



Fisheries New Zealand

Tini a Tangaroa

A 2017 Stock Assessment of ORH 3B Puysegur

New Zealand Fisheries Assessment Report 2019/20

P.L. Cordue

ISSN 1179-5352 (online)

ISBN 978-0-9951269-4-7 (online)

July 2019



Requests for further copies should be directed to:

Publications Logistics Officer
Ministry for Primary Industries
PO Box 2526
WELLINGTON 6140

Email: brand@mpi.govt.nz
Telephone: 0800 00 83 33
Facsimile: 04-894 0300

This publication is also available on the Ministry for Primary Industries websites at:
<http://www.mpi.govt.nz/news-and-resources/publications>
<http://fs.fish.govt.nz> go to Document library/Research reports

© Crown Copyright – Fisheries New Zealand

Table of Contents

EXECUTIVE SUMMARY	1
1. INTRODUCTION	2
2. METHODS	2
2.1 Catch history	2
2.2 Data quality, input data, and statistical assumptions	3
2.3 Model structure	6
2.4 Estimation methods and model runs	6
3. RESULTS	8
3.1 Model diagnostics	8
3.2 MCMC results.....	13
3.3 Biological reference points, management targets and yield	16
3.4 Projections	17
4. DISCUSSION AND CONCLUSIONS	20
5. ACKNOWLEDGEMENTS.....	22
6. REFERENCES	22
APPENDIX 1: MCMC residuals for the base model.....	24
APPENDIX 2: CASAL input files for the base model.....	27

EXECUTIVE SUMMARY

Cordue, P.L. (2019). A 2017 stock assessment of ORH 3B Puysegur.

New Zealand Fisheries Assessment Report 2019/20. 35 p.

The Puysegur orange roughy stock is part of ORH 3B. It was last assessed in 1997 using a deterministic model fitted to trawl survey and CPUE indices. That assessment estimated that the stock was severely depleted and because of that the fishery has essentially been closed since the 1997–98 fishing year. An acoustic survey in 2015 found a spawning plume of orange roughy on the main hill in the fishing grounds. The biomass estimate from the 2015 survey together with age frequencies from that survey and a 1992 trawl survey were the main inputs into the 2017 stock assessment. The assessment used very similar methods to those used in the four orange roughy stock assessments in 2014.

The stock assessment model was single-sex and age-structured, with maturity estimated separately (i.e., fish were classified by age and as mature or immature). Two time steps were used to model a non-spawning season fishery and a spawning season fishery. Spawning was taken to occur after 50% of the spawning-season mortality and 100% of mature fish were assumed to spawn each year.

Natural mortality was fixed at 0.045 and the stock-recruitment relationship was assumed to follow a Beverton-Holt function with steepness of 0.75. The remaining fixed biological parameters were set equal to those used previously for the east and south Chatham Rise.

The assessment was completed using the general Bayesian estimation package CASAL. The final assessment was based on the marginal posterior distributions of parameters and derived parameters of interest (e.g., virgin biomass (B_0), current biomass (B_{2017}), and current stock status (B_{2017}/B_0)). The marginal posterior distributions were produced using Markov chain Monte Carlo methods (hence termed “MCMC” runs). Preliminary analysis and many sensitivity runs were performed using just the Mode of the Posterior Distribution (hence “MPD” runs) which can be obtained much more quickly than the full posterior distribution.

In the base model, B_0 was estimated at 17 000 t (95% CI: 13 000–23 000 t), with stock status at 49% B_0 (95% CI: 36–62% B_0). This is at the top end of the target biomass range of 30–50% B_0 . For the base model, (and all sensitivity runs) the stock is considered to be fully rebuilt according to the Harvest Strategy Standard (at least a 70% probability that the lower end of the management target range of 30–50% B_0 has been achieved).

Application of the orange roughy Harvest Control Rule (HCR) to the Puysegur assessment to calculate a 2017–18 catch limit is complicated because of the poorly estimated non-spawning season selectivity. The estimated non-spawning season selectivity suggests that much younger fish are caught during the non-spawning season compared to the spawning season. If this is true then a higher catch limit is appropriate for a pure non-spawning season fishery compared to a pure spawning season fishery. However, if the non-spawning season selectivity is close to the maturity ogive then the calculated catch limit for a non-spawning season fishery could be far too high. It is therefore prudent to base catch limits on spawning season biomass. The HCR applied to spawning season biomass gives a catch limit of 460 t.

The results of projections, taken at face value, suggest that there is a tradeoff between the level at which the catch limit can be set and the year of the next stock assessment. If an assessment is planned in 2019–20 then, according to the projections, annual catches of 600–800 t pose little risk. If the assessment is planned for 2020–21 then, according to the projections, annual catches of 400–600 t pose little risk.

1. INTRODUCTION

The Puysegur orange roughy stock is part of ORH 3B. It was last assessed in 1997 using a deterministic model fitted to trawl survey and CPUE indices (Annala et al. 2000). The fishery has essentially been closed since the 1997–98 fishing year. An acoustic survey in 2015 found a spawning plume of orange roughy on the main hill in the fishing grounds (Ryan & Tilney 2016). The biomass estimate from the 2015 survey together with age frequencies from that survey and a 1992 trawl survey were the main inputs into the 2017 stock assessment. The assessment used very similar methods to those used in the four orange roughy stock assessments in 2014 (Cordue 2014a). The assessment was conducted using NIWA’s Bayesian stock assessment package CASAL (Bull et al. 2012).

2. METHODS

A Bayesian stock assessment was performed for the Puysegur stock in 2017 using very similar methods to those used in the 2014 orange roughy stock assessments (Cordue 2014a). An age-structured population model was fitted to an acoustic-survey estimate of spawning biomass, two trawl-survey indices and associated length frequencies, two spawning-season age frequencies, and a small number of length frequencies from the commercial fishery.

2.1 Catch history

The catch history was taken from earlier Plenary reports, split into spawning (June–August) and non-spawning seasons (October–May and September) using the ratio of estimated catches, with the addition of catches during 2005, 2006, and 2015 when fish were caught during acoustic surveys, and some small catches within the Puysegur box (Table 1).

Table 1: Catches in the spawning and non-spawning seasons by fishing year (1990 is 1989–90) used for the Puysegur stock assessment. A zero catch is assumed in 2016–17.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
N.Sp. (t)	150	484	6285	5018	1516	1448	709	270	0	0
Spawn (t)	0	366	665	182	1084	102	91	280	0	0
Total (t)	150	850	6950	5200	2600	1550	800	550	0	0
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
N.Sp. (t)	7	8	0	0	1	21	0	10	0	0
Spawn (t)	0	26	0	12	3	96	187	0	0	0
Total (t)	7	34	0	12	4	117	187	10	0	0
	2010	2011	2012	2013	2014	2015	2016	2017		
N.Sp. (t)	0	0	0	26	0	0	0	0		
Spawn (t)	0	0	0	0	0	145	0	0		
Total (t)	0	0	0	26	0	145	0	0		

The large majority of the catch was taken during the non-spawning season with the spawning season catch only exceeding 1000 t in 1993–94 (Table 1, Figure 1). The vast majority of the catch was taken in and around the two features Goomzy and Lady Godiva.

It is usual to apply an overrun to historical orange roughy catches to allow for fish loss due to lost and burst bags. However, in the Puysegur fishery, which developed much later than the other ORH 3B fisheries, an overrun has never been applied. The explanation given in the 2000 Plenary report is: “For Puysegur and other southern fisheries there is no reason to believe that, if there was an overrun in catches, this shows any trend over time. For this reason, it was assumed that there was no overrun for this area.” This policy has been continued although a sensitivity run was done where a 5% overrun was assumed throughout.

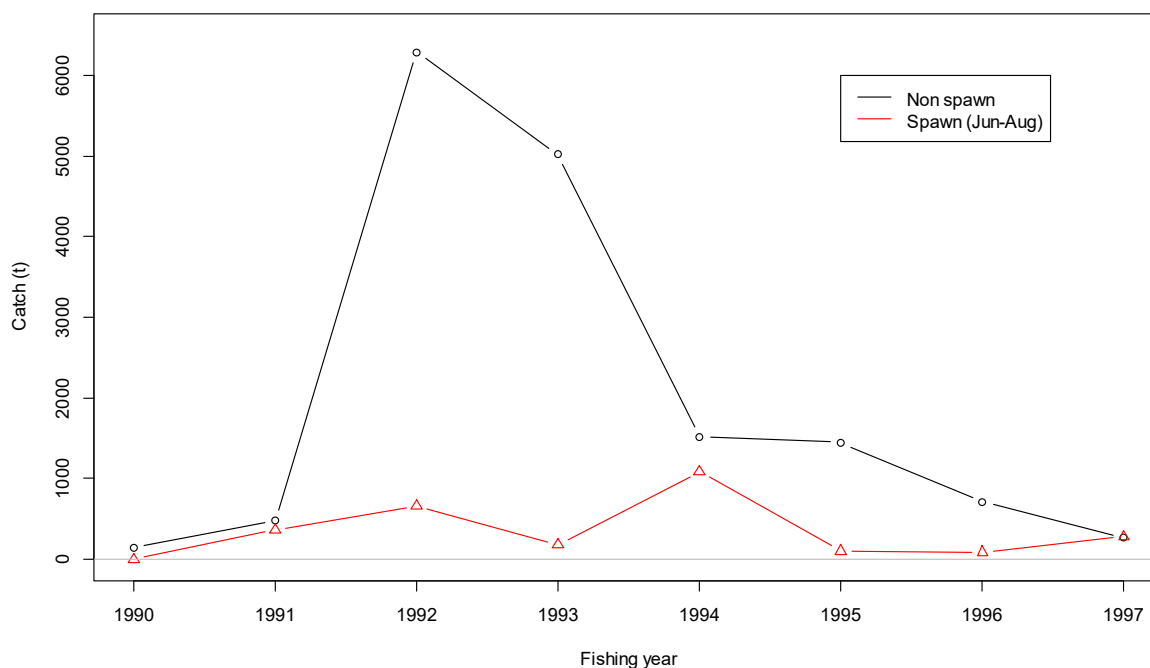


Figure 1: The catch history for the Puysegur fishery split into an extended spawning season (June–August) and a non-spawning season.

2.2 Data quality, input data, and statistical assumptions

A high quality threshold was imposed on data before they were allowed to be used in the assessment. Therefore, a number of biomass indices that were used in the 1997 assessment were excluded. The CPUE indices were excluded because they were likely to be exhibiting hyper-depletion (going down faster than the stock biomass). This is typical of orange roughy fisheries on hill features where CPUE indices often decline rapidly when a new feature is fished (e.g., see Dunn 2007).

There have been three trawl surveys of the Puysegur area in winter (1991, 1992, and 2006) but three different vessels were used. Even though very similar gear was used it is still unlikely that the surveys are comparable and the indices were not used in the stock assessment.

There were four main data sources used in the assessment: an acoustic-survey spawning biomass estimate in 2015 from the main spawning hill (Goomzy); two age frequencies during the spawning seasons in 1992 and 2015; biomass indices and length frequencies from trawl surveys in 1992 and 1994; and scaled length frequencies developed from Scientific Observer data collected from the commercial fishery in 1994 and 1997.

Acoustic estimate

Two types of acoustic-survey estimates were available for use in the assessment: an estimate from a 38 kHz hull-mounted system during an AOS survey (AOS is a multi-frequency towed system, e.g., see Kloser et al. 2011) and 38 kHz estimates from a hull-mounted system. The reliability of the data from the different surveys and the two main hills was considered and only the estimate from the 2015 survey on Goomzy was used in the base model (Table 2). The estimates from Godiva were unreliable because the surveyed marks contained a mix of species (Hampton et al. 2005, 2006). In 2005 and 2006 it was not clear that the marks on Goomzy were exclusively orange roughy but in 2015 there was strong evidence from both trawling and the multi-frequency system that the surveyed marks were almost exclusively orange roughy (Ryan & Tilney 2016).

