

7th MEETING OF THE SCIENTIFIC COMMITTEE

La Havana, Cuba, 7 to 12 October 2019

SC7-DW05

A 2019 Orange Roughy Stock Assessment for Louisville Ridge

New Zealand

South Pacific Regional Fisheries Management Organisation

7th Meeting of the Scientific Committee

La Havana, Cuba 7-12 October 2019

A 2019 orange roughy stock assessment for Louisville Ridge

Patrick Cordue
Innovative Solutions Ltd
Wellington
New Zealand

6 September 2019

Contents

Executive summary	2
1. Purpose of paper	3
2. Background	3
3. Methods.....	3
3.1 Catch history	3
3.2 Composition data.....	4
3.3 Estimation of growth	5
3.4 Estimation of the length weight relationship	5
3.5 Model structure	6
3.6 Estimation method	6
3.7 Model runs.....	7
4. Results.....	8
4.1 Catch history	8
4.2 Composition data.....	9
4.3 Growth parameters.....	13
4.4 The length weight relationship	15
4.5 Model diagnostics	16
4.6 Stock assessment results	18
5. Discussion and conclusion	26
6. Recommendations.....	27
7. Acknowledgments	27
8. References	28
Appendix A: Base model chain diagnostics	29
Appendix B: Base model MPD fits and likelihood profiles	35
Appendix C: Base model CASAL input files	39

Executive summary

This paper presents an updated orange roughy stock assessment for the three Louisville Ridge stocks. Estimates of virgin biomass (B_0), current stock status (ss_{19}), and long-term yield are presented for the three stocks.

The Louisville Ridge is in the western South Pacific Ocean and lies within SPRFMO's jurisdiction. It has a series of underwater topographical features which have been fished for orange roughy since 1994. Fishing has been primarily by New Zealand vessels but vessels from other countries have also participated in the fishery especially prior to 2007. Three orange roughy stocks were defined for Louisville Ridge: North, Central, and South. The stocks were last assessed in 2017 to the end of the 2015 calendar year. The current orange roughy catch limit for the whole of the Louisville Ridge is 1140 t.

A Bayesian stock assessment is presented for the Louisville Central orange roughy stock using age and length frequency data and constraints on maximum exploitation rates commonly used in New Zealand stock assessments for this species. The biological parameters and year class strengths estimated for Louisville Central are then used in catch-history based assessments for Louisville North and Louisville South (for which no age or length frequencies are currently available). Although no biomass indices were available the composition data were adequate to rule out very high exploitation rates for Louisville Central in 1995 (when there was a spike in catches) and therefore eliminate low values of B_0 and current stock status.

There is still large uncertainty in the estimates of virgin and current stock size for the Louisville Ridge orange roughy stocks. However, the new data have allowed the estimation of stock specific parameters and enabled a much more precise stock assessment for Louisville Central. The assessments for North and South have also benefited as parameters borrowed from Central are much more likely to be appropriate than those previously borrowed from New Zealand EEZ stocks. The new estimate of M (0.03) is particularly important as it points to lower yields per unit of biomass for these stocks compared to the New Zealand EEZ stocks (where $M=0.045$ is used in the assessments).

Although current stock status for each of the stocks is quite uncertain, it is likely that Louisville Central is currently above 50% B_0 , while Louisville North is likely above 30% B_0 . There is a possibility that Louisville South is below 20% B_0 but it likely well above this level.

The base model estimates for each stock are given below.

	B_0 (000 t)		ss_{19} (% B_0)		Long term yield (t)		$P(ss_{19}<20\%B_0)$	$P(ss_{19}>30\%B_0)$
	Median	95% CI	Median	95% CI	Median	95% CI		
Central	71	34-117	82	61-93	710	340-1170	0.00	1.00
North	26	8-80	78	32-96	260	82-800	0.00	0.98
South	25	11-55	64	18-86	250	110-550	0.04	0.89
Total	122	53-252			1220	530-2520		

1. Purpose of paper

This paper presents an updated orange roughy stock assessment for the three Louisville Ridge stocks. Estimates of virgin biomass, current stock status, and long-term yield are presented for the three stocks. The assessments are provided as the best available information on which to provide management advice for Louisville Ridge orange roughy stocks.

2. Background

The Louisville Ridge is in the western South Pacific Ocean and lies within SPRFMO's jurisdiction. It has a series of underwater topographical features (UTFs) which have been fished for orange roughy since 1994. Fishing has been primarily by New Zealand vessels but vessels from other countries have also participated in the fishery especially prior to 2007. Three orange roughy stocks were defined for Louisville Ridge by Clark et al. (2016): North, Central, and South. The stocks were last assessed in 2017 to the end of the 2015 calendar year (Cordue 2017, Roux et al. 2017). As a consequence of those assessments, the Commission, on the recommendation of the Scientific Committee, set an orange roughy catch limit for the whole of Louisville Ridge at 1140 t.

3. Methods

A Bayesian stock assessment is presented for the Louisville Central orange roughy stock using age and length frequency data. Growth is estimated outside the model from age-length data collected in 1995 and 2013-2015 (Horn & Maolagáin 2019). The biological parameters and year class strengths estimated for Louisville Central are then used in catch-history based assessments for Louisville North and Louisville South (for which no age or length frequencies are currently available).

3.1 Catch history

Catch histories for each of the SPRFMO orange roughy stocks to the end of 2015 (calendar year) were constructed by Roux et al. (2017). However, it is not entirely clear how the catch histories were constructed. For this assessment the catch histories for the Louisville stocks were constructed using a table in New Zealand's 2018 plenary report (for catches up to 2007 including countries other than New Zealand; FNZ 2018) and from estimated catches in the tow-by-tow records for New Zealand vessels.

The catches in the 2018 plenary report (up to 2007) were for Louisville Ridge as a whole and were by New Zealand fishing year (October to September). These were converted into calendar year using estimated catch proportions by month from the New Zealand tow-by-tow data. The catch by stock (and fishery for Louisville Central – see below) were calculated using estimated catch proportions by area. For calendar years from 2008 to 2019 inclusive the estimated catches by year and area from the tow-by-tow data were used directly. A small addition was made to the 2019 catches based on a single voyage that was yet to land fish. No provision has been made for catches by other countries since 2007. However, such catches, if any, will be small relative to the New Zealand landings and will make little or no difference to the stock assessment results.

3.2 Composition data

Length frequency data from New Zealand scientific observers were available for several years from 1995 to 2018. The associated positional data (start positions) were plotted and it was seen that the tows were clustered about four UTFs (Mt. Ghost, Mt. Whales, Valerie, and 1485 – see Clark et al. 2016). Most data were available for clusters 1-3 with data from cluster 4 only available in 2014 and 2015. The fish sampled from cluster 3 were obviously smaller than those in the other clusters (this was confirmed by fitting a linear model to the individual fish length with cluster 3 having a mean length 2.2 cm smaller than the other clusters).

To target spawning fish and for consistency across years samples were restricted to June and July (Table 1). Clusters 1 and 2 were combined as there was little difference in mean lengths. Scaled length frequencies were produced for cluster 1&2 and cluster 3 for years in which at least 4 tows had been sampled. The length frequencies were scaled to catch numbers within tow and then summed across tows within length (1 cm bins). This was done individually by sex and the sexes were combined giving them equal weight.

Table 1: The number of tows by New Zealand vessels in Louisville Central in June and July sampled for length by scientific observers by year and cluster. Clusters 1-4 are respectively associated with the UTFs Mt. Ghost, Mt. Whales, Valerie, and 1485.

Year	Cluster			
	1	2	3	4
1995	5	4	5	0
2003	24	2	1	1
2004	0	1	5	0
2005	1	0	3	0
2006	2	0	1	0
2010	10	8	10	0
2011	6	4	5	0
2012	4	4	7	0
2013	11	4	6	0
2014	8	5	5	3
2015	12	9	7	4
2016	0	0	0	0
2017	11	13	4	0
2018	1	2	0	0

Age frequencies were produced using the data from Horn & Maolagáin (2019). They read otoliths for fish sampled by scientific observers in June and July in 1995 and 2013-2015 (Tables 2 & 3). Most of the samples were from clusters 1-3 and scaled age frequencies were produced for cluster 1&2 and cluster 3 for each year. As for the length frequencies, scaling was to catch numbers within tow, done individually by sex, and then the sexes were combined giving them equal weight.

Table 2: The number of tows by New Zealand vessels in Louisville Central in June and July sampled for otoliths by scientific observers by year and cluster. Clusters 1-4 are respectively associated with the UTFs Mt. Ghost, Mt. Whales, Valerie, and 1485.

Year	Cluster			
	1	2	3	4
1995	5	4	5	0
2013	10	3	5	0
2014	8	4	6	3
2015	12	9	4	3

Table 3: The number of fish aged by Horn & Maolagáin (2019) from Louisville Central in June and July by year and cluster. Clusters 1-4 are respectively associated with the UTFs Mt. Ghost, Mt. Whales, Valerie, and 1485.

Year	Cluster			
	1	2	3	4
1995	86	67	85	0
2013	179	52	81	0
2014	156	78	121	60
2015	195	135	75	57

3.3 Estimation of growth

Length and age measurements for individual fish were available from Horn & Maolagáin (2019) (1435 age-length pairs, 607 male, 828 female). These data were fitted by least squares to estimate growth parameters by sex. An average relationship was calculated by averaging the individual sex parameters. A von Bertalanffy curve was fitted but this did not fit the data well so a Schnute curve was also fitted (see the CASAL manual, Bull et al. 2012). In each case, because of the absence of young fish, one of the parameters was fixed at an appropriate value. For von Bertalanffy, t_0 was fixed at -0.5 and for Schnute, the mean length at age 1 year, y_1 was fixed at 5 cm.

3.4 Estimation of the length weight relationship

The scientific observer length frequency data for Louisville Ridge included sample weights for the measured fish. These data were fitted by least squares to estimate a length-weight relationship for the whole of Louisville Ridge. As the samples contained different numbers of fish, the average fish weight by sample was fitted with the sum of the squared residuals weighted by fish number.

$$objective\ function = \sum_i n_i (obs_i - pred_i)^2$$

Where n_i = number of fish in the i th sample, obs_i is the observed mean fish weight, and $pred_i$ is the predicted mean fish weight.

3.5 Model structure

For Louisville Central, a single-stock, single-area, single-sex age and maturity structured model was used (i.e., fish numbers were kept track of by age for both immature and mature fish). Ages were from 1 to 150 years with a plus group. The stock was assumed to be in age-structured equilibrium before the start of fishing. Maturation was assumed to produce a logistic curve for the proportion mature at age when the stock was in equilibrium.

Two fisheries were modelled. One for the smaller and younger fish associated with cluster 3 and the second for the remainder of the stock. Both fisheries were modelled as mid-year events (half the natural mortality removed, the catch removed, and then the other half of the natural mortality removed). Both fisheries were applied just to mature fish. A constant selection at age was assumed for the non-cluster-3 fishery (which has lots of old fish present in the age frequencies). A double normal selectivity was used for the cluster-3 fishery. For Louisville North and Louisville South, the same model structure was used except that there was only a single fishery (the non-cluster-3 fishery). For the sensitivity model that assumed Louisville Ridge was a single stock, the full Louisville Central model was used (with additional catch for the non-cluster-3 fishery).

The model was implemented in CASAL (Bull et al. 2012). The main input files for the base model are given in Appendix C (Louisville Central, North, and South).

3.6 Estimation method

Bayesian estimation as implemented in CASAL was used to estimate: virgin biomass (B_0); natural mortality (M); year class strengths (YCS); the logistic-producing maturation curve; the cluster-3 selectivity; and two parameters associated with the spread of length at mean length at age (cv1 and cv2) (see Bull et al. 2012). A Beverton-Holt stock recruitment relationship was assumed with steepness (h) equal to 0.75 (a default value – results are not sensitive to this assumption).

Uninformative priors were used on all parameters except for M where a normal distribution was used (mean=0.045, CV=15%) (as used in all EEZ stock assessments based on estimates from early age frequencies – see Cordue 2014a). For the sensitivity model where a Ricker stock recruitment relationship was used, h was estimated with an informed prior (lognormal mean=1.66 and CV = 69% as used by Cordue 2014b).

Within the stock assessment models a maximum exploitation rate of 67% was assumed (as used in all orange roughy stock assessments within New Zealand's EEZ – see Cordue 2014a). This assumption restricts B_0 on the low side as there has to have been enough biomass present to allow the given catch history to be taken. An additional constraint, as used by Cordue (2017) was placed on the maximum exploitation rate to restrict B_0 on the high side. For Louisville Central, which had a particularly high catch in 1995, it was required that the maximum exploitation rate was at least 10%. For North and South it was required that the maximum exploitation rate was at least 5%.

The stock assessments for Louisville North and Louisville South were without any data other than the catch histories. Nevertheless, a Bayesian assessment was performed for each stock by borrowing the samples from the joint posterior distribution for Louisville Central. The

samples for all parameters were supplied except for the cluster-3 selectivity (no such fishery exists for Louisville North and South), the cv1 and cv2 parameters (no length frequencies have been developed that could be fitted), and B_0 . For B_0 , samples were generated from the prior distribution (uniform in log space from 5000 to 200 000 t).

A two-step approach was used in the Bayesian estimation for Louisville Central. In the first step, the mode of the joint posterior distribution (MPD) was calculated by minimization of the objective function. The fit to the data at the MPD was plotted and Pearson residuals were calculated. The fits were examined to see if the model was adequate (if the best fit to the data is dreadful then the model is probably not adequate). The residuals were used to judge if the assumed effective sample sizes were appropriate (the number of tows sampled was used for the length frequencies and twice the number of tows was used for the age frequencies).

The second step is the sampling of the joint posterior distribution using Markov chain Monte Carlo (MCMC) sampling. This was done using three chains each of 5 million steps with 1 in every 1000 samples stored. Each chain started at a random jump away from the MPD estimate.

Long-term yield was estimated using the average yield estimates in Cordue (2014b) for specific values of M and h . The point estimate of h (0.6) was based on the latest point estimates for New Zealand EEZ stocks ORH7A (0.61) and Mid-east Coast (0.53) (Cordue 2019). The point estimate of M (0.03) comes from the Louisville Central base stock assessment model (see below). From Cordue (2014b) the long-term yield for $M=0.03$ and $h=0.6$ is approximately 1% B_0 . This is considerably lower than the proportion used in the 2017 Louisville assessment which was 1.4% B_0 (Cordue 2017).

3.7 Model runs

For Louisville Central a base model and several sensitivity runs were produced, some just to MPD estimates and some taken through to full MCMC. For Louisville North and South, only the base model was produced.

For Louisville Central the sensitivities just done to MPDs were:

- Half the effective sample sizes
- Double the effective sample sizes
- No length frequencies

Those taken through to full MCMC were:

- A uniform prior on M
- A Ricker stock recruitment relationship
- A single-stock model

4. Results

4.1 Catch history

The estimated catches for Louisville Central peaked early in the fishery in 1995 with an annual catch of over 10 000 t (Figure 1). This is easily the highest annual catch for any of the Louisville fisheries. For Louisville North and South the peak annual catch occurred in 1996 (Figure 1). Catches for each of the three stocks have been under 1000 t annually since 2000 (Figure 1).

Most of the catch in each year was taken in the spawning period of the three stocks (June–August, spawning starts in the north in June and finishes in the South in August – see Clark et al. 2016) (Figure 2). This is the reason for the mid-year timing of the fisheries in the stock assessment models. The exact catches used in the models are given in the population.csl files in Appendix C.

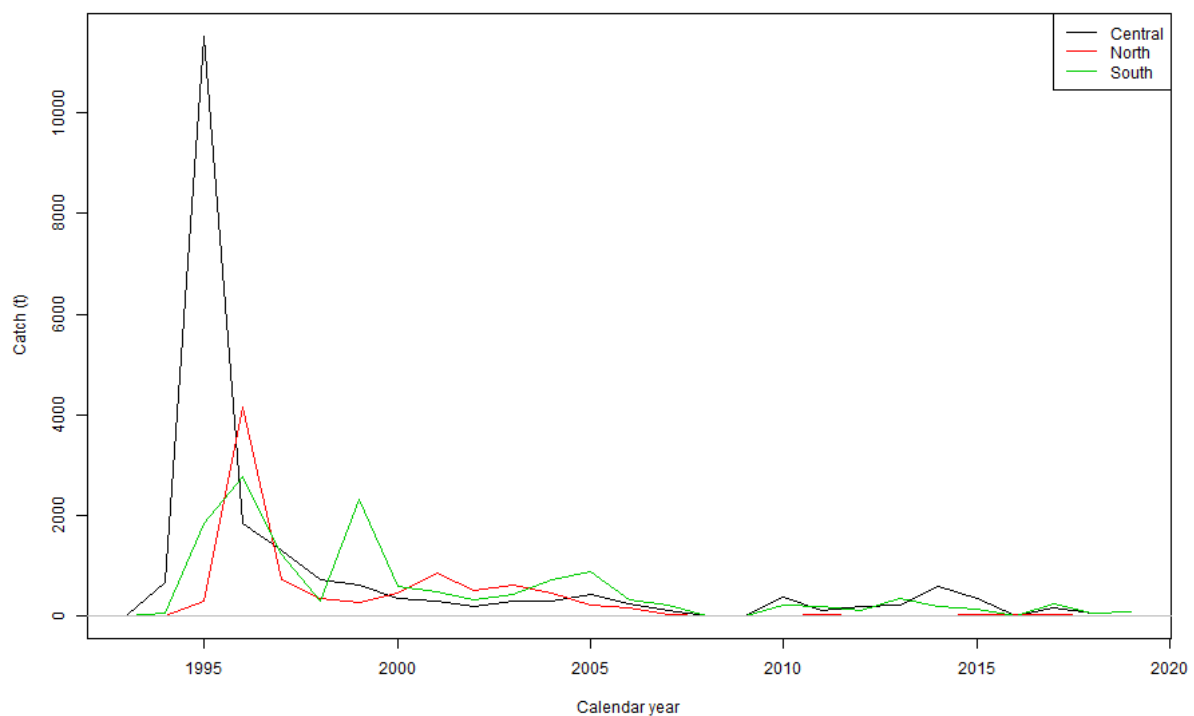


Figure 1: Estimated total annual catches by calendar year for the three Louisville stocks, Central, North, and South.

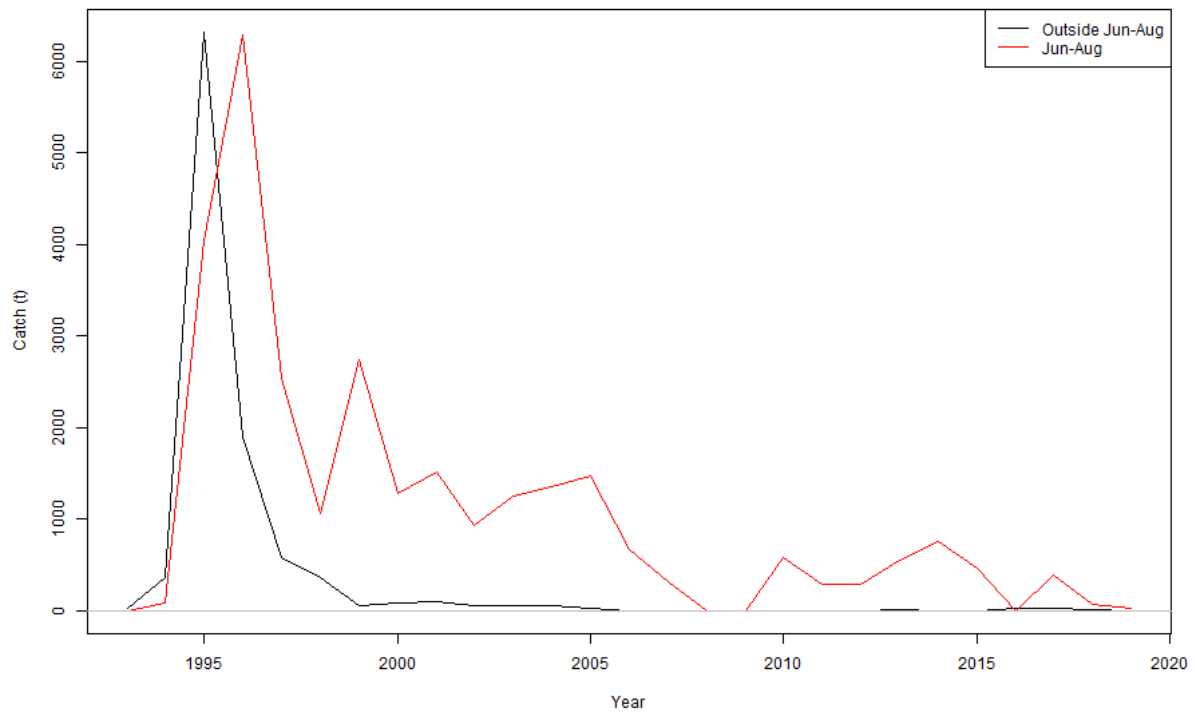


Figure 2: Estimated catches in June-August and the remainder of the calendar year for the three Louisville stocks, Central, North, and South.

4.2 Composition data

The earliest composition data are from 1995 and the length frequencies from that year by cluster show that the fish from cluster 3 are smaller than those from clusters 1 and 2 (which have similar sized fish) (Figure 3). It is also noticeable that female fish are larger than the male fish (Figure 3). The flat length frequency seen in 1995 in clusters 1 and 2 is seen again in 2003 (Figure 4). In 2010 the length frequency is starting to appear different to that from 1995 and 2003 with an increased proportion of smaller fish (Figure 4).

