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Stock assessments for NW Challenger & Lord Howe Rise orange roughy

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A 2020 orange roughy stock assessment for Northwest Challenger and Lord Howe Rise

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Executive summary

This paper presents an updated orange roughy stock assessment for two Tasman Sea stocks: Northwest Challenger (NWC) and Lord Howe Rise (LHR). Estimates of virgin biomass (B_0), current stock status (ss_{2020}), and long-term yield are presented for the two stocks.

Five orange roughy stocks have been defined for the Tasman Sea: NWC, LHR (north and south), South Tasman Rise, and West Norfolk Ridge (WNR). South Tasman Rise has been closed to fishing for some years. There has been little orange roughy catch on north LHR and it is essentially south LHR that is assessed. The Tasman Sea stocks were last assessed in 2017 to the end of the 2015 calendar year. 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 the Tasman Sea at 346 t.

A Bayesian stock assessment is presented for the NWC orange roughy stock using age frequency data collected in 1993 and 2013, and 2018. The maturity parameters and year class strengths estimated for NWC are then used in a catch-history based assessment for LHR (for which no age frequencies are currently available). The 2017 assessment of WNR is not updated and remains the best available information for that stock.

For both assessed stocks, current stock status is estimated to be higher than in the 2017 stock assessment. For NWC this is because the previous assessment contained no data other than the catch history. The addition of the age frequencies has greatly reduced the estimated probability of low virgin biomass levels and associated low levels of current stock status. There is also qualitative evidence from the fishery that current stock status is not seriously depleted as catch rates have been maintained or slightly increased since a low point in 2005.

For LHR a new catch history was used which, compared with the previous catch history, has a large spike in catches in the first year of the fishery. The previous catch history only used catches that were reported to SPFRMO. However, there is solid evidence of early catches by Japanese and Norwegian vessels which were not reported to SPRFMO and the catch history was revised on this basis. The change in catch history, with the substantial early catches, is responsible for the higher estimates of virgin biomass and current stock status.

Although current stock status for each of the stocks is quite uncertain, it is likely that NWC is currently above 40% B_0, while LHR is likely above 30% B_0. Based on the 2017 assessment, WNR is likely above 20% B_0. The total estimated long-term yield for the three stocks combined is 852 t.

The base model estimates for the Tasman sea stocks which can be fished for orange roughy are given below. *: 2015 stock status.

Stock	B_0 (000 t)		ss_{2020} (%B_0)		Long-term yield (t)	
	Median	95% CI	Median	95% CI	Median	95% CI
NWC	33	19-43	68	46-81	396	228-516
LHR	29	11-75	72	29-93	348	132-900
WNR	9	4-21	63[*]	19-84[*]	108	48-252

1. Purpose of paper

This paper presents an updated orange roughy stock assessment for two Tasman Sea stocks, Northwest Challenger (NWC) and Lord Howe Rise (LHR). Estimates of virgin biomass, current stock status, and long-term yield are presented for the two stocks. The assessments for the other two Tasman Sea stocks, South Tasman Rise and West Norfolk Ridge (WNR), are not updated. The South Tasman Rise is closed to fishing and the 2017 assessment for WNR was not updated as it would be little changed. The assessments are provided as the best available information on which to base management advice for Tasman Sea orange roughy stocks.

2. Background

The NWC and LHR are in the Tasman Sea and lie within SPRFMO's jurisdiction. The NWC has several underwater topographical features (UTFs) which have been fished for orange roughy since the late 1980s (e.g., Clark 1998). It also has an extensive area of flats which are within the depth preference of orange roughy (Clark 1998). Fishing has been primarily by New Zealand vessels but vessels from other countries have also participated in the fishery especially prior to 2007. LHR (south) is an area of features north and west of NWC. The first recorded fishing was by a Japanese vessel in 1988 when approximately 4000 t was taken (Clark 2008, Clark & Tilzey 1996).

Five orange roughy stocks have been defined for the Tasman Sea: NWC, LHR (north and south), South Tasman Rise, and West Norfolk Ridge (WNR) (Clark et al. 2016). South Tasman Rise has been closed to fishing for some years. There has been very little orange roughy catch on north LHR (Roux & Edwards 2017) and it is essentially south LHR that is assessed. The Tasman Sea stocks were last assessed in 2017 to the end of the 2015 calendar year (Cordue 2017, Roux & Edwards 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 the Tasman Sea at 346 t.

3. Methods

A Bayesian stock assessment is presented for the NWC orange roughy stock using age frequency data. Growth is estimated outside the model from age-length data collected in 1993 and 2013, and 2018 (Saunders et al. in prep.). The maturity parameters and year class strengths estimated for NWC are then used in a catch-history based assessment for Lord Howe Rise (for which no age frequencies are currently available). The 2017 assessment of WNR is not updated.

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 & Edwards (2017). However, they only used catches which were reported to SPRFMO and this excluded catches by Japanese and Norwegian vessels in the early years of the Lord Howe Rise fishery (in particular). For this assessment the catch histories for NWC and LHR were constructed using the catches reported in New Zealand's

annual plenary report (e.g., FNZ 2018) up to 1997, the catch histories in Roux & Edwards (2017) from 1998 to 2015, and the estimated catch totals from New Zealand and Australian tow-by-tow records from 2016 to 2019. The catch in 2020 was assumed to be the same as in 2019. NWC catches were split into "short" and "long" tow fisheries (see below). The annual short-tow and long-tow proportions in the New Zealand tow-by-tow data were used to split the annual totals.

The catches in the plenary reports (up to 2007) 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.

3.2 Composition data

Length frequency data and otoliths from New Zealand scientific observers were available for NWC in many years from 1989 to 2019. The length data were used as a proxy for age in an analysis to determine which years otoliths should be read to produce age frequencies (Cordue 2020). It appeared that tow duration was a strong driver of the mean size of orange roughy in the catch. The years 1993, 2013, and 2018 were chosen for the reading of otoliths based on the number of available otoliths and the coverage of "short" and "long" tows.

Subsequently a more detailed analysis of the length data (unsexed) was undertaken as part of the stock assessment. Length frequencies were produced for short and long tows (where the cut-off was 1 hour of tow duration) for all months in each year combined and also restricted to just June and July. The length frequencies were scaled to catch numbers within tow and then summed across tows within length (1 cm bins). At least 10 tows had to have been sampled for a scaled length frequency to be produced (in any year for short or long tows).

Age frequencies were produced for short and long tows separately using the data from Saunders et al. (in prep.). They read otoliths for fish sampled by scientific observers primarily in June and July in 1993, 2013, and 2018 (Tables 1 & 2). Scaling was to catch numbers within tow, done individually by sex, and then the sexes were combined giving them equal weight. A plus group at age 120 years was used.

Table 1: The number of tows by New Zealand vessels in NWC sampled for otoliths by scientific observers by year and tow-duration class. The tow duration cut-off for short/long tows is 1 hour.

Year	Tow duration	
	Short	Long
1993	26	9
2013	19	4
2018	20	44

Table 2: The number of fish aged by Saunders et al. (in prep) from NWC by year and tow-duration class. The tow duration cut-off for short/long tows is 1 hour.

Year	Tow duration	
	Short	**Long**
1993	168	57
2013	241	44
2018	252	284

3.3 Estimation of growth

For NWC, length and age measurements for individual fish were available from Saunders et al. (in prep.) (1046 age-length pairs, 508 male, 538 female). A von Bertalannfy curve was fitted to these data by least squares to estimate growth parameters by sex (t_0 was fixed at -0.5). An average relationship was calculated by averaging the individual sex parameters.

The fish on LHR are known to grow to larger sizes than those on NWC (e.g., Clark & Tilzey 1996). For LHR, the east and south Chatham Rise growth parameters were used (e.g., FNZ 2018).

3.4 Length weight relationship

The default orange roughy length-weight parameters were used for all calculations (e.g., estimating fish numbers in a tow) and in the CASAL stock assessment models (e.g., see FNZ 2018 or Appendix D for the values).

3.5 Model structure

For NWC, 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 120 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 short tows (tow duration less than or equal to 1 hour) and one for the longer tows (tow duration greater than 1 hour). 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). The short-tow fishery was applied to mature fish with equal selection at age. A double normal selectivity was used for the long-tow fishery.

For LHR, the same model structure was used except that there was only a single fishery (modelled as for the NWC short-tow fishery).

The model was implemented in CASAL (Bull et al. 2012). The main input files for the base model are given in Appendix D (NWC and LHR).

3.6 Estimation method

Bayesian estimation as implemented in CASAL was used to estimate virgin biomass (B_0), year class strengths (YCS), the logistic-producing maturation curve, and the long-tow selectivity. Natural mortality (M) was fixed at 0.045 (the standard value for New Zealand orange roughy stocks – see FNZ 2018). A Beverton-Holt stock recruitment relationship was assumed with steepness (h) equal to 0.75 (a default value for New Zealand orange roughy stocks – results are not sensitive to this assumption).

Uninformative priors were used on B_0 and the YCS parameters (uniform on $\log(B_0)$ and near uniform on each YCS parameter – see Cordue 2014a). Informative priors were used on the maturity parameters and the long-tow selectivity as the estimates were tending to become unrealistically large in some preliminary Markov chain Monte Carlo (MCMC) runs. See Appendix D for the prior distributions. For the logistic producing maturation, the estimate from the nearby ORH 7A stock was used to provide the means of the prior.

Within the stock assessment models a maximum exploitation rate of 67% was assumed for each fishery (as used in all New Zealand EEZ stock assessments – see Cordue 2014a). This assumption restricts B_0 on the low side as there had 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 the NWC short-tow fishery and the LHR fishery it was required that the maximum exploitation rate was at least 5%.

A two-step approach was used in the Bayesian estimation for NWC. 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. The fits were considered to see if the model was adequate (if the best fit to the data is dreadful then the model is probably not adequate).

The second step is the sampling of the joint posterior distribution using MCMC sampling. For NWC, this was done using three chains each of 10 million steps with 1 in every 1 thousand samples stored. Each chain started at a random jump away from the MPD estimate. For LHR, a single chain of 10 000 samples was constructed by sampling from the NWC joint posterior for YCS and maturation (with independent sampling for B_0 (uniform in log space from 5000 to 100 000 t)).

Exploitation rate, for the purposes of presentation, was calculated in each year as total catch divided by catch-weighted vulnerable biomass (at the beginning of the year). For LHR there is only one fishery, so this is just the usual exploitation rate. For NWC there are two fisheries so the denominator in the calculation is an average vulnerable biomass (the vulnerable biomass for each fishery weighted by the catch in that year).

Long-term yield was calculated using the average annual yield estimate for the New Zealand orange roughy Harvest Control Rule (HCR) (Cordue 2014b) as given in a recent review of the HCR (Cordue 2019). The review used the latest posterior distributions of M and h from New Zealand EEZ stock assessments which gave an average annual yield of 1.2% B_0. This is lower than the original estimate of 1.4% B_0 (Cordue 2014b) as used in the 2017 assessments of

SPRFMO orange roughy stocks (Cordue 2017). The long-term yield estimate for West Norfolk Ridge was updated using 1.2% B_0 and the 2017 assessment results (Cordue 2017).

3.7 Model runs
For NWC and LHR a base model and several sensitivity runs were done with most taken through to full MCMC.

For NWC the MCMC sensitivities were:
- Half, double, and four times the effective sample sizes
- A minimum maximum-exploitation-rate of 3%, 4%, 6%, 7% (base = 5%)
- A maximum exploitation rate of 90% (base = 67%)
- M = 0.035 and 0.04 (base = 0.045)
- The catch history of Roux & Edwards (extended to 2020)
- B forced low: a prior on B_0: N(10 000 t, CV = 10%)

For LHR the MCMC sensitivities were:
- A minimum maximum-exploitation-rate of 3%, 4%, 6%, 7% (base = 5%)
- A maximum exploitation rate of 90% (base = 67%)
- The catch history of Roux & Edwards (extended to 2020)
- A 1988 catch of 3000 t, 3500 t, 4500 t, or 5000 t (base = 4000 t)

3.8 Projections
Five-year, constant-catch projections at the estimated long-term annual yield were performed for the base model for both stocks. A "worst case" projection scenario was also constructed for each stock: being the base model MCMC samples which produced the lowest 10% of projected stock status in 2025.

Stochastic recruitment for YCS from 1996 onwards was implemented by randomly sampling from the last 10 estimated YCS (1986 to 1995).

4. Results

4.1 Catches and catch history
The NWC fishery has a complex dynamic in terms of tow duration and the proportion of the catch taken in short tows and long tows (Figures 1 & 2). In most years, most of the catch has been taken during the spawning season in June and July (Figure 3). There are two peaks in the catch history, one in 1993 associated with the short-tow fishery, and another in 2002 associated with long tows (Figure 4).
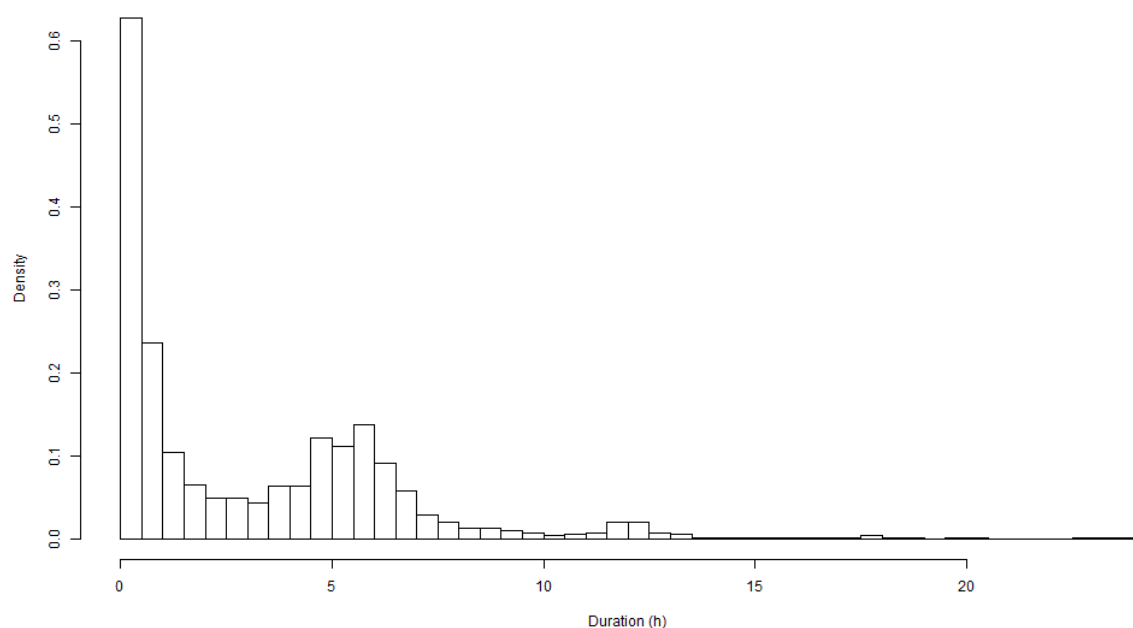
Figure 1: Histogram of tow duration for the NWC fishery (New Zealand data from all years).
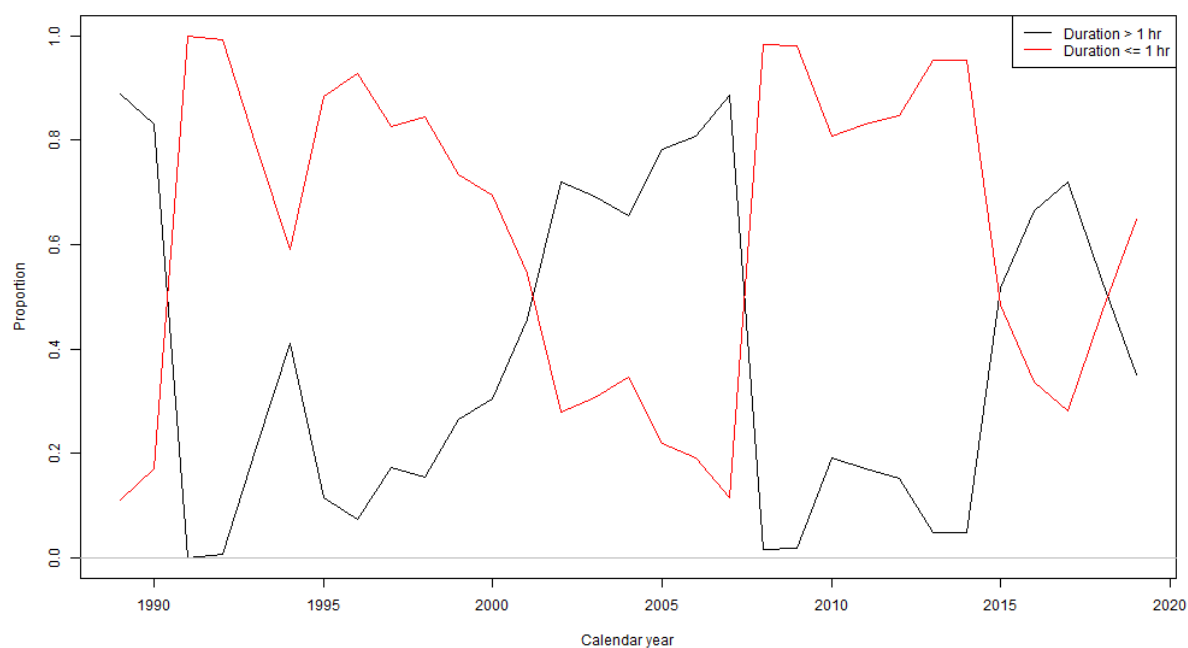

Figure 2: The annual proportion of orange roughy catch taken by short (duration ≤ 1 hour) and long tows (duration > 1 hour) in the NWC fishery (New Zealand data from all years).
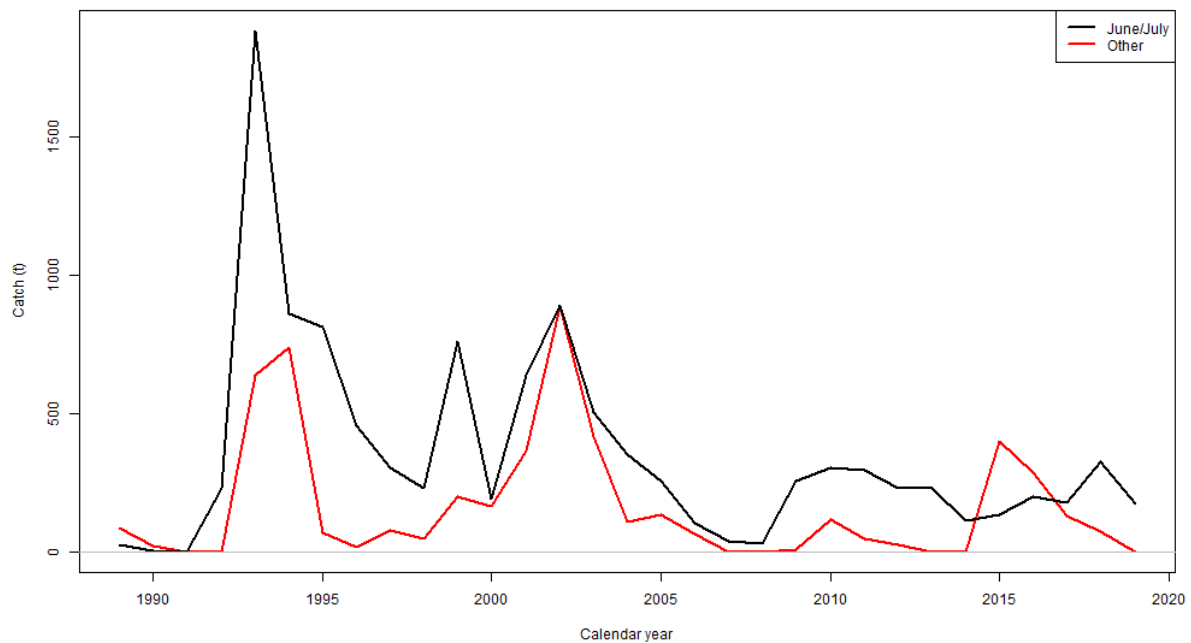
Figure 3: Annual catch by season (June-July, rest of year) for the NWC fishery (New Zealand data from all years).
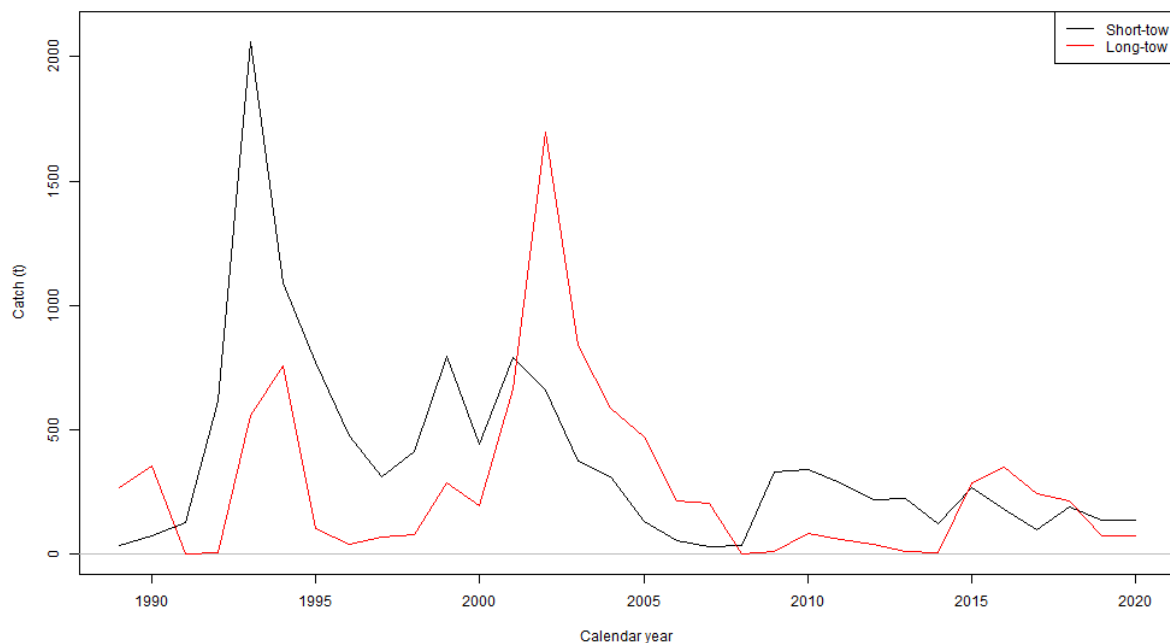

Figure 4: The short-tow and long-tow catch histories for NWC used in the base model.

The catch history for LHR constructed by Roux & Edwards (2017) and used in the 2017 assessment by Cordue (2017) is missing large catches from Japanese and Norwegian vessels in 1988 and 1989 (Figure 5). These catches were not reported to SPRFMO but there is solid

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evidence that they did occur as they have been reported in New Zealand's Plenary reports and elsewhere for many years (e.g., see Clark & Tilzey 1996, Clark 2008). The peak in 1988 is a major feature of the catch history and is almost double the subsequent peak in 1993 (Figure 6).
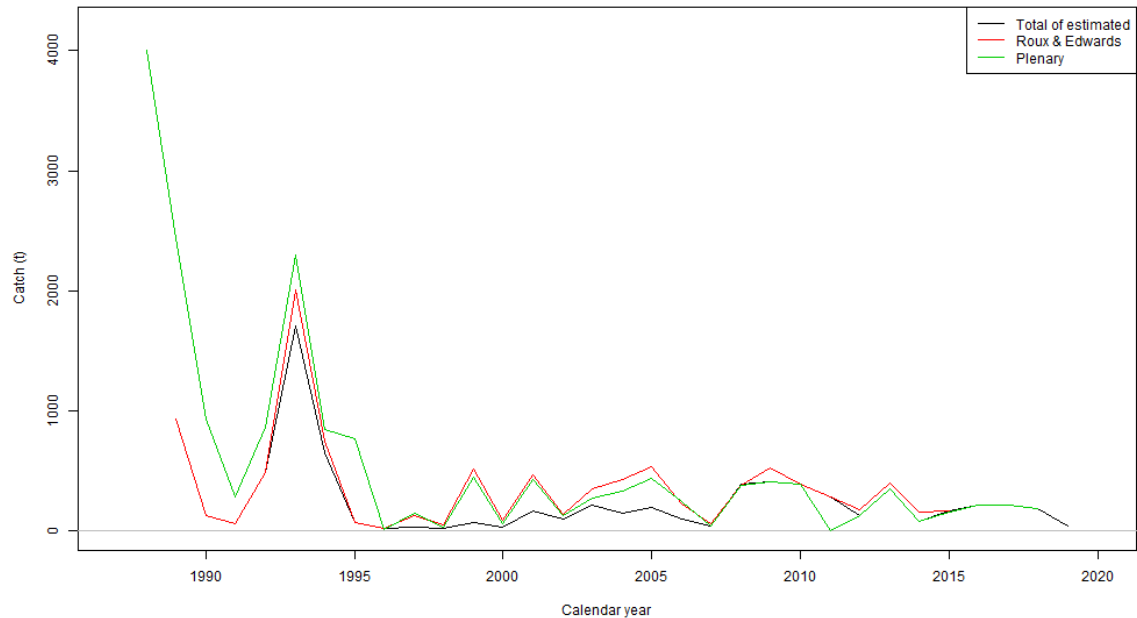

Figure 5: A comparison of three alternative sources of the LHR catch history: the annual total of estimated catches from the New Zealand tow-by-tow data ("Total of estimated"); Roux & Edwards (2017); and the annual totals reported in New Zealand's plenary reports (e.g., FNZ 2018)
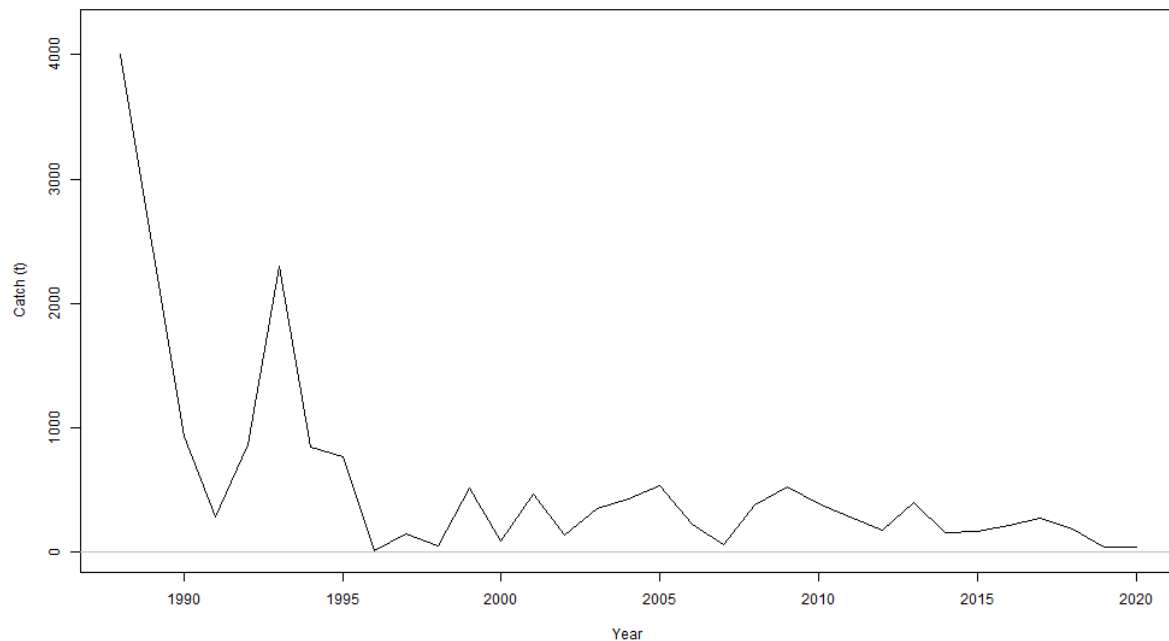

Figure 6: The catch history for LHR used in the base model.