Table 2: Acoustic survey estimates of spawning biomass available to the stock assessment. Only the 2015 estimate from Goomzy was used in the base model.

Year	Area	Snapshots	Estimate (t)	CV (%)
2005	Godiva	3	2600	23
	Goomzy	4	4000	22
2006	Godiva	4	900	51
	Goomzy	3	3200	50
2015	Godiva	2	180	Not calculated
	Goomzy	2	4200	26

The acoustic estimate in 2015 from Goomzy was assumed to represent “most” of the spawning biomass in that year. This was modelled by treating the acoustic estimate as relative biomass and estimating the proportionality constant (q) with an informed prior. The prior was lognormally distributed with a mean of 0.8 (i.e., “most” = 80%) and a CV of 19% (as developed and used by Cordue 2014a).

Age frequencies

Age frequencies were constructed for the *Giljanes* spawning-season trawl survey in 1992 (Clark & Tracey 1993) and the targeted trawling on spawning marks during the 2015 acoustic survey (Ryan & Tilney 2016) (Ian Doonan, NIWA, pers. comm.). Approximately 400 otoliths were used for each age frequency and CVs were calculated for each proportion at age from bootstrapping. In 2015, the mode (for the smoothed distribution) is at about 40 years whereas in 1992 the mode is closer to 60 years (Figure 3). It is notable that in both years the ages extend out to at least 130 years (Figure 3). In the base model, the age frequencies were fitted as multinomial with effective sample sizes of 80 and 60 respectively. The sample size of 80 is the approximate number of trawl stations during the survey in 1992 and the value of 60 was derived from the between year ratio of equivalent multinomial sample sizes derived from the bootstrap CVs.

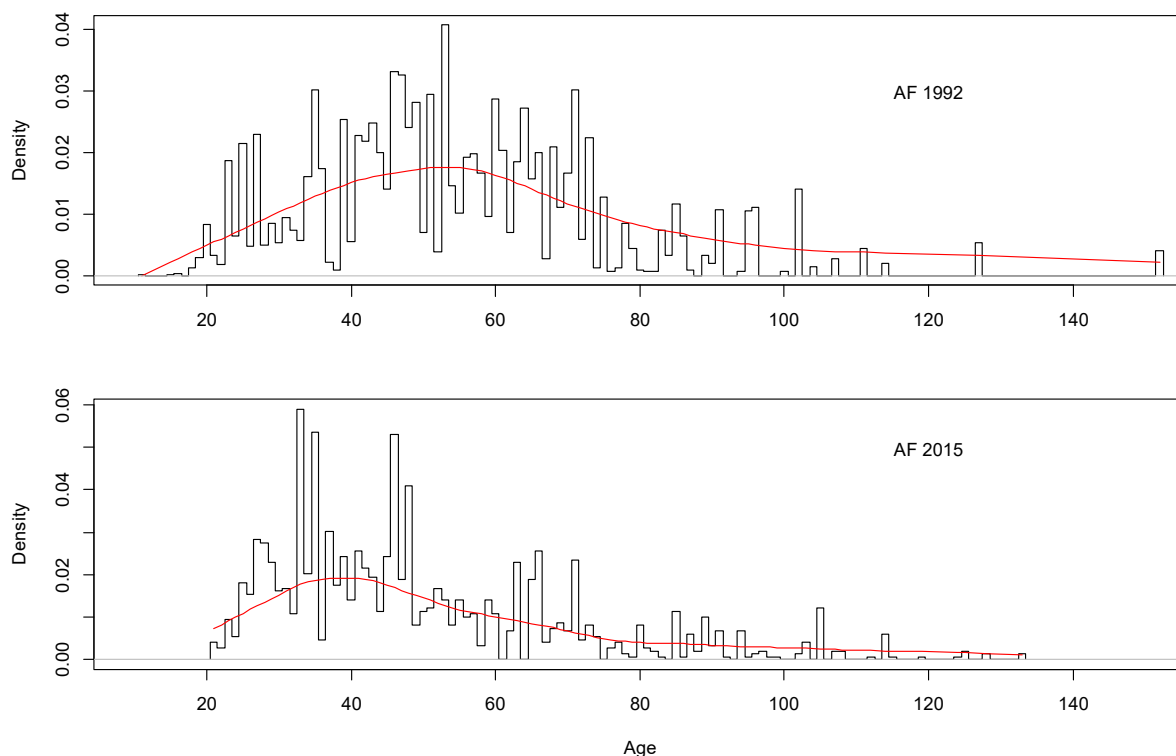


Figure 3: Age frequencies from 1992 and 2015 used in the base model. The red lines were produced using the lowest smoother in R.

Trawl survey data

Trawl surveys of the Puysegur area were undertaken on *Tangaroa* in 1992 and 1994 (Clark & Tracey 1994, Clark et al. 1996). However, the timing of the surveys was not ideal with the second survey being more than a month later than the first (Puysegur strata occupied in 1992: 8 August-11 September, and in 1994: 24 September-23 October). An analysis of seasonal CPUE suggested that catch rates in the later period could be expected to be 50% of those in the earlier period. Also, an analysis of fish length data suggested that larger fish were caught in the June-August period – the period taken to be the “spawning season” in the model (although spawning occurs in July). It appears that during the June-August period larger fish are more available to the fishing fleet and could have been more available to the trawl survey. There was a very large reduction in the biomass indices for such a short period (Table 3).

Table 3: Trawl survey biomass indices for all fish from the *Tangaroa* trawl surveys of the Puysegur area in 1992 and 1994. The CVs given are those used in the modelling and include no process error.

	Biomass index (t)	CV (%)
1992	6630	28
1994	1160	24

To allow for a possible reduction in availability between the 1992 and 1994 surveys, due to the change in timing, the selectivity for the trawl survey was modelled separately for mature and immature fish and an availability parameter for mature fish was estimated for the 1994 survey. The length frequencies from the trawl surveys are bimodal which could be partly explained by two groups of fish distinguished by maturity (Figure 4).

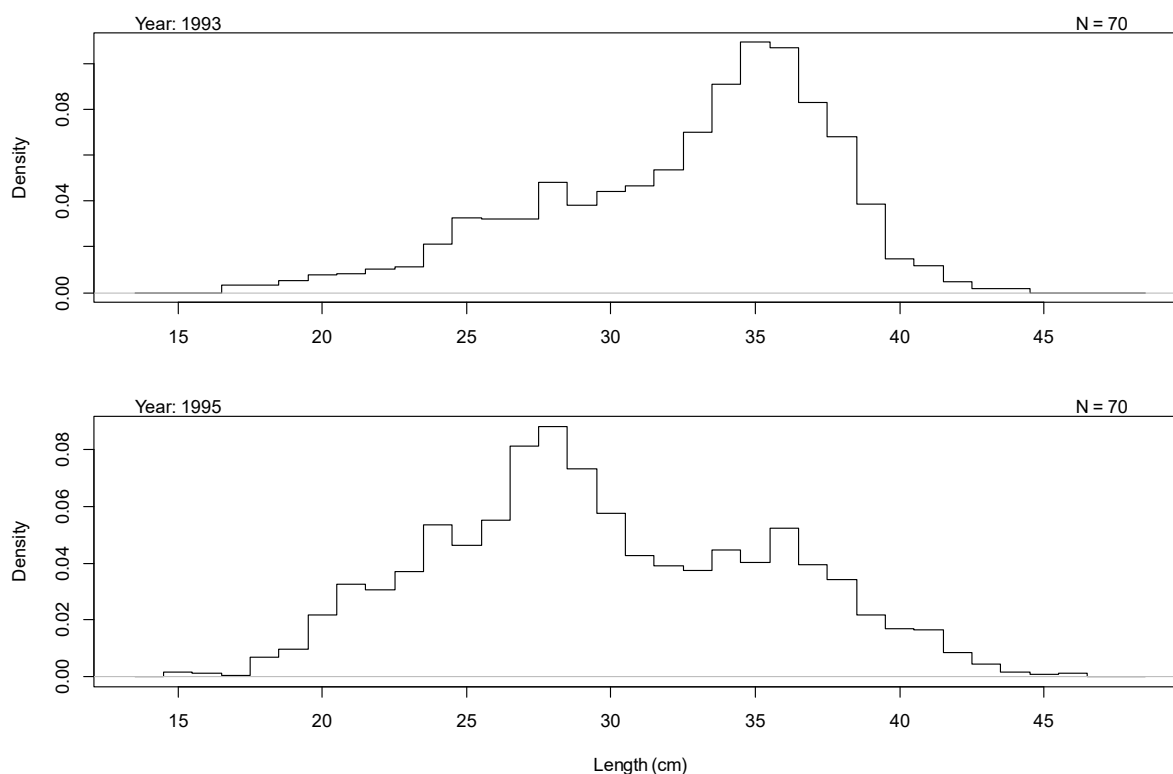


Figure 4: Length frequency distributions for the *Tangaroa* trawl surveys of the Puysegur area in 1992 and 1994 (fitted in the model as beginning of year in 1993 and 1995). The effective samples sizes of $N = 70$ were the approximate number of stations in each survey.

Length frequencies (commercial fishery)

Scientific observer coverage of the Puysegur fishery was very patchy over the small number of years when the fishery operated. The best coverage was in the 1993–94 fishing year when there were 15

samples in the non-spawning season and 44 samples in the spawning season. The next best year, when more than one month was sampled in the non-spawning season, was 1996–97 when there were 6 non-spawning season samples and 3 spawning season samples. Scaled length frequencies were produced in those two years for the spawning and non-spawning seasons. The data were assumed to be multinomial with effective sample sizes equal to the number of samples.

2.3 Model structure

The model was single-sex and age-structured (1–120 years with a plus group), with maturity estimated separately (i.e., fish were classified by age and as mature or immature). Two time steps were used to model a non-spawning season fishery and a spawning season fishery. Spawning was taken to occur after 50% of the spawning-season mortality and 100% of mature fish were assumed to spawn each year.

Natural mortality was fixed at 0.045 and the stock-recruitment relationship was assumed to follow a Beverton-Holt function with a steepness of 0.75. The remaining fixed biological parameters were borrowed from estimates for ESCR (see Cordue 2014a).

The fixed biological parameters were:

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

2.4 Estimation methods and model runs

The estimation methods were almost identical to those used in the 2014 orange roughy assessments (Cordue 2014a). The stock assessments were done using the general Bayesian estimation package CASAL (Bull et al. 2012). The CASAL input files for the base model are given in Appendix 2. The final assessments were based on the marginal posterior distributions of parameters and derived parameters of interest (e.g., virgin biomass (B_0), current biomass (B_{2017}), and current stock status (B_{2017}/B_0)). The marginal posterior distributions were produced using Markov chain Monte Carlo methods (hence termed “MCMC” runs). Preliminary analysis and many sensitivity runs were performed using just the Mode of the Posterior Distribution (MPD) which can be obtained much more quickly than the full posterior distribution (hence “MPD” runs). The MPD estimate is associated with the “best fit” that can be obtained – it is useful to check that the “best fit” is not too bad otherwise there would be concerns about the appropriateness of the model.

In the base model, the acoustic estimate from Goomzy in 2015 was used along with the *Tangaroa* trawl survey data, and natural mortality (M) was fixed at 0.045. There were six main sensitivity runs: exclude the *Tangaroa* trawl survey data; low weight on the age frequencies; high weight on the age frequencies; estimate M ; and the LowM-Highq and HighM-Lowq “standard” runs (LowM-Highq has M fixed and reduced by 20% and simultaneously has the mean of the acoustic q prior increased by 20% - both changes are expected to reduce estimated stock status; similarly the HighM-Lowq run has changes of 20% in the opposite directions and the changes are expected to increase estimated stock status). There were also a number of additional sensitivity runs: treating the trawl surveys as strictly comparable; using lognormal priors on the free year class strength parameters; alternative fixed non-spawning season fishing selectivities; adding a 5% overrun to the catch history; and using a higher CV on the acoustic q prior.

