A 2020 stock assessment update of ORH 3B east and south Chatham Rise

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EXECUTIVE SUMMARY

The East and South Chatham Rise (ESCR) stock was one of four orange roughy stocks assessed in 2014. The assessment was updated in 2017 using data up to the end of the 2016–17 fishing year. That assessment was then immediately updated to the end of 2017-18 to allow application of the orange roughy Harvest Control Rule (HCR) to provide a recommended catch limit for the 2018–19 fishing year. The HCR gave a catch limit recommendation of 5970 t. FNZ recommended to the Minister of Fisheries that the catch limit for ESCR be increased in steps over a three year period (the final step occurring on 1 October 2020) to the HCR catch limit which they incorrectly stated as 5670 t.

The assessment was updated in 2020 to apply the HCR to calculate a catch limit recommendation for 2020–21. As in previous assessments an age-structured population model was fitted to biomass and composition data using Bayesian estimation. As well as the updated base model (denoted as the "current model") there were two additional models. The q-ratio model addressed three issues with the current model: the complex fishery structure; the poor fit to the acoustic indices; and the absence of *a priori* information linking the two acoustic time series. The LowMhighq model was constructed as a "worst case" scenario having natural mortality (M) reduced by 20% and the mean of the acoustic q priors increased by 20% (in relation to the current model).

As in previous assessments, virgin biomass (B_0) was estimated to be about 300 000–350 000 t for the three models. Current stock status was similar for the current and q-ratio models, with the 95% CIs ranging from 30–44% B_0. The pessimistic LowMhighq run has stock status estimated just below 30% B_0.

The HCR was applied to the current model and the q-ratio model. The medians of the marginal posterior distributions are used in the calculation. As current stock status is estimated to be less than 40% B_0 in both runs the exploitation rates applied to estimated vulnerable biomass are less than 0.045 (the exploitation rate applied at 40% B_0). The slightly higher stock status for the q-ratio model gives a higher exploitation rate than the current model but because of the lower vulnerable biomass the recommended catch limit from both models is similar.

Model	**Stock status (%B_0)**	**Exploitation rate**	**Vulnerable biomass (t)**	**Catch limit (t)**
Current model	36	0.04050	156 735	6 348
q-ratio model	38	0.04275	146 977	6 283

For both models, if the recommended catch limit is taken for the next 8 years, stock status is predicted to slowly increase and stay within the target biomass range of 30–50% B_0. If the "worst case" scenario of the LowMhighq model is assumed and the highest recommended catch limit is taken for the next 8 years, stock status is expected to slowly increase and there is close to zero probability of it being below the soft limit (20% B_0) in any year.

1. INTRODUCTION

The East and South Chatham Rise (ESCR) stock was one of four orange roughy stocks assessed in 2014 with the return to model-based assessment for orange roughy (Cordue 2014a). The assessment was updated in 2017 using data up to 2016–17 (Dunn & Doonan 2018). That assessment was then immediately updated to the end of 2017–18 to allow application of the orange roughy Harvest Control Rule (HCR) to provide a recommended catch limit for the 2018-19 fishing year (Cordue 2014b, 2018). The HCR gave a catch limit recommendation of 5970 t (Cordue 2018).

Rather than recommending the HCR catch limit to the minister, it was proposed by FNZ that the catch limit for ORH 3B ESCR be increased in steps over a three year period to a limit of 5670 t (the final step occurring on 1 October 2020). The reason for the difference in the HCR catch limit (5970 t) and the figure used by FNZ (5670 t) is because FNZ incorrectly adjusted the original figure by 5% to make an allowance for incidental catch (see sections 3.4 & 3.5 in FNZ 2020). The HCR delivers a recommended catch limit and should not be adjusted in any way (incidental catch of 5% was used in the Management Strategy Evaluation – see Cordue 2014b).

The assessment has been updated in 2020 to apply the HCR to calculate a catch limit recommendation for 2020–21. As in previous assessments an age-structured population model was fitted to biomass and composition data using Bayesian estimation implemented in CASAL (Bull et al. 2012). No new data, other than annual catches, have been added since the 2017 assessment.

2. METHODS

The 2014 assessment for this stock was one of four orange roughy assessments carried out in 2014 which all used similar methods (Cordue 2014a). The same approach has been used in the updates since then and is continued in this update. An age-structured population model is fitted to acoustic estimates of spawning biomass, trawl survey biomass indices, age frequencies from spawning plumes, and length frequencies from the commercial fisheries.

2.1 Catch history

The catch history used in the 2017 assessment was updated to the end of the 2019–20 fishing year. The total ORH 3B reported catch was apportioned across areas and into the four model fisheries using catch proportions from estimated catch on TCEPR forms following Dunn & Doonan (2018). The catch in 2019–20 was assumed to be in the same proportions across fisheries as the 2018–19 catch. As in past assessments for ESCR an annual 5% over-run was assumed (for the years where the catch was updated).

The total catch over the history of the fishery has generally been dominated by catches in the "spawning box" and on the eastern flats ("Boxflat" in Figure 1). The exception to this was a period from the early 1990s to the early 2000s (Figure 1). The spawning box was closed to commercial fishing in the three years from 1992–93 to 1994–95.

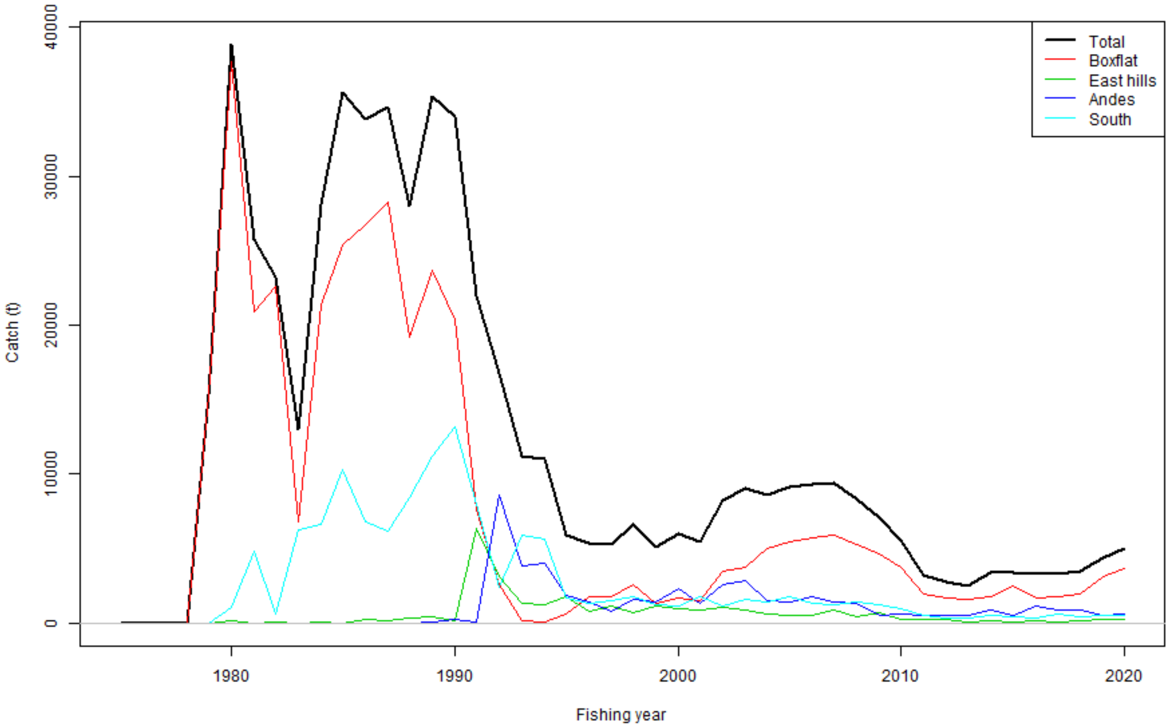

Figure 1: The catch history (including over-runs) used in the update of ORH 3B ESCR. Catches are shown for the four fisheries used in the model and the total catch.

2.2 Data quality, input data, and statistical assumptions

As in the 2014 stock assessment, a high quality threshold was imposed on data before they were allowed to be used in the assessment.

There were four main data sources for observations fitted in the assessment: acoustic-survey spawning biomass estimates from the Old plume (2002–2014, 2016), Rekohu (2011–2014, 2016) and the Crack (2011, 2013, 2016); age frequencies from the spawning areas (2012, 2013, and 2016); trawl survey biomass indices and length frequencies; and length frequencies collected from the commercial fisheries.

Acoustic estimates

The Old plume was acoustically surveyed as early as 1996, but the survey estimates are only considered to represent a consistent time series from 2002–2012 (see Cordue 2008; Hampton et al. 2008, 2009, 2010; Doonan et al. 2012). Like the Rekohu plume, which was first noted in 2010 and first surveyed in 2011, the Old plume occurs on an area of flat bottom and can be adequately surveyed using a hull-mounted transducer. In 2011, 2013 and 2016, the spawning area known as the Crack (or Mt. Muck) was also surveyed. It is an area of rough terrain which requires a towed-body or trawl-mounted system to be used to reduce the height of the shadow or dead zone (i.e., with the transducer at a depth of about 500–700 m).

The estimates selected by the DWFAWG for use in the stock assessment are shown in Table 1. In order to make the estimates as comparable as possible across years only biomass estimates from 38 kHz transducers were used and those from the hull-mounted system were weather-adjusted in the same way as earlier estimates (see Cordue 2010, 2014a).

A key question evaluated in the 2014 assessment was how long has the Rekohu plume been in existence (Cordue 2014a). If the Rekohu plume had always existed (and was not discovered until 2010) then it would be one of three major spawning sites and could be modelled as such along with the Old plume and the Crack. This would imply that the Old-plume time series was tracking a consistent part of the spawning biomass (and its decline over time was therefore an important indicator of stock status). If, on the other hand, the Rekohu plume had very recently formed, this would imply that the Old-plume time series was a biomass index only up until the year before the Rekohu plume came into existence.

Following the base model in Cordue (2014a), it is assumed that the Old-plume time series cannot be relied on to provide a consistent index for any part of the spawning biomass. In 2011, 2013 and 2016, the estimates of average spawning biomass across the three areas were summed to form comparable indices for each year. The 2012 and 2014 estimates from Rekohu and the Old plume were summed to provide a 2012 and 2014 index with a different proportionality constant or q. The Old-plume indices from 2002–2010 were used, but each point in the time series was given its own q. Informed priors were used for all of the qs in the Old-plume series, for the 2012 and 2014 biomass indices, and the indices comprising the 2011, 2013, and 2016 observations.

For 2011, 2013, and 2016, it was assumed that "most" of the biomass was being indexed so the "standard" acoustic q prior was used for this proportionality constant (q_1): lognormal (mean = 0.8, CV = 19%) (Cordue 2014a). The mean of the q prior for 2012 and 2014 was derived from the observed biomass proportions across the three areas and the assumption that 80% of the spawning biomass was indexed in 2011, 2013 and 2016. This gave a mean of 0.7 for the proportionality constant (q_2) of the 2012 and 2014 indices, a reflection that this index did not include an estimate for the Crack. For 2002 to 2010 the means of the q priors were assumed to decrease linearly from 0.7 (2002) down to 0.30 (2010), reflecting the gradual increase in the relative importance of the Rekohu plume. The linear sequence was derived by assuming 0.7 in 2002 (i.e., assuming that the Rekohu plume did not exist and only the Crack was missing from the survey estimate) and using the observed biomass proportions in 2011 with the 80% assumption (which gave the Old plume being about 25% of the total spawning biomass). To reflect the increased uncertainty in the acoustic qs in years before 2011 the priors were given an increased CV of 30%.