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4.2 Composition data

The basis for having a short-tow and a long-tow fishery in the NWC model was that they captured different sizes and therefore ages of fish. This conclusion was reached because the mean length of fish in short tows was consistently larger than the mean length of fish in long tows (Figure 7). In comparison, there was no consistent seasonal pattern across the years (Figure 8). Indeed, the pattern of larger fish in short tows was consistent even when the season was restricted to the spawning months of June and July (Figure 9).
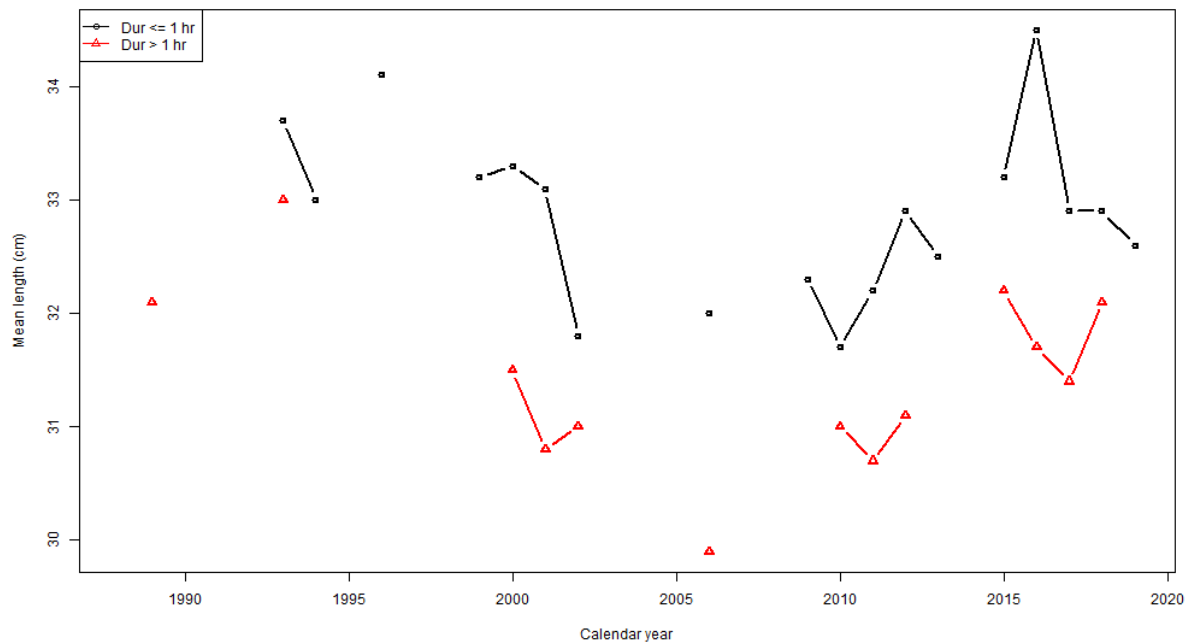

Figure 7: Mean length by tow-duration class calculated annually from scaled length frequencies when at least 10 tows were sampled in each class in each year.
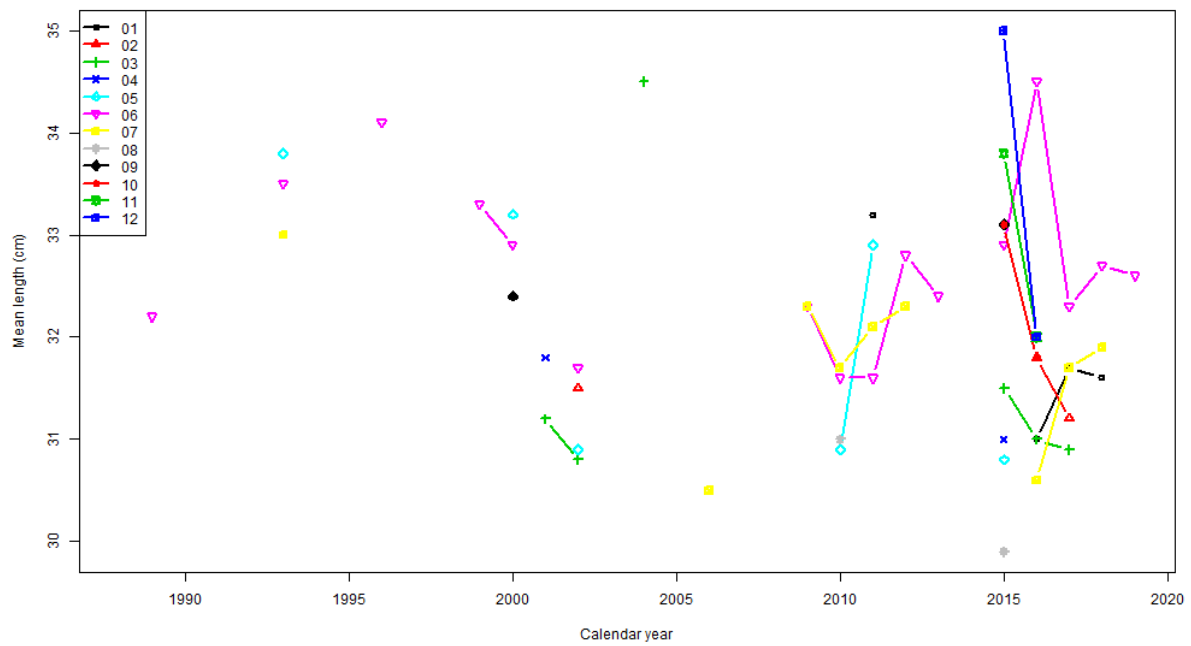
Figure 8: Mean length by month calculated annually from scaled length frequencies when at least 10 tows were sampled in each month in each year.
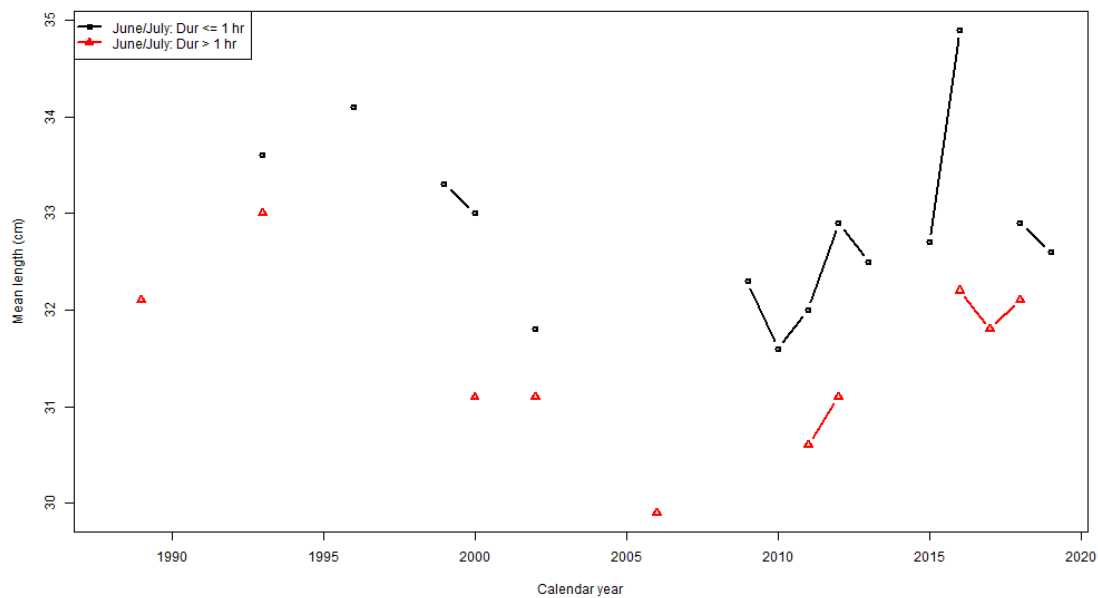

Figure 9: Mean length by tow-duration class in June-July calculated annually from scaled length frequencies when at least 10 tows were sampled in each class in June-July in each year.

The pattern of larger fish from short tows in the length frequencies is reflected as older fish from short tows in the age frequencies (Figures 10-12).

Figure 10: Scaled age frequencies for short and long tows in 1993. Single-year age classes (left) and five-year age classes (right). n is the number of fish sampled for age.
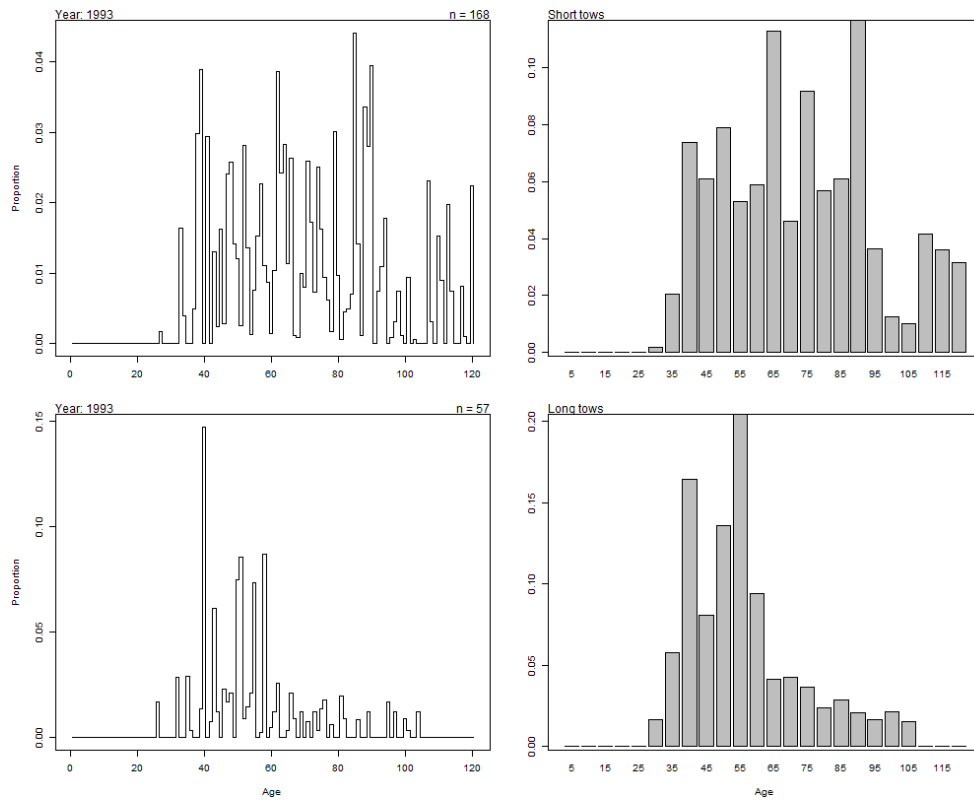

Figure 11: Scaled age frequencies for short and long tows in 2013. Single-year age classes (left) and five-year age classes (right). n is the number of fish sampled for age.
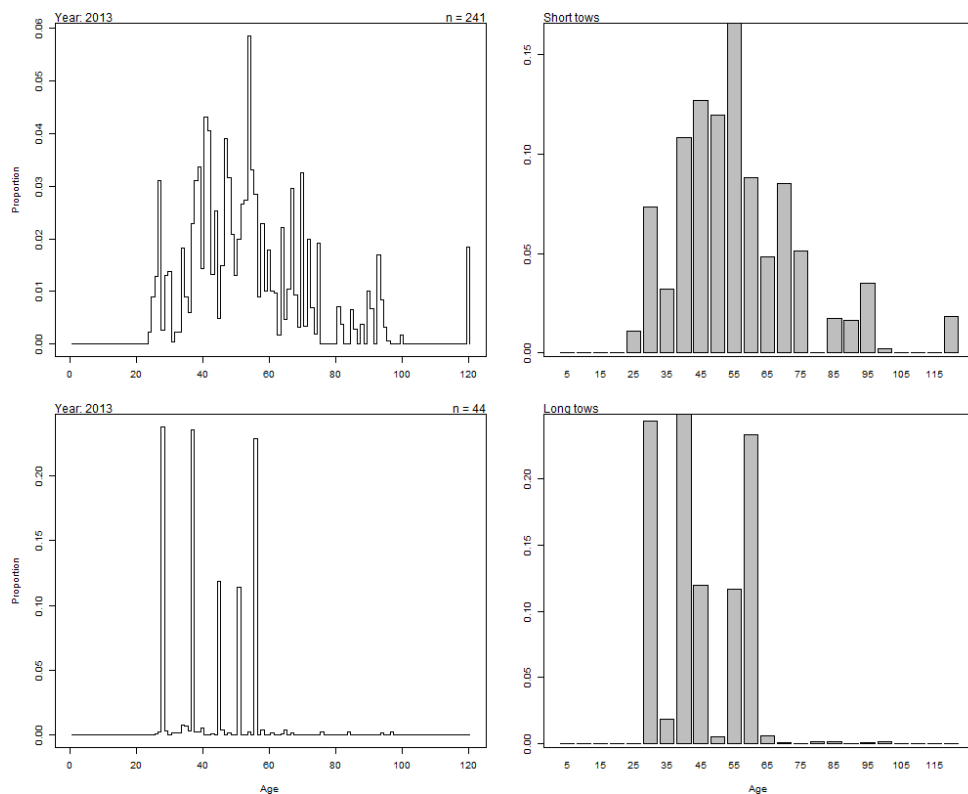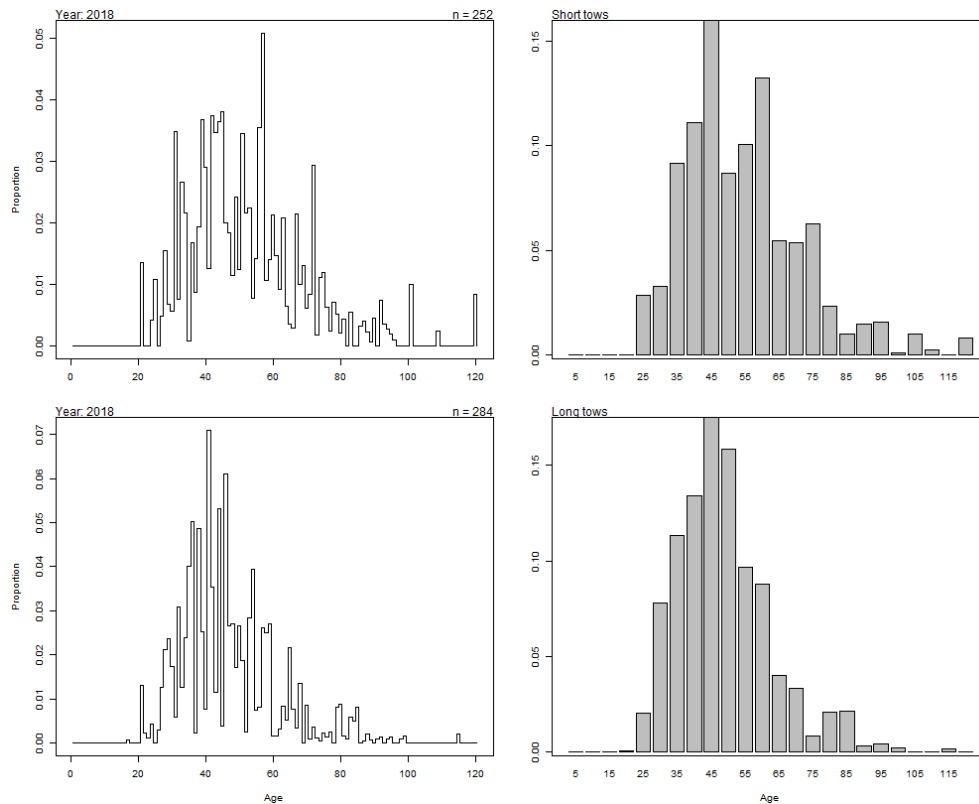
Figure 12: Scaled age frequencies for short and long tows in 2018. Single-year age classes (left) and five-year age classes (right). n is the number of fish sampled for age.

4.3 Growth parameters

For NWC, the fit of von Bertalanffy curves to the age-length data was adequate (Figure 13). The estimated parameters by sex are:

	t_0 (fixed)	k	l_∞ (cm)
Male	-0.5	0.069	34.0
Female	-0.5	0.059	36.1
Average	-0.5	0.064	35.05

Figure 13: The least squares fit of von Bertalanffy growth curves to the age-length data by sex and the average curve.

4.4 Model diagnostics

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

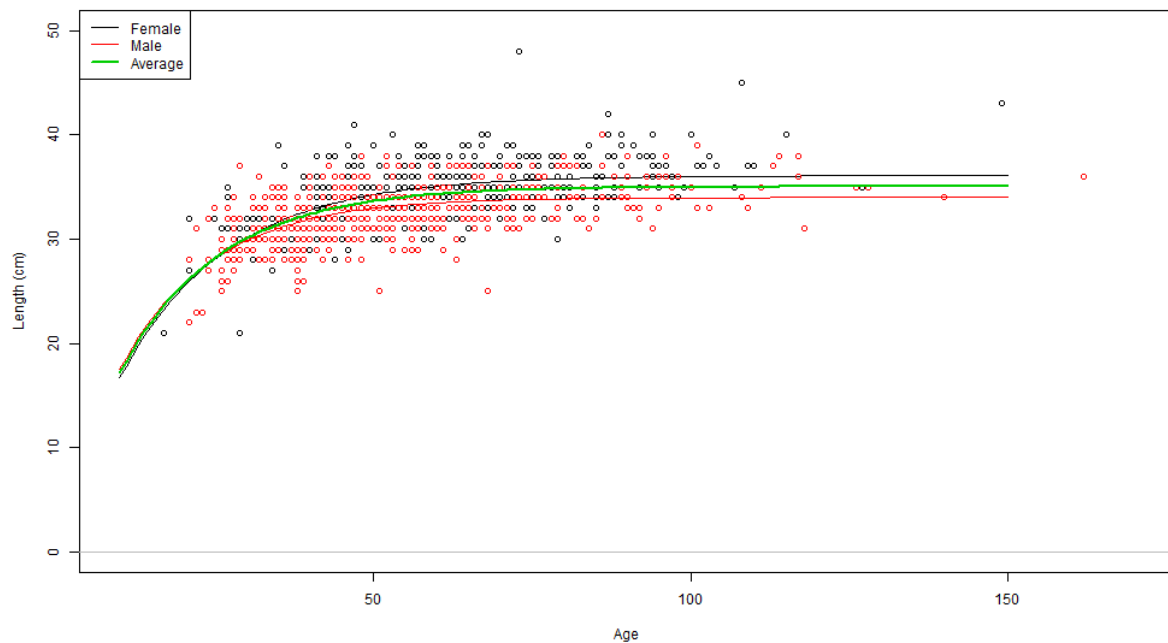The MPD fits to the composition data were generally good (see Appendix B). The MCMC fits were very similar to the MPD fits (see Appendix B for a full set of fits). For example, the 2018 age frequency for short tows was very well fitted and the Pearson residuals were fairly well balanced (Figure 14). The worst fit to an age frequency was for long tows in 2013 where the predicted proportions were sometimes much lower than those observed and there are particularly large residuals (Figure 15). There is very little data for the 2013 long-tow age frequency, and it has an effective sample size of just N = 4 so it is of no consequence to the assessment results.

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Figure 14: The MPD (red line) and MCMC fit (box and whiskers) to the observed age frequency for short tows in 2018 (histogram). 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. The MCMC Pearson residuals are also plotted as a box and whiskers plot (right).
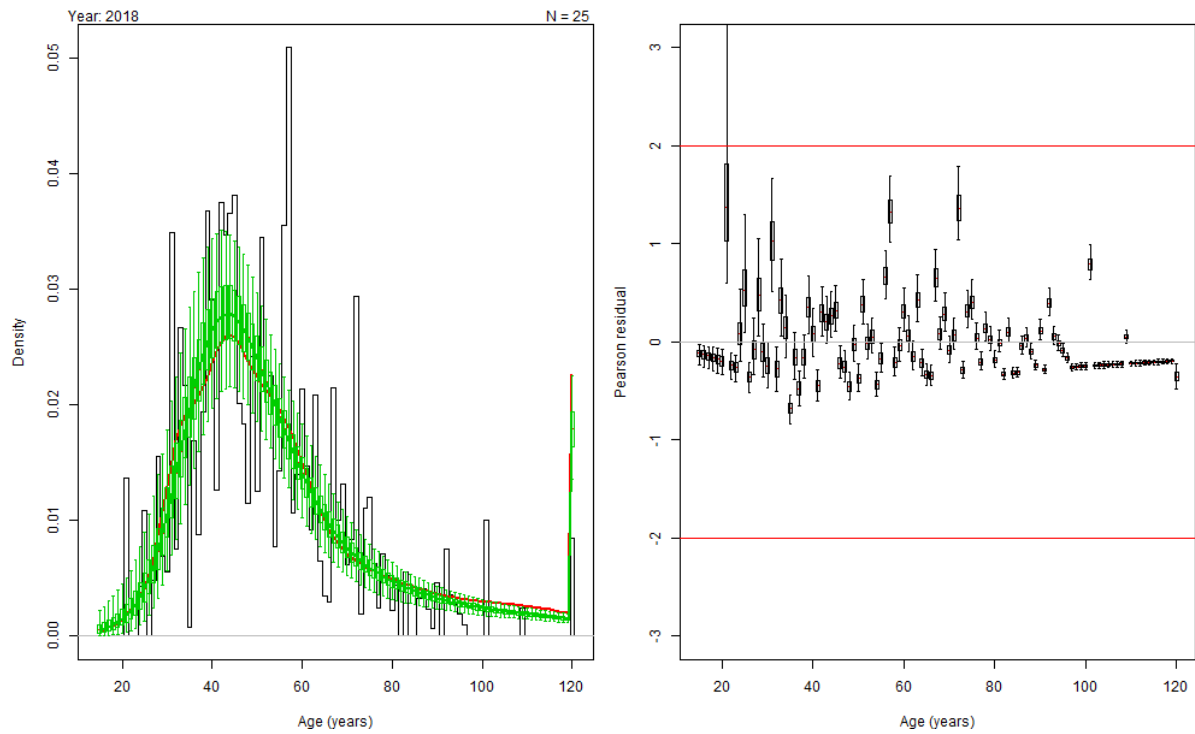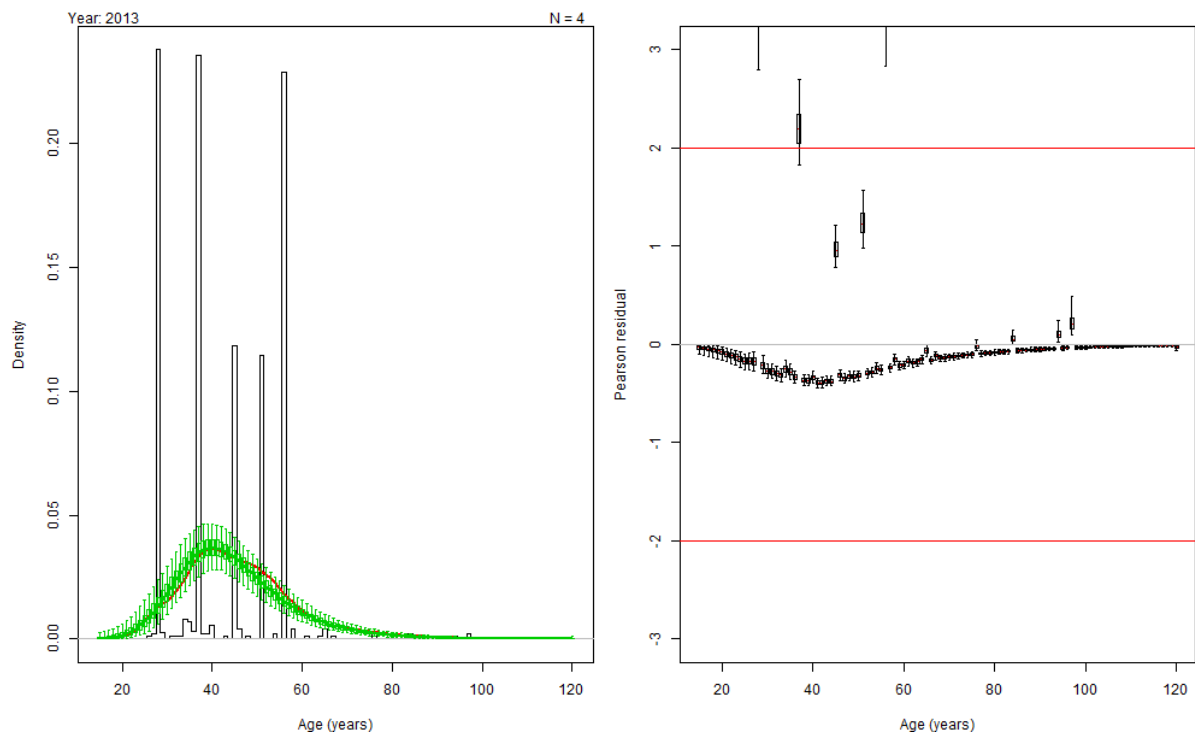

Figure 15: The MPD (red line) and MCMC fit (box and whiskers) to the observed age frequency for short tows in 2018 (histogram). The box for each age class covers the middle 50% of the distribution and the whiskers extend to 95% CIs. N is the effective sample size. The MCMC Pearson residuals are also plotted as a box and whiskers plot (right).

