



# A 2013 stock assessment of Mid-East Coast orange roughy

New Zealand Fisheries Assessment Report 2014/32

P.L. Cordue

ISSN 1179-5352 (online)

ISBN 978-0-478-43713-3 (online)

July 2014



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## EXECUTIVE SUMMARY

**Cordue, P.L. (2014). A 2013 stock assessment of Mid-East Coast orange roughy.**

***New Zealand Fisheries Assessment Report 2014/32. 54 p.***

This document summarizes and provides details of the 2013 stock assessment of Mid-East Coast orange roughy that was developed in consultation with the Deep Water Working Group and presented at the 2013 Plenary. In some ways, the assessment was an update of the previous assessment in 2011. The intention was to use a new model structure with previously used data and only to update the catch history. However, as it happened, a substantial amount of new data was incorporated into the assessment.

The assessment was performed using the Bayesian stock assessment package CASAL. A single-stock, single-area, single-sex, age-structured model was fitted to CPUE indices, trawl-survey indices, an egg-survey spawning-biomass estimate, two acoustic-survey spawning-biomass estimates, and age and length frequencies from the commercial fisheries and the trawl surveys. The main new data (since 2011) were age frequencies from the 1993 and 2010 trawl surveys which, together with spawning-season age frequencies from 1989, 1990, and 1991, allowed the estimation of a large number of year class strengths.

The final assessment consisted of a base model and a single sensitivity taken through to MCMC calculations to determine the marginal posterior distributions of virgin biomass, current biomass, and stock status (current biomass as a percentage of virgin biomass). The base model used the “Haist” parameterisation of year class strengths (YCS) with uniform priors. The sensitivity used the “Francis” parameterisation of YCS with lognormal priors. The Haist model had fewer constraints on the YCS estimates and was able to fit the data much better than the Francis model. In particular, it had a better fit to the downward trend in the trawl survey biomass indices.

The Haist model estimated current stock status at 21%  $B_0$  with a 95% CI of 12–33%  $B_0$ . If natural mortality was lower than the assumed value of 0.045 then current stock status would also be lower; similarly, if natural mortality were higher, stock status would be higher. The Francis sensitivity, which should be given less weight than the Haist model, provided a higher estimate of stock status at 29%  $B_0$  with a 95% CI of 21–38%  $B_0$ .

It seems reasonable to conclude that the stock is very unlikely to be below the hard limit, as likely as not to be below the soft limit, and unlikely to be at or above the target (30%  $B_0$ ). Projections for both models suggest that spawning stock biomass will increase at current catch levels.

## 1. INTRODUCTION

This document summarizes and provides details of the 2013 stock assessment of Mid-East Coast (MEC) orange roughy that was developed in consultation with the Deep Water Working Group (DWWG) and presented at the 2013 Plenary. In some ways, the assessment was an update of the previous assessment of Anderson & Dunn (2011). The intention was to use a new model structure with previously used data and only to update the catch history. However, as it happened, a substantial amount of new data was incorporated into the assessment.

This document starts with a background section to provide the context for the stock assessment and to describe the less than ideal development of the assessment. Some relevant pre-assessment results and the results of some early runs are also summarized in this section. The remainder of the document is primarily concerned with the assessment that was presented to and accepted by the Plenary.

## 2. BACKGROUND

The MEC orange roughy stock was previously assessed in 2011 (Anderson & Dunn, 2011). However, that stock assessment was unsatisfactory in that two base runs were presented which showed strongly contrasting stock status (9%  $B_0$  and 23%  $B_0$ ). There were two runs because it was not possible to find a single run which could adequately fit all of the defensible data. One run had a low value of natural mortality specified (0.025) so that it could reasonably well fit the trend in the trawl time series, although it seemed inconsistent with the age frequencies. In the other run, the right-hand limbs of the age frequencies were fitted and natural mortality was estimated (0.054). However, this run had a very poor fit to the trawl time series (Figure 1).

Alternative stock assessment models, which partitioned the data into “flats” and “hills”, were explored by Dunn (2011). He used models which assumed that there were two types of mature fish, those associated with “prime habitat” (hills) and those in less than ideal conditions (sub-prime habitat which was equated with flats). He attempted to fit the models to almost all of the available data (including CPUE indices from hills and flats in non-spawning and spawning seasons both pre and post 1997–98) and did not find any satisfactory model runs.

A 2013 project was developed which was aimed at achieving a satisfactory MEC stock assessment. It was not assumed that such an assessment could be achieved and the project took a staged approach with two objectives:

1. Determine if a satisfactory stock assessment of MEC orange roughy is likely to be achievable.
2. If appropriate, complete an MEC orange roughy stock assessment.

The exploratory work of objective 1 was presented to a DWWG meeting on 14 February 2013 and, on the basis of that work, the DWWG recommended that a full assessment be completed.

The model exploration considered three alternative model structures: episodic recruitment, a regime shift, and a prime-habitat assumption (following Dunn 2011). In the prime-habitat models explored, there were two types of mature fish, prime and sub-prime, and only the prime fish were engaged in spawning. The hypothesis supporting this approach is that orange roughy are territorial to some extent and that older, larger fish are able to secure “prime” habitat which gives them an “energetic”

advantage (so that they can spawn each year); while the mature fish in the sub-prime habitat cannot spawn until they are able to move into prime habitat.

The DWWG concluded that the episodic-recruitment models explored (which had occasional large recruitments up to 20 times the average) did not provide satisfactory fits to the available data. Regime-shift and prime-habitat models were consistent with the data. The latter required that some year class strengths (YCS) were estimated to allow for the poor recruitment seen in the 2010 trawl survey (Figure 2). It was recommended that a prime-habitat model be used in the 2013 assessment. It was decided that there was no need to consider a regime shift when the simpler explanation of a block of poor recruitment appeared to be all that was needed to fit the data.

In an ideal stock assessment, all of the available data are gathered together and critically reviewed before any model runs are performed. The development of this assessment was far from ideal as the data used in the assessment were modified on a number of occasions during the period over which models were being fitted. Consequently, numerous model runs (MPDs and MCMCs) were done which did not use the data that were used in the final runs. The final assessment consists of only two model runs, a base and a single sensitivity.

The main timeline and changes to the assessment data were:

- The model exploration presented to the DWWG meeting on 14 February 2013 used data available from Anderson & Dunn (2011) and Dunn (2011) with the addition of age frequencies from the 1993 and 2010 trawl surveys.
- The first set of model runs were presented to the DWWG on 13 April 2013. These runs used the data from Anderson & Dunn (2011), the 1993 and 2010 trawl-survey age frequencies, and estimates of proportion spawning-at-age from the 1993 and 2010 trawl surveys.
- The runs presented at the 29 April 2013 meeting used age-frequencies from the spawning fishery in 1989, 1990, and 1991 that were constructed from “new” age readings (following the protocol of Tracey et al. 2007). The 2002 age frequency was unchanged. In previous runs the 1989–91 and 2002 age frequencies had all been based on age readings from an old protocol.
- At the final DWWG meeting to discuss the MEC assessment on 9 May 2013, the 2002 age frequency was excluded from runs and a recently available age frequency from 2010 was included in some runs. It was decided by the DWWG that the final runs would only use the “new-protocol” 1989–91 age frequencies. It was thought to be too early to include the 2010 age frequency as the data and the sampling methods had not been carefully reviewed and it was not clear that the 2010 data had the same selectivity as the earlier data.
- After the last DWWG meeting and prior to the Plenary meeting on 23 May 2013, a long-standing error in the construction of the catch history was discovered and corrected. The error affected the distribution of catches between “north” and “south” fisheries and did not alter the total catch. New runs were done for the Plenary but the results were very similar to those presented to the last DWWG meeting.

The first set of model runs were mainly point estimates from the mode of the posterior (MPDs). Three different main runs were presented with various sensitivities to each main run (e.g., low  $M$ , high  $M$ , logistic instead of double normal trawl selectivity). The three main runs used different parameterisations and priors for YCS: Haist parameterisation with a uniform prior; Haist with a lognormal prior; and Francis with a lognormal prior (these are defined and discussed later). In particular, it was shown that there was an issue with using a lognormal prior on YCS when there were lots of them being estimated (this is also discussed later). Also, a logistic selectivity for the trawl survey was shown to provide much worse fits to the data than a double-normal selectivity. The main contrast across the three main runs was between Haist-uniform and Francis, so it was decided to just go forward with these two main runs. The Haist-lognormal runs were fairly similar to the Haist-uniform runs.

In the second set of model runs, the new age data were used for the spawning fishery in 1989–91. This caused some of the early YCS to be estimated at the upper bound of 10 for the Haist-uniform model and so additional YCS were estimated – which reduced the very high estimates. There were no such problems for the Francis model and so the number of YCS was not changed for Francis. Both models showed a bad fit to the new spawning age frequencies as they contained very few fish younger than 35 years. This was in contrast to the old age frequencies (no longer fitted), the 2002 spawning age frequency, and the trawl-survey spawning proportions at age (which suggested fish younger than 35 years were spawning). The fit to Francis was especially bad.

Runs which estimated a spawning selectivity were tried, but these gave an unrealistically high estimated stock status (MPDs at about 50%  $B_0$ ). Investigation showed that this was due to strong estimated YCS that corresponded to the peak in the 1993 trawl survey age frequency, but which were not seen in any other age data. In particular, they were not seen in the 1989–91 age frequencies because of the estimated selectivity. It was decided not to pursue estimation of a selectivity for the spawning fishery.

The runs presented to the final DWWG meeting looked at excluding the 2002 age frequency, including the 2010 age frequency, and estimating  $M$ . Excluding the 2002 data made little difference to MPD or MCMC results. However, inclusion of the 2010 data made a fairly large difference as did estimation of  $M$  (both gave lower estimates of current stock status). The models gave a very bad fit to the 2010 data as they predicted that much younger fish would be present. As the 2010 data were collected on board a single fairly large vessel and the 1989–91 data were collected from shed-sampling of tows from several small vessels it seemed possible that the mismatch was due to different selectivity patterns. As a short-term fix it was decided to exclude the 2010 data. Also, the estimation of  $M$  was not pursued because the bad fits to the age data gave the DWWG group little confidence that there was useful information on  $M$  in the data.

### 3. METHODS

The 2011 stock assessment of MEC orange roughy was updated using the Bayesian stock assessment package CASAL (Bull et al. 2012). New data were added and the model structure and data assumptions were also altered. However, the main change was the estimation of a large number of YCS that was made possible by the availability of a substantial quantity of age data. A single stock assumption was maintained and length frequencies and CPUE indices used in the 2011 assessment were unaltered.

#### 3.1 Data inputs

##### Catch history

The catch history from the 2011 assessment was updated for 2010–11 and 2011–12 by requesting Monthly Harvest Returns (MHR) from the Research Data Manager at MPI for QMA 2A south (Ritchie), 2B (Wairarapa), and 3A (Kaikoura). The north and south fishery catches used in the model were obtained from the reported catches in each of the three areas plus the over-runs (see Anderson & Dunn, 2011) (Table 1). The assumed “reported” catches in 2012–13 were taken as the catch limits for that fishing year reduced by the voluntary shelving of 25% (MPI 2013).

The fishery first developed off Wairarapa in the early 1980s and then spread to Kaikoura and Ritchie in the mid 1980s (Table 1). In terms of the stock assessment model, the north fishery (Ritchie and Wairarapa combined) has almost always been the dominant fishery (Figure 3).



The long-standing error in the catch history, that was not discovered until late in the 2013 assessment process, was the simple mistake of equating the north fishery to 2A south and the South fishery to 2B plus 3A, rather than using 2A south plus 2B for the north and just 3A for the south. The definition of the north and south fisheries was checked against the 2011 source document (Anderson & Dunn 2011) early in the 2013 assessment. Unfortunately, the first reference to the fisheries in that document gave the wrong definition, and since it agreed with the catch history in the 2011 CASAL input files (which were updated for the 2013 assessment) the error was not immediately detected.

**Table 1: The north and south fishery catch histories used for the final stock assessment runs. The north fishery catches are the sum of the reported catches from 2A south and 2B plus the specified over-runs. The south fishery catches are the reported catches from 3A plus the specified over-runs.**

	Catch (t)		Catch (t)		Catch (t)		Catch (t)	
	2A south Ritchie	over- run (%)	2B Wairarapa	over- run (%)	3A Kaikoura	over- run (%)	North fishery 2A south + 2B	South fishery 3A
1981–82	-	-	554	30	-	-	720	-
1982–83	-	-	3 510	30	253	30	4 563	329
1983–84	162	50	6 685	30	554	30	8 934	720
1984–85	1 858	50	3 310	30	3 266	30	7 090	4 246
1985–86	2 778	50	867	30	4 326	30	5 294	5 624
1986–87	4 934	40	963	30	2 555	30	8 160	3 322
1987–88	6 203	30	982	30	2 510	30	9 341	3 263
1988–89	5 710	25	1 236	25	2 431	25	8 683	3 039
1989–90	6 239	20	1 400	20	2 878	20	9 167	3 454
1990–91	6 051	15	1 384	15	2 553	15	8 551	2 936
1991–92	6 329	10	1 327	10	2 443	10	8 422	2 687
1992–93	5 807	10	1 080	10	2 135	10	7 576	2 349
1993–94	3 173	10	1 259	10	2 131	10	4 875	2 344
1994–95	3 281	5	754	5	1 686	5	4 237	1 770
1995–96	1 033	5	245	5	612	5	1 342	643
1996–97	1 270	5	272	5	580	5	1 620	609
1997–98	1 416	5	254	5	570	5	1 754	599
1998–99	1 434	5	257	5	582	5	1 776	611
1999–00	1 666	5	234	5	617	5	1 995	648
2000–01	1 083	5	190	5	479	5	1 337	503
2001–02	901	5	180	5	400	5	1 135	420
2002–03	546	5	105	5	235	5	683	247
2003–04	533	5	103	5	250	5	668	263
2004–05	849	5	206	5	416	5	1 107	437
2005–06	859	5	172	5	415	5	1 082	436
2006–07	902	5	203	5	401	5	1 160	421
2007–08	868	5	209	5	432	5	1 130	454
2008–09	884	5	173	5	414	5	1 110	435
2009–10	850	5	213	5	390	5	1 117	410
2010–11	906	5	158	5	420	5	1 117	441
2011–12	631	5	140	5	428	5	810	449
2012–13	510	5	106	5	314	5	647	330

### Biomass indices

Biomass indices and estimates were available from four different sources (Table 2). The CPUE indices were derived by Anderson & Dunn (2011) from a standardization of catch and effort data in 2A south and 2B from 1983–84 to 1996–97. They also derived CPUE indices for the later period 1997–98 to 2009–10 but this time series was not used in the assessment as it was considered unlikely that it was an abundance index (during this period there were major cuts in TACC and corresponding changes in fisher behaviour). The CV of 20% for each point was derived following the recommendation of Francis (2011) to fit a smoother to the indices outside of the stock-assessment model (see Appendix 1).

The trawl survey biomass indices and CVs are total biomass using “first at site” stations as derived by Doonan & Dunn (2011). The CVs were not inflated by the addition of process error in model runs as it was desired to obtain a good fit to the downward trend in the indices – which was not really achieved in 2011 (see Figure 1).

The acoustic-survey spawning biomass estimates and CVs are from surveys in 2001 (Doonan et al. 2003) and 2003 (Doonan et al. 2004). The much lower estimate in 2003 (see Table 2) is partly because of a difference in survey area (a much smaller area being surveyed in 2003). The acoustic spawning biomass estimates were used as relative abundance indices with informed priors on the proportionality constants ( $qs$ ). There was an informed prior on the 2001  $q$  (mean = 0.91) and a prior on the ratio of the 2001  $q$  to the 2003  $q$  (mean = 1.91). The priors were the same as those used by Anderson & Dunn (2011). The priors accounted for various potential biases including the difference in the size of 2001 and 2003 survey areas and the difference between the (old) orange roughy target strength (Coombs & Barr 2007) used in deriving the estimates, and the latest estimates of orange roughy target strength (Ryan et al. 2009).

The egg-survey estimate of spawning biomass from Zeldis et al. (1997) was used as an absolute estimate ( $q = 1$ ). With the large CV of 49% it was not expected to have much influence.

**Table 2: Biomass indices and CVs used in the MEC stock assessment: standardised CPUE indices, trawl-survey biomass estimates, and egg-survey and acoustic-survey spawning biomass estimates.**

Fishing year	CPUE (early)	CV (%)	Trawl survey (t)	CV (%)	Egg survey (t)	CV (%)	Acoustic survey (t)	CV (%)
1983–84	3.77	20	-	-	-	-	-	-
1984–85	2.34	20	-	-	-	-	-	-
1985–86	2.38	20	-	-	-	-	-	-
1986–87	2.02	20	-	-	-	-	-	-
1987–88	2.86	20	-	-	-	-	-	-
1988–89	-	-	-	-	-	-	-	-
1989–90	1.35	20	-	-	-	-	-	-
1990–91	1.89	20	-	-	-	-	-	-
1991–92	1.21	20	20 838	29	-	-	-	-
1992–93	1.03	20	15 102	27	11 900	49	-	-
1993–94	0.78	20	12 780	14	-	-	-	-
1994–95	0.52	20	-	-	-	-	-	-
1995–96	0.57	20	-	-	-	-	-	-
1996–97	0.98	20	-	-	-	-	-	-
1997–98	-	-	-	-	-	-	-	-
1998–99	-	-	-	-	-	-	-	-
1999–00	-	-	-	-	-	-	-	-
2000–01	-	-	-	-	-	-	14 900	38
2001–02	-	-	-	-	-	-	-	-
2002–03	-	-	-	-	-	-	3 800	22
2003–04	-	-	-	-	-	-	-	-
2004–05	-	-	-	-	-	-	-	-
2005–06	-	-	-	-	-	-	-	-
2006–07	-	-	-	-	-	-	-	-
2007–08	-	-	-	-	-	-	-	-
2008–09	-	-	-	-	-	-	-	-
2009–10	-	-	7 074	19	-	-	-	-

### Commercial fishery composition data

Composition data (length and age frequencies) from the commercial fisheries were fitted in all of the assessment runs. The existing length frequencies from Anderson & Dunn (2011) were used: 16 years between 1988–89 and 2009–10 for the north fishery (ORH 2A south and ORH 2B) and 9 years between 1989–90 and 2008–09 for the south fishery (ORH 3A) (see Appendix 2). There is a fair amount of variability in the sizes of fish caught in the two fisheries but, on average, fish caught in the north fishery are 5 cm larger than fish caught in the south fishery (Figure 4). There was a downward trend in mean

fish size in the north fishery from 1989–90 to 2002–03, with a small increase from 2003–04 to 2009–10 (Figure 5). There was no temporal trend in mean fish size in the south fishery (Figure 5).

The spawning-fishery age frequencies constructed by Anderson & Dunn (2011) were not used but the raw data were reanalysed. For the early model runs, the “old” age readings (Green & Ackerman 2003) were used to construct age frequencies in 1989, 1990, 1991, and 2002 for the spawning fishery. Later runs, including the final model runs, used age readings for 1989, 1990, and 1991 produced using the “new” protocol (Tracey et al. 2007). In all cases, the age frequencies were calculated directly from the age readings: raw age frequencies within each landing were used to estimate the number of fish in each landing; proportions-at-age were scaled to landing numbers and then combined across landings; male and female proportions-at-age were calculated separately and then averaged to get a combined-sex estimate (which assumes equal proportions of males and females in the spawning fishery).

The re-ageing of the otoliths from the 1989–91 samples using the new protocol substantially altered the age readings (Table 3, Figure 6). The bimodal nature of the age frequencies constructed using the old age readings was primarily due to a failure to identify transition zones in the otoliths – which generally leads to under-ageing. The 2002 samples were not re-aged and the corresponding age frequency was not used in the base model or the main sensitivity.

**Table 3: Details of age samples from the spawning fishery giving the number of trips sampled, the number of age samples and the median, minimum and maximum age from the old (1989–91, 2002) and new reading protocols (1989–1991).**

Year	Number of landings	Number of ages	Median Age		Age range	
			Old	New	Old	New
1989	3	150	65	67	26–164	31–161
1990	4	200	60	66	24–174	30–173
1991	5	249	53	60	17–192	25–151
2002	7	795	44		21–145	

### **Trawl survey composition data**

Length frequencies were available from each of the trawl surveys (1992, 1993, 1994, and 2010) but age frequencies were only available for 1993 and 2010. The trawl-survey length frequencies were constructed by Anderson & Dunn (2011). All four length frequencies were fitted in some early runs when effective sample sizes were determined following Francis (2011) (see Appendix 1). However, once the effective sample sizes were determined the 1993 and 2010 length frequencies were not fitted (to avoid double use of data as the age frequencies were constructed using the age readings *and* the length frequencies).

The calculation of the trawl-survey age frequencies is described by Doonan et al. (2013). The main feature of the trawl-survey composition data is the presence of a number of weak cohorts in the 2010 survey – there are relatively low numbers of fish 20–30 cm in length and 15–25 years of age (see Figure 2).

### **Trawl survey proportion spawning**

The gonad staging data from the 1993 and 2010 trawl surveys was combined with the age and length data to produce estimates of the proportion of females at age with maturing gonads (stage 3). The trawl surveys were conducted in April–May and all female fish were in stages 1, 2, or 3. It was assumed that all stage 3 fish and only stage 3 fish would be spawning later that year (in June–July). The calculations were done in the same way as for the full age frequencies (age length key for northern and southern areas applied to scaled length frequencies and then combined – see Doonan et al. 2013) except that the methods were applied to produce numbers of females at age by stage. The proportion spawning at age was calculated, for each age, as the number of stage 3 females at age

divided by the total number of females at age. A plus group was used at age 50 years. A few missing values (at ages greater than 40 years) were filled in by interpolation.

The proportion spawning at age data are very noisy but in both years it appears that very few females younger than 25 years spawned and most females older than about 40 years did spawn (Figure 7). The main trends by age are different in each year. In 2010 there appear to be more females aged 25–30 years spawning than in 1993, but the opposite is true for females aged 30–35 years (Figure 7).

### 3.2 Model structure and data assumptions

The stock assessment was performed using the Bayesian stock assessment program CASAL (Bull et al. 2012). The text files used to specify the base model and the estimation procedure are given in Appendix 2.

The model structure was quite simple:

- age-structured, 1–120 years with a plus group
- no-sex/single-sex model
- maturity in the partition
- single area
- single time-step
- mid-year spawning season
- two year-round fisheries (north, south)
- “instantaneous mortality equation” from Bull et al. (2012), whereby half the natural mortality was applied, followed by the fishing mortality, then the remaining natural mortality.

The following parameterisations were used (see Bull et al. (2012) for definitions):

- constant natural mortality (independent of age)
- von Bertalanffy growth
- mean-weight at age from a length-weight relationship
- size at age: CVs at ages 1 and 120 with a linear relationship (by length)
- maturation ogive: logistic producing
- trawl-survey selectivity: double normal
- north fishery selectivity: logistic
- south fishery selectivity: double normal
- year class strengths: Haist (base model), Francis (sensitivity).

