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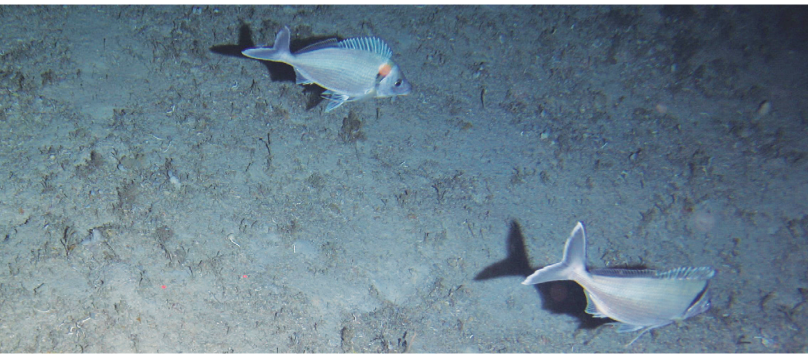
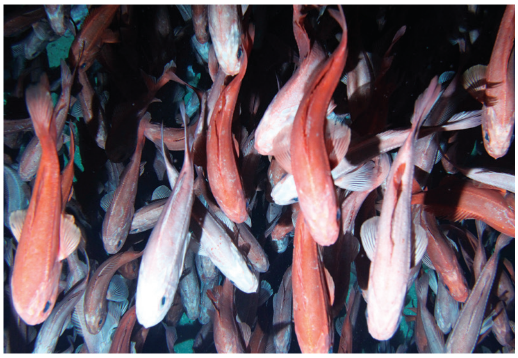
Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery: 2014

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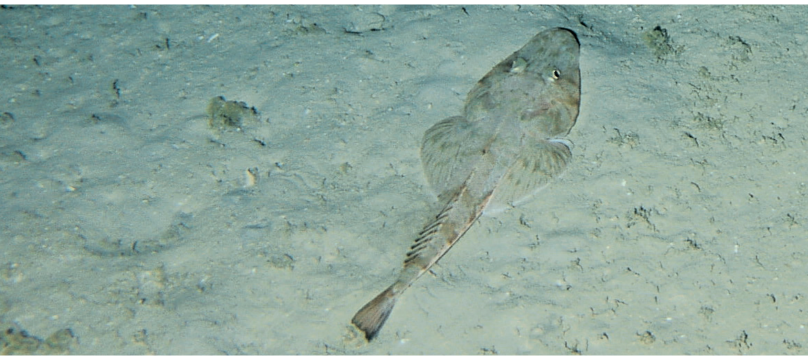
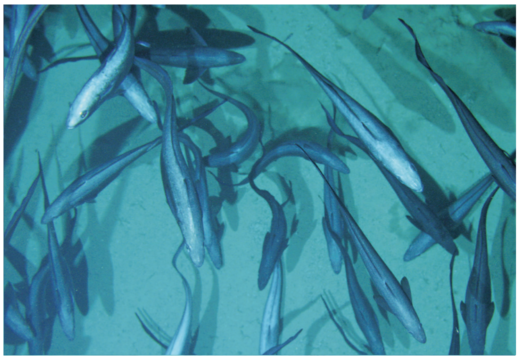

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Cover photographs

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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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).

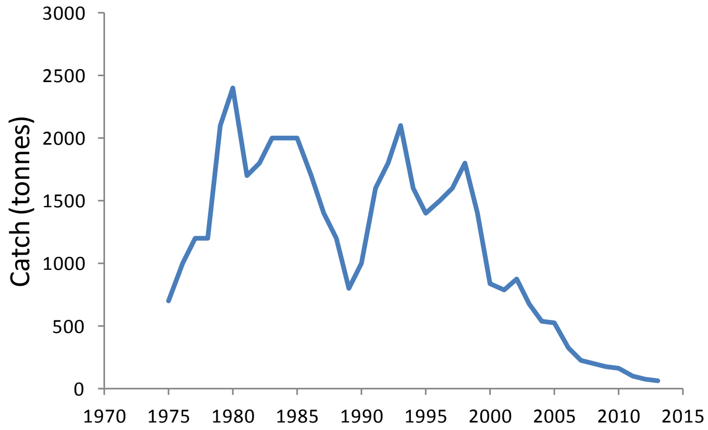


Figure 7.1. The time series of catches for redfish estimated by the various redfish assessment groups and supplemented by AFMA data.

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.

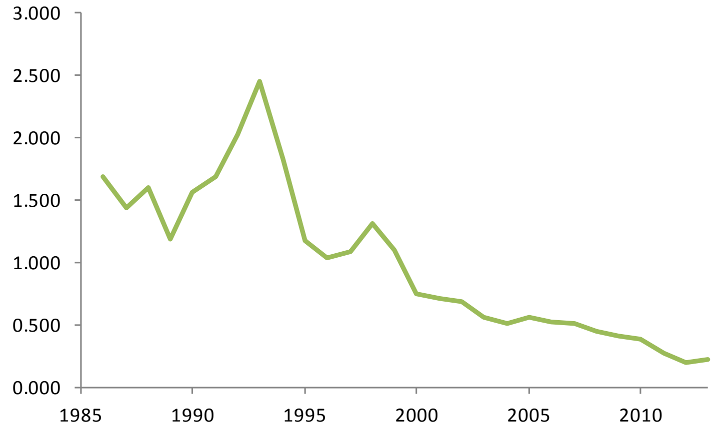


Figure 7.2.The annual catch rate series for redfish (Sporcic and Haddon, 2014).

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

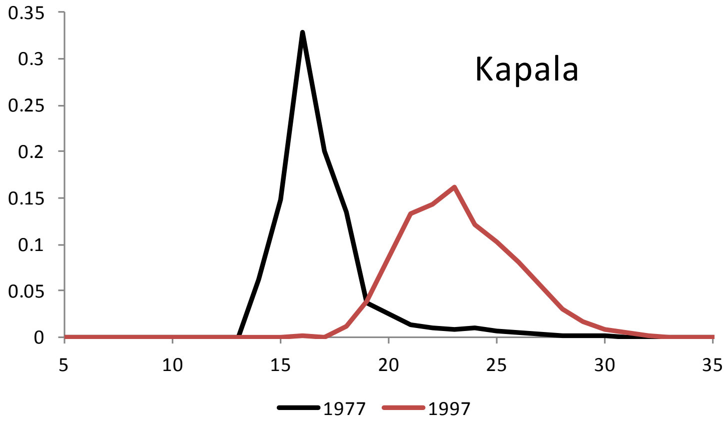
7.6.1 Alternative natural mortality, steepness and data weightings

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.

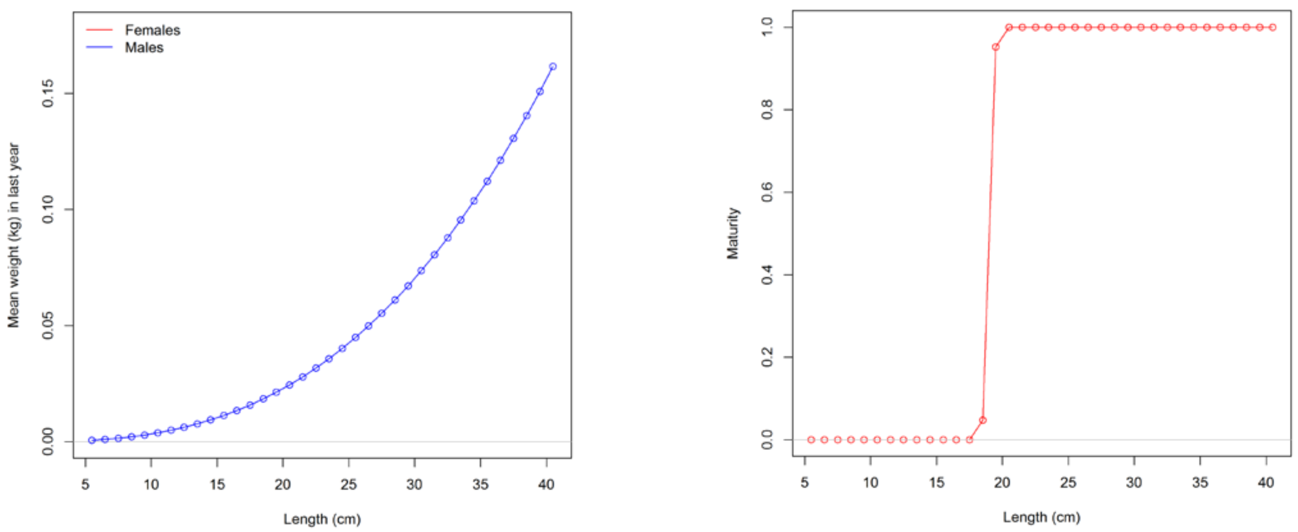


Figure 7.4.The length-weight relationship (left) and maturity (right) functions for eastern redfish.

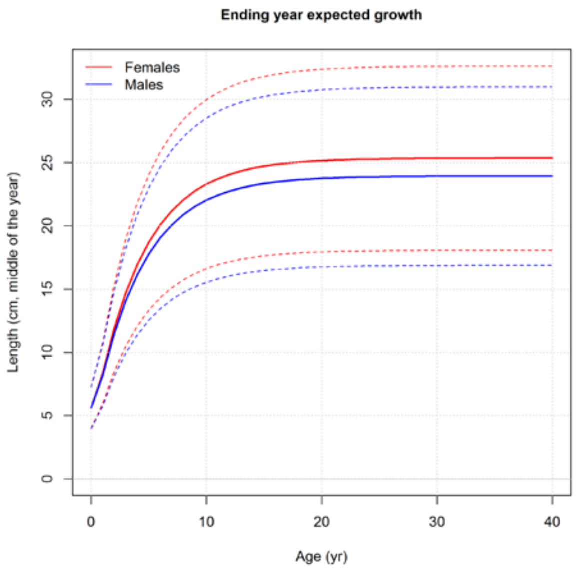


Figure 7.5.The estimated length-at-age relationship for males (blue) and females (red) under BC1.

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.

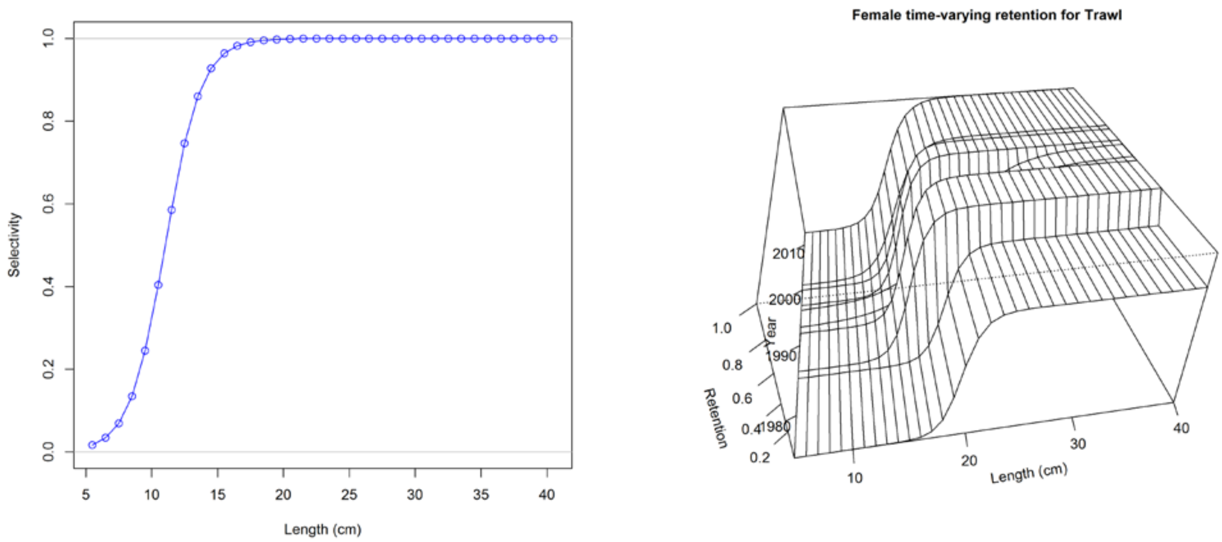


Figure 7.6.The estimated selectivity (left) and retention (right) functions for eastern redfish under BC1.

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.