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An MPD profile across B_0 was performed to check that the limited data were providing some information on stock size (see Appendix B for a full set of results). The likelihood profile for B_0 shows very little contrast for values of B_0 greater than about 25 000 t (Figure 16). At lower values of B_0 there is an increase in the objective function value for every component except the prior on B_0 (which by design favours lower values) (Figure 16). Importantly, both data sets show an increase in objective function value at lower B_0 (Figure 16).
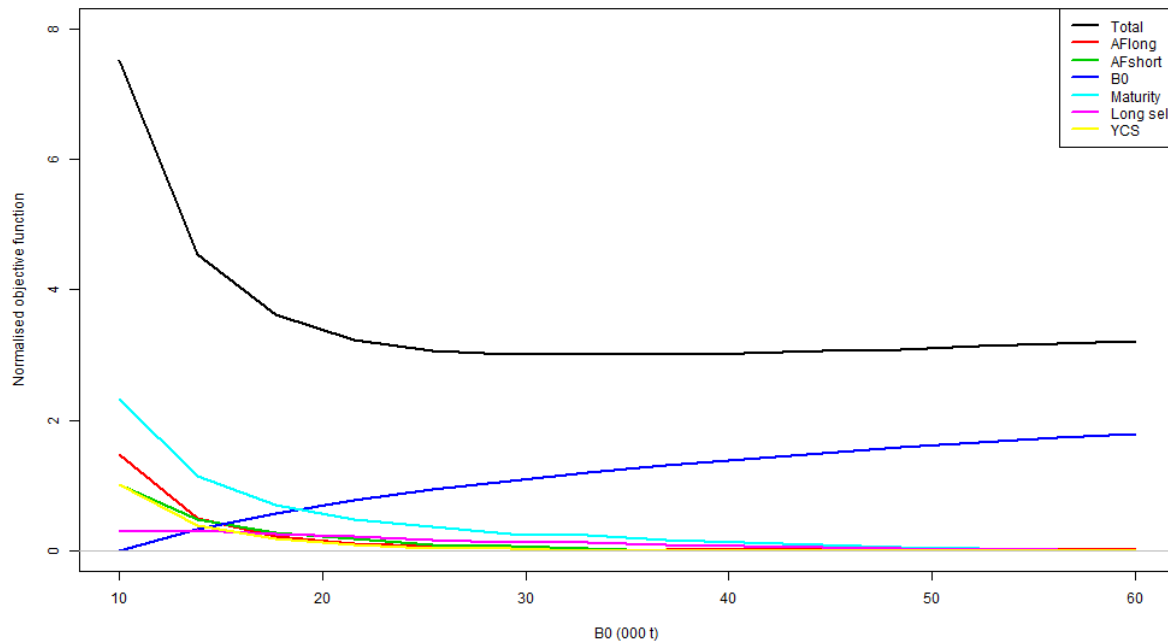
Figure 16: Base model MPD: likelihood profile for B_0. The relative objective function (normalised to a minimum of zero for each component) is shown for each data set and the priors at fixed values of B_0. The total objective function value is offset from zero by an arbitrary amount.

4.5 Stock assessment results

NWC results

In the base model, the MCMC estimate of maturity was within the range for New Zealand EEZ orange roughy stocks (Table 3). It should be noted that it was constrained by an informed prior (see Appendix B) and would probably have gone to unrealistically old ages if it had not been so constrained. The double normal selectivity for the long-tow fishery has a similar left hand side to the maturity curve with 50% selection at about 36 years (mode – s_l) although full selection is at a younger age than full maturity (Table 3, Figure 17)

Table 3: NWC base model: MCMC estimates of maturation (logistic producing) and long-tow selectivity (double normal).

	Maturation			Selectivity	
	a_{50}	a_{to95}	Mode	s_l	s_r
Median	39	12	45	9	27
95% CI	35-43	8-17	39-50	6-13	19-36

The logistic curve for proportions mature at age (in equilibrium) is well defined with fish starting to mature at about 20 years and fully mature by about 60 years (Figure 17). The selectivity for the long-tow fishery is well determined on both sides of the mode (45 years) and is definitely domed (Figure 17).
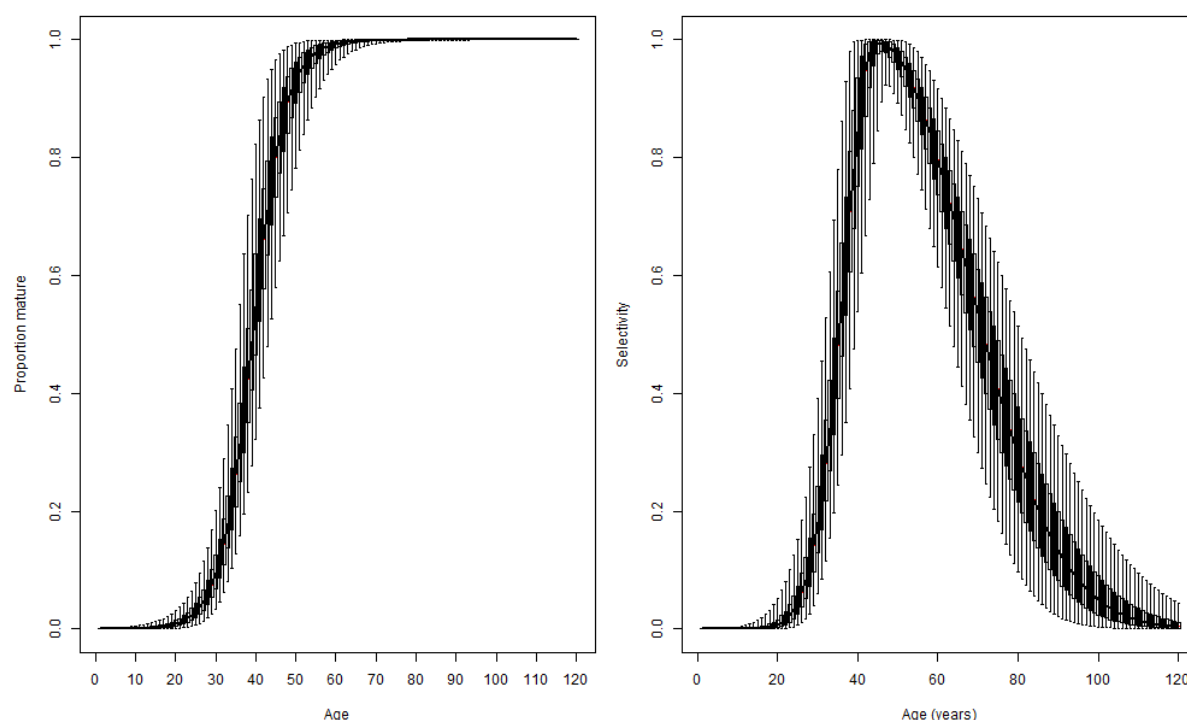
Figure 17: NWC base: MCMC estimated proportion mature at age at equilibrium (left) and long-tow fishery selectivity (right). The box for each age class covers the middle 50% of the distribution and the whiskers extend to 95% CIs.

The MCMC estimates of (true) YCS are fairly uniform with no long-term trends apparent (Figure 18). This flows through into the stock status trajectory which is driven by the catch history, with the only substantive decline from 1990 to 2005 (Figure 19). Stock status is estimated to have always been above 40% B_0 (Figure 19). Exploitation rates are estimated to have been as high as 10-15% in 1993 and 2002 but since 2006 have typically been well under 5% (Figure 20).
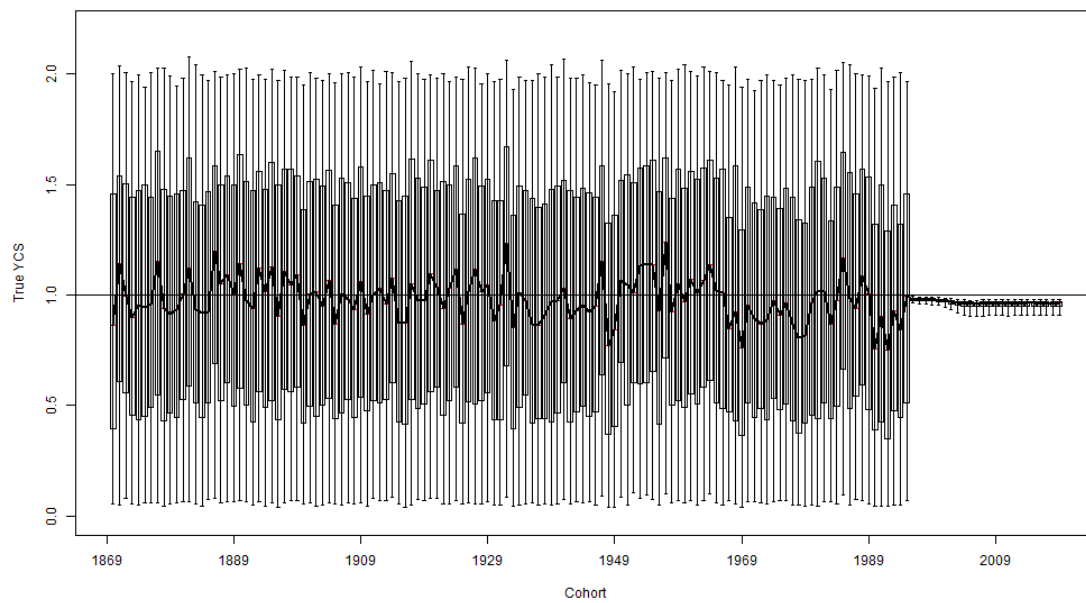
Figure 18: MCMC estimated true year class strengths (R_i/R_0) (1870 to 1995). The box for each cohort covers the middle 50% of the distribution and the whiskers extend to 95% CIs. The median estimates are shown by the bold black line.

Figure 19: NWC base: MCMC estimated stock status trajectory (last 70 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.

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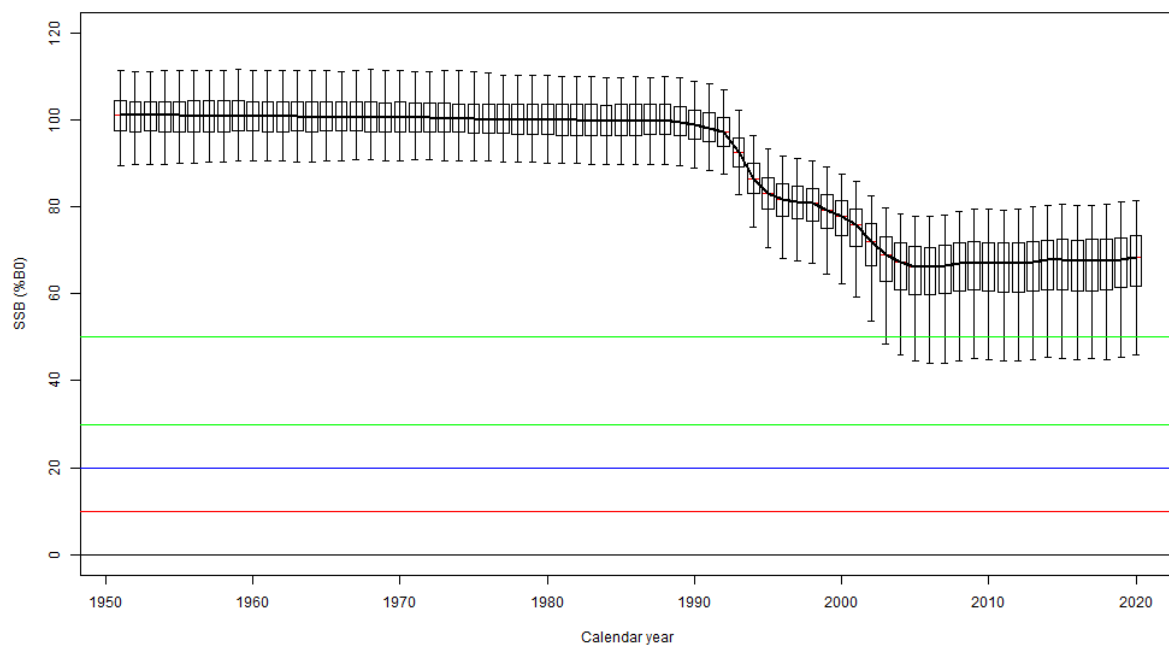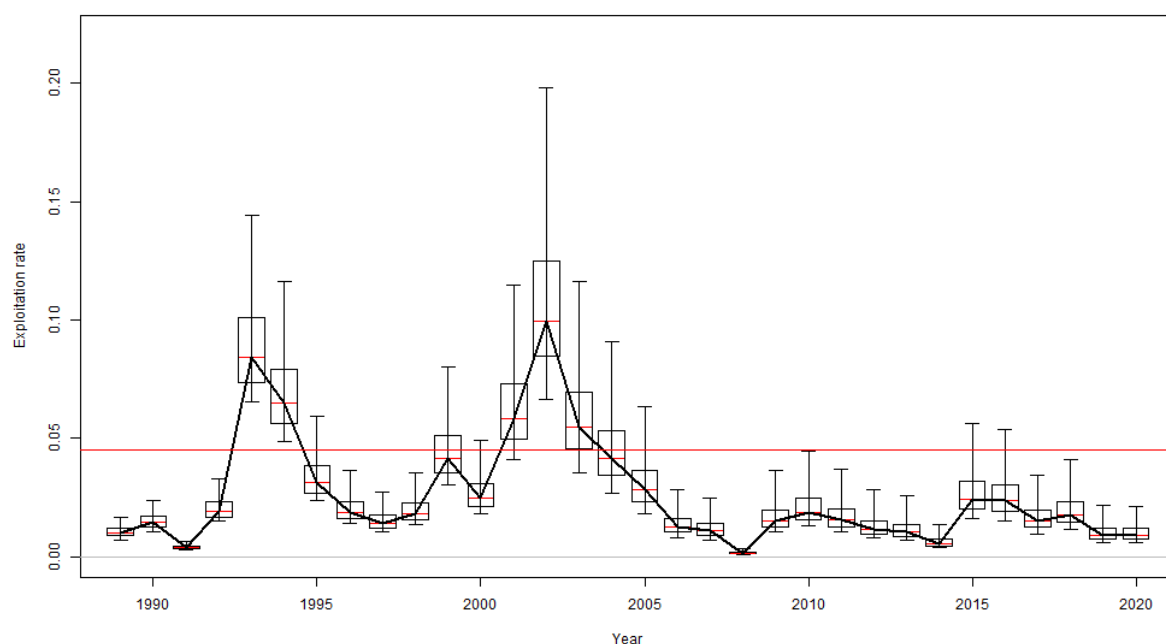**Figure 20: NWC base: MCMC estimated exploitation rates. The box for each fishing year covers the middle 50% of the distribution and the whiskers extend to 95% CIs. The red line is at M = 0.045.**

The MCMC sensitivity runs explored the effect of alternative effective samples sizes, exploitation rate restrictions, lower values of M, an alternative catch history, a change in ageing error, and forcing B_0 to a low and restricted range (Tables 4-6). There is a gentle trend of decreasing estimates of B_0 and current stock status with increasing effective sample sizes (Table 4). Similarly, there is a gentle trend associated with the exact level of the minimum maximum-exploitation-rate (Table 5). The only sensitivity run that had any substantive impact on the assessment results was forcing B_0 to very low values (Table 6). However, even in that extreme case, current stock status is estimated to be mainly above 20% B_0 (Table 6).

Table 4: NWC: MCMC estimates of B_0 and 2020 stock status for the base model and sensitivities on effective sample size.

Model	B_0 (000 t)		SS_{2020} (%B_0)	
	Median	95% CI	Median	95% CI
Half	33	19-43	68	47-82
Base	33	19-43	68	46-81
Double	32	19-44	67	44-80
Four times	28	17-44	62	40-79

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Table 5: NWC: MCMC estimates of B_0 and 2020 stock status for the base model and sensitivities on the minimum required level of maximum exploitation rate in the short-tow fishery.

Model	B_0 (000 t)		SS_{2020} (%B_0)	
	Median	95% CI	Median	95% CI
3%	46	21-71	76	51-90
4%	38	20-53	72	48-86
5% (base)	33	19-43	68	46-81
6%	29	18-37	64	43-77
7%	26	18-32	60	41-73

Table 6: NWC: MCMC estimates of B_0 and 2020 stock status for the base model and miscellaneous sensitivities (lower values of M, increased maximum exploitation rates, catch history from Roux & Edwards (2017), no ageing error for the plus group, and a prior on B_0: N[mean=10 000 t, CV = 10%]).

Model	B_0 (000 t)		SS_{2020} (%B_0)	
	Median	95% CI	Median	95% CI
M = 0.035	33	20-43	65	42-77
M = 0.040	33	20-44	66	45-79
Base	33	19-43	68	46-81
Max. expl. 0.9	33	20-44	68	47-81
R&E catch	33	19-43	69	48-82
Ageing error	33	19-44	68	46-81
Forced low B_0	12	11-14	26	17-36

The long-term yield associated with the New Zealand HCR is 1.2% of B_0 which, for the base model, gives: 396 t with a 95% CI: 228-516 t.

NWC projections

The constant catch projections at the long-term yield were used to produce a "worst case" scenario, being the MCMC samples that produced the lowest 10% of projected stock status in 2025. The distribution of B_0 values for the "worst case" scenario is approximately the same as the lowest 10% of B_0 values (Figure 21). However, they are constructed from the "worst" combination of maturity, YCS, and B_0 values.
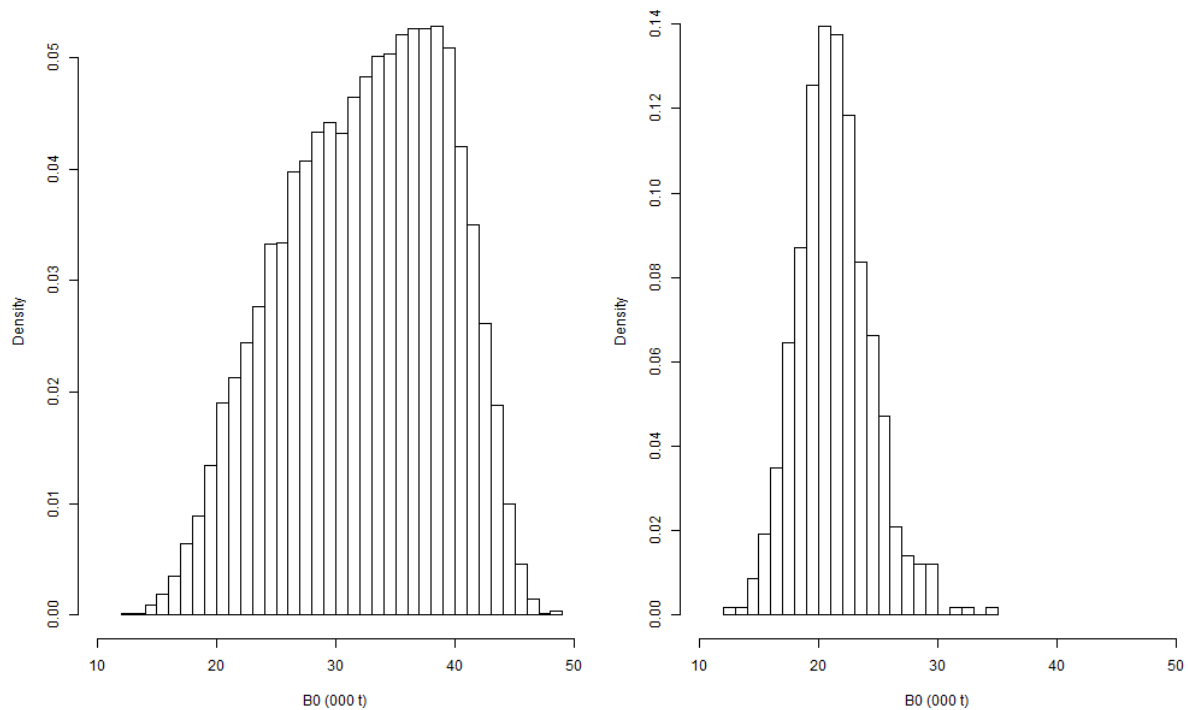
Figure 21: NWC: Marginal posterior distribution of B_0 for the base model (left) and the marginal posterior distribution for the "worst case" scenario (the MCMC samples which produce the lowest 10% of values for projected stock status in 2025).

The base model projections show little change in stock status over the next five years when annual removals are equal to the estimated annual long-term yield (Figure 22). The same is true for the "worst case" scenario except that estimated stock status is at a lower level than in the base model (Figure 23). In both cases there is no risk of catches at that level moving stock status below 30% B_0 (Figures 23-24).
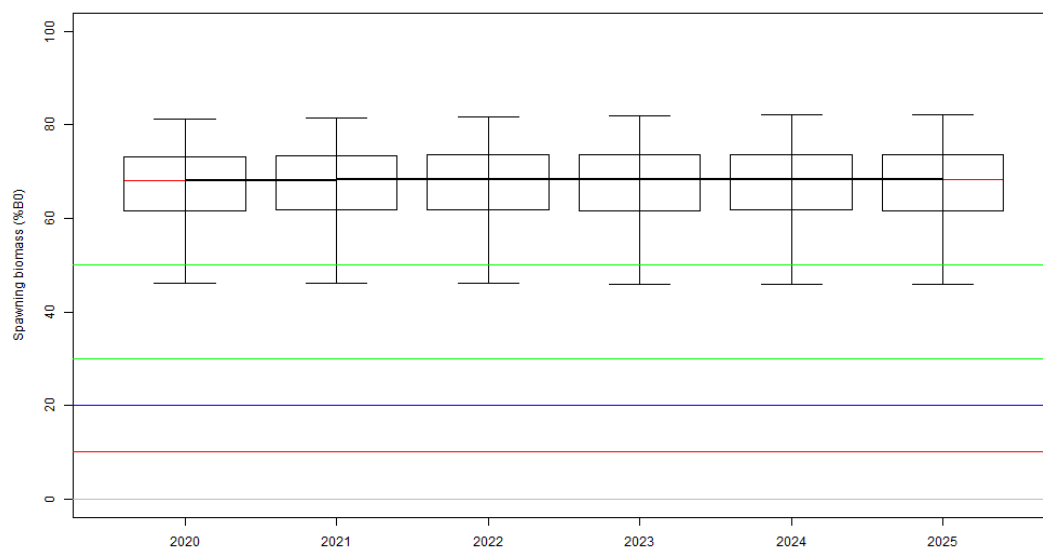
Figure 22: NWC base: MCMC projected stock status for a constant annual catch of 396 t (the estimated long-term yield). The box for each fishing year covers the middle 50% of the distribution and the whiskers extend to 95% CIs. Horizontal lines are marked at 10%, 20%, 30% and 50% B_0.
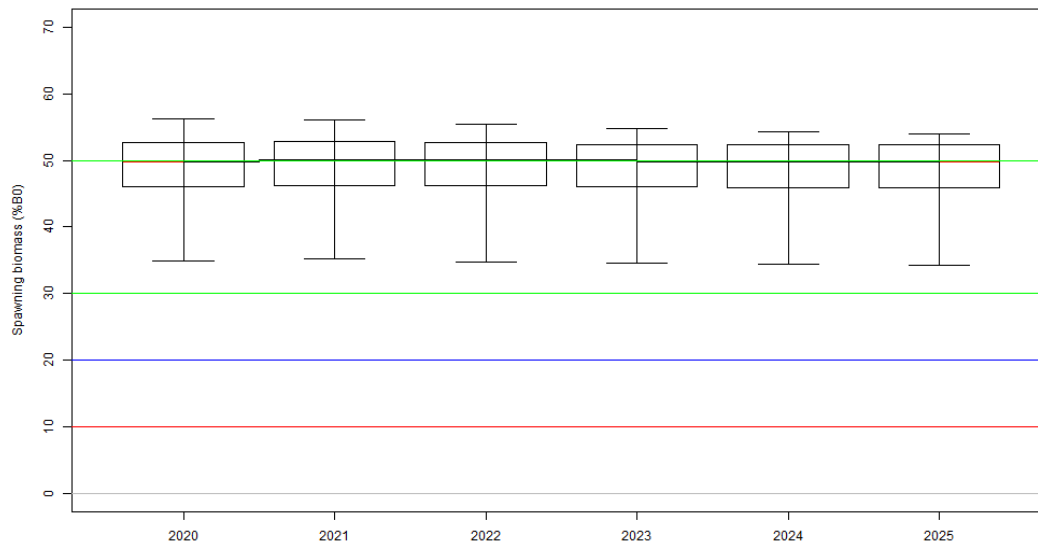
Figure 23: NWC "worst case" scenario: MCMC projected stock status for a constant annual catch of 396 t (the estimated long-term yield). The box for each fishing year covers the middle 50% of the distribution and the whiskers extend to 95% CIs. Horizontal lines are marked at 10%, 20%, 30% and 50% B_0.

LHR results

The stock assessment estimates for LHR are very imprecise because there are no data other than the catch history. The assessment borrows maturation and YCS from the NWC assessment but there is nothing to constrain B_0 other than the assumptions about maximum exploitation rate.
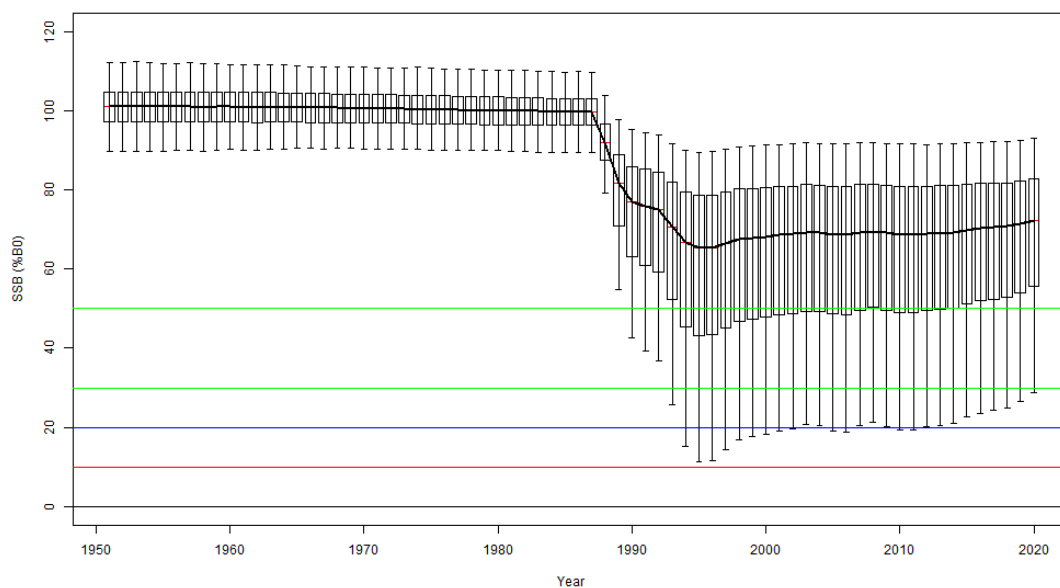
Figure 24: LHR: MCMC estimated stock status trajectory (last 70 years) The box for each fishing year covers the middle 50% of the distribution and the whiskers extend to 95% CIs. Horizontal lines are marked at 10%, 20%, 30% and 50% B_0.