Data assumptions:

- trawl survey biomass indices: relative, mid-year selected biomass, lognormal errors
- CPUE: relative, mid-year selected biomass, normal-log errors
- egg survey: absolute, mid-year spawning biomass, lognormal error
- acoustic survey: relative, mid-year spawning biomass, lognormal errors
- trawl survey age frequencies: mid-year selected proportions-at-age, multinomial
- trawl survey length frequencies: mid-year selected proportions-at-length, multinomial
- trawl survey spawning proportions: mid-year proportions mature at age, binomial
- spawning fishery age frequencies: mid-year spawning proportions-at-age, multinomial
- fishery length frequencies: proportions-at-length in the catch, multinomial.

Other model assumptions:

- Maximum “fishing pressure” (see Bull et al. 2012) set at 0.67
- Ageing error normal with a CV of 10%
- Robustifying constant for multinomial and binomial: 0.00001.

The fixed biological parameters in the model were from Anderson & Dunn (2011):

- natural mortality: 0.045
- steepness: 0.75
- sigma R: 1.1
- von Bertalanffy: k 0.065; t0 -0.5 years; Linf 37.63 cm
- length-weight: a 9.21e-5; b 2.71 (cm to kg).

### 3.3 Estimation methods

Standard Bayesian methods were used in the estimation procedure (see Bull et al. 2012). There are two main steps in the estimation procedure: the production of “MPD”s (Mode of Posterior) as initial point estimates, obtained by minimising the objective function; followed by the production of posterior distributions using MCMC (Markov chain Monte Carlo) methods. The final point estimates are taken as the median of the marginal posterior distribution.

The availability of age frequencies from the trawl survey and the spawning fishery made it feasible to estimate a large number of year class strengths (YCS). In the base model, a uniform prior was used for each YCS and the Haist parameterisation (Bull et al. 2012) was specified with the addition of a strong penalty on the estimated YCS averaging to 1 (squared error with a multiplier of 200). In the main sensitivity run, the Francis parameterisation (Bull et al. 2012) was used with a lognormal prior on each YCS (with sigma R = 1.1 as is usual for orange roughy). In the Haist and Francis models respectively, YCS were estimated from 1881–1996 and from 1909–1996.

The Haist and Francis parameterisations both ensure that the average YCS is equal to 1 over a specified time period so that  $B_0$  is consistent with average recruitment. They do this in different ways but essentially they both obtain estimates of YCS by dividing the underlying free annual parameters by their average. In the Haist and Francis models presented here, there is also the additional contrast of different priors on the YCS. The purpose of the uniform prior is to allow the model extra freedom in estimating YCS to fit the available data. The strong average-to-1 penalty is to stop the free parameters deviating substantially from the YCS.

Informed priors were used on the acoustic survey  $qs$  to account for the different areas surveyed in 2001 and 2003 and other potential biases (see Biomass indices in Section 3.1 above). All other parameters had uninformed priors specified (either uniform or log-uniform). Full details of the priors used are in Appendix 2.

The relative and absolute weighting of the data sets in the objective function is determined by specified CVs (for biomass indices) and effective sample sizes (for age and length frequencies). The procedure used to determine these weights is given Appendix 1.

For each model, the marginal posterior distributions for parameters of interest (e.g., virgin and current biomass, selectivities, YCS, etc.) were obtained from sub-sampling three combined MCMC chains. Each chain was 8–12 million in length and 1 in every 1000 samples were stored. The chains were concatenated after deleting the first 1 million samples (1000 stored samples) in each chain – termed the “burn-in”. A random sub-sample of size 2000 was taken from the concatenated chains to represent the posterior distribution. Usually a systematic sub-sample is taken, but it is preferable to use a random sample to avoid the possibility, albeit remote, that the step size in the systematic sample coincides with periodicity in the concatenated chain.

## 4. RESULTS

The MPD and MCMC results are presented below. More extensive diagnostics are presented for the MPD results as easily interpreted plots of the fits to the data can be produced. At the MCMC level, “fits” to the data are not so easily interpreted as each data point has a “predicted” distribution associated with it and the links across the distributions are not easily presented. This will be discussed further when some MCMC fits are shown.

Also, at the MPD level deterministic reference points and annual fishing intensity estimates are presented. It is straightforward to calculate such estimates at the MPD level as there is only a single vector of estimated parameters. Taking such results through to MCMC requires software features not yet available in CASAL.

### 4.1 MPD results

The Haist and Francis models have almost identical fits to the CPUE indices but the Haist model has a substantially better fit than the Francis model to the trawl survey indices (Figure 8). This was a persistent feature of the numerous sensitivity runs which were performed during the assessment – i.e., Haist models had a better fit to the trawl survey indices than Francis models. This also persisted at the MCMC level where the average fit across the MCMC samples was better for Haist than Francis (see below).

The trawl-survey length frequencies were adequately fitted by both models (Figure 9) and there were good fits to the age frequencies (Figure 10). There were “poor” fits to the north fishery length frequencies (Figure 11) but it must be remembered that these had very low effective sample sizes (mostly in the range 3–15, see Appendix 1 and 2). Likewise, the fits to the south fishery length frequencies are “poor” (Figure 12) with effective sample sizes ranging from 4–19. The length frequency fits are adequate as the main purpose of these data is to allow estimation of the fishing selectivities so that fish of an appropriate age can be removed.

The spawning-season age frequencies are very noisy and they are not well-fitted over the whole age range (Figure 13). The main problem is an over-estimation of fish aged 20–30 years. In general, the Haist model provides a better fit to these data (Figure 13). The proportion spawning at age from the trawl survey is fitted well by both models (Figure 14). The two different trends in proportion spawning across age in 1993 and 2010 were accommodated by both models. This is a consequence of ageing error and variation in YCS as both fisheries select only on the basis of age (and not on the basis of maturity) – and therefore the proportion mature-at-age in the model is constant despite maturity being in the partition.

The estimated maturity ogive and fishing and trawl survey selectivities were similar for both models with the exception of the south fishing selectivity (Figure 15). The MPD estimate for Francis has a very narrow age-range selected for the south fishery (this was not the case for the MCMC results, see Figure 29). The maturity ogive in both cases had 50% maturity at about 35 years which is substantially older than that indicated by transition zone readings. However, the current model structure assumes that only the spawning fish are mature (this is similar to “mat2sel” in earlier orange roughy models).

The Haist model estimated a very “spikey” sequence of YCS with many estimates at the lower bound of 0.01 (Figure 16). In contrast the Francis model had quite a smooth sequence of YCS, although there was one estimate near the upper bound (Figure 16). The uniform prior on YCS for the Haist model compared to the lognormal prior used with Francis is presumably the main driver of this difference. The Haist model has more freedom to choose YCS that best fit the data whereas the Francis model is constrained by the lognormal assumption.

The Haist and Francis MPD estimates of stock status are very different with the Haist estimate at the hard limit and the Francis estimate above the soft limit (Table 4, Figure 17). In the MCMC runs the median values are closer together than the MPD estimates and are higher for both runs (see below).

**Table 4: MPD estimates of virgin and current biomass for the Haist and Francis models.**

	$B_0$ (000 t)	$B_{2013}$ (000 t)	$B_{2013}$ (% $B_0$ )
Haist	130	11.9	9
Francis	112	27.5	25

### Deterministic reference points and estimated fishing intensity

The deterministic MSY,  $B_{MSY}$  and associated equilibrium biomass for the north and south fisheries were determined for the MPD estimates of the Haist and Francis models (Table 5). It was assumed that the catches in the north and south were in constant proportions of 66% and 34% respectively.

**Table 5: Deterministic  $B_{MSY}$ , MSY, and the equilibrium levels of north and south fishery vulnerable biomass for the Haist and Francis models**

	$B_{MSY}$ (% $B_0$ )	MSY (% $B_0$ )	North vulnerable biomass (%virgin)	South vulnerable biomass (%virgin)
Haist	23.1	2.33	29	57
Francis	21.1	2.37	25	66

The overfishing threshold was calculated, for both models, as the fishing intensity that would cause the biomass to reach equilibrium at the target of 30%  $B_0$  (Table 6). It is expressed in terms of an equivalent annual F (Cordue 2012) which combines the fishing pressures from the north and south fisheries.

**Table 6: Equivalent annual F and yield at the target of 30%  $B_0$ , and the associated equilibrium levels of north and south fishery vulnerable biomass for the Haist and Francis models**

	$F_{equiv}$ at 30% $B_0$	Yield at 30% $B_0$ (% $B_0$ )	North vulnerable biomass (%virgin)	South vulnerable biomass (%virgin)
Haist	0.045	2.27	36	64
Francis	0.048	2.30	34	74

The estimated fishing intensity for the two models show strong contrast (Figure 18). The Haist model suggests that over-fishing is currently occurring and that it has been common in the past. The Francis model suggests that over-fishing only occurred prior to about 2000. The fact that these are only MPD results needs to be noted especially as the median MCMC stock status for the Haist model is substantially higher than the MPD estimate.

For both models, the composite or combined selectivity for the north and south fisheries has changed substantially over the years (Figure 19). The fishery started in the north where older fish are removed (and the composite selectivity was mainly just the logistic north fishery selectivity); as the south fishery developed, the composite selectivity became a combination of the domed south fishery selectivity and the logistic north fishery selectivity (Figure 19). The estimated current composite selectivities are quite different between the two models with Haist suggesting full selection at about 30–40 years, but Francis suggesting it occurs at under 30 years (Figure 19).

## 4.2 MCMC results

During the WG process, three MCMC chains were run for each model and the median estimates and distributions of  $B_0$  and  $B_{2013}/B_0$  were compared across chains to ensure that there were no obvious convergence issues. Prior to the Plenary, longer chains were run for the final Haist and Francis models. These gave almost identical results to the shorter chains but had somewhat smoother distributions.

Each chain started a small jump away from the MPD estimate. This gets the chain immediately into “sensible space” but has the disadvantage that it is not in “typical space” (i.e., it is starting near the place where the objective function is minimised but this is not necessarily where the bulk of posterior probability density resides). The progress of a chain from near the MPD to “typical space” can be followed by plotting the objective function for each stored sample in the chain (e.g., see Figure 20). The length of an appropriate burn-in can be determined from such plots. Figure 20 shows the three Francis chains and it appears that a burn-in of 1 million samples is reasonable (though, perhaps 1.5 million would have been better). It is not necessarily the case that a burn-in is required – it depends on the length of the chain and whether the MPD estimates are near to the median of the posterior distribution. However, it is a sensible precaution to always check these types of plot and choose an appropriate burn-in length.

The chain convergence diagnostics are adequate but not good. For the Haist model, the three  $B_0$  distributions are similar in shape and the medians are close to each other (Figure 21). The same is not true for the three stock status distributions with one chain having a much broader distribution (Figure 22). Fortunately, the stock-status medians are all similar being about 20%  $B_0$  (Figure 22).

For the Francis model, the convergence diagnostics are similar to those for Haist. The  $B_0$  convergence looks better than that for stock status, where there is one chain which is quite different from the other two (Figures 23 and 24). However, the stock status medians are all close to 30%  $B_0$  (Figure 24).

Figures 25 and 26 show the MCMC “fit” of the two models to the CPUE indices and the trawl-survey indices. For each individual observation a 99% confidence interval is given together with the distribution of the corresponding model predictions. The width of the confidence interval (CI) is determined only by the specified CV, whereas the width of the predicted distribution is determined by all of the model inputs. Therefore, it would be expected that the predicted distribution would be somewhat tighter than the confidence interval. The test of whether the model fit is good or not is to see whether the 99% CI covers most of the predicted distribution. The point being that the large CI is likely to contain the “true” value and the predicted distribution is meant to be centred on the true value. The *wrong* way to examine these plots is to check if the observation is contained within the predicted distribution – that is not relevant.

The Haist model has an excellent “fit” to the CPUE indices as the bulk of almost every predicted distribution is contained within the CIs (Figure 25). The “fit” to the trawl indices is not nearly so good as 1 out of the 4 observations does not have its CI covering the bulk of the predicted distribution (Figure 25). The same comments apply to the Francis model except that the “fit” to the trawl indices is even worse (Figure 26).

These types of plots also have another interpretation difficulty. The eye is naturally drawn to the trend in the median predictions and it is “implied” that most of the individual fits will be parallel to the fit of the medians. This is not always the case. For the Haist model we know it is not true because the MPD fit does not follow the trend of the medians (see Figure 8). The MPD provides an excellent fit which is much steeper than the median trend. Histograms of each model’s MCMC fit to the trawl indices show that the Haist model has a number of samples which provide good fits to the trawl indices, but the Francis model does not have any samples with a good fit to the trawl indices (Figure 27)

Both models estimate similar maturity and selectivity ogives (Figures 28 and 29). The north fishery selectivity is similar to the maturity ogive except that it is steeper and selects fish at a slightly earlier age



(Figures 28 and 29). The south fishery and trawl survey selectivities are also similar; although they are both domed they do select fish over a broad range of ages (Figures 28 and 29).

Year class strength estimates are very uncertain for both models but they agree that there was strong recruitment in the late 1960s-early 1970s and weak recruitment in the early-mid 1990s (Figures 30 and 31).

The models both estimate virgin biomass at about 115 000 t but have different estimates of current biomass (Table 7). The base model (Haist) suggests that current biomass is between the hard limit and the target (Table 7, Figure 32). The sensitivity run (Francis) suggests that current biomass is approaching the target and could be as high as 40%  $B_0$  (Table 7, Figure 33).

**Table 7: Median MCMC estimates of virgin biomass, current biomass, stock status, and the probabilities of being below the hard and soft limits and above the target for the Haist and Francis models. 95% CIs are given in parenthesis.**

	$B_0$ (000 t)	$B_{2013}$ (000 t)	$B_{2013}$ (% $B_0$ )	$P(B_{2013} < 10\%B_0)$	$P(B_{2013} < 20\%B_0)$	$P(B_{2013} > 30\%B_0)$
Haist	113 (100–135)	23 (13–44)	21 (12–33)	0.00	0.45	0.06
Francis	118 (103–136)	34 (23–50)	29 (21–38)	0.00	0.01	0.40

The two models also have contrasting results with regard to the trajectories for the north and south fishery vulnerable biomass. The Haist model suggest that north vulnerable biomass is about 20–30% of its virgin level and that the south is at 40–50% (Figure 34). The Francis model suggests estimates of about 30–40% of virgin for the north and 50–60% of virgin for the south (Figure 35).

## Projections

The two MCMC models were projected forward 5 years assuming catch limits of 600 t, 930 t (current) and 1200 t. In each case, north and south catch was split 66%-34% and a 5% over-run was assumed. Random recruitment was sampled from the last 10 estimated years (1987–1996) and was begun in 1997.

Under both models the biomass is expected to increase over the range of projected catches (Figures 36–38). Projections are more optimistic under the Francis model than the Haist model primarily because it starts at a higher level (e.g., Figure 36). For current catch limits, the Haist model suggests that the stock will probably be between the soft limit and the target in 2018, but the Francis model suggests it will be at or above the target (Table 8, Figure 36).

**Table 8: Estimated probabilities of the biomass in 2018 being below the hard or soft limit or above the target for the Haist and Francis models under the current catch limits.**

	$P(B_{2018} < 10\% B_0)$	$P(B_{2018} < 20\% B_0)$	$P(B_{2018} > 30\% B_0)$
Haist	0.00	0.32	0.18
Francis	0.00	0.00	0.74

## 5. DISCUSSION AND CONCLUSIONS

Despite the less than ideal development of the assessment it appears that a satisfactory assessment was achieved.

### Fits to the data

The base model (Haist) achieved a good fit to the biomass indices at the MPD level (Figure 8) and a satisfactory fit to the other data. At the MCMC level, the fits to the biomass indices were mixed. The predicted values for the CPUE time series were in agreement with the CPUE observations (Figure 25). However, the predictions for the trawl time series included many samples that did not follow the

trend of the trawl indices. That is, the bulk of posterior density was not supportive of the trend in the trawl time series – certainly the trend of the median predicted values was much flatter (Figure 25).

The sensitivity run (Francis) adequately fitted at the MPD level except for the trawl indices and the spawning-season age data. It had less freedom than the Haist model to choose the best YCS to fit the data because of its parameterisation and the lognormal priors. The fits to the spawning-season age data were not as “shapely” as those from the Haist model (Figure 13) as the YCS estimates were less variable (Figure 16). It didn’t fit the trawl time series at all well (Figure 8) – presumably a consequence of not being able to choose the best YCS. At the MCMC level it had a good fit to the CPUE indices but a poor fit to the trawl time series – the trend in the median predicted values was very flat (Figure 26)

### **YCS parameterisation and priors**

There are two important differences between the Haist and Francis models: the different parameterisation of YCS and mean recruitment; and the different priors on the free annual parameters (the  $Y_i$ ). The difference between a uniform prior on each  $Y_i$  and a lognormal prior is exaggerated in this assessment because of the large number of YCS being estimated. In some early runs it was seen that the Francis model could obtain about 100 likelihood units advantage in the minimisation by choosing  $Y_i$  near the mode of the lognormal prior (at around about 0.2). The YCS (on  $R_0$ ) are the  $Y_i$  divided by their mean – so having the free parameters down at about 0.2 doesn’t matter as the YCS still average to 1. The Haist parameterisation with lognormal priors would do exactly the same thing – i.e., take advantage of the likelihood units near the mode of the prior. At the MPD level this sort of behaviour appears undesirable as YCS are being determined on the basis of curvature in the lognormal density near the mode (unless there is a lot of information in the data on YCS).

At the MCMC level the lognormal priors are probably less of a problem, but they are priors on the free annual parameters and not priors on the actual YCS that we are interested in. Francis sets up the free annual parameters as YCS on  $R_{mean}$  but we are interested in the YCS on  $R_0$ . A similar criticism applies to the Haist parameterisation, the priors are on the free annual parameters and not the YCS – the Francis parameterisation was meant to solve this problem, but it has simply moved it to a different part of the equation.

It would be interesting to do more runs to explore the effect of the different parameterisations and priors. Certainly, Haist with lognormal priors might yield some insights. It is not possible to do Francis with uniform because then there would be nothing to anchor the free annual parameters (Francis has a confounding between the  $Y_i$  and  $R_{mean}$  – e.g., doubling  $R_{mean}$  and halving the  $Y_i$  has no effect on the fit to any of the data – it is only the “shape” in the prior on the  $Y_i$  that gives them any “stability”).

### **MCMC convergence**

The convergence diagnostics for the Haist and Francis MCMC chains were barely satisfactory. For each model, the three chains had similar distributions, and quite similar medians but there was room for much closer agreement – certainly many other models (including earlier runs done in this assessment) have had closer agreement across three independent chains.

The reasons for the relatively bad MCMC performance have not been fully explored. However, for the Haist model further chains were run after the Plenary to check that the convergence really had been adequate. Five chains each of 20 million were run and their combined distribution did provide very similar results to the estimates presented in this document. Despite each of the five chains being very long, there was still some inconsistency between the chains for the distributions of  $B_0$  and especially  $B_{2013}/B_0$  (1 of the 5 chains was a bit aberrant, medians for  $B_{2013}/B_0$  were 0.2, 0.2, 0.21, 0.23, 0.25).

The bad convergence probably has most to do with the high dimensionality of the parameter space (the large number of YCS) and relatively little information in the data. It is apparent that different chains are exploring only a subset of the full parameter space – especially with regard to YCS – and are therefore delivering somewhat different marginal distributions for virgin biomass, current, biomass, and stock status. Better performance could probably be achieved by some rationalisation of the number of YCS estimated and some further experimentation on step size and proposal distributions.

### **Future assessment**

Some improvements can be made to the structure of the model to provide a better assessment even in the absence of new data.

The main change required is to model a spawning fishery in addition to the north and south non-spawning fisheries. This would account for the changing pattern of catches during the spawning season which preferentially removes spawning fish – an important point under a prime-habitat model. It would more accurately reflect the age of fish being removed and would allow for a temporal shift in the proportion of spawning fish at age (which is what happens when there is a spawning fishery and maturity is in the partition). Currently, the model fits the different shapes of the proportion spawning at age data in 1993 and 2010 by using ageing error and variation in YCS. It is interesting that it can accommodate the two different shapes just by this mechanism. However, it would be much more natural to allow catches in the spawning fishery to drive the temporal shift in spawning proportion at age. The length frequencies may have to be reworked if they include any spawning fishery samples in the north fishery.

New data will improve the assessment. The spawning fishery samples in 2002 should be aged under the new protocol and the 2010 age frequency should be incorporated (possibly with its own selectivity). The new ageing data implies somewhat different growth parameters to those used which appear to somewhat inconsistent with the length frequencies. Some conditional age-at-length data should probably be used in the modelling and growth parameters estimated within the model.

A new abundance index, either from a trawl survey and/or an acoustic survey of spawning plumes (should these occur) would be very useful. There may be some potential for a new CPUE series to be developed for a period during which the TACC has been stable.

### **Status of the stock**

The Haist model estimates current stock status at 21%  $B_0$  with a 95% CI of 12–33%  $B_0$ . If natural mortality was lower than the assumed value of 0.045 then current stock status would also be lower; similarly, if natural mortality were higher, stock status would be higher. The Francis sensitivity, which should be given less weight than the Haist model, provides a higher estimate of stock status at 29%  $B_0$  with a 95% CI of 21–38%  $B_0$ .

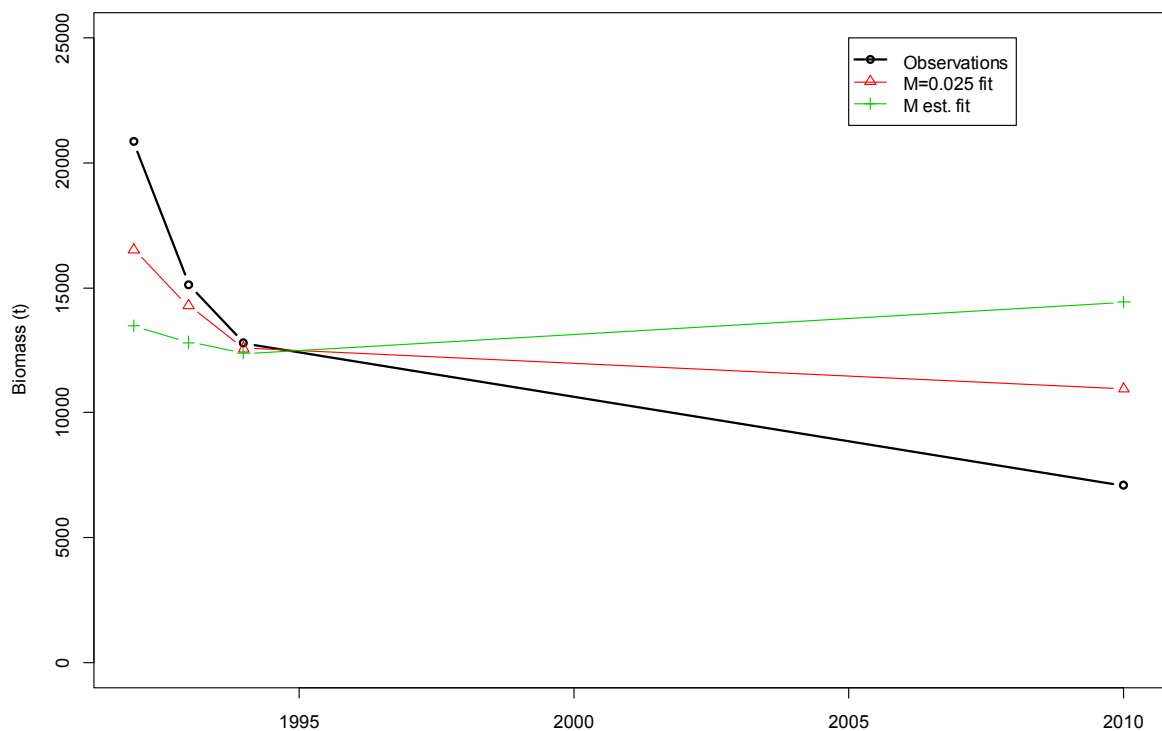
It seems reasonable to conclude that the stock is very unlikely to be below the hard limit, as likely as not to be below the soft limit, and unlikely to be above the target. Projections for both models suggest that spawning stock biomass will increase at current catch levels.