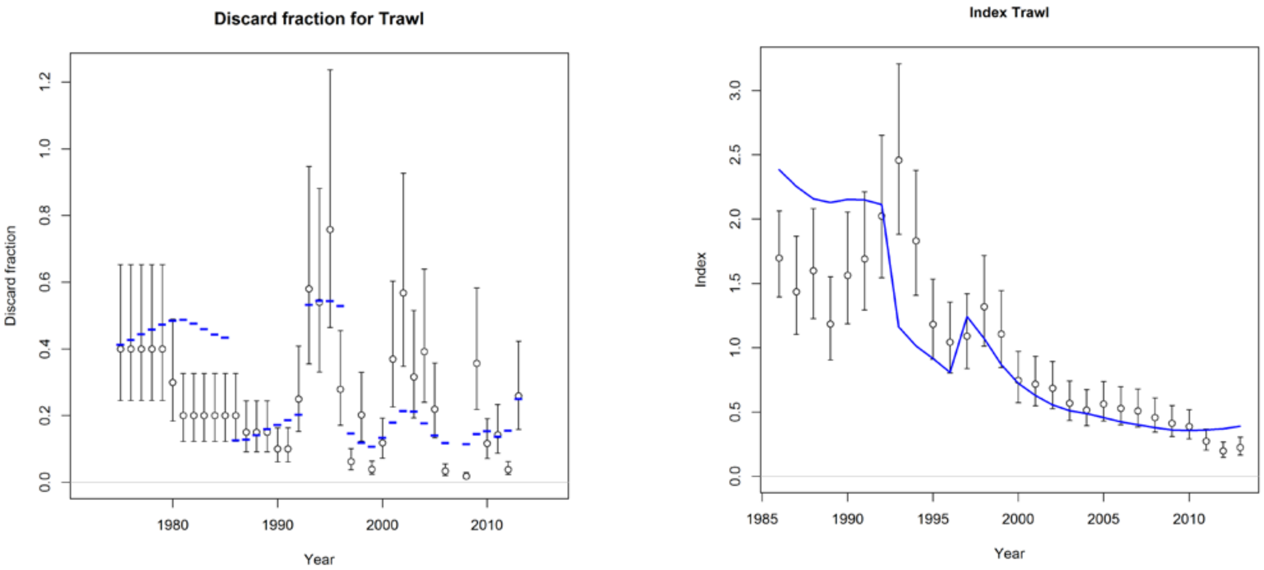


Figure 7.7. The fit to the discard rate data (left) and the catch rate data (right) under BC1; blue dashes/lines are the model fitted estimates.

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.

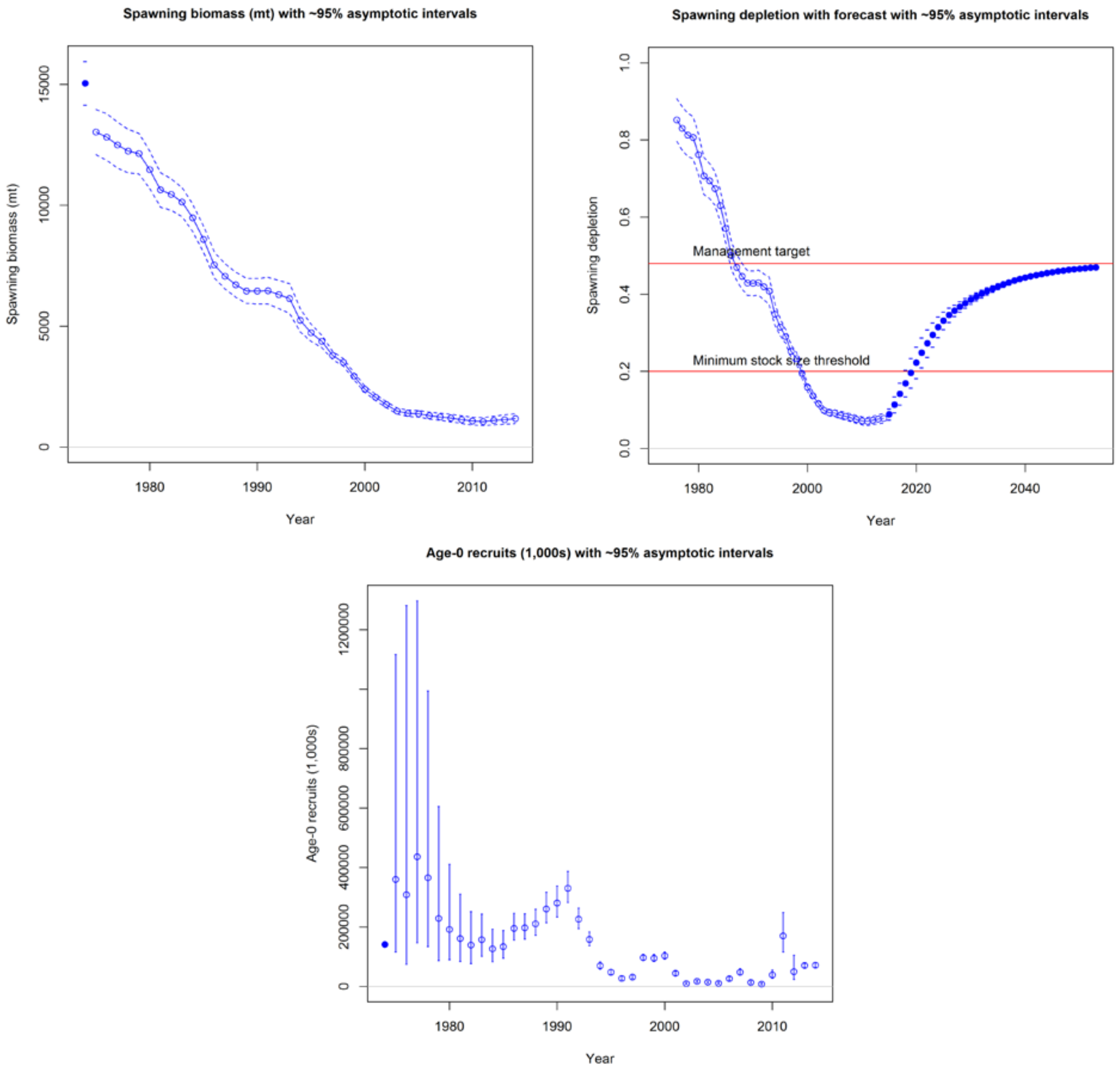


Figure 7.8. The annual time-series of female spawning biomass (absolute left and relative right) and recruitment (bottom) under BC1.

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.

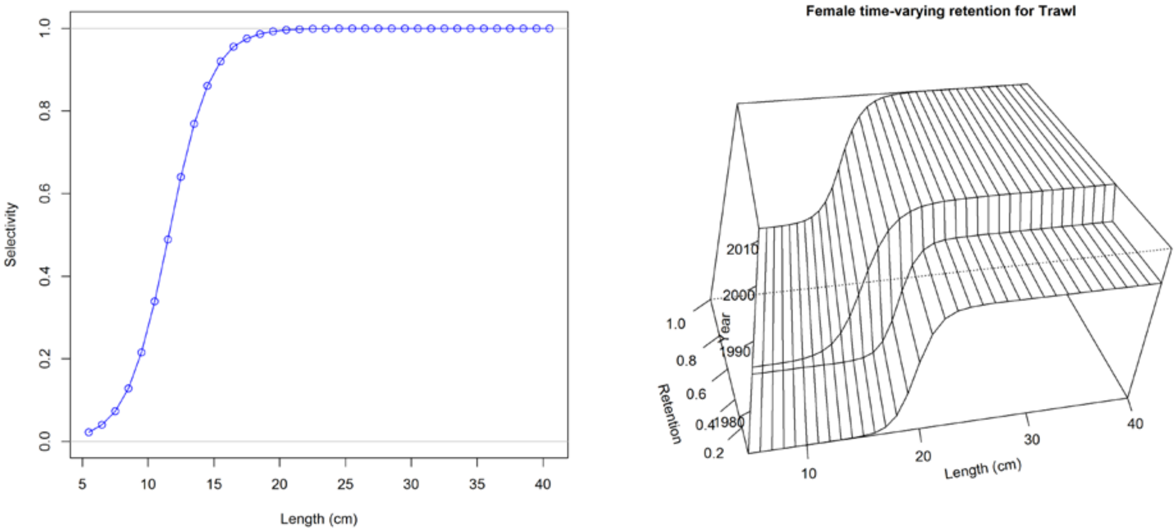


Figure 7.9.The estimated selectivity (left) and retention (right) functions for eastern redfish under BC3.

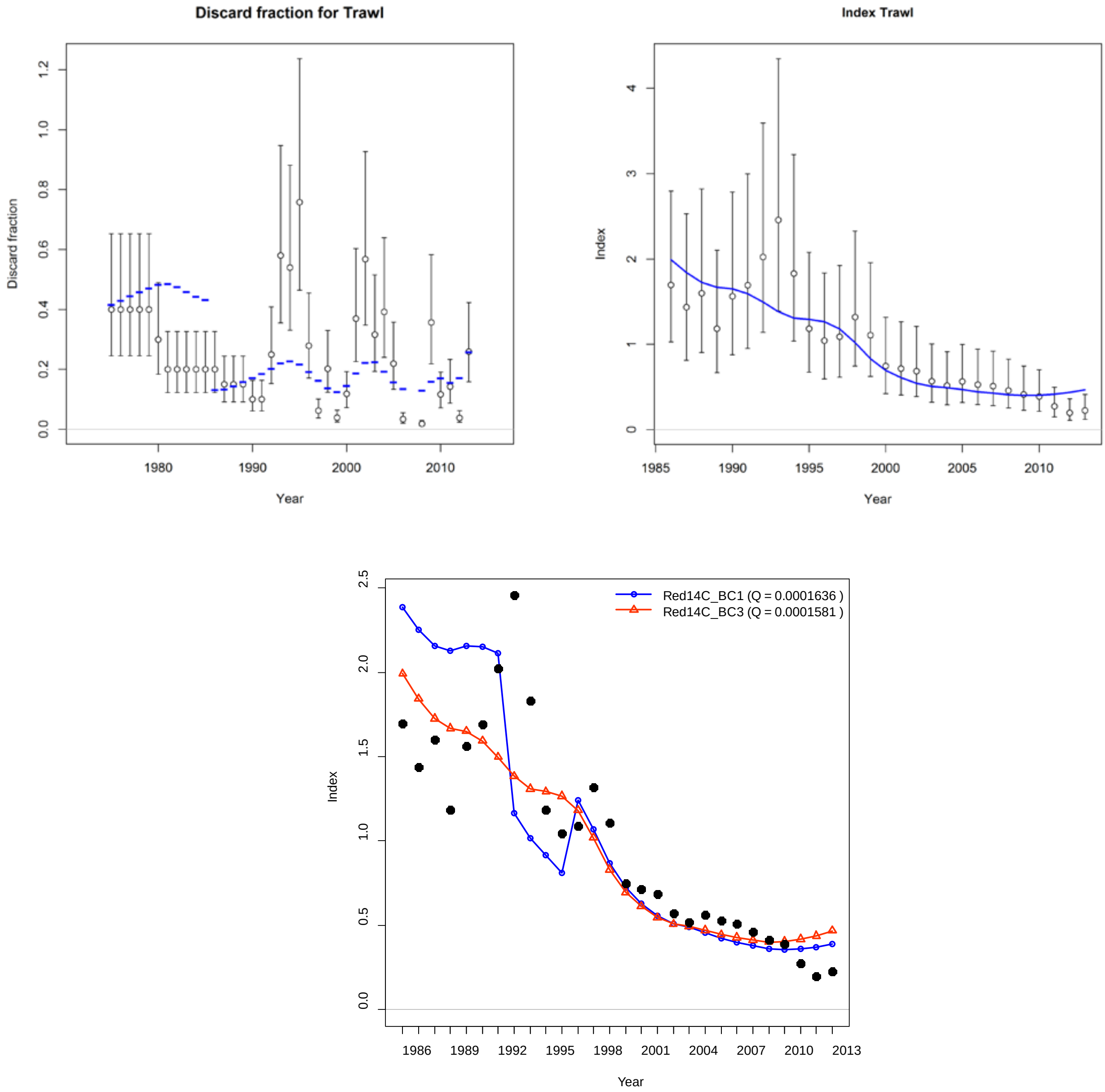


Figure 7.10. The fit to the discard rate data (top-left) and the catch rate data (top-right) under BC3; blue dashes/lines are the model fitted estimates, and a comparison of catch rate fits between BC1 (blue) and BC3 (red) (bottom).