Table 1: Acoustic estimates of average pluming spawning biomass in the three main spawning areas as used in the assessment. All estimates were obtained from surveys on *FV San Waitaki* from 38 kHz transducers. Each estimate is the average of a number of snapshots. Some estimates have been revised since the 2014 assessment (see Dunn & Doonan 2018).

	Old plume		Rekohu		Crack	
	Estimate (t)	CV (%)	Estimate (t)	CV (%)	Estimate (t)	CV (%)
2002	63 950	6	–	–	–	–
2003	44 316	6	–	–	–	–
2004	44 968	8	–	–	–	–
2005	43 923	4	–	–	–	–
2006	47 450	10	–	–	–	–
2007	34 427	5	–	–	–	–
2008	31 668	8	–	–	–	–
2009	28 199	5	–	–	–	–
2010	21 205	7	–	–	–	–
2011	16 422	8	28 113	18	6 794	21
2012	19 392	7	27 121	10	–	–
2013	15 554	14	33 348	10	5 471	16
2014	19 360	18	44 421	25	–	–
2015	–	–	–	–	–	–
2016	11 192	13	27 027	13	5 341	10

As well as updating the base model, two additional runs were made which had different assumptions with regard to the acoustic qs. In the standard LowMhighq sensitivity run the means of the acoustic q priors were all increased by 20% and the value of M was decreased by 20% (see Cordue 2014a). In the "q-ratio model" a prior was placed on the ratio q_1/q_2. The standard prior was used for q_1 and a uniform prior for q_2. A lognormal prior was used for the ratio with the mean equal to 1.14 (0.8/0.7) and a CV of 7.5% which strongly encouraged the ratio to be greater than 1 (reflecting that three areas had been surveyed for the first time series but only two of those areas for the second time series) (Figure 2).

There was no agreement in the DWFAWG as to whether the updated base model or the q-ratio model was to be preferred. The LowMhighq model was run relative to the updated base model as that had the lowest estimated stock status and therefore the LowMhighq model would be a "worst case" scenario as intended. The updated base model is denoted as the “current model” rather than the base model.

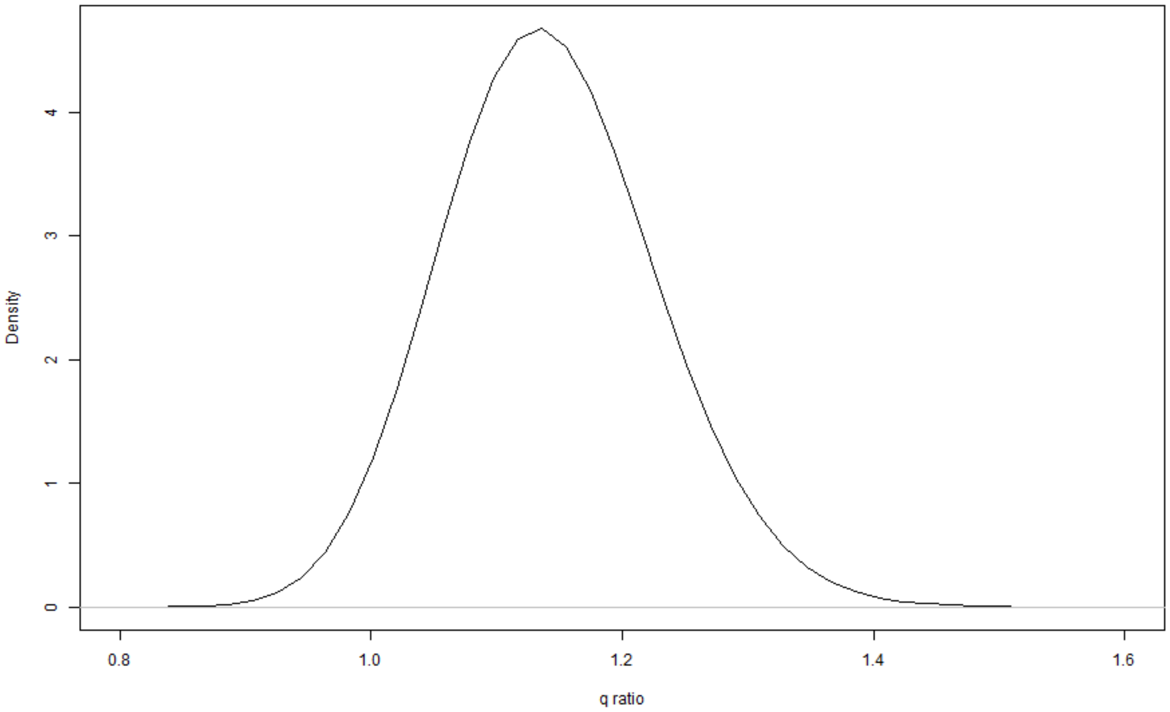

Figure 2: The prior used for the ratio of the two acoustic *q*s in the q-ratio model. It is lognormal with a mean of 1.14 and a CV of 7.5%.

Trawl survey data

Research trawl surveys of the Spawning Box during July were completed from 1984 to 1994, using three different vessels: FV *Otago Buccaneer*, FV *Cordella*, and RV *Tangaroa* (Figure 3). A consistent area was surveyed using fixed station positions (with some random second phase stations each year).

The biomass indices were fitted as relative indices with a separate time series for each vessel (with uninformed priors on the *q*s). The second point in the *Tangaroa* time series, although very large (driven by a single high catch), has a large CV and so is unlikely to have had much effect on the assessment results.

Data from two wide-area surveys by *Tangaroa* in 2004 and 2007 were also used. These surveys covered the area which extends from the western edge of the Spawning Box around to the northern edge of the Andes. The area surveyed did not include the Old-plume, the Northeast Hills, or the Andes. The survey used a random design over sixteen strata grouped into five sub-areas. The trawl net used was the full-wing and relatively fine mesh ‘ratcatcher’ net. The surveys covered the same survey area as the Spawning Box trawl surveys from 1984 to 1994 as well as additional strata to the east. In 2007, the survey ran from 4–27 July and 62 trawl tows were completed. In 2004, the survey ran from 7–29 July and 57 trawl tows were completed. The surveys had almost identical estimates of total biomass in each year (17 000 t) with low CVs (10% and 13% respectively). They were fitted as relative biomass with an uninformed prior on the *q*.

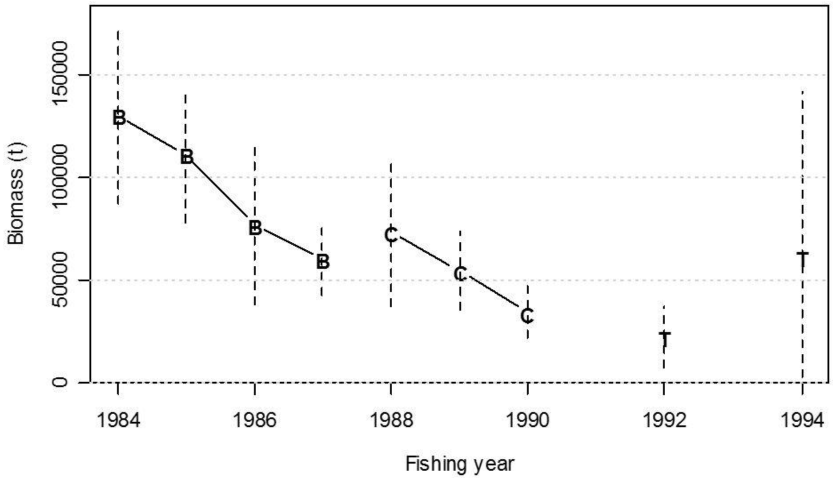

Figure 3: The Spawning Box trawl survey biomass indices (assuming a catchability of 1 for each vessel), with 95% confidence intervals shown as vertical lines. Vessels indicated as B, FV *Otago Buccaneer*; C, FV *Cordella*; T, RV *Tangaroa*.

Length frequencies

The length frequencies from all trawl surveys were fitted in the model as multinomial random variables. Effective sample sizes (N) were taken from Dunn (2007) for the Spawning Box surveys and were assumed equal to the number of tows for the wide-area surveys (across all surveys the effective Ns ranged from about 20–80). Trawl survey length frequencies were fitted assuming that all mature fish were selected, but immature fish were selected assuming capped-logistic ogives. A single selectivity ogive for immature fish was shared by the *Buccaneer*, *Cordella*, and *Tangaroa* Spawning Box surveys, with a second ogive for the immature fish caught in the *Tangaroa* wide-area survey.

Length frequencies from the commercial fisheries developed by Hicks (2006) were also fitted in the model. For the Spawning Box and associated flat ground fishery, three years of length-frequency data from the period 1989–91 were combined into a single length-frequency that was centred on 1990, and four years 2002–05 were combined and centred on 2004. In a similar way, for Andes four years 1992–95 were combined and centred on 1993, three years 1997–99 combined and centred on 1998, and five years combined 2001–05 and centred on 2003. For the eastern hills, seven years 1991–97 were combined and centred on 1995, and five years 2001–05 combined and centred on 2003. These were fitted as multinomial with effective sample sizes ranging from 8–38.

Age frequencies

Age frequencies were developed for the Old plume and Rekohu plume in 2012, and for the Old plume, Rekohu, and the Crack in 2013 and 2016 (Doonan et al. 2014a, b; 2018). Approximately 300 otoliths were randomly selected from each area in 2012 and 2016, and 250 from each area in 2013. The fish in the Old plume were noted to be generally older than those in the Rekohu plume. The fish from the Crack, showed a mixture of ages from new spawners (20–30 years) through to much older fish (80–100 years). The age frequencies were combined across areas and fitted as multinomial with effective sample sizes of 50 (2012) and 60 (2013 and 2016) respectively, reflecting the low number of trawls from which samples were taken.

2.3 Model structure

The model was single-sex and age-structured (1–100 years with a plus group), with maturity estimated separately (i.e., fish were classified by age and as mature or immature). A single-time step was used and, in the updated base model, four year-round fisheries, with logistic selectivities, were modelled: Box & flats, Eastern hills, Andes, and South Rise. These fisheries were chosen following Dunn (2007) who assessed the Box & flats, Eastern hills, and Andes as separate stocks. No length frequencies were available from the South Rise fishery and its selectivity was assumed to be the same as the Andes (so effectively there were three fisheries in the model). Spawning was taken to occur after 75% of the mortality and 100% of mature fish were assumed to spawn each year.

Natural mortality was fixed and the stock-recruitment relationship was assumed to follow a Beverton-Holt function.

The fixed biological parameters were:

Natural mortality: 0.045
Beverton-Holt steepness: 0.75
Length-weight (a, b): 8.0e–5, 2.75 (cm to kg)
von Bertalanffy (L_∞, k, t_0): 37.78 cm, 0.059, –0.491 years

2.4 Estimation methods and model runs

The estimation methods were almost identical to those used in the 2014 orange roughy assessments (Cordue 2014a). The stock assessments were done using the general Bayesian estimation package CASAL (Bull et al. 2012). The final model results used the marginal posterior distributions of parameters and derived values of interest (e.g., virgin biomass (B_0), current biomass (B_{2020}), and current stock status ($ss_{2020} = B_{2020}/B_0$)). The marginal posterior distributions were produced using Markov chain Monte Carlo methods (hence termed "MCMC" runs). Preliminary analysis was performed using the Mode of the Posterior Distribution (MPD) which can be obtained much more quickly than the full posterior distribution (hence "MPD" runs). An MPD estimate is associated with the "best fit" that can be obtained – it is useful to check that the "best fit" is not too bad otherwise there would be concerns about the appropriateness of the model.