## **6. ACKNOWLEDGEMENTS**

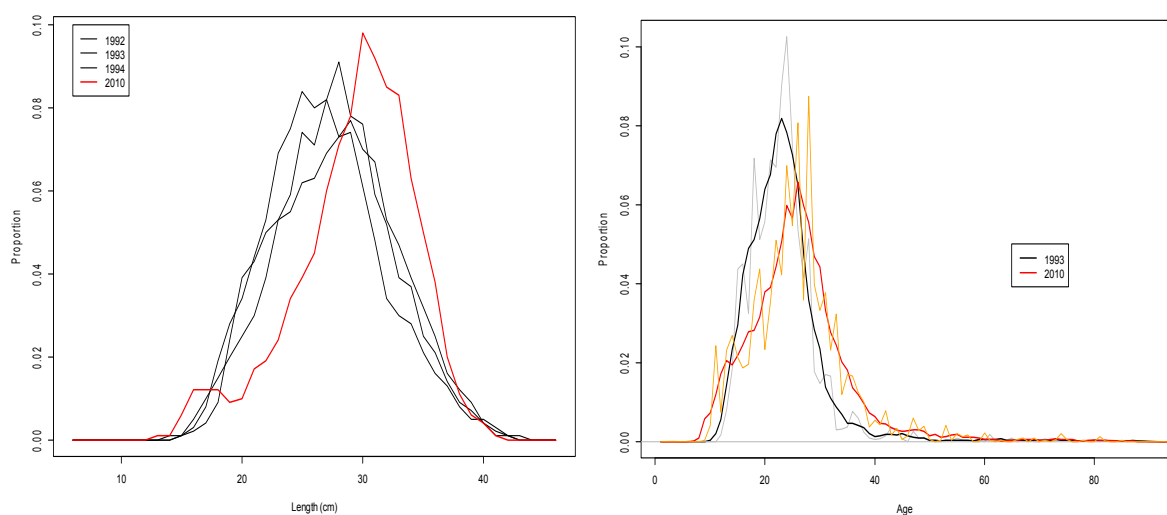
This work was funded by MPI. Thanks to members of the DWWG for providing useful comments and guidance on the assessment. Thanks also to NIWA for making their excellent stock assessment package CASAL available for general use.

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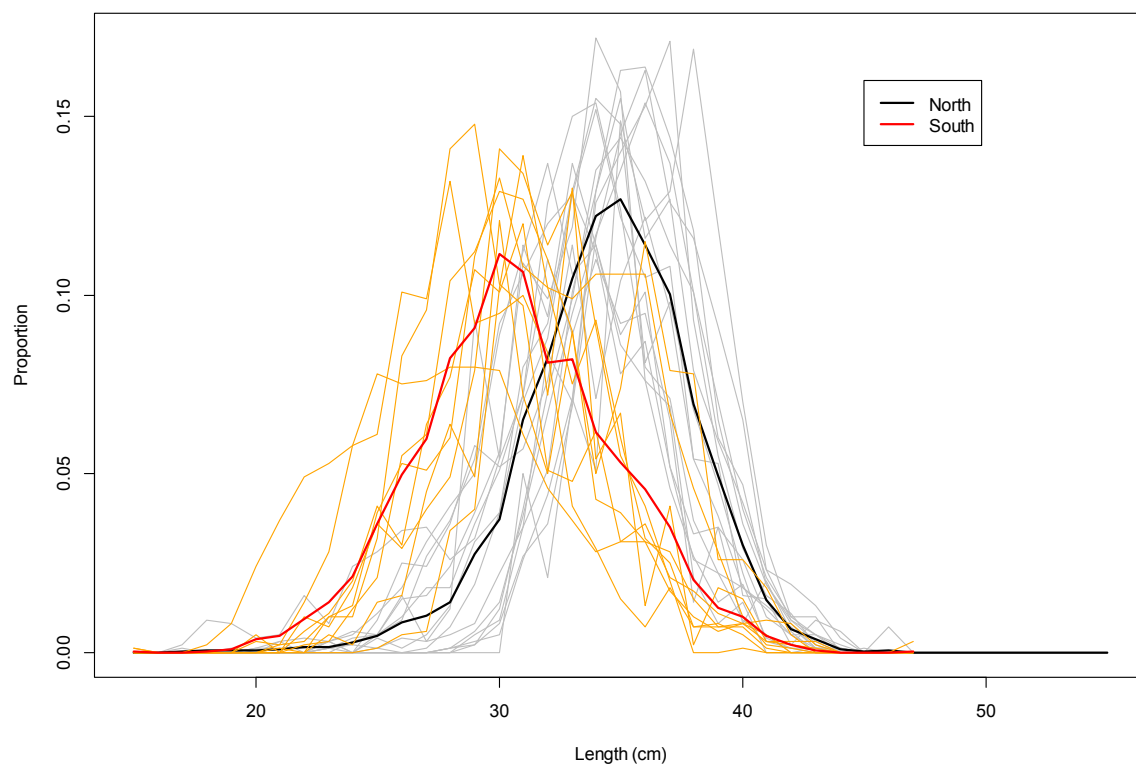
**Figure 1: The fit to the trawl survey biomass indices for the two base runs in the 2011 assessment (Anderson & Dunn, 2011). In one run,  $M$  was fixed at 0.025 ( $M=0.025$ ) and in the other run it was estimated ( $M$  est.).**



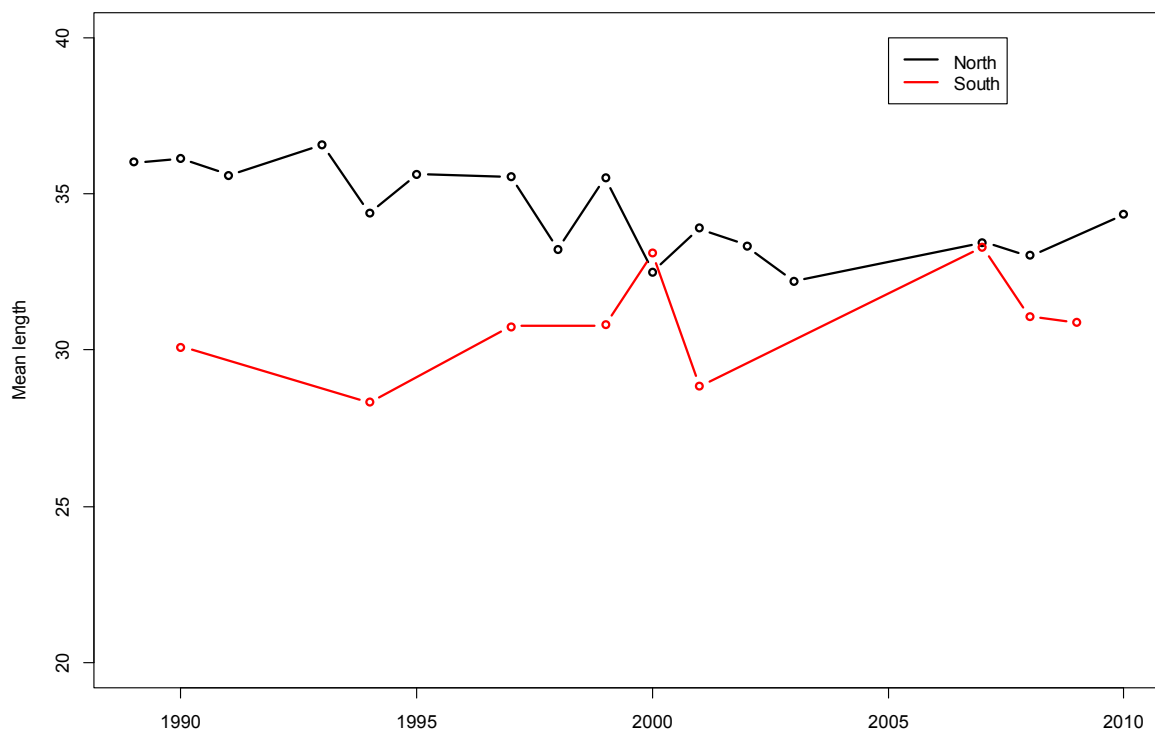
**Figure 2: The 1992–94 and 2010 trawl survey length frequencies (left) and the 1993 and 2010 trawl survey age frequencies (right). Raw age frequencies and smoothed versions (bold lines) are shown.**



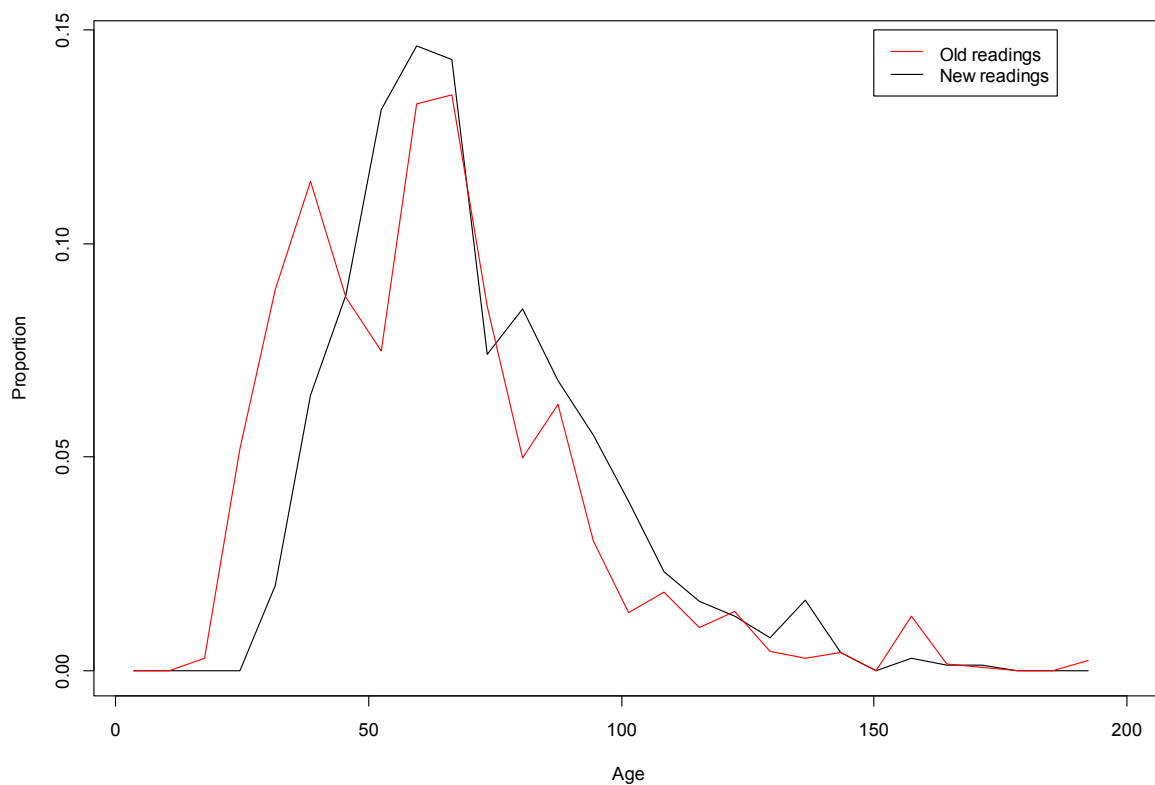
**Figure 3: The north and south fishery catch histories used in the final assessment runs.**



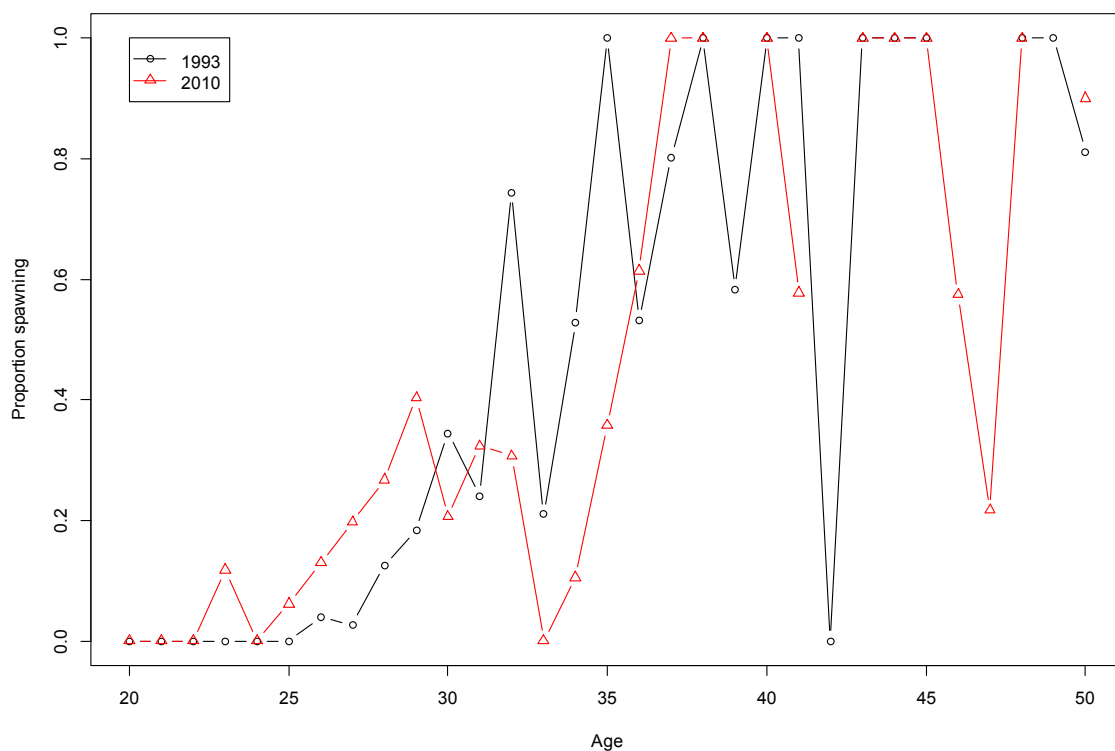
**Figure 4: Length frequency distributions from the north and south fisheries for all years, together with the mean distribution (bold) across all years.**



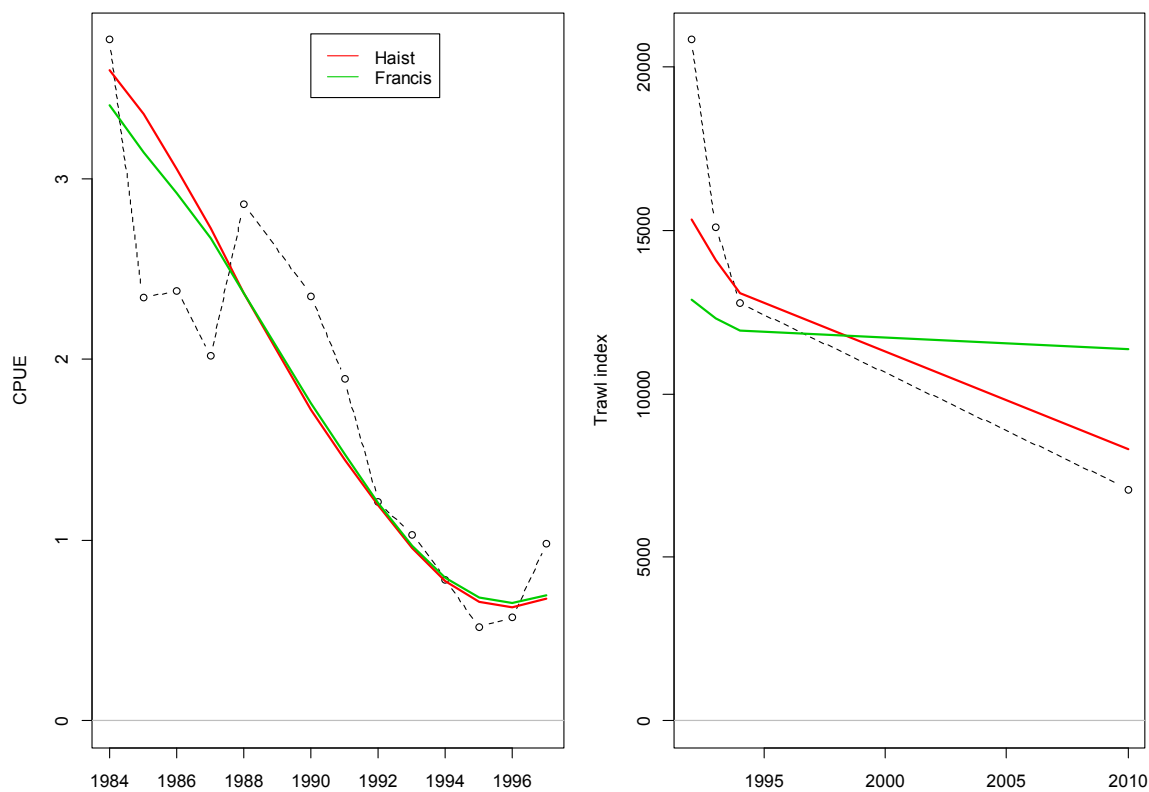
**Figure 5: The trend in mean lengths for the north and south fishery commercial length frequencies.**



**Figure 6: Spawning-fishery age frequencies combined across years and sexes for 1989–91 produced from age readings using the “old” and “new” reading protocols (7-year bins used for both age frequencies).**

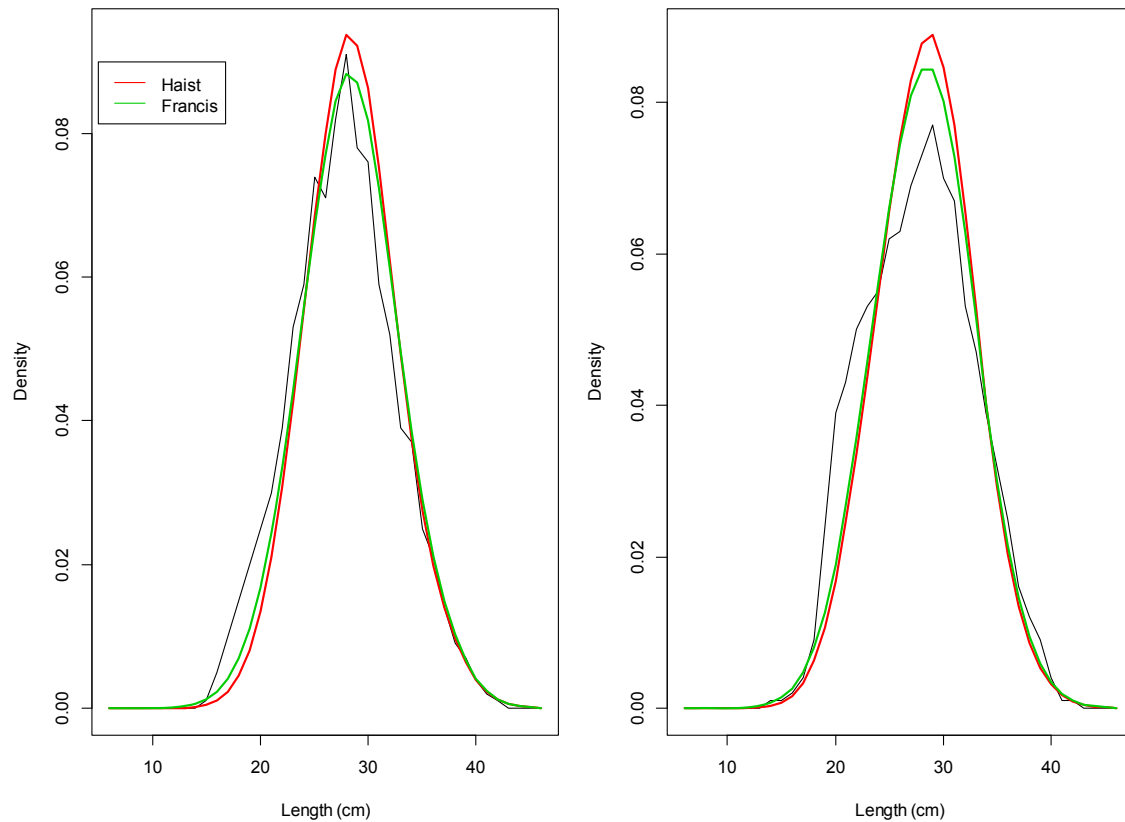


**Figure 7: Estimated proportion spawning at age for the 1993 and 2010 trawl surveys. Estimates were calculated for females only with a plus group at 50 years. Note, there are some missing values.**

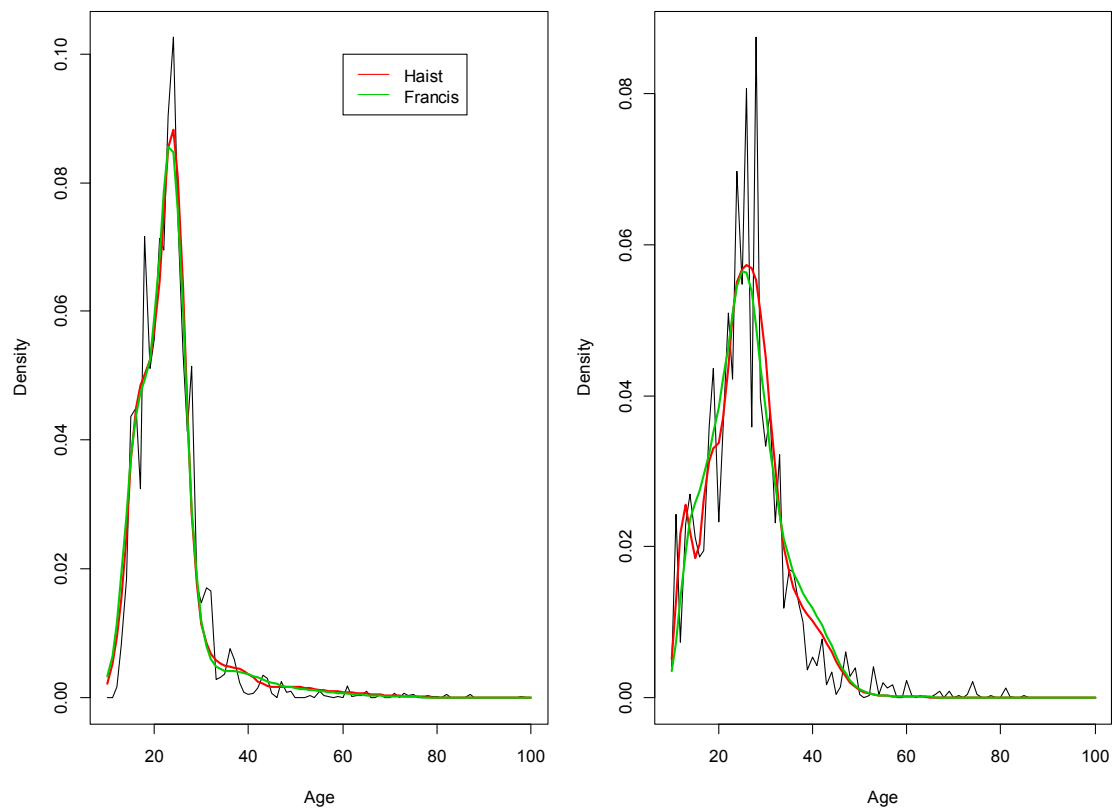


**Figure 8: MPD fits to the CPUE and trawl survey biomass indices (circles and dashed lines) for the Haist (red lines) and Francis (green lines) models.**