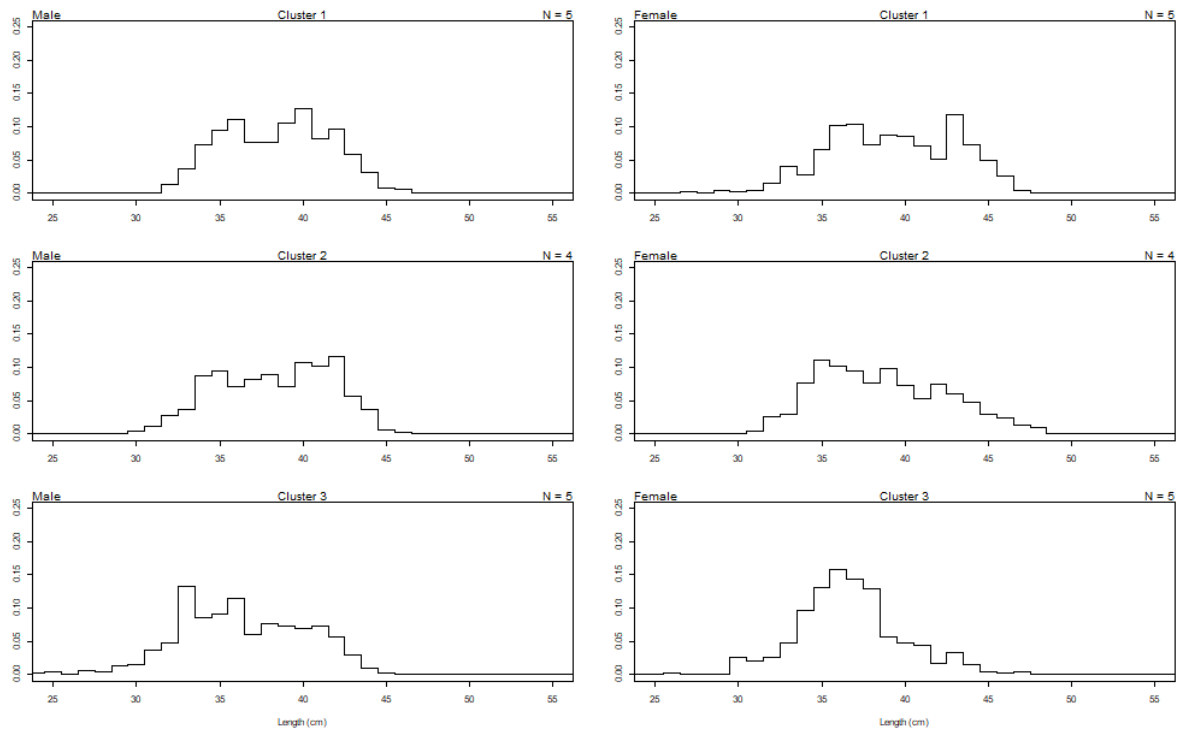


Figure 3: Scaled length frequencies by sex for clusters 1-3 in 1995. N is the number of tows sampled for length.

For the age frequencies the data are quite sparse when they are split by cluster and sex. However, it is noticeable that the age frequencies for cluster 1&2 (the two clusters combined) contain a good proportion of very old fish (by New Zealand EEZ standards) with the oldest fish at 230 years being a female sampled in 2015 (Figure 5). In comparison, fish aged more than 100 years are uncommon in the cluster 3 age frequencies and there are no fish aged 150 years or older (Figure 6).

When the age frequencies are combined by sex for use in the models they are more substantial (in that the shape is better defined) (Figure 7).

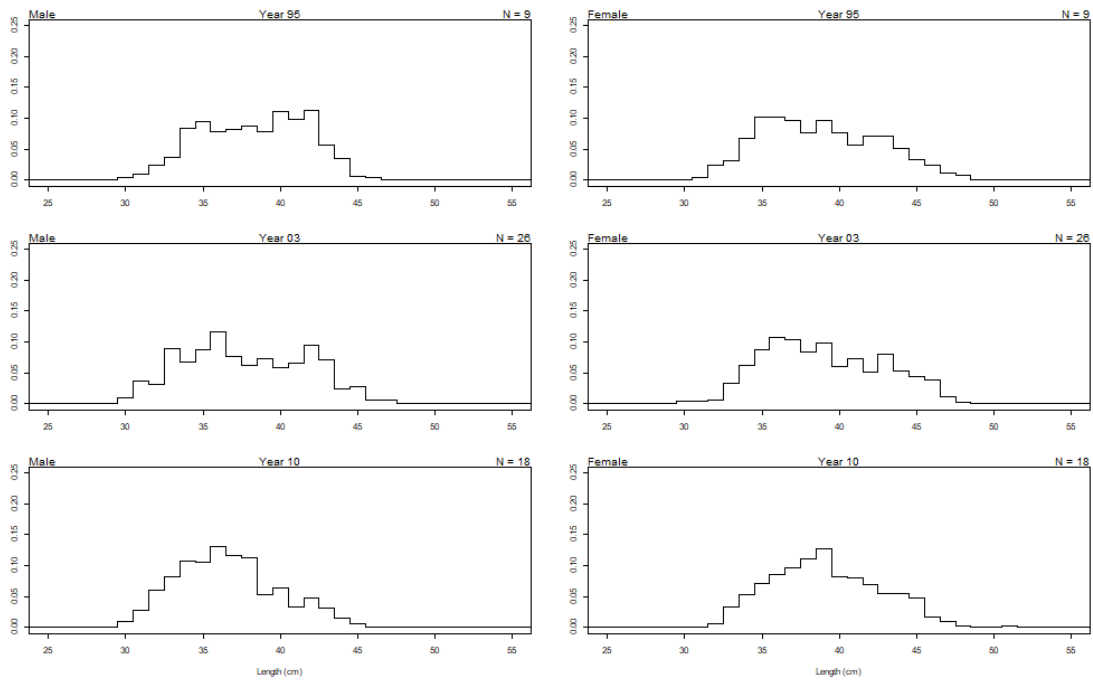


Figure 4: Scaled length frequencies by sex for cluster 1&2 in 1995, 2003, and 2010. N is the number of tows sampled for length.

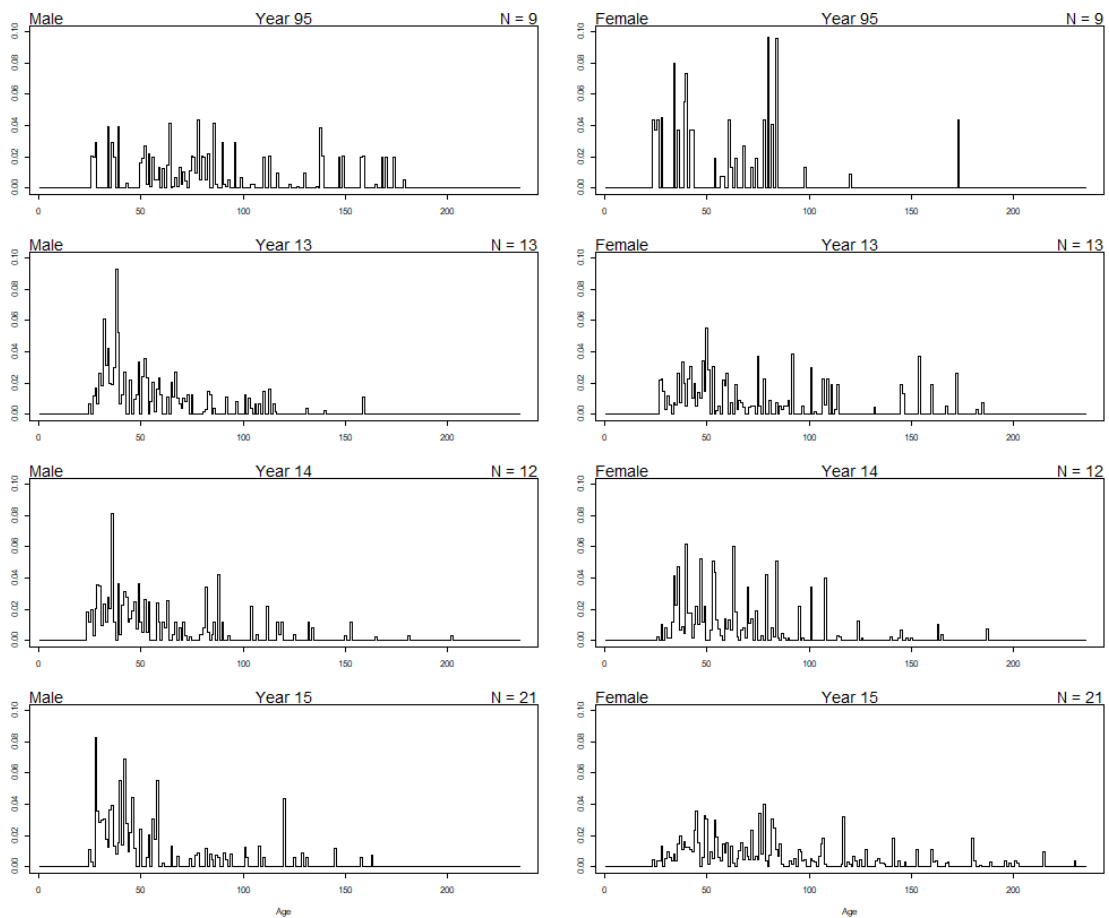


Figure 5: Scaled age frequencies by sex for cluster 1&2 in 1995, 2003-2015. N is the number of tows sampled for otoliths.

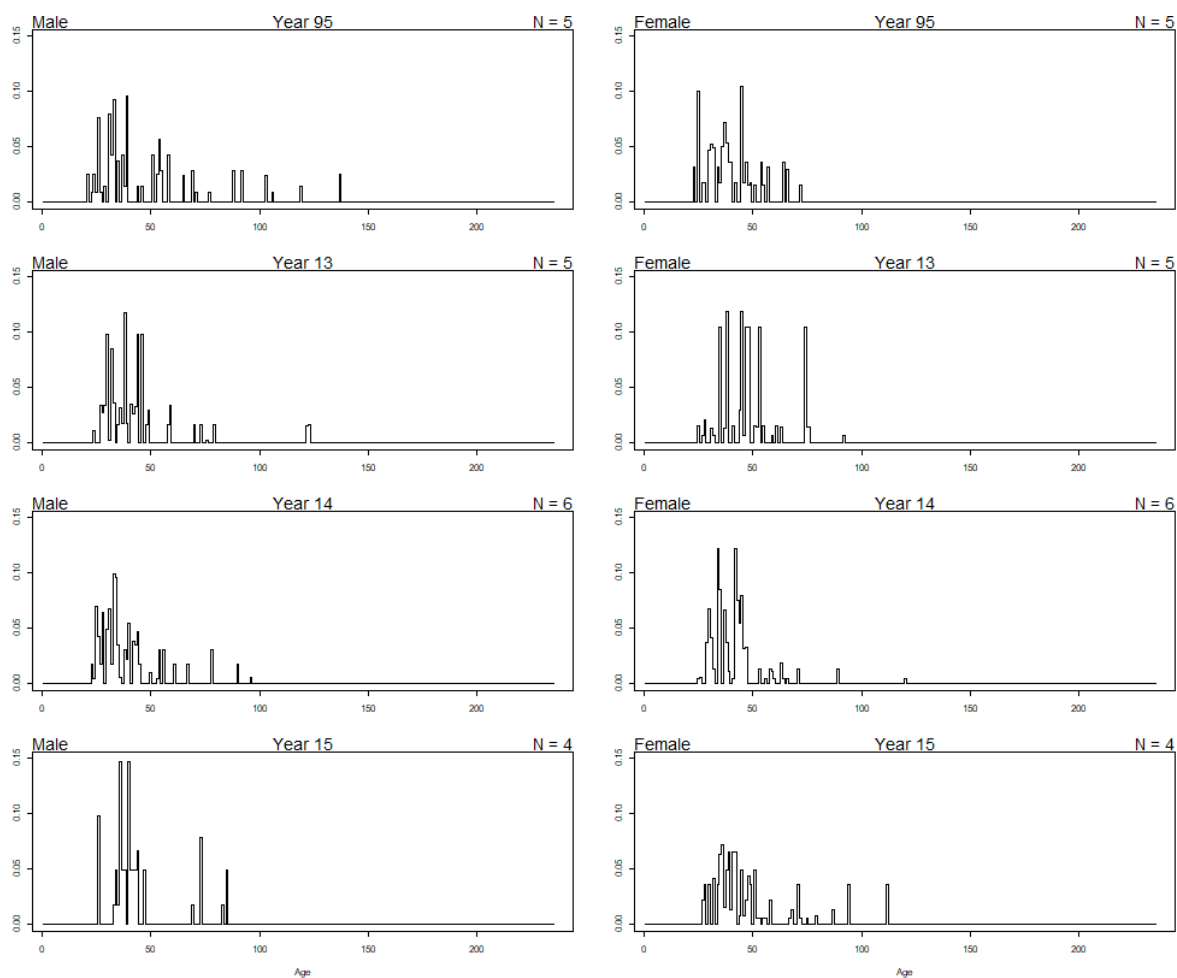


Figure 6: Scaled age frequencies by sex for cluster 3 in 1995, 2013-2015. N is the number of tows sampled for otoliths.

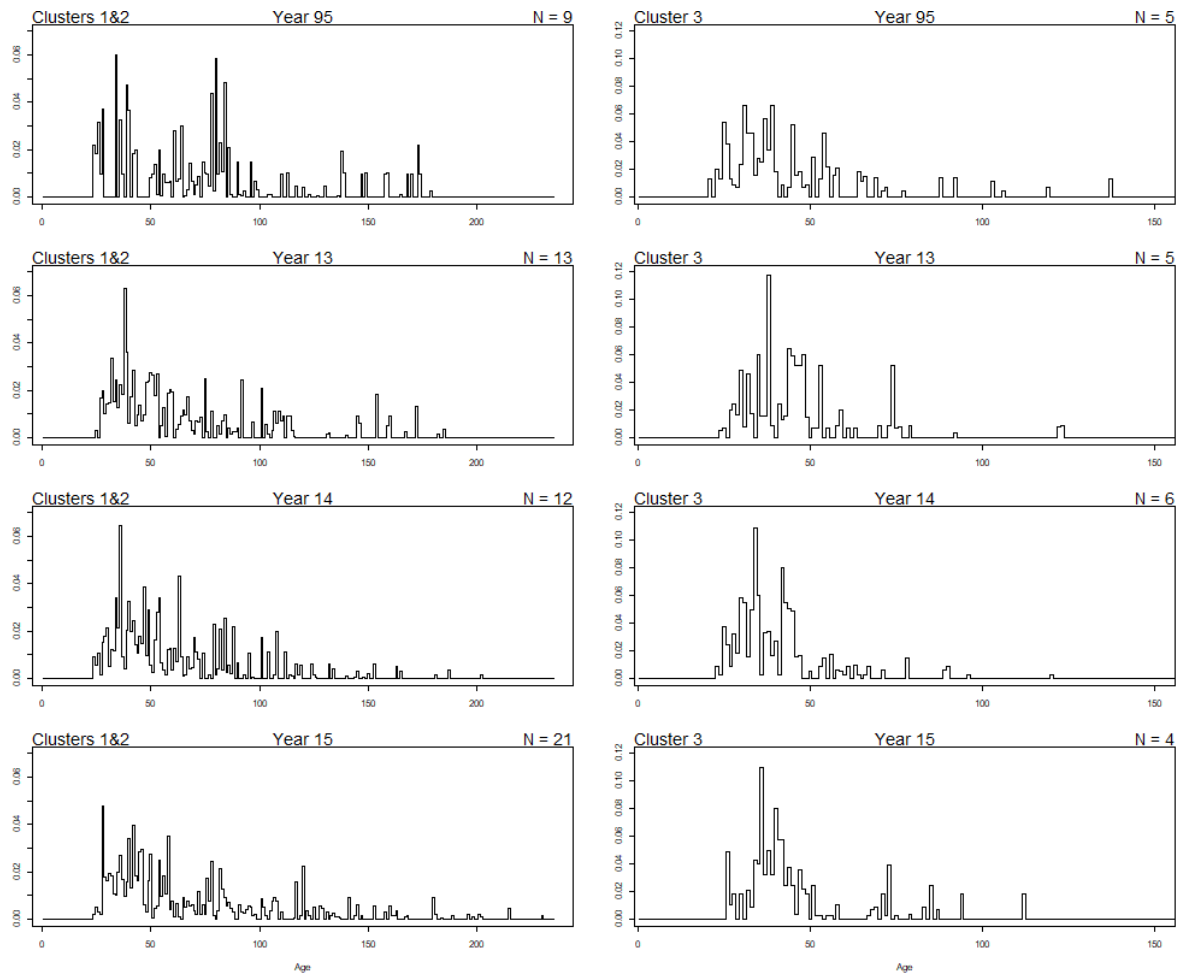


Figure 7: Scaled age frequencies for cluster 1&2 in 1995, 20013-2015 as used in the base model. N is the number of tows sampled for otoliths. These age frequencies were produced by giving equal weight to males and females.

4.3 Growth parameters

The fit of von Bertalanffy curves to the age-length data produced a very poor fit for older ages (Figure 8). The problem is that the fish appear to be still slowly growing even when they are 100 years old (Figure 8).

The Schnute growth model provides a much better fit (Figure 9). For the record the estimated Schnute growth parameters by sex were:

	a	b	y₂ (cm)
Male	0.016	4.2	40.8
Female	0.008	5.4	43.0

Where $y_1 = 5$ cm was fixed and y_1 and y_2 are the mean length at ages 1 and 100 years respectively.

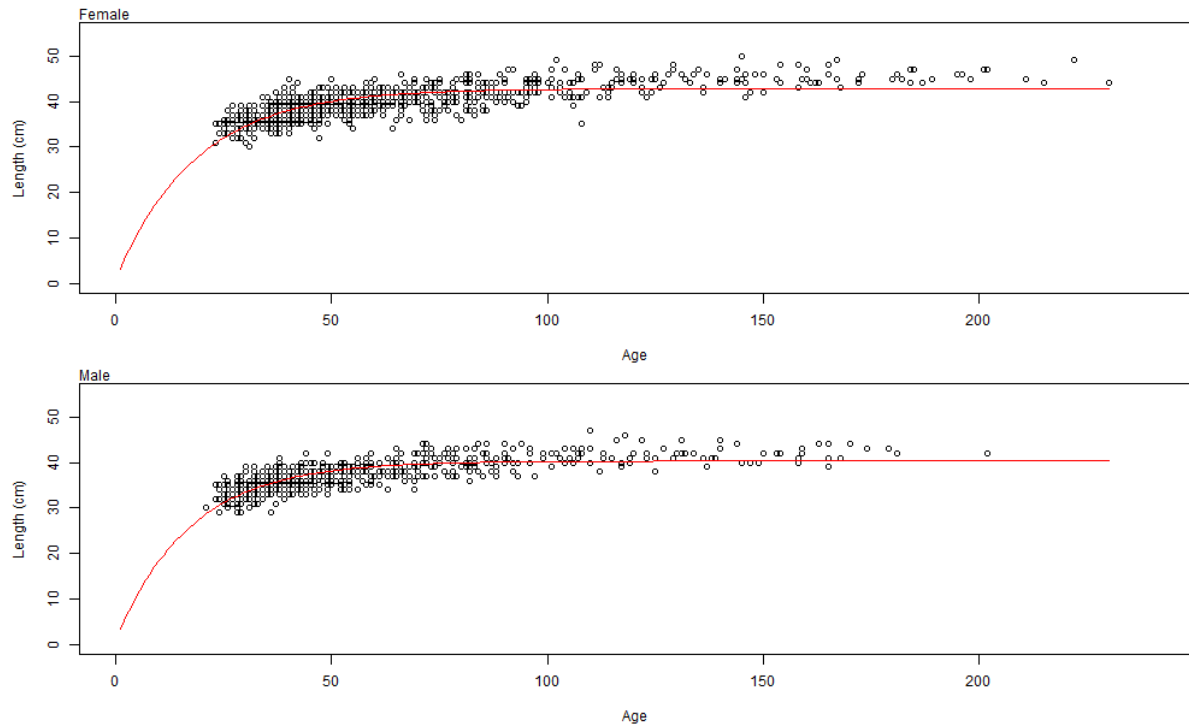


Figure 8: The least squares fit of von Bertalanffy growth curves to the age-length data by sex.

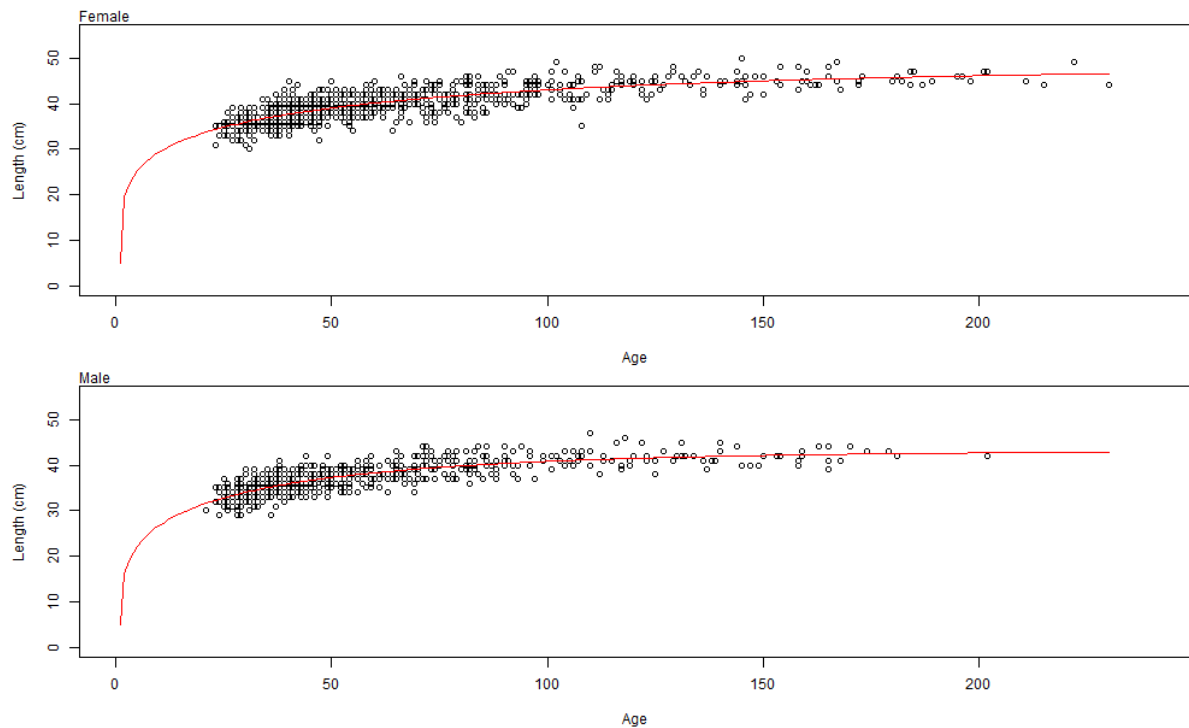


Figure 9: The least squares fit of Schnute growth curves to the age-length data by sex.