As well as the updated base model (denoted as the "current model") there were two additional models: the q-ratio model which assumed a single fishery on mature fish, had a prior on q_1/q_2, and added 20% process error to the associated acoustic biomass indices; and the standard LowMhighq model (see Cordue 2014a). The CASAL input files for the q-ratio and current model are given in Appendix 2.

In all three models, the main parameters estimated were: virgin (unfished, equilibrium) biomass (B_0), the maturity ogive, trawl-survey selectivities, fisheries selectivities, CV of length-at-mean-length-at-age for ages 1 and 100 years (linear relationship assumed for intermediate ages), and year class strengths (YCS) from 1930 to 1990 (with the Haist parameterisation and "nearly uniform" priors on the free parameters). There were also the numerous acoustic and trawl-survey qs.

The general approach taken to data weighting within the stock assessment was to down-weight age and length frequency data relative to biomass indices to allow any scale and trend information in the biomass indices to drive the assessment results. This is very much in the spirit of Francis (2011) who argued that composition data were generally given far too much weight in stock assessment models and were often allowed to dominate the signals from biomass indices.

MCMC chain diagnostics

Mathematical theory proves that MCMC chains will eventually converge to provide the joint posterior distribution. However, one can never be certain that a chain, or multiple chains, have been run long enough to achieve "sufficient" convergence. There is never proof that a chain has converged but there may be evidence that a chain has not yet converged. Many diagnostics exist to help determine whether a chain has achieved sufficient convergence.

In New Zealand, a common approach to judge convergence is to use multiple chains (each with a different random number seed) and to compare the marginal posterior distributions for the (derived) parameters of interest. The idea is that the chains are sufficiently converged when all of the chains give the "same" answer. For each model, three chains of fifteen million iterations were run. One sample in each one thousand iterations were stored and the first one thousand samples were discarded as a "burn-in" (the chains start near the MPD estimate and early samples may be unrepresentative of the posterior distribution). The traces of the main free parameters were checked to make sure that they did not exhibit any long term trends and the estimates of B_0 and current stock status ($ss_{2020} = B_{2020}/B_0$) from each chain were checked to see that they were the same to two significant figures. Points estimates (median) and 95% credibility intervals (95% CIs) were constructed using all three chains combined after the burn-in (a total of 42 000 samples).

Fishing intensity

Fishing intensity was estimated in each year as the total exploitation rate (total catch over beginning of year vulnerable biomass – which was a catch weighted average in the current model).

The exploitation rate associated with the fishing intensity reference points $U_{30\%B0}$ and $U_{50\%B0}$ were determined for the catch split assumed in 2018–19. Note, in general, the fishing intensity that forces the stock to deterministic equilibrium at x% B_0 is denoted as $U_{x\%B0}$.

Projections

Projections at the HCR recommended catch limits (plus 5% to allow for incidental mortality) were performed for the current model and the q-ratio model. The highest of the two catch limits was used in a projection for the LowMhighq model. This was to check that the highest HCR recommended catch limit was still safe even if the pessimistic scenario represented by the LowMhighq model was true. Projections were done over 8 years as the HCR is meant to applied ever four years. Random recruitment was brought in from 1991 by resampling from the last ten years of estimated YCS (1981–1990).

3. RESULTS

3.1 Model diagnostics

MPD fits and MCMC fits and residuals and marginal posterior distributions for the *q*s were examined for the current model and the q-ratio model. In general, the fits were excellent and the standardised residuals were acceptable (e.g., see Figures 4–6). The main exception was for the current model where the normalised residuals for the 2016 acoustic estimate are well outside the expected range (Figure 7). In the q-ratio model the residuals are much improved because of the addition of 20% process error (the CV is only 10% in the current model which is just a measure of observation error).

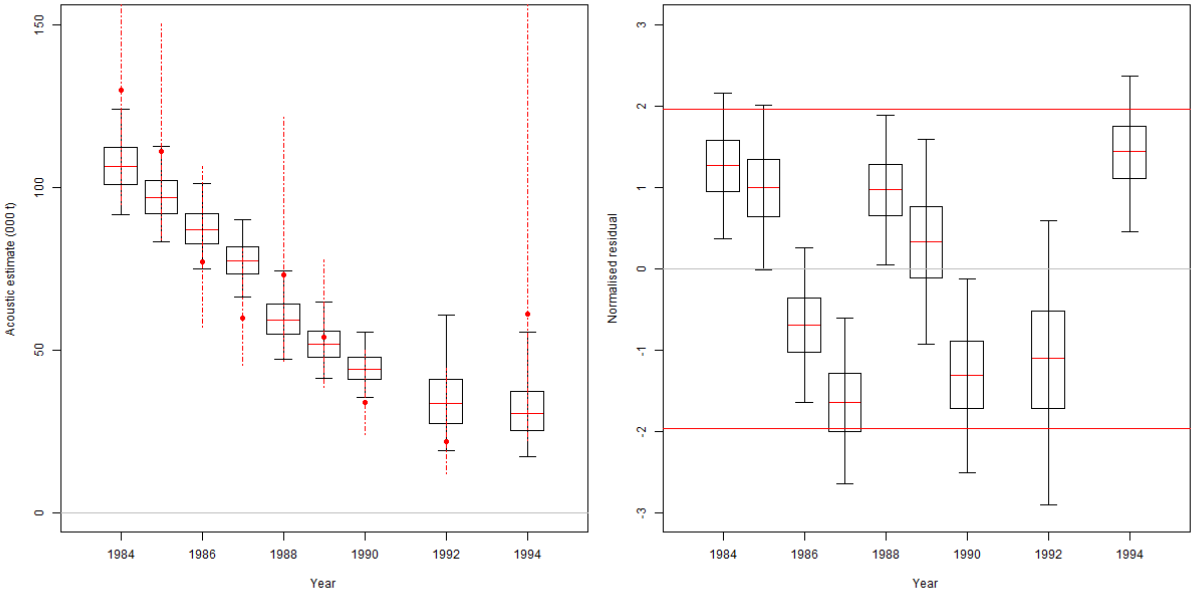

Figure 4: Current model: the MCMC fits and normalised residuals for the trawl survey biomass estimates in the spawning box. The observations are plotted with 95% confidence intervals (left plot, red vertical lines). The MCMC predictions (left plot) and normalised residuals (right plot) are plotted as a "box and whiskers". The middle 50% of the distribution is in the box with the whiskers extending to a 95% C.I.

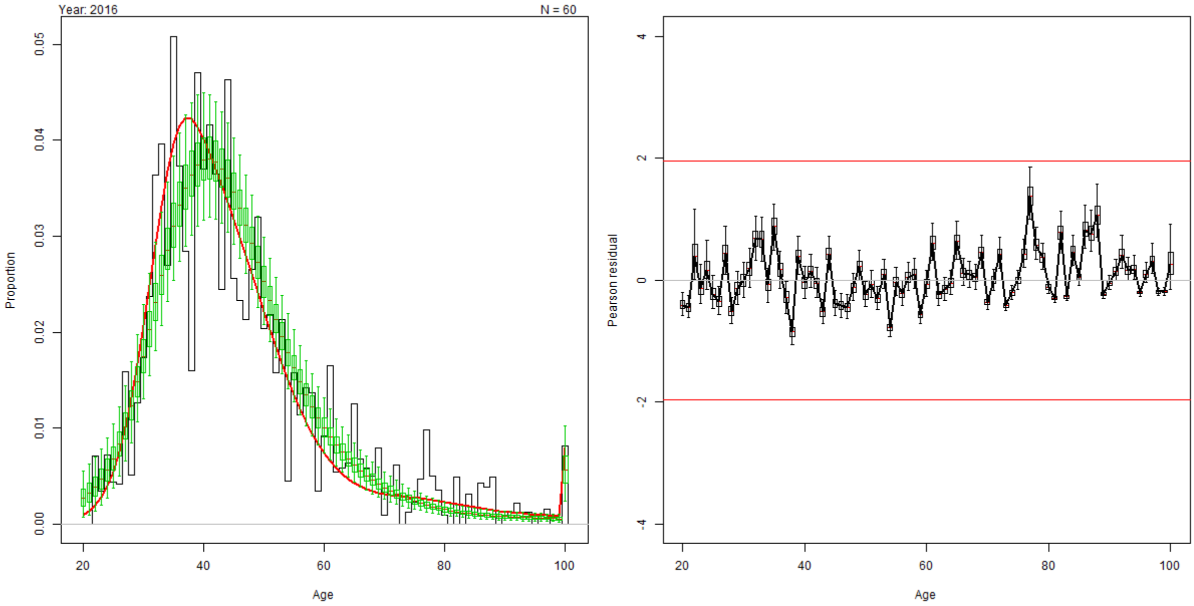

Figure 5: Current model: the MCMC fits and normalised residuals for the 2016 spawning population age frequency (left plot, histogram in black). The MPD fit is shown as the red line in the left plot. The MCMC predictions (left plot) and Pearson residuals (right plot) are plotted as a "box and whiskers". The middle 50% of the distribution is in the box with the whiskers extending to a 95% C.I.

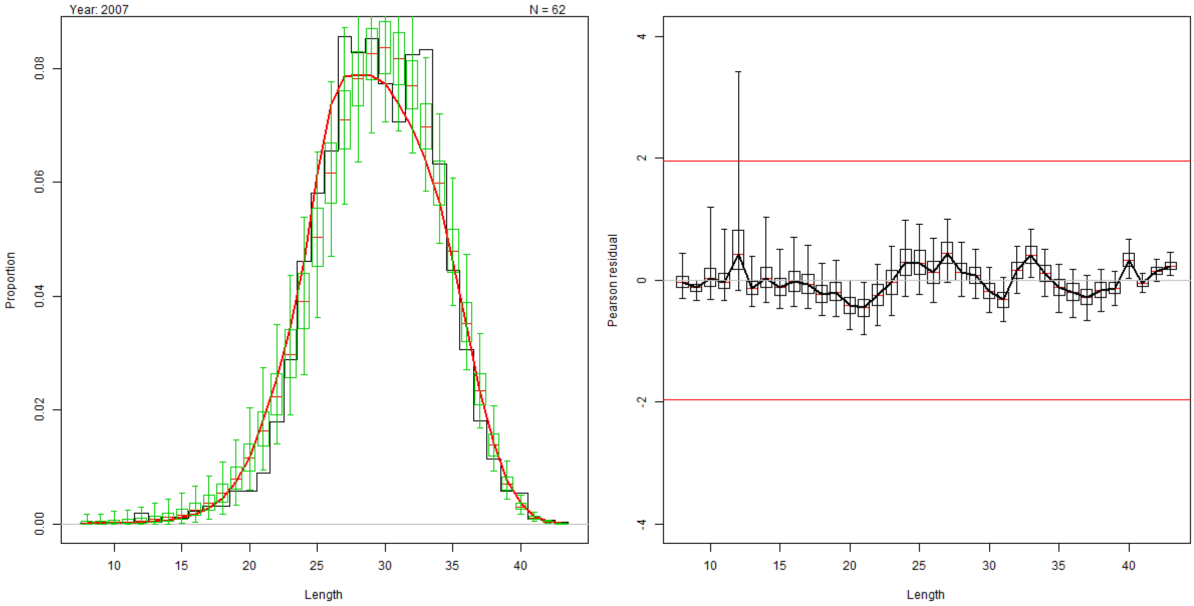

Figure 6: Current model: the MCMC fits and normalised residuals for the 2007 wide-area trawl survey length frequency (left plot, histogram in black). The MPD fit is shown as the red line in the left plot. The MCMC predictions (left plot) and Pearson residuals (right plot) are plotted as a "box and whiskers". The middle 50% of the distribution is in the box with the whiskers extending to a 95% C.I.