Stock status for LHR may have been as low as 10% B$_0$ in the mid-1990s but current stock status is estimated to most likely be above 30% B$_0$ (Figure 24, Table 7). Exploitation rates may have been over 30% from 1993 to 1995 but, since 2014, have most likely been below 5% (Figure 25).
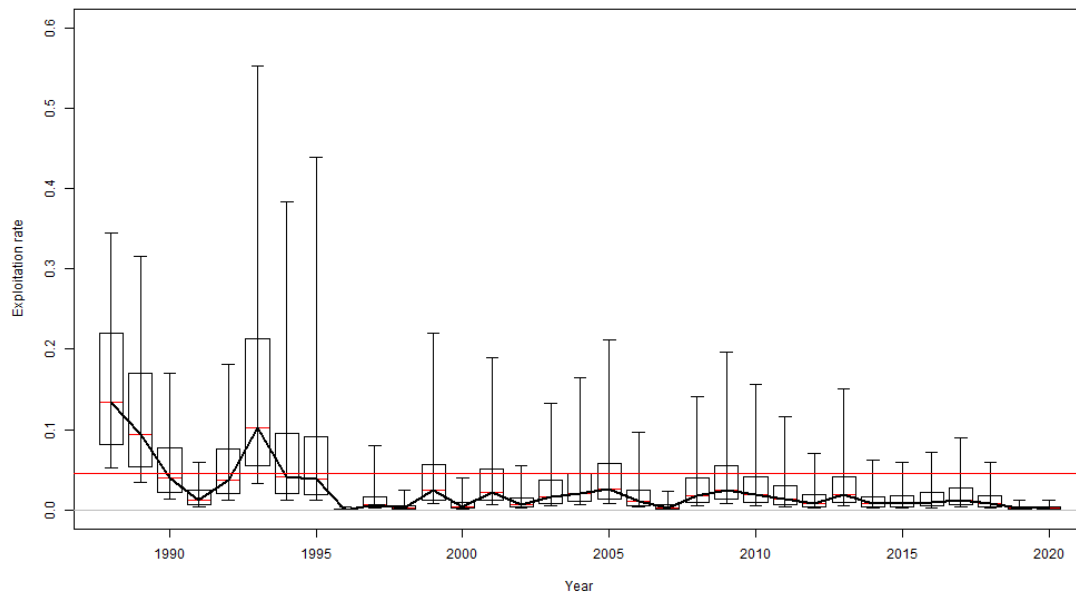
Figure 25: LHR: MCMC estimated exploitation rates. The box for each fishing year covers the middle 50% of the distribution and the whiskers extend to 95% CIs.

The LHR sensitivity runs showed the same gentle trend with the maximum exploitation rate restriction as NWC (Table 7). There was also a trend with the 1988 catch level, with higher catches producing higher current stock status (Table 7). However, the only sensitivity run to show any substantive difference from the base model was when the early catches were eliminated using the Roux & Edwards (2017) catch history.

Table 7: LHR: MCMC estimates of B_0 and 2020 stock status for the base model and sensitivities (alternative values of the minimum level of maximum exploitation rate (base = 5%), increased maximum exploitation rate, alternative catch in 1988 (the first year of the fishery), and the catch history from Roux & Edwards (2017)).

Model	B_0 (000 t)		ss_{2020} (%B_0)	
	Median	95% CI	Median	95% CI
Base	29	11-75	72	29-93
max. expl. ≥ 3%	33	11-94	75	29-95
max. expl. ≥ 4%	33	11-92	75	29-95
max. expl. ≥ 6%	27	11-63	70	28-91
max. expl. ≥ 7%	25	11-55	68	28-89
max. expl. 90%	29	11-75	72	29-93
1988: 3000 t	25	11-57	68	25-90
1988: 3500 t	27	11-66	71	27-92
1988: 4500 t	32	12-84	74	30-94
1988: 5000 t	34	12-92	75	31-95
R & E catch	16	6-39	65	14-89

The long-term yield associated with the New Zealand HCR is 1.2% of B_0 which, for the base model, gives: 348 t with a 95% CI: 132-900 t.

LHR projections

The constant catch projections at the long-term yield were used to produce a "worst case" scenario, being the MCMC samples that produced the lowest 10% of projected stock status in 2025. The distribution of B_0 values for the "worst case" scenario is approximately the same as the lowest 10% of B_0 values (Figure 26). However, they are constructed from the "worst" combination of maturity, YCS, and B_0 values.
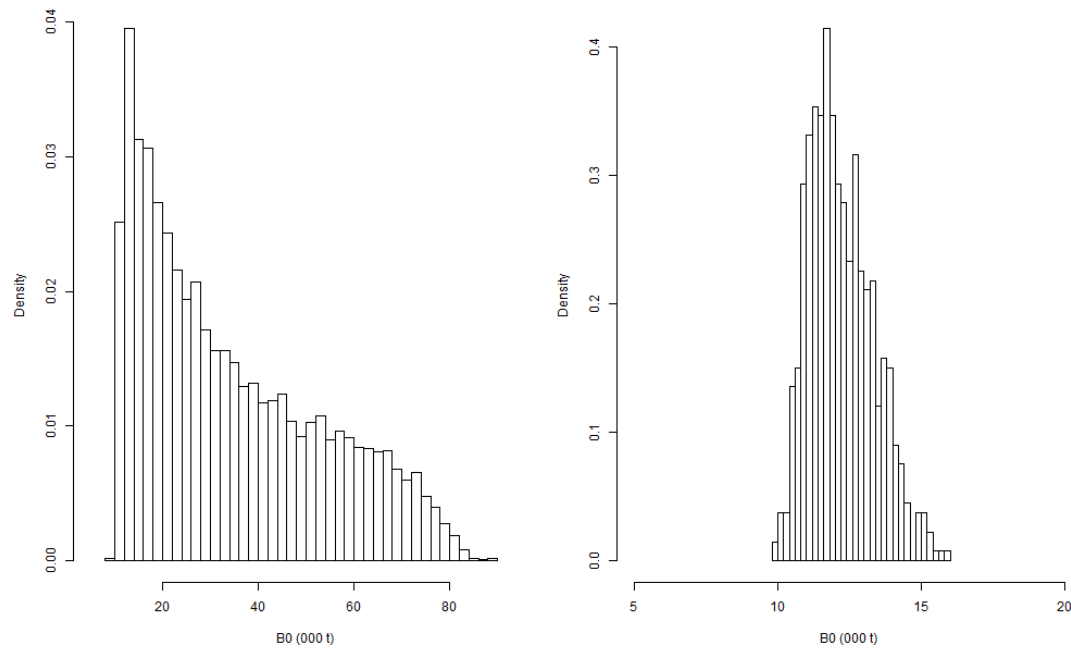
Figure 26: LHR: Marginal posterior distribution of B_0 for the base model (left) and the marginal posterior distribution for the "worst case" scenario (the MCMC samples which produce the lowest 10% of values for projected stock status in 2025).

The base model projections show little change in stock status over the next five years when annual removals are equal to the estimated annual long-term yield (Figure 27). The same is true for the "worst case" scenario except that estimated stock status is at a much lower level than in the base model (Figure 28). For the base model there is no risk of catches at that level moving stock status below 20% B_0 (Figure 27). For the "worst case" scenario there is a small chance that stock status may already be below 20% B_0 and the projections show a small increase in this probability (Figure 28).

Figure 27: LHR base: MCMC projected stock status for a constant annual catch of 348 t (the estimated long-term yield). 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 28: LHR "worst case" scenario: MCMC projected stock status for a constant annual catch of 348 t (the estimated long-term yield). The box f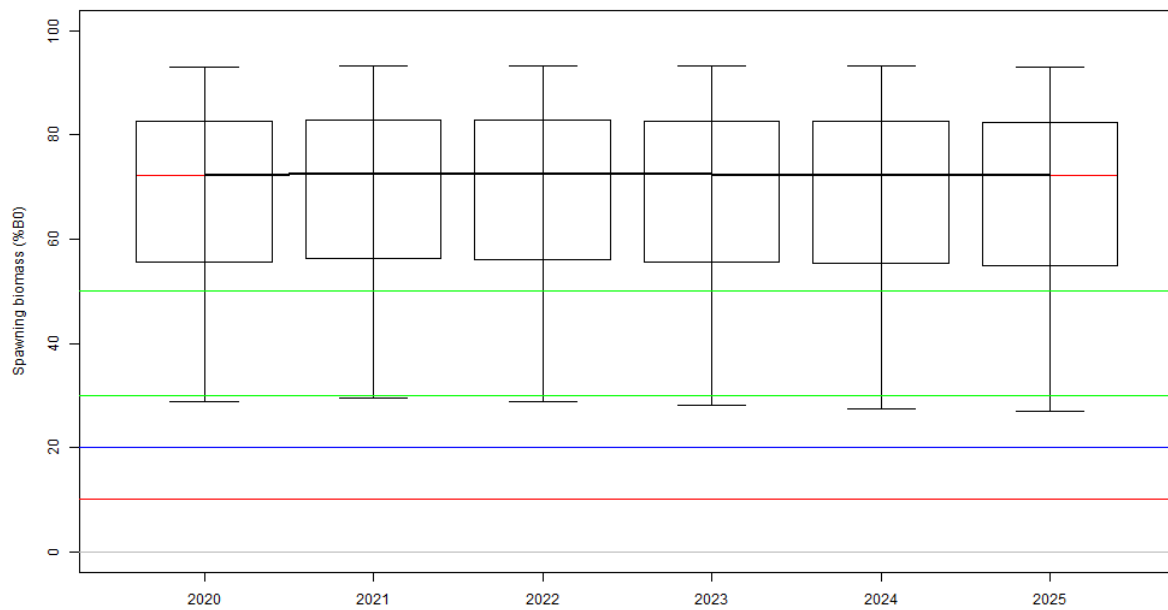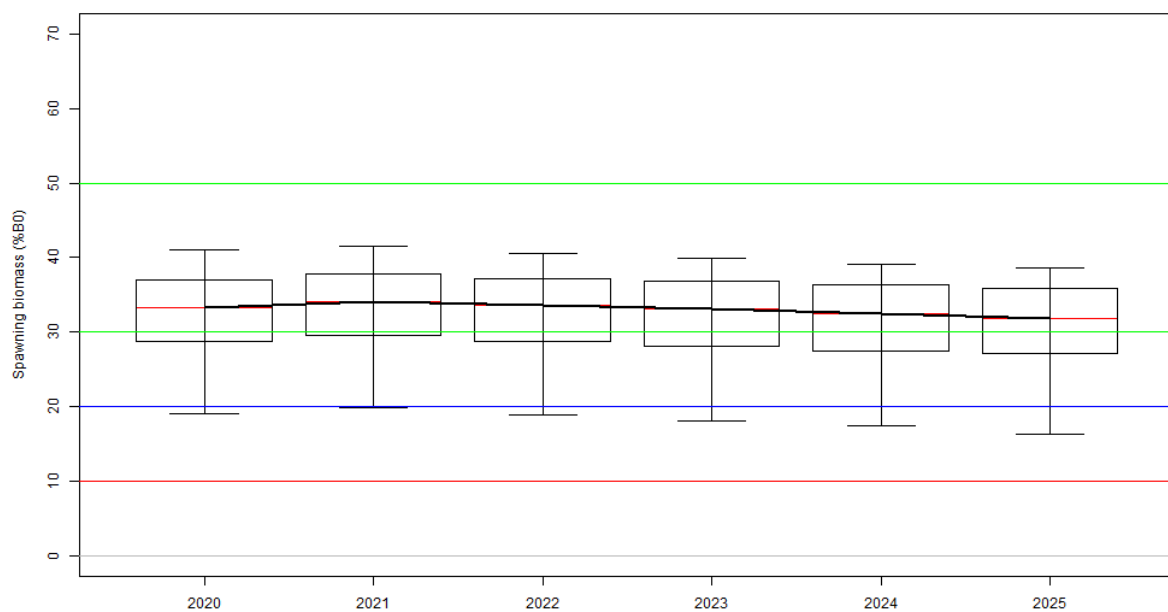or each fishing year covers the middle 50% of the distribution and the whiskers extend to 95% CIs. Horizontal lines are marked at 10%, 20%, 30% and 50% B$_0$.

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5. Discussion and conclusion

The stock assessment estimates for Tasman Sea stocks 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) and stock status in 2015 (ss_{2015}). STR: south Tasman Rise.

Stock	B_0 (000 t)		ss_{2015} (%B_0)	
	Median	95% CI	Median	95% CI
STR	26	10-69	75	42-91
NWC	26	12-53	56	13-79
LHR	14	6-36	57	7-83
WNR	9	4-21	63	19-84

In contrast, for the current NWC assessment, data specific to the stock were available to estimate growth curves, maturity, and YCS in addition to virgin and current stock size. Although no biomass indices were available the age frequencies were adequate to greatly reduce the probability of low values of B_0 and therefore low values of current stock status. This is best seen by comparing the marginal posterior distribution of B_0 (before imposition of the minimum maximum-exploitation-rate restriction) with the prior distribution (Figure 29). In the 2017 assessment, the posterior distribution was the same as the prior distribution and there was a substantial probability mass at the low end of the range of B_0. With the addition of the age frequencies, most of the probability mass at the low end of the range for B_0 has been removed (Figure 29). The requirement that the minimum exploitation rate must have been at least 5% removes much of the probability mass for the higher values of B_0 (above about 50 000 t) (Figure 30).
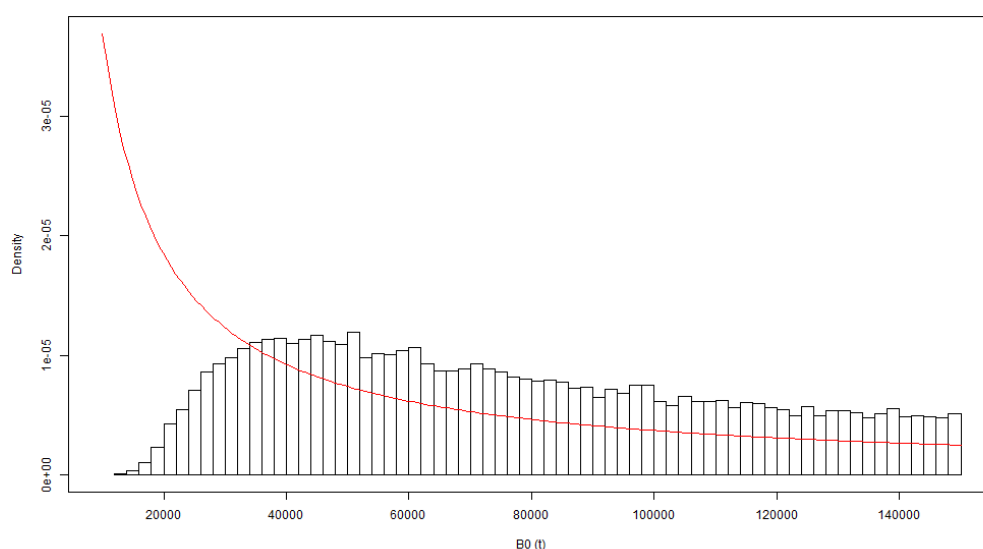
Figure 29: NWC: marginal posterior distribution of B_0 in the base model (before the minimum maximum exploitation rate restriction) compared to the prior distribution (red line).
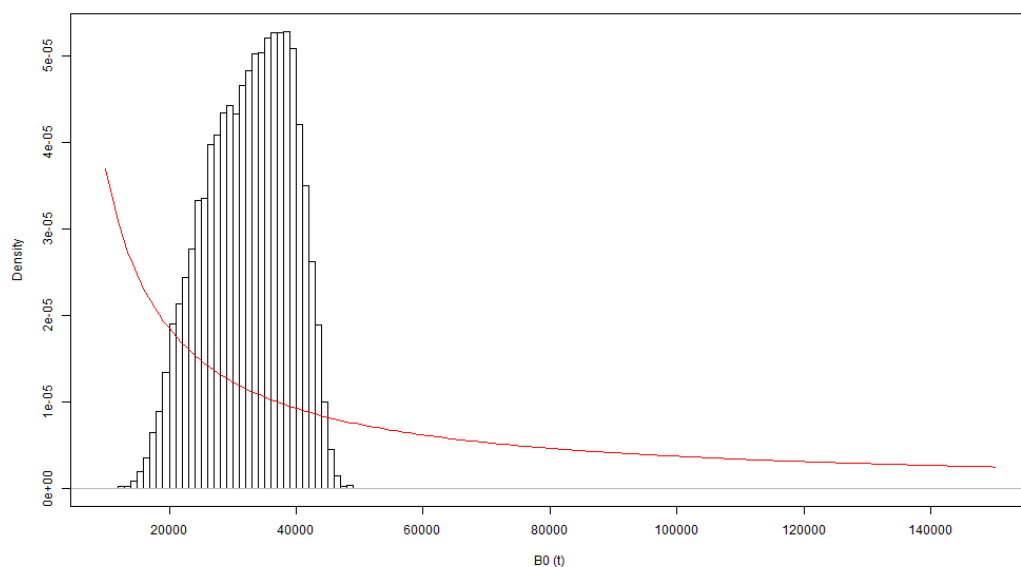
Figure 30: NWC base: marginal posterior distribution of B_0 compared to the prior distribution (red line).

By greatly decreasing the probability of low values of B_0, the introduction of the age frequencies to the NWC assessment has produced larger and more precise estimates of virgin biomass and current stock status. The contrast in the results illustrates this point with the previous 95% CI for B_0: 12 000-53 000 t, and the current 95% CI: 19 000-43 000 t. Stock status in 2015 was estimated at 13-79 %B_0 but for 2020 it is estimated at 46-81 %B_0.

There is also qualitative evidence from the NWC fishery that current stock status is not at a low level as catch rates have been maintained or slightly increased since a low point in 2005 (Figures 31-32).
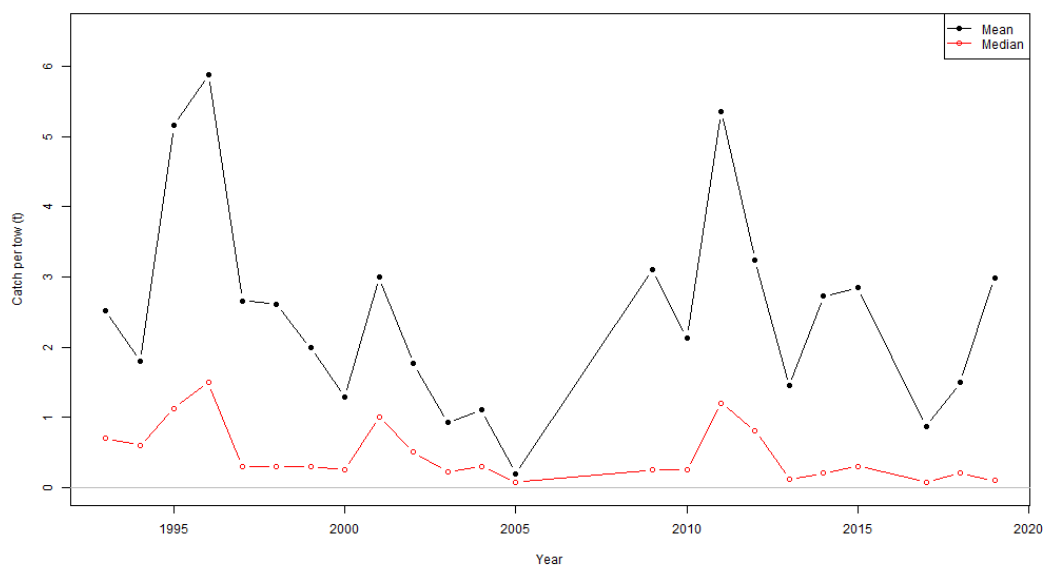
Figure 30: Mean and median orange roughy catch per tow for short tows in June for each year in which at least 30 tows were recorded.

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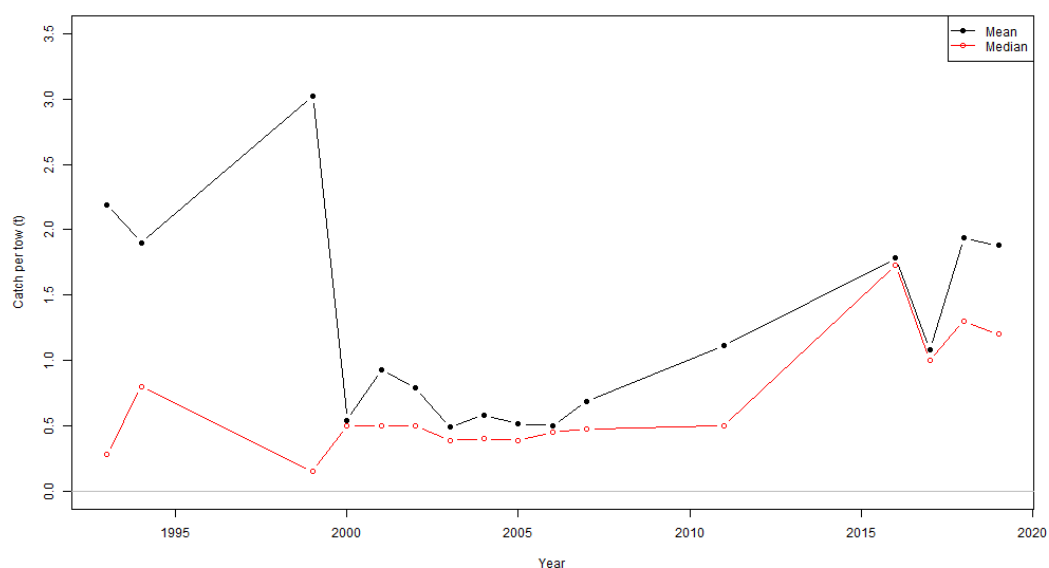
Figure 31: Mean and median orange roughy catch per tow for long tows in June for each year in which at least 30 tows were recorded.

For LHR the current estimates of B_0 and stock status are much higher than the previous estimates (Tables 7 & 8). This is to be expected given the new catch history which has a large spike in catches in the first year of the fishery compared with the previous catch history of Roux & Edwards (2017) who only used catches that were reported to SPFRMO. There is solid evidence for the early catches taken by vessels from nations that did not report their catches to SPRFMO (e.g., Clark & Tilzey 1996, Clark 2008).

When the catch history of Roux & Edwards (2017) is used in this assessment (which has median estimated YCS which are near average) then the results are almost identical to those from the 2017 assessment when the near-average northwest Chatham Rise YCS were used. In both cases, B_0 was estimated as 6 000-39 000 t. In 2017, stock status in 2015 was estimated as 7-83 %B_0 and in the current assessment at 10-88 %B_0. This is further confirmation that the important difference in the two assessments is the new catch history.

As for every stock assessment, the results are conditional on the stock hypothesis and the representativeness of the data. As the input data does not include any biomass estimates the results should be treated with some caution even though the results appear very robust.

Although current stock status for each of the stocks is quite uncertain, it is likely that NWC is currently above 40% B_0, while LHR is likely above 30% B_0. Based on the 2017 assessment, WNR is likely above 20% B_0.

In summary, the most current stock assessment estimates for the Tasman Sea stocks which can be fished are given below. *: 2015 stock status.

Stock	B_0 (000 t)		SS_{2020} (%B_0)		Long-term yield (t)	
	Median	95% CI	Median	95% CI	Median	95% CI
NWC	33	19-43	68	46-81	396	228-516
LHR	29	11-75	72	29-93	348	132-900
WNR	9	4-21	63[*]	19-84[*]	108	48-252

The total estimated long-term yield for the three stocks combined is 852 t.

6. Recommendations

It is recommended that the Scientific Committee:

- **notes** that two Tasman Sea stock assessments have been updated (Northwest Challenger and Lord Howe Rise)
- **notes** that the current stock status for Northwest Challenger is likely above 40% B_0;
- **notes** that the current stock status for Lord Howe Rise is likely above 30% B_0;
- **notes** that current stock status for West Norfolk Ridge is likely above 20% B_0;
- **notes** that the current catch limit of 346 t for the Tasman Sea is much lower than the total long-term yield estimate of 852 t;
- **agrees** that the current stock assessment for Northwest Challenger and Lord Howe Rise together with the 2017 assessment of West Norfolk Ridge provide the best currently available information on which to base management advice for Tasman Sea orange roughy stocks.

7. Acknowledgments

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Appendix A: NWC base model chain diagnostics

Three chains each of 10 million were used for the NWC base model with 1 sample in every 1000 stored. A burn in of 100 samples was used on the basis of the movement away from the MPD as seen in the objective function value (Figure A1, top left). The chains appeared to mix well as they move from high to low values and back again with high frequency (Figure A1).