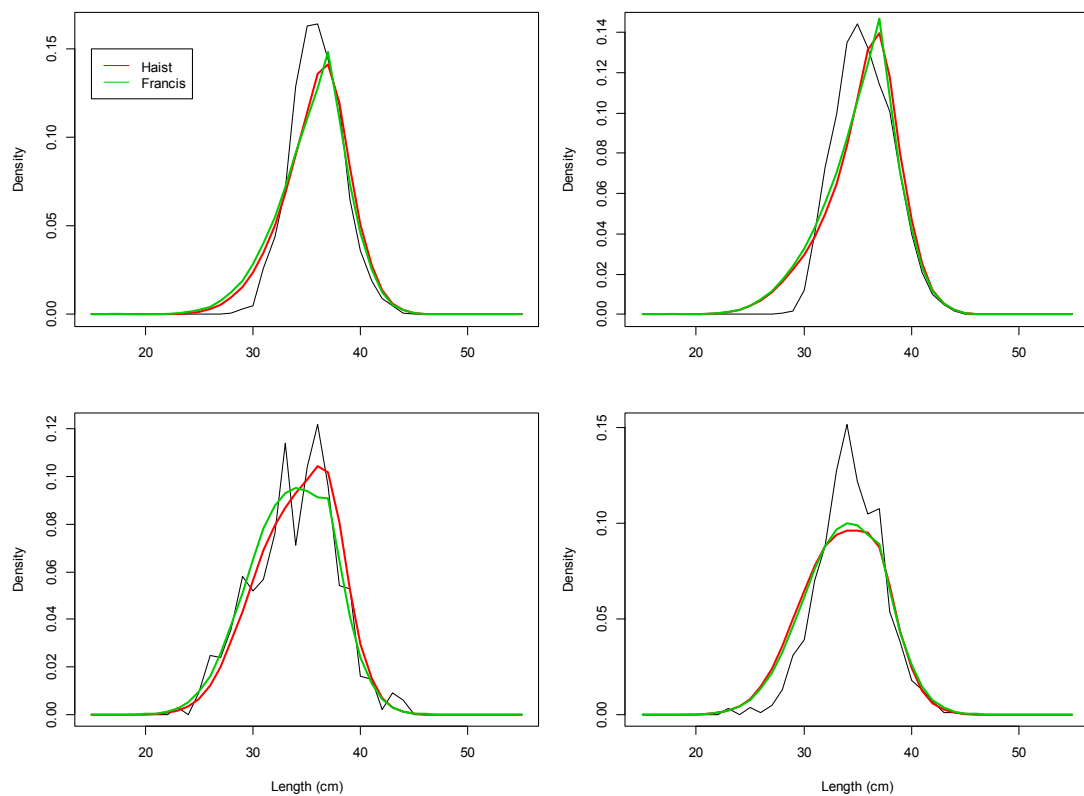




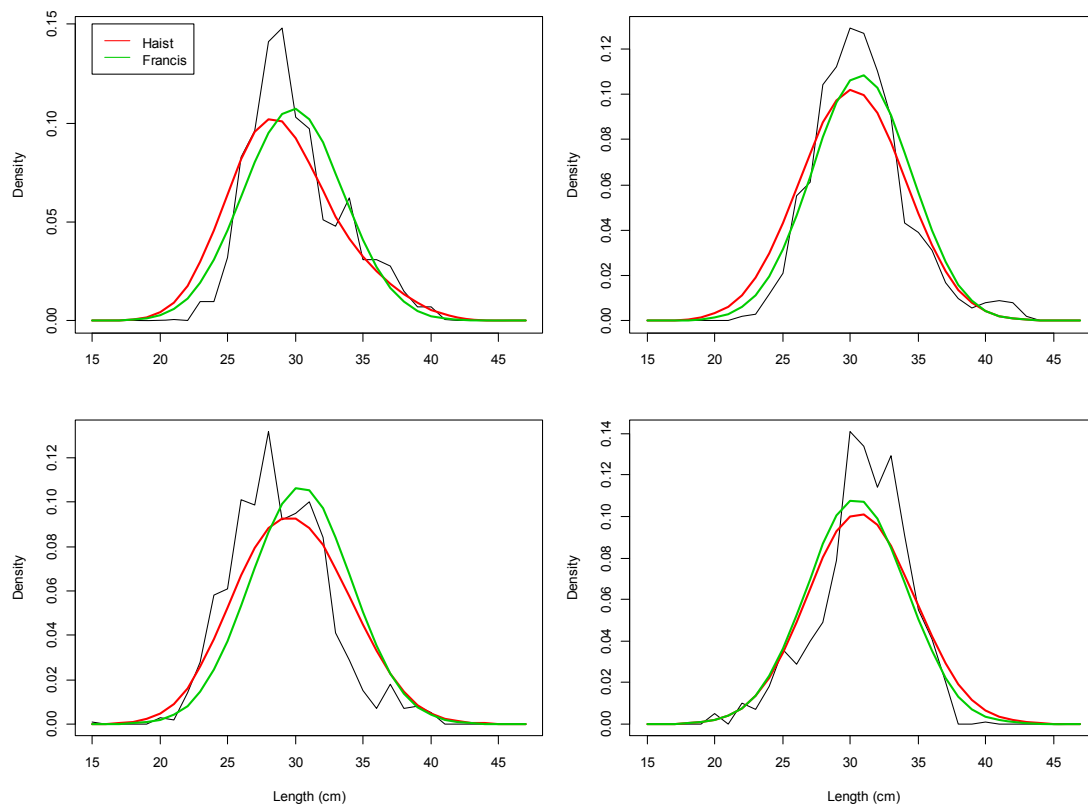
**Figure 9: MPD fits to the trawl survey length frequencies (1992 left, 1994 right) for the Haist and Francis models.**



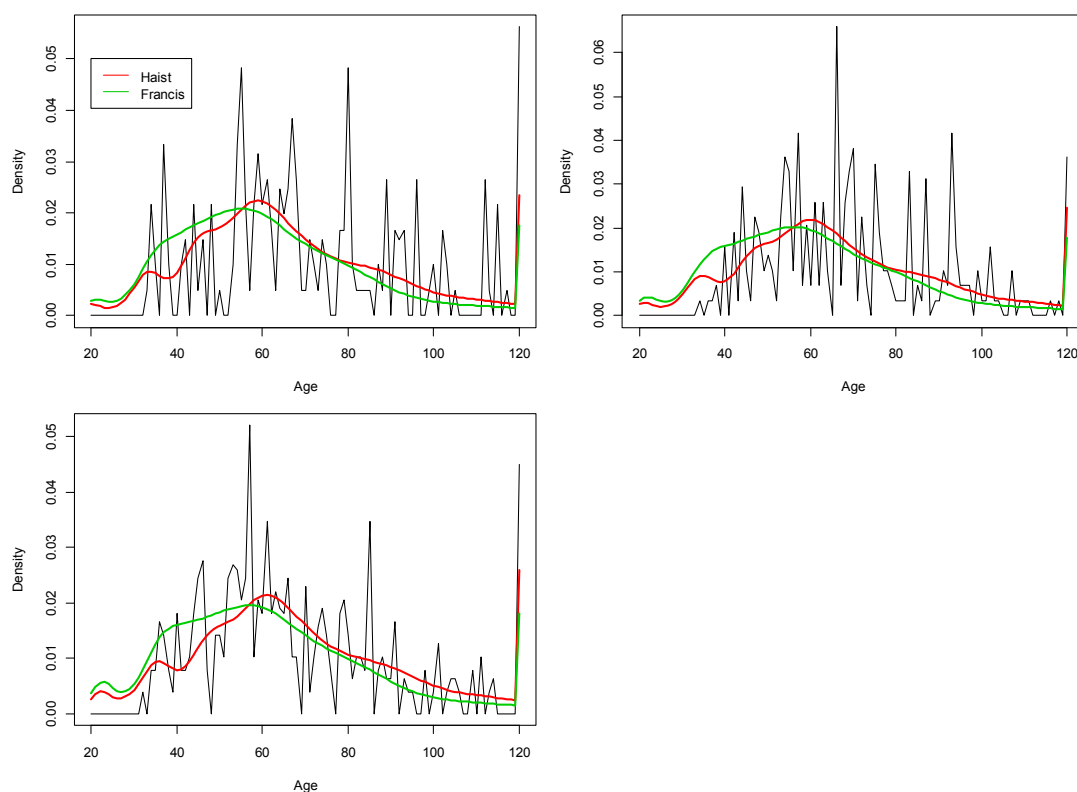
**Figure 10: MPD fits to the trawl survey age frequencies (1992 left, 1994 right) for the Haist and Francis models.**



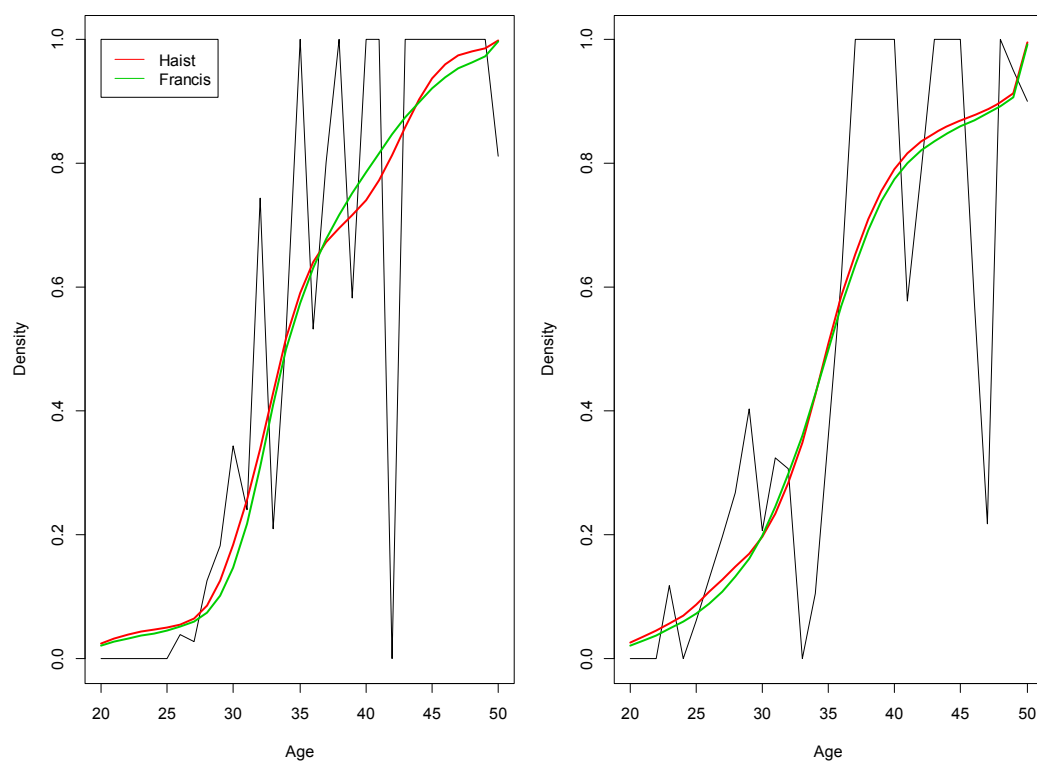
**Figure 11: Example MPD fits to the north fishery length frequencies (left to right by row: 1989, 1995, 2001, 2010) for the Haist and Francis models.**



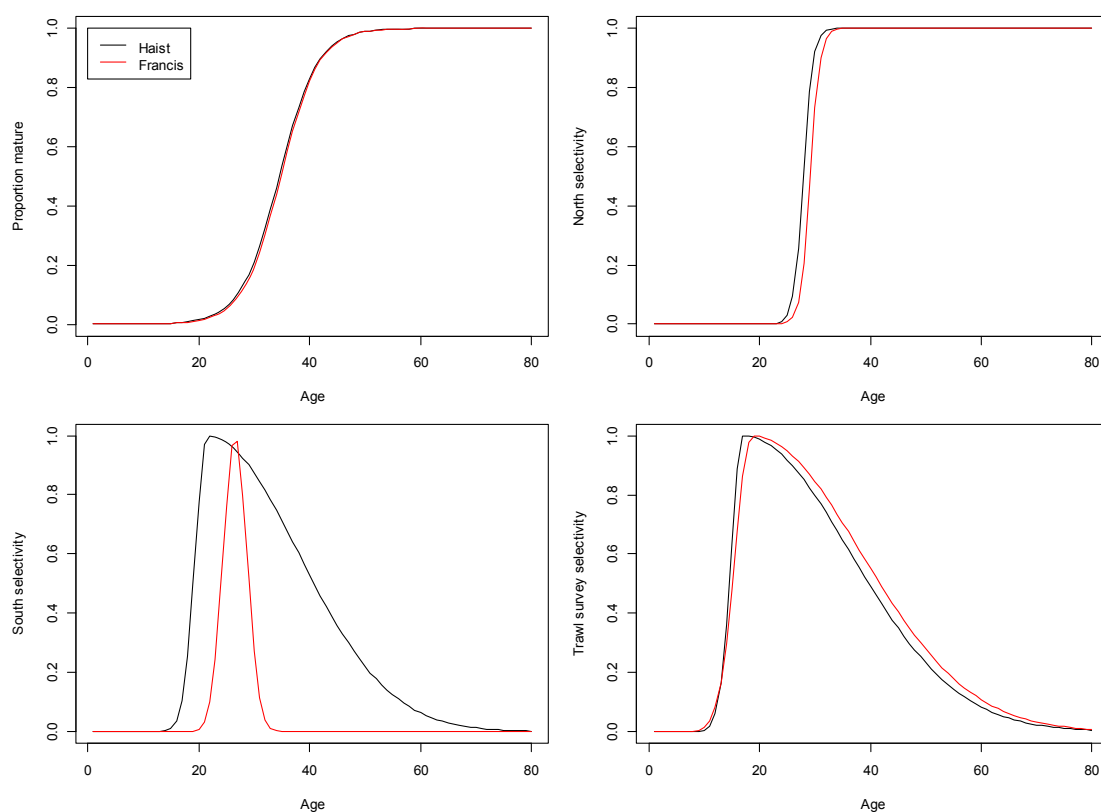
**Figure 12: Example MPD fits to the south fishery length frequencies (left to right by row: 1990, 1997, 2001, 2009) for the Haist and Francis models.**



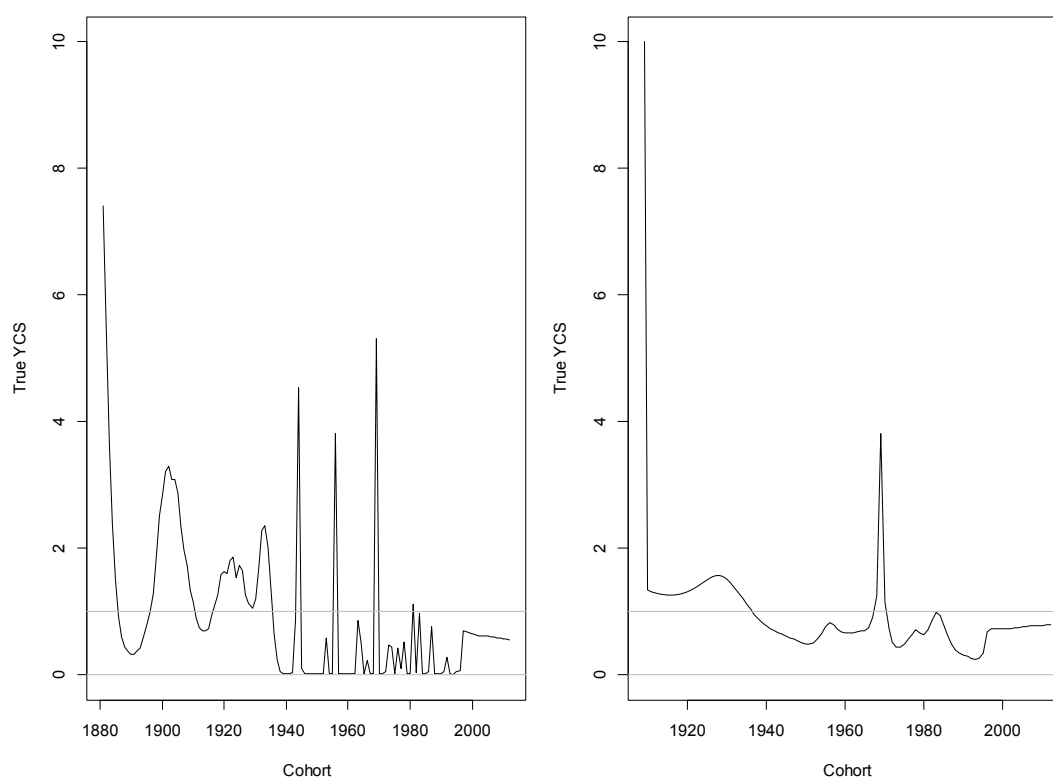
**Figure 13: MPD fits to spawning-season age frequencies (left to right by row: 1989, 1990, 1991) for the Haist and Francis models.**



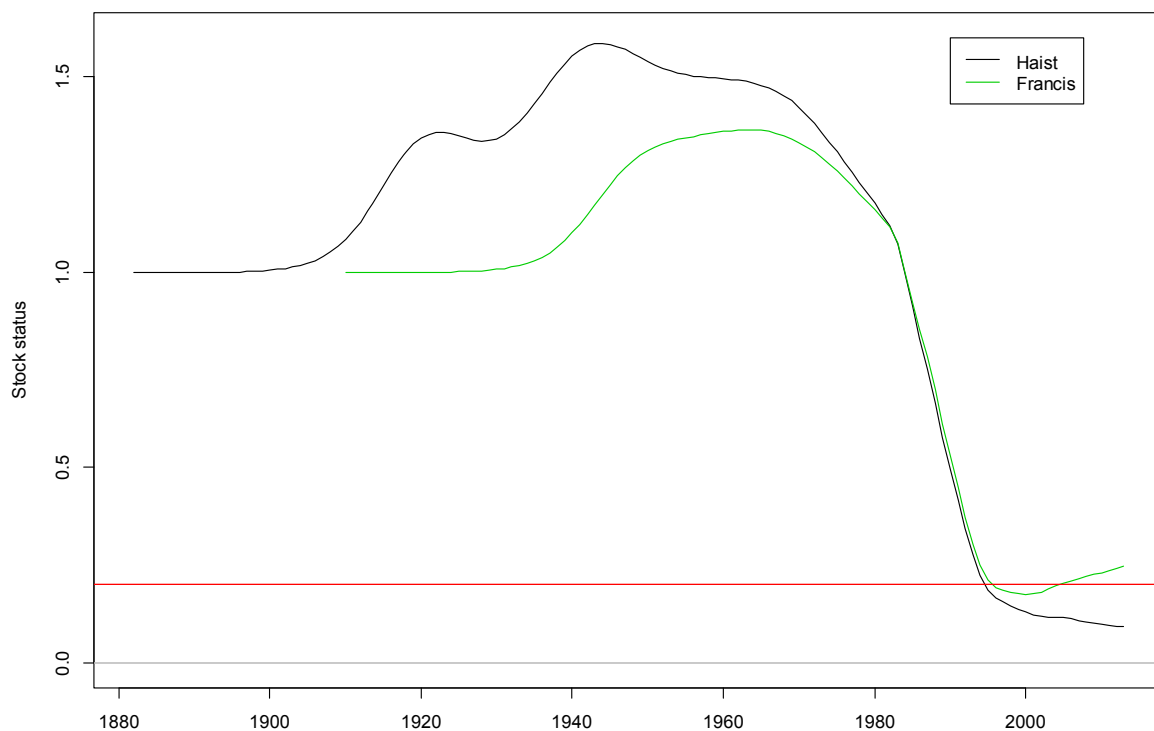
**Figure 14: MPD fits to trawl-survey proportion spawning at age (1993 left, 2010 right) for the Haist and Francis models.**



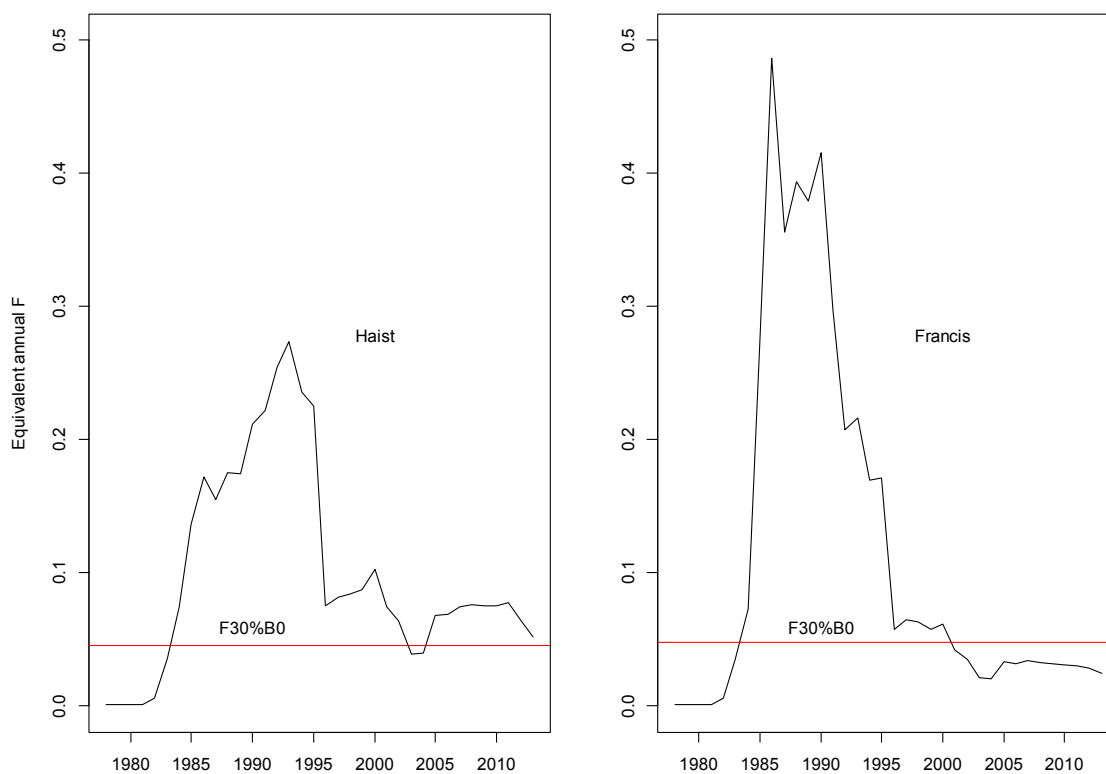
**Figure 15: MPD estimates of maturity at age and the fishing and trawl survey selectivities at age for the Haist and Francis models.**