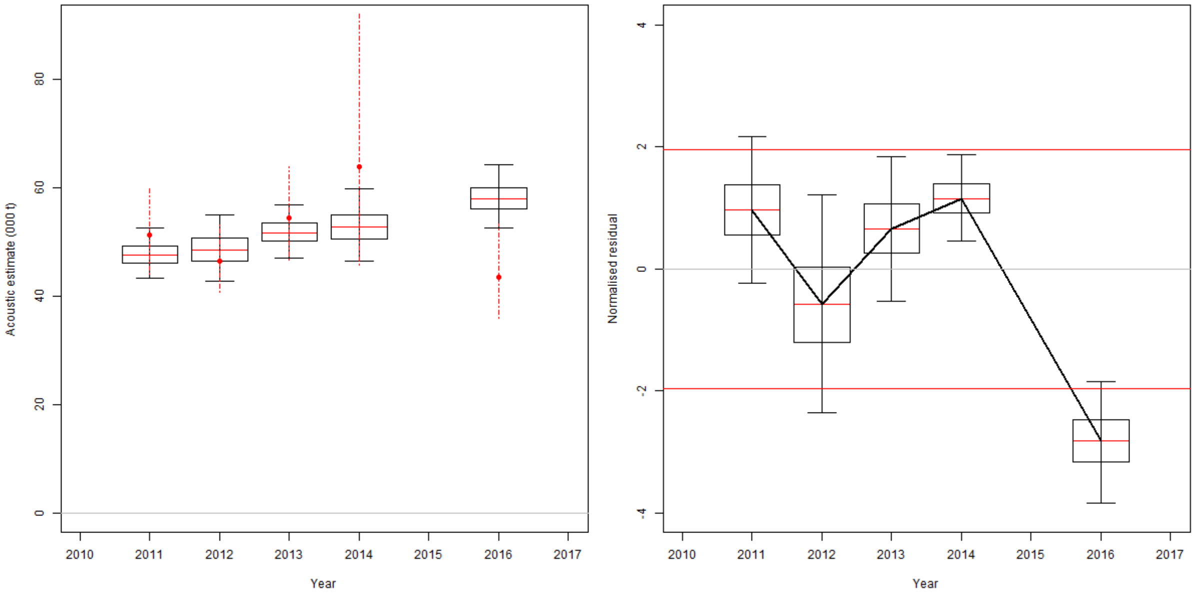

Figure 7: Current model: the MCMC fits and normalised residuals for the acoustic survey biomass estimates since 2011. The observations are plotted with 95% confidence intervals (left plot, red vertical lines). The MCMC predictions (left plot) and normalised residuals (right plot) are plotted as a "box and whiskers". The middle 50% of the distribution is in the box with the whiskers extending to a 95% C.I.

The marginal posterior distributions for the two main acoustic *q*s are individually unremarkable being well within their prior distributions (Figure 8). However, in the current model the ratio of the two *q*s has a probability for being less than 1 of 39%. A value less than 1 must be considered very unlikely as an extra area is surveyed for the q_1 time series. This is the main reason for the q-ratio model which corrects this diagnostic through the informed prior (and has a marginal posterior distribution with only a 5% probability of being less than 1).

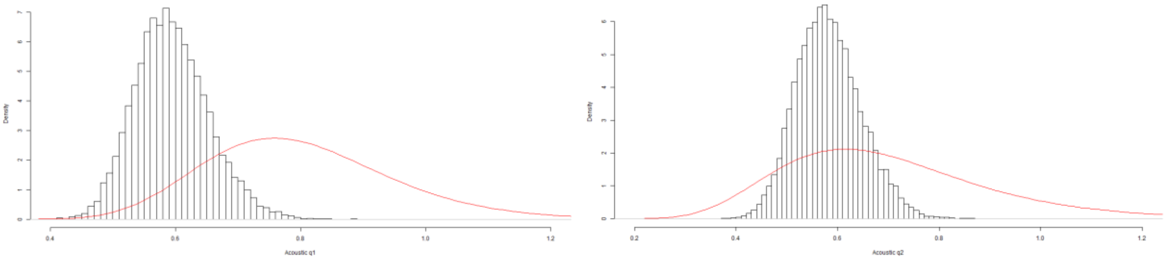

Figure 8: Current model: the prior distributions (red lines) and marginal posterior distributions (histograms) for the two main acoustic *q*s.

3.2 MCMC results

Virgin biomass, B_0, was estimated to be about 300 000–350 000 t for the three models (Table 2). Current stock status was similar for the current and q-ratio models, both having the 95% CIs above 30% B_0 (Table 2). The pessimistic LowMhighq run has stock status estimated just below 30% B_0 (Table 2).

Table 2: ESCR, MCMC estimates of virgin biomass (B_0), current biomass (B_{2020}), and stock status (B_{2020} as %B_0) for the three models.

	B_0 (000 t)		B_{2020} (000 t)		Stock status (%B_0)	
	Median	**95% CI**	**Median**	**95% CI**	**Median**	**95% CI**
Current model	312	281–346	111	91–135	36	30–41
q-ratio model	354	331–380	135	109–164	38	32–44
LowMhighq	337	308–363	90	71–111	27	22–32

The estimated YCS show little variation across cohorts but do exhibit a long-term trend (Figure 9). The stock status trajectory shows a steady decline from the start of fishery until the mid-1990s, where it remained in the 20–30% range until an upturn in about 2010 (Figure 10).

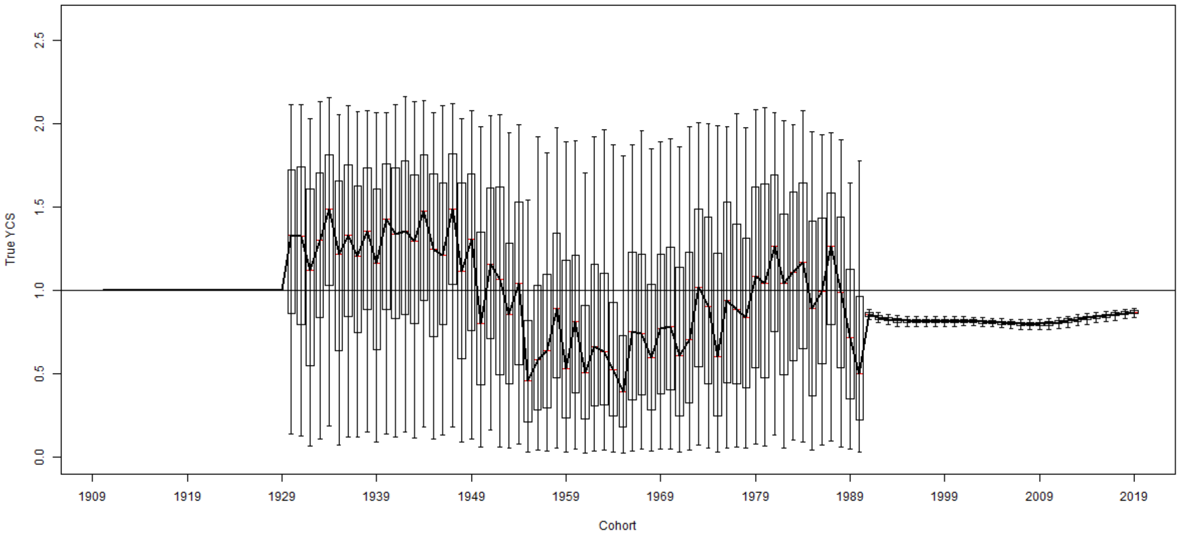

Figure 9: ESCR current model, MCMC estimated "true" YCS (R_y/R_0). The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution.

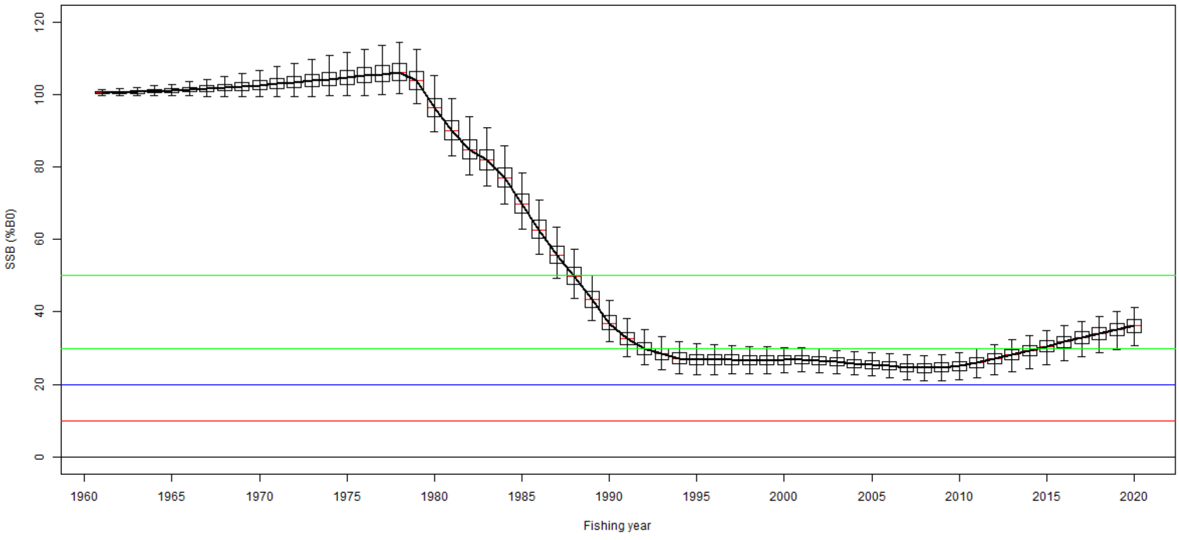

Figure 10: ESCR current model, MCMC estimated spawning-stock biomass trajectory. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. Horizontal lines are plotted at the hard limit (10% B_0), the soft limit (20% B_0), and the biomass target range (30–50% B_0).

For the current model, fishing intensity was approximated using an average exploitation rate (total catch divided by catch-weighted beginning-of-year vulnerable biomass). Estimated exploitation rates were within or above the target range ($U_{30\%B0}$–$U_{50\%B0}$) up to 2009–10. Since 2010–11 they have generally been below the target range (Figure 11).

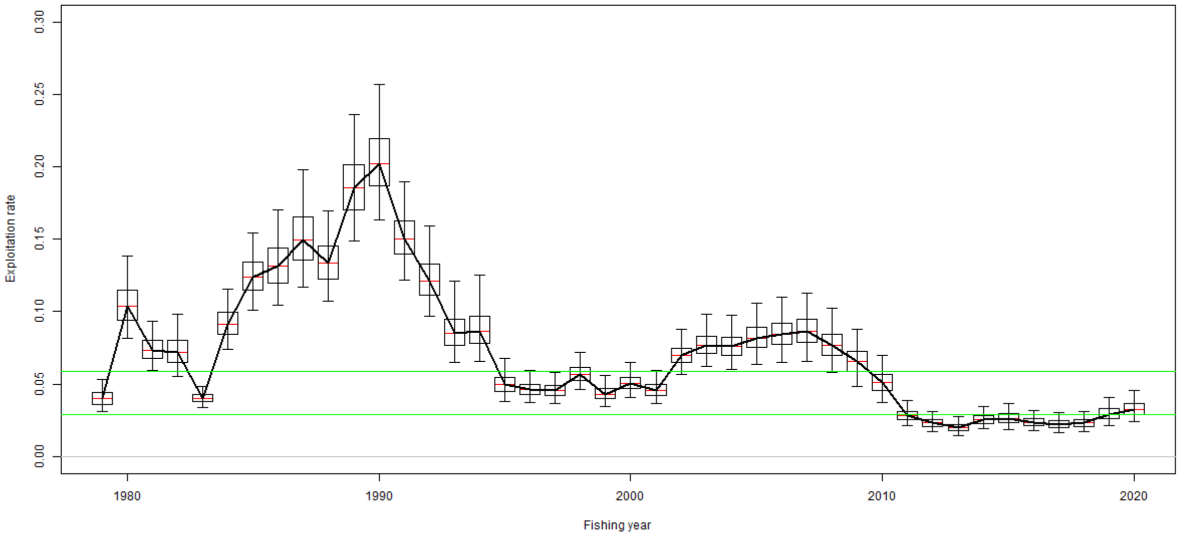

Figure 11: ESCR current model, MCMC estimated exploitation rates. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. The exploitation rates associated with the biomass target of 30–50% B_0 are marked by horizontal lines at $U_{30\%B0}$ and $U_{50\%B0}$.