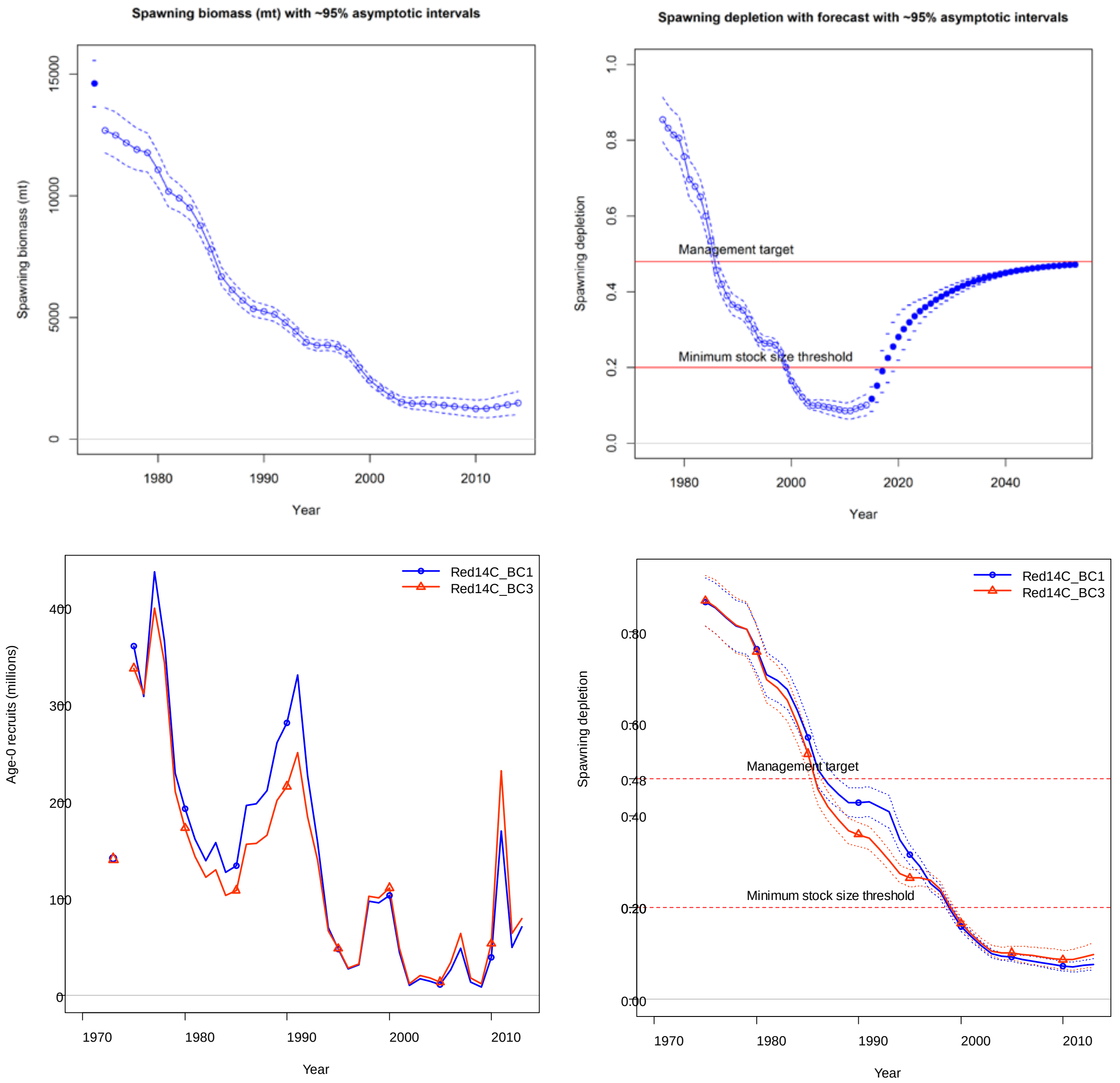


Figure 7.11. The annual time-series of female spawning biomass (absolute biomass, top left, and relative biomass, top right) and recruitment and spawning biomass for BC3 (red) in comparison to BC1 (blue) (bottom).

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).

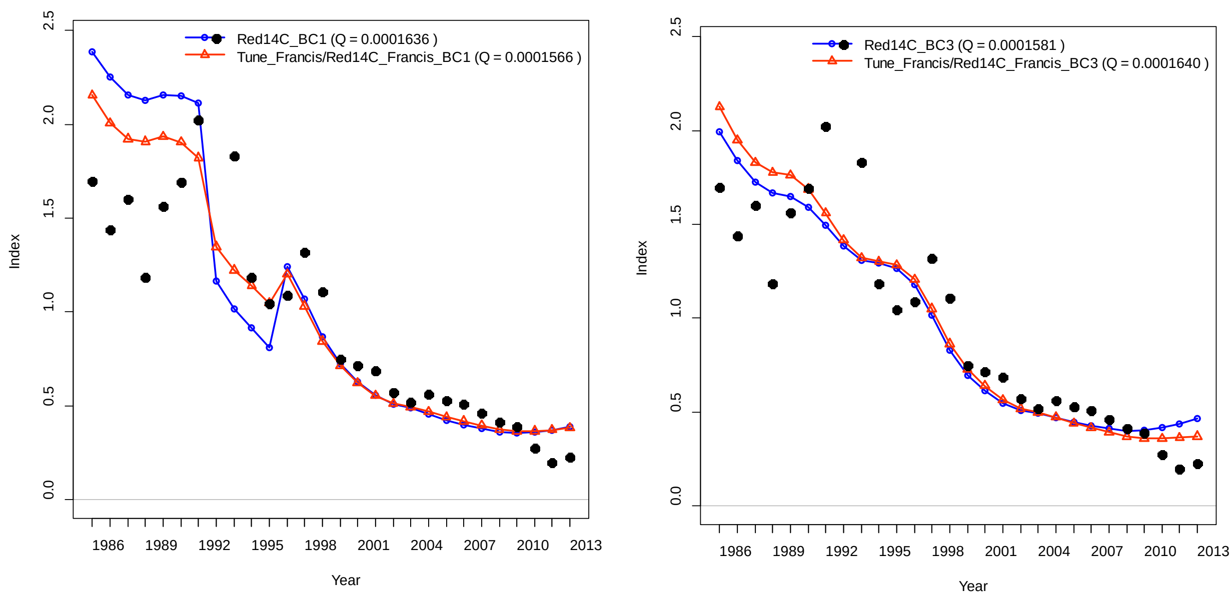


Figure 7.12. A comparison of catch rate fits using the standard method (blue) and the Francis method (red) for base-case models BC1 (left) and BC3 (right).

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*

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. 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.

