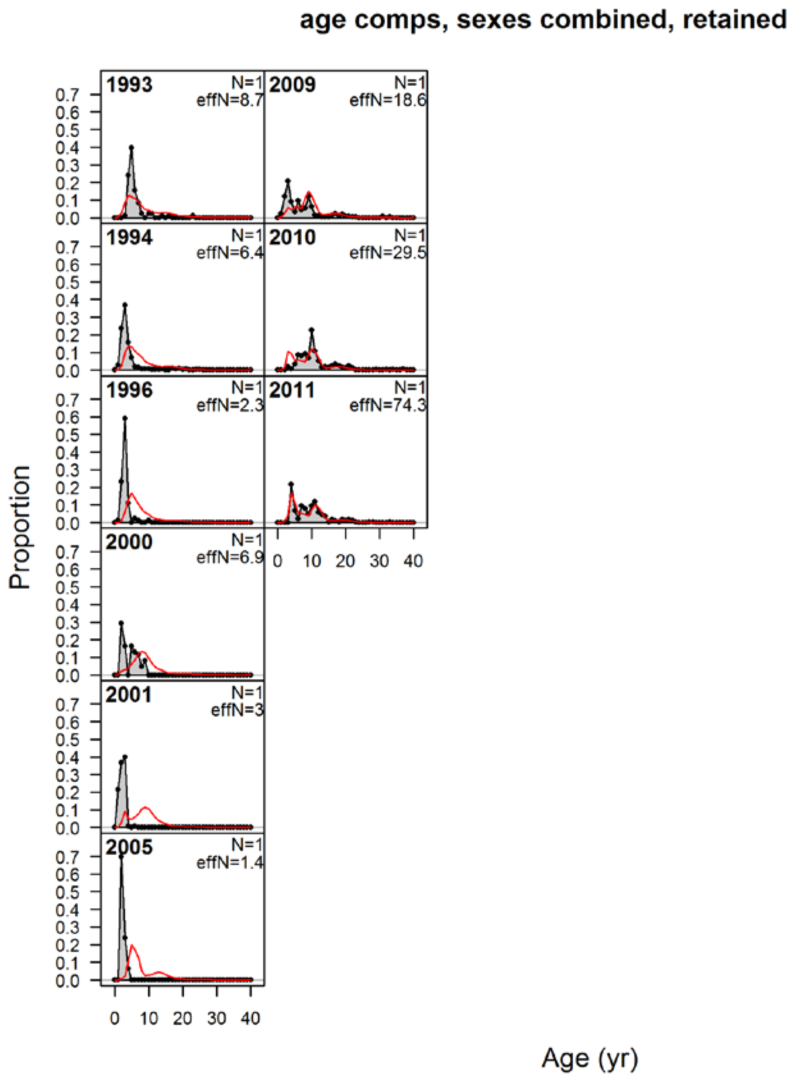