The median value of B_0 was identical to two significant figures across the three chains (Figure A2, left). The chains were also adequate for 2020 stock status as evidenced by the comparison of the marginal posterior distributions across the three chains (Figure A2, right). The chains were also adequate for the calculation of the maturity and long-tow selectivity parameters (Figures A3-5).
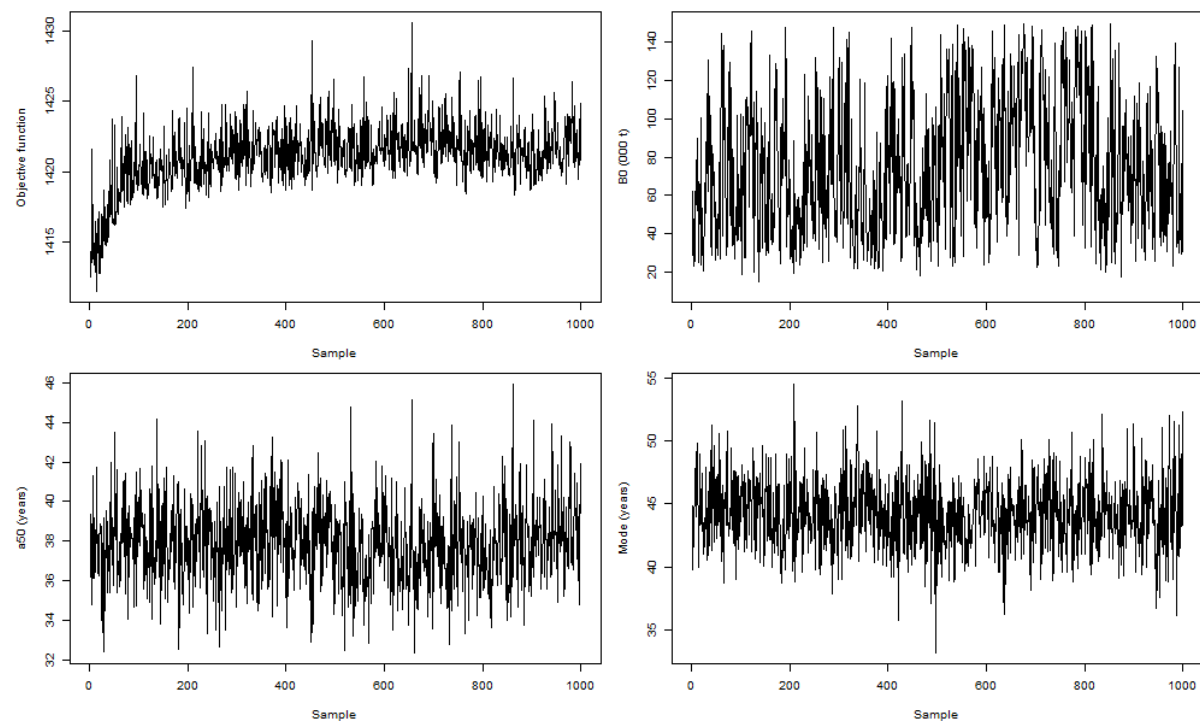
Figure A1: For the first 1000 stored samples of the first of the three base model chains: the objective function (top left), B_0 (top right), a_{50} (bottom left), and the mode of the long-tow selectivity (bottom right). The chain starts at a random jump from the MPD estimate which is why the lowest objective values are at the start of the chain. The first 100 stored samples were deleted as a "burn in" (i.e., they were not used in the calculation of estimates).
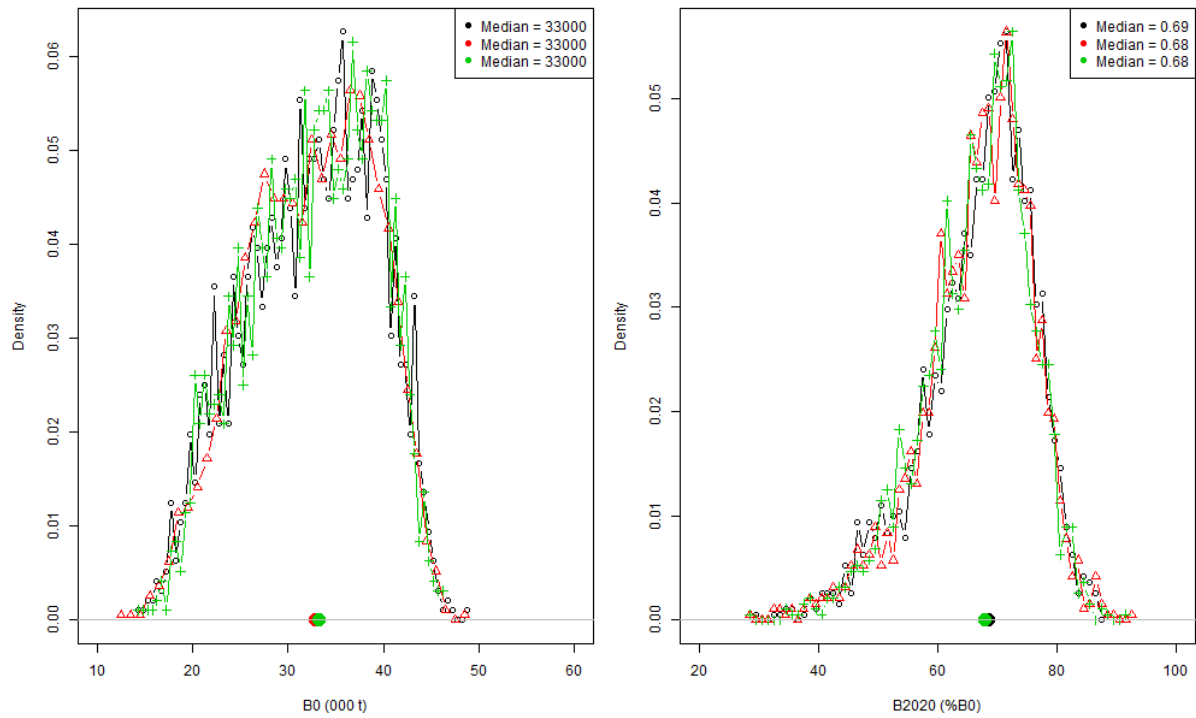
Figure A2: The marginal posterior distributions of B_0 and B_{2020} (as %B_0) for each of the three base model chains (after burn in). The median for each chain is plotted as a solid circle on the horizontal line x = 0.
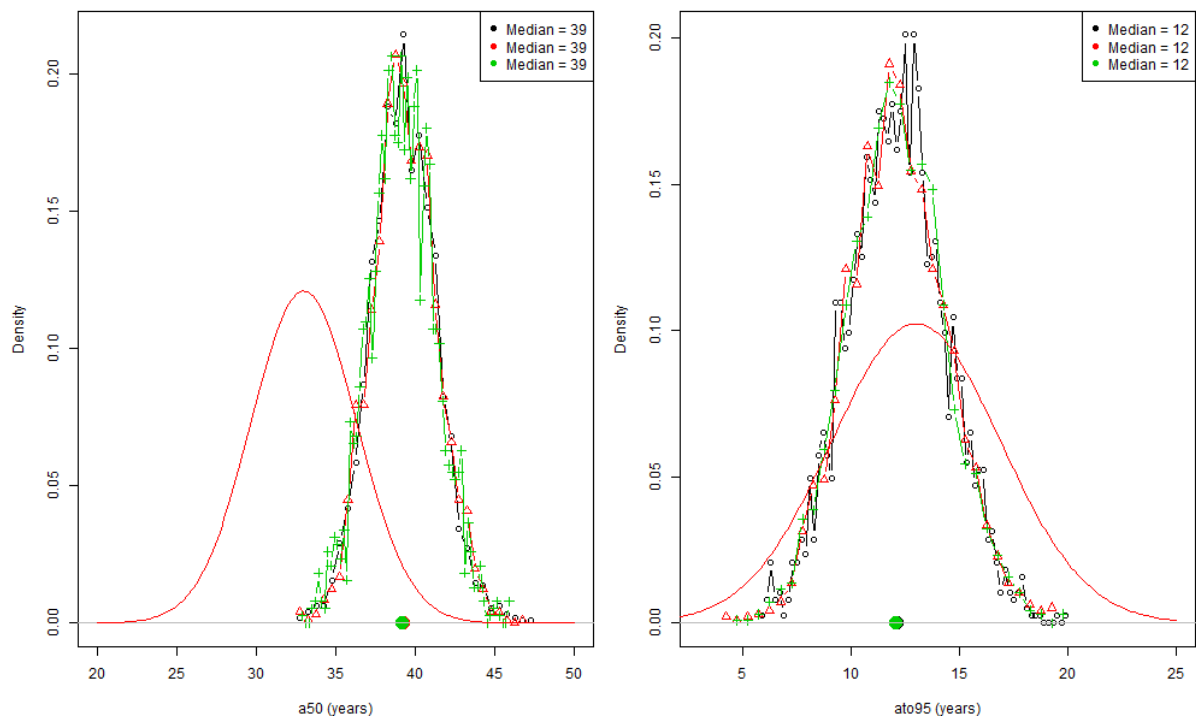
Figure A3: The marginal posterior distributions of a_{50} and a_{to95} (maturity parameters) for each of the three base model chains (after burn in). The median for each chain is plotted as a solid circle on the horizontal line x = 0. The prior distribution is shown in red.

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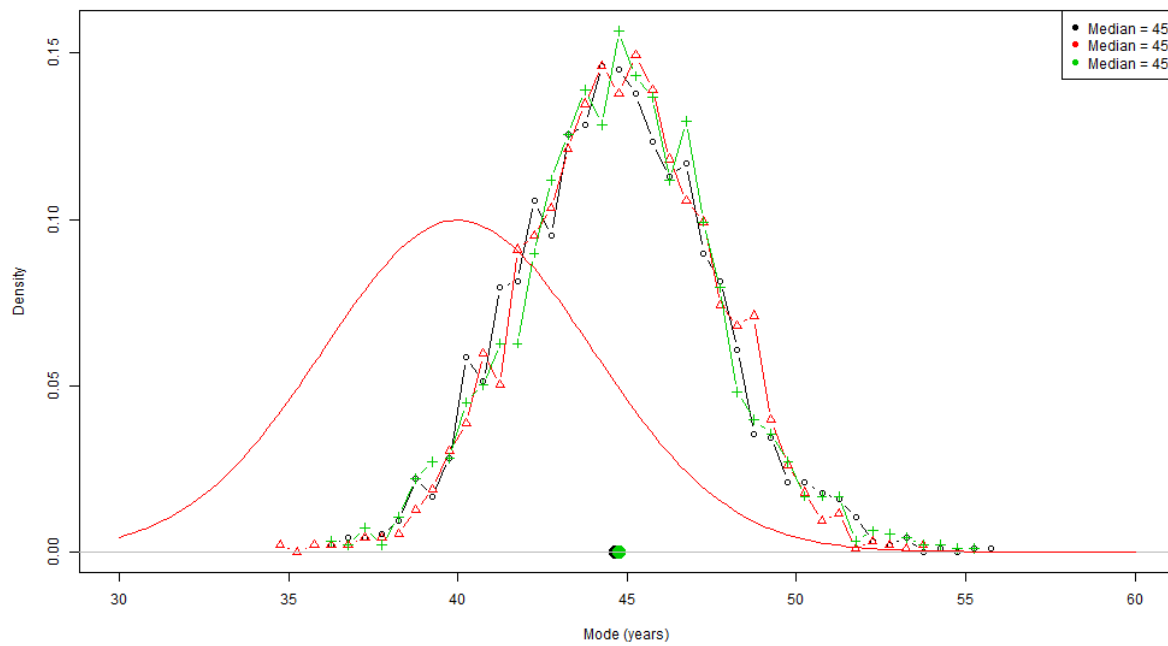
Figure A4: The marginal posterior distribution of the mode of the long-tow selectivity for each of the three base model chains (after burn in). The median for each chain is plotted as a solid circle on the horizontal line x = 0. The prior distribution is shown in red.
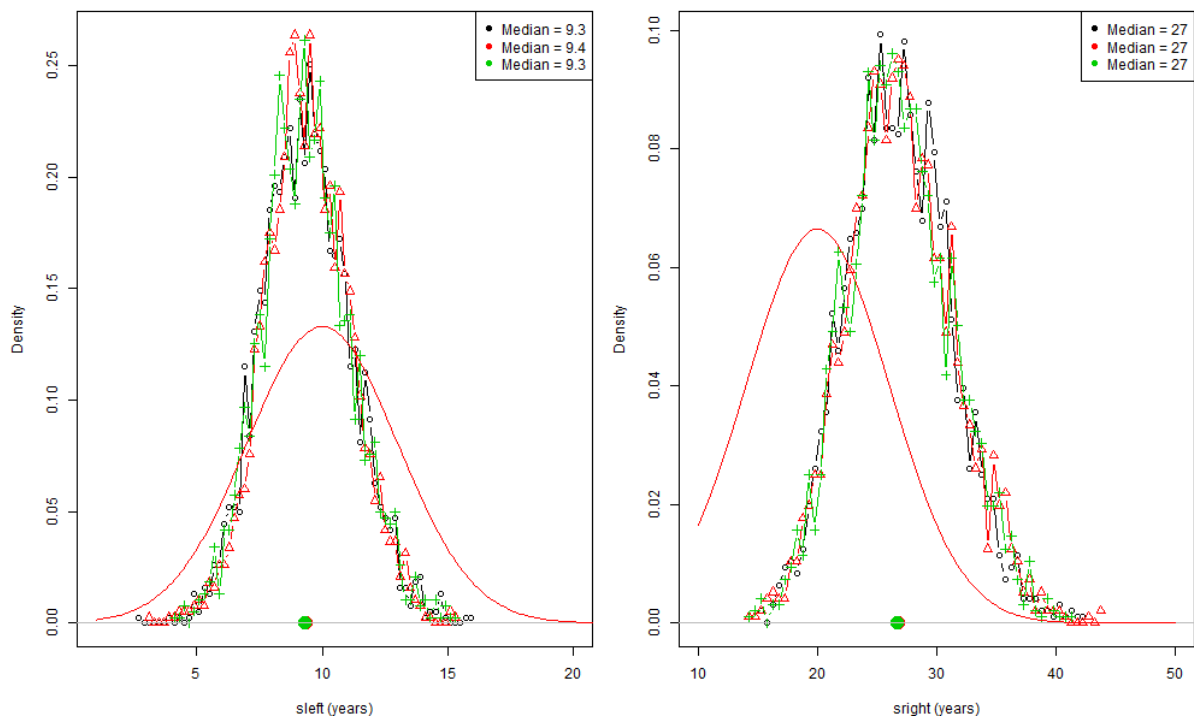
Figure A5: The marginal posterior distributions of the long-tow selectivity variance parameters for each of the three base model chains (after burn in). The median for each chain is plotted as a solid circle on the horizontal line x = 0. The prior distribution is shown in red.

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Appendix B: NWC base model fits and likelihood profiles

The MPD and MCMC fits to the age frequencies are as good as can be expected (Figures B1-6). It is not possible for the detail of very "spikey" data to be fitted well. The positive observed proportion in the plus group is well fitted in each of the three years for the short-tow age frequencies (Figures B1-3). The long-tow age frequencies have no fish in the plus group and this is well fitted (Figures B4-6) as the estimated selectivity is domed. The residuals are generally within 95% range expected except for the 2013 long-tow age frequency which has some very high residuals despite the very small effective sample size of N = 4 (Figure B5). In general, the effective sample sizes appear appropriate based on the magnitude of the MCMC residuals.
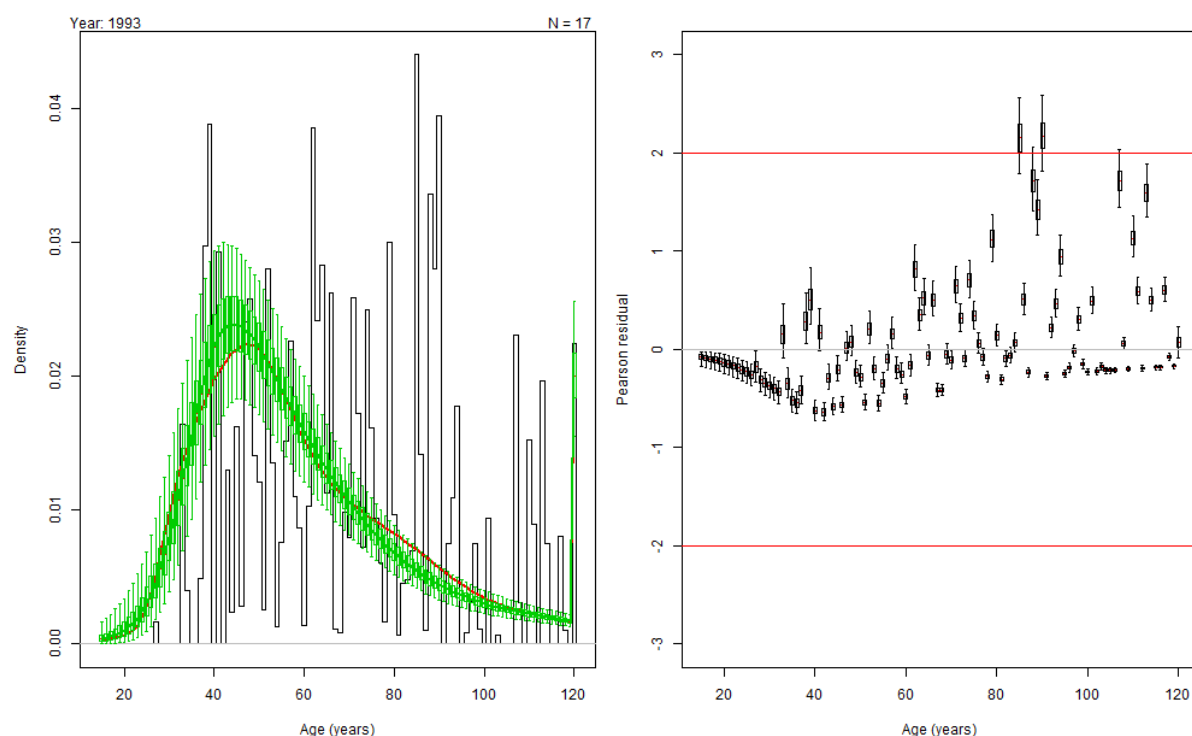
Figure B1: Base model: MPD and MCMC fits to the 1993 short-tow age frequency (left) and the MCMC residuals (right). The data are plotted as a histogram and the MPD predicted proportions at age are plotted as a smooth line (in red). The MCMC predictions (left, green) and residuals (right) are given as a box and whiskers plot at each age. Each box covers the middle 50% of the distribution and the whiskers extend to a 95% CI. N is the effective sample size.

Figure B2: Base model: MPD and MCMC fits to the 2013 short-tow age frequency (left) and the MCMC residuals (right). See Figure B1 caption.
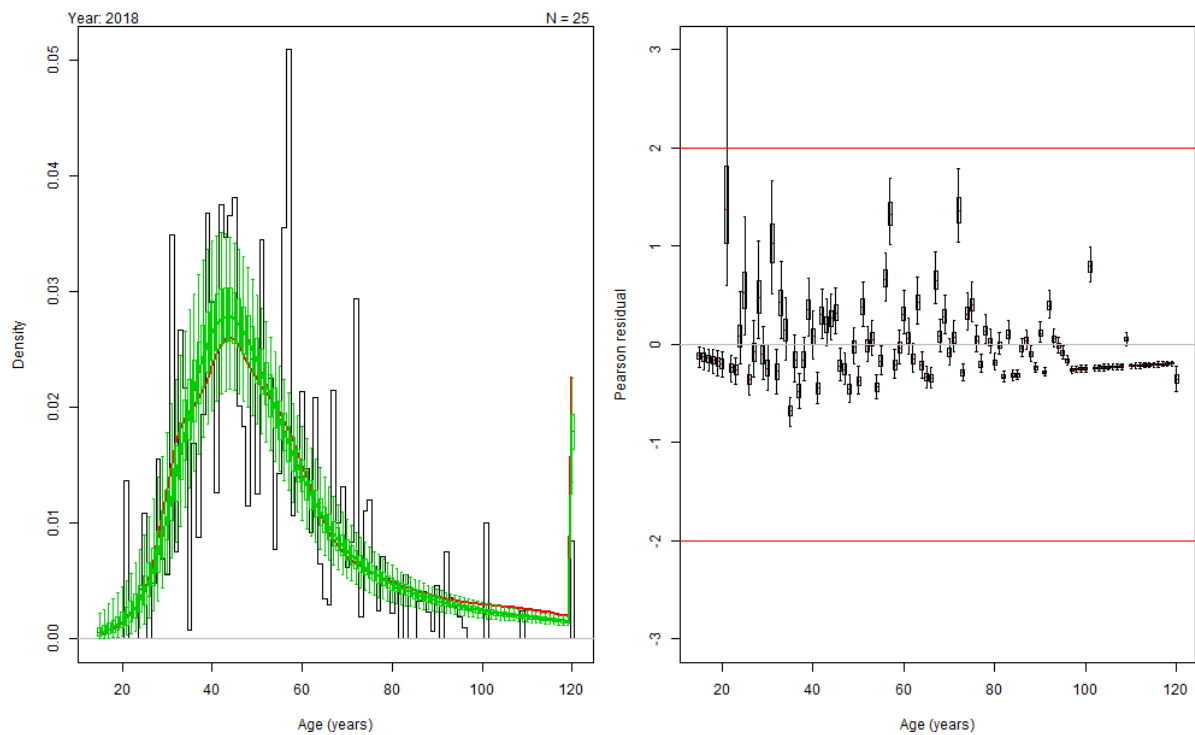
Figure B3: Base model: MPD and MCMC fits to the 2018 short-tow age frequency (left) and the MCMC residuals (right). See Figure B1 caption.
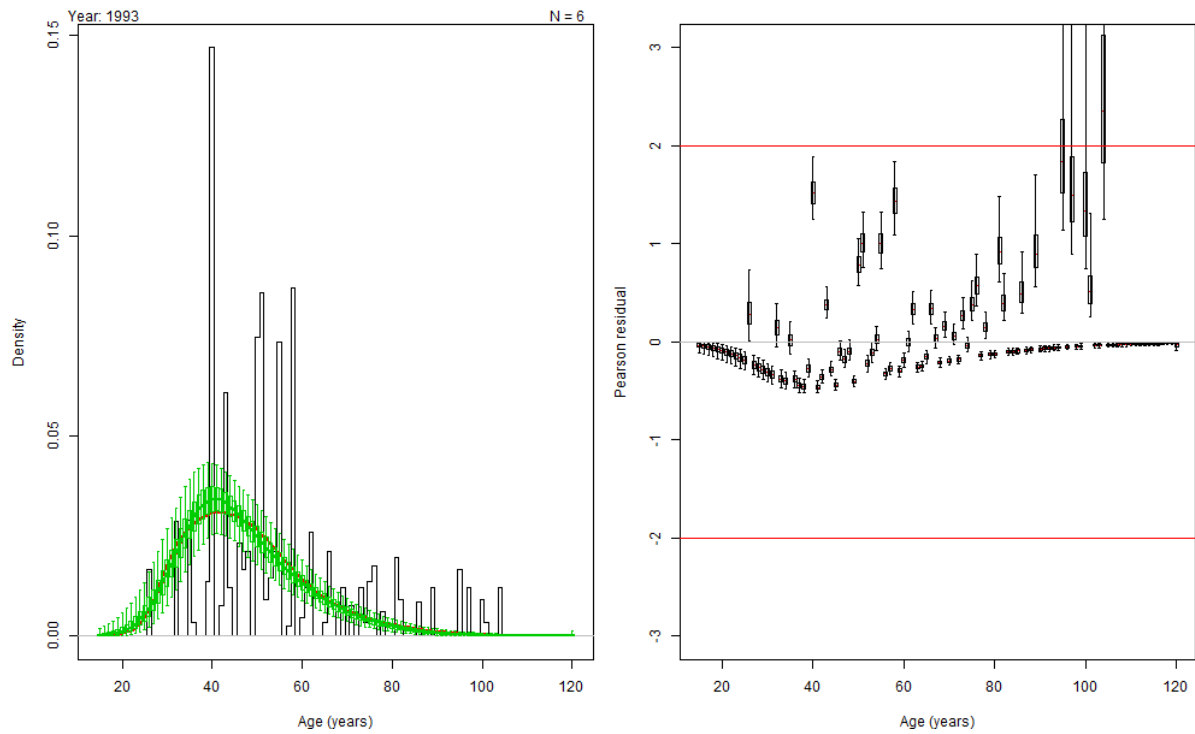
Figure B4: Base model: MPD and MCMC fits to the 1993 long-tow age frequency (left) and the MCMC residuals (right). See Figure B1 caption.
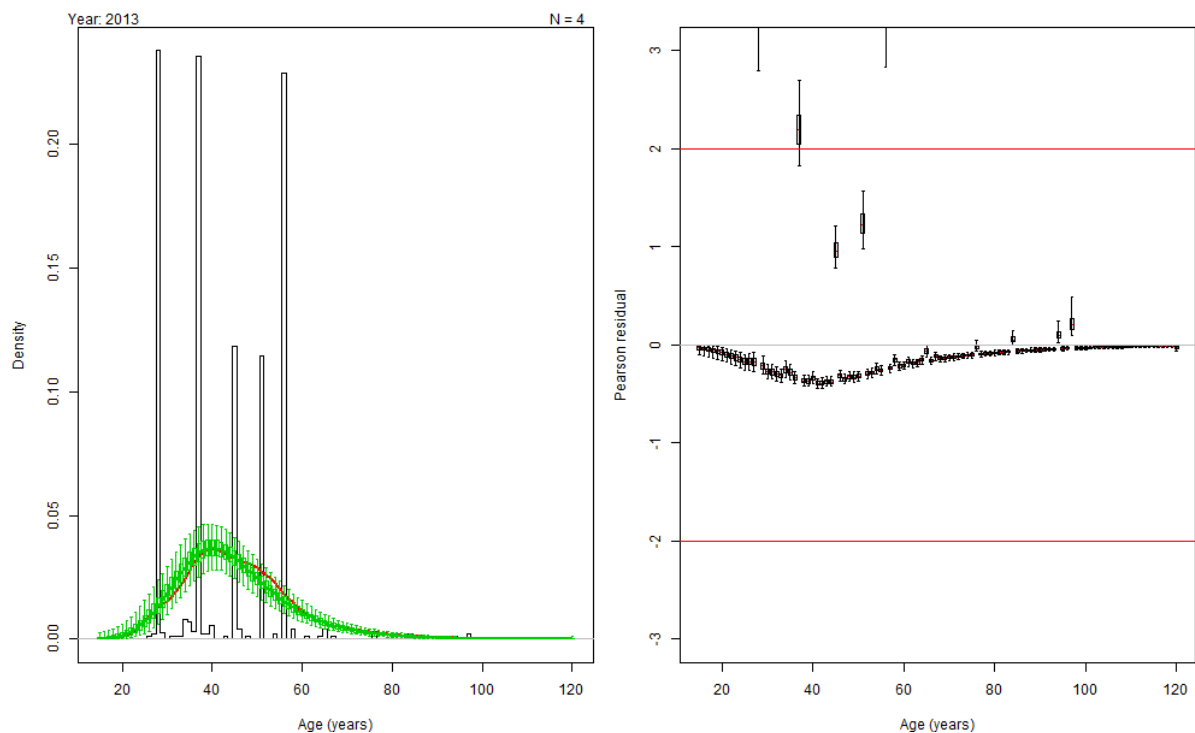
Figure B5: Base model: MPD and MCMC fits to the 2013 long-tow age frequency (left) and the MCMC residuals (right). See Figure B1 caption.
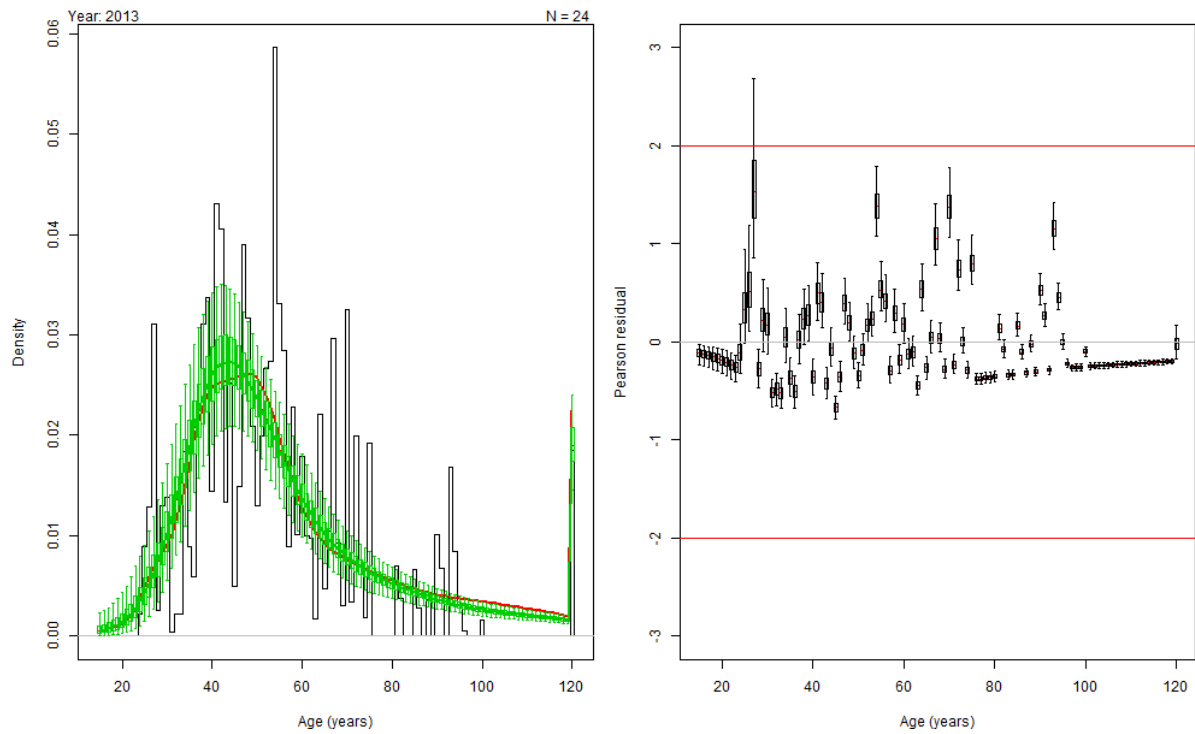
38
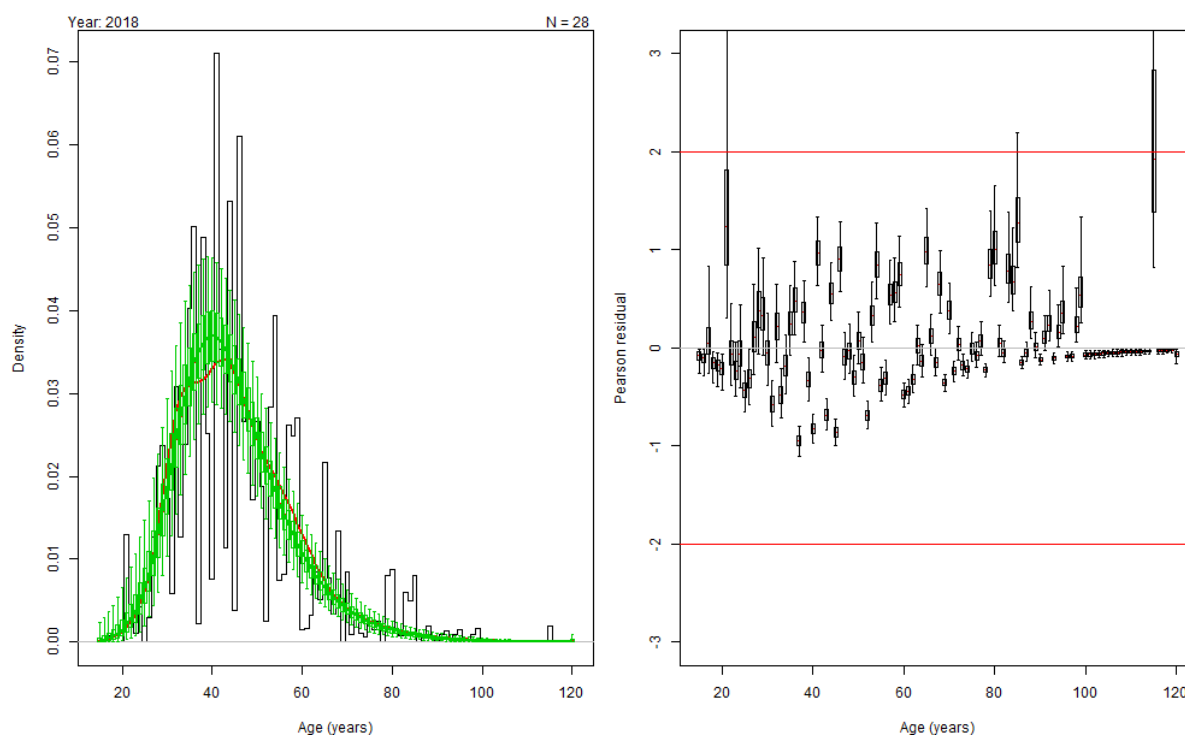
Figure B6: Base model: MPD and MCMC fits to the 2018 long-tow age frequency (left) and the MCMC residuals (right). See Figure B1 caption.