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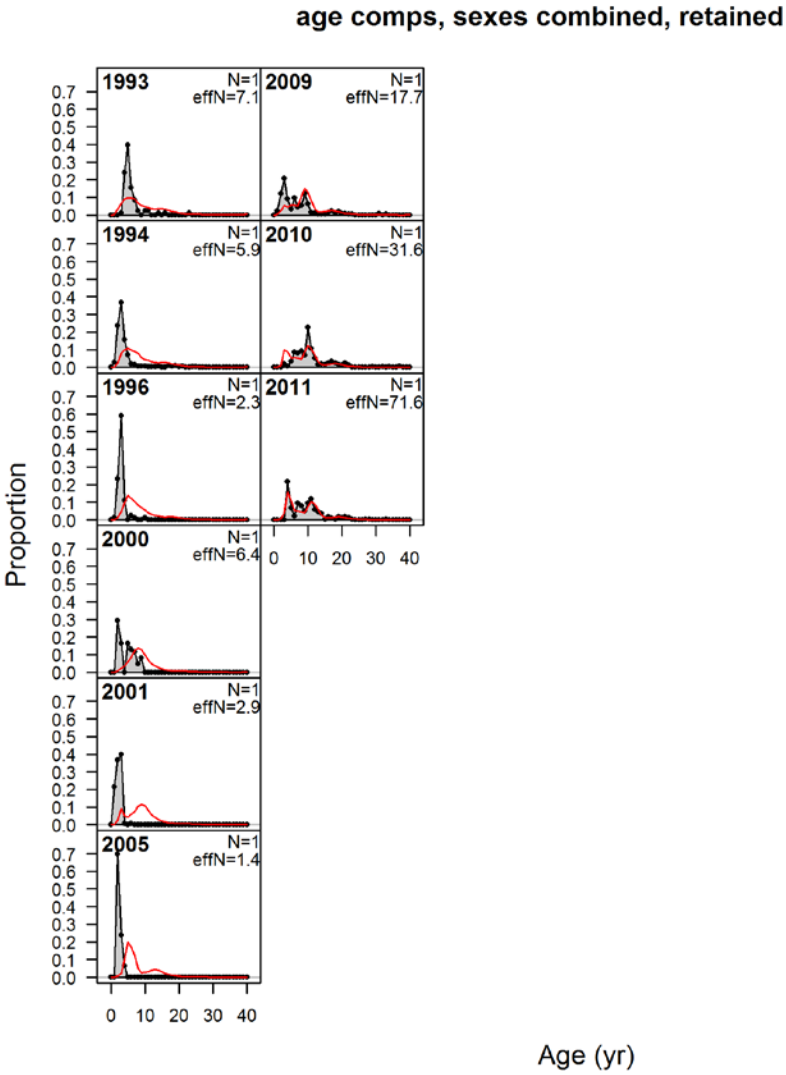
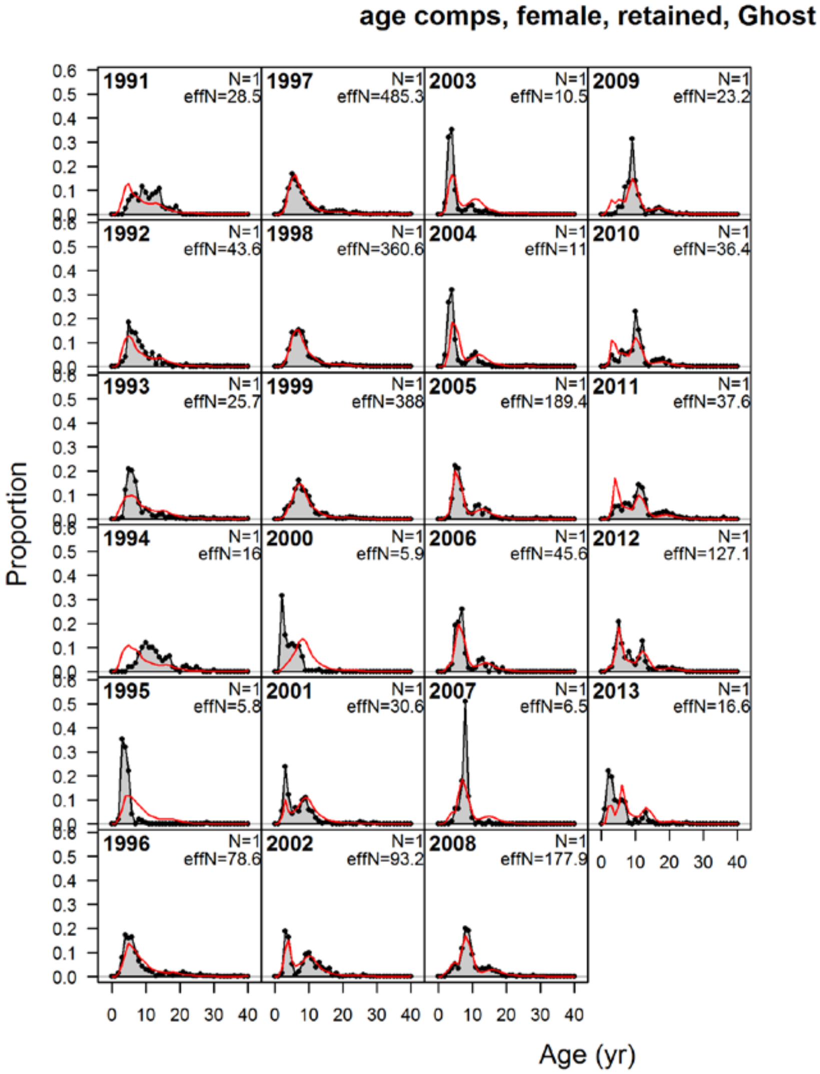
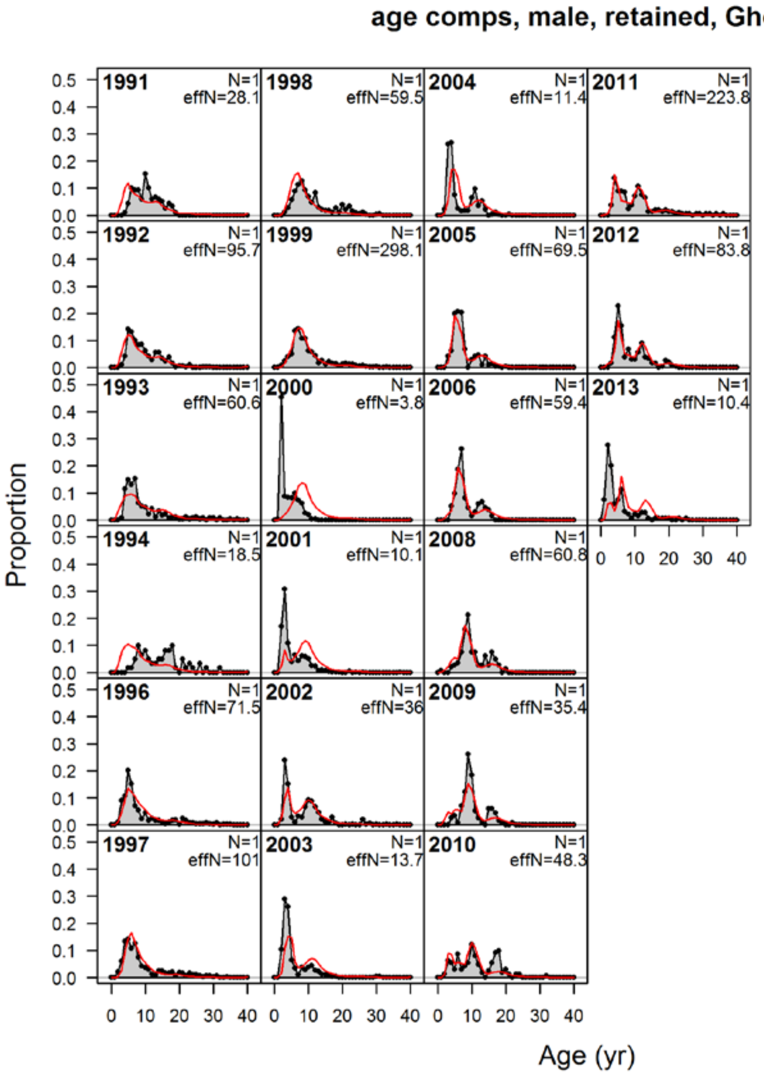
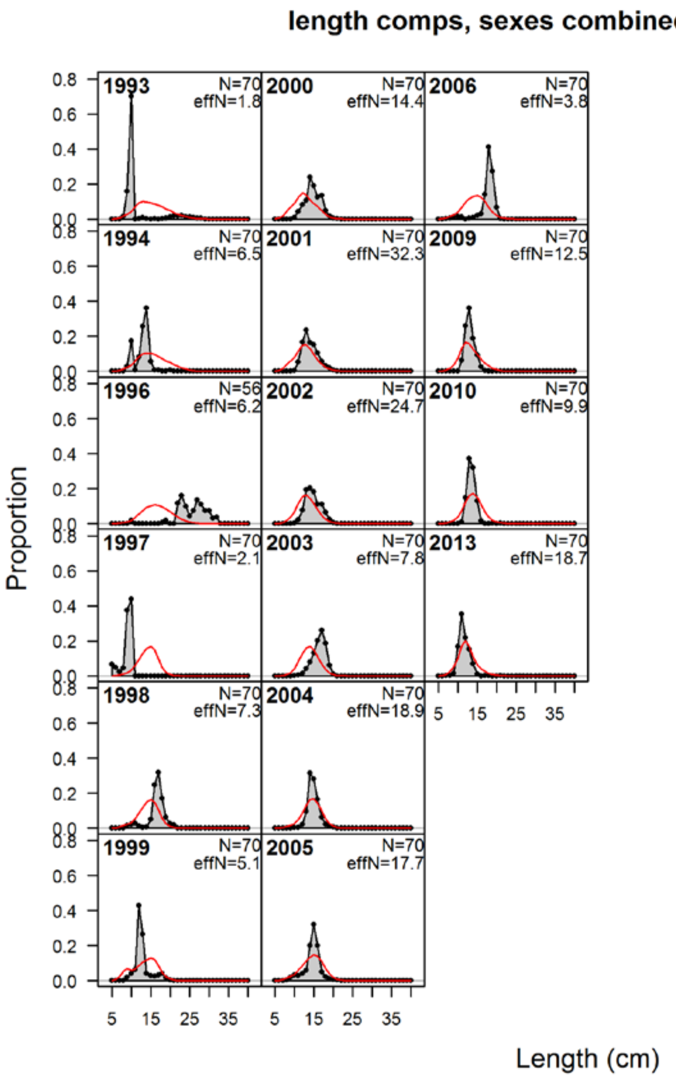
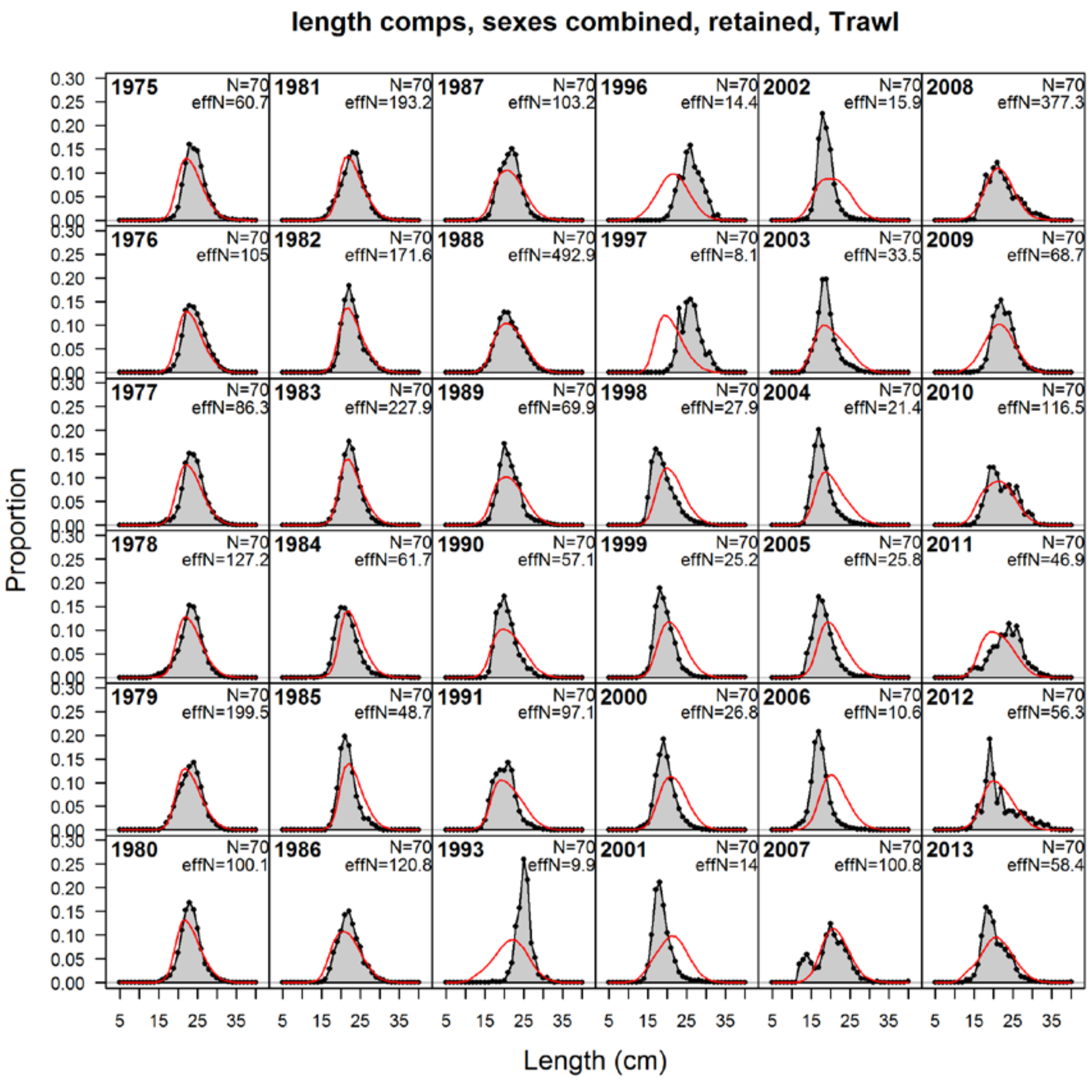
7.10 Appendix 1: Base case 1 (BC1)

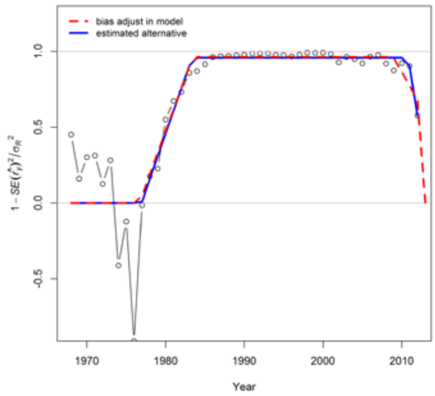


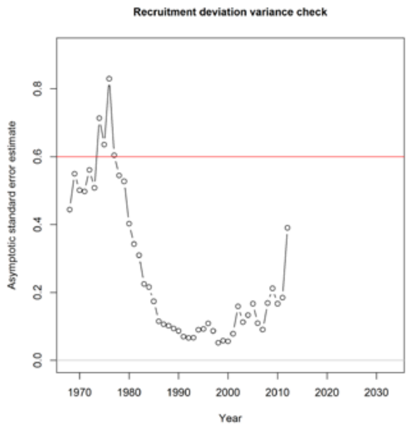

age comps, female, retained, Ghost
1991 N=1 effN=28.5
1997 N=1 effN=485.3
2003 N=1 effN=10.5
2009 N=1 effN=23.2
1992 N=1 effN=43.6
1998 N=1 effN=360.6
2004 N=1 effN=11
2010 N=1 effN=36.4
1993 N=1 effN=25.7
1999 N=1 effN=388
2005 N=1 effN=189.4
2011 N=1 effN=37.6
1994 N=1 effN=16
2000 N=1 effN=5.9
2006 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
Proportion
Age (yr)

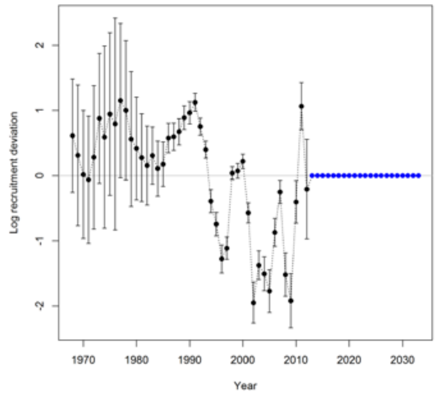

age comps, male, retained, Ghost
1991 N=1 effN=28.1
1998 N=1 effN=59.5
2004 N=1 effN=11.4
2011 N=1 effN=223.8
1992 N=1 effN=95.7
1999 N=1 effN=298.1
2005 N=1 effN=69.5
2012 N=1 effN=83.8
1993 N=1 effN=60.6
2000 N=1 effN=3.8
2006 N=1 effN=59.4
2013 N=1 effN=10.4
1994 N=1 effN=18.5
2001 N=1 effN=10.1
2008 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)

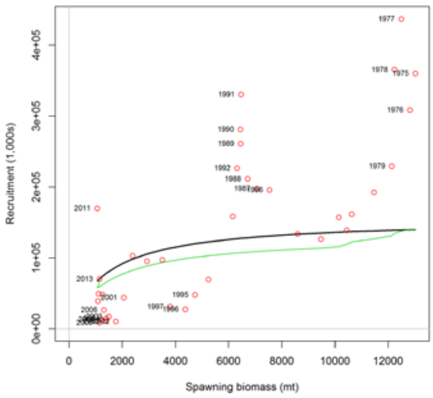

length comps, sexes combined, discard, Trawl
1993 N=70 effN=1.8
2000 N=70 effN=14.4
2006 N=70 effN=3.8
1994 N=70 effN=6.5
2001 N=70 effN=32.3
2009 N=70 effN=12.5
1996 N=56 effN=6.2
2002 N=70 effN=24.7
2010 N=70 effN=9.9
1997 N=70 effN=2.1
2003 N=70 effN=7.8
2013 N=70 effN=18.7
1998 N=70 effN=7.3
2004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