4.4 The length weight relationship

The fit to the observed mean fish weights was adequate with a strong linear relationship between observed and predicted mean fish weight (Figure 10). The estimated relationship ($a = 1.96e-4$, $b = 2.52$, going from cm to kg) was very similar to the default relationship recommended for New Zealand EEZ stocks (Figure 11).

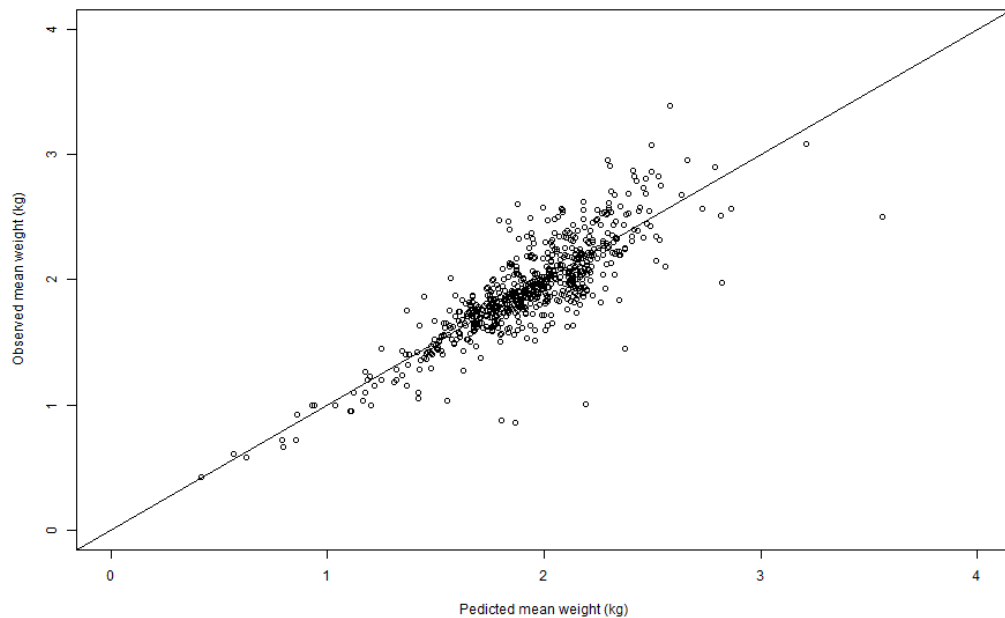


Figure 10: Observed mean fish weight versus predicted mean fish weight from the least squares fit to the weighed length frequency samples.

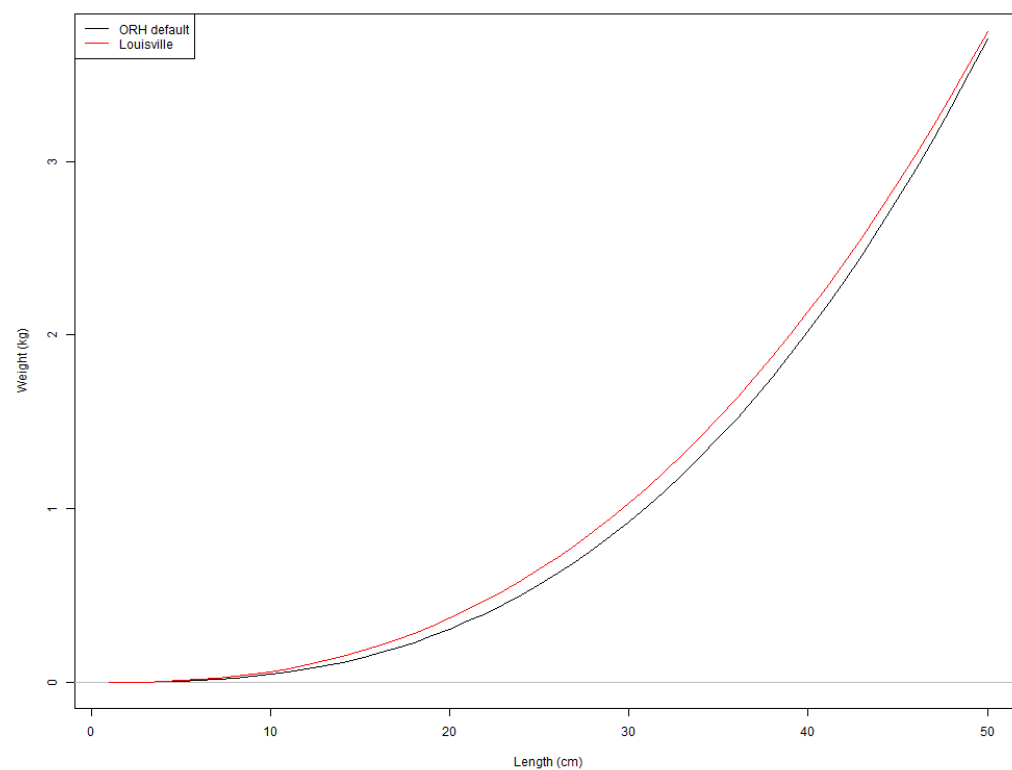


Figure 11: The estimated length-weight relationship for Louisville Ridge compared to the default length-weight relationship used for New Zealand EEZ orange roughy.

4.5 Model diagnostics

Chain convergence diagnostics were adequate and are not considered in this section (see Appendix A).

The MPD fits to the composition data were generally very good (see Appendix B). The MCMC fits were very similar to the MPD fits. For example, the 1995 length frequency for cluster 1&2 was very well fitted (Figure 12). The worst fit to a length frequency was for cluster 1&2 in 2017 where the predicted proportions were much lower than those observed near the mode of the length frequency (Figure 13).

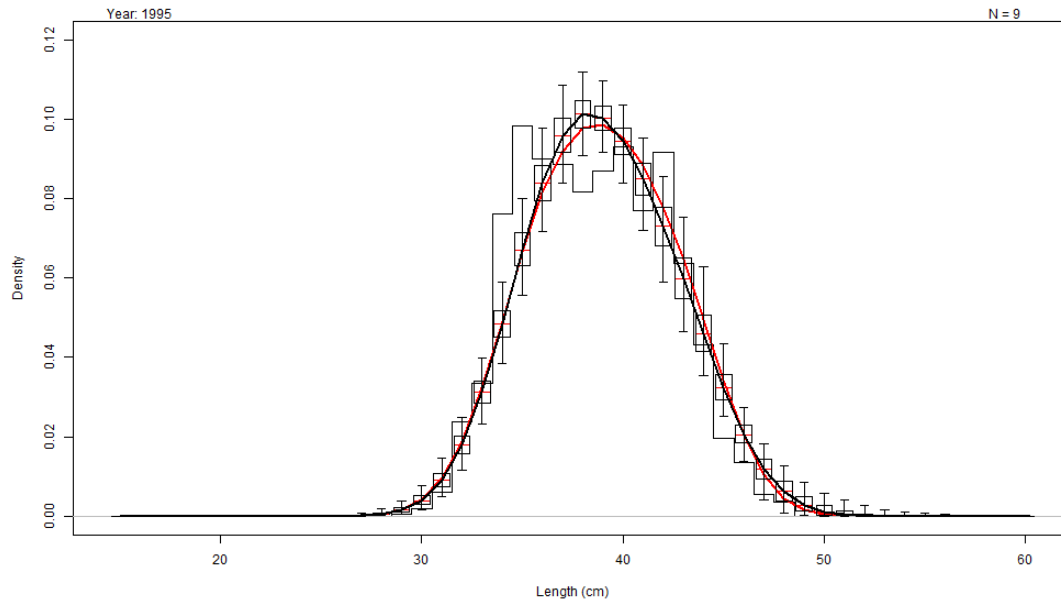


Figure 12: The MPD (red line) and MCMC fit (box and whiskers) to the observed length frequency in cluster 1&2 in 1995 (histogram). The box for each length class covers the middle 50% of the distribution and the whiskers extend to 95% CIs. N is the number of tows which is the effective sample size.

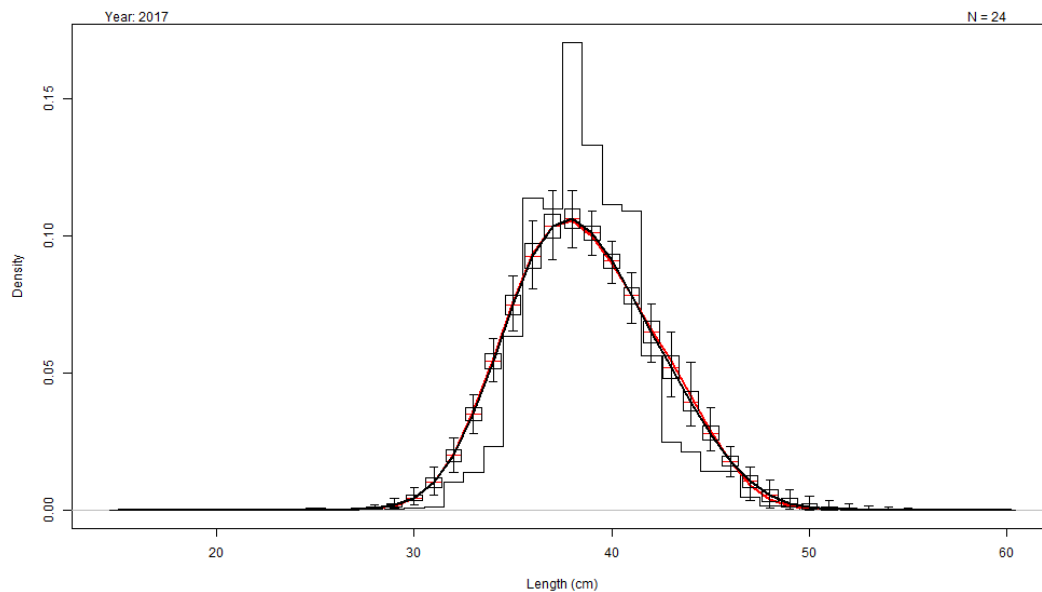


Figure 13: The MPD (red line) and MCMC fit (box and whiskers) to the observed length frequency in cluster 1&2 in 2017 (histogram). The box for each length class covers the middle 50% of the distribution and the whiskers extend to 95% CIs. N is the number of tows which is the effective sample size.

Similarly, the age frequencies were well fitted at the MPD and MCMC level (e.g., Figure 14).

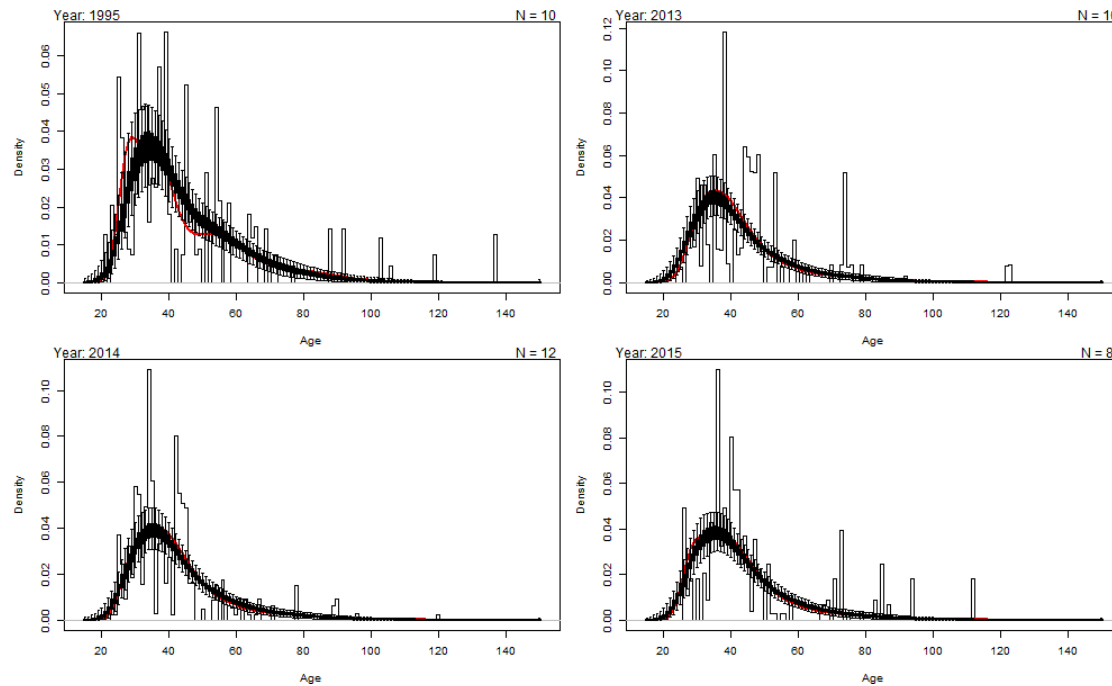


Figure 14: The MPD (red line) and MCMC fit (box and whiskers) to the observed age frequencies in cluster 3. The box for each age class covers the middle 50% of the distribution and the whiskers extend to 95% CIs. N is the effective sample size which is twice the number of tows.

The Pearson residuals for the length and age frequencies were generally no more than about 3 which suggests that the effective sample sizes were appropriate (e.g., Figure 15). The standard deviation of the Pearson residuals being approximately equal to 1 was not used as a diagnostic as the residuals are not normally distributed. The age data for cluster 3, in particular, are very “spikey” with some fish occasionally observed at older ages. These observations are contrary to the effective sample sizes and the assumption of a domed selectivity and occasionally produced some enormous residuals (Figure 16). The solution to this technical problem is an alternative selectivity rather than a reduction in effective sample size. However, an improvement in the fit for cluster 3 age frequencies is not going to affect the main results of the stock assessment.

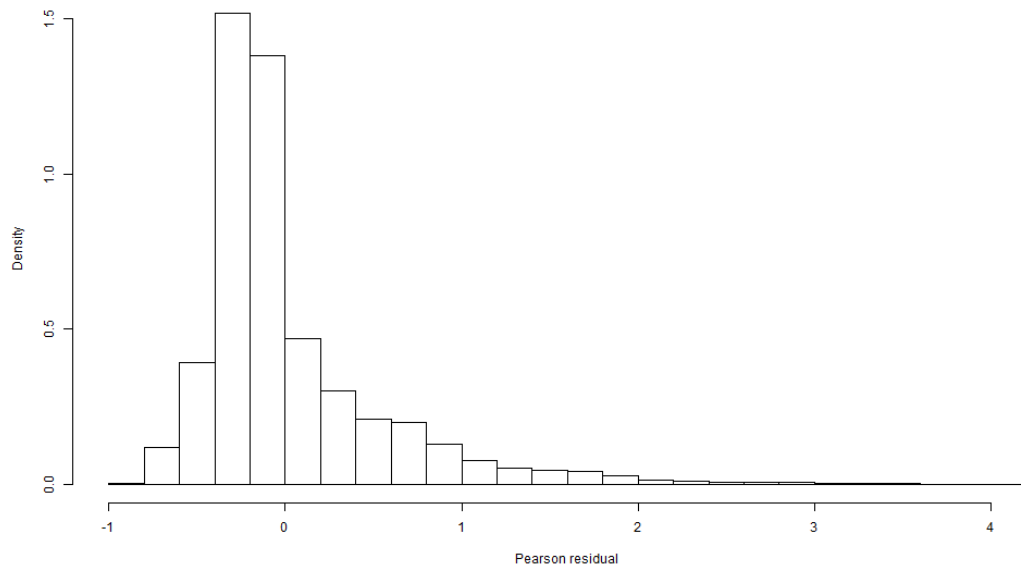


Figure 15: A histogram of the MCMC residuals for cluster 1&2 age frequencies (all years and ages).

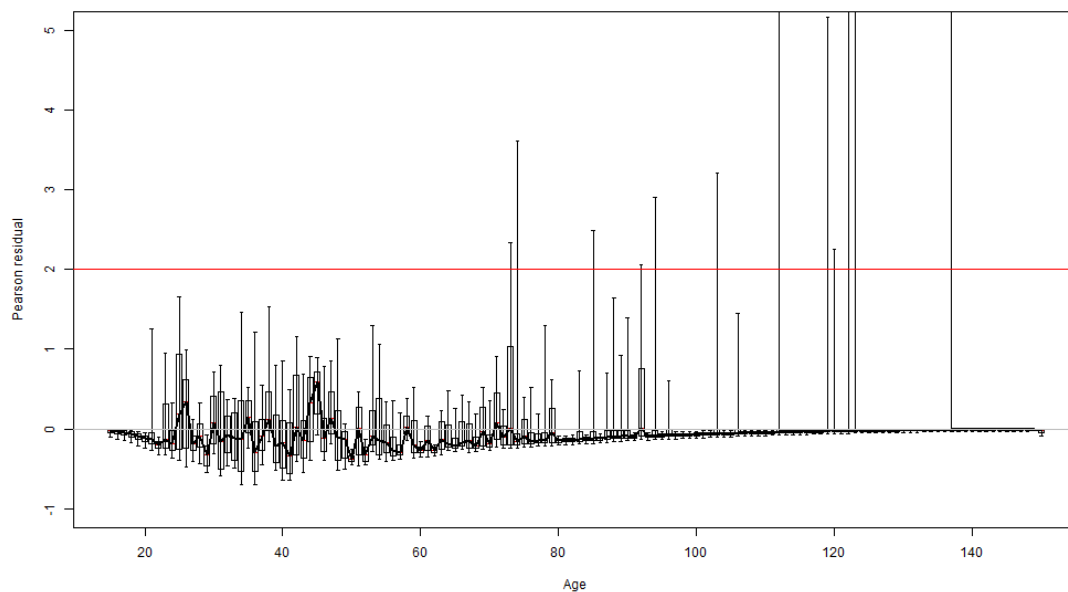


Figure 16: The MCMC Pearson residuals for age frequencies in cluster 3 as a function of age. The box for each age class covers the middle 50% of the distribution and the whiskers extend to 95% CIs. The y axis is truncated to just above 5. The maximum Pearson residual is 22.

4.6 Stock assessment results

In the base model, the MCMC estimates were largely consistent with New Zealand EEZ orange roughy stock estimates except that M was on the low side (0.03 compared to the prior mean of 0.045) as was maturation ($a_{50} = 29$ years is slightly lower than the EEZ estimates) (Table 4).

Table 4: MCMC estimates of M, maturation (logistic producing), cluster-3 selectivity (double normal), and spread of length at mean length at age parameters cv1 and cv2.

		Maturation		Selectivity				
	M	a ₅₀	a _{t095}	Mode	Sl	Sr	cv1	cv2
Median	0.030	29	5.3	18	16	41	0.07	0.05
95% CI	0.025-0.035	26-32	1.3-11	10-31	1.7-29	28-57	0.05-0.09	0.02-0.12

The logistic curve for proportions mature at age (in equilibrium) is well defined with fish starting to mature at about 25 years and fully mature by about 40 years (Figure 17). The selectivity for cluster 3 is very poorly determined on the left hand side of the mode (18 years) because it is applied only to mature fish and they do not start maturing until about 25 years (Figure 18). This is a parameterisation issue and the more useful curve is the proportion selected at age (in equilibrium) which is well defined being the product of maturation and selectivity (Figure 19).

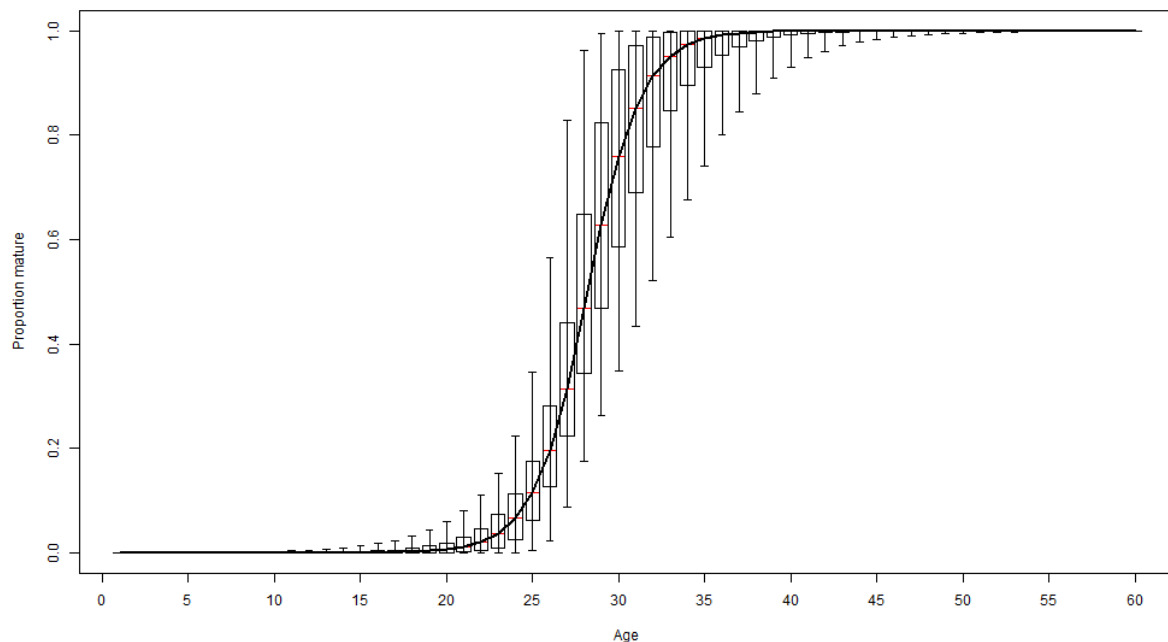


Figure 17: MCMC estimated proportion mature at age at equilibrium. The box for each age class covers the middle 50% of the distribution and the whiskers extend to 95% CIs.

The MCMC estimates of YCS are fairly uniform with no long-term trends apparent (Figure 20). This flows through into the stock status trajectory which is driven by the catch history, with the only substantive decline from 1994 to 1996 (Figure 21). Stock status is estimated to have always been above 50% B_0 (Figure 21). Exploitation rates are estimated to have been as high as 35% in 1995 but since 2000 have been well under 5% (Figure 22).