The sensitivity runs using lognormal priors on the free year class strength parameters required specification of sigmaR (the standard deviation of the log of year class strength). A value of 1.1 has been used for many years (Francis & Robertson 1990, Doonan 1994). However, a review of the derivation of this value found that it was based on fish counts from *targeted* trawling that had been done to obtain samples of juvenile orange roughy for age and growth studies (Mace et al. 1990). The estimation methods had assumed that representative numbers of fish had been caught across four

cohorts that were found in the catches. This is not a defensible assumption given that the trawling was aimed at maximising the catch of small roughy based on the results of past trawling. A stratified random trawl survey over the full depth range and spatial distribution of juvenile roughy would have been required to obtain representative numbers. Also, even if representative numbers had been obtained, a variance estimate from only four cohorts is inadequate to obtain a precise estimate (unless the variance is very small).

Cordue (2014a) estimated sigmaR for the four stocks assessed in 2014. He concluded that there was little information available on sigmaR from the stock assessments because of a paucity of age data and the imprecision of orange roughy ageing. However, he found that values of 1.1 and higher were unlikely. For the Puysegur MCMC sensitivity runs, values of 0.5, 0.7, and 0.9 were used.

In the base model, the main parameters estimated were: virgin (unfished, equilibrium) biomass (B_0), maturity ogive, trawl-survey selectivity, CV of length-at-mean-length-at-age for ages 1 and 120 years (linear relationship assumed for intermediate ages), and year class strengths (YCS) from 1917 to 1990 (with the Haist parameterisation and “nearly uniform” priors on the free parameters as used by Cordue 2014a).

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

MCMC chain diagnostics

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

In New Zealand, a common approach to judge convergence is to use multiple chains (each starting at a random jump from the MPD estimate) and compare the marginal posterior distributions for the (derived) parameters of interest. The idea is that the chains are sufficiently converged when all of the chains give the “same” answer. For this assessment, three chains were used and they were run up to a maximum of 15 million samples. The three posterior distributions were judged primarily on the basis of their median values as to whether they were sufficiently similar that the chains could be stopped. “Near identical” median values were required (e.g., two out of three chains being the same to two significant figures with the third almost the same; e.g., stock status medians across the three chains of 48, 49, and 49 % B_0 were considered close enough).

Fishing intensity

Fishing intensity was measured in units of 100 – ESD (Equilibrium Stock Depletion, see Cordue 2012). That is, the question of “how hard was the stock being fished each year?” was answered by running the model through to deterministic equilibrium at the given level and pattern of fishing each year (using the MPD estimate of parameters or, for MCMCs, doing it at every sample from the posterior). The equilibrium level of spawning biomass is defined to be the ESD for that sample and year (e.g., if the stock is fished at a very high fishing intensity, the equilibrium spawning stock biomass will be close to zero: $ESD = 0\% B_0$; if the stock is being very lightly fished, then $ESD = 100\% B_0$). 100 – ESD ranges from 0–100 with 100 denoting any pattern and level of fishing that would eventually force the stock down to zero spawning biomass. In general, the fishing intensity that forces the stock to deterministic equilibrium at $x\% B_0$ is denoted as $U_{x\%B_0}$.

Reference points and the HCR

For orange roughy there is a Harvest Control Rule (HCR) which is applied to the three stocks that were MSC certified in 2016 (ESCR, NWCR, ORH7A). The biomass target range is 30–50% B_0 and catch limits are estimated as a function of estimated stock status and the beginning-of-year vulnerable biomass

(see Figure 5 and Cordue 2014b). The HCR was applied to the Puysegur stock assessment to estimate possible catch limits for the 2017–18 fishing year. Three potential limits were calculated based on the assumptions of all fishing in the spawning season, all fishing outside the spawning season, or a mix of half in and half outside the spawning season.

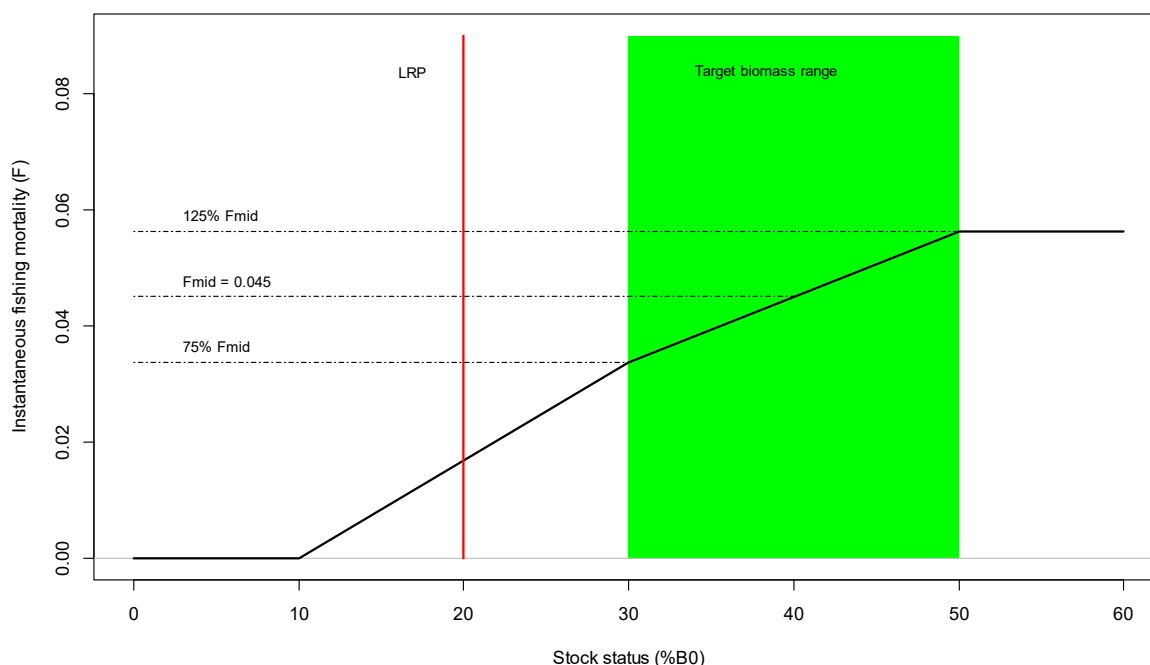


Figure 5: The orange roughy HCR: LRP = 20% B_0 , target biomass range = 30–50% B_0 , initial $F_{mid} = 0.045$, slope within the target range: $p = 25\%$; ramps down to zero at 10% B_0 .

Projections

Projections were done over a 5-year time period for each of the three potential catch limits from the HCR. In each case, the random YCS were brought in immediately after the last estimated YCS and were resampled from the last 10 years of estimates (this is done because YCS are possibly correlated rather than being independent from year to year). Projections were done for the base model and the LowM-Highq model (the most pessimistic run).

3. RESULTS

3.1 Model diagnostics

The model provided good MPD fits to the data (Figures 6–9). The fits to the commercial length frequencies may appear poor but they have very low effective sample sizes (Figure 9). Residuals were examined mainly at the MCMC level and these were all acceptable suggesting that the data weightings (CVs and effective sample sizes) were reasonable (see Appendix 1).

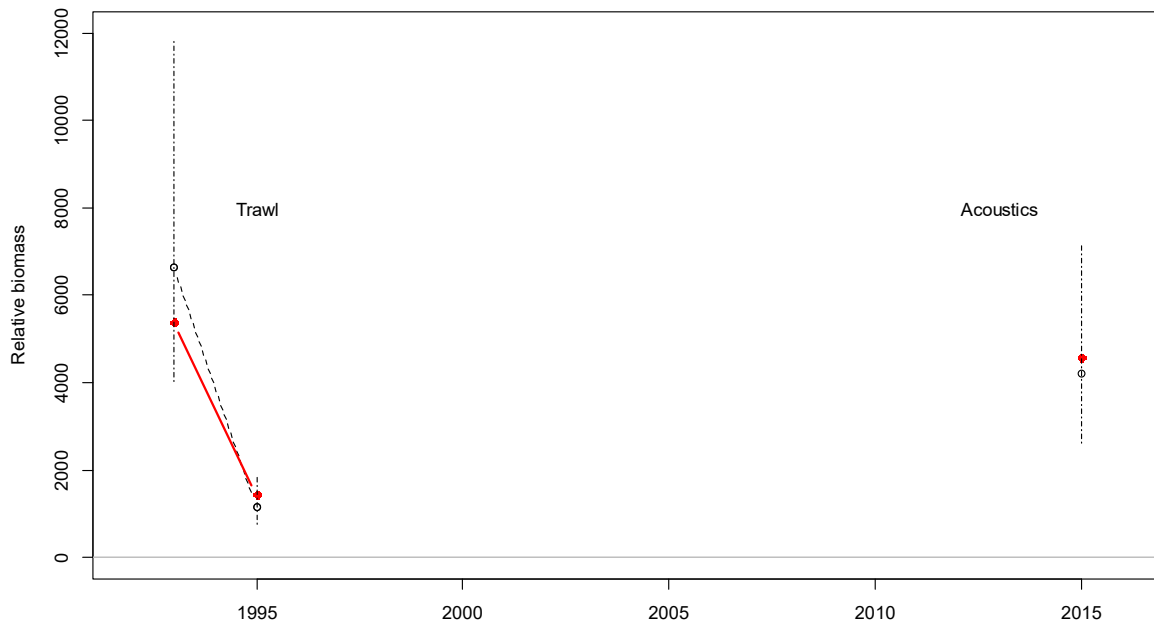


Figure 6: Base model: MPD fit to relative biomass indices. Open circles and dotted lines are the observations and 95% CIs. The filled red circles and lines are the fitted values.

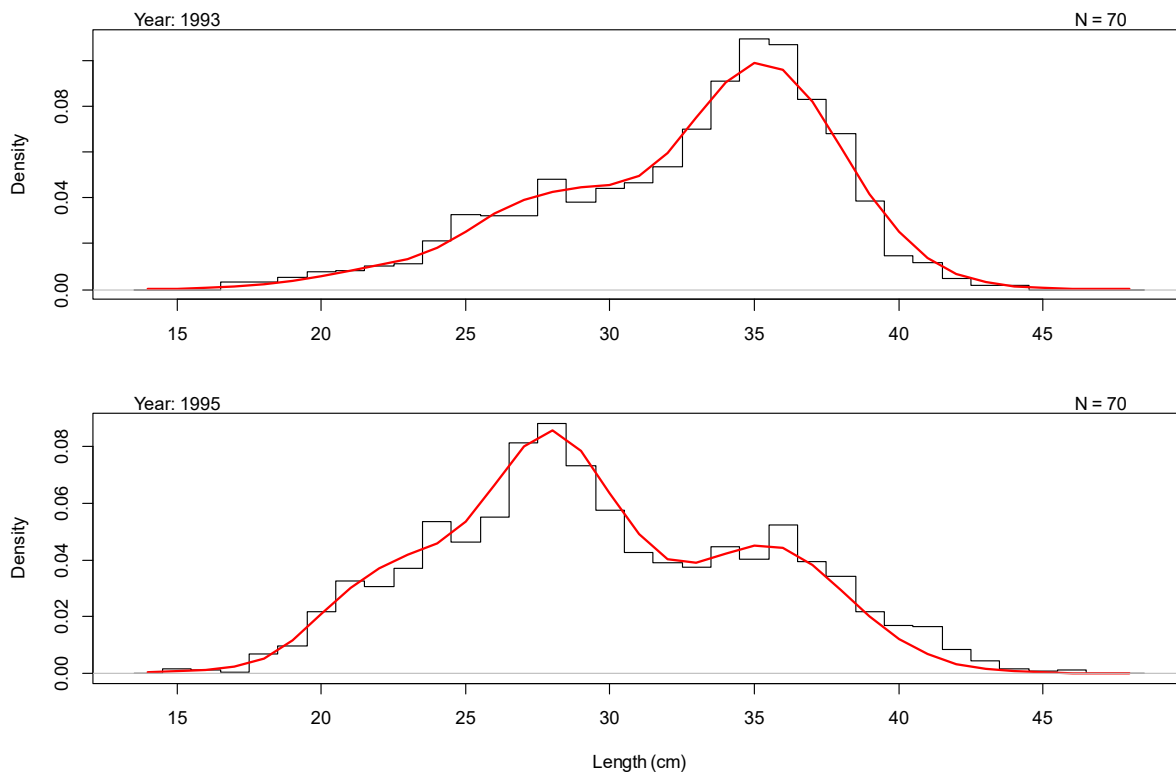


Figure 7: Base model: MPD fit to length frequency distributions from *Tangaroa* trawl surveys in 1992 and 1994 (fitted in the model as beginning of year in 1993 and 1995). The effective samples sizes of $N = 70$ were the approximate number of stations in each survey. The histograms show the observed length frequency distributions and the red lines show the predicted values.