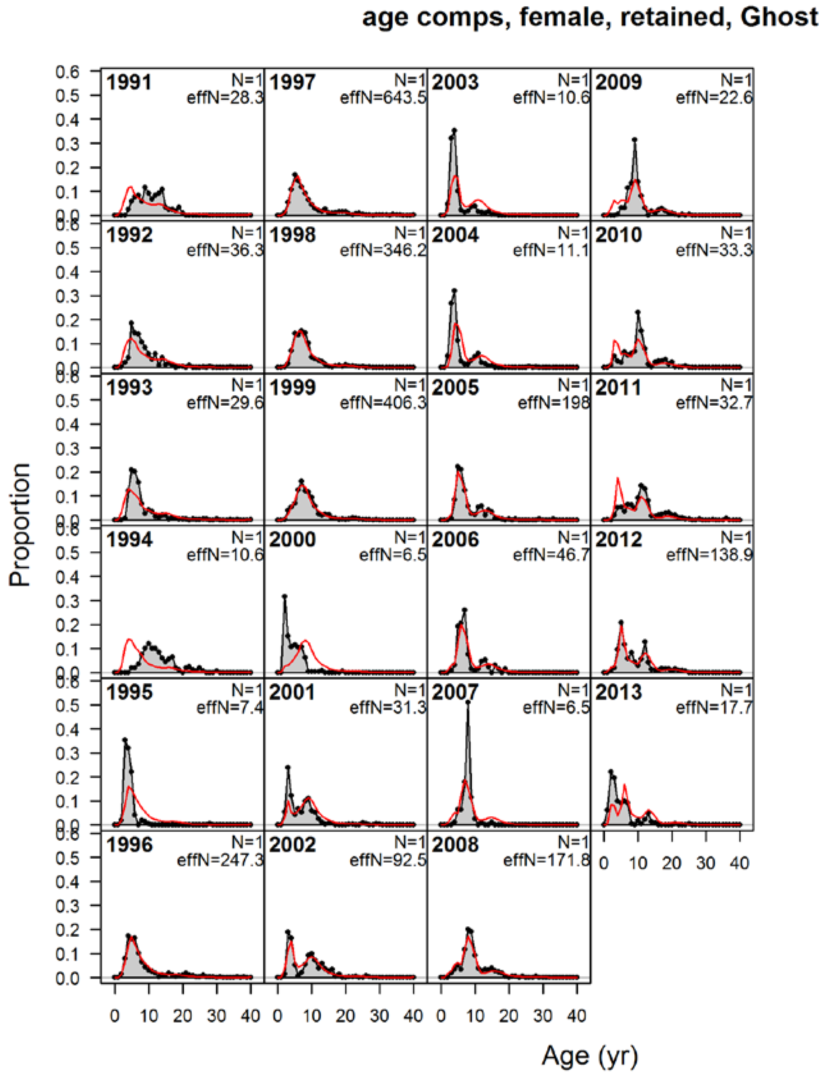
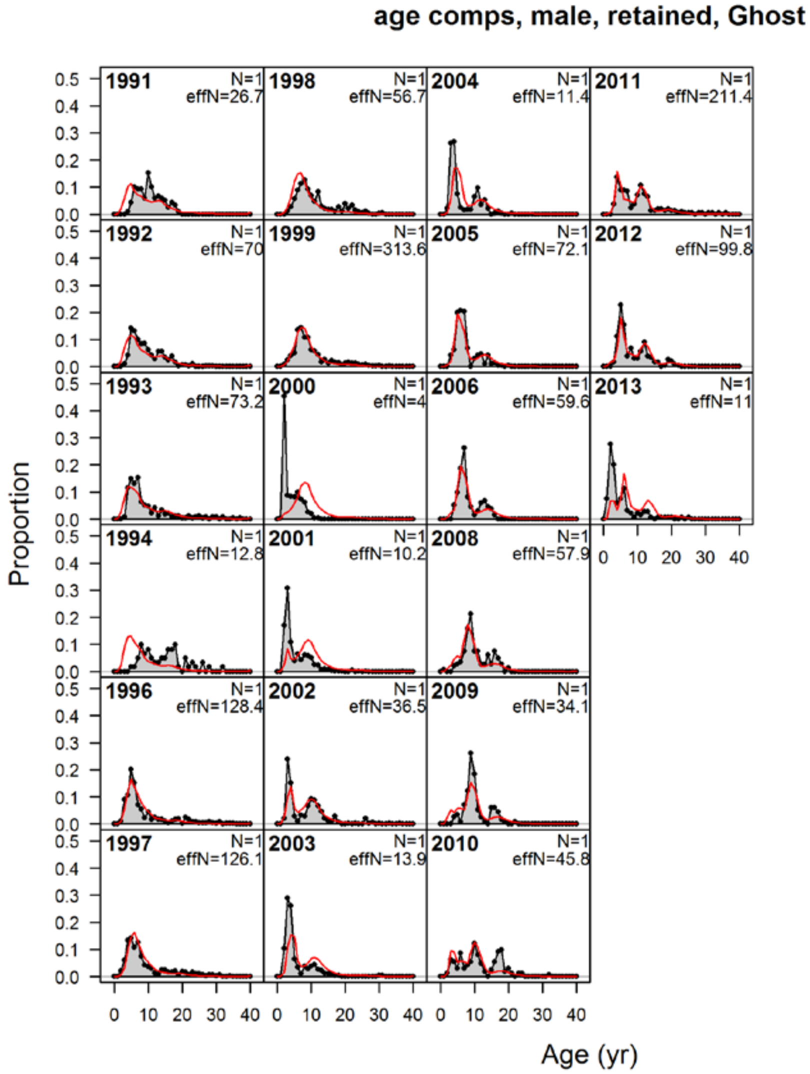