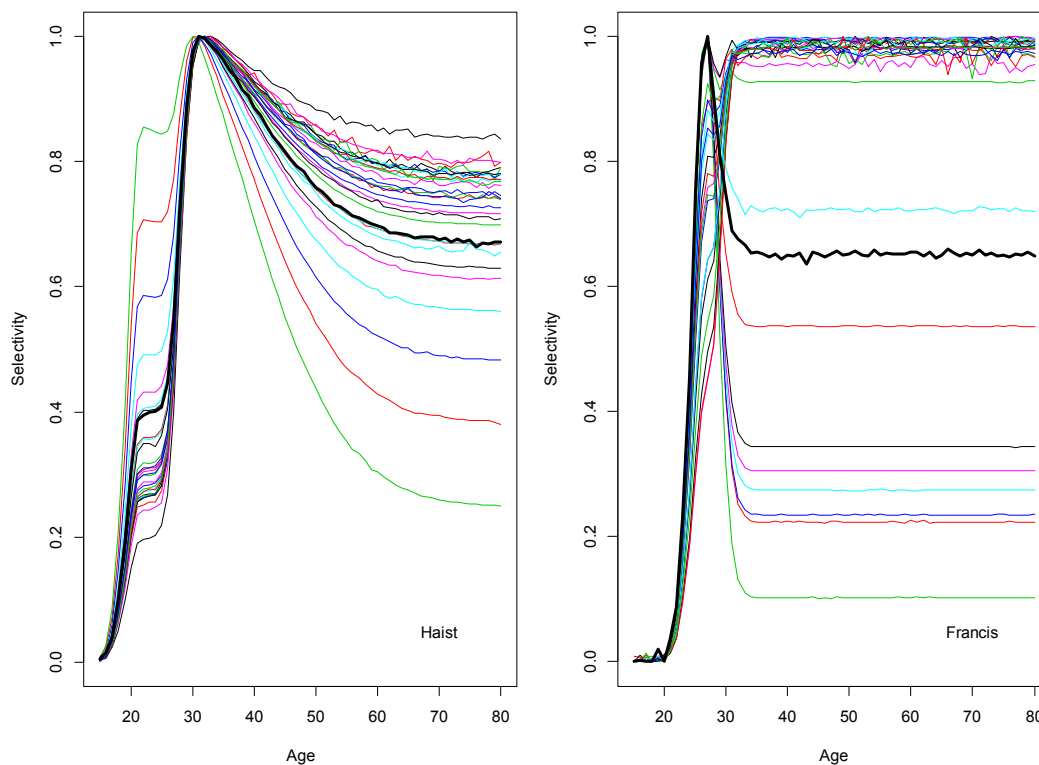
**Figure 16: MPD estimates of true YCS (relative annual recruitment) for the Haist and Francis models.**



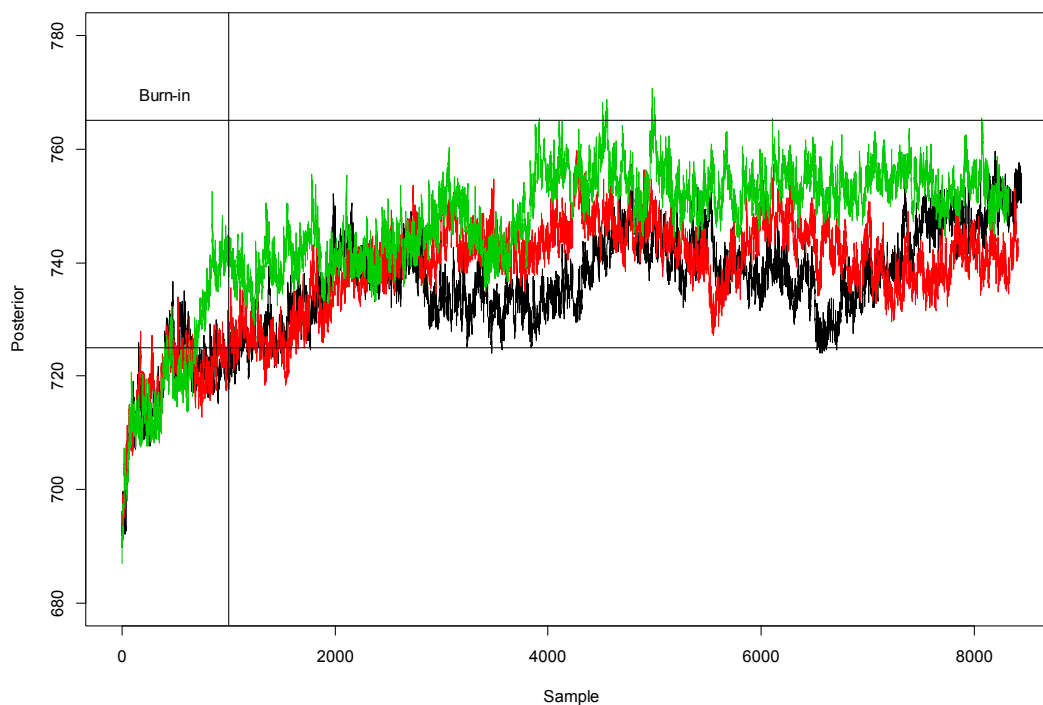
**Figure 17: MPD estimates of spawning biomass trajectories (proportion  $B_0$ ) for the Haist and Francis models. The horizontal line is at the Soft Limit  $0.2 B_0$ .**



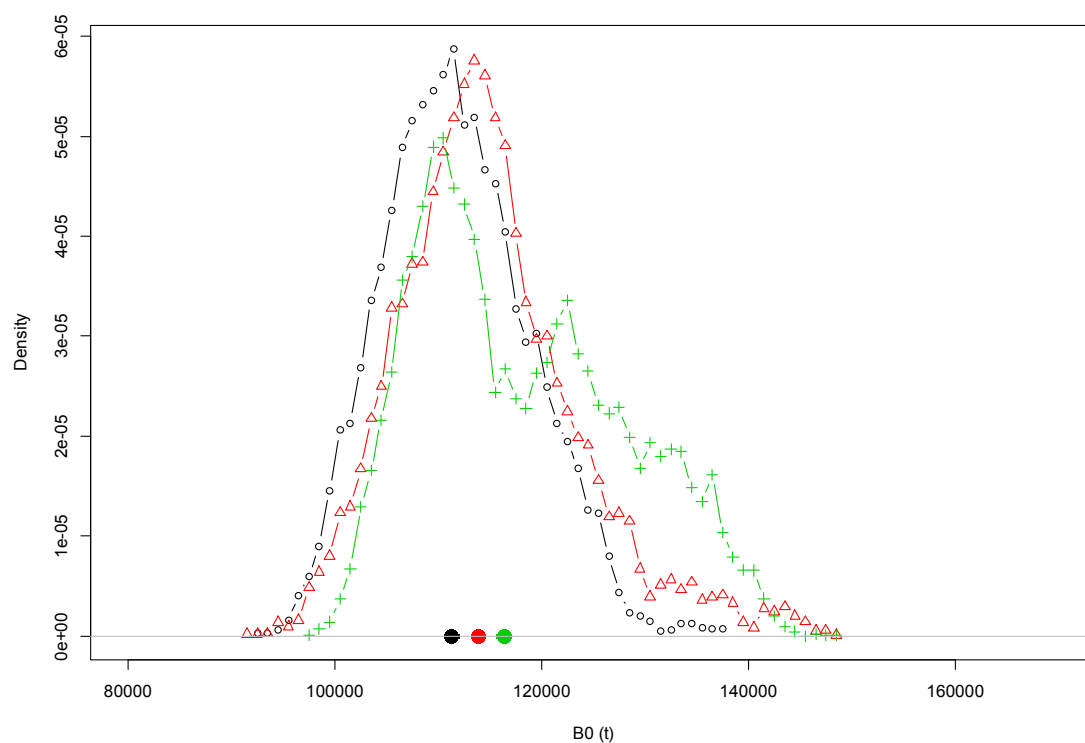
**Figure 18: MPD estimates of annual fishing intensity for the Haist and Francis models. The horizontal line is at the fishing intensity which would reduce spawning biomass to 30%  $B_0$  if applied indefinitely.**



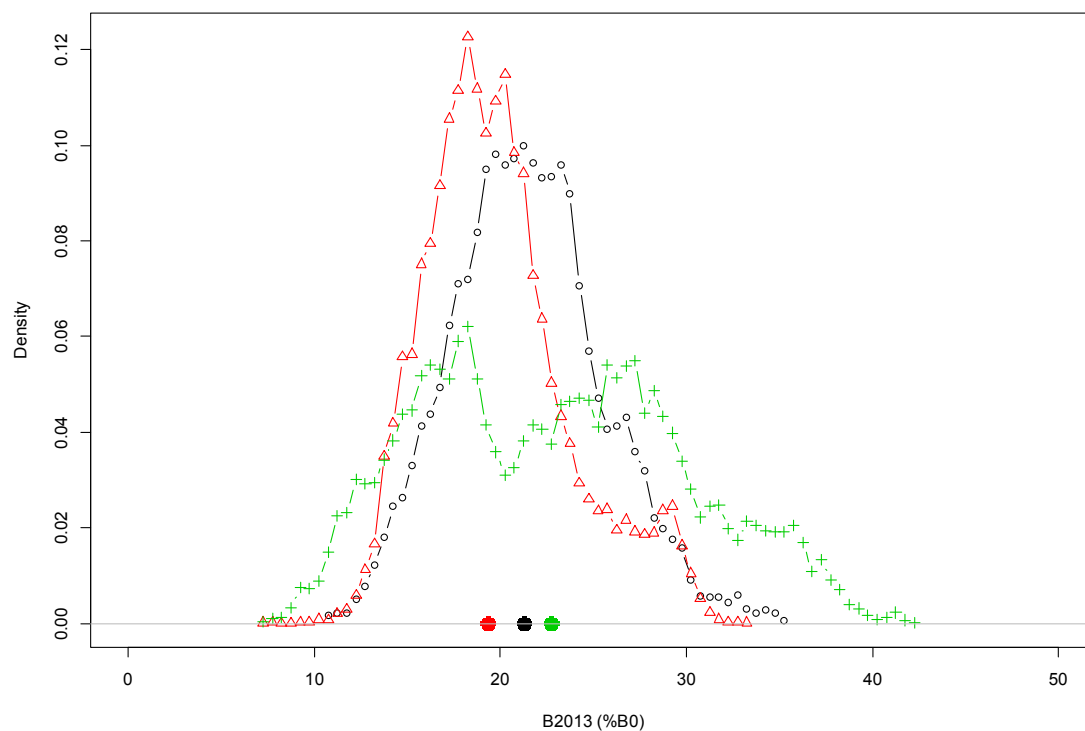
**Figure 19: MPD estimates of the annual composite fishing selectivity for the Haist and Francis models. The bold line is the estimate for the most recent year.**



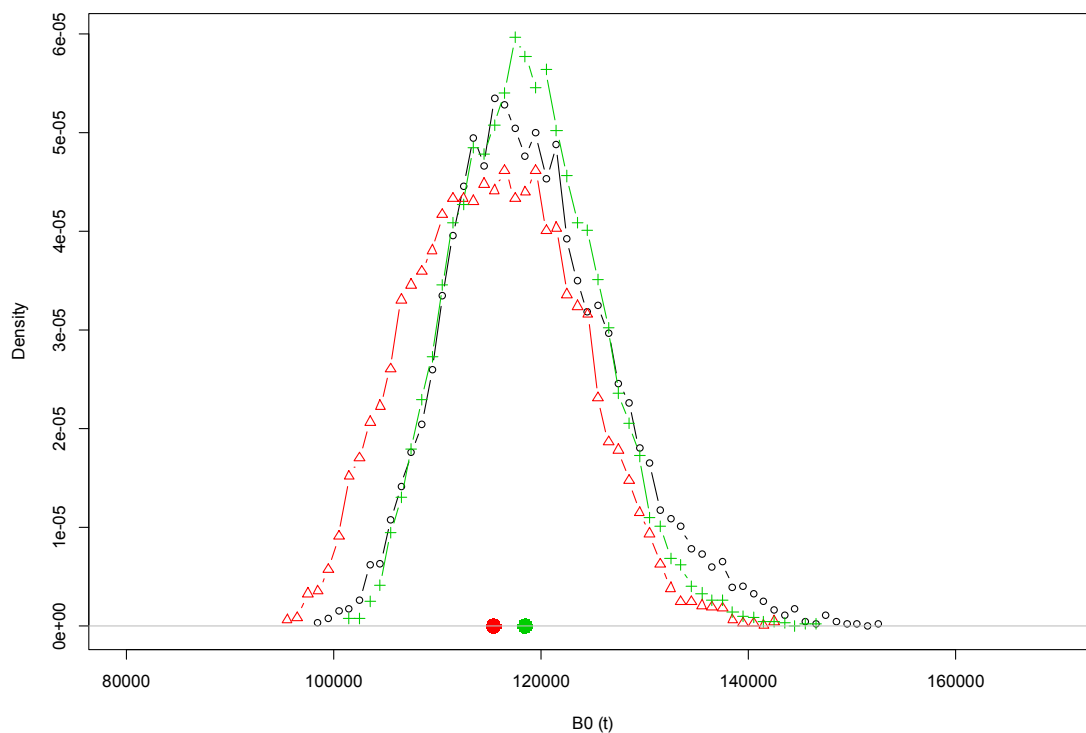
**Figure 20: Traces for the three Francis chains showing the total objective function at each stored sample (1 in every 1000). The vertical line marks the “burn-in” period (1000 stored samples) during which chains move away from the MPD. The horizontal lines encompass the region of typical objective function values.**



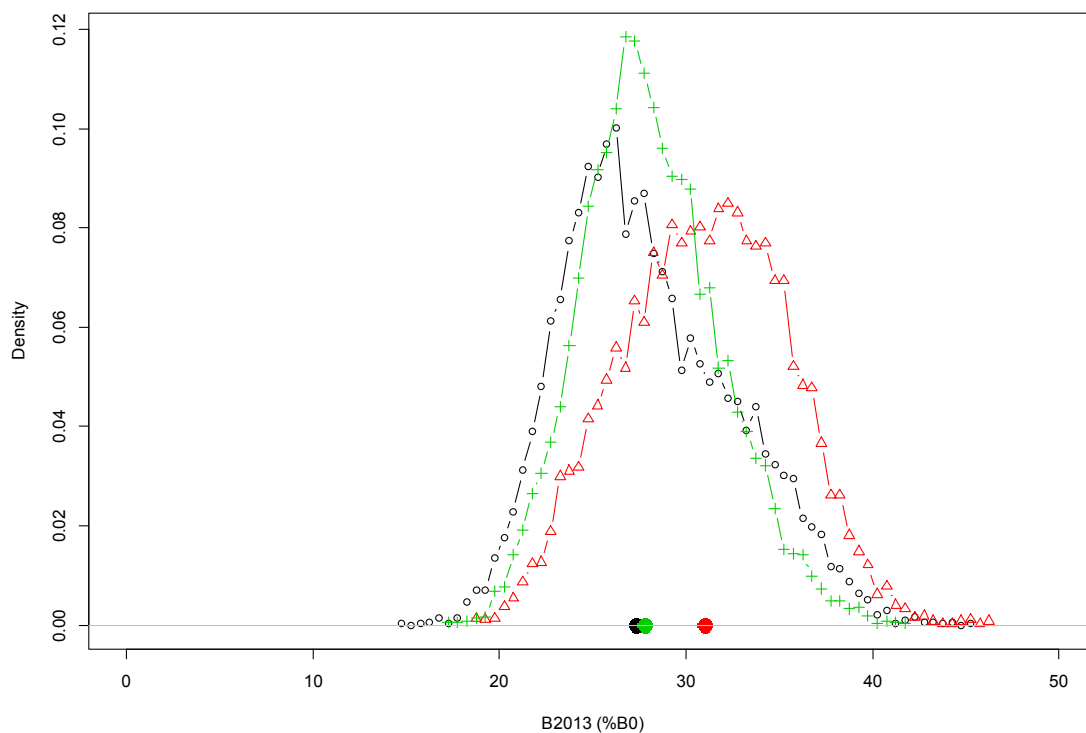
**Figure 21: Marginal posterior distributions of  $B_0$  for the three Haist chains. The solid circles mark the medians of each distribution.**



**Figure 22: Marginal posterior distributions of  $B_{2013}$  (% $B_0$ ) for the three Haist chains. The solid circles mark the medians of each distribution.**

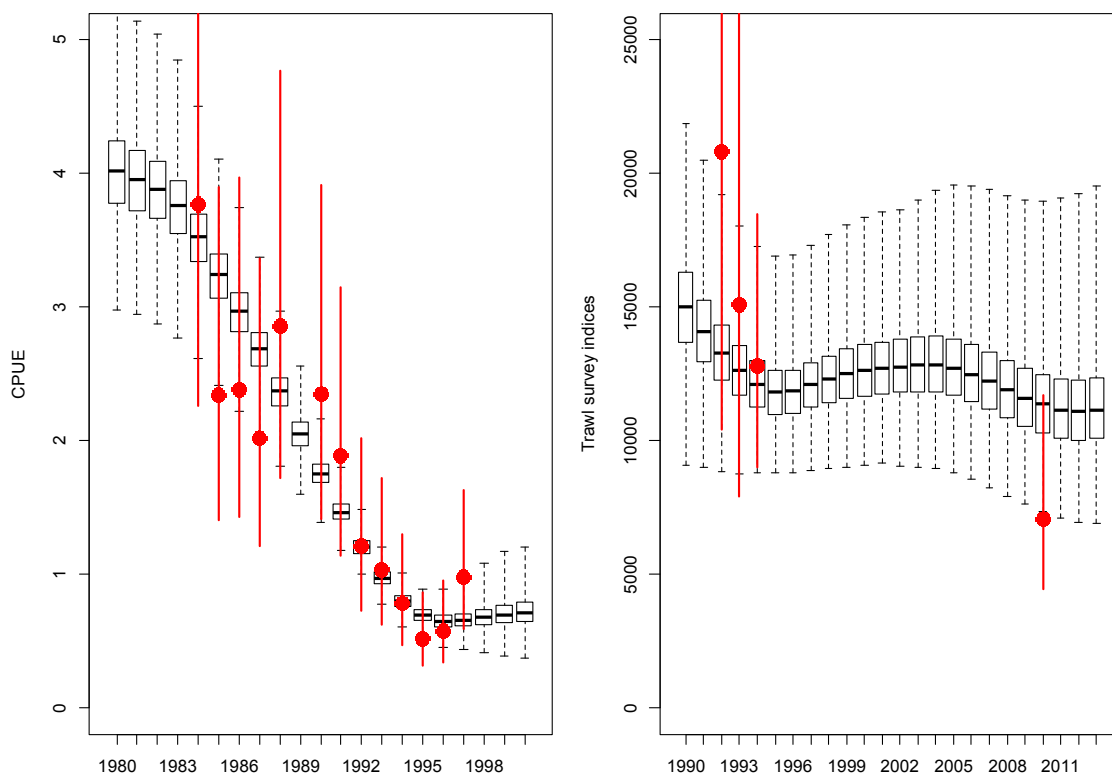


**Figure 23: Marginal posterior distributions of  $B_0$  for the three Francis chains. The solid circles mark the medians of each distribution.**

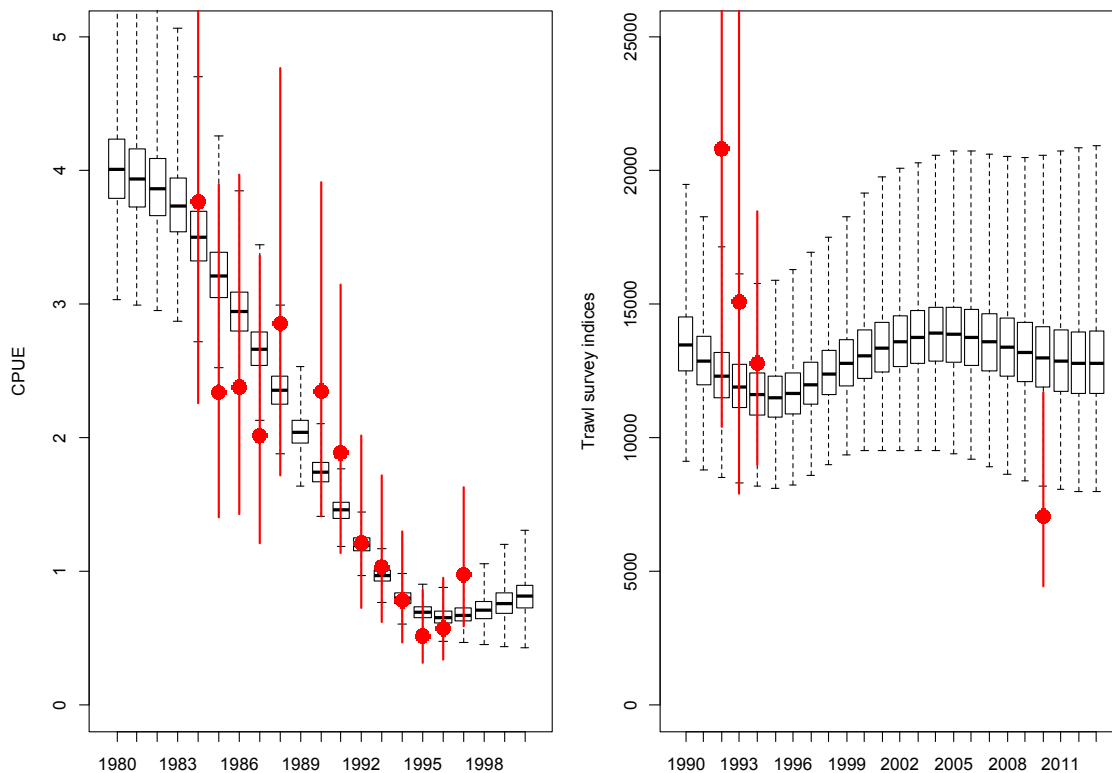


**Figure 24: Marginal posterior distributions of  $B_{2013}$  (% $B_0$ ) for the three Francis chains. The solid circles mark the medians of each distribution.**