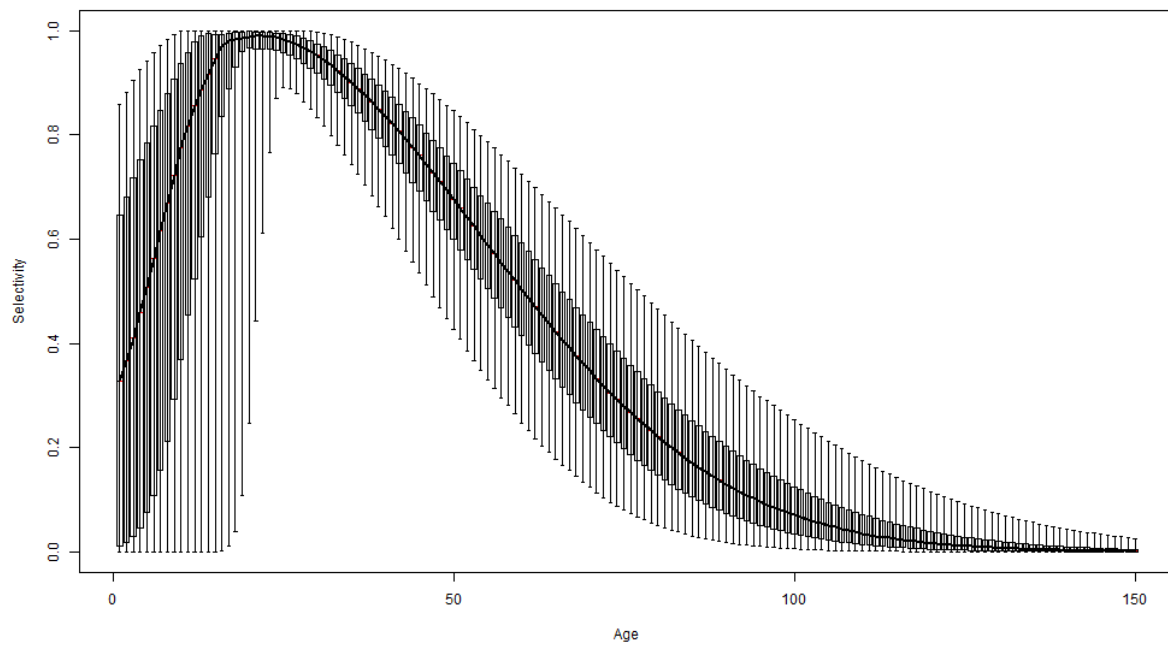


Figure 18: MCMC estimated selectivity for the cluster 3 fishery (which is only applied to mature fish). The box for each age class covers the middle 50% of the distribution and the whiskers extend to 95% CIs.

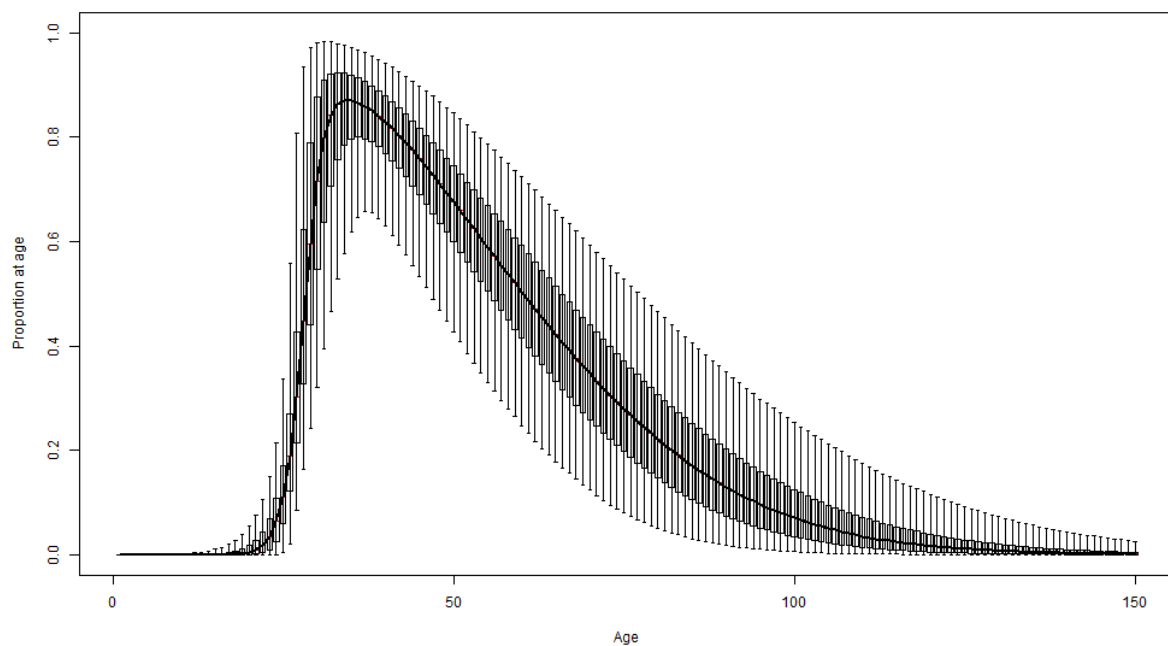


Figure 19: MCMC estimated proportion selected at age for the cluster 3 fishery when the population is at equilibrium. The box for each age class covers the middle 50% of the distribution and the whiskers extend to 95% CIs.

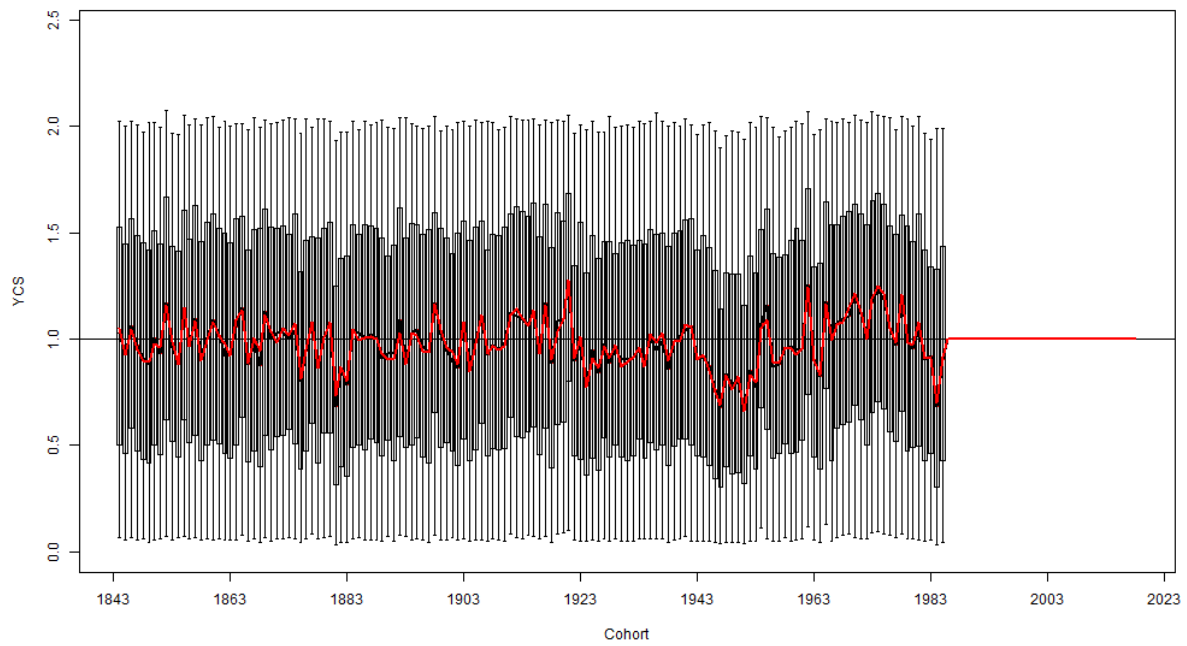


Figure 20: MCMC estimated year class strengths (1844 to 1985). The box for each cohort covers the middle 50% of the distribution and the whiskers extend to 95% CIs.

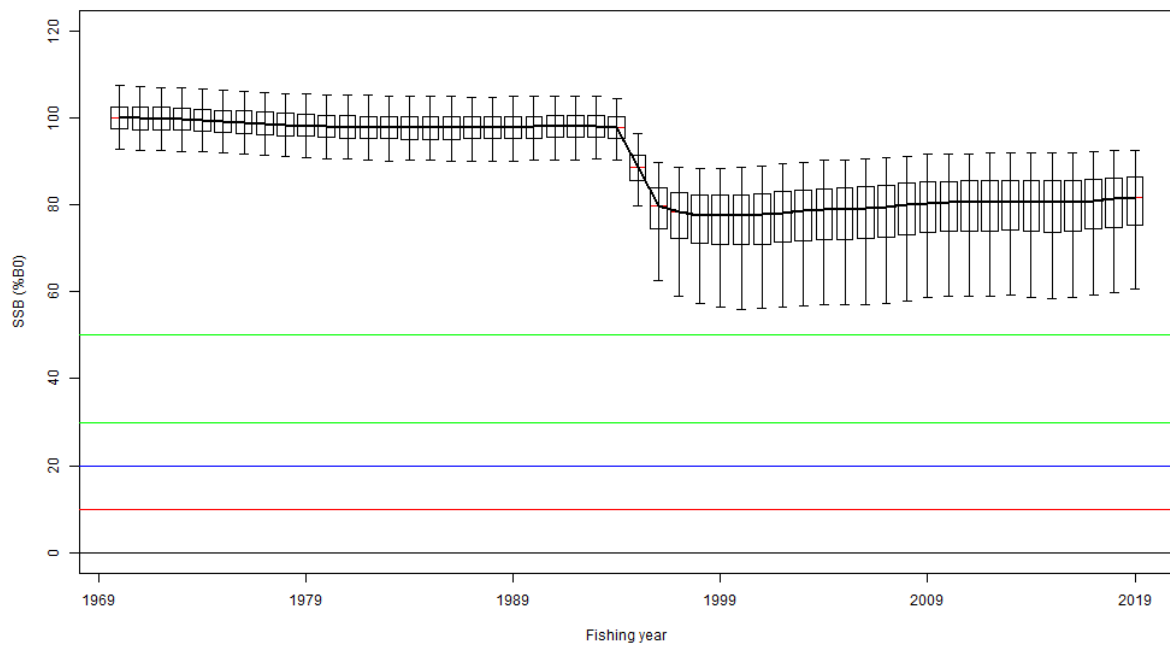


Figure 21: MCMC estimated stock status trajectory (last 50 years) The box for each fishing year covers the middle 50% of the distribution and the whiskers extend to 95% CIs. Horizontal lines are marked at 10%, 20%, 30% and 50% B_0 .

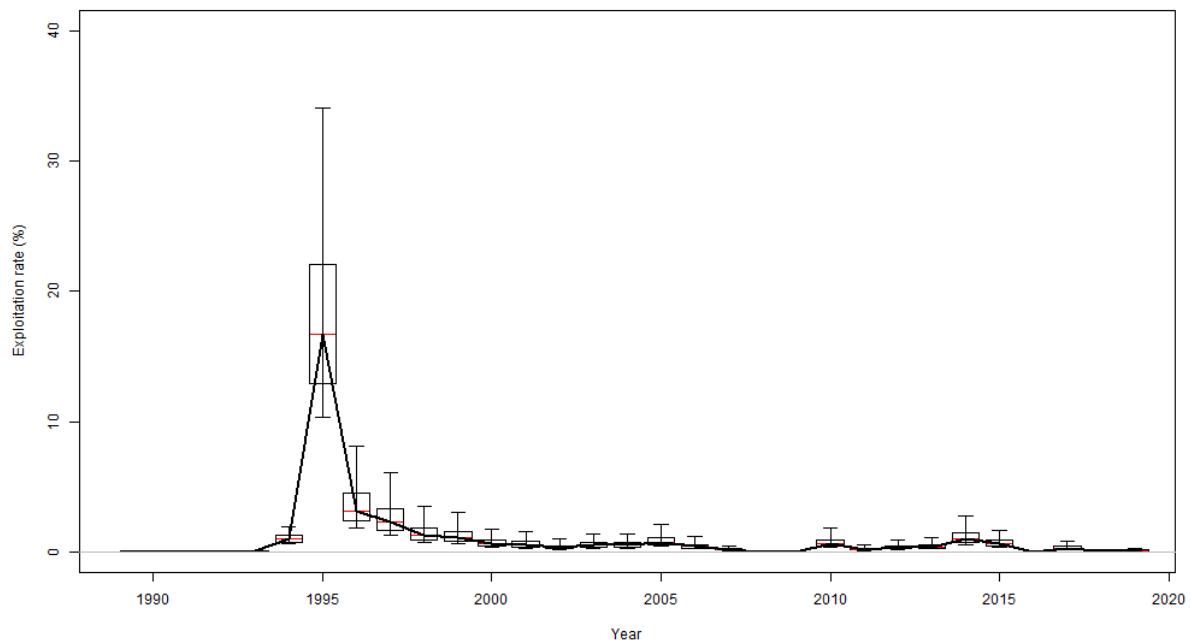


Figure 22: MCMC estimated exploitation rates. The box for each fishing year covers the middle 50% of the distribution and the whiskers extend to 95% CIs.

The MPD sensitivity runs show that stock status and B_0 estimates are sensitive to the data weightings while the estimate of M is strongly influenced by the prior (Table 5). However, the estimates of current stock status range from 55-78% B_0 and are well above any sensible target or limit reference points (and these are only MPD estimates – the final stock assessment estimates are the MCMC estimates). It is notable that larger effective sample sizes provide the highest estimates of B_0 and stock status. Use of a Ricker stock recruitment relationship instead of a Beverton-Holt relationship made little difference to the estimates (Table 5).

Table 5: MPD estimates of M , B_0 , and 2019 stock status for the base model and sensitivities (respectively: half the effective sample sizes, double the effective sample sizes, removal of the length frequencies, a uniform prior on M , and a Ricker stock recruitment relationship with h estimated at 0.93).

	M	B_0 (000 t)	ss_{19} (% B_0)
Half N	0.033	44	59
Base	0.030	52	67
Double N	0.028	65	78
No LFs	0.031	47	55
Uniform M	0.022	37	74
Ricker (0.93)	0.029	46	67

The MCMC sensitivity runs show that in terms of probability mass the estimate M is not particularly sensitive to the use of the informed prior (0.027 compared to 0.030) (Table 6). As for the MPD runs, the use of Ricker makes little difference to the estimates (Table 6). It is

notable that the MCMC median estimates of B_0 and current stock status are all higher than the corresponding MPD estimates (Tables 5 & 6).

Table 6: MCMC estimates of M , B_0 , and 2019 stock status for the base model and sensitivities (respectively: a Ricker stock recruitment relationship with h estimated: median = 1.12, 95% CI: 0.38-2.37; and a uniform prior on M).

	M		B_0 (000 t)		ss_{19} (% B_0)	
	Median	95% CI	Median	95% CI	Median	95% CI
Base	0.030	0.025-0.035	71	34-117	82	61-93
Ricker	0.030	0.025-0.036	71	34-118	82	60-95
Uniform M	0.027	0.023-0.033	63	31-114	80	57-93

The stock assessment estimates for the North and South stocks are very imprecise because no data other than catch history are used in the assessments. They borrow the biological parameters and YCS from the Central assessment but there is nothing to constrain B_0 other than the assumptions about maximum exploitation rate.

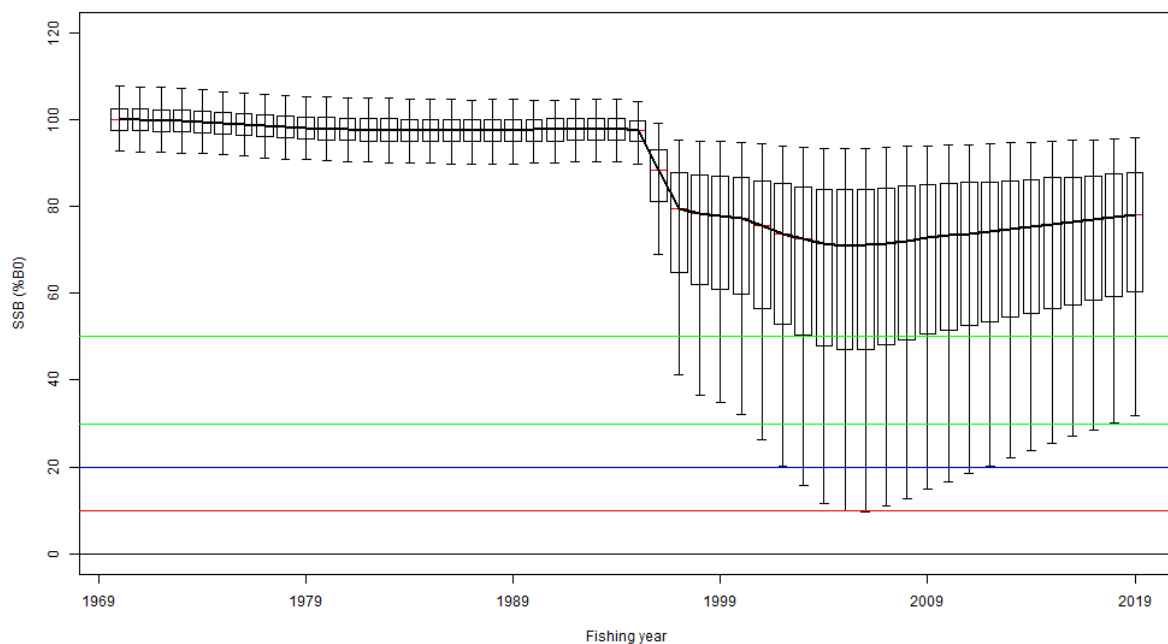


Figure 23: Louisville North: MCMC estimated stock status trajectory (last 50 years) The box for each fishing year covers the middle 50% of the distribution and the whiskers extend to 95% CIs. Horizontal lines are marked at 10%, 20%, 30% and 50% B_0 .

Stock status for Louisville North may have been as low as 10% B_0 in the mid-2000s but current stock status is estimated to almost certainly be above 30% B_0 (Figure 23, Table 7). Exploitation rates may have been over 50% in 1996 but since 2007 there has been almost no catch and exploitation rates are very low (Figure 24).

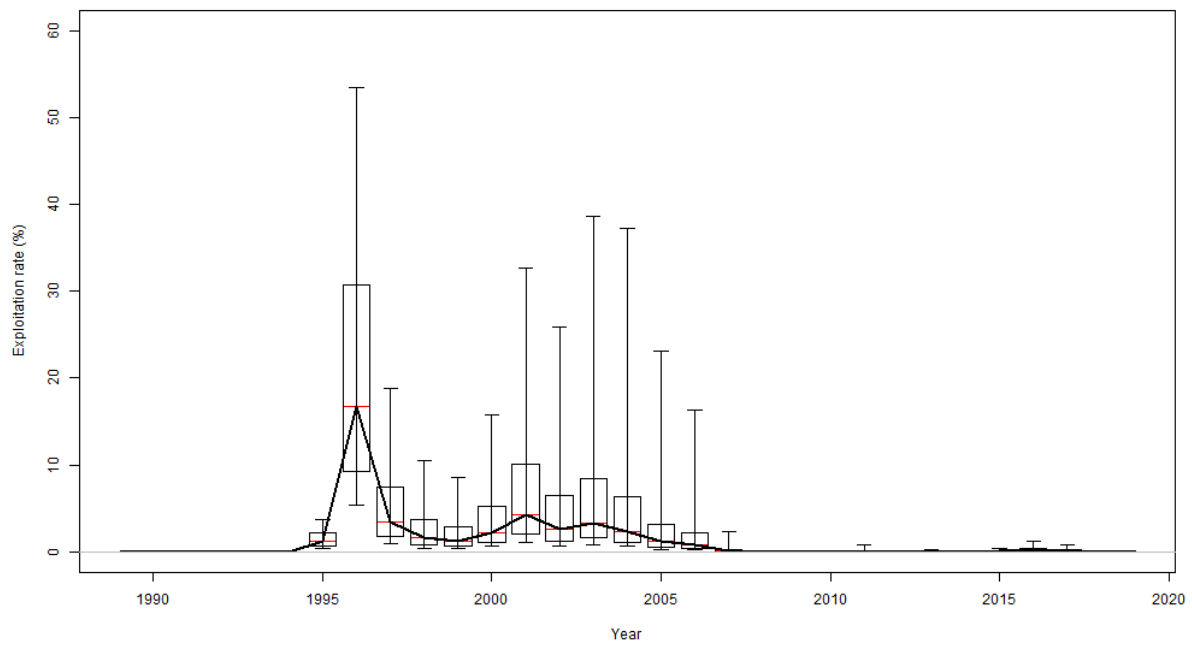


Figure 24: Louisville North: MCMC estimated exploitation rates. The box for each fishing year covers the middle 50% of the distribution and the whiskers extend to 95% CIs.

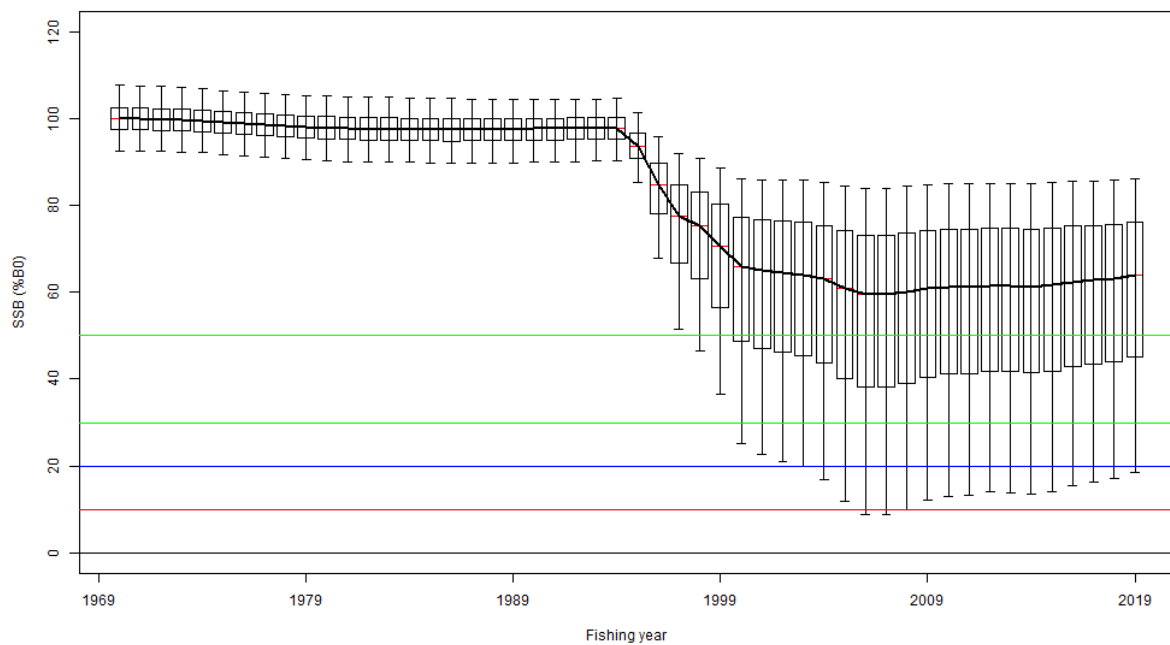


Figure 25: Louisville South: MCMC estimated stock status trajectory (last 50 years) The box for each fishing year covers the middle 50% of the distribution and the whiskers extend to 95% CIs. Horizontal lines are marked at 10%, 20%, 30% and 50% B_0 .