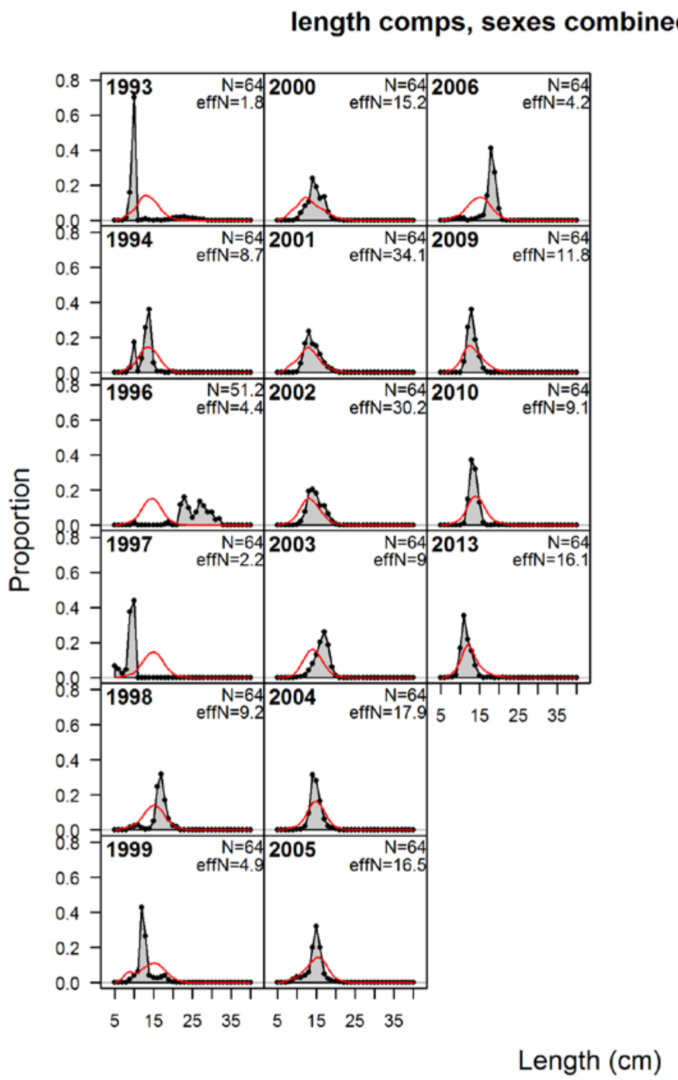