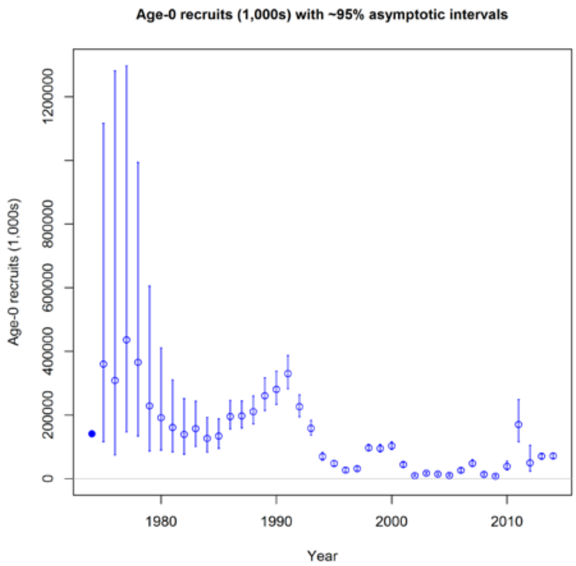

length comps, sexes combined, retained, Trawl
1975 N=70 effN=60.7
1981 N=70 effN=193.2
1987 N=70 effN=103.2
1996 N=70 effN=14.4
2002 N=70 effN=15.9
2008 N=70 effN=377.3
1976 N=70 effN=105
1982 N=70 effN=171.6
1988 N=70 effN=492.9
1997 N=70 effN=8.1
2003 N=70 effN=33.5
2009 N=70 effN=68.7
1977 N=70 effN=86.3
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
Proportion
0.00 0.05 0.10 0.15 0.20 0.25 0.30
5 15 25 35
Length (cm)


bias adjust in model
estimated alternative
Year

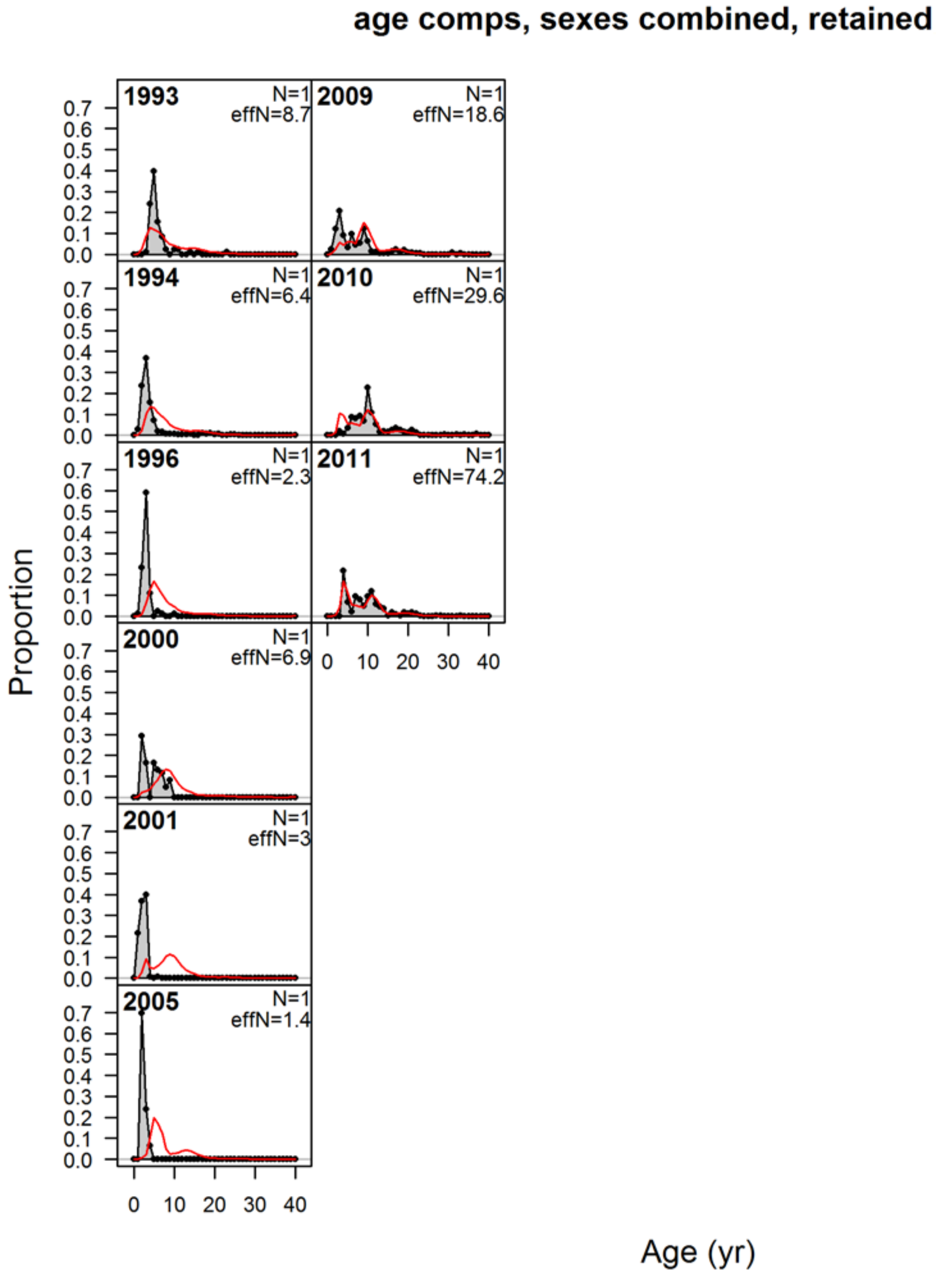

Recruitment deviation variance check
Asymptotic standard error estimate
Year

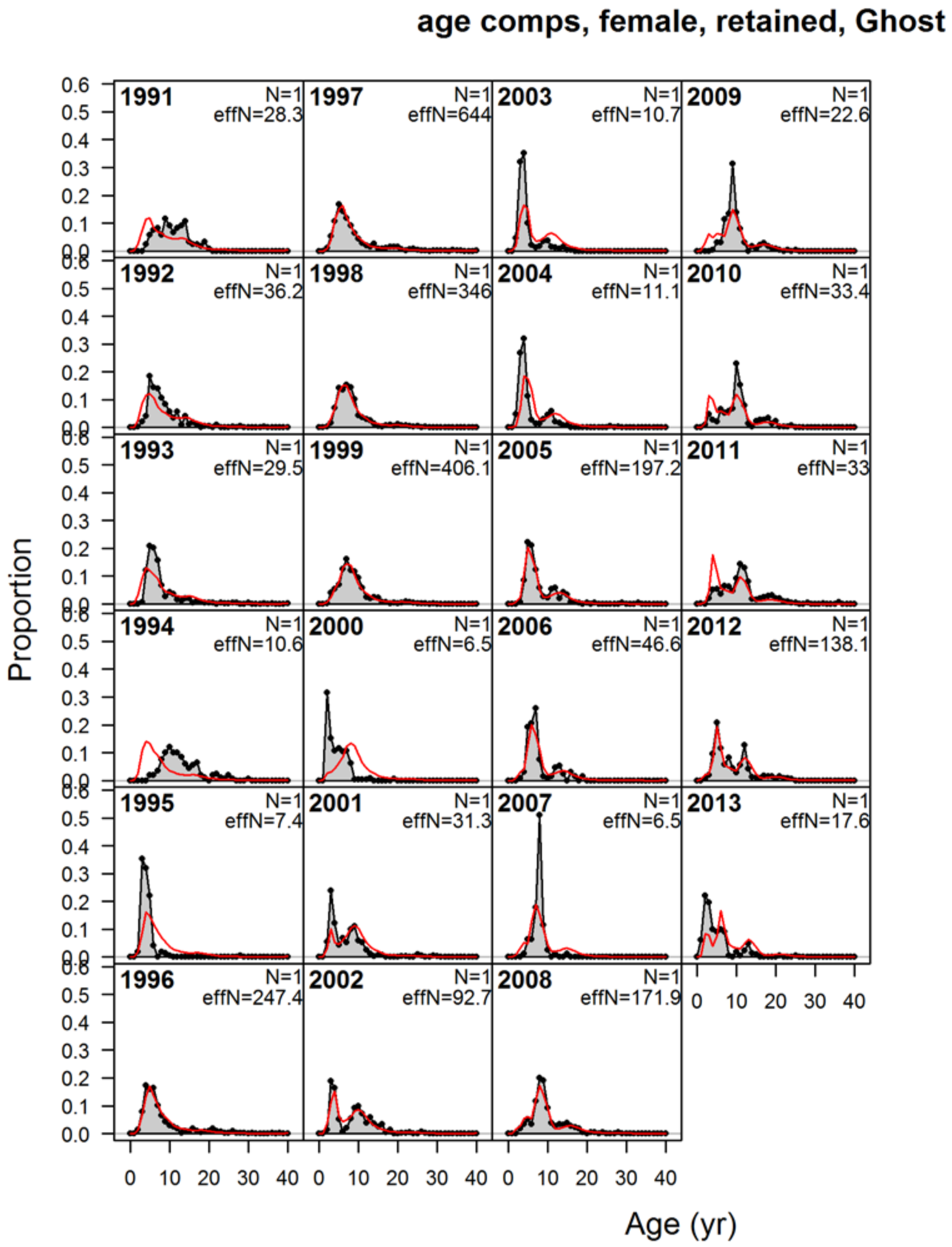

Log recruitment deviation
Year

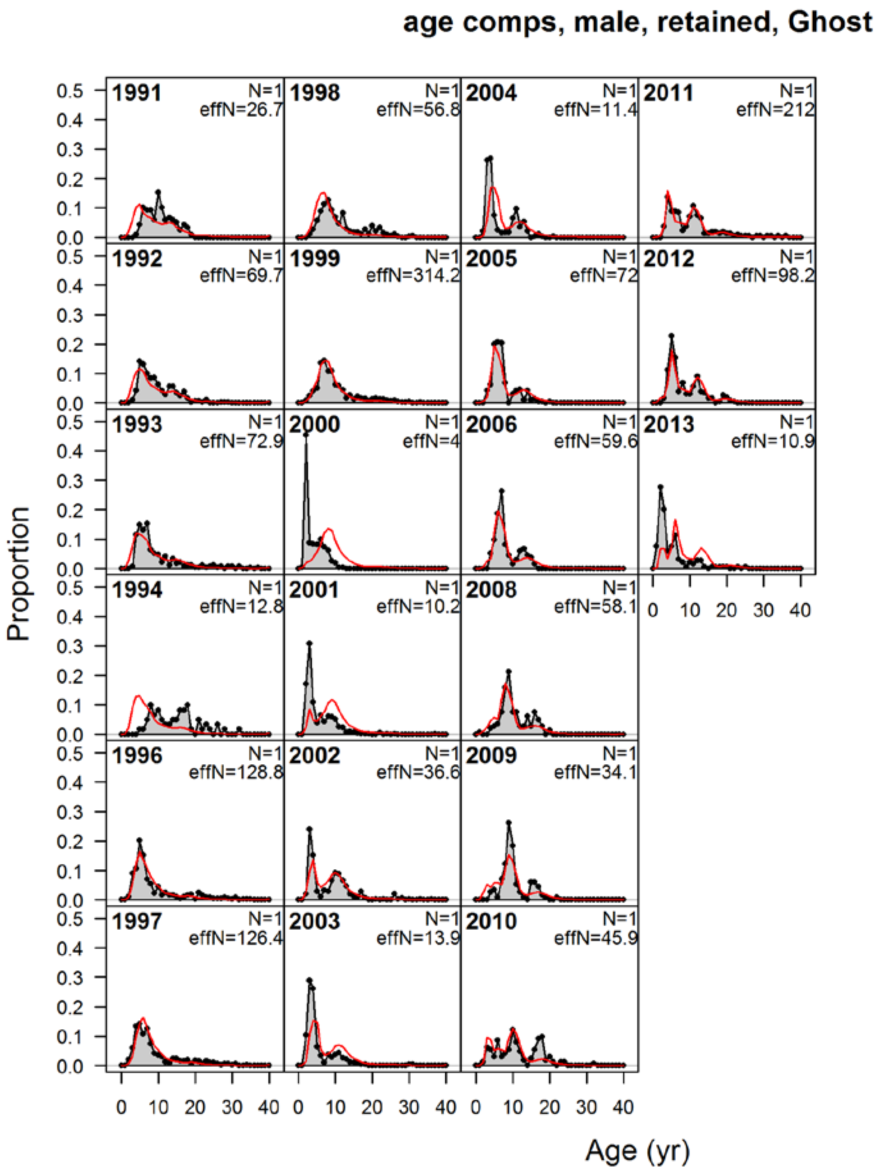

Recruitment (1,000s)
Spawning biomass (mt)