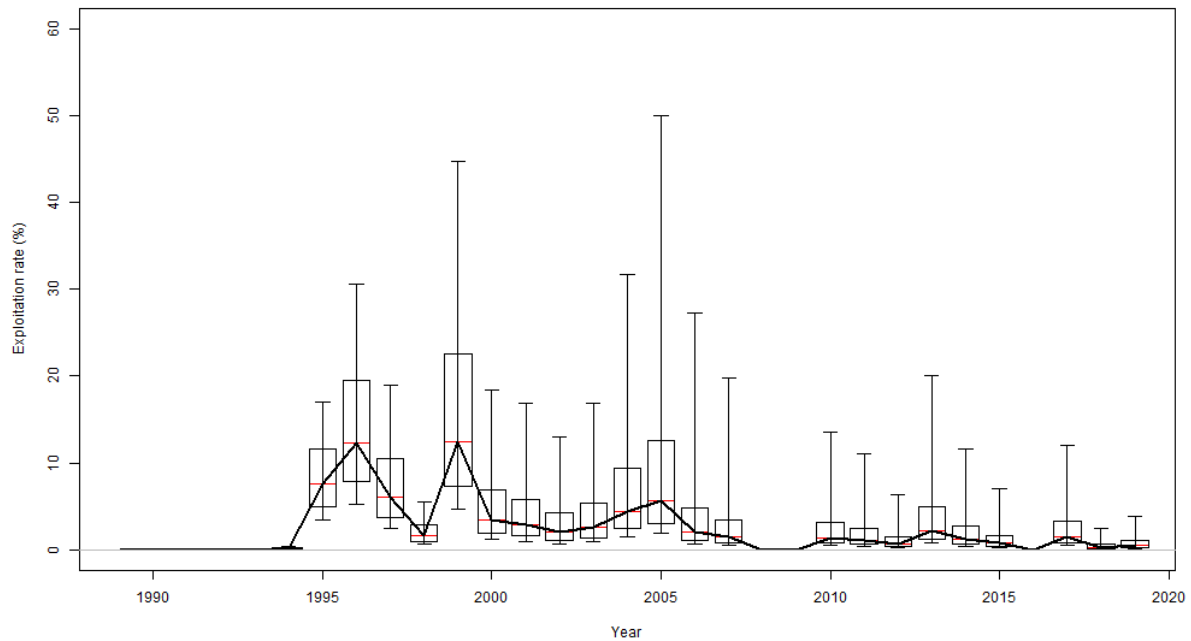


Figure 26: Louisville South: MCMC estimated exploitation rates. The box for each fishing covers the middle 50% of the distribution and the whiskers extend to 95% CIs.

Stock status for Louisville South may have been as low as 10% B_0 in the mid-2000s but current stock status is estimated to very likely be above 20% B_0 (Figure 25, Table 7). Exploitation rates may have been over 10% in most years up to 2017 but in the last two years are estimated to be under 5% (Figure 26).

When the Louisville Ridge is modelled as a single stock the results are similar to the totals derived from adding the results from the three stock assessments together (Table 7). Two variations of the single stock model are given using different maximum exploitation rate assumptions – a 10% minimum requirement limits the upper range of estimates compared to a 5% minimum requirement and therefore gives higher median estimates (Table 7).

Table 7: MCMC estimates of B_0 , 2019 stock status, and long-term yield for the Louisville Ridge base models and single stock sensitivities (a single stock with maximum exploitation rate $\geq 10\%$ or $\geq 5\%$). The probability of 2019 stock status being less than 20% B_0 or greater than 30% B_0 is also given.

	B_0 (000 t)		ss_{19} (% B_0)		Yield (t)		$P(ss_{19} < 20\% B_0)$	$P(ss_{19} > 30\% B_0)$
	Median	95% CI	Median	95% CI	Median	95% CI		
Central	71	34-117	82	61-93	710	340-1170	0.00	1.00
North	26	8-80	78	32-96	260	82-800	0.00	0.98
South	25	11-55	64	18-86	250	110-550	0.04	0.89
Total	122	53-252			1220	530-2520		
One 10%	108	65-140	74	56-84	1080	650-1400	0.00	1.00
One 5%	133	69-196	80	59-90	1330	690-1960	0.00	1.00

5. Discussion and conclusion

The stock assessment estimates for Louisville Ridge produced by Cordue (2017) used biological parameters and YCS borrowed from New Zealand EEZ stocks. No data other than catch histories were available and consequently the estimates were very imprecise (Table 8).

Table 8: From Cordue (2017): combined results for each SPRFMO stock giving the five individual models equal weight. Estimates of virgin biomass (B_0), stock status in 2015 (ss_{15}), the probability of being below 20% B_0 in 2015 ($P(ss < 20)$), the probability of being above 30% B_0 in 2015 ($P(ss > 30)$), and the long term annual yield (1.4% of B_0) are given. Point estimates are in grey as they are unreliable being driven by the minimum maximum exploitation rate assumption.

	B_0 (000 t)	95% CI	ss_{15}	95% CI	$P(ss < 20)$	$P(ss > 30)$	Yield (t)	95% CI
Louis N	24	8-69	74	32-92	0	99	340	110-970
Louis C	34	15-87	66	24-87	1	93	480	200-1200
Louis S	23	11-49	60	18-82	5	87	320	150-690

In contrast, for the current Louisville Central assessment, data specific to the stock were available to estimate growth curves, length-weight parameters, YCS, and M, in addition to virgin and current stock size. Although no biomass indices were available, the composition data were adequate to rule out very high exploitation rates in 1995 (when there was a spike in catches) and therefore eliminate low values of B_0 and current stock status. The contrast in the results illustrates this point with the previous 95% CI for B_0 : 15 000-87 000 t, and the current 95% CI: 34 000-117 000 t. Stock status in 2015 was estimated at 24-87 % B_0 but for 2019 it is estimated at 61-93 % B_0 .

The increased upper limit on B_0 compared to the previous assessment will be almost entirely due to a difference in the estimated catch in 1995. In the previous assessment the catch histories derived by Roux et al. (2017) were used and they had a lower catch for Louisville Central in 1995 (about 9000 t compared to about 11 500 t). It may be that Roux et al. (2017) did not include catches from other countries in the early years.

For Louisville North and South the current estimates of B_0 and stock status are very similar to the previous estimates (Table 7 & 8). This is not surprising as the results are driven by the catch histories (which are little changed) and the maximum exploitation rate assumptions (which are identical). The big difference is in the estimates of long-term yield because 1% of B_0 is now being used instead of 1.4% B_0 because of the stock specific estimate of M (0.03) and the revised estimate of h (0.6). The point estimate of total long-term yield is little changed because the increase for Central compensates for the decrease for North and South (previous total 1140 t, current total 1220 t).

There is still large uncertainty in the estimates of virgin and current stock size for the Louisville Ridge orange roughy stocks. However, the new data have allowed the estimation of stock specific parameters and enabled a much more precise stock assessment for Louisville Central. The suite of sensitivity runs was designed to explore situations in which the model for Louisville Central might be optimistic with respect to the probability of stock status being very low. Encouragingly, none of the sensitivity runs returned an appreciably higher probability of low stock status than the base model.

The assessments for North and South have also benefited as parameters borrowed from Central are much more likely to be appropriate than those previously borrowed from New Zealand EEZ stocks. The new estimate of M is particularly important as it points to lower yields per unit of biomass for these stocks compared to the New Zealand EEZ stocks.

As for every stock assessment, the stock assessment results are conditional on the stock hypothesis and the representativeness of the data. For Louisville Central, the composition data could be unrepresentative of the population if the cluster 1&2 seamounts where the fishery concentrates are highly preferred spawning locations for older, more dominant fish and such fish were replaced by others from surrounding areas as they were removed by the fishery. We have no data to test this hypothesis.

As the input data does not include any biomass estimates the results should be treated with some caution. The median estimates of stock status and long term yield are driven by the maximum exploitation rate assumptions and are less reliable than the estimates of “minimum” biomass (e.g., the lower bounds of the 95% CIs and the probability of being below 20% B_0).

Although current stock status for each of the stocks is quite uncertain, it is likely that Louisville Central is currently above 50% B_0 , while Louisville North is likely above 30% B_0 . There is a possibility that Louisville South is below 20% B_0 but it likely well above this level.

6. Recommendations

It is recommended that the Scientific Committee:

- **notes** that the Louisville Ridge stock assessments have been updated using age and length frequency data from Louisville Central;
- **notes** that the current stock status for Louisville Central and North is likely above 30% B_0 ;
- **notes** that current stock status for Louisville South is likely above 20% B_0 ;
- **notes** that the current catch limit of 1140 t for Louisville Ridge is close to the total long-term yield estimate of 1220 t;
- **agrees** that the current stock assessment is the best currently available information on which to base management advice for Louisville Ridge orange roughy stocks.

7. Acknowledgments

This work was funded by the New Zealand Ministry for Primary Industries.
Thanks to NIWA for the use of their stock assessment package CASAL

8. References

- Bull, B; Francis, R.I.C.C; Dunn, A.; Gilbert, D.J.; Bian, R.; Fu, D. (2012). CASAL (C++ algorithmic stock assessment laboratory): CASAL User Manual v2.30-2012/03/21. *NIWA Technical Report* 135. 280 p.
- Clark, M.R; McMillan; P.J.; Anderson, O.F.; Roux, M.-J. (2016). Stock management areas for orange roughy (*Hoplostethus atlanticus*) in the Tasman Sea and western South Pacific Ocean. *New Zealand Fisheries Assessment Report* 2016/19.
- Cordue, P.L. (2014)a. The 2014 orange roughy stock assessments. *New Zealand Fisheries Assessment Report* 2014/50. 135 p.
- Cordue, P.L. (2014)b. A management strategy evaluation for orange roughy. ISL Client Report for Deepwater Group Ltd. 42 p.
- Cordue, P.L. (2017). Catch-history based stock assessments of seven SPRFMO orange roughy stocks. Paper for the Scientific Committee of the South Pacific Regional Fisheries Management Organisation, Shanghai, 23-28 August 2017. 25 p. SC5-DW14.
- Cordue, P.L. (2019). Review of the Harvest Control Rule for orange roughy fisheries in New Zealand. ISL Client Report for Deepwater Group Ltd. 28 p.
- Fisheries New Zealand (2018). Fisheries Assessment Plenary, May 2018: stock assessments and stock status. Compiled by the Fisheries Science and Information Group, Fisheries New Zealand, Wellington, New Zealand. 1674 p.
- Horn, P.L.; Ó Maolagáin, C. (2019). A comparison of age data of orange roughy (*Hoplostethus atlanticus*) from the central Louisville Seamount Chain in 1995 and 2013–15. *New Zealand Fisheries Assessment Report* 2019/29. 34 p.
- Roux, M.-J.; Doonan, I.; Edwards, C.; Clark, M.R. (2017). Low information stock assessment of orange roughy *Hoplostethus atlanticus* in the South Pacific Regional Fisheries Management Organisation Convention Area. *New Zealand Fisheries Assessment Report* 2017/01. 62 p.

Appendix A: Base model chain diagnostics

Three chains each of 5 million were used for the base model with 1 sample in every 1000 stored. A burn in of 500 samples was used on the basis of the movement away from the MPD as seen in the objective function value (Figure A1). The chains appeared to mix well (e.g., the mixing of B_0 shown in Figure A2).

Although the median value of B_0 was a bit different across the three chains (Figure A3) the three chains were of adequate length as evidenced by the convergence of the median estimate and the 95% CI (Figures A4 & A5). The chains were also adequate for 2019 stock status (Figures A6-A8) and M (Figures A9-A11).

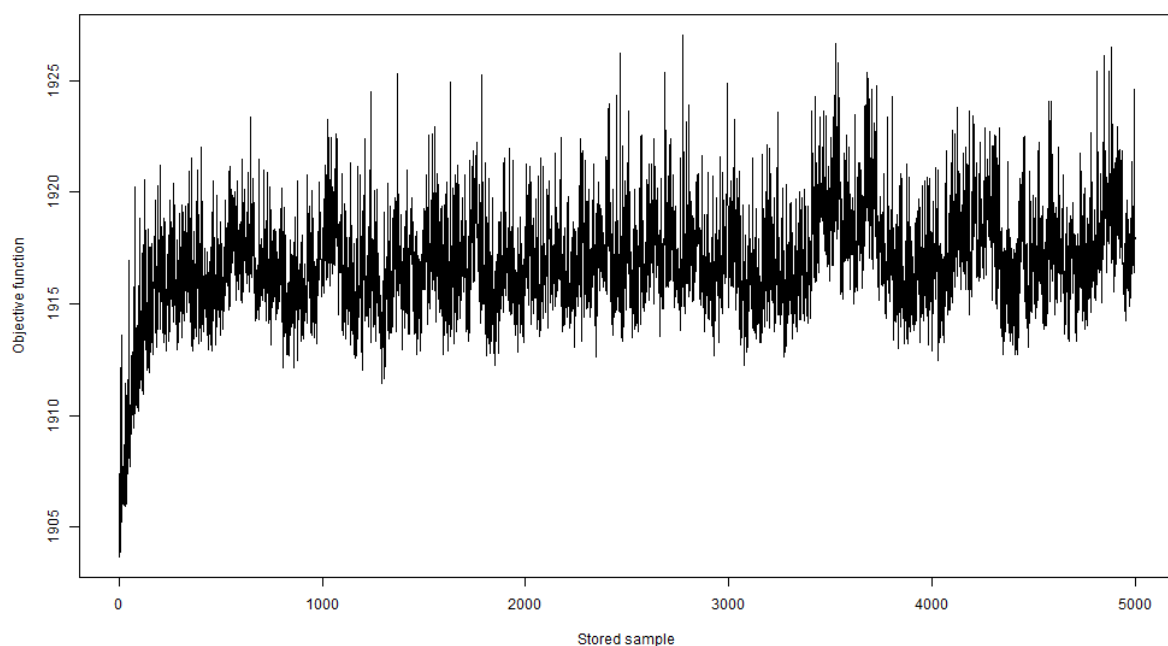


Figure A1: The objective function for the first of the three base model chains. The chain starts at a random jump from the MPD estimate which is why the lowest values are at the start of the chain. The first 500 stored samples were deleted as a “burn in” (i.e., they were not used in the production of plots or the calculation of estimates).

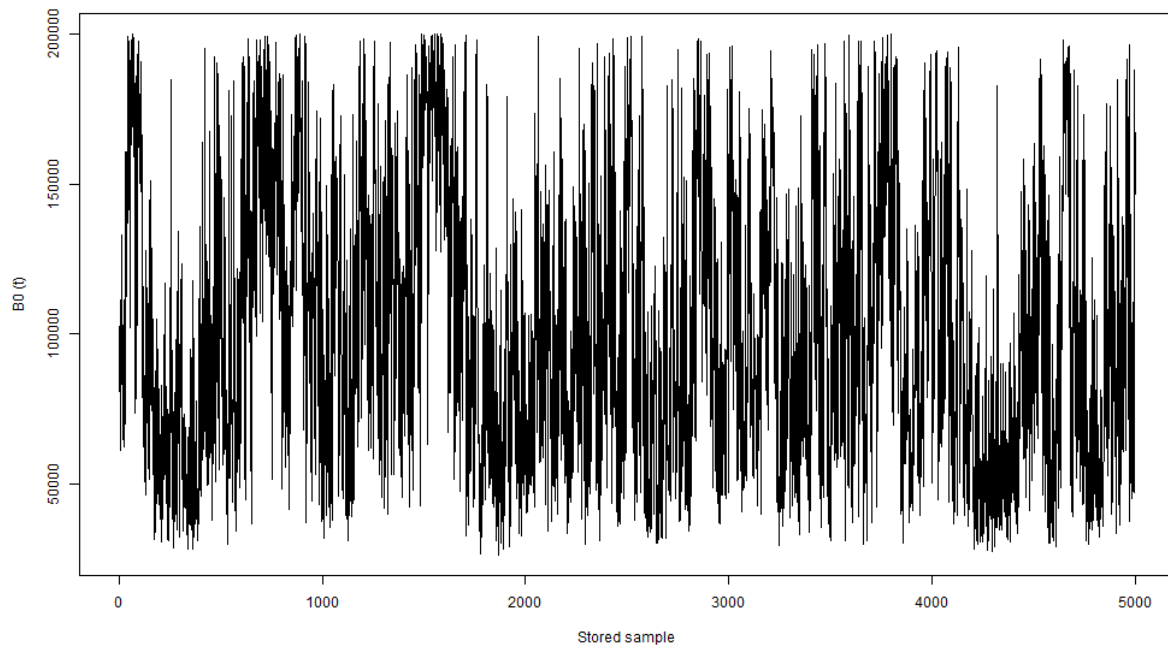


Figure A2: The B_0 samples for the first of the three base model chains. The chain is mixing well as evidenced by the frequency with which the full range of B_0 values is sampled (the upper bound was 200 000 t).

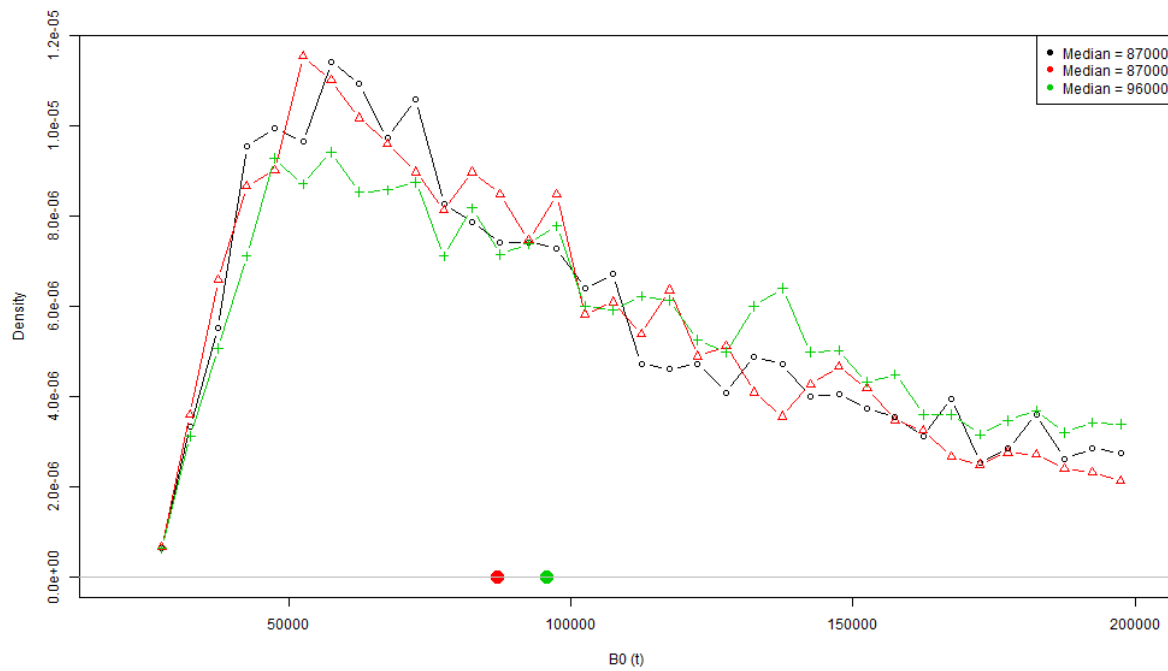


Figure A3: The marginal posterior distributions of B_0 for each of the three base model chains (after burn in). The median for each chain is plotted on the x axis.

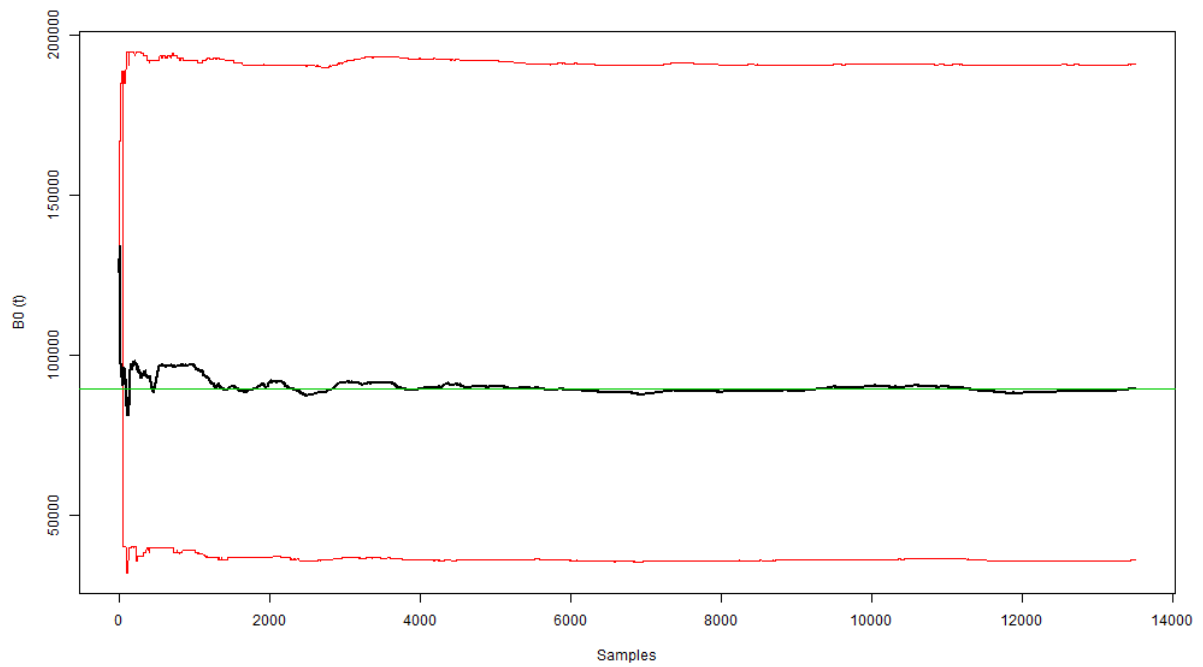


Figure A4: The median and 95% CI for B_0 as a function of chain length when the three chains are merged in parallel (after burn in, but before application of the maximum exploitation rate constraint). A horizontal line is drawn at the final median estimate of B_0 .