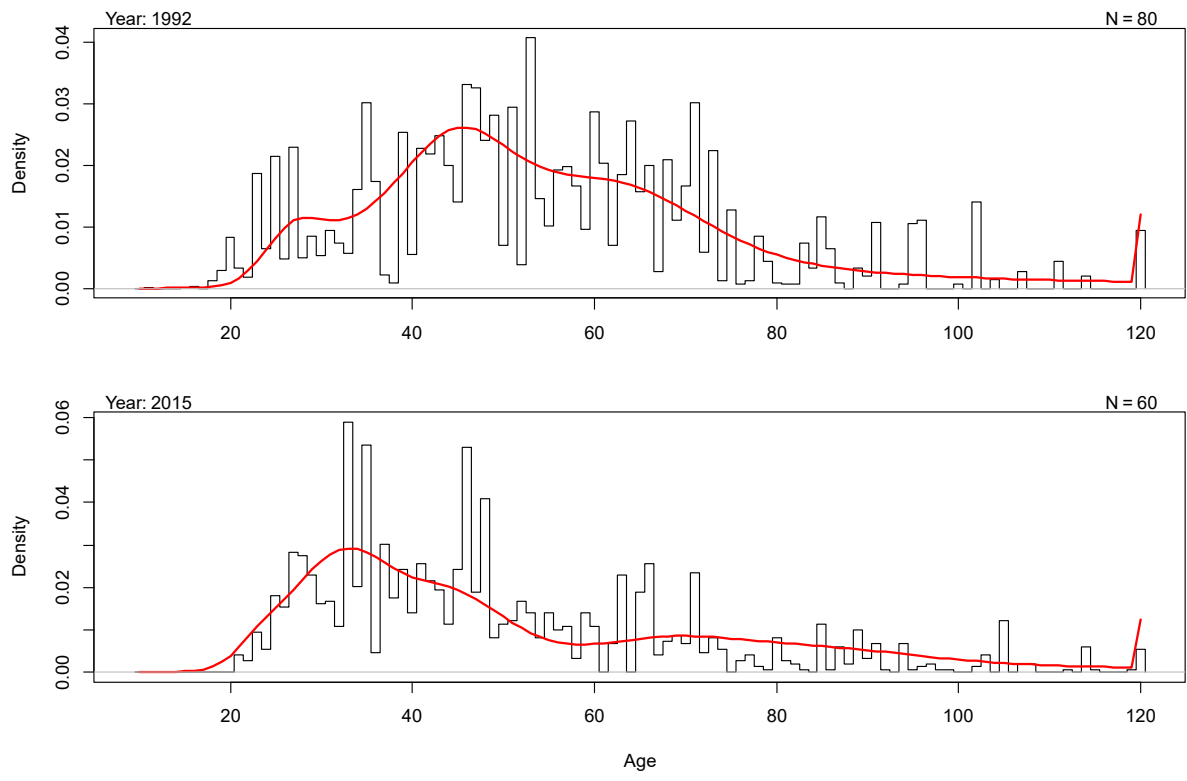


Figure 8: Base model: MPD fit to age frequency distributions in 1992 and 2015. N is the effective sample size used in the model. The histograms show the observed age frequency distributions and the red lines show the predicted values.

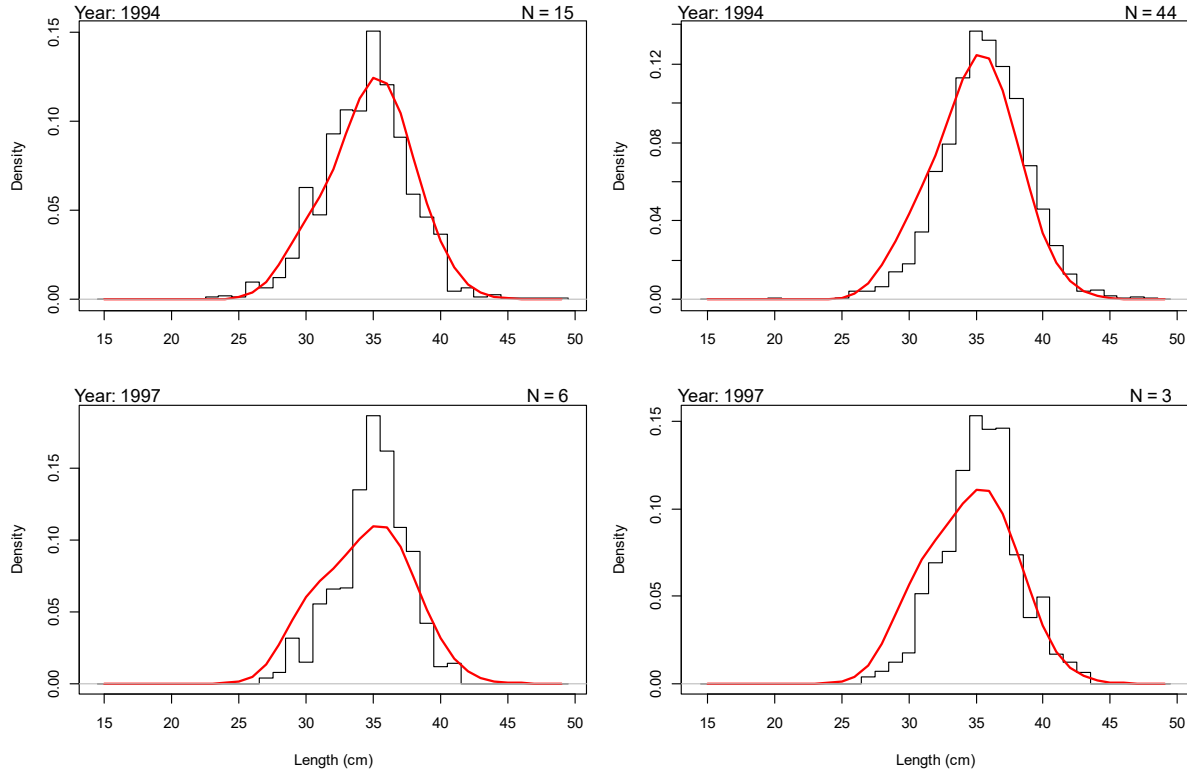


Figure 9: Base model: MPD fit to observer length frequency distributions in 1994 and 1997 for the non-spawning (left) and spawning seasons (right). N is the effective sample size used in the model. The histograms show the observed length frequency distributions and the red lines show the predicted values.

The marginal posterior distribution of the acoustic q is shifted somewhat to the left of the prior but remains well within the distribution of the prior (Figure 10).

The MPD sensitivity runs in which the trawl surveys were assumed to be strictly comparable, despite the difference in timing, were unable to fit the decline in the trawl indices and showed poorer fits to the trawl survey length frequencies than the base model. The objective function decreased by 7 likelihood units when the availability parameter for 1994 was estimated (which supports the inclusion of the single additional parameter).

When lognormal priors were used for the free YCS parameters the trawl survey indices were fitted adequately (as the availability parameter was estimated) but the fits to the composition data (length and age frequencies) were degraded compared to the base model (which used nearly uniform priors on the free YCS parameters). The worst example of the poor fits was for the *Tangaroa* trawl survey length frequency distribution in 1994 (Figure 10). The reason for the poorer fits to the composition data was because the use of a lognormal prior severely constrained the estimated YCS (Figure 11). The near uniform prior allows much more freedom in the pattern of estimated YCS (Figure 11). Behaviour in the MCMC runs is much improved for the lognormal priors but there is the issue that the choice of sigmaR is arbitrary.

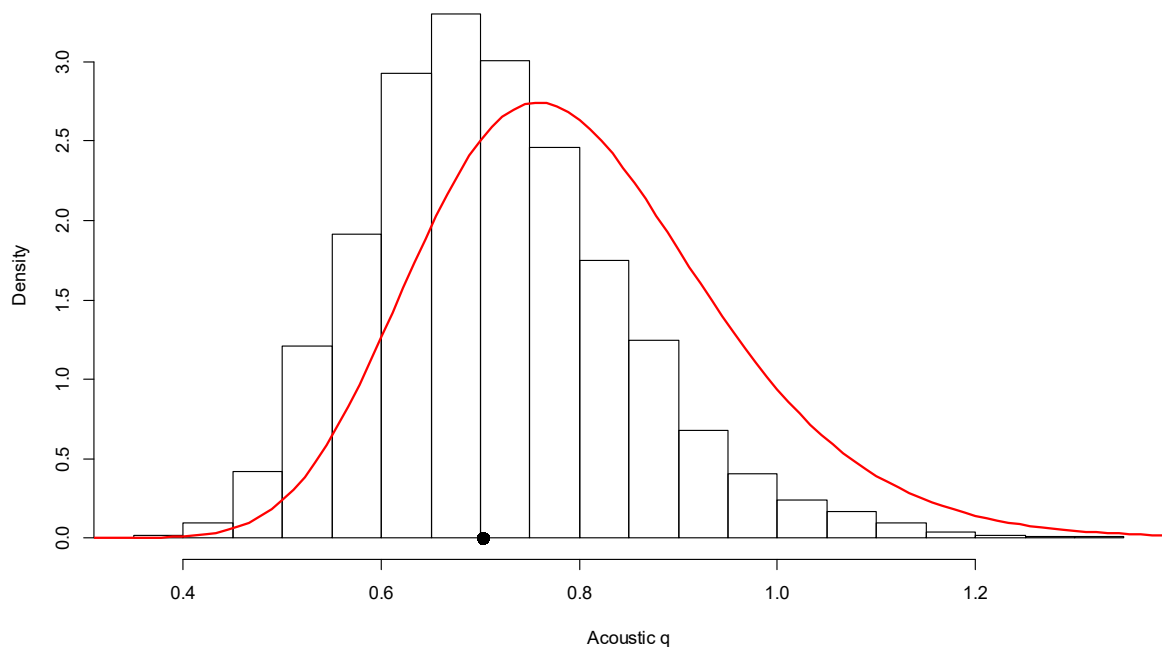


Figure 10: Base model: the marginal posterior distribution of the acoustic q (histogram) compared to its prior (red line). The black dot marks the median of the marginal posterior.