The likelihood profile for B_0 shows very little contrast for values of B_0 greater than about 25 000 t (Figure B7). At lower values of B_0 there is an increase in the objective function value for every component except the prior on B_0 (which by design favours lower values) (Figure B7). Importantly, both data sets show an increase in objective function value at lower B_0 (Figure B7).

The poorer MPD fits to the age frequency data are not obvious by eye (Figures B8-13). At the lowest value of B_0 (10 000 t) the fits are clearly different to those at higher values but they are not obviously inferior (Figures B8-13). The lowest value of B_0 produces the highest age at maturity and there is a consistent pattern of decreasing age at maturity with the increasing size of B_0 (Figure B14). Higher ages of maturity produce lower levels of virgin biomass if everything else is held constant (given the effects of natural mortality and the low levels of growth at these ages). There was little change in the MPD estimates of the long-tow selectivity across B_0 (Figure B15).

There were strong changes in the estimated YCS across B_0 (Figure B16). The lowest value of B_0 produced the most extreme estimated YCS (hence the increased objective function value for the YCS prior at low B_0) with a pattern of low early YCS and then a strong peak in the early 1960s to increase the vulnerable biomass at the start of the fishery to support the catches that were taken (Figure B16). The stock status trajectories reflect the pattern of YCS and the values of B_0 with lower B_0 producing lower current stock status (Figure B17).

39
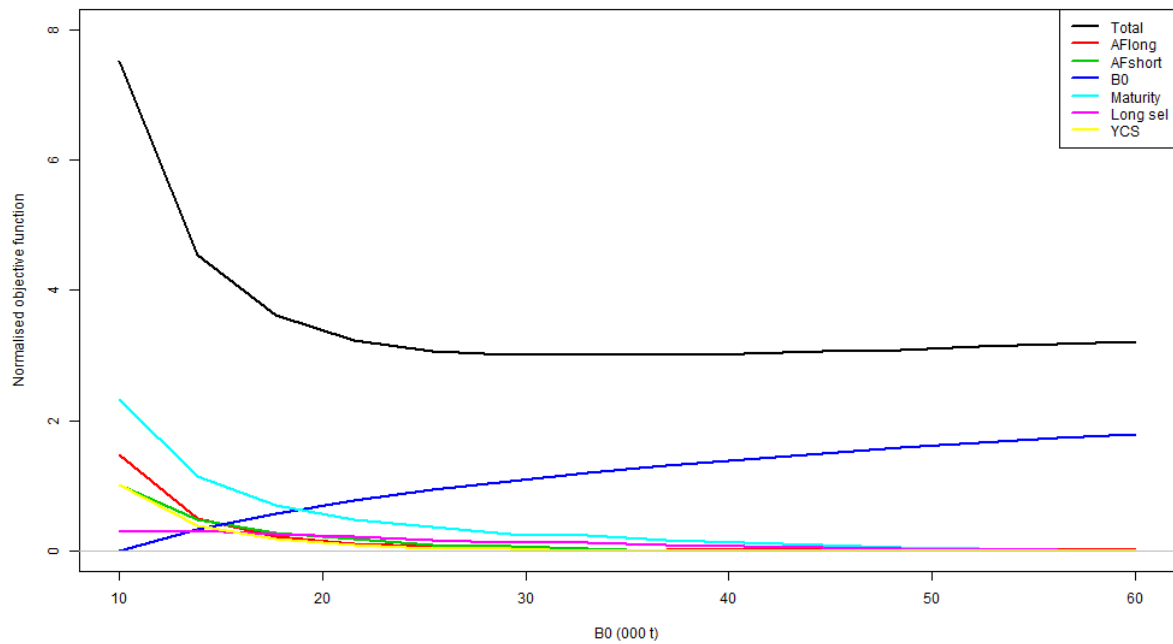
Figure B7: Base model MPD: likelihood profile for B₀. The relative objective function (normalised to a minimum of zero for each component) is shown for each data set and the priors at fixed values of B₀. The total objective function value is offset from zero by an arbitrary amount.
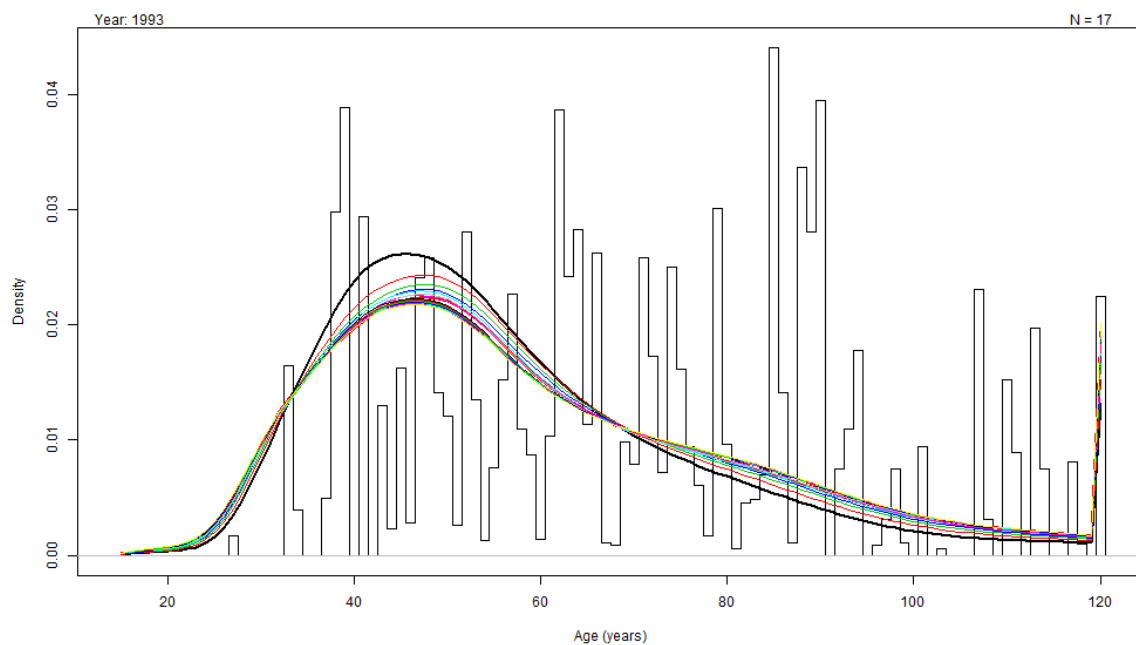
Figure B8: Base model likelihood profile for B₀: the MPD fit to the 1993 short-tow age frequency for each fixed value of B₀ in the profile (the lowest value of B₀ = 10 000 t is the bold black line). N is the effective sample size.
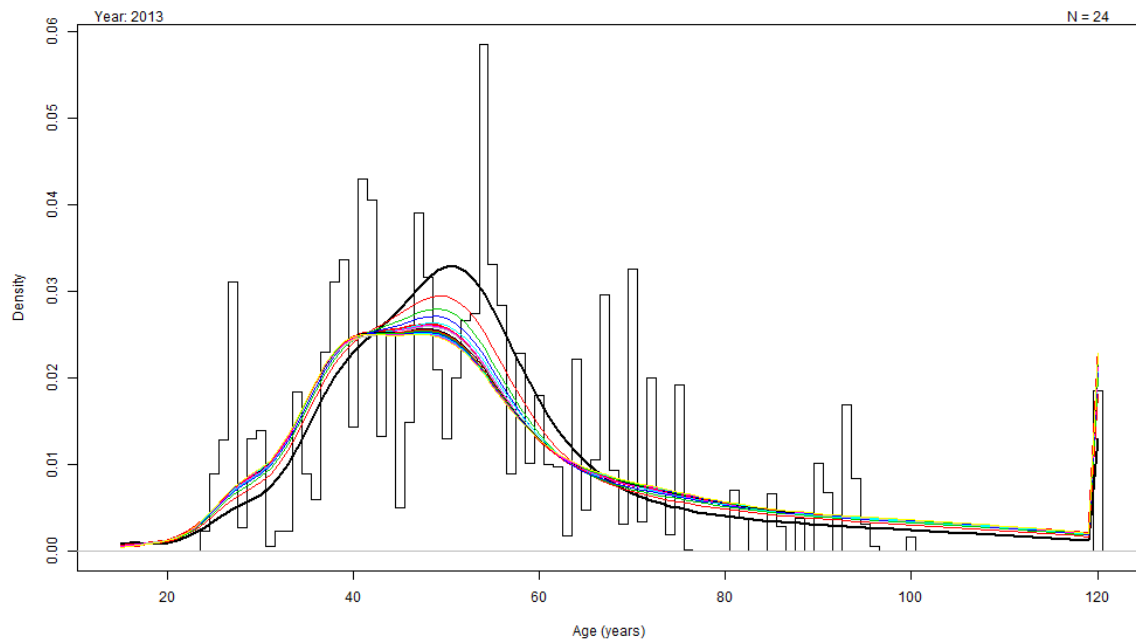
Figure B9: Base model likelihood profile for B₀: the MPD fit to the 2013 short-tow age frequency for each fixed value of B₀ in the profile (the lowest value of B₀ = 10 000 t is the bold black line). N is the effective sample size.
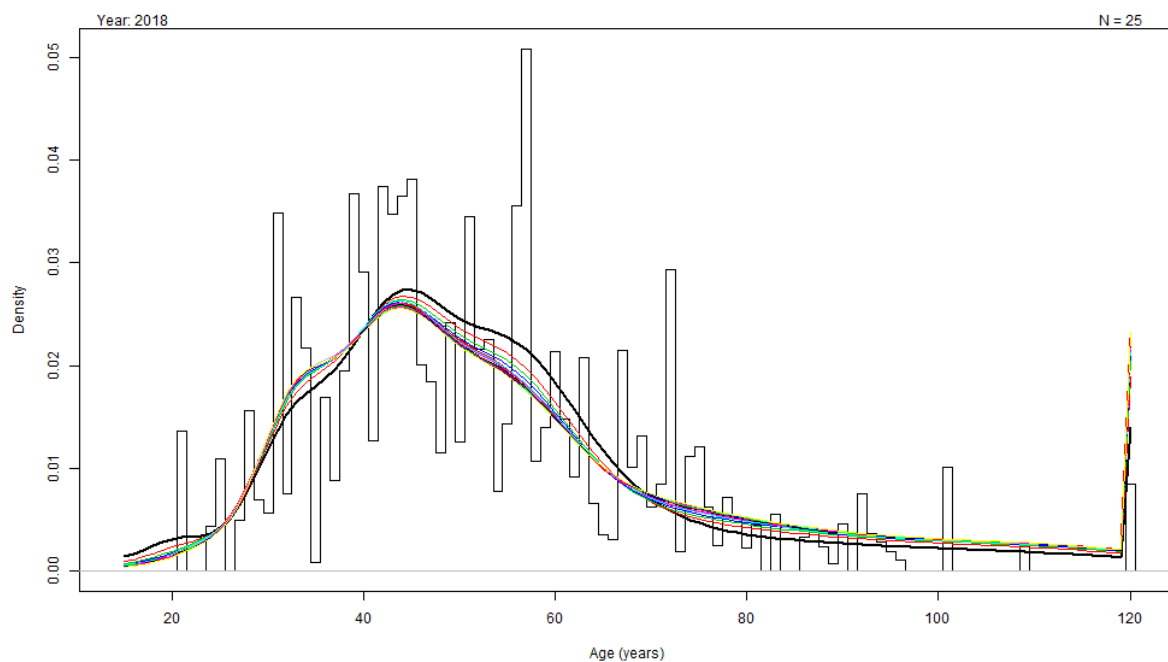
Figure B10: Base model likelihood profile for B₀: the MPD fit to the 2018 short-tow age frequency for each fixed value of B₀ in the profile (the lowest value of B₀ = 10 000 t is the bold black line). N is the effective sample size.
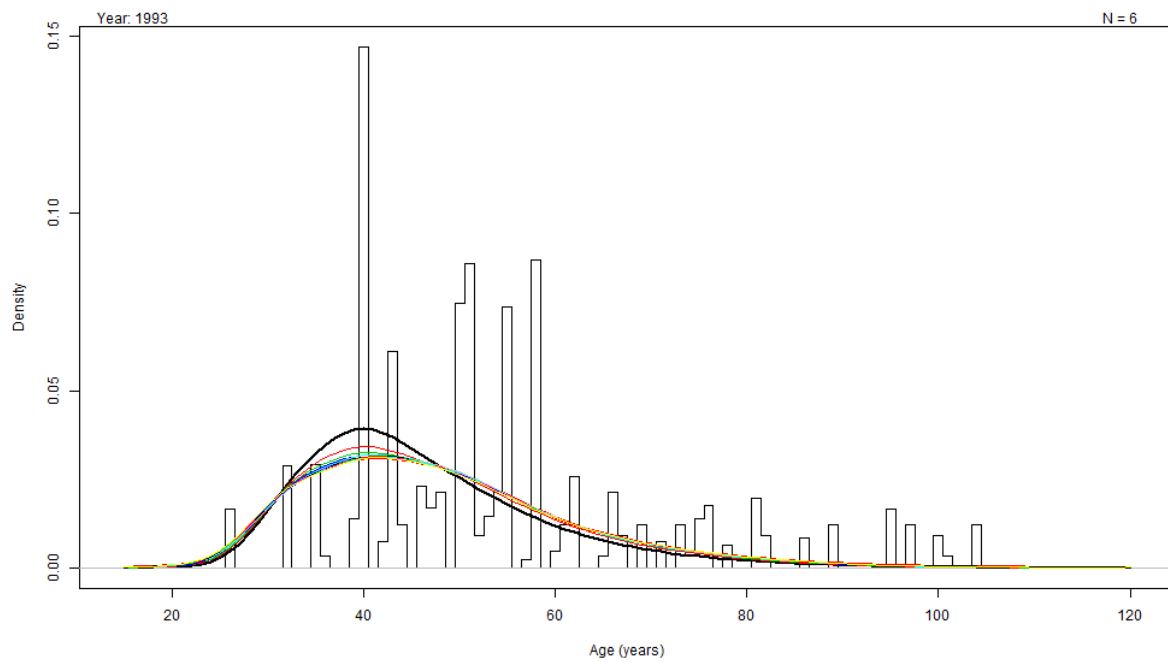
Figure B11: Base model likelihood profile for B$_0$: the MPD fit to the 1993 long-tow age frequency for each fixed value of B$_0$ in the profile (the lowest value of B$_0$ = 10 000 t is the bold black line). N is the effective sample size.
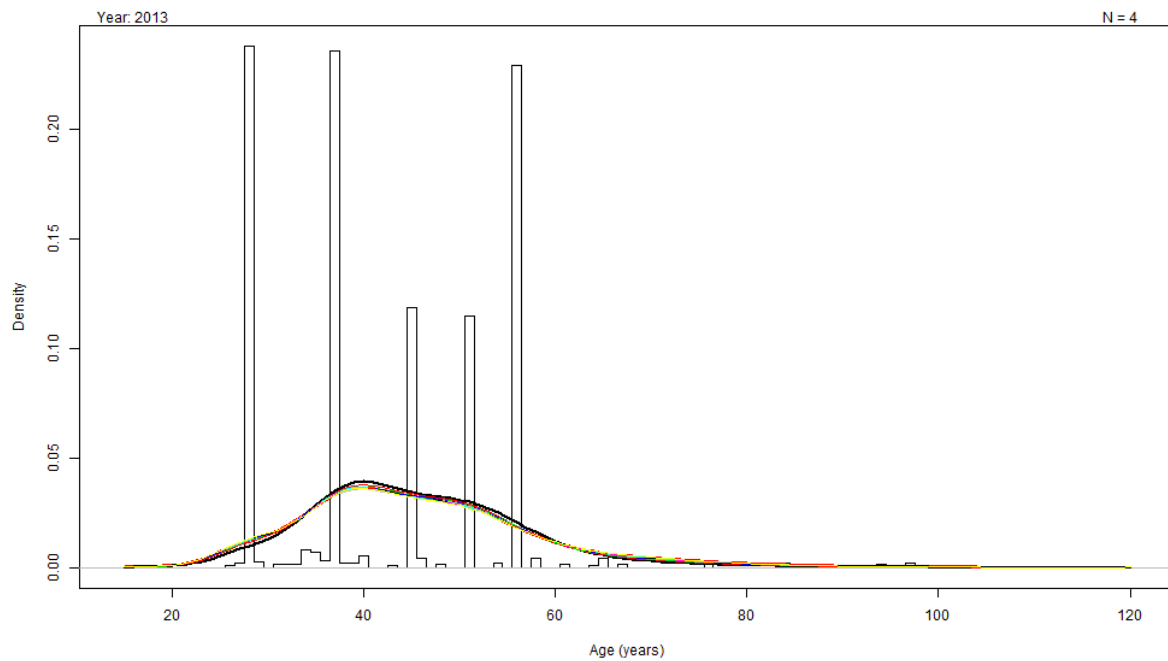
Figure B12: Base model likelihood profile for B$_0$: the MPD fit to the 2013 long-tow age frequency for each fixed value of B$_0$ in the profile (the lowest value of B$_0$ = 10 000 t is the bold black line). N is the effective sample size.
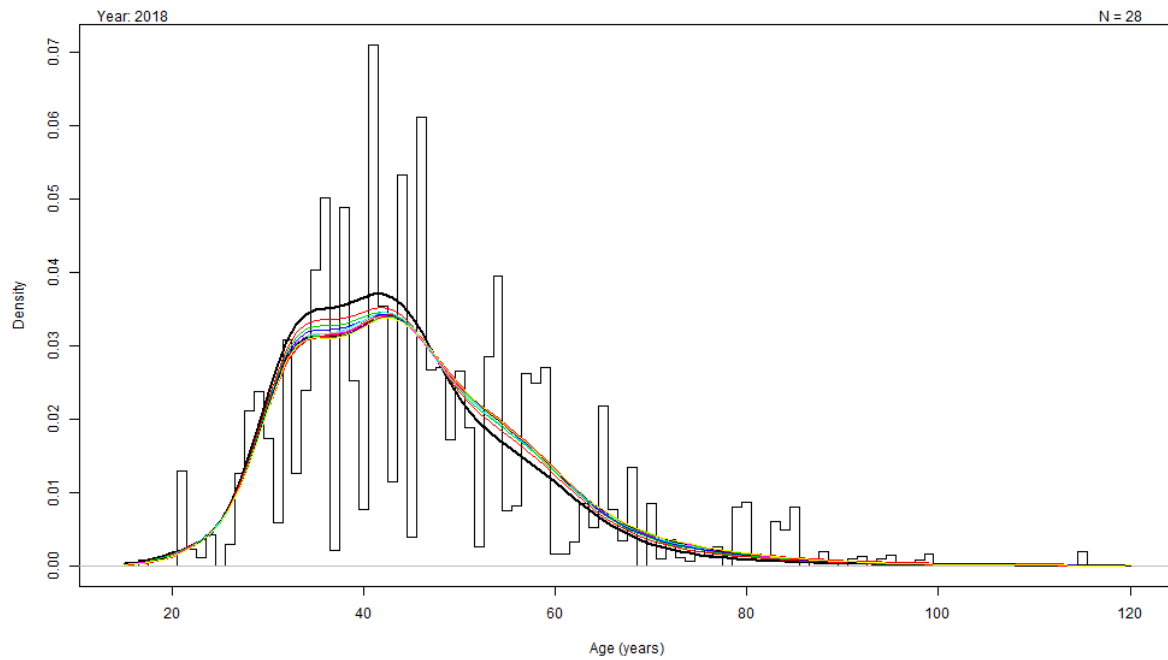
Figure B13: Base model likelihood profile for B$_0$: the MPD fit to the 2018 long-tow age frequency for each fixed value of B$_0$ in the profile (the lowest value of B$_0$ = 10 000 t is the bold black line). N is the effective sample size.
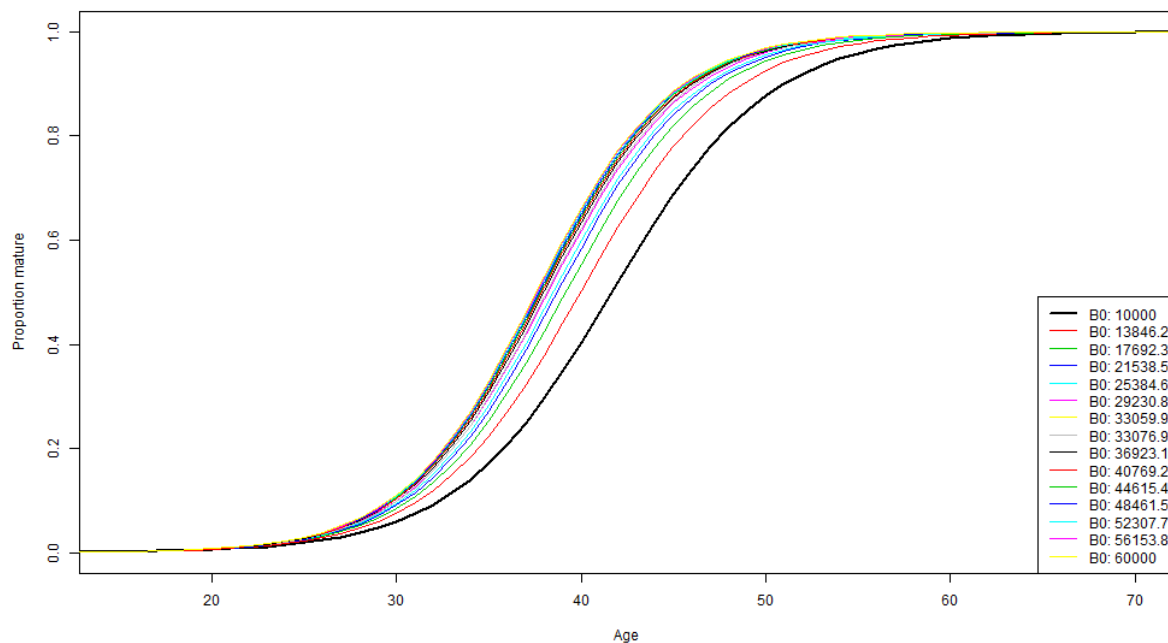
Figure B14: Base model likelihood profile for B$_0$: the MPD estimates of maturity for each fixed value of B$_0$ (the lowest value of B$_0$ = 10 000 t is the bold black line).