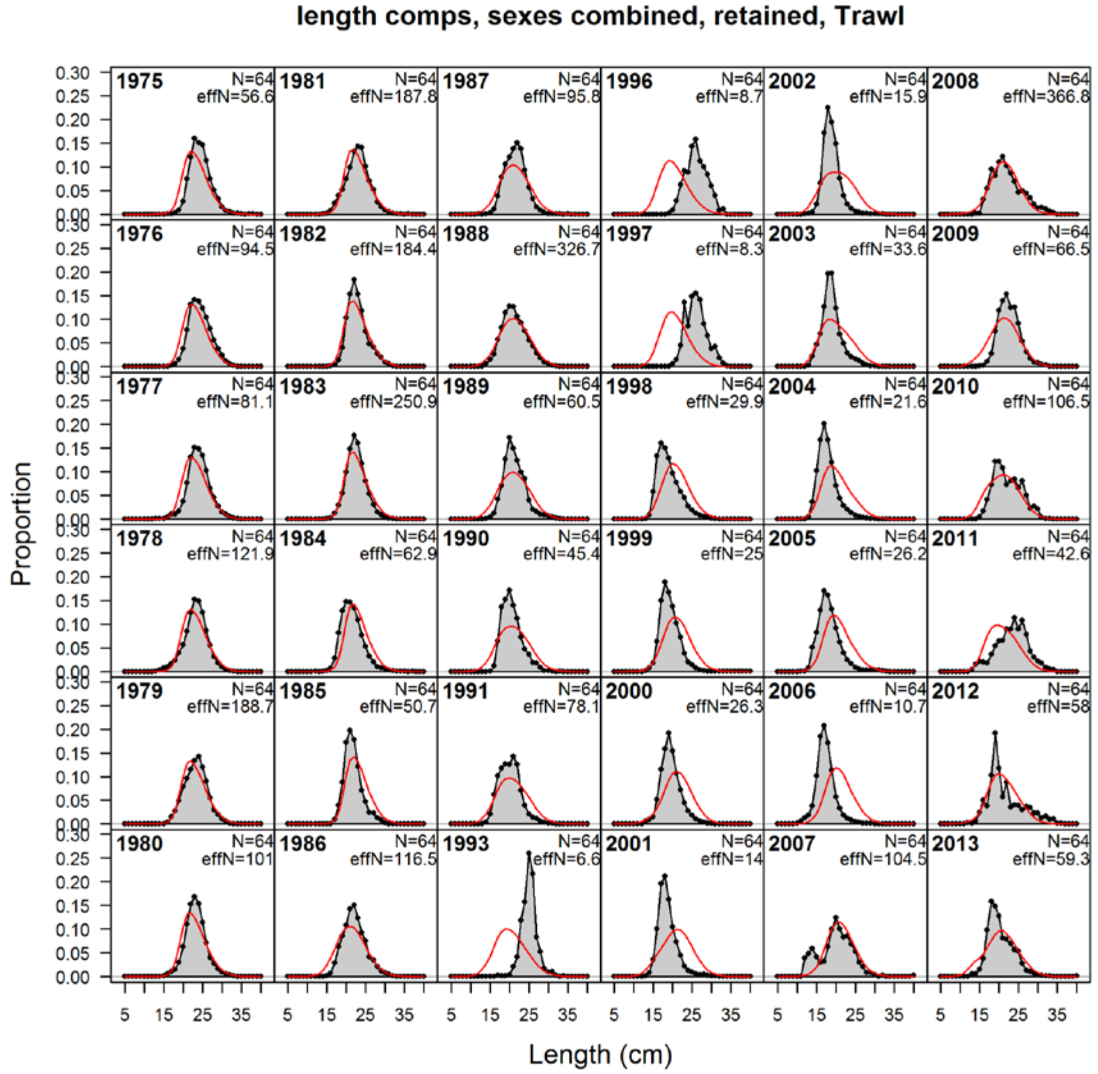
8.8 Appendix 1: Base case 4 (BC4)