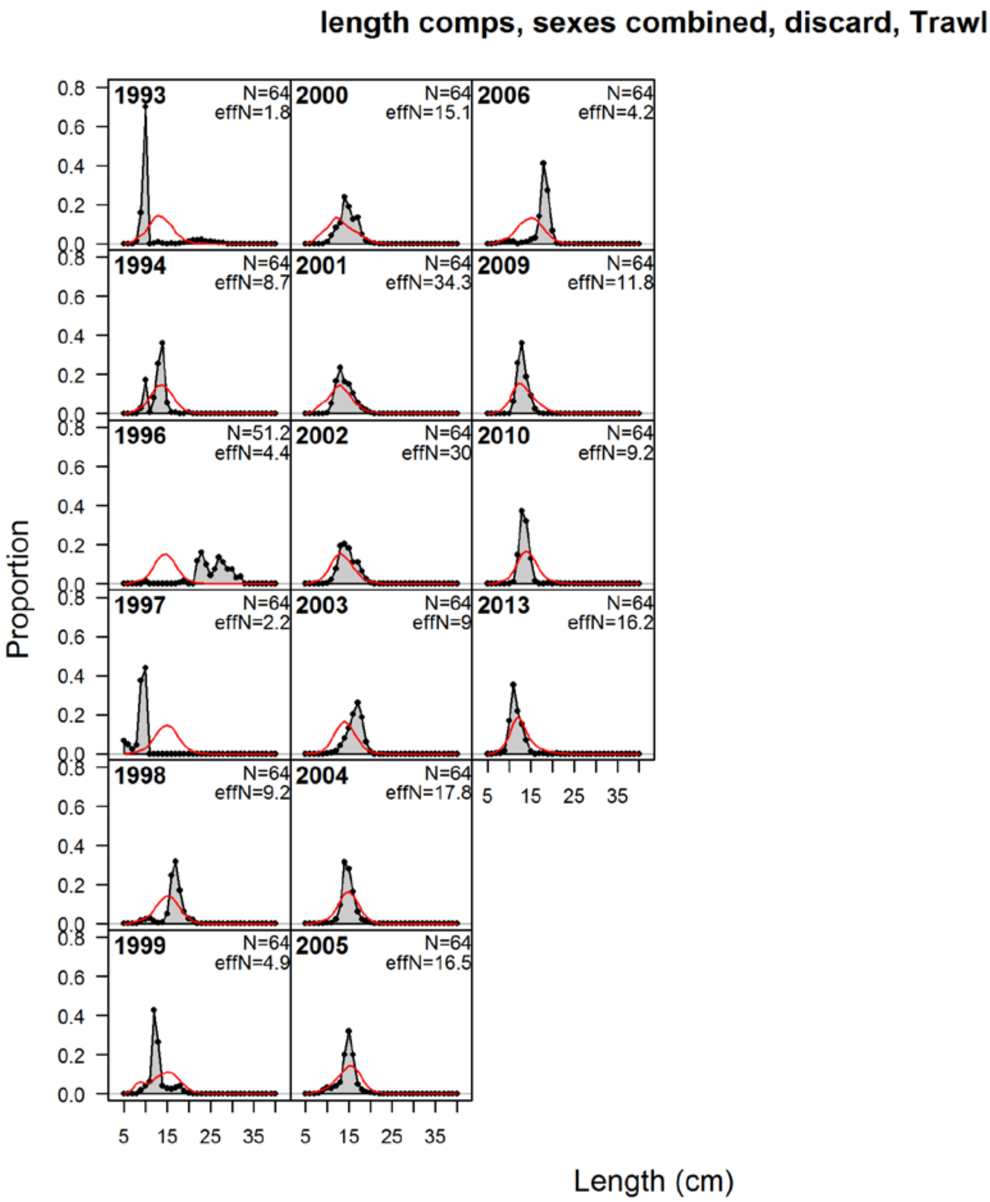

Age-0 recruits (1,000s) with ~95% asymptotic intervals
Age-0 recruits (1,000s)
Year

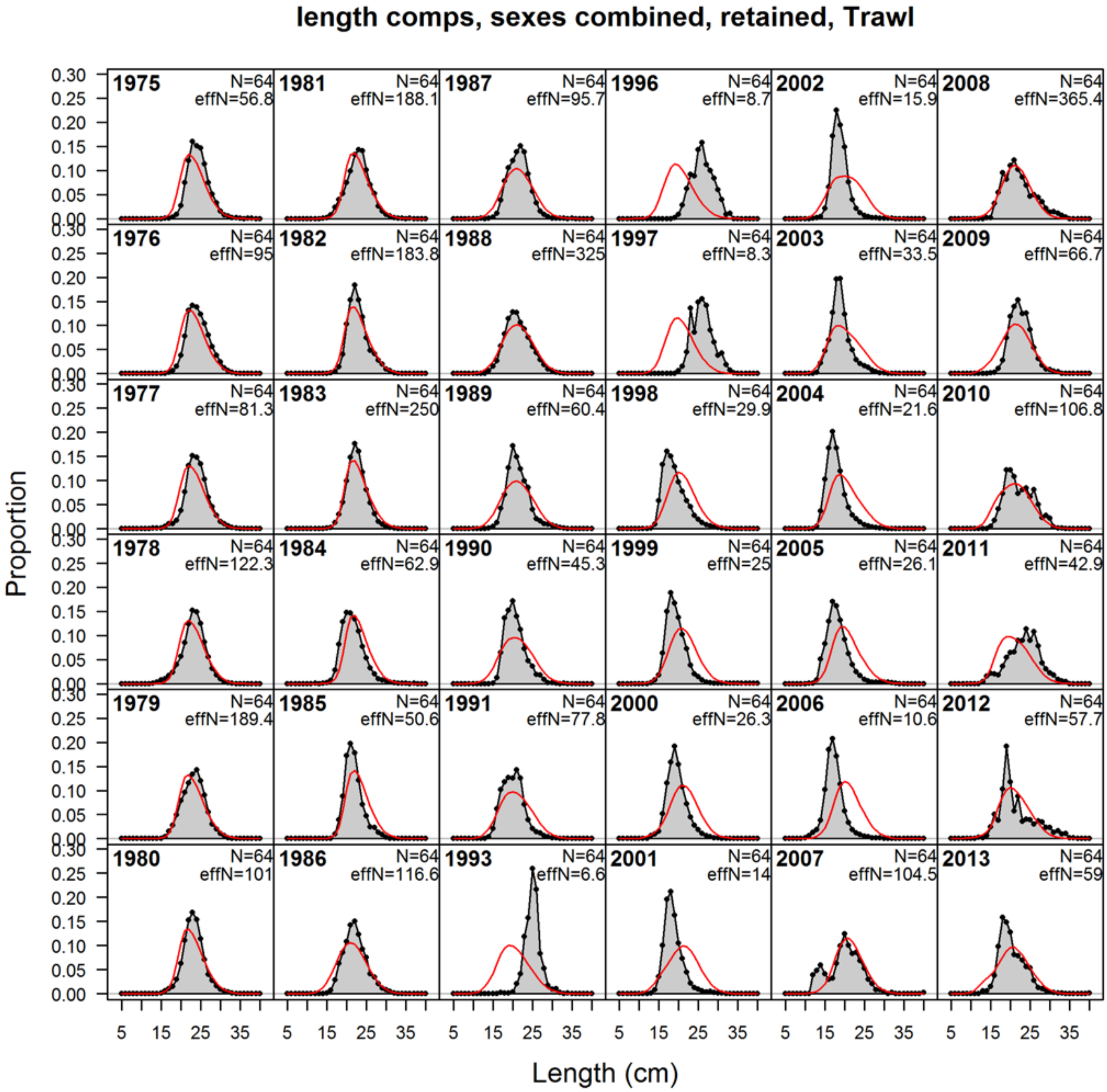
7.11 Appendix 2: Base case 3 (BC3)

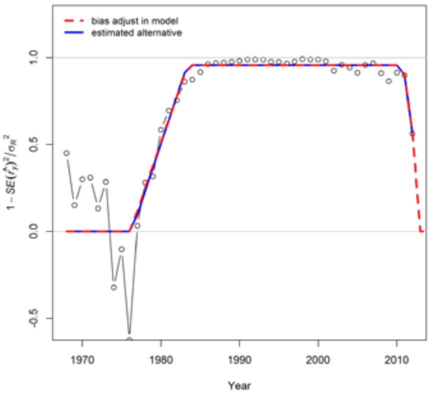


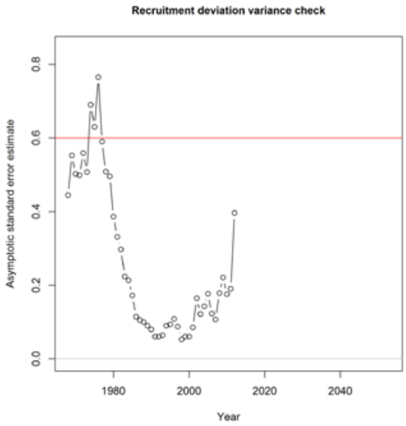

age comps, female, retained, Ghost
Proportion
Age (yr)
1991 N=1 effN=28.3
1997 N=1 effN=644
2003 N=1 effN=10.7
2009 N=1 effN=22.6
1992 N=1 effN=36.2
1998 N=1 effN=346
2004 N=1 effN=11.1
2010 N=1 effN=33.4
1993 N=1 effN=29.5
1999 N=1 effN=406.1
2005 N=1 effN=197.2
2011 N=1 effN=33
1994 N=1 effN=10.6
2000 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

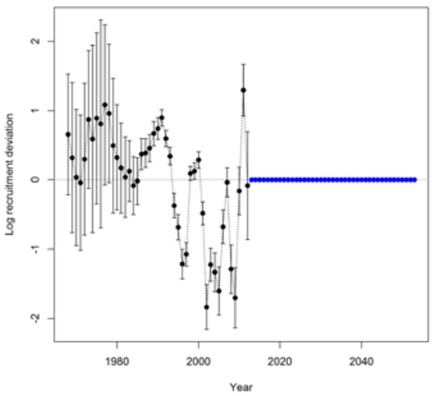

age comps, male, retained, Ghost
1991 N=1 effN=26.7
1998 N=1 effN=56.8
2004 N=1 effN=11.4
2011 N=1 effN=212
1992 N=1 effN=69.7
1999 N=1 effN=314.2
2005 N=1 effN=72
2012 N=1 effN=98.2
1993 N=1 effN=72.9
2000 N=1 effN=4
2006 N=1 effN=59.6
2013 N=1 effN=10.9
1994 N=1 effN=12.8
2001 N=1 effN=10.2
2008 N=1 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)

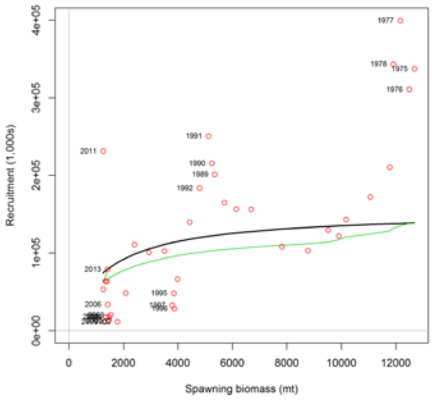

length comps, sexes combined, discard, Trawl
1993 N=64 effN=1.8
2000 N=64 effN=15.1
2006 N=64 effN=4.2
1994 N=64 effN=8.7
2001 N=64 effN=34.3
2009 N=64 effN=11.8
1996 N=51.2 effN=4.4
2002 N=64 effN=30
2010 N=64 effN=9.2
1997 N=64 effN=2.2
2003 N=64 effN=9
2013 N=64 effN=16.2
1998 N=64 effN=9.2
2004 N=64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

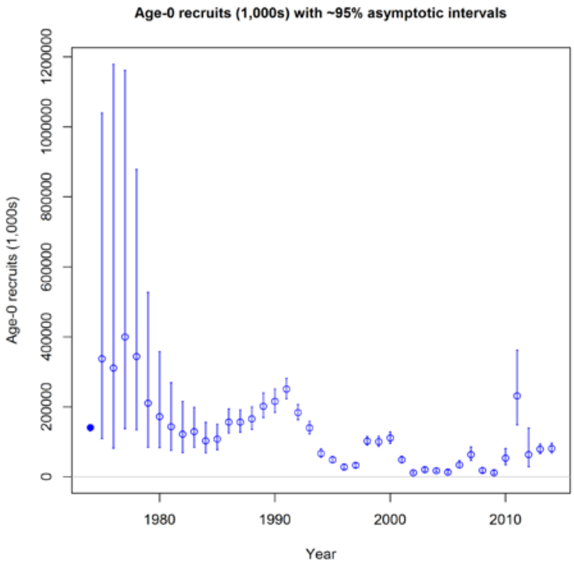

length comps, sexes combined, retained, Trawl
Proportion
Length (cm)
1975 N=64 effN=56.8
1981 N=64 effN=188.1
1987 N=64 effN=95.7
1996 N=64 effN=8.7
2002 N=64 effN=15.9
2008 N=64 effN=365.4
1976 N=64 effN=95
1982 N=64 effN=183.8
1988 N=64 effN=325
1997 N=64 effN=8.3
2003 N=64 effN=33.5
2009 N=64 effN=66.7
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