Biological reference points, management targets and yield

Catch limits for the ESCR stock are recommended from the Harvest Control Rule (HCR) that was developed in 2014 using a Management Strategy Evaluation (MSE) (Cordue 2014b). The HCR has a target management range of 30–50% B_0. Within that range there is a linear relationship between current estimated stock status and the instantaneous fishing mortality (exploitation rate) that is applied to next year's beginning-of-year vulnerable biomass to obtain the recommended catch limit (Figure 12).

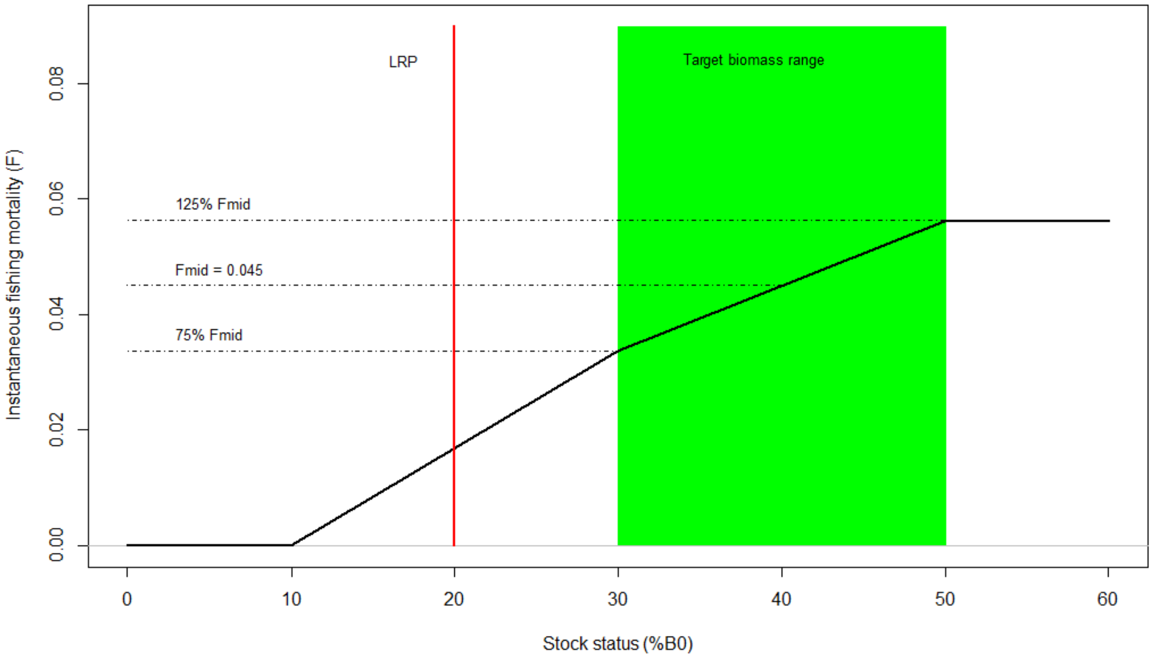

Figure 12: The orange roughy HCR showing the relationship between current estimated stock status and the instantaneous fishing mortality rate (or exploitation rate) applied to next year's beginning-of-year vulnerable biomass to derive the recommended catch limit. The target biomass range is 30–50% B_0 and the limit reference point (LRP) is 20% B_0 (see Cordue 2014b).

The HCR was applied to the current model and the q-ratio model. The medians of the marginal posterior distributions are used in the calculation. As estimated stock status is less than 40% B_0 in both runs the exploitation rates are less than F_{mid} = 0.045 (Figure 12, Table 3). The slightly higher stock status for the q-ratio model gives a higher exploitation rate than the current model but because of the lower vulnerable biomass the recommended catch limit from both models is similar (Table 3).

Table 3: The estimated stock status in 2019–20, the catch-weighted vulnerable biomass at the beginning of 2020–21, and the associated exploitation rate and recommended catch limit from the HCR for the current model and the q-ratio model.

Model	Stock status (%B_0)	Exploitation rate	Vulnerable biomass (t)	Catch limit (t)
Current model	36	0.04050	156 735	6 348
q-ratio model	38	0.04275	146 977	6 283

3.3 Projections

Projections at the recommended catch limits (plus 5% to allow for incidental mortality) were performed for the current model and the q-ratio model. The highest of the two catch limits was used in a projection for the LowMhighq model. This was to check that the highest HCR recommended catch limit was still safe even if the pessimistic scenario represented by the LowMhighq model was true.

In each case, stock status was projected to rise slowly from the current estimated stock status and there was close to zero probability of the stock status being below 20% B_0 over the next 8 years (Figure 13).

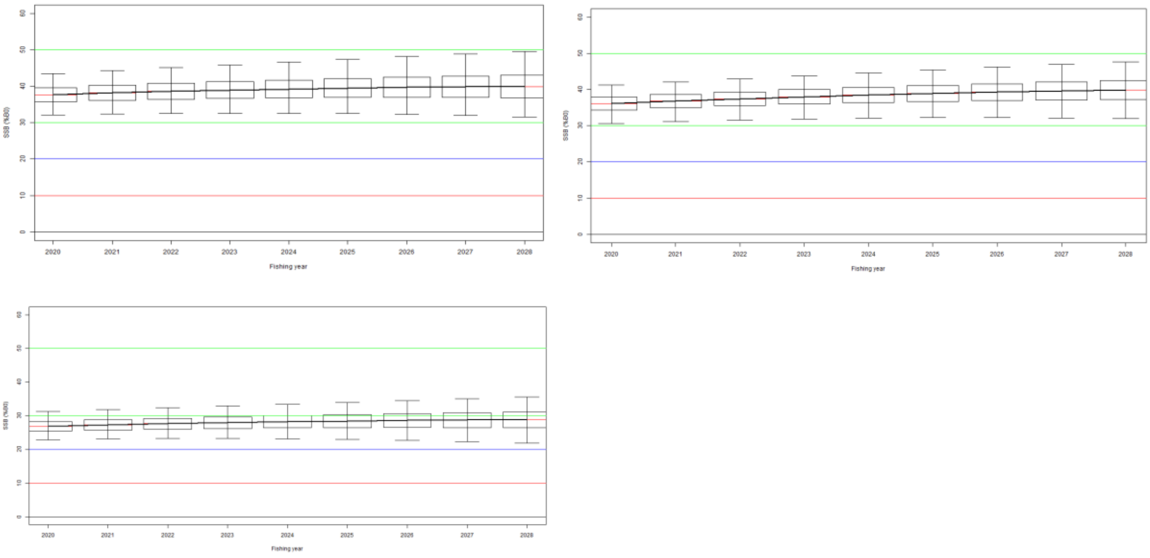

Figure 13: Projected stock status for catches at the HCR recommended catch limits plus 5% to allow for incidental mortality. Top left: q-ratio model projected at 6 283 t (plus 5%). Top right: current model projected at 6 348 t (plus 5%). Bottom left: LowMhighq model projected at 6 348 t (plus 5%). Each box covers the middle 50% of the distribution and the whiskers extend to 95% CIs.

4. DISCUSSION AND CONCLUSIONS

This was an unscheduled update for the ESCR and as such the number of models considered was kept to a minimum. The current model had two obvious problems which were addressed in the q-ratio model. In addition, the q-ratio model also simplified the structure of the commercial fisheries by moving to a single fishery on mature fish instead of having three different estimated selectivities. In an interim model where the only change from the current model was a move to the single fishery the

MPD fits to the data were identical.

The addition of process error to the main acoustic indices used in the q-ratio model is best practice for two reasons. First, there are known processes which would be expected to produce annual variability in the acoustic *q*s (e.g., variation in: the proportion of spawning biomass surveyed; the proportion of mature biomass spawning; the signal lost due to vessel motion and absorption; calibration errors; target identification errors; species contamination). Second, it is usually best to have the input variance assumptions matching the output variance (which is not the case for the current model with the huge residuals for the acoustic index in 2016).

The use of a q-ratio penalty for the two acoustic *q*s is also an obvious modification to supply the model with known *a priori* information (i.e., that one series surveys an additional area and would be expected to have a higher *q*).

The q-ratio model is superior to the current model and has a slightly higher estimate of current stock status. However, the recommended catch limits from both models are very similar as the higher stock status of the q-ratio model is cancelled out by having a lower vulnerable biomass (as maturity is to the right of the average commercial selectivity when selectivities are estimated).

For both models, if the recommended catch limit is taken for the next 8 years, stock status is predicted to slowly increase and stay within the target biomass range. If the “worst case” scenario of the LowMhighq model is assumed and the highest recommended catch limit is taken for the next 8 years, stock status is expected to slowly increase and there is close to zero probability of it being below the soft limit (20% B_0) in any year.

5. ACKNOWLEDGEMENTS

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APPENDIX 1: MCMC chain diagnostics for the current model

The chains for the objective function show the need for a burn-in as the chains move away from the MPD estimate (Figure A1). The objective function values appear to mix well – they are not getting stuck at high or low values for an extended period (Figure A1.). The same is true for the B_0 and current stock status chains although they show some “medium frequency” structure (Figures A2 & A3). The three chains gave almost identical median estimates of B_0 and current stock status (Figure A4).

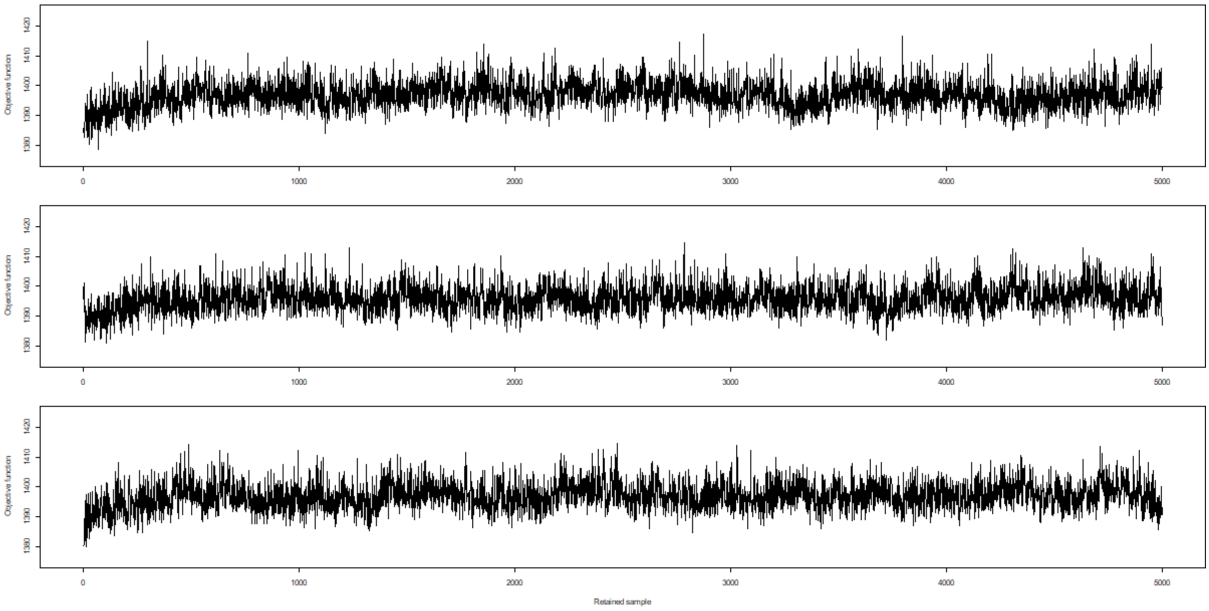

Figure A1: MCMC current model: objective function values for the first 5000 retained samples for each of the three chains including the burn-in (the first 1000 retained samples).