43
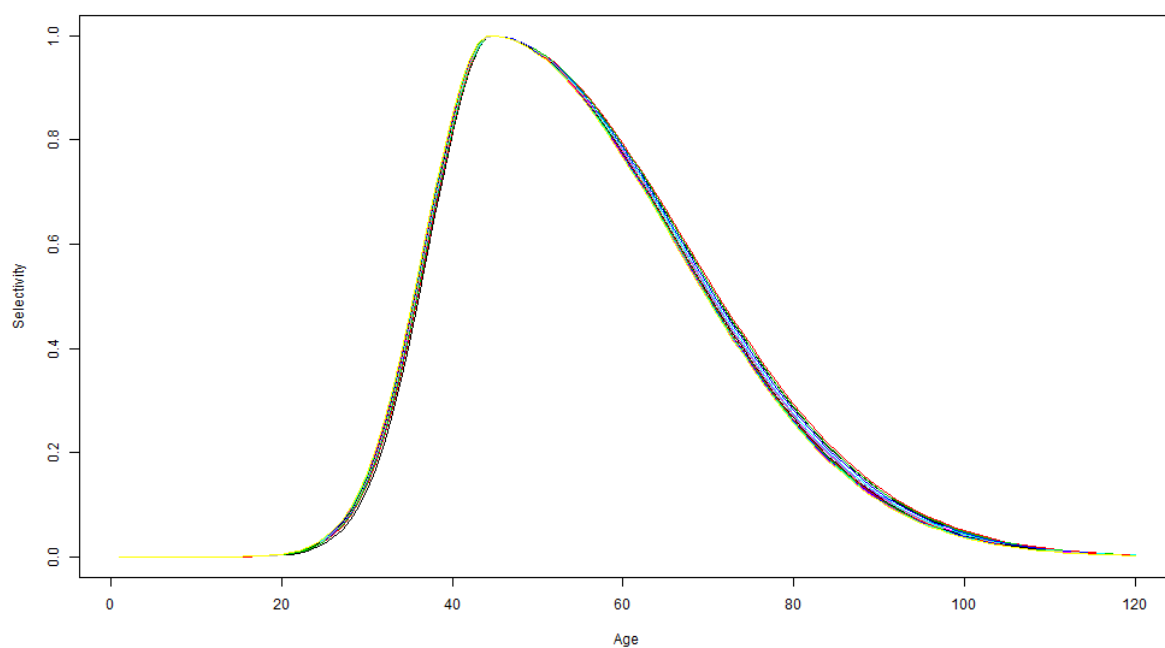
Figure B15: Base model likelihood profile for B₀: the MPD estimates of long-tow selectivity for each fixed value of B₀ (the lowest value of B₀ = 10 000 t is the bold black line).
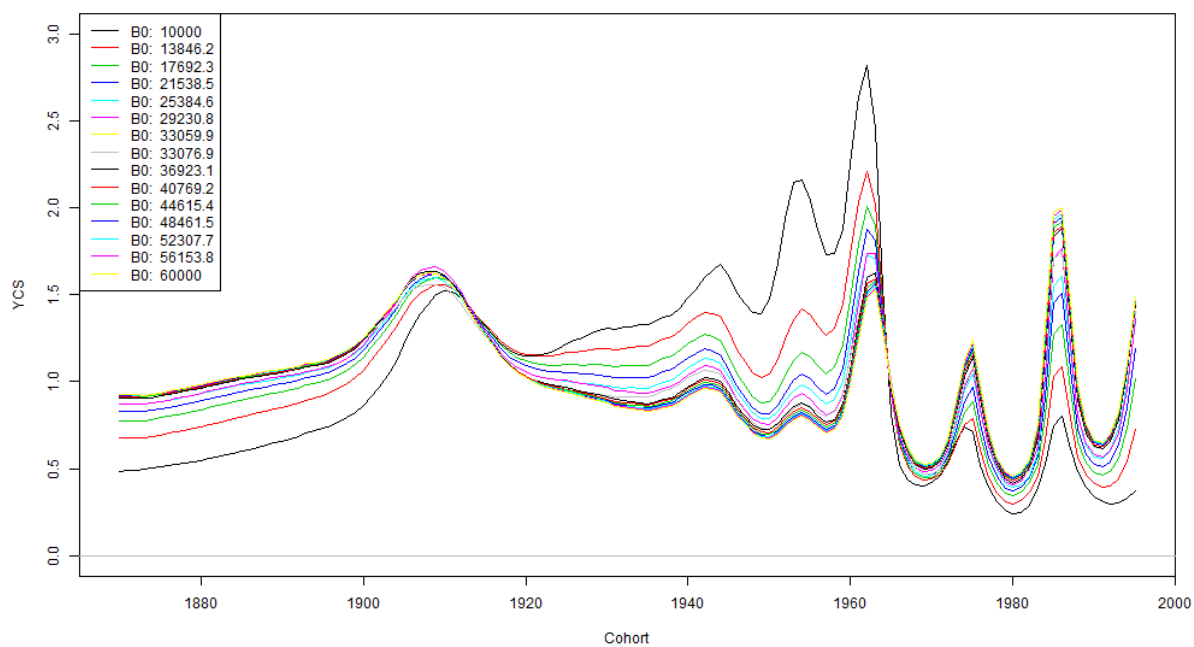
Figure B16: Base model likelihood profile for B₀: the MPD estimates of YCS for each fixed value of B₀.

44
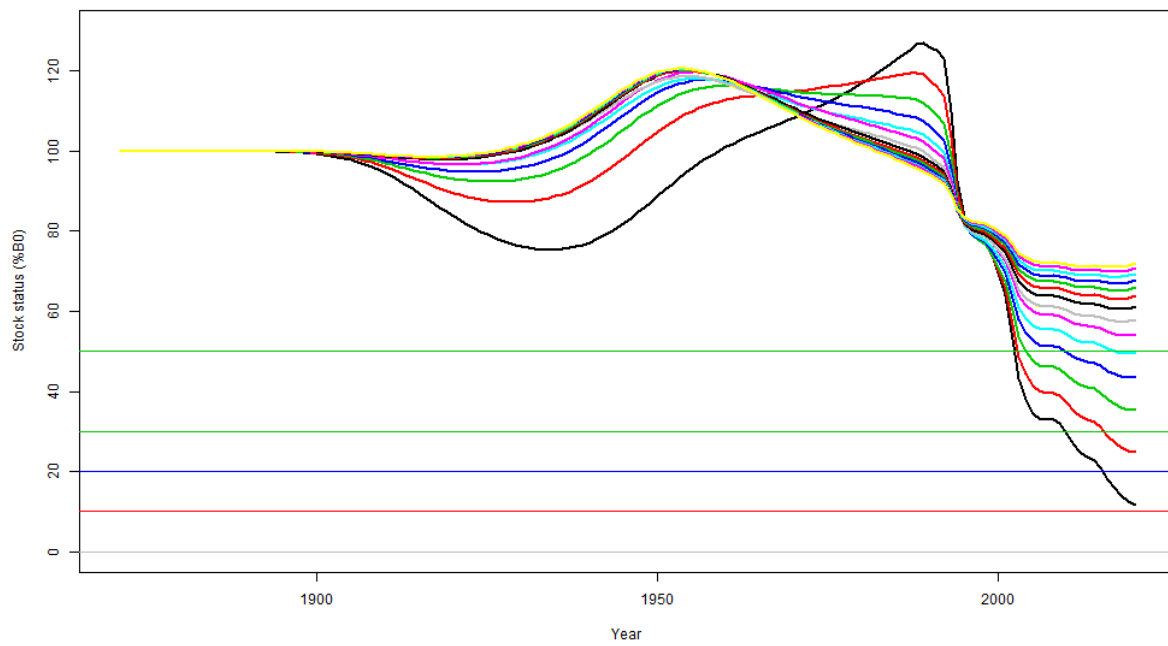
Figure B17: Base model likelihood profile for B₀: the MPD estimates of stock status trajectory for each fixed value of B₀ (the lowest value of B₀ = 10 000 t is the bold black line).

Appendix C: Descriptive analysis of NWC catch rates

A descriptive analysis of orange roughy catch rates for New Zealand vessels fishing in the core area of NWC was performed to look for qualitative signals on changes in stock size. A full analysis of catch and effort data was outside of the scope of this project and was not considered likely to produce defensible biomass indices in any case. However, if stock size is currently severely depleted then it would be expected that there would be some indication of this in recent catch rates.

The focus of the analysis was on catch per tow as there is little relationship between tow duration and catch (Figure C1). Indeed, shorter tows tend to produce larger catches than longer tows. This is a reflection of the two contrasting catch strategies. Short tows are targeted at features (where fish tend to aggregate) or aggregations (on the flat). Long tows are necessarily on the flat and often appear to be untargeted (i.e., on low densities of orange roughy and other fish).

The largest estimated catches of orange roughy have been in June with catches of over 20 t per tow also seen in May, July, and August (Figure C2). There is little variation in median catch rates by month (Figure C3) which suggests that the fish are resident in the wider NWC area all year round. However, mean catch per tow no doubt peaks in June when mature fish are aggregated for spawning.

To obtain a qualitative biomass signal across years, without a spurious seasonal effect, the remaining analysis was restricted to trawls that occurred in June each year. Short tows (duration ≤ 1 hour) produced some catches in excess of 50 t per tow but only in the years before 2000 (Figure C4). However, there is no obvious reduction in the typical catch per tow from short tows in June over the whole time frame (Figure C5). For long tows in June, catches in excess of 30 t were seen in the years before 2000 but not since then (Figure C6). However, in terms of the typical catch per tow, 2016 to 2019 are at a higher level than earlier years (Figure C7).

This is surprising and it appears in part due to longer tow duration for the long tows in June in 2016 to 2018 (Figure C8). For long tows on the flat, all other things being equal, it would be expected that longer tows would catch more fish than shorter tows. In 2019, the tow duration was much reduced from 2016 to 2018 but the catch per tow was similar. The catch per hour was similar to that achieved by long tows in the 1990s (Figure C9). Presumably, in 2019, vessels performing tows longer than 1 hour in June were involved in more targeting on orange roughy through appropriate depth selection.

The mean and median catch rates, for short and long tows, suggest that there was a decline in biomass from the start of the fishery through to 2005 and then biomass has been stable or increasing (Figures C10-11). From catch rates, there is no indication that the fishery is struggling or that the population is severely depleted.
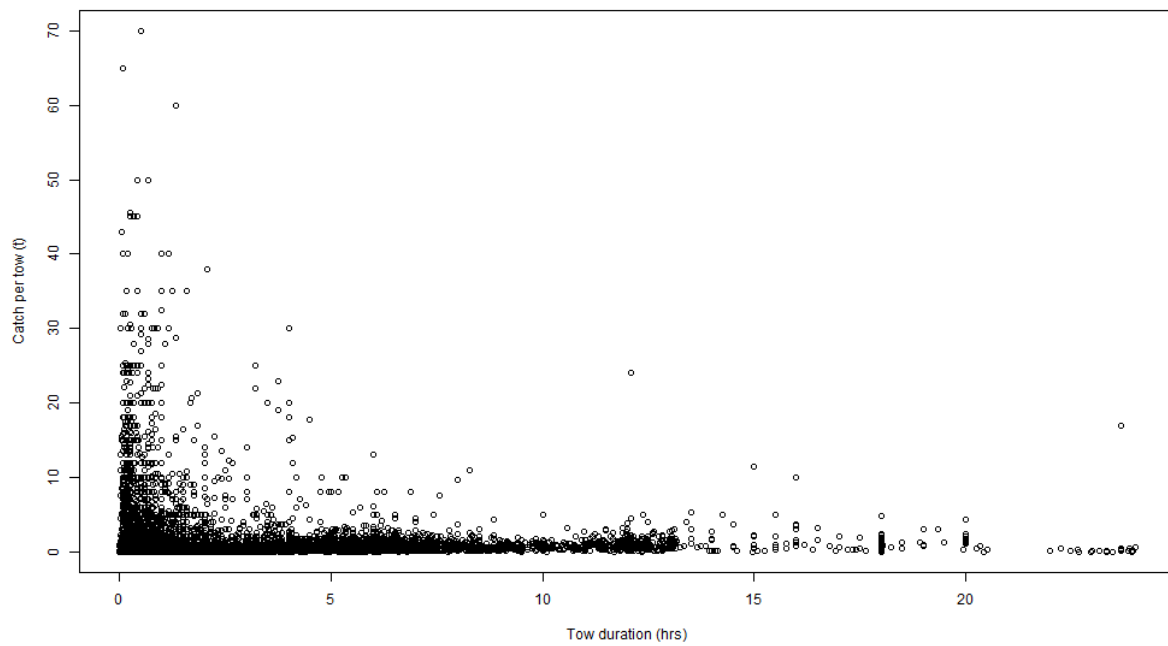
Figure C1: Orange roughy catch per tow vs tow duration for bottom trawls by New Zealand vessels in the core NWC area across all years.
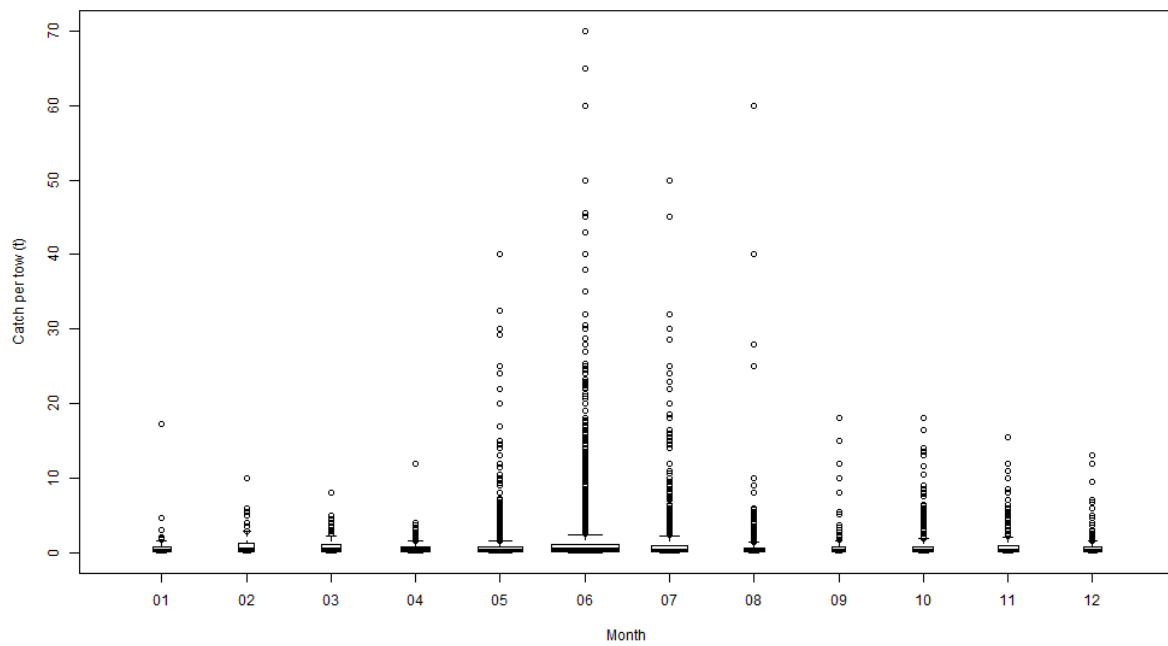
Figure C2: Box and whiskers plot of orange roughy catch per tow, by month, for New Zealand vessels in the core NWC area. Each box covers the middle 50% of the distribution and the whiskers extend to 1.5 times the inter-quartile range (observations outside this range are plotted as points). The width of each box is proportional to the number of tows.
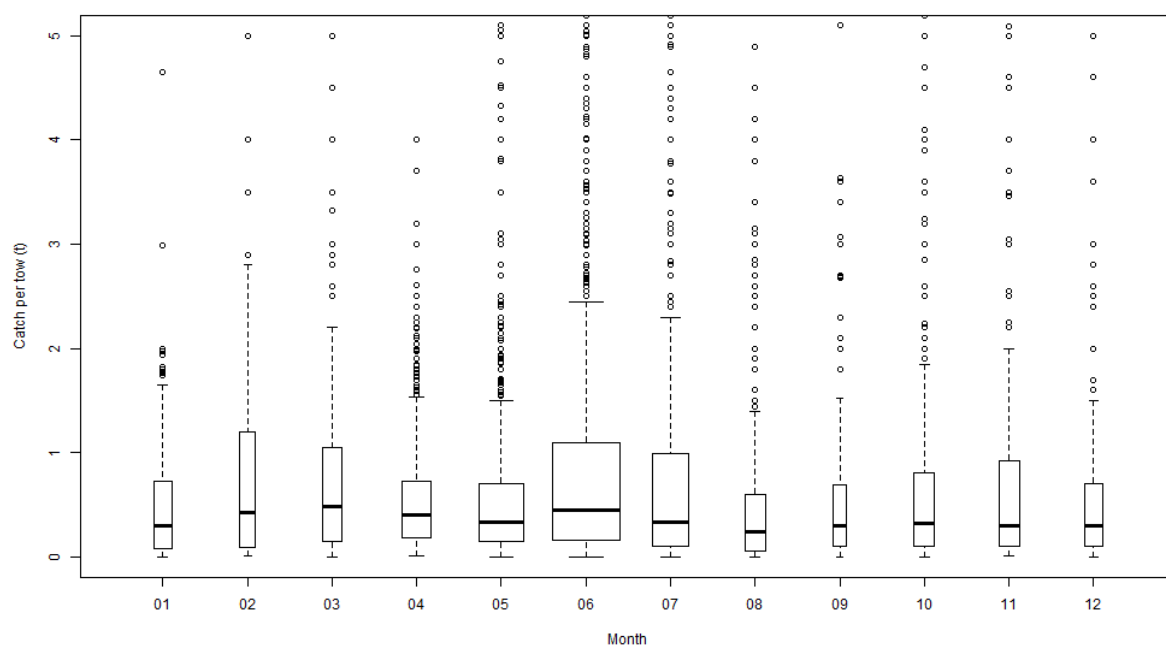
Figure C3: Box and whiskers plot of orange roughy catch per tow, by month, for New Zealand vessels in the core NWC area (reduced Y-axis). See Figure C2 caption.
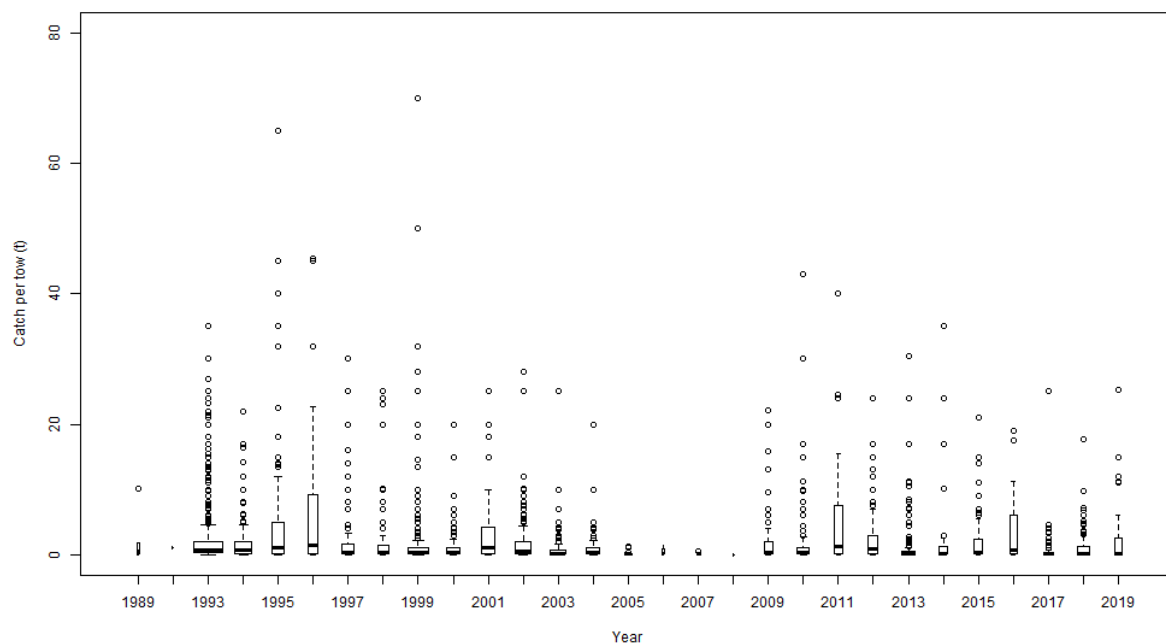
Figure C4: Box and whiskers plot of orange roughy catch per tow, by year, for short tows (duration ≤ 1 hour) in June. Each box covers the middle 50% of the distribution and the whiskers extend to 1.5 times the inter-quartile range (observations outside this range are plotted as points). The width of each box is proportional to the number of tows.
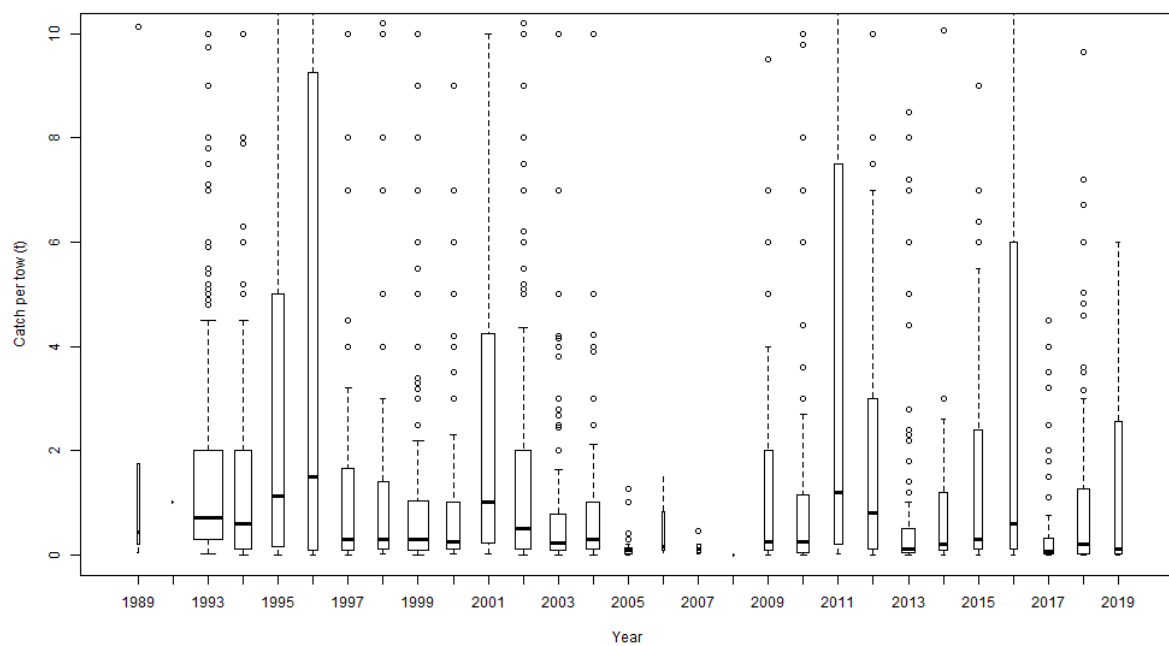
Figure C5: Box and whiskers plot of orange roughy catch per tow, by year, for short tows in June (reduced Y-axis). See Figure C4 caption.
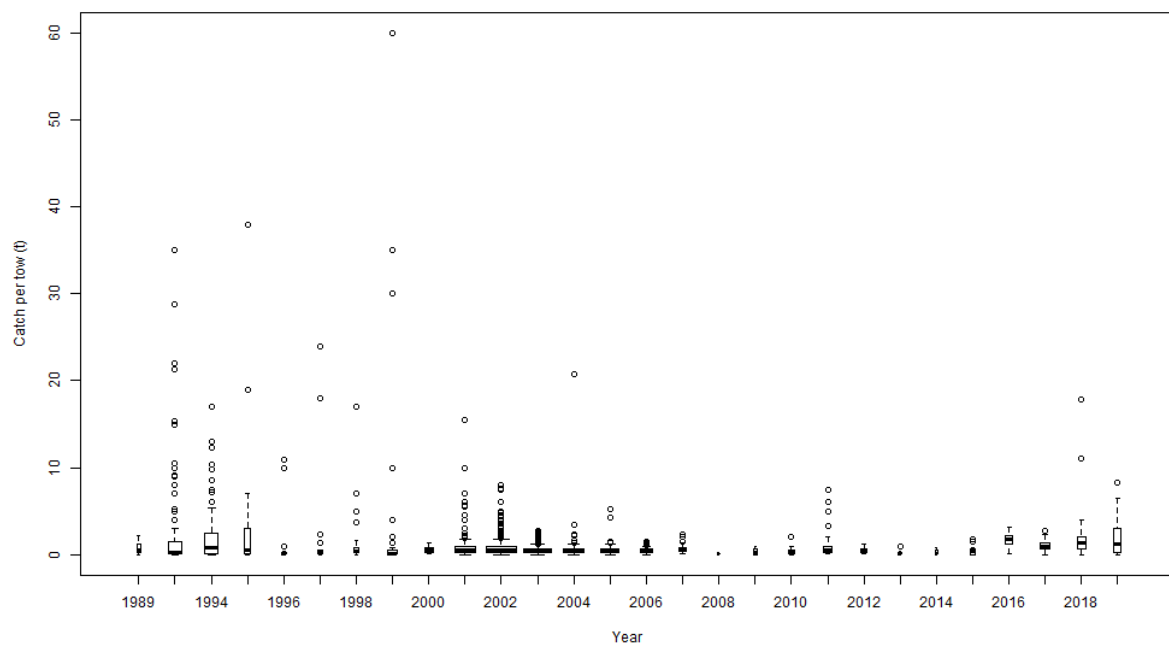
Figure C6: Box and whiskers plot of orange roughy catch per tow, by year, for long tows (duration > 1 hour) in June. Each box covers the middle 50% of the distribution and the whiskers extend to 1.5 times the inter-quartile range (observations outside this range are plotted as points). The width of each box is proportional to the number of tows.