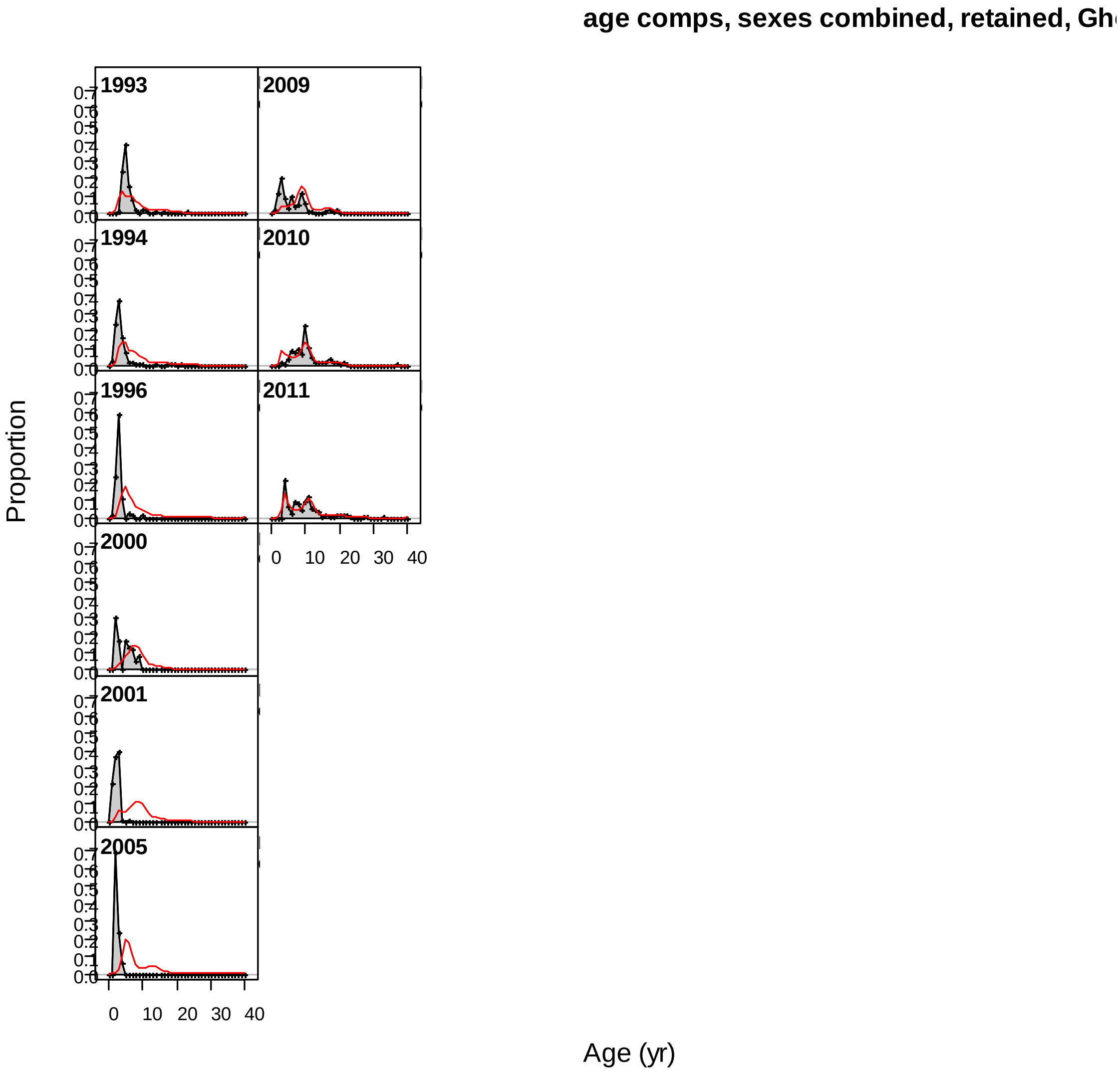

Recruitment deviation variance check
Asymptotic standard error estimate
Year

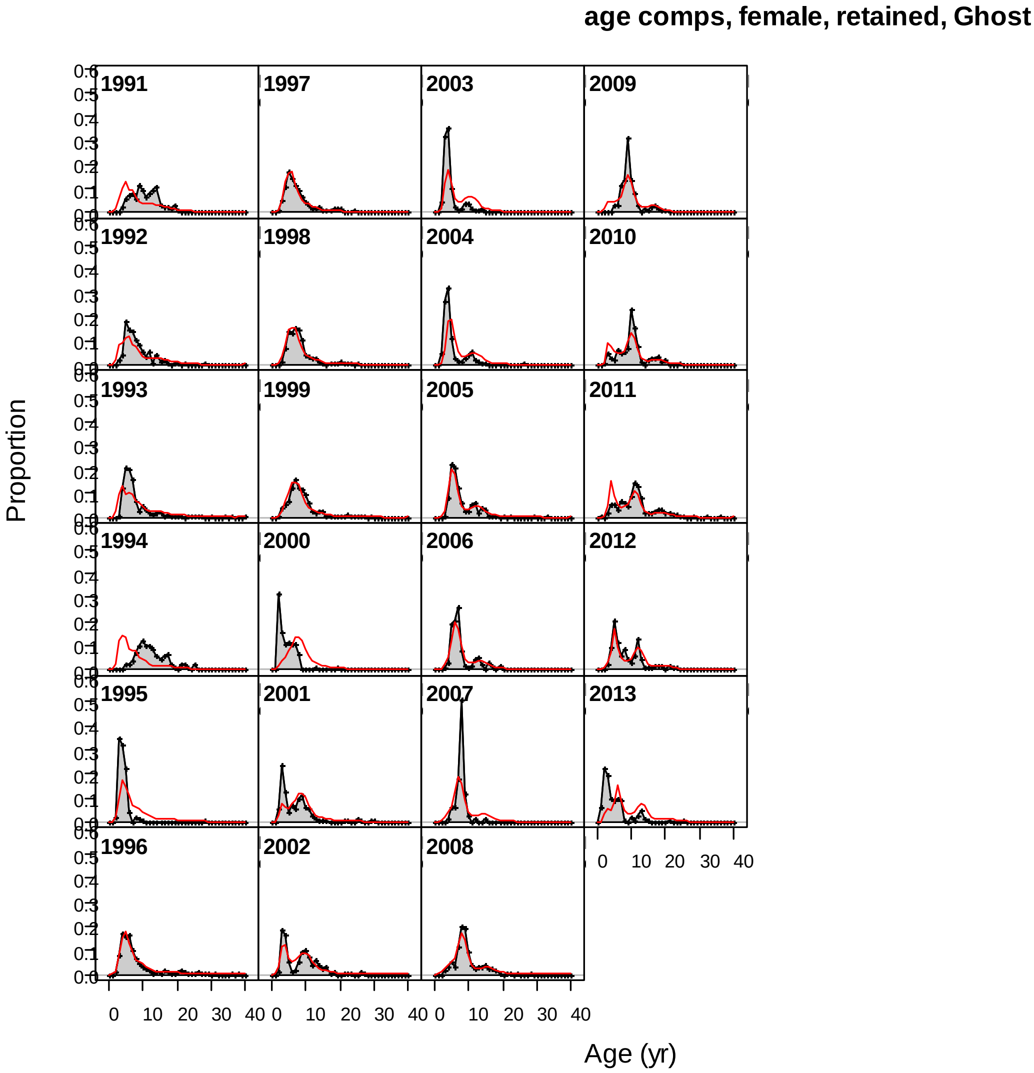

Log recruitment deviation
Year

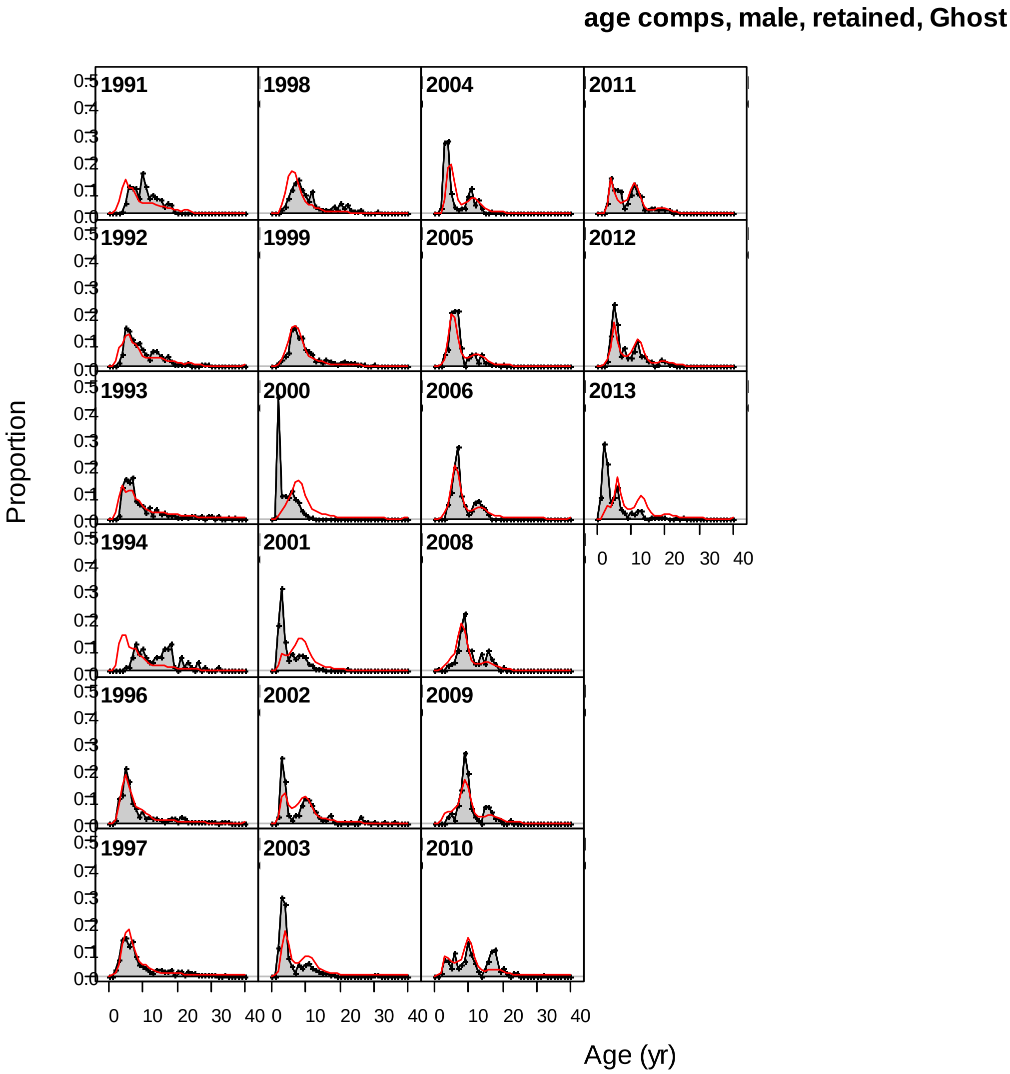

Recruitment (1,000s)
Spawning biomass (mt)