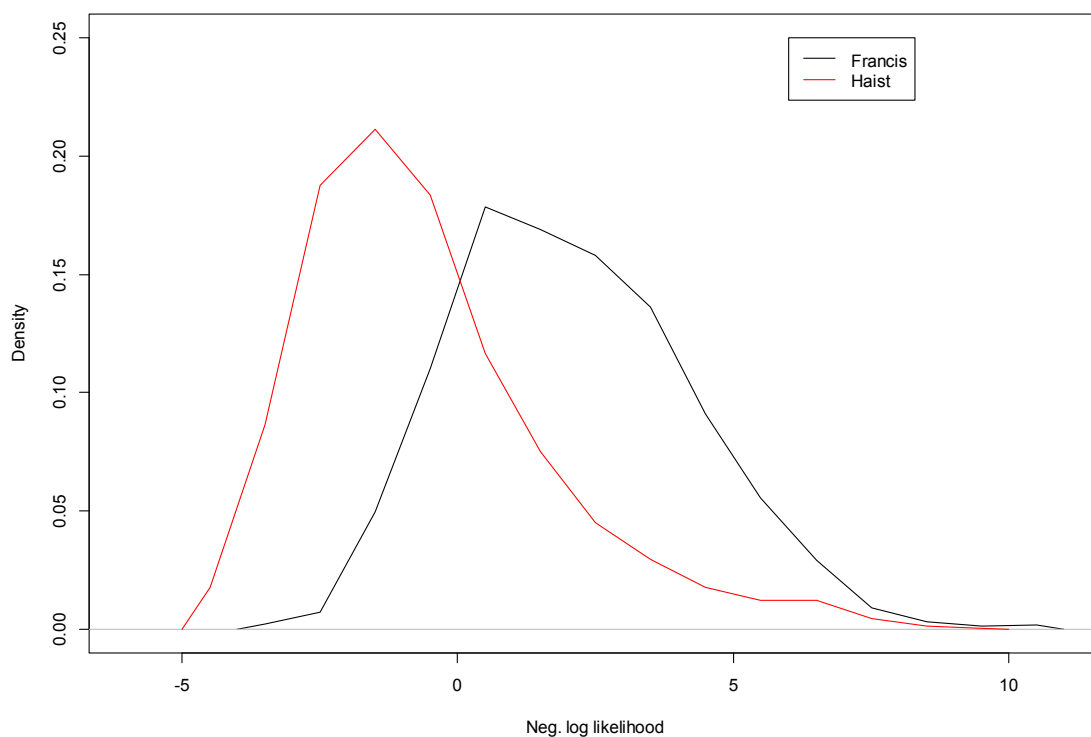




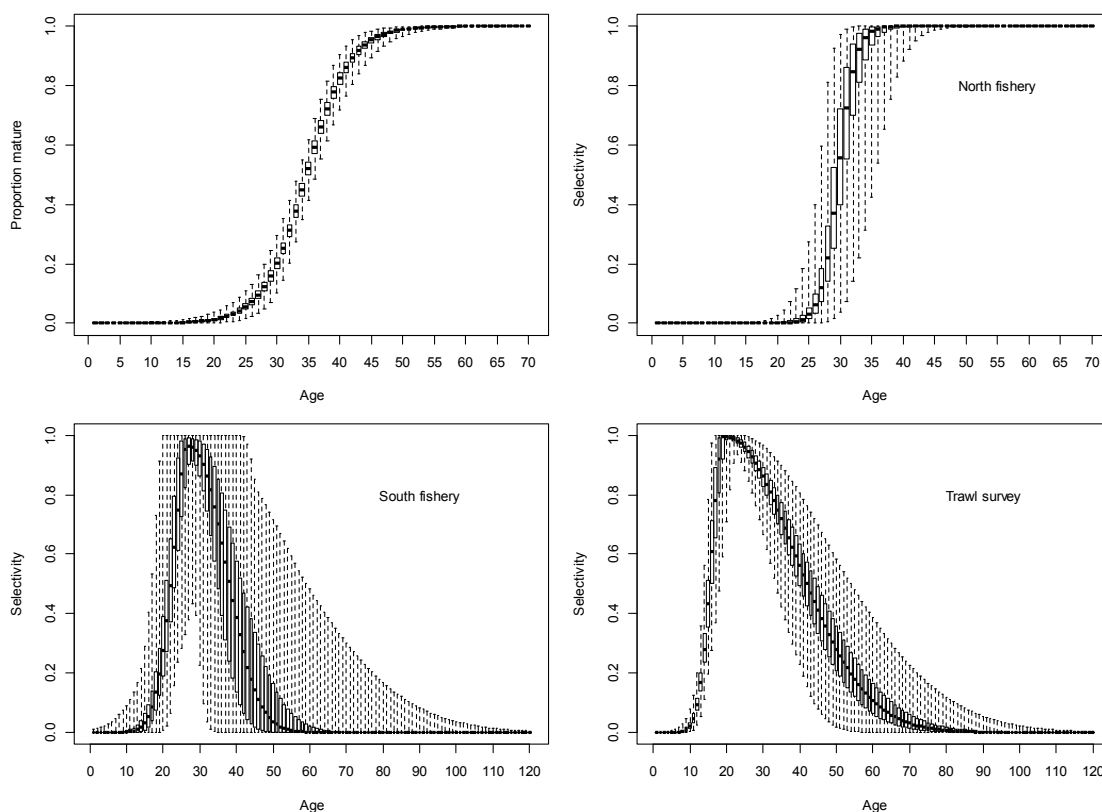
**Figure 25: Haist model: MCMC predictions of north fishery CPUE (left) and relative trawl survey biomass (right). The observations with 99% CIs are in red. The predictions are in black: each box contains 50% of the distribution and the whiskers cover the full range.**



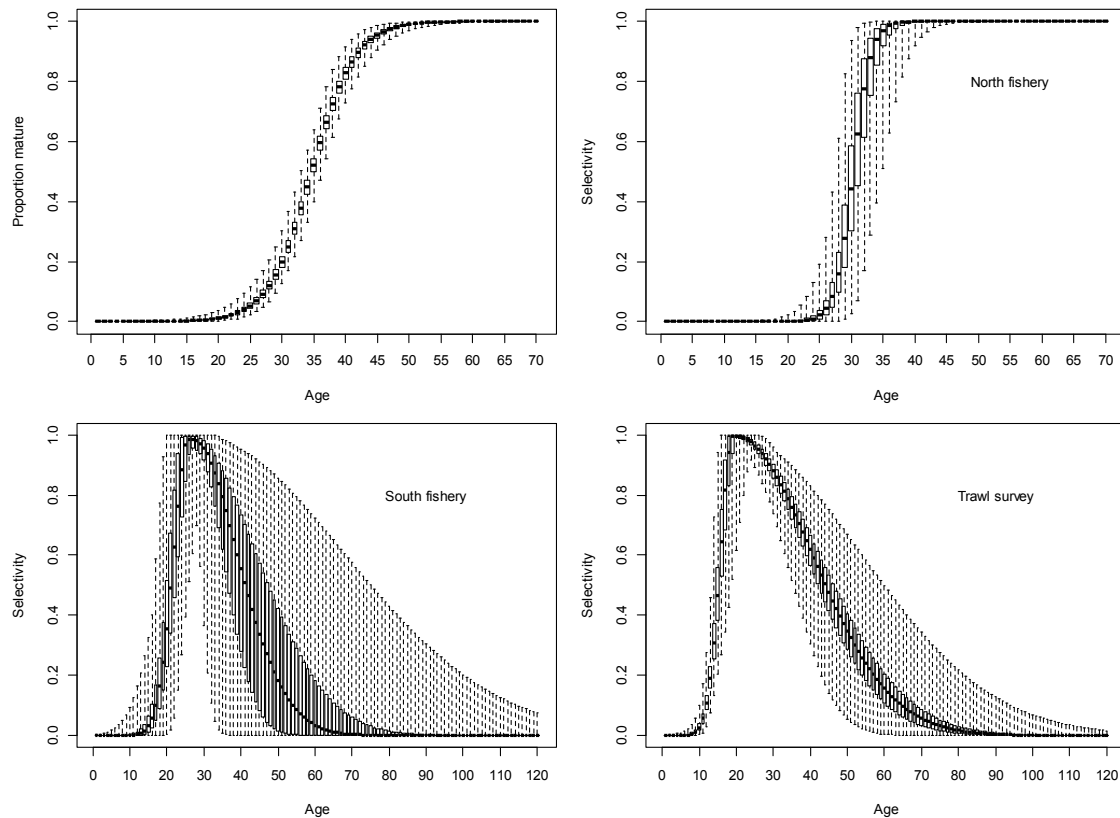
**Figure 26: Francis model: MCMC predictions of north fishery CPUE (left) and relative trawl survey biomass (right). The observations with 99% CIs are in red. The predictions are in black: each box contains 50% of the distribution and the whiskers cover the full range.**



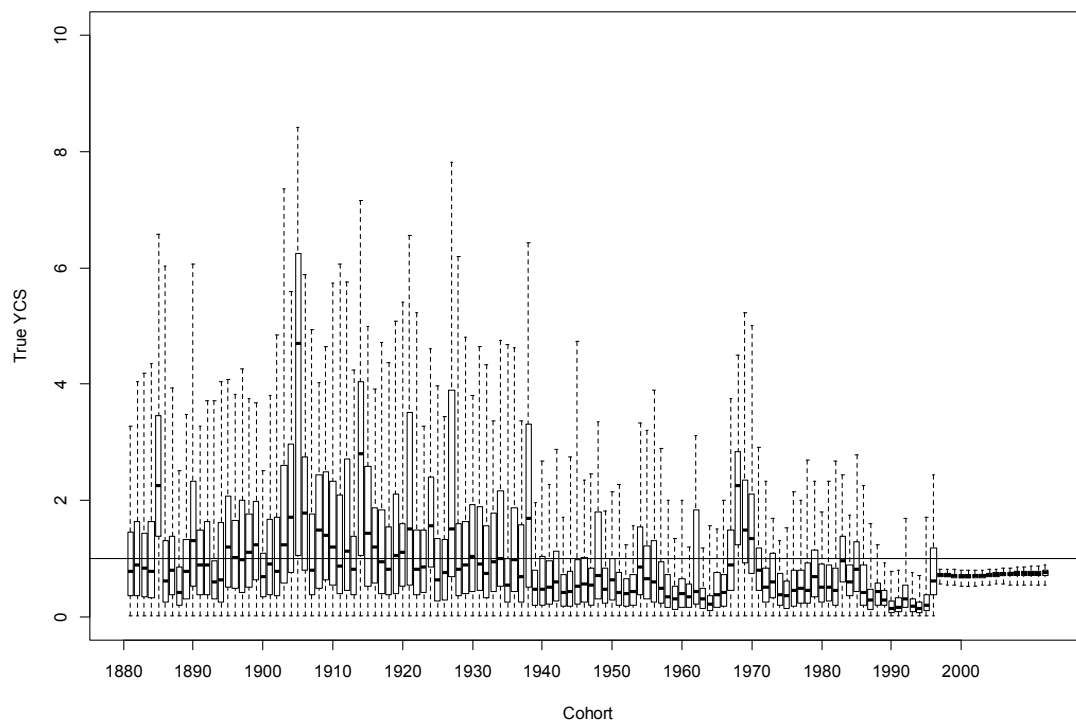
**Figure 27: Negative log likelihood distributions for the trawl-survey biomass indices from the Haist and Francis models (MCMCs). Lower values indicate a better fit.**



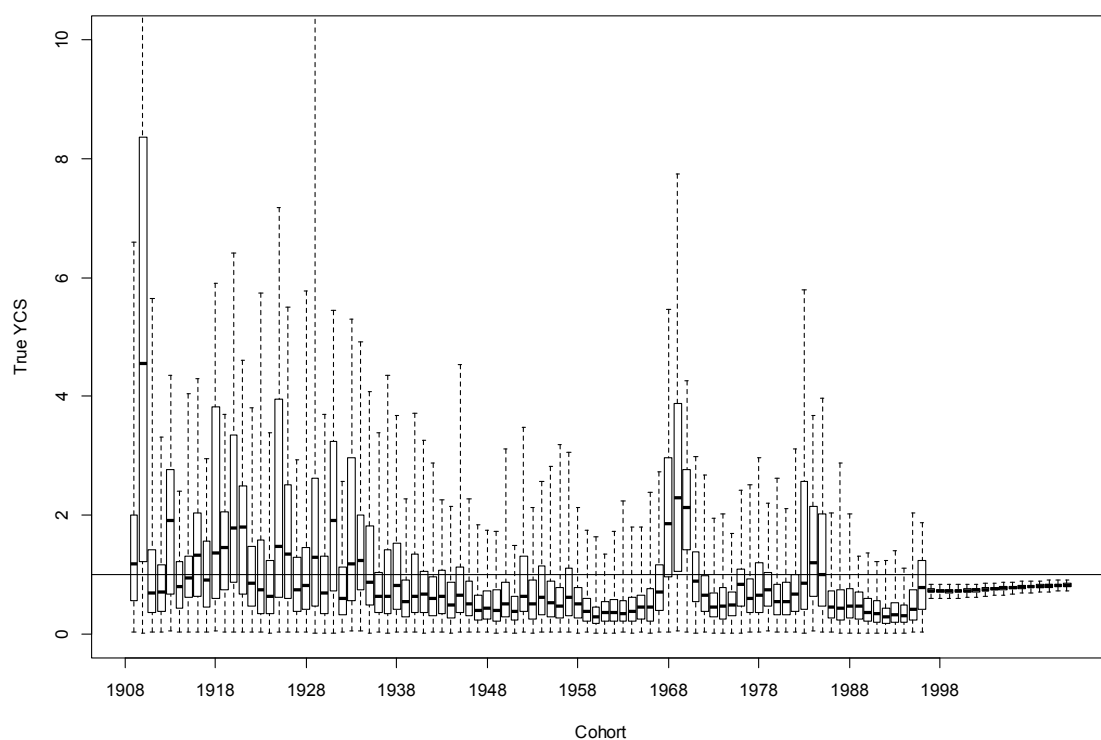
**Figure 28: MCMC estimates of maturity at age and the fishing and trawl survey selectivities at age for the Haist model. Each box contains 50% of the distribution and the whiskers cover the full range.**



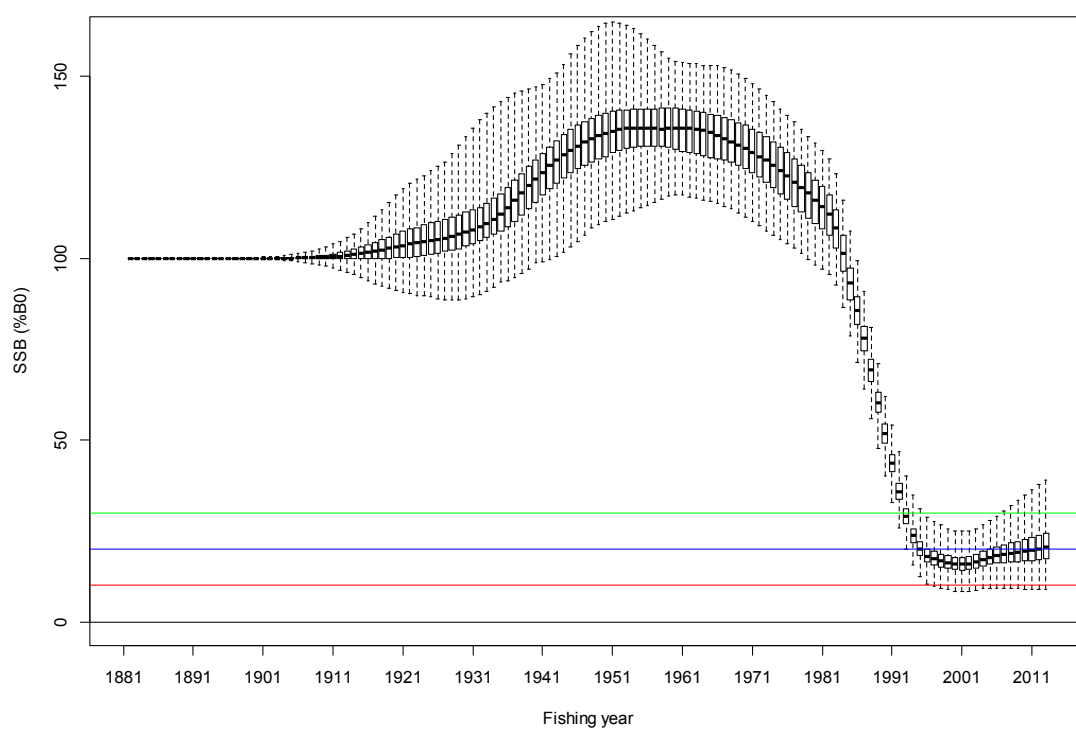
**Figure 29: MCMC estimates of maturity at age and the fishing and trawl survey selectivities at age for the Francis model.**



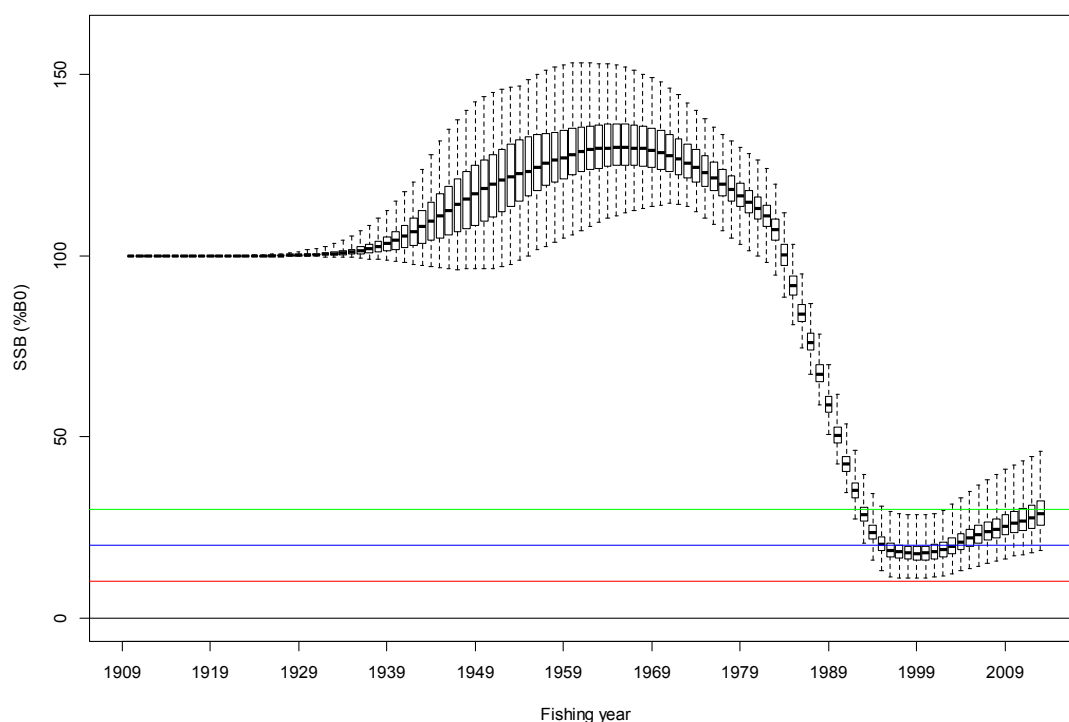
**Figure 30: MCMC estimates of true year class strength (YCS) for the Haist model. Each box contains 50% of the distribution and the whiskers cover the full range.**



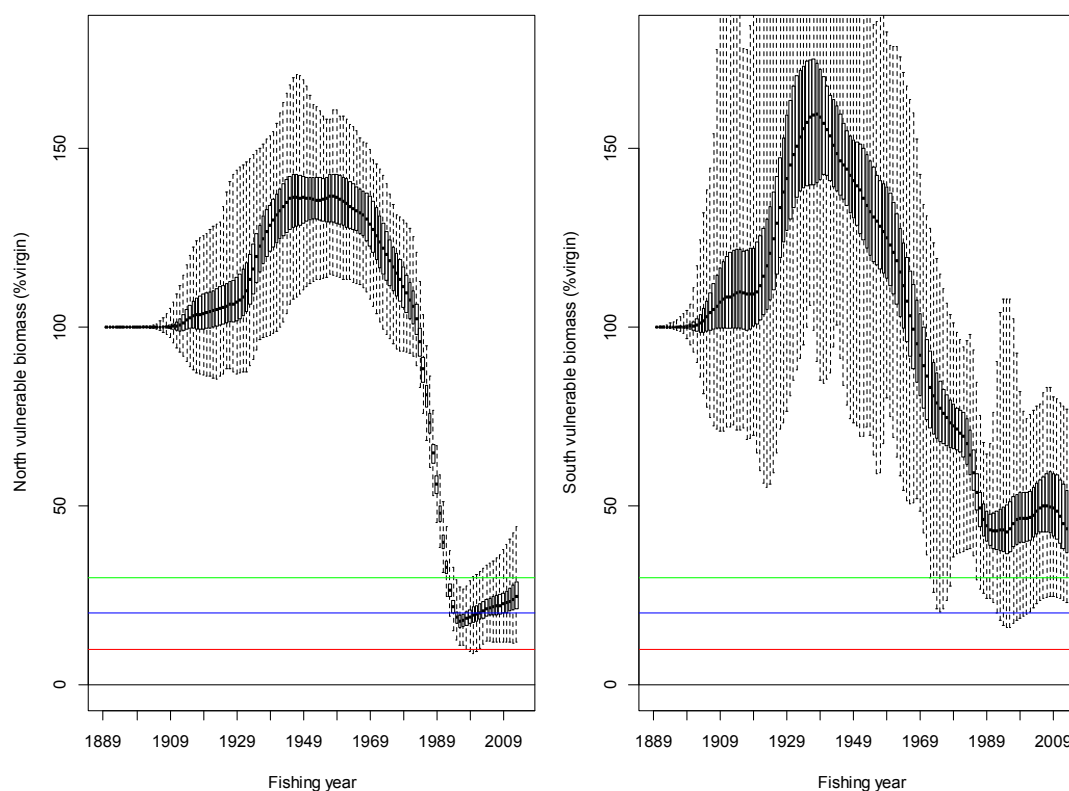
**Figure 31: MCMC estimates of true year class strength (YCS) for the Francis model.**