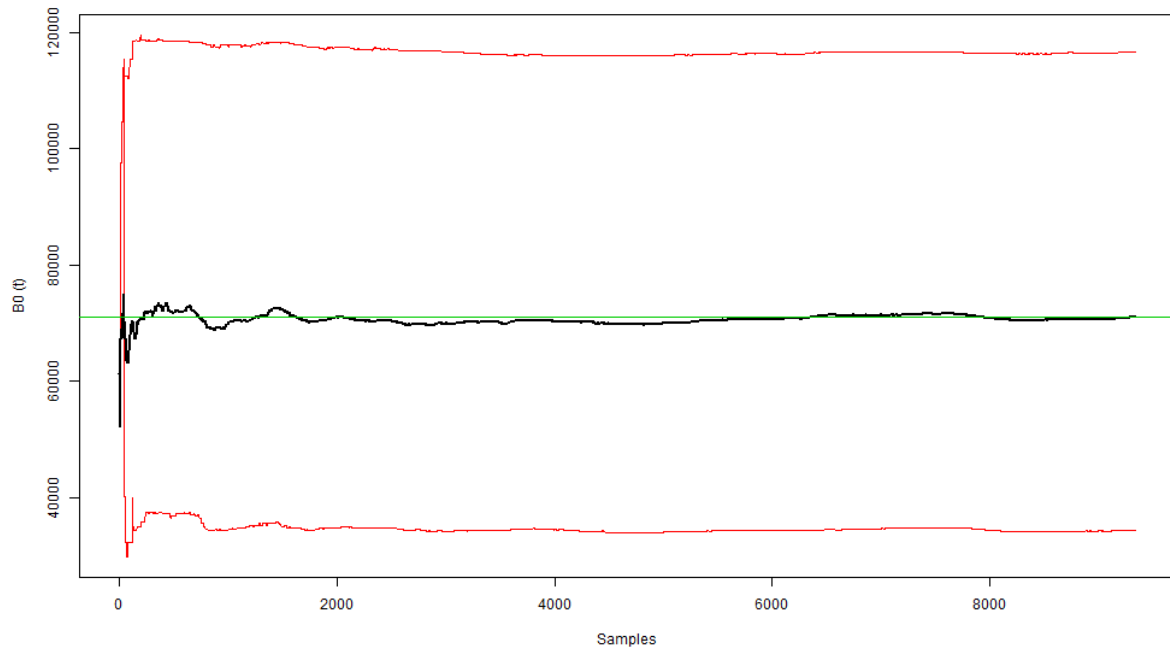


Figure A5: The median and 95% CI for B_0 as a function of chain length when the three chains are merged in parallel (after burn in and application of the maximum exploitation rate constraint). A horizontal line is drawn at the final median estimate of B_0 .

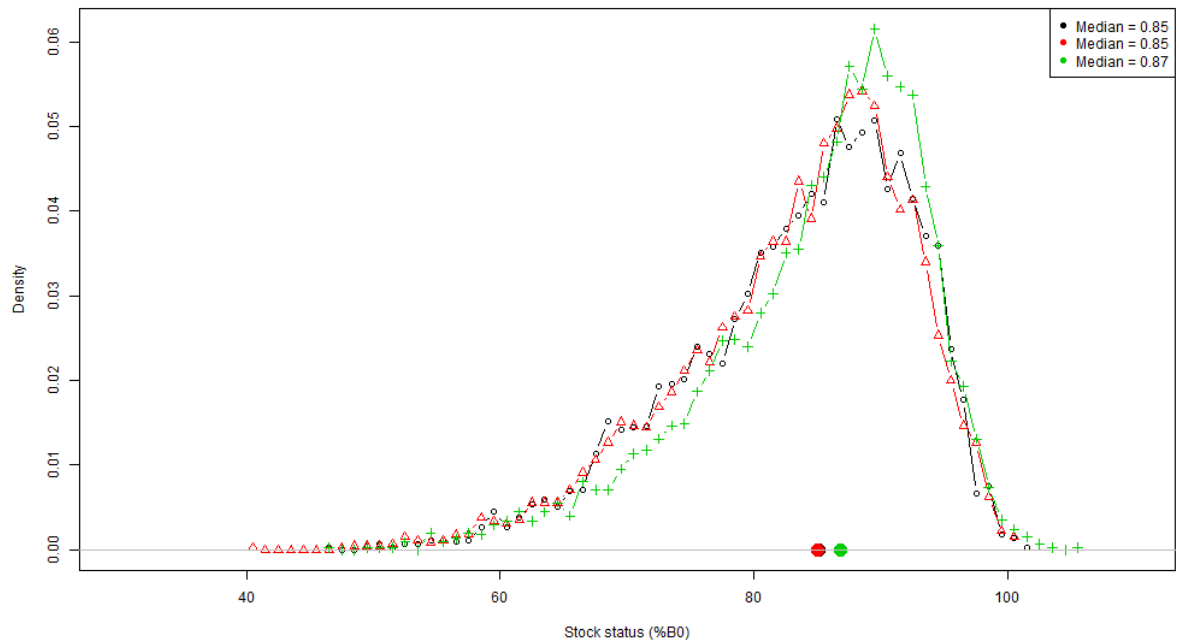


Figure A6: The marginal posterior distributions of 2019 stock status (B_{19}/B_0) for each of the three base model chains (after burn in). The median for each chain is plotted on the x axis.

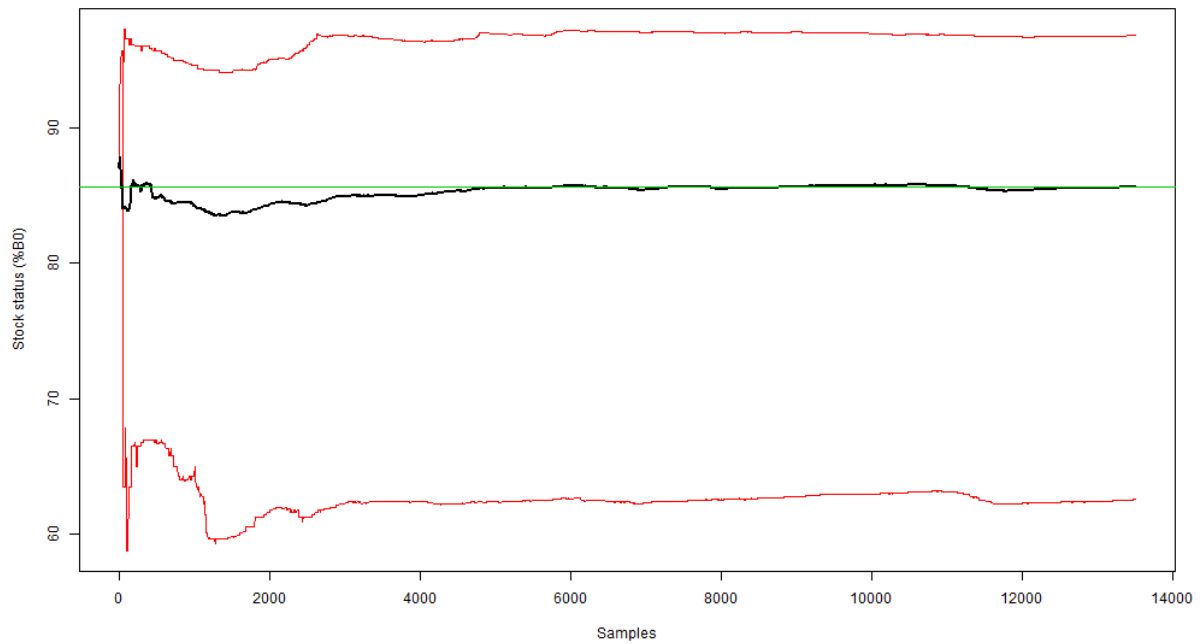


Figure A7: The median and 95% CI for 2019 stock status (B_{19}/B_0) as a function of chain length when the three chains are merged in parallel (after burn in, but before application of the maximum exploitation rate constraint). A horizontal line is drawn at the final median estimate of 2019 stock status.

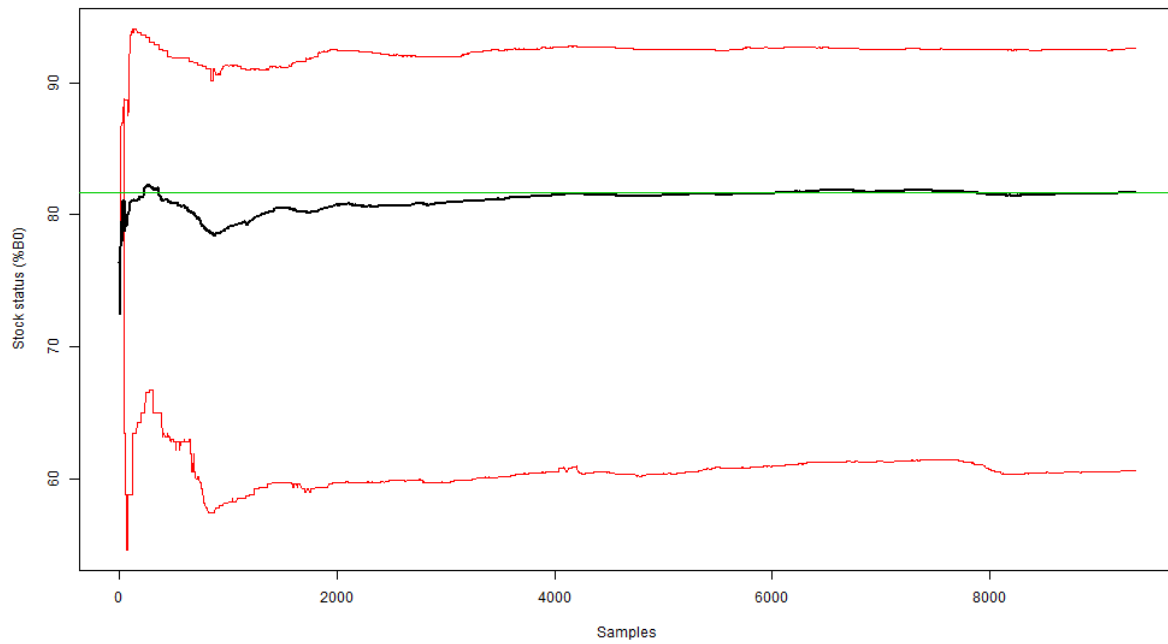


Figure A8: The median and 95% CI for 2019 stock status (B_{19}/B_0) as a function of chain length when the three chains are merged in parallel (after burn in and application of the maximum exploitation rate constraint). A horizontal line is drawn at the final median estimate of 2019 stock status.

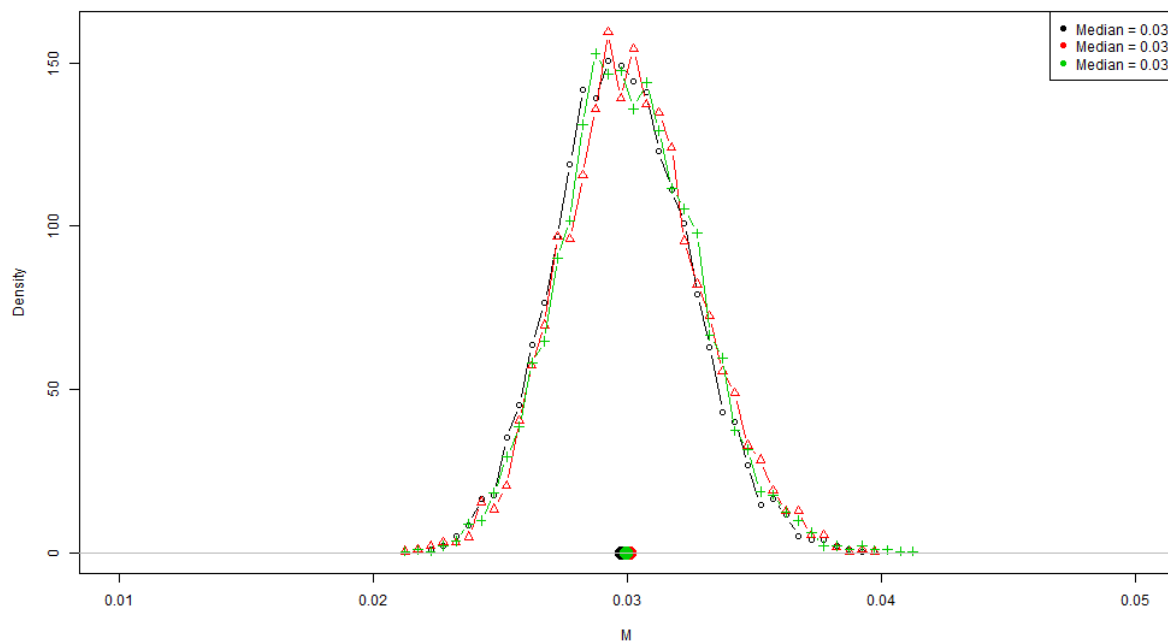


Figure A9: The marginal posterior distributions of M for each of the three base model chains (after burn in). The median for each chain is plotted on the x axis.

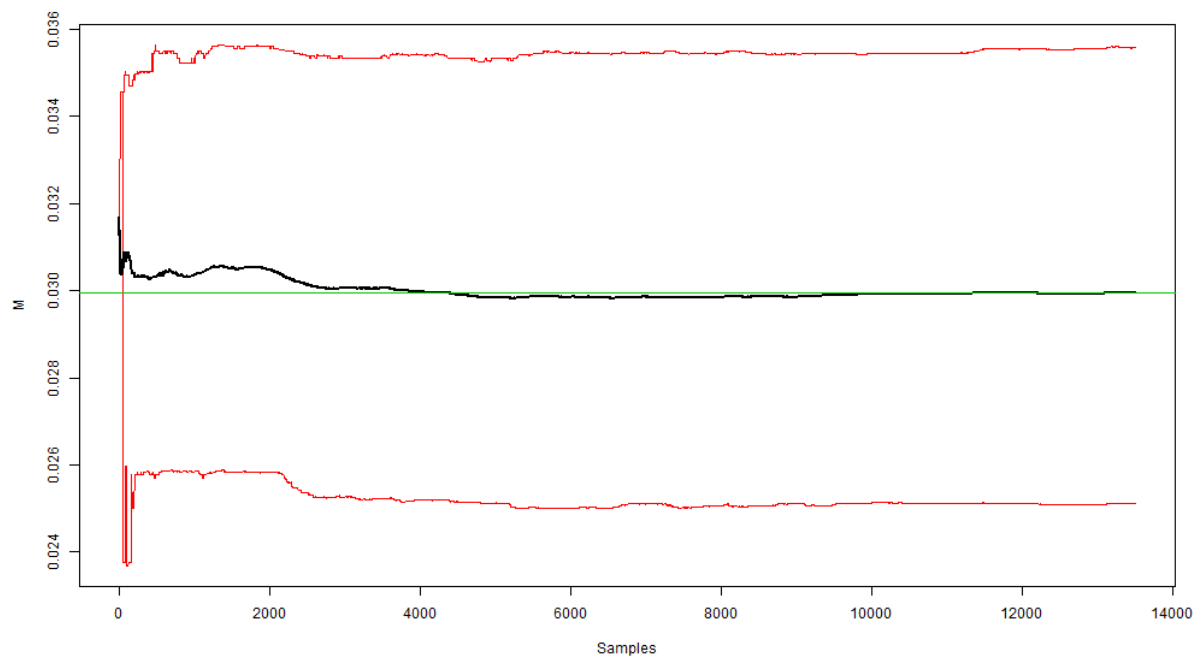


Figure A10: The median and 95% CI for M as a function of chain length when the three chains are merged in parallel (after burn in, but before application of the maximum exploitation rate constraint). A horizontal line is drawn at the final median estimate of M .

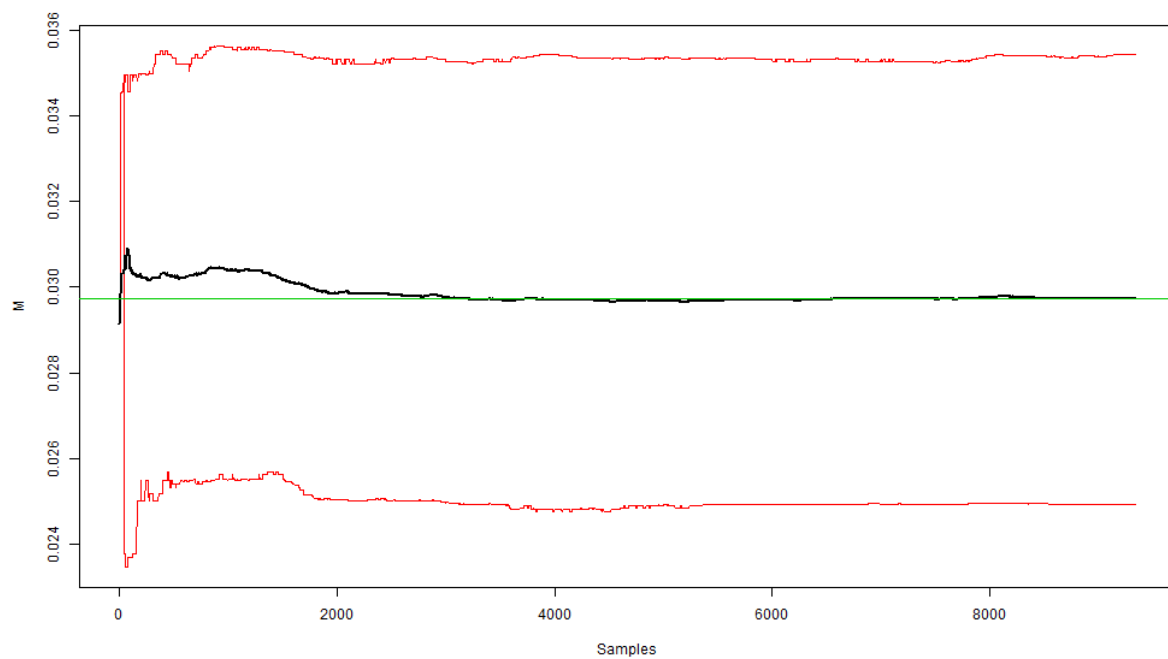


Figure A11: The median and 95% CI for M as a function of chain length when the three chains are merged in parallel (after burn in and application of the maximum exploitation rate constraint). A horizontal line is drawn at the final median estimate of M .

Appendix B: Base model MPD fits and likelihood profiles

The MPD fits to the age frequencies for cluster 1&2 (Figure B1) and cluster 3 (Figure B2) are as good as can be expected. It is not possible for the detail of very “spikey” data to be fitted well. The observed proportion in the plus group is under-estimated in each of the four years for cluster 1&2 (Figure B1). However, it must be remembered that this is only a single observation for each age frequency which has 136 age classes.

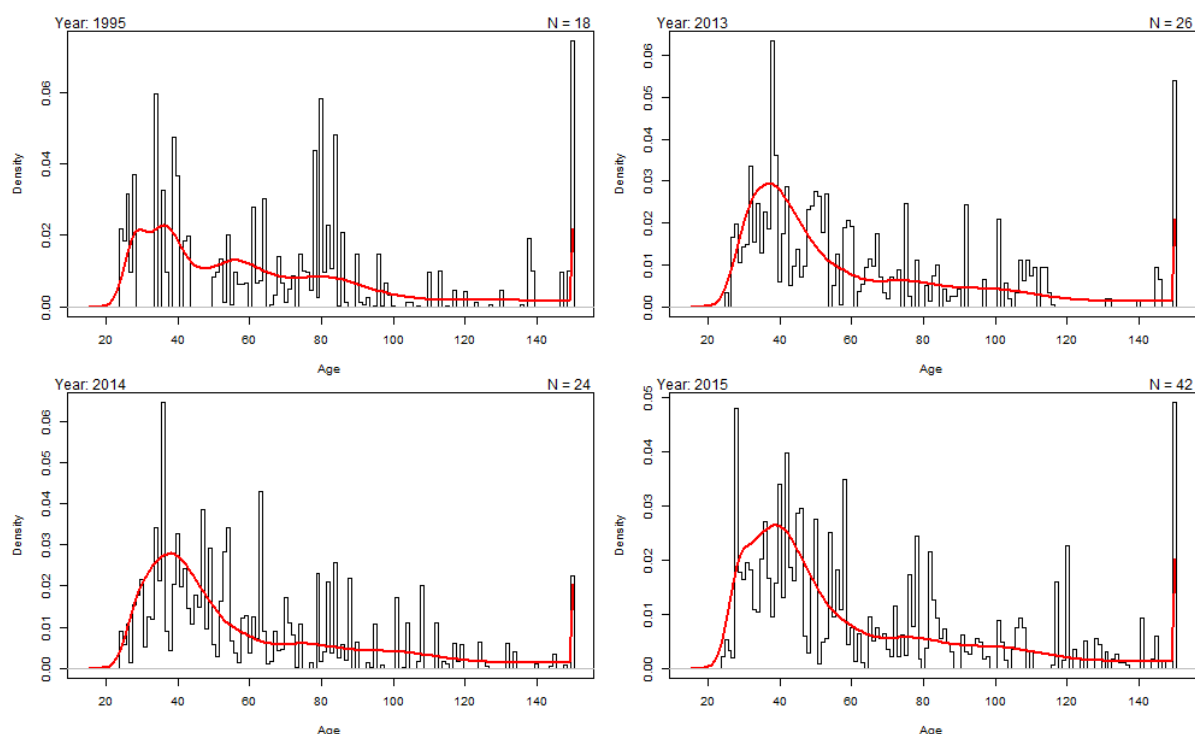


Figure B1: Base model MPD: fits to the cluster 1&2 age frequencies. The data are plotted as a histogram and the predicted proportions at age are plotted as a smooth line (in red). N is the effective sample size.