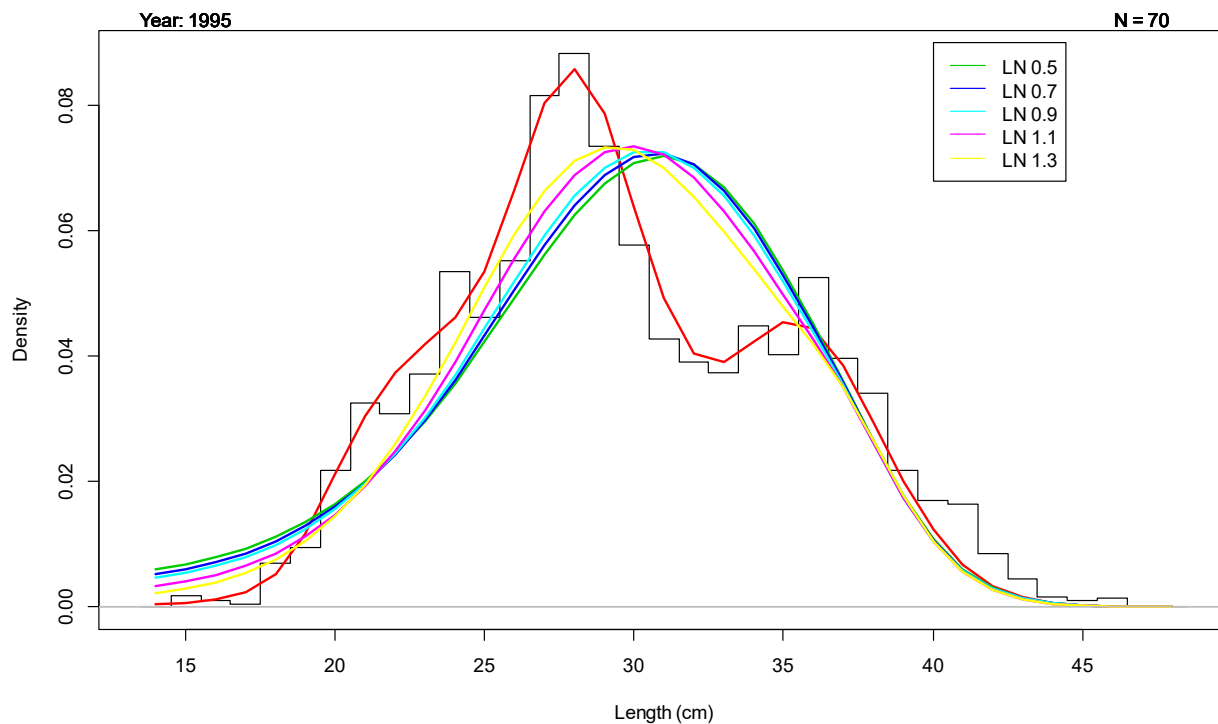


Figure 11: MPD fit to length frequency distribution from *Tangaroa* trawl survey 1994 (fitted in the model as beginning of year 1995). The effective samples size of $N = 70$ was the approximate number of stations in the survey. The histogram shows the observed length frequency distributions and the red line shows the fit from the base model. The other lines are MPD fits from models using lognormal priors on the free YCS parameters with different values of σ_{MR} .

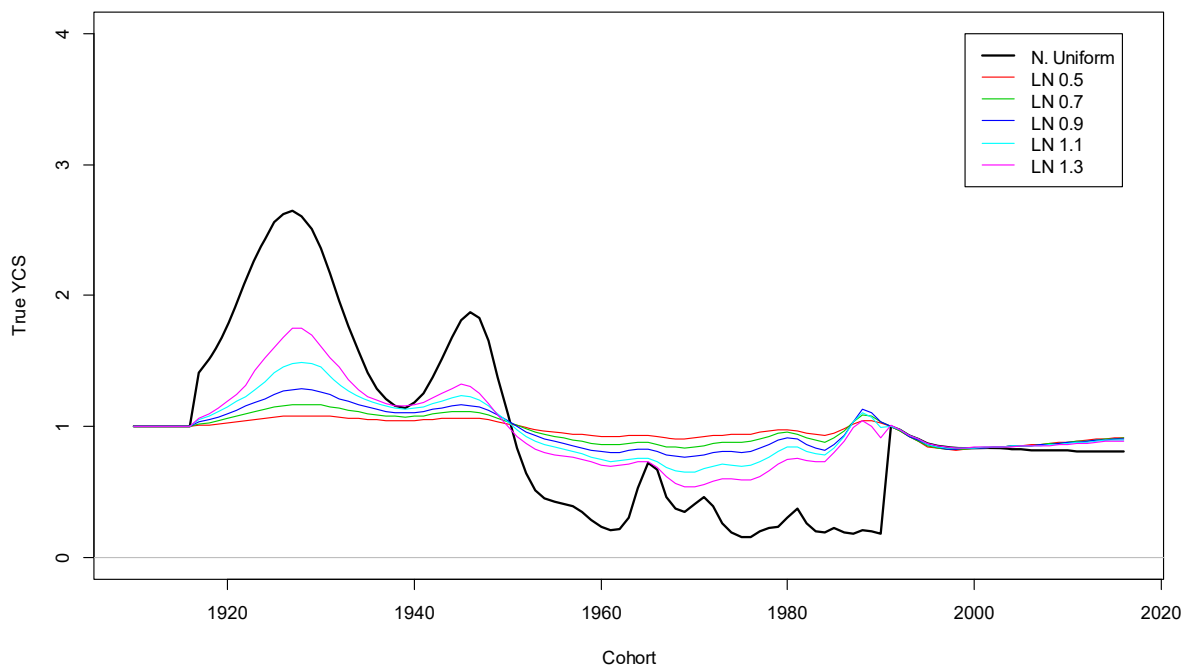


Figure 12: MPD estimates of year class strength for the base model (using nearly uniform prior on free YCS parameters) and sensitivity runs using lognormal priors with different values of σ_{MR} (0.5–1.3).

The likelihood profile for B_0 showed very little conflict between data sets (Figure 13). The strongest contrast across B_0 is shown by the age frequency data which is incompatible with lower values of B_0 presumably because they would imply a truncated age distribution – which was not seen in the data (see Figure 8).

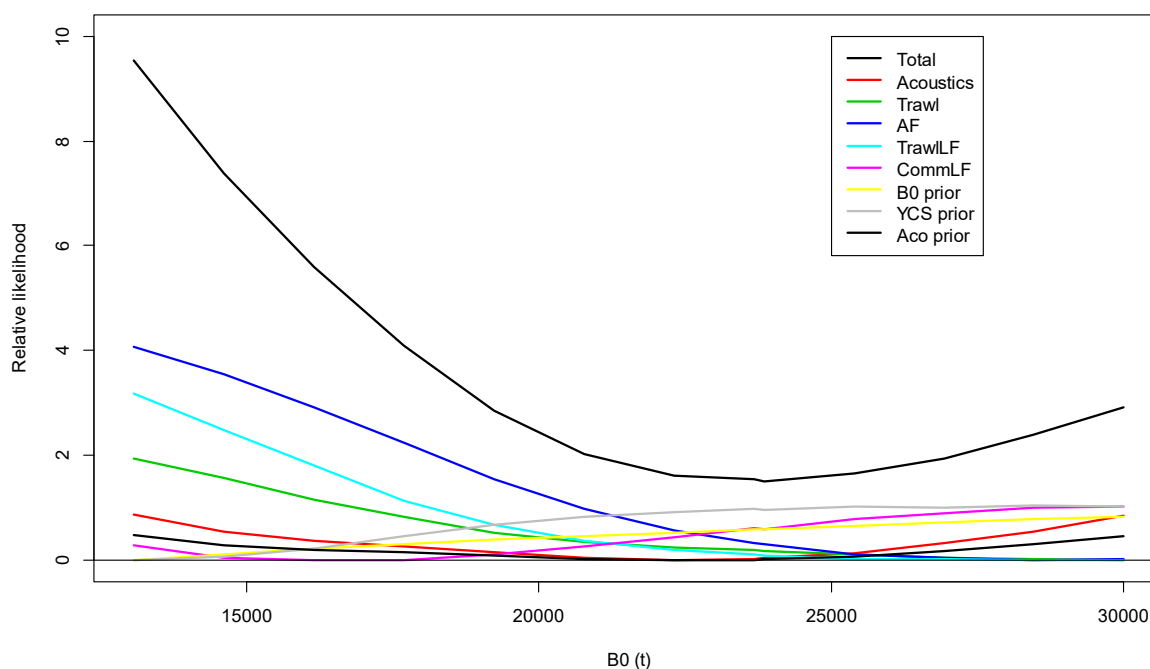


Figure 13: Base model: likelihood profile for B_0 . The units on the Y axis are negative log-likelihood normalised to zero for individual components (with the total offset an arbitrary amount). AF = age frequencies, TrawlLF = trawl survey length frequencies, CommLF = commercial length frequencies, Aco prio = prior for acoustics q .

3.2 MCMC results

For the base model, and the sensitivity runs, MCMC convergence diagnostics were excellent. Virgin biomass, B_0 , was estimated to be between 12 000–26 000 t for all runs (Table 4). Current stock status was similar across the base and the first four sensitivity runs (Table 4). The slightly lower stock status when M was estimated reflects the lower estimates of M (0.040 rather than 0.045). For the two “bounding” runs, where M and the mean of the acoustic q prior were shifted by 20%, median current stock status was estimated to be within or above the biomass target range of 30–50% B_0 for both runs (Table 4). All other sensitivity runs (not reported) gave results within those of the two bounding runs. The sensitivity with a higher CV on the acoustic q prior gave similar results to the base model with a slighter higher B_0 and stock status. The runs with lognormal priors showed a trend in estimated stock status with higher sigmaR giving lower stock status. Assuming a 5% overrun in the catch history made no almost no difference to the results.

Table 4: MCMC estimates of virgin biomass (B_0) and stock status (B_{2017} as % B_0) for the base model and six sensitivity runs. “Low AF” and “High AF” refer to lower and higher effective sample sizes for the age frequencies compared to the base model. See section 2.4 for a detailed explanation of “LowM-Highq” and “HighM-Lowq”.

	M	B_0 (000 t)	95% CI	B_{2017} (% B_0)	95% CI
Base	0.045	17	13–23	49	36–62
No trawl	0.045	17	13–24	51	39–64
Low AF	0.045	15	12–21	46	34–61
High AF	0.045	18	14–26	51	39–63
Estimate M	0.040	18	13–25	47	34–61
LowM-Highq	0.036	18	14–23	42	30–55
HighM-Lowq	0.054	17	12–25	57	44–69

For the base model, (and all sensitivity runs) the stock is considered to be fully rebuilt according to the Harvest Strategy Standard (at least a 70% probability that the lower end of the management target range

of 30–50% B_0 has been achieved).

The estimated YCS show a trend across cohorts with above average recruitment prior to 1950 with below average recruitment up until about 1980 (Figure 14). The variation in the more recent (true) YCS is due to variation in depletion levels across the MCMC samples (and hence different levels of recruitment were generated from the stock-recruitment relationship).

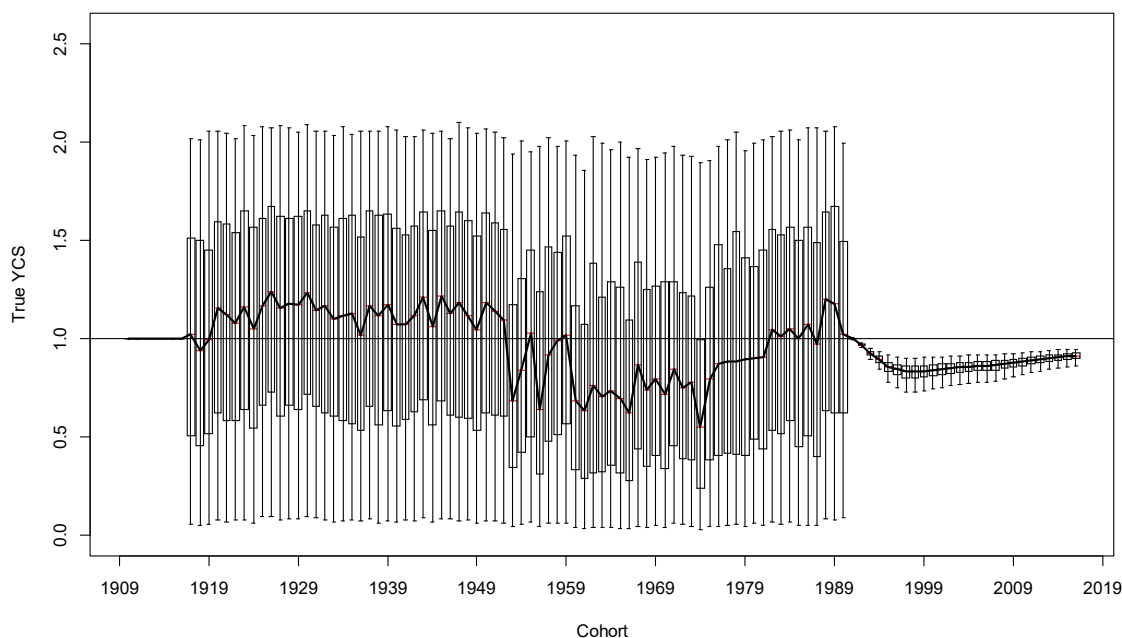


Figure 14: Base model: MCMC estimated “true” YCS (R_y/R_0). The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution.