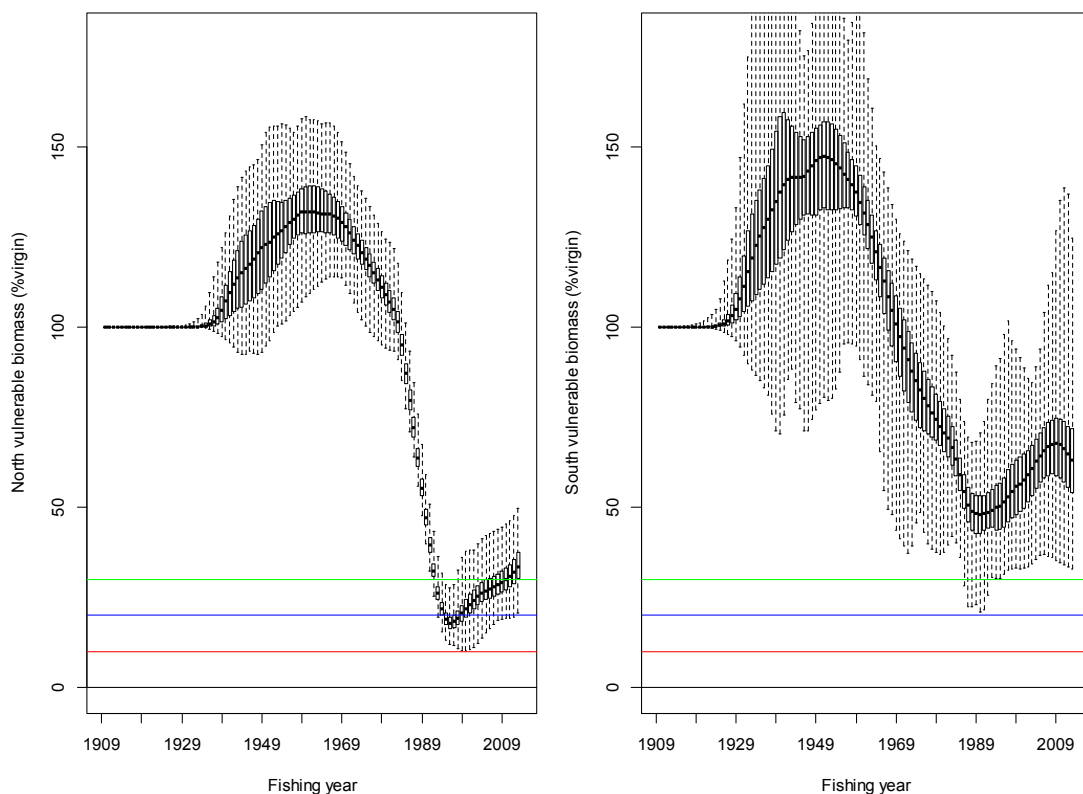
**Figure 32: MCMC estimate of spawning stock biomass trajectory (% $B_0$ ) for the Haist model. The hard and soft limits and the target (30%  $B_0$ ) are marked by horizontal lines. Each box contains 50% of the distribution and the whiskers cover the full range.**



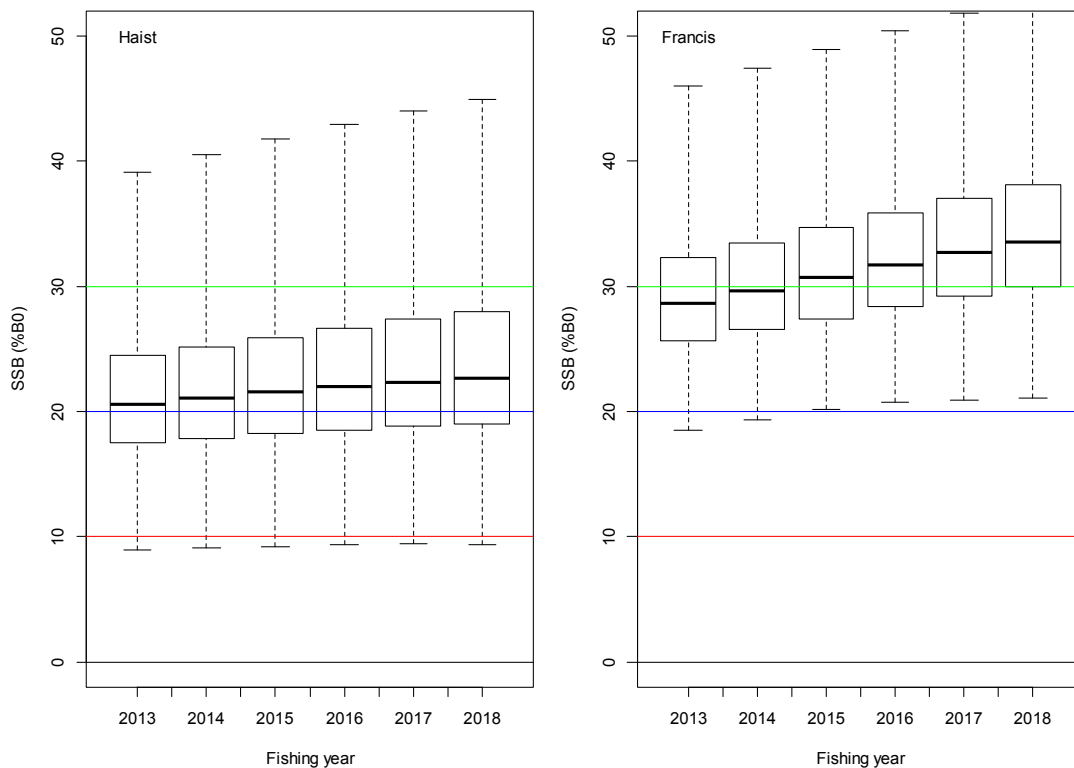
**Figure 33: MCMC estimate of spawning stock biomass trajectory ( $\%B_0$ ) for the Francis model. The hard and soft limits and the target ( $30\% B_0$ ) are marked by horizontal lines.**



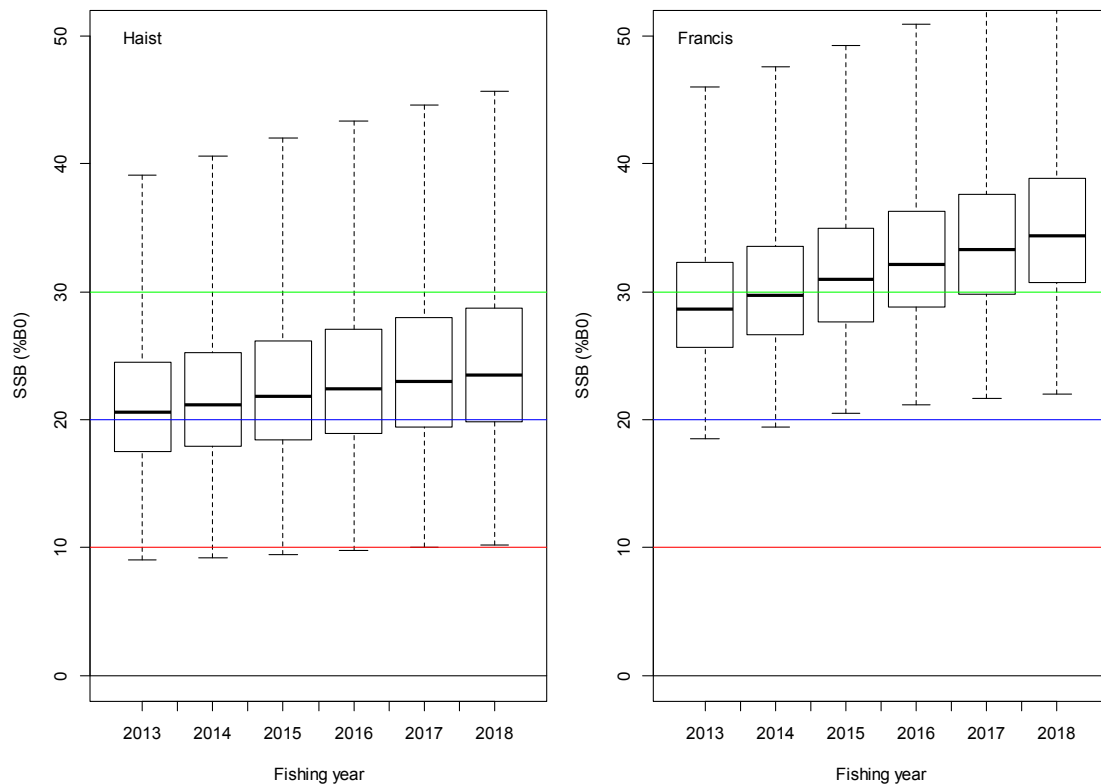
**Figure 34: Haist model: MCMC estimates of north and south fishery vulnerable biomass as a percentage of the virgin vulnerable biomass. Each box contains 50% of the distribution and the whiskers cover the full range.**



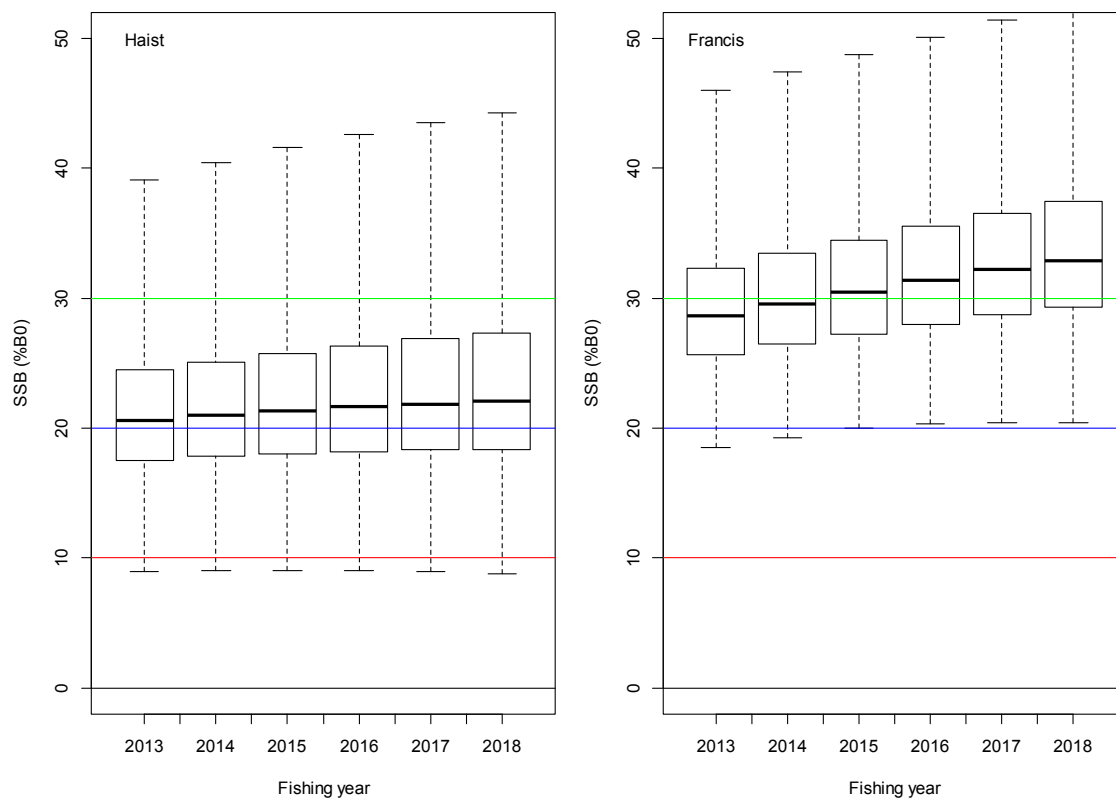
**Figure 35: Francis model: MCMC estimates of north and south fishery vulnerable biomass as a percentage of the virgin vulnerable biomass.**



**Figure 36: MCMC projections of spawning biomass (SSB) at the current catch limit of 930 t (+ 5% over-run) for the Haist and Francis models. The box contains 50% of the distribution and the whiskers cover the full range.**



**Figure 37: MCMC projections of spawning biomass (SSB) at a catch limit of 600 t (+ 5% over-run) for the Haist and Francis models.**



**Figure 38: MCMC projections of spawning biomass (SSB) at a catch limit of 1200 t (+ 5% over-run) for the Haist and Francis models.**

## APPENDIX 1 : Data weighting for the assessment models

This appendix covers the methods and results for the data weights used in the final assessment models. For biomass indices and estimates the weights are the CVs, for length and age frequencies and the proportion spawning at age data, the weights are effective sample sizes. Weights used in the final models are in Appendix 2.

### Biomass indices and estimates

For the egg survey and the acoustics estimates the CVs used were the estimated survey CVs taken from the original source documents. With only one and two data points respectively there is no prospect of estimating sensible values for process error and in both cases there appears little point in doing that as even with no process error the data are not influential.

The trawl survey CVs were also taken as the survey CVs with no process error. With only four data points it would not be sensible to estimate process error in the model, but there was the alternative of adding 20% for process error following the recommendation of Francis et al. (2001). This was not done because it was desired to give the models every incentive to fit the downward trend in the trawl survey indices – the inability to adequately fit this trend was one of the failings of the previous assessment.

The CVs for the CPUE indices were estimated following Francis (2011) by fitting the main trend in the indices using a smoother outside the model. The CPUE indices ( $X_i$ ) were assumed to be median-unbiased relative biomass indices with a constant CV:

$$\ln(X_i) = \ln(qB_i) + \ln(\varepsilon_i)$$

where  $q$  is the proportionality constant,  $B_i$  is the selected biomass in year  $i$ , and  $\ln(\varepsilon_i) \sim N(0, \sigma^2)$ . The maximum likelihood estimator of the CV was used for given  $qB_i$  (which are obtained from the fit given by the smoother):

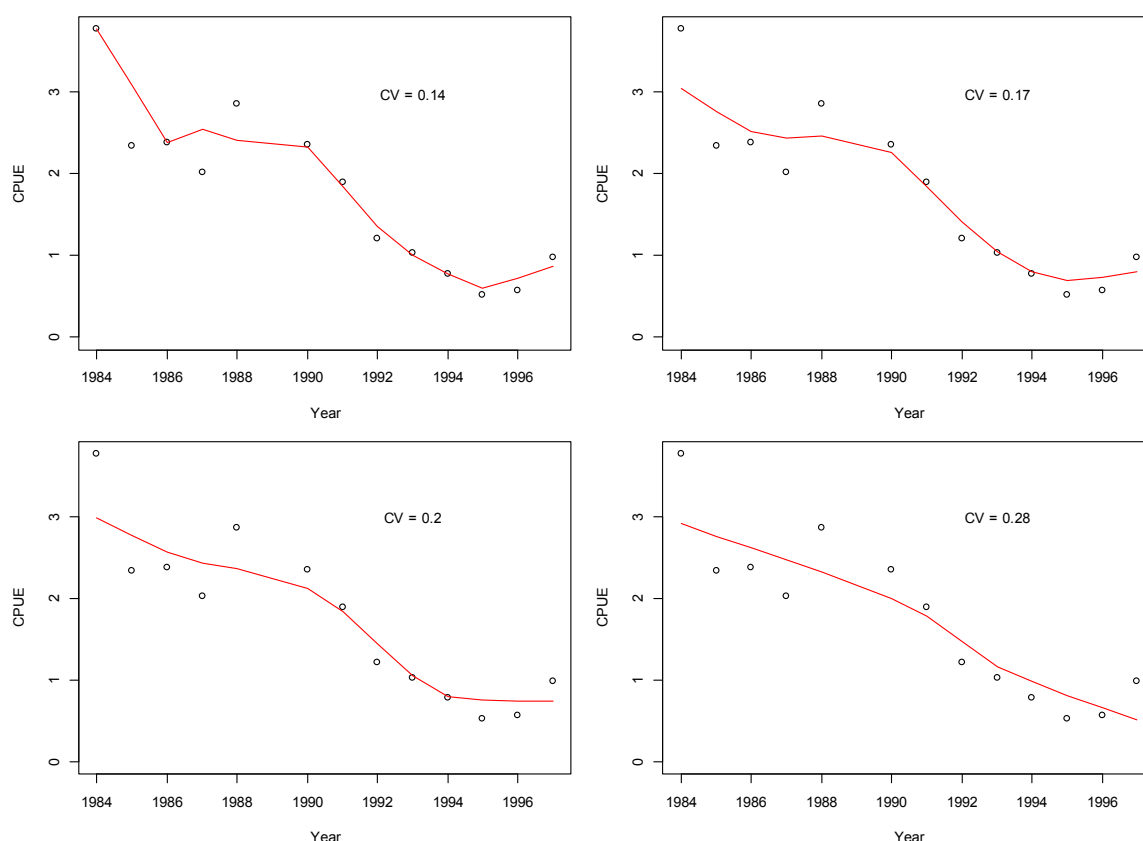
$$\widehat{\sigma^2} = \frac{1}{n} \sum_i \left[ \ln\left(\frac{x_i}{qB_i}\right) \right]^2$$

and

$$\widehat{CV} = \sqrt{e^{\widehat{\sigma^2}} - 1}$$

The lowess smoother in R was used and a CV of 20% was chosen by eye (Figure A1.1).





**Figure A1.1: North fishery CPUE indices fitted with different levels of smoothing for a lowest fit ( $f = 0.4, 0.5, 0.6, 0.7$  from left to right by rows). The maximum likelihood estimate of the CV is given in each case.**

### Length frequencies

The iterative reweighting method, TA1.8, of Francis (2011) was used to determine effective sample sizes for the north fishery, south fishery, and trawl survey length frequencies. This method is applied in the model fitting procedure. A vector of effective sample sizes is specified for each data set and then, on the basis of how well the predicted mean lengths each year match the observed mean length each year, the vector of sample sizes is rescaled (and the model is rerun). The procedure continues until the “input variance” matches the “output variance” (i.e., the input effective sample sizes are consistent with the variance of the residuals of annual mean length).

The procedure was applied to early Haist and Francis models which included all four years of the trawl-survey length frequencies. The iterative procedure was slow to converge after an initial large scaling down of sample sizes and it was stopped after about 5 iterations. The results were somewhat different for the Haist and Francis models but it was decided to use the same values for both models so that likelihoods could be legitimately compared.

The starting values for the north and south fisheries were taken from the bootstrap results in Anderson & Dunn (2011). For the trawl surveys an arbitrary starting value of 100 was used each year. The starting and finishing ranges (across years) for the effective sample sizes were:

	Start range	Finish range
North fishery	112–1740	3–28
South fishery	115–583	4–19
Trawl survey	100–100	62–62

### **Age data**

The trawl survey age frequencies were based on 500 otolith readings in each year while the spawning-season age frequencies were from 131, 177, and 207 otoliths in 1989, 1990, and 1991 respectively (these were the number of otolith readings with a quality rank of 4 or better). A fairly arbitrary rule-of-thumb was used to choose effective sample sizes for the age frequencies: otolith number  $\times$  0.4 for the trawl surveys ( $n = 200$ ); and otolith number  $\times$  0.2 for the commercial age frequencies ( $n = 26, 35, 41$ ). The higher multiplier for the trawl survey age frequencies was chosen because as a stratified random trawl survey it provides “top quality” age frequencies. The commercial data can be expected to contain more process error because of variation in selectivity patterns and the proportion of catch sampled. All age frequency data suffers from fish tending to school by age and hence having lower effective sample size than the number of otoliths read.

The proportion spawning at age estimates were fairly arbitrarily assigned a sample size of 10 at each age. This was a ballpark figure based on some effective sample size calculations using bootstraps from the raw data. It is probably on the high side as ages 20–50 years were used so it equates to about 300 otoliths which is a bit more than the number of female otoliths that would have been aged each year. A sample size of 4 or 5 may have been better (some sensitivity runs were done with these data excluded and also with lower sample size and the data were not influential).

## APPENDIX 2 : CASAL input files for the Haist model

The following files were used for the MCMC chains for the final base model, which uses the Haist parameterisation. The MPD files had much wider bounds on the priors to encourage a “full” search of the parameter space for the global minimum (and a much lower gradient tolerance). The Francis files were slightly different as  $B_{mean}$  was estimated rather than  $B_0$  (which is a derived parameter under the Francis parameterisation).

### population.csl

```
# PARTITION
@size_based False
@min_age 1
@max_age 120
@plus_group True
@sex_partition False
@mature_partition True
@n_areas 1

# TIME SEQUENCE
@initial 1882
@current 2013
@final 2018
@annual_cycle
time_steps 1
aging_time 1
recruitment_time 1
spawning_time 1
spawning_p 1
spawning_part_mort 0.5
M_props 1
fishery_names North South
fishery_times 1 1

# maturation
n_maturations 1
maturation_times 1

# RECRUITMENT
@y_enter 1
@standardise_YCS True
@recruitment
YCS_years 1881 1882 1883 1884 1885 1886 1887 1888 1889 1890 1891
1892 1893 1894 1895 1896 1897 1898 1899 1900 1901 1902 1903 1904
1905 1906 1907 1908 1909 1910 1911 1912 1913 1914 1915 1916 1917
1918 1919 1920 1921 1922 1923 1924 1925 1926 1927 1928 1929 1930
1931 1932 1933 1934 1935 1936 1937 1938 1939 1940 1941 1942 1943
1944 1945 1946 1947 1948 1949 1950 1951 1952 1953 1954 1955 1956
1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969
1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982
1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995
1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008
2009 2010 2011 2012
```

---

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Ministry for Primary Industries

```

future_years 2014 2015 2016 2017 2018
future_catches 332.01 332.01 332.01 332.01 332.01
selectivity SELsouth
U_max 0.67

```

```

# SELECTIVITIES
@selectivity_names SELnorth SELsouth SELspawn SELtrawl
@selectivity SELnorth
all logistic 43.5709 9.2542
@selectivity SELsouth
all double_normal 30.3334 6.74983 7.36724
@selectivity SELtrawl
all double_normal 20 5 5
@selectivity SELspawn
mature constant 1
immature constant 0

```

```

# SIZE AT AGE
@size_at_age_type von_Bert
@size_at_age_dist normal
@size_at_age
k 0.065
t0 -0.5
Linf 37.63 # From FAR
cv1 0.1
cv2 0.05
by_length True

```

```

# SIZE WEIGHT
@size_weight
a 9.21e-8
b 2.71

```

```

# INITIALISATION
@initialization
B0 140000

```

### **estimation.csl**

```

# ESTIMATION
@estimator Bayes
@max_iters 4000
@max_evals 4000
@grad_tol 0.01

```

```

# MCMC
@MCMC
start 0.2
length 15000000
keep 1000
stepsize 0.006
proposal_t True

```

```

df 2
burn_in 1000
subsample_size 2000
systematic False

# OBSERVATIONS - STANDARDISED CPUE

@relative_abundance MECcpueEarly
biomass True
ogive SELnorth
proportion_mortality 0.5
dist normal-log
q qMECcpueEarly
years 1984 1985 1986 1987 1988 1990 1991 1992 1993 1994 1995 1996
1997
step 1
curvature False
1984 3.77
1985 2.34
1986 2.38
1987 2.02
1988 2.86
1990 2.35
1991 1.89
1992 1.21
1993 1.03
1994 0.78
1995 0.52
1996 0.57
1997 0.98
cv 0.20

### Age freqs from spawning fishery
# Use as proportions-at-age for spawning fish
@proportions_at spawn_age_freq

years 1989 1990 1991
step 1
proportion_mortality 0.5
sexed F
sum_to_one TRUE
at_size FALSE
plus_group TRUE
ageing_error True
ogive SELspawn
min_class 20
max_class 120
1989 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0.004950495 0.02161716 0.00990099 0
0.03333333 0.00990099 0 0 0.00990099 0.01485149 0 0.02161716
0.004950495 0.01485149 0 0.02161716 0 0.004950495 0 0 0.00990099
0.03333333 0.04818482 0.02161716 0.004950495 0.02161716 0.03151815
0.02161716 0.02656766 0.01666667 0.004950495 0.02475248 0.01980198
0.02475248 0.03828383 0.02656766 0.004950495 0.004950495 0.01485149
0.00990099 0.004950495 0.01485149 0.00990099 0 0 0.01666667
0.01666667 0.04818482 0.00990099 0.004950495 0.004950495 0.004950495
0.004950495 0 0.00990099 0.004950495 0.02656766 0 0.01666667