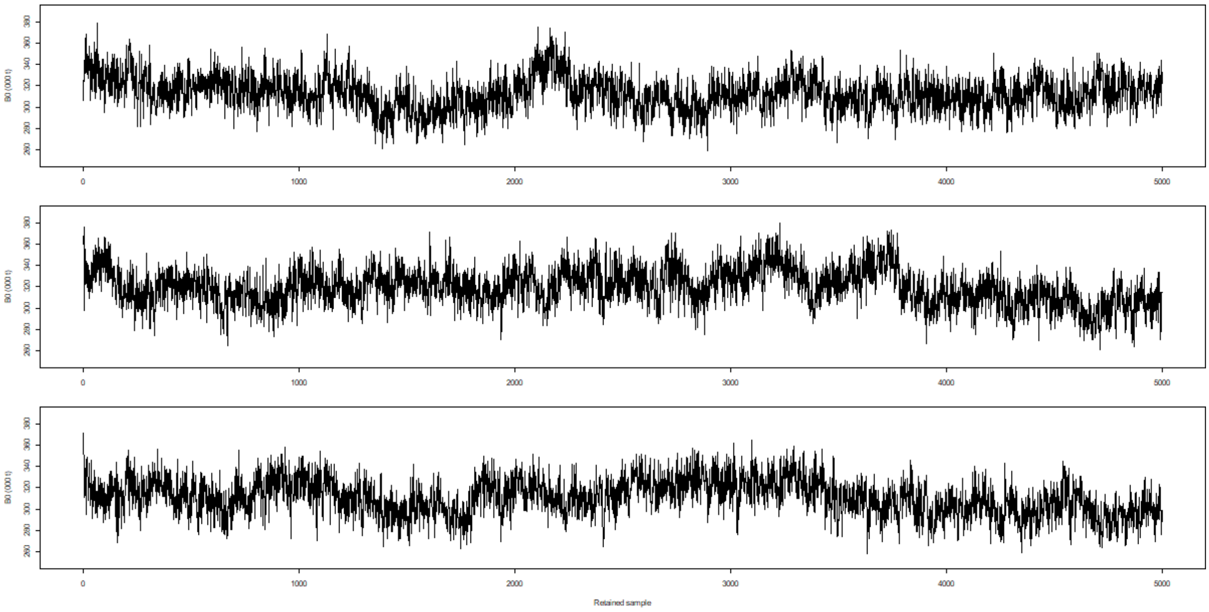

Figure A2: MCMC current model: B_0 estimates for the first 5000 retained samples for each of the three chains including the burn-in (the first 1000 retained samples).

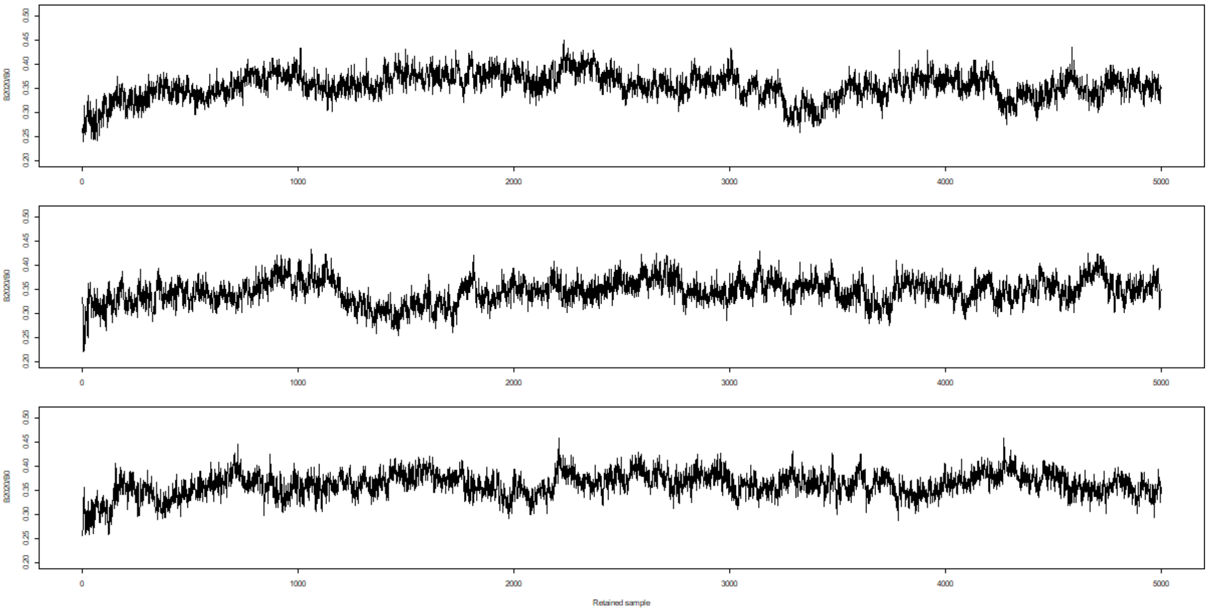

Figure A3: MCMC current model: current stock status estimates (B_{2020}/B_0) for the first 5000 retained samples for each of the three chains including the burn-in (the first 1000 retained samples).

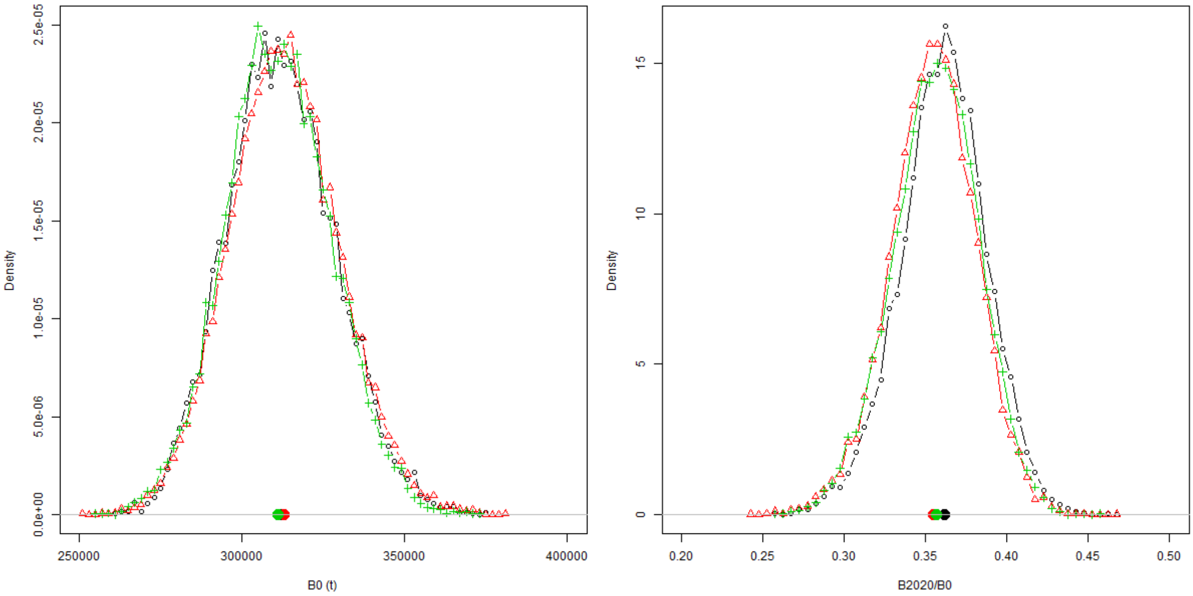

Figure A4: MCMC current model: histograms of estimates of B_0 (left) and current stock status (B_{2020}/B_0, right) for the retained samples for each of the three chains excluding the burn-in (the first 1000 retained samples).

APPENDIX 2: CASAL input files

The population and estimation files used in the MCMC q-ratio model are given below. The variations needed for the current model are noted at the end of the appendix.

population.csl

```
# Commercial selectivities set equal to maturity

@size_based False
@min_age 1
@max_age 100
@plus_group True
@sex_partition False
@mature_partition True
@n_areas 1

@initial 1911
@current 2020
@final 2028
@annual_cycle
time_steps 1
aging_time 1
recruitment_time 1
fishery_names boxflat hills andes south
fishery_times 1 1 1 1
spawning_time 1
spawning_p 1
spawning_part_mort 0.75
M_props 1
baranov False
n_maturations 1
maturation_times 1

@y_enter 1
@standardise_YCS True
@recruitment
YCS_years 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 2019
YCS 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1
SR BH
steepness 0.75
sigma_r 1.1
first_free 1930
last_free 1990
year_range 1981 1990

# recruitment variability
@randomisation_method empirical
@first_random_year 1991
```

```
@natural_mortality
all 0.045

@fishery boxflat
years 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 2019 2020
catches 15338 37660 20910 22560 6760 21360 25350 26720 28270 19220 23710 20320 7570 2590
190 90 570 1800 1800 2570 1280 1640 1500 3460 3720 5026 5482 5711 5857 5260 4625 3787 1966
1659 1558 1791 2451 1680 1794.875 1974.947 3156.280 3616.096
selectivity matsel
U_max 0.67
future_constant_catches 4749.948

@fishery hills
years 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 2019 2020
catches 0 160 20 60 0 90 0 290 200 370 400 200 6370 3100 1280 1250 1740 810 1170 710 1120 930
880 1040 870 616 543 544 836 383 686 247 202 218 59 150 46 148 42.03642 185.37908 211.32850
242.11543
selectivity matsel
U_max 0.67
future_constant_catches 329.8575

@fishery andes
years 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 2019 2020
catches 0 0 0 0 0 0 0 0 0 0 50 240 100 8620 3820 4060 1900 1380 820 1550 1390 2270 1300 2540
2870 1528 1381 1776 1448 1307 514 577 558 529 528 875 524 1132 845.3546 855.8804 531.2104
608.5986
selectivity matsel
U_max 0.67
future_constant_catches 857.6295

@fishery south
years 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 2019 2020
catches 0 1040 4810 650 6240 6630 10270 6784 6174 8432 11224 13200 7935 2420 5940 5610 1680
1365 1470 1785 1260 1155 1785 1155 1575 1409 1757 1310 1273 1419 1231 976 484 320 307 528
412 376 581.9388 456.8088 477.3924 546.9403
selectivity matsel
U_max 0.67
future_constant_catches 659.715

@selectivity_names Bucsel Corsel Tansel Tanwidesel matsel

@selectivity Bucsel
mature constant 1
immature logistic_capped 10 3 0.1
@selectivity Corsel
mature constant 1
immature logistic_capped 10 3 0.1
@selectivity Tansel
```

```
mature constant 1
immature logistic_capped 10 3 0.1
@selectivity Tanwidesel
mature constant 1
immature logistic_capped 17 4 0.8

@selectivity matsel
mature constant 1
immature constant 0

@size_at_age_type von_Bert
@size_at_age_dist normal
@size_at_age
k 0.059
t0 -0.491
Linf 37.78
cv1 0.10
cv2 0.06
by_length True
@size_weight
a 8.0e-8
b 2.75

@maturation
rates_all logistic_producing 10 100 37 4.56

@initialization
B0 350000
```