The commercial selectivity in the non-spawning season was estimated to be well to the left of the maturity ogive (Table 5). The maturity estimate is similar to that for the ESCR (see Table 14) and is based on two age frequency distributions during the spawning season. The non-spawning season selectivity must be considered to be poorly estimated as it is based on just two commercial length frequency distributions and assumed growth parameters. The estimated selectivity on immature fish for the trawl survey extends well to the left (5% selected at 12 years) as is to be expected for a wide area survey. The estimated proportion of mature fish available in the 1994 trawl survey (which was more than a month later than the 1992 survey) was well below 100% with a point estimate of just 21% (Table 5). For completeness, the estimates of the spread of length at mean length at age were: cv1: 0.12, 95%CI: 0.05–0.15 and cv2: 0.05, 95%CI: 0.03–0.10.

Table 5: Base model: MCMC estimates of the commercial selectivity during the non-spawning season, maturity, the immature selectivity for the trawl surveys, and the proportion of mature fish selected in the 1994 trawl survey.

	Non-sp. selectivity (years)		Maturity (years)		Immature trawl selectivity (years)		Trawl 92 mature	Trawl 94 mature
	a50	a _{to95}	a50	a _{to95}	a50	a _{to95}	prop.	prop.
Median	26	5	40	15	28	16	1	0.21
95% CI	20–33	3–13	35–46	11–21	19–36	6–20	Fixed	0.06–0.66

The estimated spawning-stock biomass (SSB) trajectory showed a declining trend from 1990 (when the fishery started) through to 1998 when the fishery was closed (Figure 15). Since 1998 the estimated biomass has increased steadily and has been well within the target range for the last decade (Figure 15).

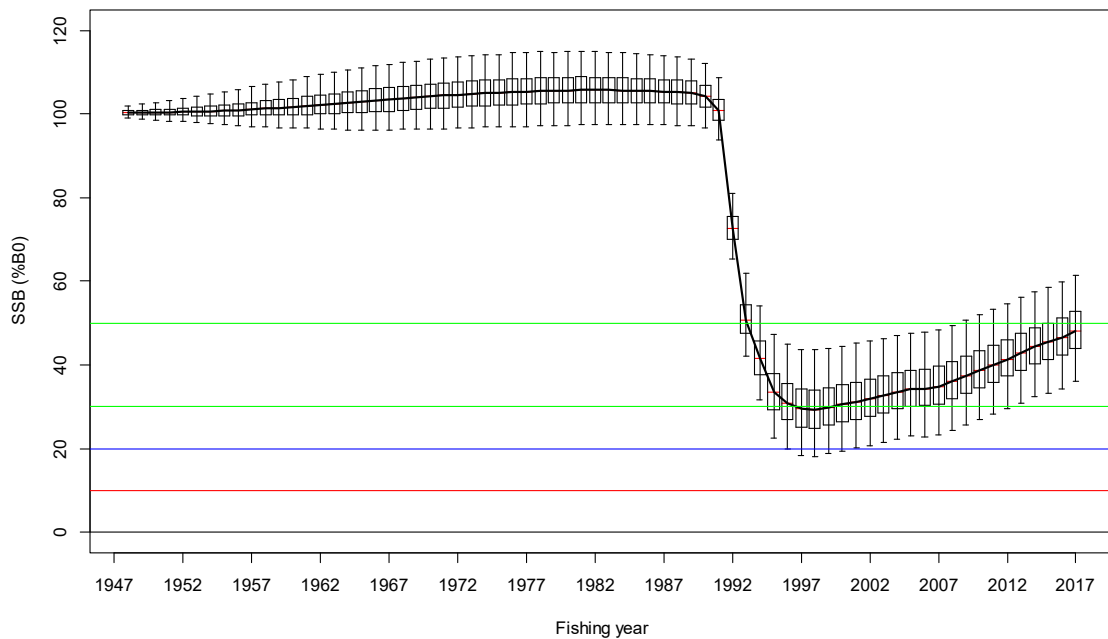


Figure 15: Base model: MCMC estimated spawning-stock biomass trajectory. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. The hard limit (red), soft limit (blue), and biomass target range (green) are marked by horizontal lines.

Fishing intensity was estimated in each year for each MCMC sample to produce a posterior distribution for fishing intensity by year. Fishing intensity is represented in term of the median exploitation rate and the Equilibrium Stock Depletion (ESD). For the latter, a fishing intensity of $U_{x\%B_0}$ means that fishing (forever) at that intensity will cause the SSB to reach deterministic equilibrium at $x\% B_0$ (e.g., fishing at $U_{30\%B_0}$ forces the SSB to a deterministic equilibrium of 30% B_0). Fishing intensity in these units is plotted as 100–ESD so that fishing intensity ranges from 0 ($U_{100\%B_0}$) up to 100 ($U_{0\%B_0}$).

Estimated fishing intensity was above $U_{20\%B_0}$ for most of the history of the fishery before it was closed in 1998; it was briefly in the target range ($U_{30\%B_0}$ – $U_{50\%B_0}$) in 2006 when there was a combined acoustic and trawl survey (Figure 16).

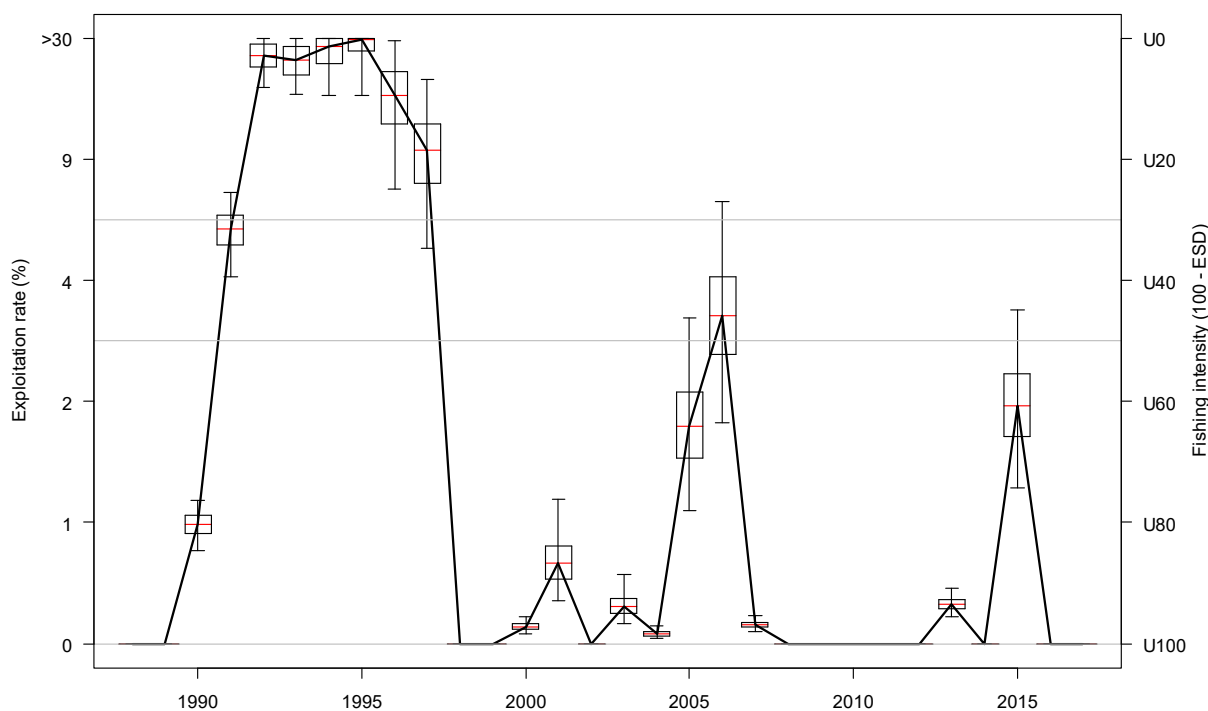


Figure 16: Base model: MCMC estimated fishing-intensity trajectory. The box in each year covers 50% of the distribution and the whiskers extend to 95% of the distribution. The fishing-intensity range associated with the biomass target of 30–50% B_0 is marked by horizontal lines.

3.3 Biological reference points, management targets and yield

Orange roughy stocks within the target biomass range of 30–50% B_0 are managed according to the Harvest Control Rule (HCR) that was developed in 2014 using a Management Strategy Evaluation (MSE)(Cordue 2014b). From the MSE the expected long-term yield has a 95% CI of 0.8–2.1 % B_0 which, for a given stock, depends on the actual (rather than assumed) values of natural mortality (M) and steepness (h) in the stock-recruitment relationship.

For Puysegur, combining the uncertainties in B_0 and expected long-term yield, the 95% CI for long-term annual yield is 130–400 t. Given that the stock is estimated to be at the top of the target range the yield for the next fishing year is higher than the long-term average.

Estimated stock status in the base model is 49% B_0 and for a stock status within the range 30–50% B_0 the HCR specifies that:

$$F = 0.1125 B_{current} / B_0$$

Which is the equation of the line in the range of 30–50% B_0 (see Figure 5).

Therefore, the exploitation rate is $F = 0.055$.

The median beginning-of-season vulnerable biomasses for 2017–18 were:

Spawning season:	8 340 t
Non-spawning:	16 600 t

This results in catch limits associated with a pure spawning-season fishery *or* a pure non-spawning-season fishery of:

Spawning season: 460 t
 Non-spawning: 910 t

If the total exploitation rate was split equally between the two seasons then the catch limit is the average of the two numbers above: 685 t.

3.4 Projections

Five year projections were done for seven scenarios:

Scenario	Model	Non spawn catch (t)	Spawn catch (t)
1	Base	910	0
2	Base	0	460
3	Base	0	685
4	Base	0	910
5	LowM-Highq	0	460
6	LowM-Highq	0	685
7	LowM-Highq	0	910

The risk of going below the limit reference point of 20% B₀ for either of the pure-season fisheries, at the catch levels specified by the HCR under the base model, are zero for the next five years (Figure 17). Because the age of selection is much lower in the non-spawning fishery compared to the spawning fishery it has a much larger vulnerable biomass and therefore it is safe to take a much larger catch.