```

```

0.01485149 0.01666667 0 0 0.02656766 0 0 0.004950495 0.00990099 0
0.01666667 0.00990099 0 0.004950495 0 0 0 0 0 0.02656766
0.004950495 0 0.02161716 0 0.004950495 0 0 0.05627063
1990 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0.003448276 0 0.003448276
0.003448276 0.006896552 0 0.015625 0 0.01907328 0.003448276
0.0294181 0.01034483 0.003448276 0.02252155 0.01907328 0.01034483
0.0137931 0.01034483 0.003448276 0.02252155 0.03631466 0.03286638
0.01034483 0.04159483 0.006896552 0.02068966 0.006896552 0.02596983
0.006896552 0.02596983 0.01034483 0 0.06594828 0.006896552
0.02596983 0.03286638 0.03814655 0.003448276 0.02252155 0.006896552
0 0.03469828 0.01907328 0.01034483 0.01034483 0.006896552
0.003448276 0.003448276 0.003448276 0.03286638 0 0.006896552
0.003448276 0.03125 0 0.003448276 0.003448276 0.01034483 0.006896552
0.04159483 0.015625 0.006896552 0.006896552 0.006896552 0 0.01034483
0.003448276 0.003448276 0.015625 0.003448276 0.003448276 0 0
0.01034483 0 0.003448276 0.003448276 0.003448276 0 0 0 0.003448276
0 0.003448276 0 0.03631466
1991 0 0 0 0 0 0 0 0 0 0 0 0 0.003937008 0 0.007874016 0.007874016
0.01659524 0.01420313 0.007874016 0.003937008 0.01814014 0.007874016
0.007874016 0.01026612 0.01814014 0.02446925 0.02755906 0.007874016
0 0.01420313 0.01420313 0.01026612 0.02446925 0.02686136 0.02601415
0.02053224 0.02446925 0.05217781 0.01026612 0.02053224 0.01814014
0.03473537 0.01814014 0.02207715 0.01898734 0.01814014 0.02446925
0.01026612 0.01026612 0 0.02292435 0.003937008 0.01026612 0.01574803
0.01898734 0.01420313 0.007874016 0 0.01814014 0.02053224 0.01420313
0.006329114 0.01026612 0.01026612 0.007874016 0.03473537 0
0.007874016 0.01026612 0.006329114 0.006329114 0.01659524 0
0.006329114 0.003937008 0.003937008 0 0 0.007874016 0 0.003937008
0.01265823 0 0.003937008 0.006329114 0.006329114 0.003937008 0 0
0.007874016 0 0.01026612 0 0.003937008 0.006329114 0 0 0 0
0.0450015

```

```

dist multinomial
r 0.00001

```

```

N_1989      26
N_1990      35
N_1991      41

```

```

@proportions_at Trawl_age
years 1993 2010
step 1
proportion_mortality 0.5
ogive SELtrawl
sexed F
sum_to_one True
at_size False
min_class 10
max_class 100
plus_group True
ageing_error True
1993 0 0 0.00163 0.00804 0.01833 0.04376 0.04505 0.03249 0.07162
0.05118 0.05558 0.07139 0.06942 0.09030 0.10252 0.07508 0.05355
0.04137 0.05142 0.01761 0.01476 0.01697 0.01660 0.00288 0.00316
0.00372 0.00754 0.00597 0.00234 0.00087 0.00047 0.00061 0.00148

```

```

0.00341 0.00302 0.00063 0.00000 0.00253 0.00088 0.00100 0.00008
0.00000 0.00000 0.00026 0.00008 0.00095 0.00027 0.00016 0.00000
0.00024 0.00000 0.00187 0.00021 0.00041 0.00036 0.00092 0.00000
0.00005 0.00047 0.00000 0.00000 0.00067 0.00008 0.00059 0.00026
0.00054 0.00000 0.00000 0.00029 0.00010 0.00021 0.00000 0.00047
0.00000 0.00000 0.00000 0.00000 0.00047 0.00008 0.00005 0.00000
0.00000 0.00000 0.00000 0.00005 0.00000 0.00000 0.00000 0.00017
0.00000 0.00000
2010 0.00412 0.02428 0.00740 0.02305 0.02692 0.02117 0.01857 0.01954
0.03591 0.04367 0.02330 0.03533 0.05091 0.04214 0.06975 0.05477
0.08077 0.03580 0.08743 0.03967 0.03327 0.03762 0.02308 0.03218
0.01185 0.01690 0.01660 0.01245 0.00998 0.00360 0.00540 0.00430
0.00772 0.00170 0.00338 0.00048 0.00135 0.00600 0.00277 0.00392
0.00049 0.00000 0.00024 0.00404 0.00036 0.00192 0.00123 0.00170
0.00000 0.00000 0.00226 0.00030 0.00000 0.00030 0.00000 0.00000
0.00049 0.00086 0.00000 0.00085 0.00000 0.00030 0.00000 0.00042
0.00205 0.00044 0.00000 0.00000 0.00030 0.00000 0.00000 0.00121
0.00011 0.00000 0.00000 0.00024 0.00000 0.00000 0.00000 0.00000
0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
0.00000 0.00000 0.00000

```

```

dist multinomial
r 0.00001
N 200

```

```

@ageing_error
type normal
c 0.1

```

```

# Proportion mature from trawl surveys

```

```

@proportions_mature Mature_age
years 1993 2010
step 1
proportion_mortality 0.5
sexed F
at_size False
min_class 20
max_class 50
plus_group True
ageing_error True
1993 0 0 0 0 0 0 0.03905646 0.02680013 0.1253618 0.1829738 0.3443686
0.2408688 0.7437104 0.2102544 0.5283447 1 0.5322298 0.8021025 1
0.5828449 1 1 0 1 1 1 1 1 1 0.8115202
2010 0 0 0 0.1183311 0 0.06118033 0.129729 0.1972661 0.2672396
0.4031943 0.2060199 0.3236865 0.3069467 0 0.1054707 0.3578779
0.6137749 1 1 1 1 0.5774974 0.79 1 1 1 0.5746427 0.2171537 1 0.95
0.9003207

```

```

dist binomial
r 0.00001
N 10

```

```

### Commercial LFs

```



@catch\_at commercial\_LFs\_North

```

fishery      North
years 1989 1990 1991 1993 1994 1995 1997 1998 1999 2000 2001 2002
2003 2007 2008 2010
sexed F
sum_to_one TRUE
at_size     TRUE
plus_group FALSE
class_mins 15  16  17  18  19  20  21  22  23  24  25
          26  27  28  29  30  31  32  33  34  35  36  37
          38  39  40  41  42  43  44  45  46  47  48  49
          50  51  52  53  54  55  56
1989      0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
          0.000 0.000 0.000 0.001 0.003 0.005 0.026 0.044 0.071 0.129 0.163
          0.164 0.144 0.118 0.065 0.036 0.019 0.009 0.005 0.001 0.000 0.000
          0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
1990      0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
          0.001 0.000 0.000 0.000 0.002 0.008 0.027 0.036 0.069 0.116 0.145
          0.163 0.126 0.116 0.091 0.065 0.023 0.009 0.003 0.000 0.000 0.000
          0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
1991      0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
          0.000 0.000 0.000 0.001 0.006 0.014 0.038 0.067 0.095 0.117 0.135
          0.154 0.137 0.101 0.060 0.047 0.019 0.008 0.001 0.000 0.000 0.000
          0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
1993      0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
          0.000 0.000 0.000 0.000 0.000 0.000 0.050 0.021 0.071 0.051 0.149
          0.121 0.129 0.169 0.119 0.070 0.030 0.010 0.010 0.000 0.000 0.000
          0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
1994      0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
          0.000 0.000 0.001 0.007 0.019 0.039 0.080 0.092 0.129 0.155 0.148
          0.081 0.098 0.068 0.047 0.022 0.003 0.001 0.000 0.000 0.000 0.007
          0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
1995      0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
          0.000 0.000 0.000 0.001 0.002 0.012 0.040 0.073 0.099 0.135 0.144
          0.132 0.114 0.101 0.070 0.040 0.021 0.010 0.005 0.002 0.000 0.000
          0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
1997      0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
          0.000 0.000 0.000 0.000 0.005 0.009 0.035 0.084 0.070 0.126 0.140
          0.153 0.171 0.093 0.055 0.029 0.016 0.011 0.002 0.000 0.000 0.000
          0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
1998      0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.001 0.000
          0.005 0.015 0.016 0.024 0.039 0.056 0.109 0.099 0.119 0.172 0.157
          0.076 0.069 0.021 0.008 0.014 0.000 0.000 0.000 0.000 0.000 0.000
          0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
1999      0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.001 0.002
          0.001 0.004 0.003 0.005 0.008 0.022 0.035 0.051 0.101 0.129 0.155
          0.116 0.127 0.079 0.059 0.042 0.023 0.019 0.013 0.004 0.000 0.000
          0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
2000      0.000 0.000 0.000 0.000 0.000 0.000 0.001 0.003 0.004 0.003 0.005
          0.011 0.018 0.031 0.041 0.050 0.089 0.112 0.137 0.106 0.114 0.086
          0.076 0.046 0.027 0.014 0.019 0.004 0.001 0.001 0.000 0.001 0.000
          0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
2001      0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.003 0.000
          0.009 0.025 0.024 0.036 0.058 0.052 0.057 0.076 0.114 0.071 0.104

```

	0.122	0.096	0.054	0.053	0.016	0.015	0.002	0.009	0.006	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
2002		0.000	0.000	0.001	0.000	0.001	0.000	0.003	0.000	0.001	0.004
	0.005	0.010	0.018	0.018	0.036	0.051	0.072	0.126	0.150	0.154	0.124
	0.080	0.071	0.037	0.022	0.009	0.005	0.000	0.001	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
2003		0.000	0.000	0.002	0.009	0.008	0.004	0.005	0.016	0.008	0.024
	0.028	0.034	0.035	0.026	0.032	0.054	0.072	0.110	0.089	0.110	0.092
	0.095	0.065	0.014	0.035	0.008	0.020	0.006	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
2007		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003
	0.005	0.016	0.003	0.012	0.093	0.054	0.114	0.094	0.137	0.114	0.089
	0.101	0.052	0.033	0.035	0.026	0.010	0.005	0.005	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
2008		0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.003	0.006
	0.005	0.009	0.027	0.037	0.054	0.092	0.106	0.120	0.128	0.112	0.078
	0.087	0.052	0.026	0.022	0.018	0.012	0.005	0.001	0.001	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
2010		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.000
	0.004	0.001	0.005	0.013	0.031	0.039	0.070	0.088	0.128	0.152	0.122
	0.105	0.108	0.054	0.038	0.018	0.013	0.007	0.001	0.001	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		

dist multinomial  
r 0.00001

N_1989	12
N_1990	19
N_1991	13
N_1993	3
N_1994	4
N_1995	28
N_1997	3
N_1998	3
N_1999	9
N_2000	13
N_2001	3
N_2002	8
N_2003	3
N_2007	7
N_2008	15
N_2010	8

@catch\_at commercial\_LFs\_South  
fishery South

years 1990 1994 1997 1999 2000 2001 2007 2008 2009

sexed F

sum\_to\_one TRUE

at\_size TRUE

plus\_group FALSE

class_mins	15	16	17	18	19	20	21	22	23	24	25
	26	27	28	29	30	31	32	33	34	35	36
	38	39	40	41	42	43	44	45	46	47	48
1990	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.010	0.010
	0.032	0.083	0.096	0.141	0.148	0.103	0.097	0.051	0.048	0.062	0.031

```

0.031 0.028 0.015 0.007 0.007 0.001 0.000 0.000 0.000 0.000 0.000
0.000
1994      0.001 0.000 0.000 0.002 0.008 0.024 0.037 0.049 0.053 0.058
0.078 0.075 0.076 0.080 0.080 0.079 0.061 0.046 0.037 0.028 0.031
0.036 0.021 0.017 0.011 0.008 0.005 0.000 0.000 0.000 0.000 0.000
0.000
1997      0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.002 0.003 0.012
0.021 0.055 0.061 0.104 0.112 0.129 0.127 0.110 0.090 0.043 0.039
0.031 0.017 0.010 0.006 0.008 0.009 0.008 0.002 0.000 0.000 0.000
0.000
1999      0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.002 0.003 0.010 0.013
0.039 0.053 0.051 0.060 0.111 0.133 0.108 0.102 0.075 0.093 0.060
0.032 0.025 0.007 0.007 0.008 0.003 0.002 0.001 0.000 0.000 0.000
0.000
2000      0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.005 0.002
0.014 0.016 0.045 0.064 0.049 0.121 0.072 0.050 0.090 0.050 0.074
0.115 0.079 0.078 0.026 0.026 0.018 0.005 0.000 0.000 0.000 0.000
0.000
2001      0.001 0.000 0.000 0.000 0.000 0.000 0.003 0.002 0.014 0.028 0.058
0.061 0.101 0.099 0.132 0.092 0.095 0.100 0.084 0.041 0.029 0.015
0.007 0.018 0.007 0.008 0.005 0.000 0.000 0.000 0.000 0.000 0.000
0.000
2007      0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
0.001 0.005 0.006 0.034 0.040 0.102 0.139 0.102 0.099 0.106 0.106
0.106 0.067 0.046 0.028 0.010 0.002 0.001 0.000 0.000 0.000 0.000
0.000
2008      0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.006 0.011 0.020
0.041 0.030 0.064 0.077 0.107 0.101 0.120 0.072 0.130 0.054 0.067
0.013 0.041 0.002 0.018 0.015 0.003 0.003 0.003 0.000 0.000 0.000
0.003
2009      0.000 0.000 0.000 0.000 0.000 0.000 0.005 0.000 0.010 0.007 0.018
0.036 0.029 0.040 0.049 0.079 0.141 0.134 0.114 0.129 0.091 0.055
0.041 0.020 0.000 0.000 0.001 0.000 0.000 0.000 0.000 0.000 0.000
0.000

```

dist multinomial

r 0.00001

N\_1990 19

N\_1994 15

N\_1997 15

N\_1999 10

N\_2000 4

N\_2001 15

N\_2007 6

N\_2008 5

N\_2009 16

# EGG SURVEY

@abundance egg

step 1

proportion\_mortality 0.5

biomass True

ogive SELspawn

years 1993

1993 11892

```
cv_1993 0.49
dist lognormal
```

### ### ACOUSTIC SURVEYS

```
@relative_abundance acoustic_2001
step 1
q q_acoustic_2001
curvature False
proportion_mortality 0.5
biomass True
ogive SELspawn
years 2001
2001 14873
cv_2001 0.38
dist lognormal
```

```
@relative_abundance acoustic_2003
step 1
q q_acoustic_2003
curvature False
proportion_mortality 0.5
biomass True
ogive SELspawn
years 2003
2003 3800
cv_2003 0.22
dist lognormal
```

### # OBSERVATIONS - TRAWL SURVEYS

```
@relative_abundance trawl_surveys
step 1
q qtrawl_surveys
curvature False
proportion_mortality 0.5
biomass True
ogive SELtrawl
years 1992 1993 1994 2010
1992 20838
1993 15102
1994 12780
2010 7074
cv_1992 0.29
cv_1993 0.27
cv_1994 0.14
cv_2010 0.19
dist lognormal
```

### # OBSERVATIONS - TRAWL LENGTH FREQUENCY

```
@proportions_at Trawl_Survey_lengths_92_94
years 1992 1994
```

```

step 1
proportion_mortality 0.5
sexed F
sum_to_one True
at_size True
plus_group False
ogive SELtrawl
class_mins 6      7      8      9      10     11     12     13     14     15     16
           17     18     19     20     21     22     23     24     25     26     27     28
           29     30     31     32     33     34     35     36     37     38     39     40
           41     42     43     44     45     46     47
1992      0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.001
          0.005 0.010 0.015 0.020 0.025 0.030 0.039 0.053 0.059 0.074 0.071
          0.082 0.091 0.078 0.076 0.059 0.052 0.039 0.037 0.025 0.021 0.014
          0.009 0.007 0.004 0.002 0.001 0.000 0.000 0.000 0.000 0.000
1994      0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.001 0.001
          0.002 0.004 0.009 0.024 0.039 0.043 0.050 0.053 0.055 0.062 0.063
          0.069 0.073 0.077 0.070 0.067 0.053 0.047 0.039 0.032 0.025 0.016
          0.012 0.009 0.004 0.001 0.001 0.000 0.000 0.000 0.000
dist multinomial
r 0.00001
N      62

```

```
# ESTIMATION BLOCKS
```

```
# Estimate size at age CVs
```

```

@estimate
parameter size_at_age.cv1
lower_bound      0.01
upper_bound      1
prior uniform

@estimate
parameter size_at_age.cv2
lower_bound      0.01
upper_bound      1
prior uniform

@estimate
parameter q[q_acoustic_2001].q
lower_bound 1e-2
upper_bound 10
prior lognormal
mu 0.907
cv 0.620
phase 1

@estimate
parameter q[q_acoustic_2003].q
lower_bound 1e-2
upper_bound 10
prior uniform
phase 1

```

```

@ratio_qs_penalty
label acoustic_q_ratio
mu 1.909
cv 0.233
q1 q_acoustic_2001
q2 q_acoustic_2003

@q qMECcpueEarly
q 0.0001
b 1

@q qtrawl_surveys
q 0.1
b 1

@estimate
parameter q[qMECcpueEarly].q
lower_bound 1e-7
upper_bound 1e-2
prior uniform-log
phase 1

@estimate
parameter q[qtrawl_surveys].q
lower_bound 1e-2
upper_bound 10
prior uniform-log
phase 1

@q_method free

@q q_acoustic_2001
q 0.1
b 1

@q q_acoustic_2003
q 0.1
b 1

@estimate
parameter maturation[1].rates_all
lower_bound      10    2.5
upper_bound      100   100
prior uniform
phase 2

### selectivities

@estimate
parameter selectivity[SELnorth].all
lower_bound      5    2.5
upper_bound      55   100
prior uniform
phase 2

```

```

@estimate
parameter selectivity[SELsouth].all
lower_bound      5      2.5  2.5
upper_bound      55     100  100
prior uniform
phase 2

@estimate
parameter selectivity[SELtrawl].all
lower_bound      5      2.5  2.5
upper_bound      55     100  100
prior uniform
phase 2

#B0
@estimate
parameter initialization.B0
lower_bound 10000
upper_bound 1000000
prior uniform-log
phase 1

@profile
parameter initialization.B0
n 14
l 50e3
u 110e3

## YCS

@estimate
parameter recruitment.YCS
lower_bound 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01
0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01
0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01
0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01
0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01
0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01
0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01
0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01
0.01 1 1 1 1 1 1 1 1 1 1 1 1 1 1
upper_bound 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
10 10 10 10 10 1 1 1 1 1 1 1 1 1 1 1 1 1 1
prior uniform
phase 2

@vector_average_penalty
label YCS_average_1
vector recruitment.YCS
lower_bound 1
upper_bound 116

```

```

k 1
multiplier 200

# CATCH PENALTIES
@catch_limit_penalty
label CPenMECnorth
fishery North
multiplier 100
log_scale True

```

```

@catch_limit_penalty
label CPenMECsouth
fishery South
multiplier 100
log_scale True

```

### **output.csl**

```

@print

# estimation section stuff
parameters 0
fits_every_eval 0
objective_every_eval 0
parameters_every_eval 0
parameter_vector_every_eval 0
fits 1
resids 1
pearson_resids 1
normalised_resids 1
estimation_section 1
covariance 1

# population section stuff
requests 1
population_section 0
initial_state 0
state_annually 0
state_every_step 0
final_state 0
results 1

#output section stuff
yields 1
unused_parameters 1

@quantities
all_free_parameters 1
#nuisance_qs 1
true_YCS 1
YCS 1
B0 1
R0 1

```



```

SSBs 1
actual_catches 0
fishing_pressures 0
recruitments 0

@deterministic_MSY
do_MSY 1
do_yield_vs_SSB 1
F 0 0.005263158 0.01052632 0.01578947 0.02105263 0.02631579
0.03157895 0.03684211 0.04210526 0.04736842 0.05263158 0.05789474
0.06315789 0.06842105 0.07368421 0.07894737 0.08421053 0.08947368
0.09473684 0.1 0.1052632 0.1105263 0.1157895 0.1210526 0.1263158
0.1315789 0.1368421 0.1421053 0.1473684 0.1526316 0.1578947
0.1631579 0.1684211 0.1736842 0.1789474 0.1842105 0.1894737
0.1947368 0.2 0.2052632 0.2105263 0.2157895 0.2210526 0.2263158
0.2315789 0.2368421 0.2421053 0.2473684 0.2526316 0.2578947
0.2631579 0.2684211 0.2736842 0.2789474 0.2842105 0.2894737
0.2947368 0.3 0.3052632 0.3105263 0.3157895 0.3210526 0.3263158
0.3315789 0.3368421 0.3421053 0.3473684 0.3526316 0.3578947
0.3631579 0.3684211 0.3736842 0.3789474 0.3842105 0.3894737
0.3947368 0.4 0.4052632 0.4105263 0.4157895 0.4210526 0.4263158
0.4315789 0.4368421 0.4421053 0.4473684 0.4526316 0.4578947
0.4631579 0.4684211 0.4736842 0.4789474 0.4842105 0.4894737
0.4947368 0.5
guess 0.1

@catch_split 663 574

@B_pre
mature_only 0
selectivity SELnorth
proportion_mortality 0

@n_projections 1

@abundance Northvul
biomass true
all_areas true
step 1
proportion_mortality 0.5
ogive SELnorth
years 1890 1891 1892 1893 1894 1895 1896 1897 1898 1899 1900 1901
1902 1903 1904 1905 1906 1907 1908 1909 1910 1911 1912 1913 1914
1915 1916 1917 1918 1919 1920 1921 1922 1923 1924 1925
1926 1927 1928 1929 1930 1931 1932 1933 1934 1935 1936
1937 1938 1939 1940 1941 1942 1943 1944 1945 1946 1947
1948 1949 1950 1951 1952 1953 1954 1955 1956 1957 1958
1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969
1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980
1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991
1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002
2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013
2014 2015 2016 2017 2018

@abundance Southvul
biomass true

```

```

all_areas true
step 1
proportion_mortality 0.5
ogive SELsouth
years 1890 1891 1892 1893 1894 1895 1896 1897 1898 1899 1900 1901
1902 1903 1904 1905 1906 1907 1908 1909 1910 1911 1912 1913 1914
    1915 1916 1917 1918 1919 1920 1921 1922 1923 1924 1925
    1926 1927 1928 1929 1930 1931 1932 1933 1934 1935 1936
    1937 1938 1939 1940 1941 1942 1943 1944 1945 1946 1947
    1948 1949 1950 1951 1952 1953 1954 1955 1956 1957 1958
    1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969
    1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980
    1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991
    1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002
    2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013
    2014 2015 2016 2017 2018

```