estimation.csl

```
# Commercial selectivities set equal to maturity
# 20% process error added to plume+rekohu, plume+rekohu+crack
# A q-ratio penalty for plume+rekohu+crack vs plume+rekohu


@estimator Bayes
@max_iters 4000
@max_evals 4000
@grad_tol 0.0001

@MCMC
start 0.2
length 15000000
keep 1000
stepsize 0.02
proposal_t True
df 2
burn_in 1000

@relative_abundance aco
step 1
proportion_mortality 0.75
biomass True
ogive matsel
years 2011 2013 2016
```

```
2011 51329
2013 54363
2016 43560
cv_2011 0.22
cv_2013 0.22
cv_2016 0.22
dist lognormal
q acoq

@estimate
parameter q[acoq].q
prior lognormal
mu 0.8
cv 0.19
lower_bound 0.1
upper_bound 1.5

@relative_abundance aco2012
step 1
proportion_mortality 0.75
biomass True
ogive matsel
years 2012 2014
2012 46513
2014 63781
cv_2012 0.21
cv_2014 0.27
dist lognormal
q acoq2012

@estimate
parameter q[acoq2012].q
prior uniform
lower_bound 0.1
upper_bound 1.5

@ratio_qs_penalty
label qratpen
q1 acoq
q2 acoq2012
mu 1.143
cv 0.075

@relative_abundance aco2002
step 1
proportion_mortality 0.75
biomass True
ogive matsel
years 2002
2002 63950
cv 0.06
dist lognormal
q acoq2002

@estimate
parameter q[acoq2002].q
prior lognormal
```

```
mu 0.70
cv 0.30
lower_bound 0.1
upper_bound 1.5

@relative_abundance aco2003
step 1
proportion_mortality 0.75
biomass True
ogive matsel
years 2003
2003 44316
cv 0.06
dist lognormal
q acoq2003

@estimate
parameter q[acoq2003].q
prior lognormal
mu 0.65
cv 0.30
lower_bound 0.1
upper_bound 1.5

@relative_abundance aco2004
step 1
proportion_mortality 0.75
biomass True
ogive matsel
years 2004
2004 44968
cv 0.08
dist lognormal
q acoq2004

@estimate
parameter q[acoq2004].q
prior lognormal
mu 0.60
cv 0.30
lower_bound 0.1
upper_bound 1.5

@relative_abundance aco2005
step 1
proportion_mortality 0.75
biomass True
ogive matsel
years 2005
2005 43923
cv 0.04
dist lognormal
q acoq2005

@estimate
parameter q[acoq2005].q
prior lognormal
```

```
mu 0.55
cv 0.30
lower_bound 0.1
upper_bound 1.5

@relative_abundance aco2006
step 1
proportion_mortality 0.75
biomass True
ogive matsel
years 2006
2006 47450
cv 0.10
dist lognormal
q acoq2006

@estimate
parameter q[acoq2006].q
prior lognormal
mu 0.50
cv 0.30
lower_bound 0.1
upper_bound 1.5

@relative_abundance aco2007
step 1
proportion_mortality 0.75
biomass True
ogive matsel
years 2007
2007 34427
cv 0.05
dist lognormal
q acoq2007

@estimate
parameter q[acoq2007].q
prior lognormal
mu 0.45
cv 0.30
lower_bound 0.1
upper_bound 1.5

@relative_abundance aco2008
step 1
proportion_mortality 0.75
biomass True
ogive matsel
years 2008
2008 31668
cv 0.08
dist lognormal
q acoq2008

@estimate
parameter q[acoq2008].q
prior lognormal
```

```
mu 0.40
cv 0.30
lower_bound 0.1
upper_bound 1.5

@relative_abundance aco2009
step 1
proportion_mortality 0.75
biomass True
ogive matsel
years 2009
2009 28199
cv 0.05
dist lognormal
q acoq2009

@estimate
parameter q[acoq2009].q
prior lognormal
mu 0.35
cv 0.30
lower_bound 0.1
upper_bound 1.5

@relative_abundance aco2010
step 1
proportion_mortality 0.75
biomass True
ogive matsel
years 2010
2010 21205
cv 0.07
dist lognormal
q acoq2010

@estimate
parameter q[acoq2010].q
prior lognormal
mu 0.30
cv 0.30
lower_bound 0.1
upper_bound 1.5

@relative_abundance Buc
step 1
proportion_mortality 0.75
biomass True
ogive Bucsel
years 1984 1985 1986 1987
1984 130000
1985 111000
1986 77000
1987 60000
cv_1984 0.17
cv_1985 0.15
cv_1986 0.16
cv_1987 0.15
```

```
dist lognormal
q Bucq

@estimate
parameter q[Bucq].q
prior uniform
lower_bound 0.1
upper_bound 2

@relative_abundance Cor
step 1
proportion_mortality 0.75
biomass True
ogive Corsel
years 1988 1989 1990
1988 73000
1989 54000
1990 34000
cv_1988 0.25
cv_1989 0.18
cv_1990 0.19
dist lognormal
q Corq

@estimate
parameter q[Corq].q
prior uniform
lower_bound 0.1
upper_bound 2

@relative_abundance Tan
step 1
proportion_mortality 0.75
biomass True
ogive Tansel
years 1992 1994
1992 22000
1994 61000
cv_1992 0.34
cv_1994 0.67
dist lognormal
q Tanq

@estimate
parameter q[Tanq].q
prior uniform
lower_bound 0.1
upper_bound 2

@relative_abundance Tanwide
step 1
proportion_mortality 0.75
biomass True
ogive Tanwidesel
years 2004 2007
2004 16878
2007 17000
```

```
cv_2004 0.10
cv_2007 0.13
dist lognormal
q Tanwideq

@estimate
parameter q[Tanwideq].q
prior uniform
lower_bound 0.01
upper_bound 1

@proportions_at LFbuc
years 1984 1985 1986 1987
step 1
proportion_mortality 0.75
sexed F
sum_to_one True
at_size True
plus_group False
ogive Bucsel
class_mins 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
1984 0 2e-05 5e-05 0.00014 0.00021 0.00035 0.00061 0.00062 0.00136 0.00137 0.002 0.00378
0.00512 0.00461 0.00601 0.0073 0.00716 0.00795 0.0114 0.01102 0.0223 0.04037 0.06936 0.1073
0.1532 0.15673 0.1364 0.1093 0.0656 0.0375 0.01959 0.00785 0.00312 0.00014 1e-05 0 0
1985 0 0 4e-05 0 1e-05 7e-05 0.00014 0.00027 0.00039 0.00069 0.00055 0.00119 0.00188 0.00283
0.0049 0.00509 0.00765 0.00945 0.0118 0.0158 0.02144 0.04266 0.06677 0.10311 0.1459 0.1565
0.1334 0.11833 0.06624 0.04492 0.02518 0.00783 0.00375 0.00093 8e-05 0 0
1986 0.000363809 0.000201576 0.000313044 0.000724497 0.000961107 0.000762717 0.001089252
0.001902446 0.002227984 0.003025347 0.003048281 0.006573274 0.007009317 0.008361335
0.009664961 0.01068134 0.01247802 0.01166468 0.01013735 0.01380718 0.01650285 0.0369561
0.05766967 0.1023416 0.1239962 0.1479308 0.1470353 0.1112406 0.07009839 0.04860611
0.02108614 0.007855671 0.002766081 0.000415424 0.000490263 0 0
1987 0.000304629 0.00101668 0.002488507 0.003282107 0.003891475 0.002738269 0.001777553
0.001785247 0.003257106 0.003244254 0.002907047 0.005052689 0.005726629 0.005568948
0.006209599 0.006486545 0.007462302 0.007626307 0.008204232 0.008299334 0.01408508
0.02623393 0.05483458 0.07969361 0.121034 0.1483798 0.1625132 0.126157 0.08036137
0.06211313 0.02218157 0.01085796 0.002392455 0.001485995 0.000269715 0 3.17607e-05
dist multinomial
r 0.00001
N_1984 50
N_1985 50
N_1986 50
N_1987 50

@proportions_at LFcor
years 1988 1989 1990
step 1
proportion_mortality 0.75
sexed F
sum_to_one True
at_size True
plus_group False
ogive Corsel
class_mins 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
1988 5.55404e-05 0.00021537 0.000921929 0.001998269 0.002765154 0.002512129 0.001629095
```

```
0.001407058 0.001179429 0.001384099 0.001537445 0.002158094 0.002674344 0.003105022
0.004571368 0.005076823 0.006253296 0.007332135 0.01063835 0.01605556 0.02534579
0.04203481 0.07459223 0.1150154 0.1517476 0.1526584 0.1347846 0.09942918 0.06354944
0.03655482 0.01946503 0.008007625 0.002712382 0.000611234 0 0 0
1989 0 0 9.46743e-05 0.000475164 0.00128098 0.001558001 0.000982196 0.000874103
0.000634979 0.000659882 0.000802537 0.000555626 0.001381085 0.001603655 0.001934873
0.002414614 0.003675653 0.004700243 0.007055017 0.01242235 0.02061924 0.04079466
0.07401608 0.1085542 0.1380276 0.1627439 0.1465626 0.1139847 0.07534233 0.04350086
0.02223969 0.006993559 0.002610414 0.000208229 0.000535547 0.000160699 0
1990 0.000179169 0.000377355 0.000613896 0.000710887 0.002620261 0.004827357 0.004456357
0.003130915 0.002112392 0.003132623 0.00306085 0.004006348 0.004517943 0.00516196
0.007964616 0.007338077 0.009436476 0.008555876 0.01365626 0.01848624 0.0315614 0.0451531
0.07609521 0.1193685 0.1344104 0.1477283 0.1276251 0.08977252 0.06488926 0.03625016
0.01663372 0.004406653 0.001629912 0.000126773 0 0 0
dist multinomial
r 0.00001
N_1988 58
N_1989 63
N_1990 83.5

@proportions_at LFtan
years 1992 1994
step 1
proportion_mortality 0.75
sexed F
sum_to_one True
at_size True
plus_group False
ogive Tansel
class_mins 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 2.34854e-05 0.000308678 0.000262086 0.000657547 0.000931968 0.001690054 0.003369972
0.006752543 0.006809377 0.00415511 0.003710767 0.003929743 0.003134993 0.005071809
0.004991473 0.006998184 0.01168647 0.01112179 0.02059367 0.01676207 0.02333666 0.03243743
0.04916983 0.07676098 0.119692 0.1312538 0.1303823 0.1284647 0.08351715 0.05890609
0.03192849 0.01540422 0.004831111 0.000670246 0.000208728 1.61971e-05 1.67119e-05
1994 0 1.67578e-05 0 0 3.64622e-05 0.000324472 0.000508716 0.001632322 0.002363805
0.002149121 0.001742358 0.001213862 0.00117852 0.001621137 0.00418043 0.008015245
0.008473403 0.01426134 0.01209774 0.04239483 0.05211802 0.07447671 0.08996584 0.1133403
0.1321768 0.1354024 0.1045433 0.0763996 0.06015297 0.02945513 0.01554921 0.01047846
0.00167165 0.000857003 0.001150507 0 0
dist multinomial
r 0.00001
N_1992 33
N_1994 20

@proportions_at LFtanwide
years 2004 2007
step 1
proportion_mortality 0.75
sexed F
sum_to_one True
at_size True
plus_group False
ogive Tanwidesel
class_mins 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
```

```
2004 0.000421004 0.000349767 0.000108116 0 0 0 0.00072557 0.002815056 0.003046928
0.004835874 0.003571228 0.004545656 0.01283627 0.0199908 0.02980189 0.04557678 0.05473899
0.06530936 0.0635782 0.07721669 0.06946845 0.06336989 0.07409259 0.06949758 0.0671361
0.06423314 0.05536975 0.04549367 0.03175347 0.02772396 0.02059919 0.01209341 0.006035355
0.003296178 0.000369069 0
2007 0.000131565 0 0.000406217 0.000344372 0.001935977 0.000353429 0.001273066
0.001071211 0.00228752 0.003119033 0.003255851 0.005738309 0.005860219 0.00906548
0.01789553 0.02890255 0.04617305 0.05811292 0.06543589 0.08562423 0.082746 0.08521432