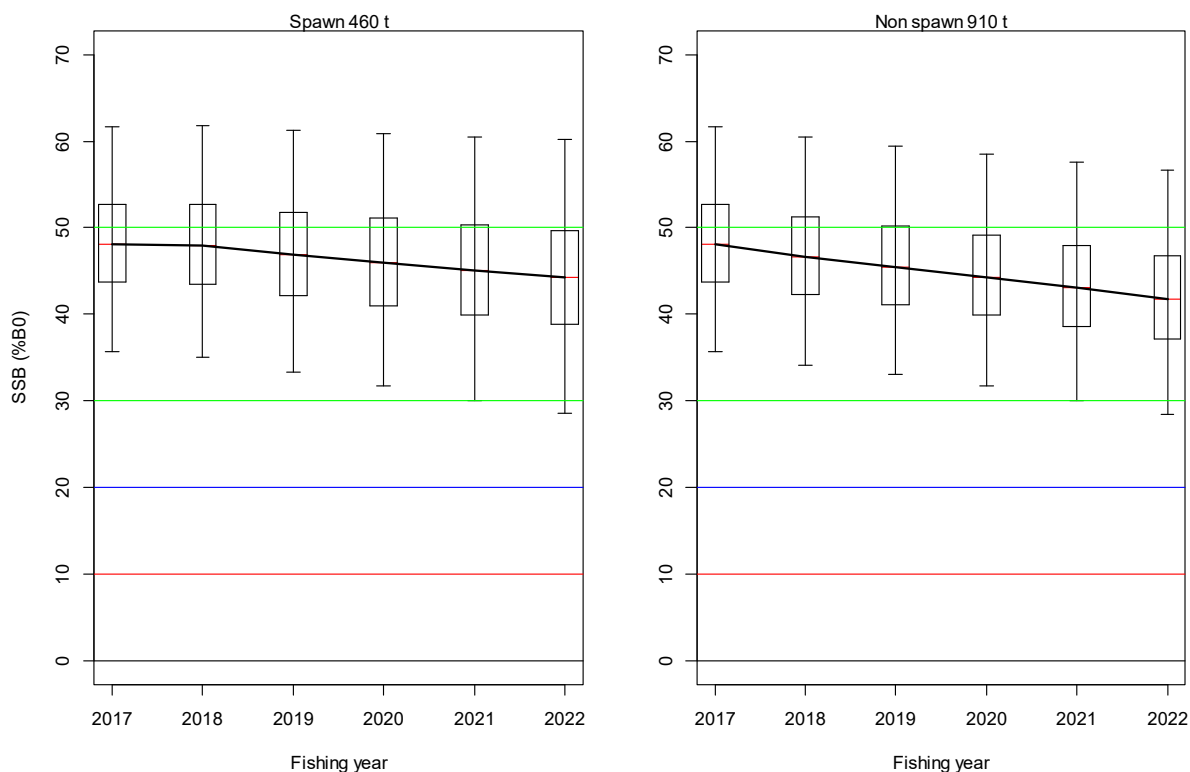


Figure 17: Five year projections for the base model under a spawning season catch of 460 t or a non-spawning season catch of 910 t. Each box covers the middle 50% of the distribution and the whiskers cover 95% of the distribution.

However, the selectivity for the non-spawning fishery is poorly estimated and it could be much closer to maturity than it was estimated to be in the model. Therefore, it is prudent to examine the risks if all of the catch is taken during the spawning season (when only mature fish are taken). It is also useful to monitor the risks when the low M model (LowM-Highq) is used instead of the base model.

Figures 18–20 show spawning biomass projections for the base model and the low model under the three different catch limits where all of the catch is assumed to be taken in the spawning season. For all scenarios the probability of spawning biomass in the next four years being below the hard limit (10% B_0) is zero. The risks of being below the lower bound of the target range (30% B_0) and the limit reference point (20% B_0) in 2020–21 (when the next assessment is due in four years) are:

Scenario	Model	Non spawn catch (t)	Spawn catch (t)	$P(B_{21} < 20\%B_0)$	$P(B_{21} < 30\%B_0)$
1	Base	910	0	0.00	0.02
2	Base	0	460	0.00	0.02
3	Base	0	685	0.01	0.10
4	Base	0	910	0.04	0.24
5	Low	0	460	0.01	0.16
6	Low	0	685	0.04	0.35
7	Low	0	910	0.15	0.55

These risks are over-estimates because some of the catch will be taken in the non-spawning season and will therefore include some immature fish. The risk assessment should primarily be based on the base model projections while monitoring the “worst case” scenarios from the low model.

If an assessment was planned for a year earlier in 2019–20 the risks are approximately halved for the base model:

Scenario	Model	Non spawn catch (t)	Spawn catch (t)	$P(B_{20} < 20\%B_0)$	$P(B_{20} < 30\%B_0)$
1	Base	910	0	0.00	0.01
2	Base	0	460	0.00	0.01
3	Base	0	685	0.00	0.05
4	Base	0	910	0.01	0.12
5	Low	0	460	0.00	0.12
6	Low	0	685	0.02	0.24
7	Low	0	910	0.06	0.39

According to the projection results, there is a tradeoff whereby a larger catch limit can be set if the stock assessment is a year earlier. If an assessment is planned in 2019–20 then annual catches of 600–800 t appear to pose little risk up until that time. If the assessment is planned for 2020–21 then lower annual catches of 400–600 t present a similar level of estimated risk.

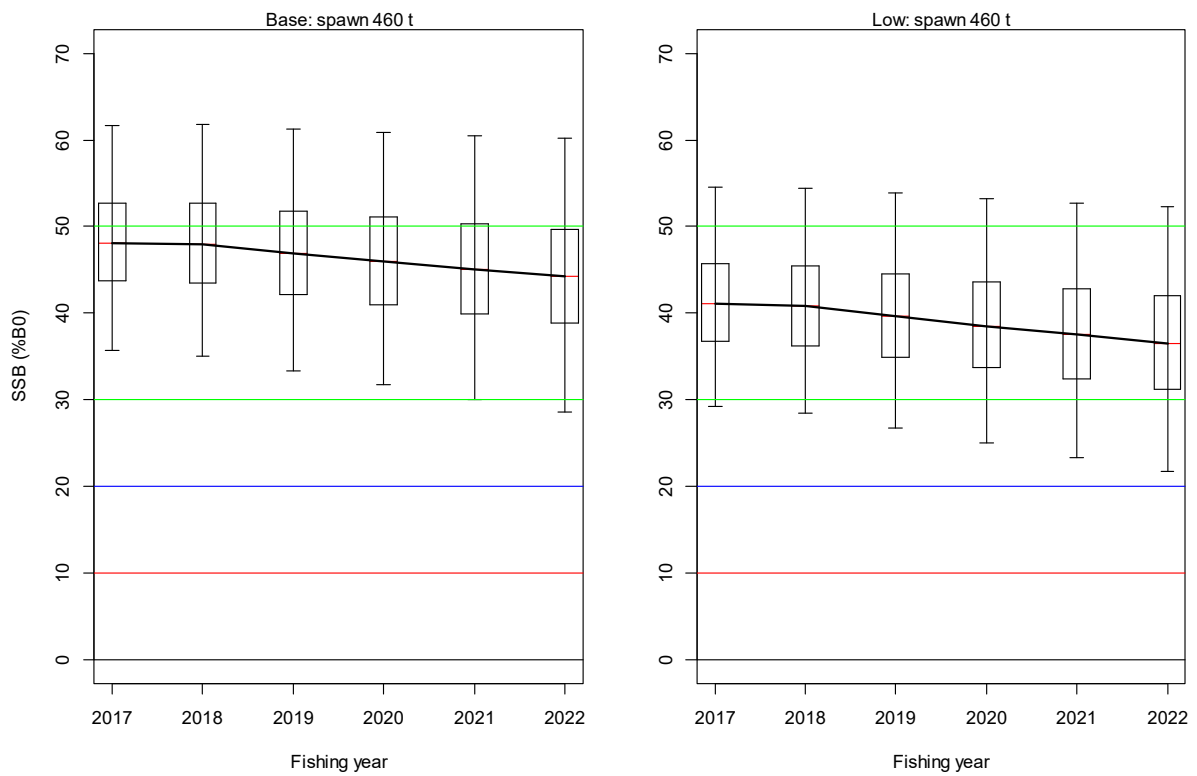


Figure 18: Five year projections for the base model and the low model under a spawning season catch of 460 t. Each box covers the middle 50% of the distribution and the whiskers cover 95% of the distribution.

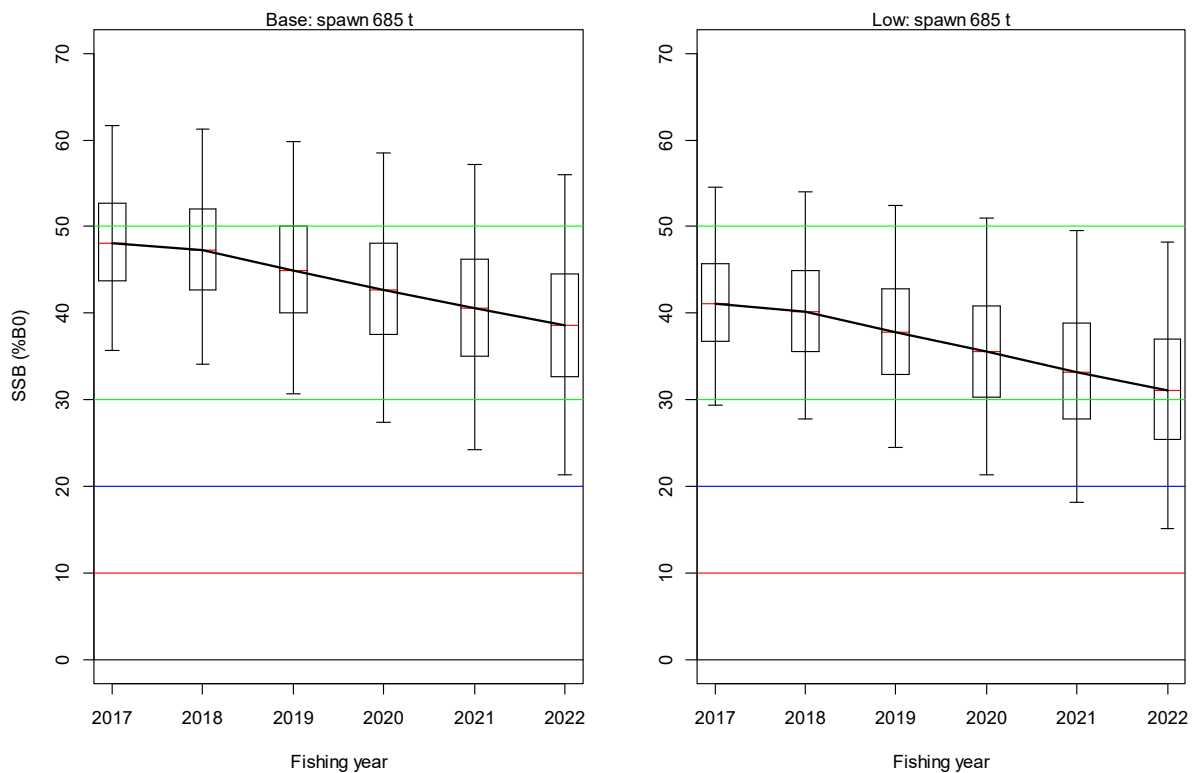


Figure 19: Five year projections for the base model and the low model under a spawning season catch of 685 t. Each box covers the middle 50% of the distribution and the whiskers cover 95% of the distribution.

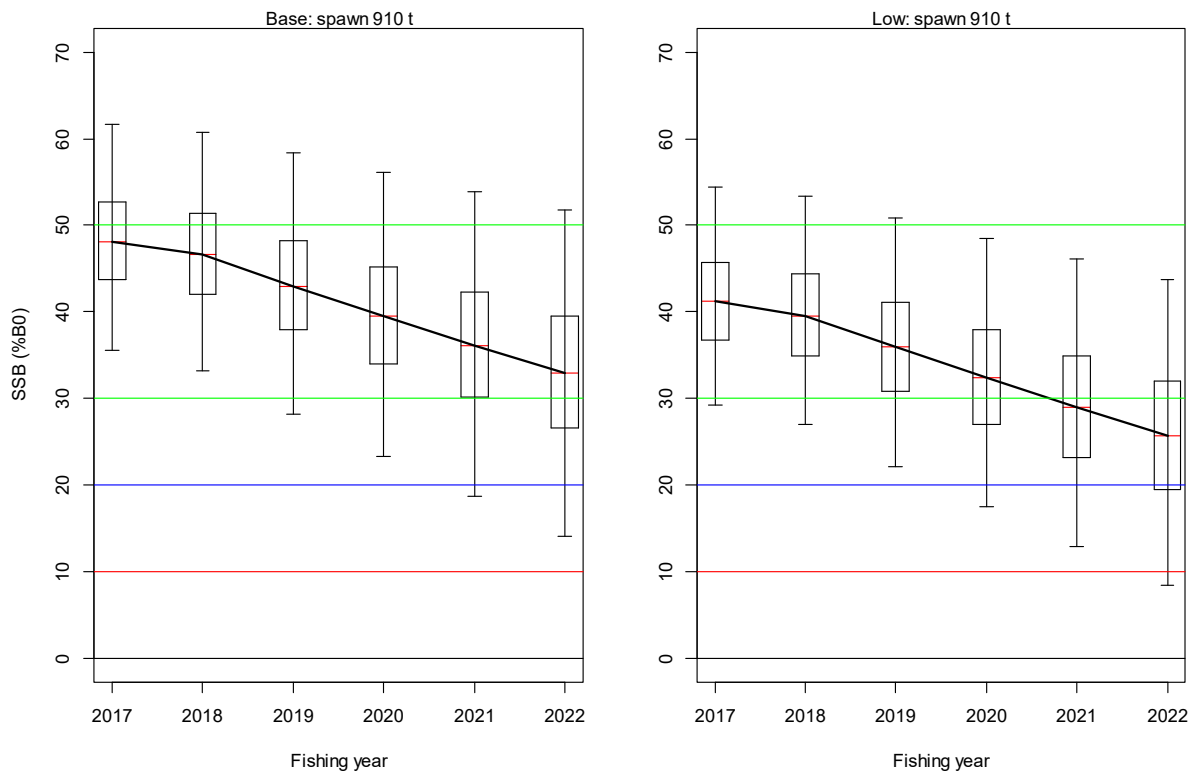


Figure 20: Five year projections for the base model and the low model under a spawning season catch of 910 t. Each box covers the middle 50% of the distribution and the whiskers cover 95% of the distribution.