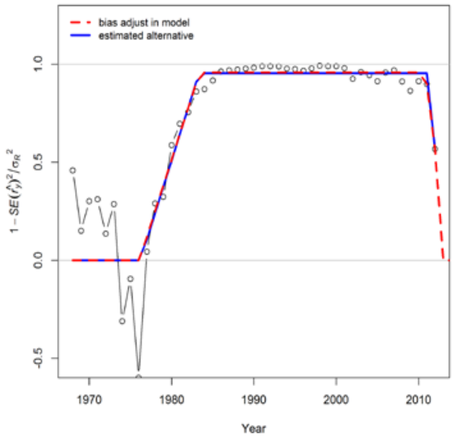


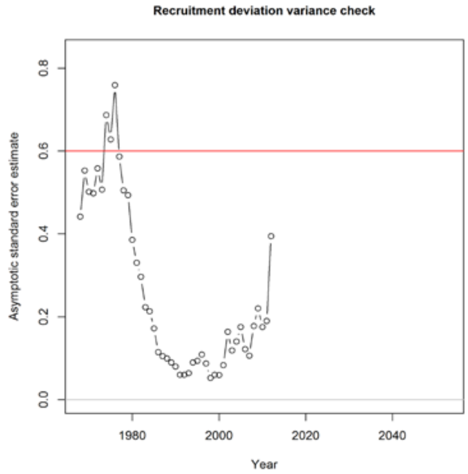

age comps, female, retained, Ghost
1991 N=1 effN=28.3
1997 N=1 effN=643.5
2003 N=1 effN=10.6
2009 N=1 effN=22.6
1992 N=1 effN=36.3
1998 N=1 effN=346.2
2004 N=1 effN=11.1
2010 N=1 effN=33.3
1993 N=1 effN=29.6
1999 N=1 effN=406.3
2005 N=1 effN=198
2011 N=1 effN=32.7
1994 N=1 effN=10.6
2000 N=1 effN=6.5
2006 N=1 effN=46.7
2012 N=1 effN=138.9
1995 N=1 effN=7.4
2001 N=1 effN=31.3
2007 N=1 effN=6.5
2013 N=1 effN=17.7
1996 N=1 effN=247.3
2002 N=1 effN=92.5
2008 N=1 effN=171.8
Proportion
Age (yr)

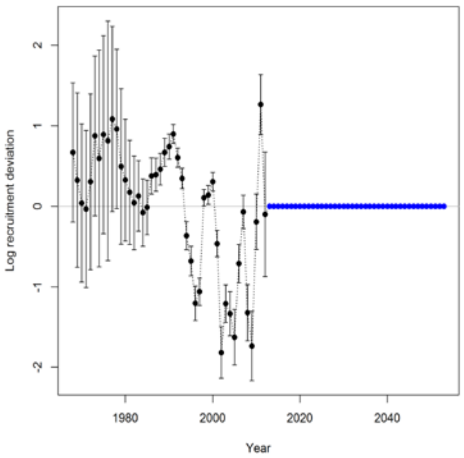

age comps, male, retained, Ghost
Proportion
Age (yr)
1991 N=1 effN=26.7
1998 N=1 effN=56.7
2004 N=1 effN=11.4
2011 N=1 effN=211.4
1992 N=1 effN=70
1999 N=1 effN=313.6
2005 N=1 effN=72.1
2012 N=1 effN=99.8
1993 N=1 effN=73.2
2000 N=1 effN=4
2006 N=1 effN=59.6
2013 N=1 effN=11
1994 N=1 effN=12.8
2001 N=1 effN=10.2
2008 N=1 effN=57.9
1996 N=1 effN=128.4
2002 N=1 effN=36.5
2009 N=1 effN=34.1
1997 N=1 effN=126.1
2003 N=1 effN=13.9
2010 N=1 effN=45.8

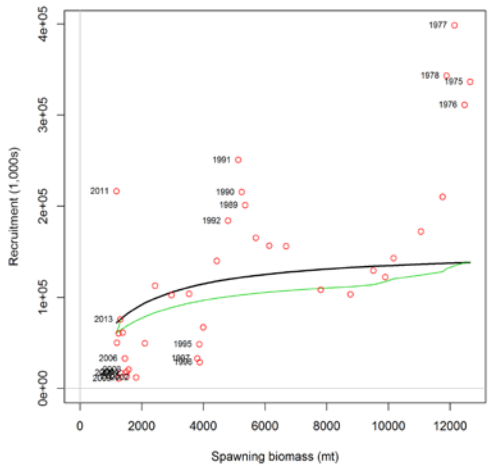

length comps, sexes combined, discard, Trawl
Proportion
Length (cm)
1993 N=64 effN=1.8
2000 N=64 effN=15.2
2006 N=64 effN=4.2
1994 N=64 effN=8.7
2001 N=64 effN=34.1
2009 N=64 effN=11.8
1996 N=51.2 effN=4.4
2002 N=64 effN=30.2
2010 N=64 effN=9.1
1997 N=64 effN=2.2
2003 N=64 effN=9
2013 N=64 effN=16.1
1998 N=64 effN=9.2
2004 N=64 effN=17.9
1999 N=64 effN=4.9
2005 N=64 effN=16.5
0.0
0.2
0.4
0.6
0.8
5
15
25
35


length comps, sexes combined, retained, Trawl
Proportion
Length (cm)


bias adjust in model
estimated alternative
Year


Recruitment deviation variance check
Asymptotic standard error estimate
Year


Log recruitment deviation
Year


Recruitment (1,000s)
Spawning biomass (mt)