The length frequencies for cluster 1&2 are fitted very well except in 2017 (Figure B3). For cluster 3 there is an indication that predicted lengths are somewhat higher than observed which may be due to some slight growth differences between cluster 1&2 and cluster 3 (Figure B4).

The likelihood profile for B_0 shows very little contrast for values of B_0 greater than about 50,000 t (Figure B5). When the profile is focused on lower values of B_0 it can be seen that the contrast in likelihood really only occurs for B_0 less than about 20,000 t (Figure B6). The data are poorly fitted at such low values of B_0 (Figure B6).

The likelihood profile for M shows that the MPD estimate (0.030) is a compromise between the low value of M preferred by the data (especially the age frequency for cluster 1&2) and the informed prior (Figure B7). When a uniform prior is used for M the MPD estimate is 0.022.

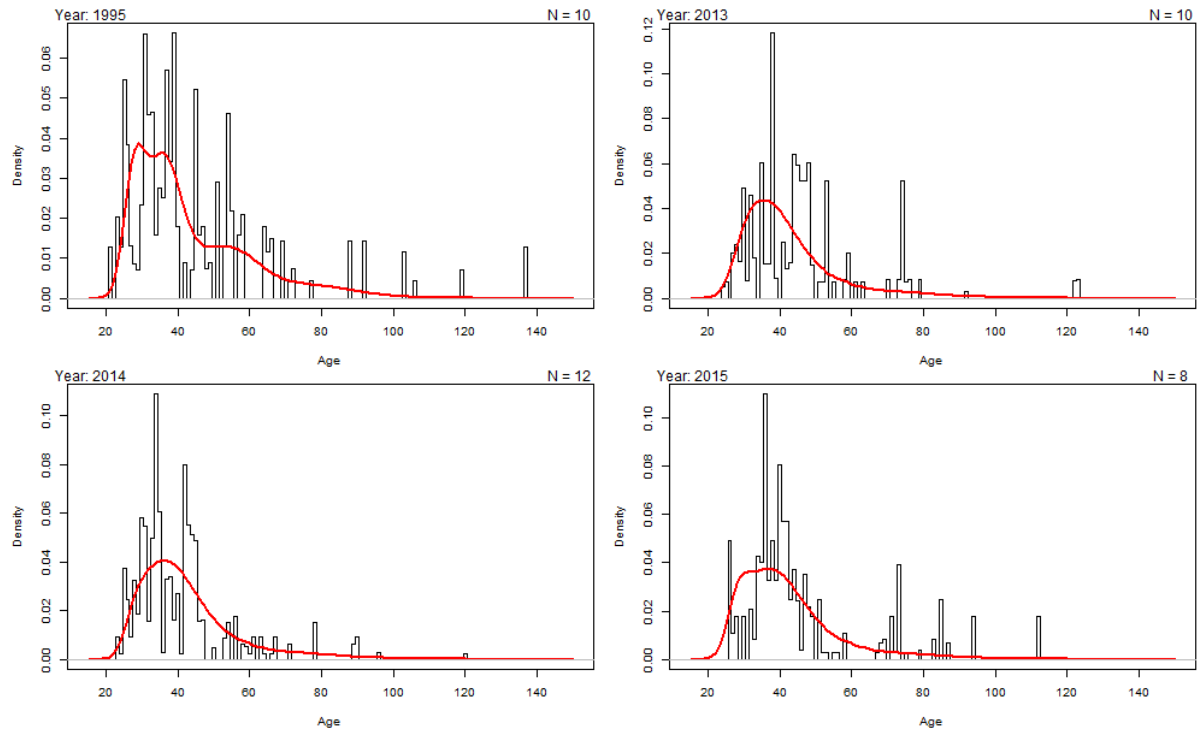


Figure B2: Base model MPD: fits to the cluster 3 age frequencies. The data are plotted as a histogram and the predicted proportions at age are plotted as a smooth line (in red). N is the effective sample size.

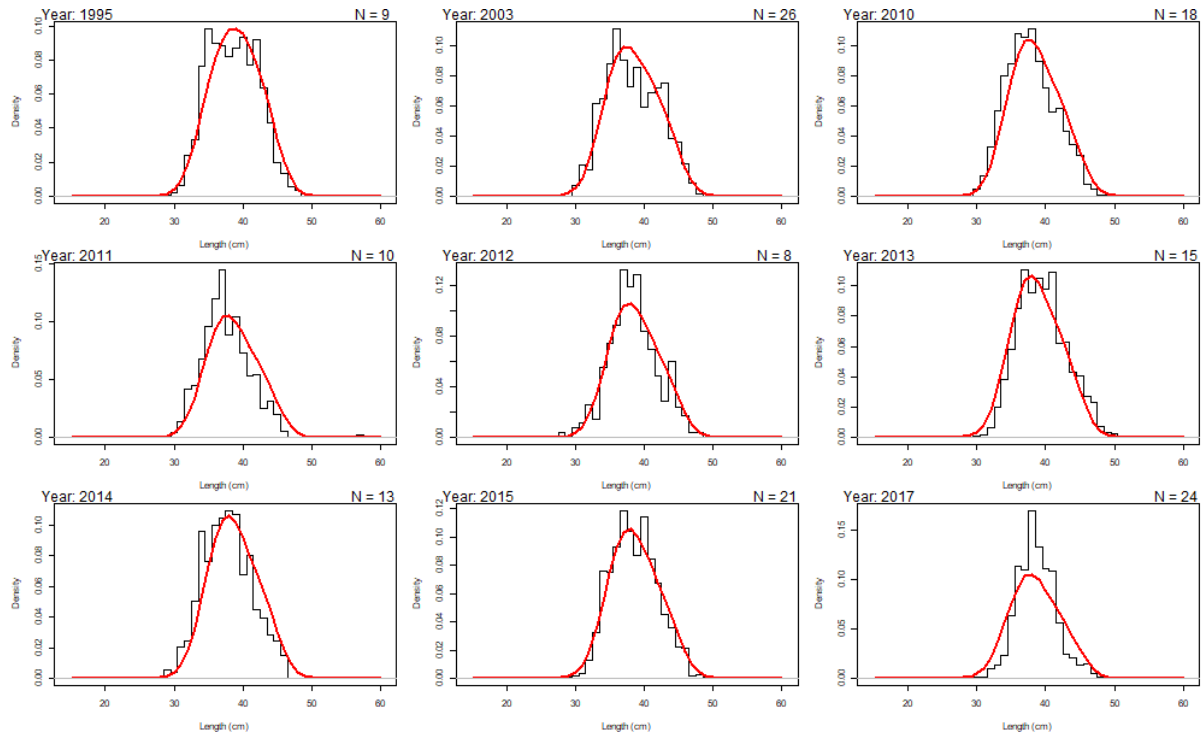


Figure B3: Base model MPD: fits to the cluster 1&2 length frequencies. The data are plotted as a histogram and the predicted proportions at length are plotted as a smooth line (in red). N is the effective sample size.

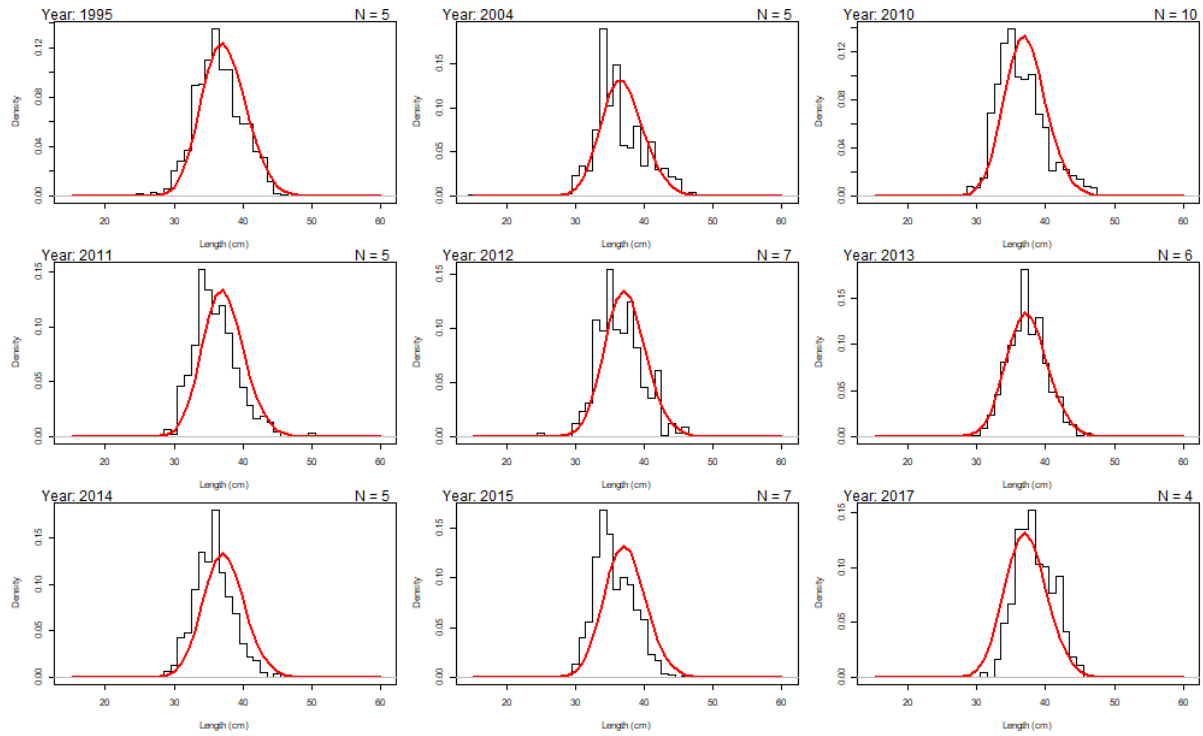


Figure B4: Base model MPD: fits to the cluster 3 length frequencies. The data are plotted as a histogram and the predicted proportions at length are plotted as a smooth line (in red). N is the effective sample size.

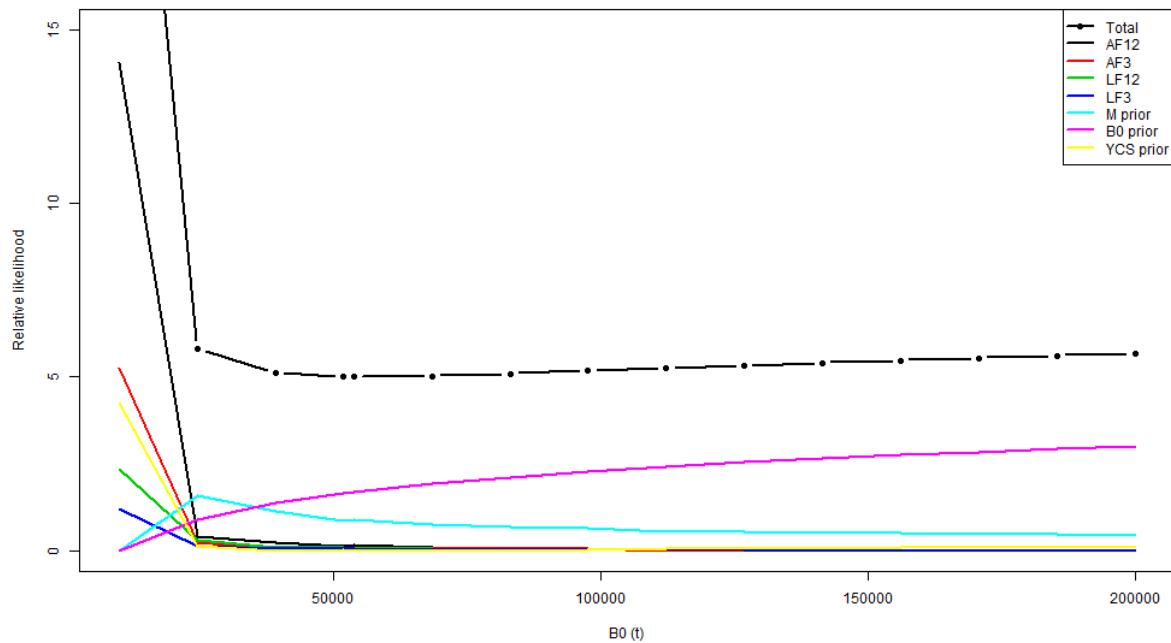


Figure B5: Base model MPD: likelihood profile for B_0 . The relative negative log likelihood is shown for each data set and the priors at fixed values of B_0 . The total negative log likelihood is offset from zero by an arbitrary amount.

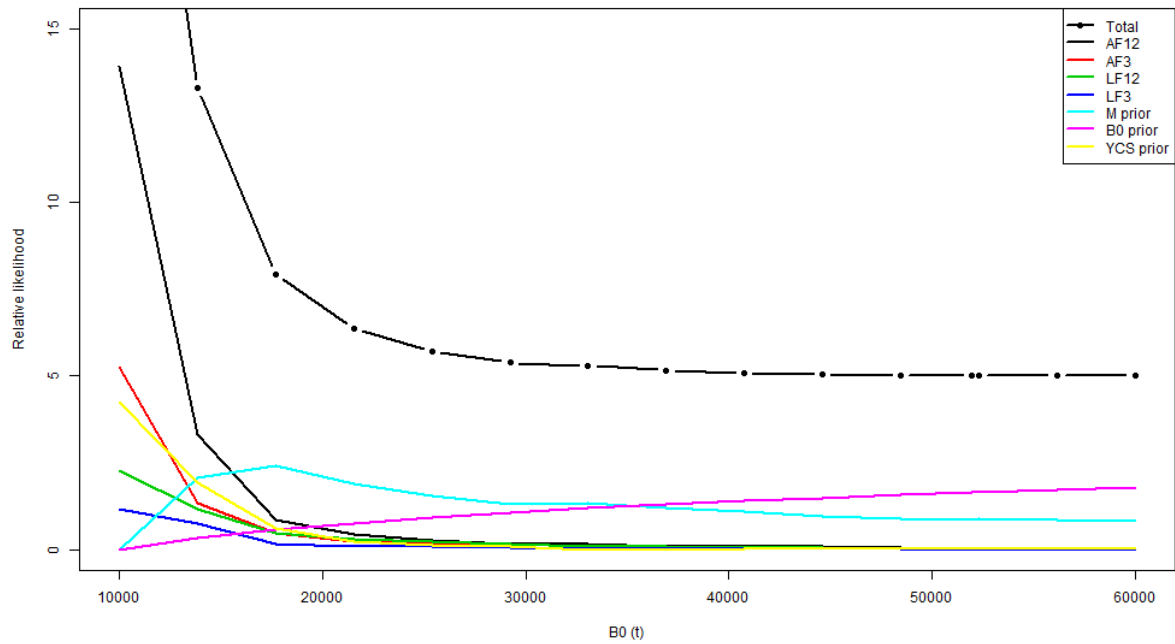


Figure B6: Base model MPD: likelihood profile for B_0 (over a restricted range for B_0). The relative negative log likelihood is shown for each data set and the priors at fixed values of B_0 . The total negative log likelihood is offset from zero by an arbitrary amount.

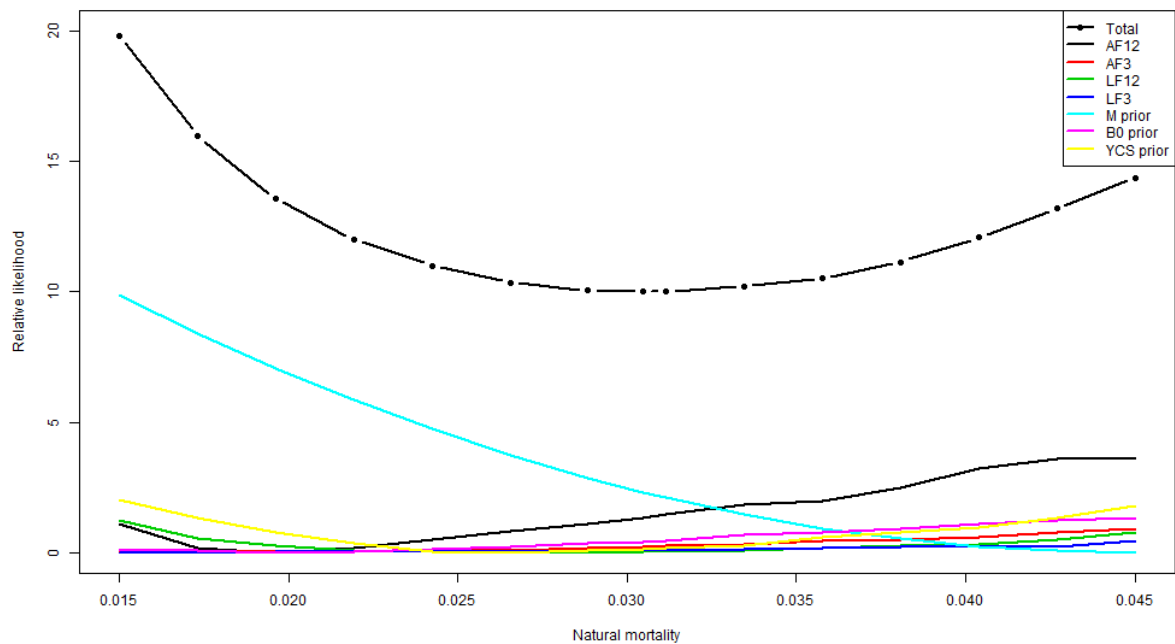


Figure B7: Base model MPD: likelihood profile for M . The relative negative log likelihood is shown for each data set and the priors at fixed values of M . The total negative log likelihood is offset from zero by an arbitrary amount.

Appendix C: Base model CASAL input files

The main input files, population.csl and estimation.csl are given below for the base Louisville Central model. For the North and South assessments only the population.csl files are given as there are no data available for the assessments (they use samples from the joint posterior distribution from the Central assessment).

Population.csl

Louisville Central: 2019 base model with two fisheries cluster3 and mainpop

PARTITION

@size_based False

@min_age 1

@max_age 150

@plus_group True

@sex_partition False

@mature_partition True

@n_areas 1

TIME SEQUENCE

@initial 1845

@current 2019

@final 2024

@annual_cycle

time_steps 1

recruitment

recruitment_time 1

spawning

spawning_time 1

spawning_part_mort 0.5

spawning_p 1

growth and mortality

aging_time 1

M_props 1

baranov False

maturation

n_maturations 1

maturation_times 1

fishery

fishery_names cluster3 mainpop

fishery_times 1 1

```

# RECRUITMENT
@y_enter 1
@standardise_YCS True
@recruitment
YCS_years 1844 1845 1846 1847 1848 1849 1850 1851 1852 1853 1854 1855 1856 1857
1858 1859 1860 1861 1862 1863 1864 1865 1866 1867 1868 1869 1870 1871 1872 1873
1874 1875 1876 1877 1878 1879 1880 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 2013 2014 2015 2016 2017
2018
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 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 1844
last_free 1985

# recruitment variability
@randomisation_method lognormal

@fishery cluster3
years      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
catches    0 25.05562 3186.836 111.5084 271.6349 144.2651 122.6058 89.78473
120.2624 76.90726 8.603759 26.52444 187.8823 8.87328 0.6067025 0 0 126.027 54.305
56.298 64.57 157.294 73.29 0 25.676 1.598 0
selectivity SEL3
U_max 0.67
future_constant_catches 0

@fishery mainpop
years      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

```

catches 25.20852 634.4088 8347.216 1715.326 1016.277 567.3 484.5868 255.4024
177.4314 108.9099 268.4393 246.7671 234.2252 215.9755 89.18326 0 0 245.23 46.363
128.869 150.929 413.461 268.134 0.239 140.537 32.896 60

selectivity SELspawn

U_max 0.67

future_constant_catches 0

MATURITY

@maturation

rates_all logistic_producing 10 60 30 3

SELECTIVITIES

@selectivity_names SELspawn SEL3

@selectivity SELspawn

mature constant 1

immature constant 0

@selectivity SEL3

mature double_normal 30 3 3

immature constant 0

NATURAL MORTALITY

@natural_mortality

all 0.045

SIZE AT AGE

@size_at_age_type Schnute

@size_at_age_dist normal

@size_at_age

y1_male 5

y2_male 40.8

tau1_male 1

tau2_male 100

a_male 0.016

b_male 4.2

y1_female 5

y2_female 43.0

tau1_female 1

tau2_female 100

a_female 0.008

b_female 5.4

cv1 0.10

cv2 0.05

by_length True

```
@size_weight
a 1.96e-7
b 2.52
verify_size_weight 35 1 3
```

```
# INITIALISATION
@initialization
B0 100000
```

```
Estimation.csl
# ESTIMATION
@estimator Bayes
@max_iters 1000
@max_evals 3000
@grad_tol 0.0001
```

```
# MCMC
@MCMC
start 0.1
length 5000000
keep 1000
stepsize 0.05
burn_in 1000
```

```
#####
##### 1995, 2013-15 Cluster 1&2 AFs
#####
```

```
@proportions_at AFreq12
years 1995 2013 2014 2015
step 1
proportion_mortality 0.5
sexed F
sum_to_one True
at_size False
plus_group True
ogive SELspawn
min_class 15
max_class 150
ageing_error True
1995 0 0 0 0 0 0 0 0 0 0.02171099 0.01837149 0.0317844 0.009660323 0.03713685 0 0 0 0
0 0.05981621 0 0.03279577 0.009660323 0 0.04752379 0.03674297 0 0.01837149
0.01995912 0 0 0 0 0 0 0.008173416 0.00952793 0.01352923 0.001087951 0.02008932
0.0004996867 0.009737844 0.006334953 0.006334953 0.006494815 0 0.02776923
0.006548864 0.007467397 0.03013314 0 0.0004996867 0.003203119 0.01410428
0.006557935 0.001160738 0.005083552 0.008724766 0 0.01488381 0.01007342
0.009737844 0.004763965 0.04392466 0.002703432 0.05830976 0.009847517 0.02297015
```