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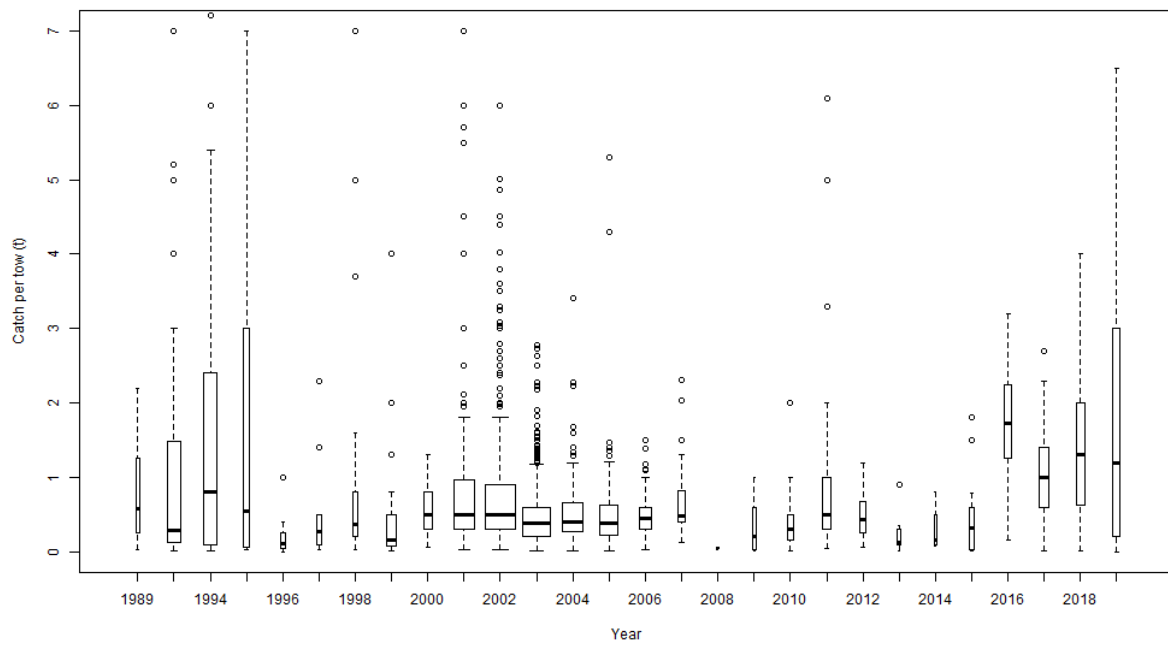
Figure C7: Box and whiskers plot of orange roughy catch per tow, by year, for long tows in June (reduced Y-axis). See Figure C6 caption.
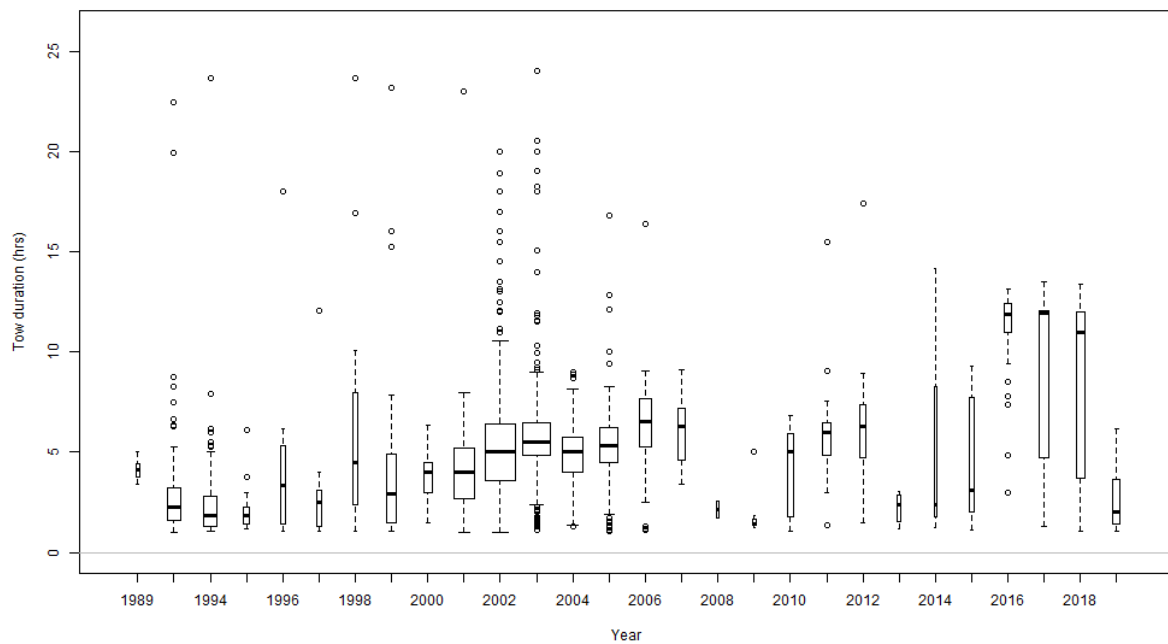
Figure C8: Box and whiskers plot of tow duration for long tows (duration > 1 hour) in June. Each box covers the middle 50% of the distribution and the whiskers extend to 1.5 times the inter-quartile range (observations outside this range are plotted as points). The width of each box is proportional to the number of tows.

50
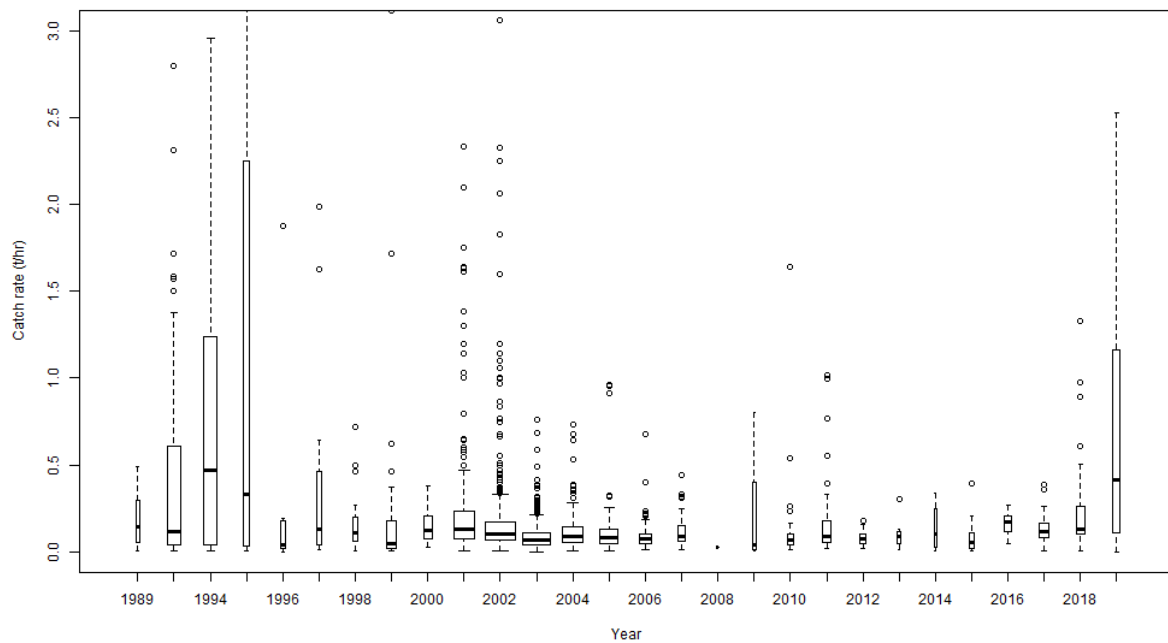
Figure C9: Box and whiskers plot of orange roughy catch per hour, by year, for long tows (duration > 1 hour) in June. Each box covers the middle 50% of the distribution and the whiskers extend to 1.5 times the inter-quartile range (observations outside this range are plotted as points). The width of each box is proportional to the number of tows.
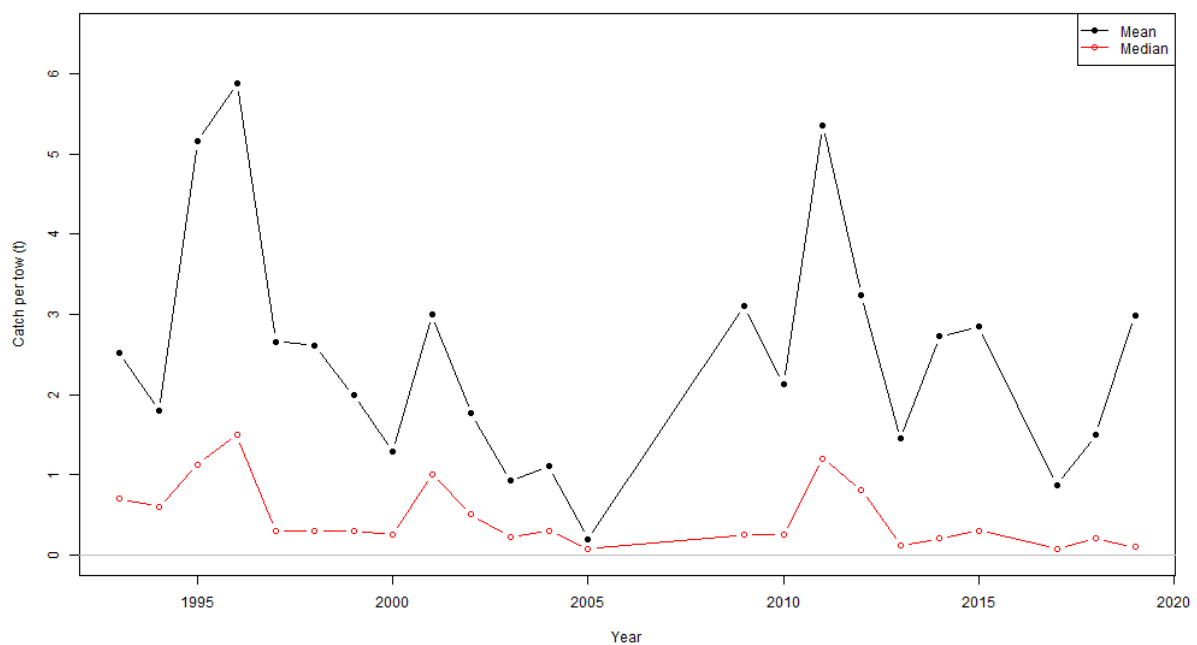
Figure C10: Mean and median orange roughy catch per tow for short tows in June for each year in which at least 30 tows were recorded.

51
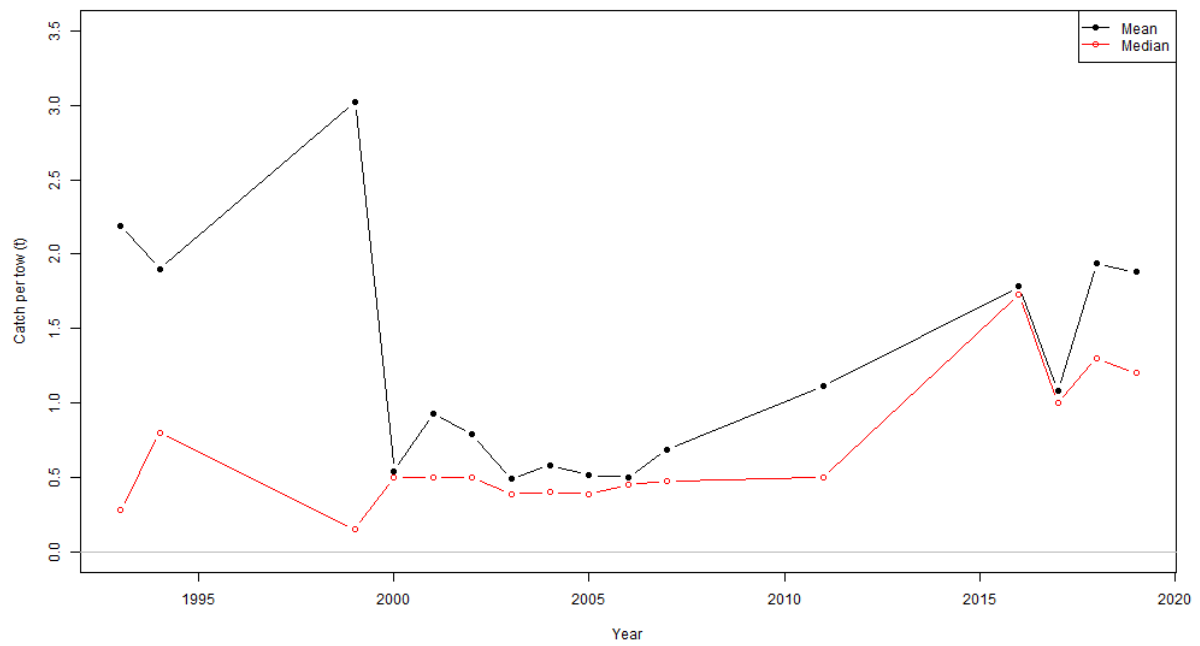
Figure C11: Mean and median orange roughy catch per tow for long tows in June for each year in which at least 30 tows were recorded.

Appendix D: Base model CASAL input files

The main input files, population.csl and estimation,csl are given below for the base NWC model. For the LHR assessment only the population.csl file is given as there are no data available for the assessment (it uses samples from the joint posterior distribution from the NWC assessment).

Population.csl
```
# NWC: 2020 model
# Two fisheries: short tows and long tows


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

# TIME SEQUENCE
@initial 1871
@current 2020
@final 2025
@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_namesshort   long
```

fishery_times 1   1

RECRUITMENT
@y_enter 1
@standardise_YCS True
@recruitment
YCS_years 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 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 1 1 1 1 1 1 1 1 1 1 1 1 1 1 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 1870
last_free 1995
year_range 1986 1995

recruitment variability
@randomisation_method empirical
@first_random_year 1996

@fishery short
years   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   32.97518 72.07121 123 615.5485 2061.029 1089.252 770.5038 474.1698
310.1488 413.2432 795.7406 440.1394 789.763 659.1516 371.6842 309.0481 130.5639
50.33924 26.28256 30.4951 329.8412 339.655 284.0606 217.8909 220.1734 118.1286
266.2344 175.83886 94.40146 186.08069 133.64601 133.64602
selectivity SELspawn
U_max 0.67
future_constant_catches 256.9118

@fishery long

54

years   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   264.0248 352.9288 0 4.451503 556.5243 756.8254 100.0207 37.18663
64.87825 75.75681 287.2594 192.8606 661.237 1698.848 840.3158 586.9519 467.4361
211.6608 204.7174 0.5049024 6.158839 80.34496 57.9394 39.10909 10.8266 5.871381
283.7656 347.16114 241.59854 211.91931 72.35399 72.35399
selectivity SELlong
U_max 0.67
future_constant_catches 139.0882

MATURITY
@maturation
rates_all logistic_producing 10 60 30 3

SELECTIVITIES
@selectivity_names SELspawn SELlong

@selectivity SELspawn
mature constant 1
immature constant 0

@selectivity SELlong
all double_normal 30 3 3

NATURAL MORTALITY
@natural_mortality
all   0.045

SIZE AT AGE
@size_at_age_type von_Bert
@size_at_age_dist normal
@size_at_age
k 0.064
t0 -0.5
Linf 35.05
cv1 0.1
cv2 0.05
by_length True

@size_weight
a 9.21e-8
b 2.71
verify_size_weight 35 1 3

55

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 10000000
keep 1000
stepsize 0.08
burn_in 1000

####
1993, 2013, 2018 short tow AFs
####

@catch_at AFshort
years 1993 2013 2018
fishery short
sexed F
sum_to_one True
at_size False
plus_group True
min_class 15
max_class 120
ageing_error True
1993 0 0 0 0 0 0 0 0 0 0 0 0 0.001673004 0 0 0 0 0 0.01643723 0.003981595 0 0
0.004933911 0.02974401 0.03885178 0 0.02934692 0 0.01300126 0.002336869 0.01626919
0.002802383 0.02408183 0.02579041 0.01410915 0.01209238 0.002571849 0.02806879
0.01355119 0.001250584 0.007561169 0.01519563 0.02268568 0.0109948 0.008707458
0.001405291 0.01032448 0.03860975 0.02417746 0.02830763 0.01132847 0.02625545
0.00114392 0.0008468653 0.009874572 0.007945009 0.02585073 0.01726771
0.007242485 0.025018 0.016182 0.009425634 0.006100718 0.001673004 0.03005799
0.009629339 0.000625292 0.004531494 0.004849893 0.007000465 0.04405619
0.01416431 0.001066744 0.0336126 0.02805083 0.03946389 0 0.007481329 0.01095708
0.01777552 0 0.0008468653 0.003147775 0.007481329 0.001120549 0 0.009425634 0
0.000625292 0 0 0 0.02305691 0.003082 0 0.01525075 0.008939516 0 0.01967847
0.007481329 0 0 0.00808935 0.0009806632 0 0.02245235

2013   0 0 0 0 0 0 0 0 0.002209731 0.008863579 0.01287457 0.03105016 0.00260949 0.01300259 0.0138439 0.0004492846 0.002209731 0.002209731 0.01833327 0.008873582 0.005949848 0.02295557 0.03113327 0.03369896 0.01437964 0.04307592 0.04058981 0.01328813 0.02526193 0.004924828 0.01492069 0.0390204 0.03168841 0.02092379 0.01296774 0.01998096 0.02661535 0.02739662 0.05859493 0.03307896 0.02841647 0.008882865 0.02282768 0.01011582 0.01790174 0.01000655 0.009774528 0.001771869 0.02212293 0.004750997 0.0105007 0.02965074 0.009324409 0.003096417 0.03257488 0.003377951 0.01997547 0.006911549 0.001822739 0.01920423 8.270073e-05 0 0 0 0 0.00704357 0.003779974 0 0 0.006598423 0.002818449 0 0.003690592 0 0.01011582 0.006768981 0 0.01685848 0.008419143 0.00311844 0.000523461 0 0 0 0.001605982 1.436728e-05 1.436728e-05 1.436728e-05 0 0 0 0 1.436728e-05 1.097207e-05 0 0 0 0 0 0 0 0 0 0 0.01852164

2018   0 0 0 0 0 0 0.01362747 0 0 0.004272874 0.01084294 0 0.004849945 0.01555408 0.006873363 0.005593512 0.03486155 0.007542889 0.02662757 0.02166874 0.0007811721 0.0168409 0.008728064 0.01942631 0.03676545 0.02907217 0.01264156 0.03747512 0.03471686 0.03654577 0.03811626 0.02007064 0.01836235 0.0115008 0.02416102 0.01249851 0.03449006 0.02162255 0.02252247 0.007773641 0.01425113 0.03551156 0.05085644 0.01067193 0.01400059 0.02138945 0.01471992 0.009171667 0.02081707 0.006531306 0.003508505 0.002985895 0.02143195 0.0100189 0.01313042 0.006214129 0.00837804 0.02936838 0.001866818 0.01107679 0.01202206 0.006254965 0.002399573 0.007110706 0.005200608 0.002177102 0.004449843 0 0.005546841 0 0 0.003262748 0.004074043 0.002307605 0.0006220948 0.004592895 0 0.007495196 0.003598826 0.002784529 0.001901685 0.001005 0 0 0 0 0.01004335 0 0 0 0 0 0 0 0.002399573 0 0 0 0 0 0 0 0 0 0.008423238
dist multinomial
r 0.00001
N_1993 17
N_2013 24
N_2018 25
Used nfish/10

@catch_at AFlong
years 1993 2013 2018
fishery long
sexed F
sum_to_one True
at_size False
plus_group True
min_class 15
max_class 120
ageing_error True
1993   0 0 0 0 0 0 0 0 0 0 0 0.0166944 0 0 0 0 0.02869591 0 0 0.02911648 0.003372566 0 0 0.01374058 0.1470036 0 0.00752991 0.06096148 0.01213587 0 0.02313108 0.01673261 0.021166 0 0.07459757 0.08566544 0.009034498 0.0146153 0.021166 0.0735018 0 0.002451661 0.08685858 0 0.004697438 0.01216364 0.02586344 0 0 0.003372566 0.021166 0.009034498 0 0.01213587 0 0.00752991 0 0.01216364 0.003372566 0.01373194 0.01757806 0 0.006210673 0 0 0.01966578 0.009034498 0 0 0 0.008543557 0 0 0.01216364

0 0 0 0 0 0.0166944 0 0.01213587 0 0 0.009034498 0.003372566 0 0 0.01216364 0 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 0.0009378197 0.001984447 0.2378724 0.002736333 0
0.001329216 0.001329216 0.001329216 0.007945279 0.007082887 0.003313663
0.2356054 0.001984447 0.001984447 0.00529811 0 0 0.0009378197 0 0.1185342
0.004085193 0 0.001329216 0 0 0.114449 0 0 0.001984447 0 0.228898 0 0.004085193 0 0
0.001329216 0 0 0.0009378197 0.004085193 0 0.001329216 0 0 0 0 0 0 0 0.001984447 0 0
0 0 0 0 0 0.001984447 0 0 0 0 0 0 0 0 0.001329216 0 0 0.001984447 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0

2018 0 0 0.0007447165 0 0 0 0.01298279 0.002321348 0.001130441 0.004211802 0
0.002969888 0.01261412 0.02117395 0.0237161 0.01729305 0.005809711 0.03082158
0.01263041 0.0239003 0.04020785 0.05019489 0.002169044 0.04876293 0.02514458
0.007595223 0.07095737 0.03535564 0.01143715 0.05315586 0.00382921 0.06105328
0.02660347 0.0270239 0.01714773 0.02654119 0.01874032 0.002565777 0.02840996
0.03944798 0.007513643 0.008194618 0.02613628 0.02491163 0.02699126 0.001519686
0.001627639 0.003266602 0.008462795 0.005125658 0.02170953 0.007736501
0.003422064 0.01347411 0 0.008507106 0.0009029403 0.003604157 0.001122937
0.0005674403 0.002352941 0.001460246 0.002541552 0 0.008031079 0.008706
0.00162808 0.0008318931 0.005978965 0.004939228 0.008031079 0 0.0004542829
0.001961467 0.0006115492 0 0.0008865112 0.001341604 0 0.0008831872 0.001460246 0 0
0.0008504117 0.00162808 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0.001961467 0 0 0 0 0
dist multinomial
r 0.00001
N_1993 6
N_2013 4
N_2018 28
Used nfish/10

@ageing_error
type normal
c 0.1

Q METHOD

@q_method free

#@q_method nuisance

@estimate
parameter maturation[1].rates_all
lower_bound 10   1
upper_bound 50   20
#prior uniform
prior normal
mu 33 13

cv 0.1 0.3

@estimate
parameter selectivity[SELlong].all
lower_bound   20 1 1
upper_bound   70 50 50
#prior uniform
prior normal
mu 40 10 20
cv 0.1 0.3 0.3

B0
@estimate
parameter initialization.B0
lower_bound 10000
upper_bound 150000
prior uniform-log

@profile
parameter initialization.B0
n 14
l 10e3
u 60e3

YCS
@estimate
parameter recruitment.YCS
lower_bound 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01
0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01
0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01
0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01
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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
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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
upper_bound 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
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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
prior lognormal
mu 26489122130 26489122130 26489122130 26489122130 26489122130 26489122130
26489122130 26489122130 26489122130 26489122130 26489122130 26489122130
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CATCH PENALTIES

@catch_limit_penalty
label CatchPenaltyShort
fishery short
multiplier 200
log_scale True

@catch_limit_penalty
label CatchPenaltyLong
fishery long
multiplier 200
log_scale True

LHR population.csl
LHR 2020
Borrowing posterior distributions from NWC base

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

TIME SEQUENCE
@initial 1871
@current 2020
@final 2025
@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_namesshort
fishery_times 1

RECRUITMENT
@y_enter 1
@standardise_YCS True
@recruitment
YCS_years 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 2019
YCS   1

SR BH
steepness 0.75
sigma_r 1.1
first_free 1870
last_free 1995
year_range 1986 1995

recruitment variability
@randomisation_method empirical
@first_random_year 1996

@fishery short
years   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   4000 2430 927 282 859 2300 840 761 5 139 48 508 86 467 130 346 426 528 225 55 380 518 385 281 173 393 157 162 207 269 179 39 39
selectivity SELspawn
U_max 0.67
future_constant_catches 348

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 (ESCR values)
@size_at_age_type von_Bert
@size_at_age_dist normal
@size_at_age
k 0.059
t0 -0.5
Linf 37.78
cv1 0.1
cv2 0.05
by_length True


@size_weight
a 9.21e-8
b 2.71
verify_size_weight 35 1 3


# INITIALISATION
@initialization
B0 30000
```