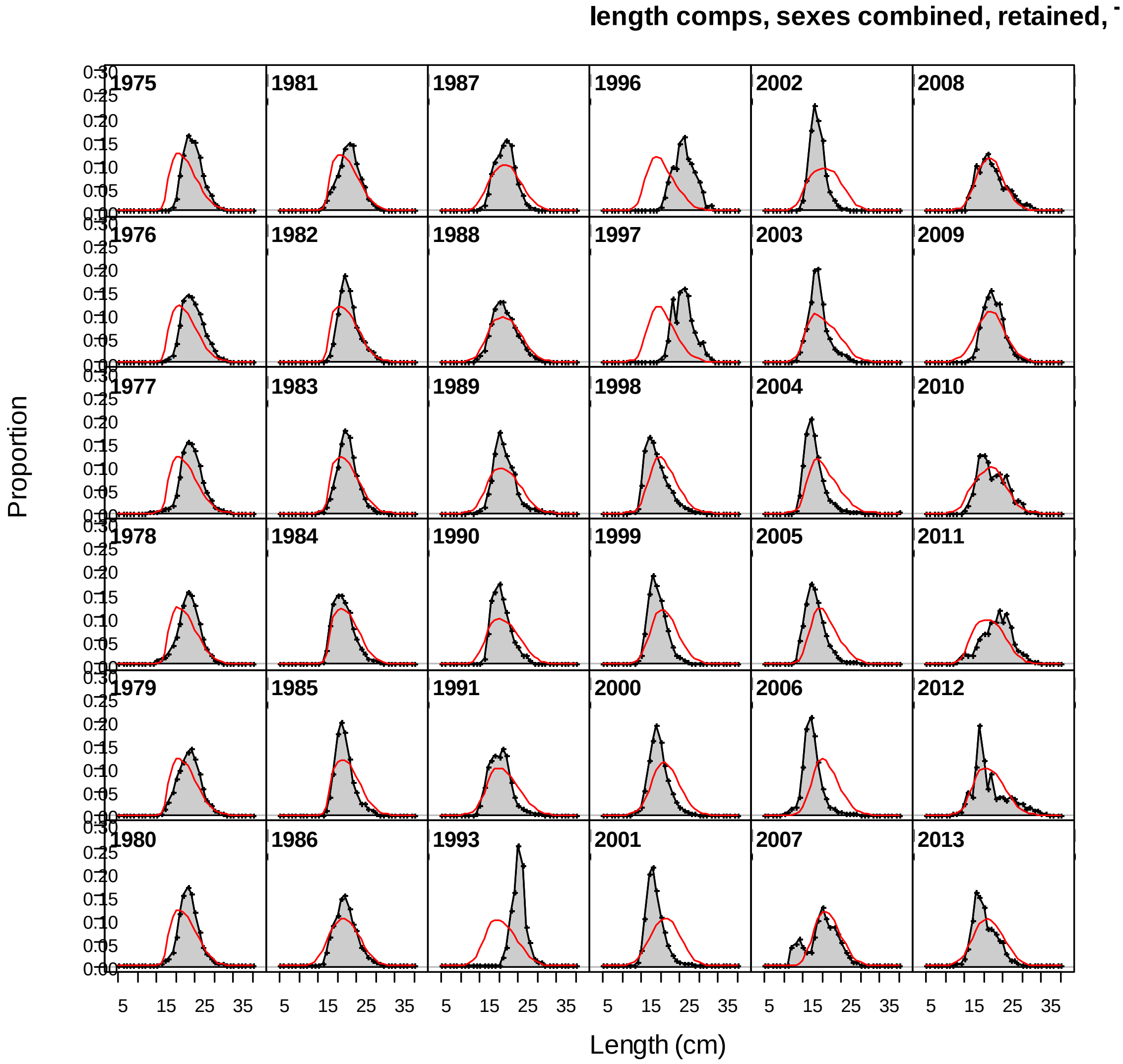

Age-0 recruits (1,000s) with ~95% asymptotic intervals
Age-0 recruits (1,000s)
Year

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

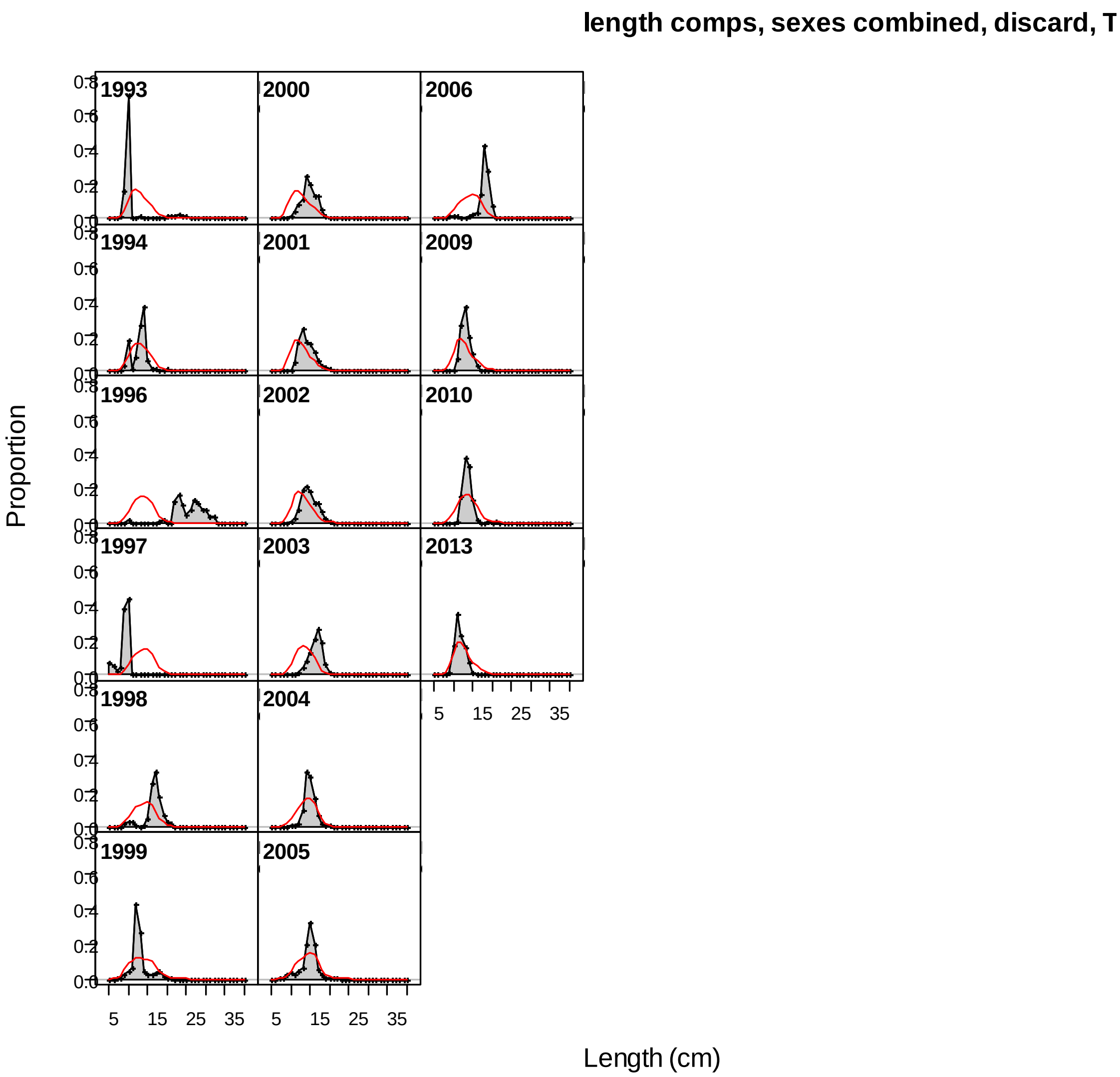


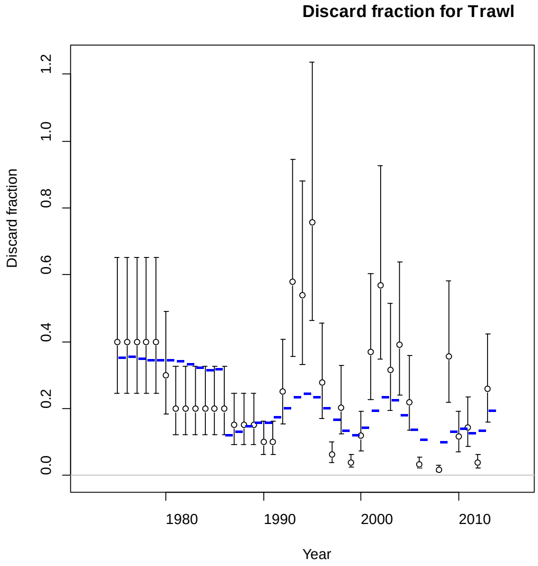

age comps, female, retained, Ghost
1991
1997
2003
2009
1992
1998
2004
2010
1993
1999
2005
2011
1994
2000
2006
2012
1995
2001
2007
2013
1996
2002
2008
Proportion
Age (yr)
0
10
20
30
40

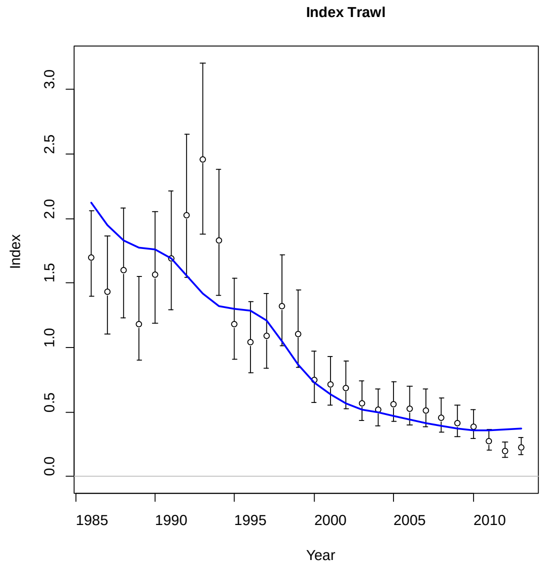

age comps, male, retained, Ghost
Proportion
Age (yr)
1991
1998
2004
2011
1992
1999
2005
2012
1993
2000
2006
2013
1994
2001
2008
1996
2002
2009
1997
2003
2010
0.0
0.1
0.2
0.3
0.4
0.5
0
10
20
30
40

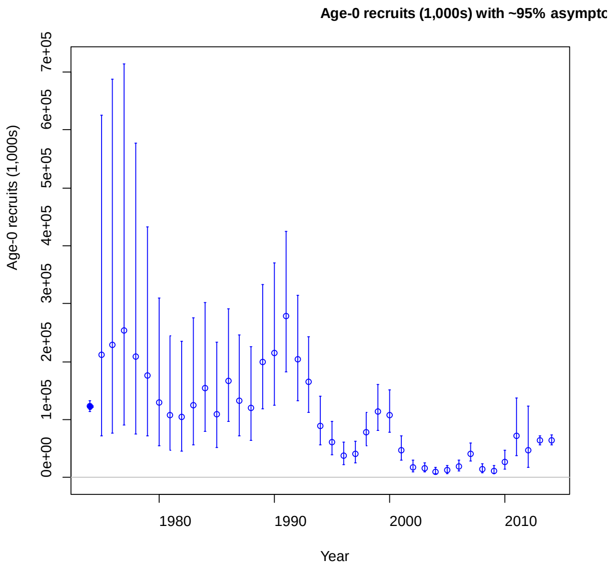


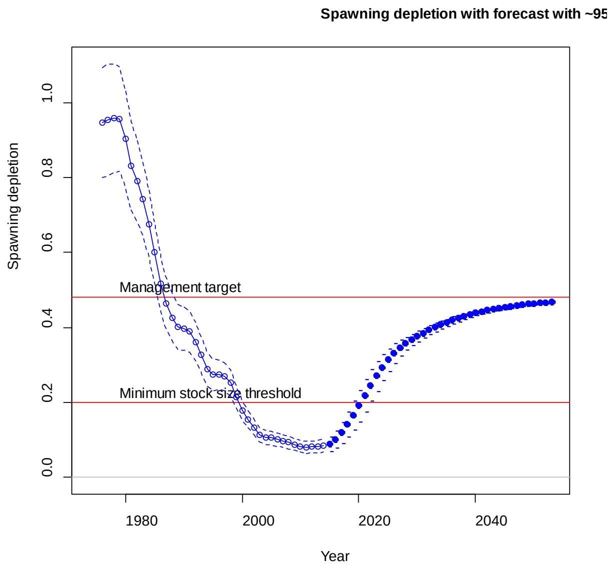
length comps, sexes combined, retained, ˉ
1975
1981
1987
1996
2002
2008
1976
1982
1988
1997
2003
2009
1977
1983
1989
1998
2004
2010
1978
1984
1990
1999
2005
2011
1979
1985
1991
2000
2006
2012
1980
1986
1993
2001
2007
2013
Proportion
0.30
0.25
0.20
0.15
0.10
0.05
0.00
5
15
25
35
Length (cm)


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


Discard fraction for Trawl
Discard fraction
Year
1980
1990
2000
2010
0.0
0.2
0.4
0.6
0.8
1.0
1.2


Index Trawl
Index
Year
1985
1990
1995
2000
2005
2010
0.0
0.5
1.0
1.5
2.0
2.5
3.0


Age-0 recruits (1,000s) with ~95% asymptc
Age-0 recruits (1,000s)
Year
1980
1990
2000
2010
0e+00
1e+05
2e+05
3e+05
4e+05
5e+05
6e+05
7e+05


Spawning depletion with forecast with ~95
Spawning depletion
Year
Management target
Minimum stock size threshold
1980
2000
2020
2040
0.0
0.2
0.4
0.6
0.8
1.0