0.01074827 0.04812309 0.0001132551 0.02075978 0.001087951 0 0 0.01474388
 0.001087951 0.0004996867 0.002703432 0 0.0001132551 0.01470814 0.0001132551
 0.006548864 0.003203119 0.0001132551 0 0 0.001087951 0.001087951 0 7.278727e-05 0
 0 0.009737844 0 0 0.01007342 0 0.0001132551 0 0.004763965 0 0 0.004263554 0 0
 0.001087951 0 0 0.0004996867 0 0 0.004763965 0 0 0 0.0004996867 0 0.01918825
 0.01007342 0 0 0 0 0 0.009737844 0 0.01007342 0.0743968
 2013 0 0 0 0 0 0 0 0.003291845 0 0.01668725 0.01971204 0.01044642 0.0144216
 0.01486526 0.03359634 0.01549714 0.02464547 0.01280978 0.02257986 0.018477
 0.06329886 0.03614419 0.005912915 0.01735504 0.02873732 0.004984806 0.009682682
 0.01359401 0.007025912 0.009652275 0.02322993 0.02411797 0.02756506 0.02629826
 0.01771289 0.02693929 0 0.005059077 0.0125285 0.0006051166 0.01901456 0.02047634
 0.0191606 0 0.003728375 0.005461046 0.009299157 0.01151701 0.009686029 0.0173332
 0.006996763 0.003291845 0.001791821 0.006996763 0.006582654 0.008754139 0
 0.02473138 0.002492403 0 0.01115986 0 0 0.005168822 0.0014656 0.00738391
 0.009861444 0 0.004284224 0.001342846 0.002608186 0.002492403 0.00435919 0
 0.02448259 0 0 0 0.006395426 0 0 0.0210213 0 0.005548505 0.001791821 0
 0.003291845 0.01115986 0.006274594 0.01115986 0.00738391 0.009299157 0
 0.009353875 0.009299157 0.003291845 0.0006051166 0 0 0 0 0 0 0 0 0 0 0
 0.001791821 0.002028222 0 0 0 0 0 0.001210233 0 0 0 0.009299157 0.006387412 0 0
 0 0.05400961
 2014 0 0 0 0 0 0 0 0.009111454 0.005683352 0.01081428 0.001367335 0.01544713
 0.0176996 0.02141866 0.005317387 0.01237649 0.01193409 0.03426736 0.02139343
 0.06445133 0.009009023 0.004348787 0.02031121 0.03274658 0.01973047 0.02421687
 0.01442178 0.01087854 0.01763087 0.01469856 0.03862317 0.009696295 0.02910677
 0.005683352 0.00273206 0.01634487 0.0282169 0.03404035 0.006651342 0.003819388
 0.001478396 0.01206275 0.01265314 0.003819388 0.01259413 0.007198214 0.04307234
 0.00901458 0.001023116 0.001739351 0.009009023 0.004184383 0.004668652
 0.01710267 0.01105526 0.008205326 0.0001104207 0.01070551 0 0 0.001415792 0
 0.02297273 0.001739351 0.003872543 0.02092615 0.003755176 0.02556422 0.002598063
 0.005683352 0.002046232 0.02180838 0 0.00647946 0 0 0.001367335 0.0001104207
 0.01075325 0 0.0007961086 0 0 0.01710267 0 0.0001104207 0.01105356 0 0
 0.001739351 0.01998397 0 0 0.01116398 0 0.001592217 0.001023116 0 0.00605321
 0.001739351 0.005838187 0 0 0 0.006221501 0.001739351 0.0006196839 0 0 0 0
 0.005942789 0 0.003872543 0 0 0 0.001133537 0 0 0.0006196839 0.003325671 0 0
 0.0007961086 0 0.02255481
 2015 0 0 0 0 0 0 0 0.002263452 0.005325114 0.003164097 0.001918915 0.04796081
 0.01781833 0.01648009 0.01954686 0.01824255 0.01077163 0.01043845 0.02012281
 0.02704624 0.01657195 0.009529809 0.0156639 0.0339693 0.01312435 0.03979738
 0.01856197 0.01621659 0.02871593 0.02959246 0.005983787 0.002900962 0.0165519
 0.0274205 0.000795046 0.0048657 0.005547541 0.02505302 0.00956438 0.01824751
 0.01074854 0.03498353 0.004328509 0.007483429 0.00120501 0.006404986 0.001128013
 0 0.009403182 0.005157443 0.007476561 0.005462713 0.006363179 0.003390692
 0.002089889 0.01155171 0.002089889 0.006106411 0.002298804 0.01723928
 0.007679917 0.02443143 0.001732942 0 0.003761696 0.0214281 0.01251499 0.009378911
 0.005548888 0.007221461 0.004503375 0.002951384 0 0 0.006209148 0.002953242
 0.002536624 0.004074442 0.005472673 0.00489445 0.001672784 0.002263452 0 0
 0.008878232 0.0048703 0.001463868 0 0.003390692 0.007420895 0.009245675

```

0.007567049 0 0.002951384 0 0 0 0 0.0006260207 0.01595643 0 0.001463868
0.02252268 0 0.003455357 0.001672784 0 0.005040223 0 0 0.005573284 0.004476206 0
0.002951384 0 0.001732942 0.002595646 0.001046837 0.001113751 0.0006260207 0 0 0
0.009245675 0 0 0.001732942 0.005983787 0 0.001463868 0 0 0.04901718
dist multinomial
r 0.00001
N_1995 18
N_2013 26
N_2014 24
N_2015 42
# Used 2 x tows to start

####
#### 1995, 2013-15 Cluster 3 AFs
####

@proportions_at AFreq3
years 1995 2013 2014 2015
step 1
proportion_mortality 0.5
sexed F
sum_to_one True
at_size False
plus_group True
ogive SEL3
min_class 15
max_class 150
ageing_error True
1995  0 0 0 0 0 0 0.0128062 0 0.02046375 0.0128062 0.05446471 0.03835301 0.01324049
0.008729167 0.007248539 0.02336837 0.06604315 0.04585834 0.0465823 0.01595244
0.02754932 0.02515676 0.05713254 0.03416748 0.06619905 0.01804852 0 0.008870414 0
0.007248539 0.05224214 0.01597771 0.01804852 0.007415933 0.008870414 0 0.02897331
0 0.0128062 0.04633255 0.02172477 0 0.01595244 0.02103549 0 0 0 0 0.01804852
0.01175986 0.01483187 0 0 0.01430884 0 0.004511318 0.007415933 0 0 0 0 0.004511318 0
0 0 0 0 0 0 0 0.01430884 0 0 0 0.01430884 0 0 0 0 0 0 0 0 0.01175986 0 0
0.004511318 0 0 0 0 0 0 0 0 0 0 0.007248539 0 0 0 0 0 0 0 0 0 0 0 0.0128062 0
0 0 0 0 0 0 0 0 0 0
2013  0 0 0 0 0 0 0 0 0.005417459 0.007467431 0 0.01998684 0.02421079 0.01669978
0.04928349 0.007707465 0.0458875 0.01783312 0 0.06045885 0.0156328 0.01552387
0.1180321 0.008949742 0 0.02476706 0.01323386 0.01616629 0.06421836 0.05926534
0.05257056 0.05210896 0.06045885 0.01490069 0 0.007467431 0.007156374 0.05210896 0
0.007467431 0 0 0.008349891 0.01998684 0 0.007467431 0 0.007156374 0 0 0 0 0
0.008349891 0 0 0.008349891 0.05210896 0.007156374 0.008289715 0 0 0.008349891 0 0
0 0 0 0 0 0 0 0 0.003287062 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0.007816401 0.008349891 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
2014  0 0 0 0 0 0 0 0.009006087 0.002473056 0.03722324 0.02435314 0.009006087
0.03227141 0.01871359 0.05839742 0.05477004 0.01546045 0.04956882 0.1089156

```

```

0.06047098 0.002946337 0.03311005 0.03395373 0.01622771 0.02719256 0.002478764
0.08017335 0.05531062 0.05104749 0.0487793 0.01591555 0.01620348 0 0 0.004946113 0
0 0.008927415 0.01524014 0 0.0177189 0 0.006454358 0.005463339 0.002478764
0.009006087 0 0.009252395 0.002478764 0 0.002478764 0.009006087 0 0 0 0.006454358 0
0 0 0 0 0.01524014 0 0 0 0 0 0 0 0 0.006454358 0.009006087 0 0 0 0 0.002946337 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0.002478764 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0
2015 0 0 0 0 0 0 0 0 0 0.04911005 0.01075664 0.01798852 0 0.01798852 0 0.02079253
0.008555789 0.04260452 0.04010496 0.1097031 0.0325196 0.04936033 0.03269696
0.08048186 0.05731296 0.05731296 0.024616 0.03712359 0.02431729 0.003951799
0.03537264 0.02194032 0.01798852 0 0.02474433 0.002804016 0.002804016 0
0.002804016 0.002804016 0 0.01075664 0 0 0 0 0 0 0.002804016 0.006755815
0.008555789 0 0.01798852 0.002804016 0.0391149 0 0.002804016 0 0 0 0.003951799 0 0 0
0.008555789 0 0.024616 0 0.006755815 0 0 0 0 0 0.01798852 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0.01798852 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
dist multinomial
r 0.00001
N_1995 10
N_2013 10
N_2014 12
N_2015 8
# Used 2 x tows to start with

@ageing_error
type normal
c 0.1

####
#### 1995, 2003, 2010-15, 2017 Cluster 1&2 LFs
####

@proportions_at LFreq12
years 1995 2003 2010 2011 2012 2013 2014 2015 2017
step 1
proportion_mortality 0.5
sexed F
sum_to_one True
at_size True
plus_group True
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 57 58 59 60
ogive SELspawn
dist multinomial
1995 0 0 0 0 0 8.011994e-05 3.111233e-05 0.0003279151 0.0002001279 0.0002555845
2.453308e-05 0.0003067471 0.0001418868 4.390085e-05 0.000479578 0.001966715
0.00600285 0.02389297 0.03350575 0.07611997 0.09838594 0.09001764 0.08864068

```

```

0.08170738 0.08706199 0.09310014 0.07710246 0.09169624 0.06357532 0.0431083
0.01961381 0.01361395 0.005363881 0.003632533 0 0 0 0 0 0 0 0 0 0
2003 0 0 0 0 0 0 0 0 0 0 0 0 3.436361e-05 0.006793706 0.02035623 0.01791292
0.06177786 0.06478126 0.08796967 0.111283 0.08987465 0.07274589 0.08565872
0.05914574 0.06848001 0.07214791 0.07481497 0.03852176 0.03600306 0.02178266
0.008446372 0.00137055 9.868594e-05 0 0 0 0 0 0 0 0 0 0
2010 0 0 0 0 0 0 0 0 0 0 0 0 0.004455602 0.01377716 0.03280142 0.0572846
0.0801291 0.08821319 0.1082821 0.1062414 0.1119603 0.08977094 0.07247612
0.05634115 0.05853807 0.0429976 0.03463396 0.02709271 0.008118571 0.00488697
0.0009031957 0.000395041 0 0.0007007608 0 0 0 0 0 0 0 0
2011 0 0.0003317045 0.0006634089 0.0003317045 0.0006634089 0.0006634089
0.001326818 0.0003317045 0.001326818 0.001326818 0 0.0006634089 0.0006634089
0.0006634089 0.0009893099 0.003611145 0.01361933 0.04201951 0.04455429
0.06736827 0.09590731 0.1195722 0.1453822 0.08870864 0.1044935 0.07282874
0.05308302 0.05469076 0.02524518 0.03106851 0.01982144 0.005674369 0 0 0 0 0 0 0
0 0.002406273 0 0 0
2012 0 0 0 0 0 0 0 0 0 0 0 0 0.003880643 0 0.00751105 0.01118919 0.02583436
0.01384195 0.05541186 0.07387184 0.088388 0.1329518 0.1188222 0.1283122 0.08434107
0.06921744 0.04870759 0.02837731 0.06008418 0.0238396 0.01740158 0.004135478
0.003880643 0 0 0 0 0 0 0 0 0 0
2013 0 0 0 0 0 0 0 0 0 0 0 0 0.001177198 0.0004698694 0.001718654 0.005953499
0.01997141 0.03836306 0.05774021 0.08515369 0.1110048 0.09511618 0.1047953
0.09828796 0.1092044 0.06209572 0.0626438 0.04306332 0.04080164 0.02678395
0.02343677 0.006932452 0.003042075 0.002244013 0 0 0 0 0 0 0 0
2014 0 0 0 0 0 0 0 0 0 0 0 0 0.005234554 0.003871865 0.0207613 0.02439537
0.05036022 0.09632385 0.07638242 0.09994262 0.1049329 0.1099309 0.1069096
0.06813353 0.08056051 0.04528766 0.03943129 0.02795814 0.02477819 0.01467012 0
0.0001350407 0 0 0 0 0 0 0 0 0 0
2015 0 0 0 0 0 0 0 0 0 0 0 0 0.000404063 0.00148978 0.003575082 0.01282827
0.03214775 0.0756595 0.07544276 0.09326149 0.1190185 0.1039068 0.0868697 0.1146078
0.08449172 0.06736435 0.04528207 0.03580172 0.02186018 0.02098368 0.001812583
0.002498168 0.0006940471 0 0 0 0 0 0 0 0
2017 0 0 0 0 0 0 0 0 0 0.0008663719 0 0 0.0002331539 0.0007847684 0.001072368
0.01027663 0.01386341 0.02325227 0.06346097 0.113824 0.1099672 0.1707223 0.1333123
0.1115228 0.1090888 0.05621351 0.0247217 0.02105458 0.01398853 0.01417568
0.004692397 0.001539123 0.001367157 0 0 0 0 0 0 0 0
r 0.00001
N_1995 9
N_2003 26
N_2010 18
N_2011 10
N_2012 8
N_2013 15
N_2014 13
N_2015 21
N_2017 24
# Used num tows to start

```


####

1995, 2004, 2010-2015, 2017 Cluster 3 LFs

####

@proportions_at LFreq3

years 1995 2004 2010 2011 2012 2013 2014 2015 2017

step 1

proportion_mortality 0.5

sexed F

sum_to_one True

at_size True

plus_group True

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 57 58 59 60

ogive SEL3

dist multinomial

1995 0 0 0 0 0 0.0001559931 0.0005454901 2.986183e-05 7.799654e-05 0.001368979

0.002164064 0.0006756197 0.002791903 0.002067066 0.006135633 0.02025978

0.02854799 0.03687229 0.09006255 0.09115409 0.1102814 0.1360181 0.1020023

0.1027112 0.06469422 0.05849899 0.05819911 0.03648531 0.03108738 0.0120897

0.002081278 0.0006461563 0.002295414 0 0 0 0 0 0 0 0 0 0 0 0

2004 0.000891524 0.0005855229 0.000891524 0.0005855229 0 0.0007319036 0

0.0001463807 0.0006120021 0 0 0 0 0.0005855229 0.001994563 0.02260881 0.03409203

0.02867562 0.07541246 0.1898078 0.1014109 0.1477719 0.05738794 0.05415654

0.07839693 0.03371569 0.06161124 0.02992289 0.03112396 0.02213269 0.01893707

0.001994563 0.00381653 0 0 0 0 0 0 0 0 0 0 0 0 0

2010 0 0 0 0 3.302196e-05 0 0 0 6.108664e-05 0 0 0 0.0005323622 0 0.00808514

0.006931083 0.01477553 0.06868538 0.09284223 0.1275966 0.1398675 0.09953944

0.09736342 0.1011833 0.06827313 0.057124 0.02070111 0.02826164 0.0221794

0.01724982 0.01387501 0.008060882 0.006506045 0.000272763 0 0 0 0 0 0 0 0 0 0

2011 0 0 0 0 0 0 0 0 0 0 0 0 0.0005043138 0.007051588 0.002215535 0.0454586

0.05639275 0.08376588 0.1528566 0.133543 0.1122626 0.119952 0.0939924 0.06230984

0.04458129 0.02832371 0.01632472 0.01857063 0.01349056 0.004376677 0.0004825469

0.0004825469 0 0 0.003062298 0 0 0 0 0 0 0 0 0 0

2012 0 0 0 0 0 0 0 0 0 0.003240555 0 0 0 0.0002096825 0.01233809 0.0228 0.03135265

0.1073422 0.09763085 0.1551234 0.09871815 0.09612972 0.1240356 0.08262031

0.04559121 0.03551318 0.0610863 0.0007264227 0.01222903 0.003804353 0.008784021

0.0007242802 0 0 0 0 0 0 0 0 0 0 0 0 0 0

2013 0 0 0 0 0 0 0 0 0 0 0 0 0.0009288902 0.0006788264 0.009278761 0.02318103

0.04568573 0.08007367 0.09939849 0.1141708 0.1815138 0.1100264 0.1284322

0.07958409 0.0481749 0.04326718 0.0156996 0.01293053 0.001797996 0.004323568 0

0.0008535535 0 0 0 0 0 0 0 0 0 0 0 0

2014 0 0 0 0 0 0 0 0 0 0 0 0 0.005792622 0.01291449 0.04332598 0.04831182

0.09449458 0.1345037 0.1241573 0.1807811 0.1126198 0.08694227 0.06890997

0.03663842 0.02168826 0.01820396 0.005012007 0 0.004300935 0 0.001402758 0 0 0 0 0

0 0 0 0 0 0

```

2015 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0.002404596 0.01270799 0.03981697 0.05514691
0.1216128 0.1690223 0.144223 0.08844248 0.1010144 0.09328254 0.06800687 0.05815868
0.02352531 0.01634029 0.003167926 0.002411916 0 0.0007150268 0 0 0 0 0 0 0 0 0 0
0
2017 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0.004420317 0 0.01649896 0.0487412 0.06625814
0.1347446 0.1339602 0.1525145 0.1030596 0.1004618 0.07687232 0.09137852 0.04164918
0.01891596 0.01052462 0 0 0 0 0 0 0 0 0 0 0 0 0 0
r 0.00001
N_1995 5
N_2004 5
N_2010 10
N_2011 5
N_2012 7
N_2013 6
N_2014 5
N_2015 7
N_2017 4
# Used num tows to start

# Q METHOD

@q_method free
#@q_method nuisance

@estimate
parameter natural_mortality.all
prior normal
mu 0.045
cv 0.15
lower_bound 0.01
upper_bound 0.10

@estimate
parameter selectivity[SEL3].mature
lower_bound 10 1 1
upper_bound 60 30 60
prior uniform

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

# B0
@estimate
parameter initialization.B0

```

[illegible]

CATCH PENALTIES

@catch_limit_penalty
label CatchPenalty3
fishery cluster3
multiplier 200
log_scale True

@catch_limit_penalty
label CatchPenaltyMain
fishery mainpop
multiplier 200
log_scale True

Louisville North population.csl

Louisville North: 2019 base model using priors from Central
Only a single fishery - mainpop

PARTITION
@size_based False
@min_age 1
@max_age 150
@plus_group True
@sex_partition False
@mature_partition True
@n_areas 1

TIME SEQUENCE
@initial 1845
@current 2019
@final 2024
@annual_cycle
time_steps 1

recruitment
recruitment_time 1

spawning
spawning_time 1
spawning_part_mort 0.5
spawning_p 1

growth and mortality
aging_time 1
M_props 1
baranov False

```

# maturation
n_maturations 1
maturation_times 1

# fishery
fishery_names mainpop
fishery_times 1

# RECRUITMENT
@y_enter 1
@standardise_YCS True
@recruitment
YCS_years 1844 1845 1846 1847 1848 1849 1850 1851 1852 1853 1854 1855 1856 1857
1858 1859 1860 1861 1862 1863 1864 1865 1866 1867 1868 1869 1870 1871 1872 1873
1874 1875 1876 1877 1878 1879 1880 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 2013 2014 2015 2016 2017
2018
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 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 1844
last_free 1985

# recruitment variability
@randomisation_method lognormal

@fishery mainpop
years      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
catches    0.7914764 2.650451 297.2783 4159.607 702.4655 331.2876 252.4637
449.8055 839.283 494.1401 618.6914 436.3584 212.5413 142.6548 20.89419 0 0 0.202
12.654 2.702 5.242 0.006 7.08 26.636 20.326 0 0
selectivity SELspawn

```

```

U_max 0.67
future_constant_catches 0

# MATURITY
@maturation
rates_all logistic_producing 10 60 30 3

# SELECTIVITIES
@selectivity_names SELspawn

@selectivity SELspawn
mature constant 1
immature constant 0

# NATURAL MORTALITY
@natural_mortality
all 0.045

# SIZE AT AGE
@size_at_age_type Schnute
@size_at_age_dist normal
@size_at_age
y1_male 5
y2_male 40.8
tau1_male 1
tau2_male 100
a_male 0.016
b_male 4.2
y1_female 5
y2_female 43.0
tau1_female 1
tau2_female 100
a_female 0.008
b_female 5.4
cv1 0.10
cv2 0.05
by_length True
@size_weight
a 1.96e-7
b 2.52
verify_size_weight 35 1 3

# INITIALISATION
@initialization
B0 100000

```

Louisville South population.csl

Louisville South: 2019 base model using priors from Central
Only a single fishery - mainpop

PARTITION

@size_based False
@min_age 1
@max_age 150
@plus_group True
@sex_partition False
@mature_partition True
@n_areas 1

TIME SEQUENCE

@initial 1845
@current 2019
@final 2024
@annual_cycle
time_steps 1

recruitment

recruitment_time 1

spawning

spawning_time 1
spawning_part_mort 0.5
spawning_p 1

growth and mortality

aging_time 1
M_props 1
baranov False

maturation

n_maturations 1
maturation_times 1

fishery

fishery_names mainpop
fishery_times 1

RECRUITMENT

@y_enter 1
@standardise_YCS True
@recruitment

YCS_years 1844 1845 1846 1847 1848 1849 1850 1851 1852 1853 1854 1855 1856 1857
1858 1859 1860 1861 1862 1863 1864 1865 1866 1867 1868 1869 1870 1871 1872 1873

NATURAL MORTALITY

@natural_mortality

all 0.045

SIZE AT AGE

@size_at_age_type Schnute

@size_at_age_dist normal

@size_at_age

y1_male 5

y2_male 40.8

tau1_male 1

tau2_male 100

a_male 0.016

b_male 4.2

y1_female 5

y2_female 43.0

tau1_female 1

tau2_female 100

a_female 0.008

b_female 5.4

cv1 0.10

cv2 0.05

by_length True

@size_weight

a 1.96e-7

b 2.52

verify_size_weight 35 1 3

INITIALISATION

@initialization

B0 10000