0.07728044 0.07057058 0.08244385 0.08325518 0.06330442 0.04462165 0.03071825 0.01817436
0.01150342 0.005737993 0.005422786 0.000929205 0.000702742 0.000388387
dist multinomial
r 0.00001
N_2004 57
N_2007 62

@proportions_at LFboxflat
years 1990 2004
step 1
proportion_mortality 0.5
sexed F
sum_to_one True
at_size True
plus_group False
ogive matsel
class_mins 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
1990 0 0.000158909 9.95e-05 0.000210533 0.000238196 0.000495422 0.001254532 0.002154919
0.004169252 0.006091242 0.01282202 0.0226635 0.04029722 0.07024916 0.1123535 0.1468239
0.1610729 0.1426804 0.1172552 0.07605526 0.04977189 0.02011213 0.008619668 0.003246983
0.000773689 0.000250078
2004 4.39e-05 7.18e-05 0.000205981 0.000496509 0.001227437 0.002327453 0.00524418
0.01091408 0.02208171 0.03721626 0.06004503 0.08323687 0.1132216 0.1275185 0.1350955
0.1320566 0.1049201 0.07721767 0.04762157 0.02328343 0.0107514 0.003991744 0.000962657
0.000194269 1.26e-05 2.76e-06
dist multinomial
r 0.00001
N_1990 23
N_2004 25

@proportions_at LFhills
years 1995 2003
step 1
proportion_mortality 0.5
sexed F
sum_to_one True
at_size True
plus_group False
ogive matsel
class_mins 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
1995 0 0 0 0 0.000177128 0.00058855 0.00158803 0.002357302 0.006323779 0.01374448
0.02131003 0.03786901 0.06439271 0.08601061 0.1088883 0.1443275 0.1420557 0.1316293
0.09576356 0.06591011 0.03948215 0.02037994 0.009371813 0.00533847 0.001398399
0.000931798 0.000136528 0 0 2.49e-05
2003 0 0 0 9.86e-06 4.13e-05 9.86e-06 0.00083073 0.003258231 0.004368276 0.01368635
0.02907073 0.04286291 0.07000064 0.1160458 0.1456387 0.1474501 0.1219139 0.1185394
0.0766867 0.04986246 0.03311733 0.01427563 0.00729351 0.004020597 0.000160994 0.000428014
0 0.000428014 0 0
```

```
dist multinomial
r 0.00001
N_1995 24
N_2003 8

@proportions_at LFandes
years 1993 1998 2003
step 1
proportion_mortality 0.5
sexed F
sum_to_one True
at_size True
plus_group False
ogive matsel
class_mins 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
1993 0 0 0 5.04e-05 5.58e-05 0.000360539 0.00101749 0.005278528 0.009547897 0.01854913
0.03644313 0.05575062 0.07536409 0.1091069 0.1356637 0.1534083 0.1440175 0.1090498
0.07130127 0.04002192 0.02231478 0.008787828 0.002937921 0.000777596 0.00013616 1.42e-05 0
4.45e-05
1998 0 0 0 0.000277354 0.001005618 0.001453453 0.004451908 0.008418377 0.01461991
0.0254765 0.04570758 0.06874018 0.1018215 0.1143803 0.1274731 0.1433809 0.1262028
0.1047362 0.0577463 0.03365968 0.009745741 0.008221494 0.001923334 0.000440636
0.000117207 0 0 0
2003 7.56e-05 0 0.00029812 0.000206231 0.000557953 0.001526929 0.003263305 0.008883888
0.0173093 0.02899803 0.04480842 0.06650869 0.1006612 0.1357634 0.1542982 0.1395754
0.1213635 0.08102189 0.05308041 0.02442391 0.01089841 0.004685455 0.001337897 0.000170828
0.000232171 5.09e-05 0 0
dist multinomial
r 0.00001
N_1993 38
N_1998 8
N_2003 29

@proportions_at AFplumes12
years 2012
step 1
proportion_mortality 0.75
sexed F
sum_to_one True
at_size False
plus_group True
ogive matsel
min_class 20
max_class 100
ageing_error True
2012 0 0 0 0 0.004934227 0.005049307 0.01426801 0.01074836 0.01315794 0.003289484
0.03476975 0.03148026 0.02754103 0.01908716 0.03511499 0.0378698 0.02490129 0.04222863
0.04069897 0.03293557 0.0346954 0.01954748 0.04502417 0.04280403 0.02830586 0.02536161
0.03018076 0.02976117 0.0226068 0.03205566 0.02471186 0.01361826 0.02184197 0.02712144
0.01648815 0.01472833 0.01285343 0.01009861 0.01197352 0.008799111 0.003519644 0.015263
0.002524653 0.01702282 0.01009861 0.008799111 0.0008799111 0.008684031 0.002524653
0.002639733 0.006159378 0.006044298 0.006044298 0.002639733 0.001759822 0.004399556
0.006044298 0.004399556 0.003519644 0.001759822 0 0.001759822 0.0008799111 0.002524653 0
0.003519644 0.002639733 0 0.001644742 0.0008799111 0.0008799111 0.0008799111 0.0008799111
0 0.001759822 0.001759822 0 0.002639733 0 0 0.01197352
dist multinomial
r 0.00001
```

```
N_2012 50

@proportions_at AFplumes1316
years 2013 2016
step 1
proportion_mortality 0.75
sexed F
sum_to_one True
at_size False
plus_group True
ogive matsel
min_class 20
max_class 100
ageing_error True
2013 0 0.0007814836 0 0 0.006726165 0.007721561 0.005457647 0.005730768 0.01529701
0.01899051 0.02372589 0.02183696 0.03957551 0.0432098 0.04079977 0.03448648 0.05753911
0.05046981 0.05509916 0.04208103 0.05553336 0.03145382 0.03317786 0.04592065 0.02275182
0.02986571 0.02657233 0.01854391 0.01539028 0.01794228 0.01548356 0.01304583 0.02524875
0.01134949 0.02380642 0.01000043 0.009284529 0.007677311 0.002632531 0.01363473
0.007956802 0.007742889 0.01036683 0.005898211 0.00355376 0.008738286 0.006887238
0.003488182 0.003274269 0.002920611 0.002558364 0.003488182 0.005398438 0.0007814836
0.002780866 0.001209309 0.004335244 0 0.0006417383 0 0.001637135 0 0.001423222 0.001562967
0 0 0 0.0008556511 0.004335244 0 0.001562967 0.001851048 0 0.0008556511 0 0.001069564
0.0007814836 0 0 0 0.003200102
2016 0 0 0.007056693 0.00347577 0.007161846 0.004409342 0.00419527 0.01585127 0.005152948
0.01261368 0.01737885 0.02373639 0.03635007 0.03963963 0.02694114 0.05080678 0.0372633
0.02846495 0.0159477 0.04707249 0.03701262 0.04157157 0.03643111 0.02442305 0.04627195
0.02556316 0.02332362 0.0212665 0.02657282 0.03195233 0.02040149 0.02184425 0.01575396
0.02127524 0.004538602 0.01575773 0.01140533 0.01418194 0.01363991 0.003487382
0.009239299 0.01655828 0.005448069 0.005848342 0.006324699 0.01257331 0.006749079
0.005896555 0.005035301 0.007953665 0.0009576786 0.003463275 0.00621578 0 0.001252799
0.002352231 0.004704462 0.009869023 0.004987088 0.00360503 0.0009576786 0 0.004914768 0
0.003119944 0.001228692 0.004324529 0.00390015 0.004938876 0 0.0006384524 0.001276905
0.002186371 0.001252799 0.001276905 0 0.0009576786 0.001596132 0 0 0.008203457
dist multinomial
r 0.00001
N_2013 60
N_2016 60

@ageing_error
type normal
c 0.1

@q_method free
@q acoq
q 1

@q acoq2012
q 0.5

@q acoq2002
q 0.6

@q acoq2003
q 1

@q acoq2004
```

```
q 0.8

@q acoq2005
q 1

@q acoq2006
q 0.6

@q acoq2007
q 0.5

@q acoq2008
q 0.4

@q acoq2009
q 0.6

@q acoq2010
q 0.6

@q Bucq
q 1

@q Corq
q 0.8

@q Tanq
q 1

@q Tanwideq
q 0.1

@estimate
parameter selectivity[Bucsel].immature
same selectivity[Corsel].immature selectivity[Tansel].immature
lower_bound 1 1 0.001
upper_bound 30 50 0.2
prior uniform

@estimate
parameter selectivity[Tanwidesel].immature
lower_bound 1 1 0.1
upper_bound 30 30 1.0
prior uniform


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

@estimate
parameter initialization.B0
lower_bound 1e5
upper_bound 6e5
prior uniform-log
```

```
@estimate
parameter size_at_age.cv1
lower_bound 0.03
upper_bound 0.3
prior uniform

@estimate
parameter size_at_age.cv2
lower_bound 0.03
upper_bound 0.3
prior uniform

@estimate
parameter recruitment.YCS
lower_bound     1       1       1       1       1       1       1       1       1       1       1
        1       1       1       1       1       1       1       1       1       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
        1       1       1       1       1       1       1       1       1       1       1       1   1
1 1
upper_bound     1       1       1       1       1       1       1       1       1       1       1
        1       1       1       1       1       1       1       1       1       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
        1       1       1       1       1       1       1       1       1       1       1       1   1
1 1
prior lognormal
mu    26489122130    26489122130    26489122130    26489122130    26489122130    26489122130
26489122130  26489122130  26489122130  26489122130  26489122130  26489122130  26489122130
26489122130  26489122130  26489122130  26489122130  26489122130  26489122130  26489122130
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cv 2980.958 2980.958 2980.958 2980.958 2980.958 2980.958 2980.958 2980.958 2980.958 2980.958
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@catch_limit_penalty
label boxflatCP
fishery boxflat
multiplier 200
log_scale True

@catch_limit_penalty
label hillsCP
fishery hills
multiplier 200
log_scale True

@catch_limit_penalty
label andesCP
fishery andes
multiplier 200
log_scale True

@catch_limit_penalty
label southCP
fishery south
multiplier 200
log_scale True
```

Variations needed for the current model

In the population file extra selectivities are needed for the commercial fisheries. The names and initial values are:

```
@selectivity_names boxflatsel hillssel andessel
@selectivity boxflatsel
all logistic 37 4.56
@selectivity hillssel
all logistic 37 4.56
@selectivity andessel
all logistic 37 4.56
```

Each selectivity is specified for the corresponding commercial fishery with andessel used for fishery south as well as andes.

In the estimation file the commercial selectivities need to be specified as the ogives for the commercial length frequencies. Also, the commercial selectivities need to be estimated:

```
@estimate
parameter selectivity[boxflatsel].all
lower_bound 10 3
upper_bound 50 50
prior uniform
```

```
@estimate
parameter selectivity[hillssel].all
lower_bound 10 3
upper_bound 50 50
prior uniform

@estimate
parameter selectivity[andessel].all
lower_bound 10 3
upper_bound 50 50
prior uniform
```