4. DISCUSSION AND CONCLUSIONS

The last assessment of Puysegur was done in 1997 using data that are not considered to be acceptable stock assessment inputs by today's standards. The trawl indices were from different vessels in each year and CPUE indices were used as biomass indices (Annala et al. 2000). The use of deterministic recruitment is also an approach that is no longer considered to be acceptable for orange roughy stock assessment. The 1997 assessment suggested that the stock had been fished down to low levels with a point estimate for B_{1997} of 7% B_0 with a 95% confidence interval of 7–25% B_0 (Annala et al. 2000).

The current approach for orange roughy stock assessment relies on age data to avoid the assumption of deterministic recruitment and the use of only the most defensible data inputs. CPUE indices are no longer used and acoustic survey estimates of spawning aggregations provide the main biomass indices (which are used with an informed prior on the acoustic q).

The Puysegur fishery has essentially been closed for twenty years so it is not surprising that the assessment has found that the stock has rebuilt to the top of the target biomass range. The absence of substantial truncation of the age distribution in the 2015 spawning-season age frequency suggests, of itself, that the stock was never severely depleted. The current stock assessment estimates B_{1997} at 30% B_0 with a 95% CI of 18–44% B_0 . This is substantially higher than the estimate in 1997 (7–25% B_0).

Application of the HCR to the Puysegur assessment to calculate a 2017–18 catch limit is complicated because of the poorly estimated non-spawning season selectivity. It appears that much younger fish are caught during the non-spawning season compared to the spawning season. If this is true then a higher catch limit is appropriate for a pure non-spawning season fishery compared to a spawning season fishery. However, if the non-spawning season selectivity is close to the maturity ogive then the calculated catch limit for a non-spawning season fishery could be far too high. It is therefore prudent to base catch limits on spawning season biomass. The HCR applied to spawning season biomass gives a catch limit of 460 t.

The results of projections suggest that there is a tradeoff between the level at which the catch limit can be set and the year of the next stock assessment. If an assessment is planned in 2019–20 then annual catches of 600–800 t appear to pose little risk. If the assessment is planned for 2020–21 then annual catches of 400–600 t appear to pose little risk.

With the completion of this stock assessment there are now five orange roughy stocks for which model based assessments have been completed using very similar methods. It is interesting to compare some of the estimated stock parameters across the five stocks. Below, the estimates of natural mortality (M), maturity, and year class strengths are compared.

For all of the stock assessments the median estimates of M from the “EstM” models were lower than the assumed value in the base model of 0.045 (Table 13). This was despite a fairly tight informed prior on M with a mean of 0.045. In each stock assessment there appears to be very little information in the data on the value of M because there are so few age frequencies. It seems premature to move to a new value of M for the base models. However, as more age data are gathered the estimates of M may improve. At the moment there is no reason to believe M is higher than 0.045 but there is some evidence to suggest that it could be a bit lower.

Table 13: Estimates of natural mortality for each orange roughy stock assessed in 2014 and for Puysegur assessed in 2017. These are MCMC estimates from the “EstM” models which are identical to the base models except that M is estimated using an informed prior $N(\text{mean} = 0.045, \text{CV} = 0.15)$

Stock	M (median)	95% CI
NWCR	0.041	0.033–0.051
ESCR	0.037	0.027–0.048
MEC	0.032	0.028–0.037
ORH7A	0.038	0.031–0.047
Puysegur	0.040	0.031–0.050

Estimates of maturity for the four stocks provide a range on age at 50% maturity (a_{50}) of 32–41 years (Table 14). This is considerably older than the estimates of transition-zone maturity which range from 23–33 years (Francis & Horn 1997). The slopes of the estimated maturity curves are also much shallower than those for transition-zone maturity. The Puysegur estimates are very similar to those for ESCR and NWCR (Table 14).

Table 14: Base model, median MCMC estimates of maturity for each stock assessed in 2014 and for Puysegur assessed in 2017. a_{50} is the age, in the virgin population, at which 50% of the fish are mature; a_{95} is the number of years that need to be added to a_{50} to get the age at which 95% of the fish are mature.

Stock	a_{50} (years)	a_{95} (years)
NWCR	37	13
ESCR	41	12
MEC	35	10
ORH7A	32	10
Puysegur	40	15

There are some similarities in the estimates of year class strength (YCS) across the five stocks (Figure 21). The MEC assessment had the most age data available and therefore it had the largest number of YCS estimated. Early YCS were generally estimated to be above average and recent YCS estimated to be below average. This same pattern was evident for ORH7A, ESCR, and Puysegur (though over a shorter duration and of lesser magnitude – see Figure 21). The NWCR was the only assessment where the pattern of recruitment was consistent with average (deterministic) recruitment (Figure 21).

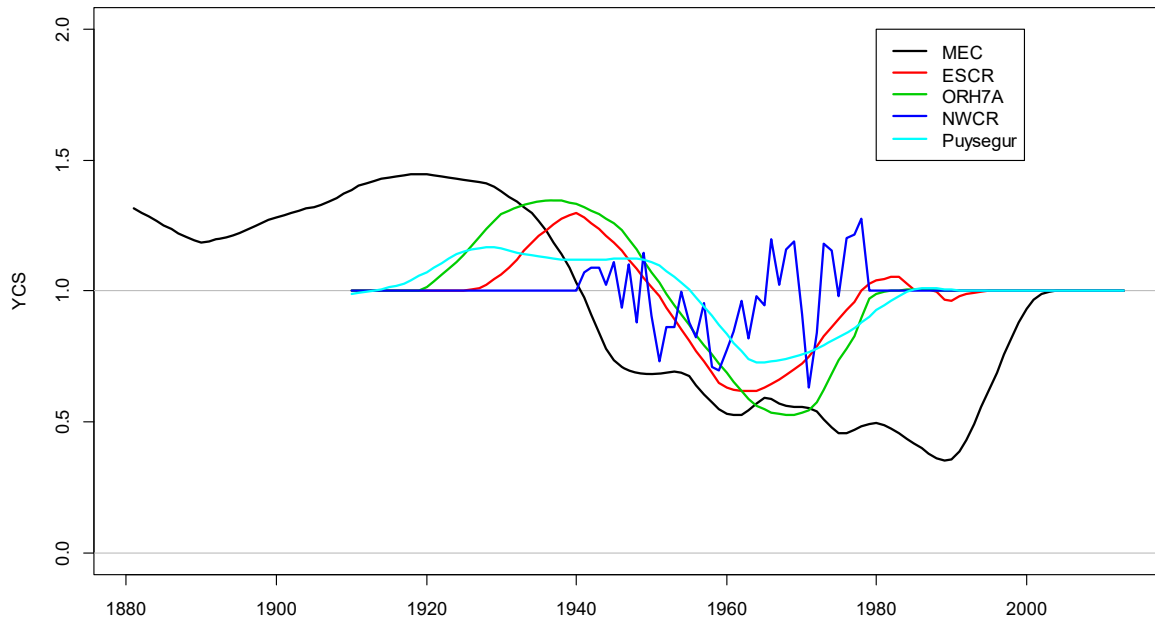


Figure 21: MCMC base models: smoothed median estimates of year class strength (YCS) for the four orange roughy stocks assessed in 2014 and for Puysegur assessed in 2017. A lowess smoother ($f = 0.15$) was applied to the MCMC median estimates for each cohort.

5. ACKNOWLEDGEMENTS

This work was funded by the Deepwater Group Ltd. Thanks to members of MPI's DFWAWG for providing useful comments and guidance on the assessment. Also, thanks to Geoff Tingley for reviewing this report. Finally, thanks to NIWA for the use of their excellent stock assessment package CASAL.

6. REFERENCES

- Annala, J.H.; Sullivan, K.J.; O'Brien, C.J. (Comps.) (2000). Report from the Fishery Assessment Plenary, May 2000: stock assessments and yield estimates. 495 p. (Unpublished report held in NIWA Greta Point library, Wellington.)
- 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.; Anderson, O.F.; Tracey, D.M. (1996). Trawl survey of orange roughy, black oreo, and smooth oreo in southern New Zealand waters, September-October 1994 (TAN9409). *New Zealand Fisheries Data Report No. 72*. 39 p.
- Clark, M.R.; Tracey, D.M. (1993). Orange roughy off the southeast coast of the South Island and Puysegur Bank: exploratory and research fishing, June-August 1992. *New Zealand Fisheries Technical Report No. 35*. 30 p.
- Clark, M.R.; Tracey, D.M. (1994). Trawl survey of orange roughy, black oreo, and smooth oreo in southern New Zealand waters, August-September 1992 (TAN9208). *New Zealand Fisheries Data Report No. 40*. 38 p.
- Cordue, P.L. (2012). Fishing intensity metrics for use in overfishing determination. *ICES Journal of Marine Science* 69: 615–623.
- Cordue, P.L. (2014a). The 2014 orange roughy stock assessments. *New Zealand Fisheries Assessment Report 2014/50*. 135 p.
- Cordue, P.L. (2014b). A management strategy evaluation for orange roughy. ISL Client Report for

- Deepwater Group Ltd. 42 p. (Unpublished report held by Fisheries New Zealand, Wellington).
- Doonan, I.J. (1994). Life history parameters for orange roughy: estimates for 1994. New Zealand Fisheries Assessment Research Document 94/19. 13 p. (Unpublished report held in NIWA Greta Point library, Wellington.)
- Dunn, M.R. (2007). CPUE analysis and assessment of the Northeast Chatham Rise orange roughy stock (part of ORH 3B) to the end of 2004–05 fishing year. *New Zealand Fisheries Assessment Report 2007/8*. 75 p.
- Francis, R.I.C.C. (2011) Data weighting in statistical fisheries stock assessment models. *Canadian Journal of Fisheries and Aquatic Sciences*. 68: 1124–1138.
- Francis, R.I.C.C.; Horn, P.L. (1997). Transition zone in otoliths of orange roughy (*Hoplostethus atlanticus*) and its relationship to the onset of maturity. *Marine Biology* 129: 681–687.
- Francis, R.I.C.C.; Robertson, D.A. (1990): Assessment of the Chatham Rise (QMA 3B) orange roughy fishery for the 1989/90 and 1990/91 fishing years. New Zealand Fisheries Assessment Research Document 90/3. (Unpublished report held in NIWA Greta Point library, Wellington.)
- Hampton, I.; Soule, M.; Leslie, R. ; Nelson, J. (2006). Acoustic and trawl survey of orange roughy on Puysegur Bank, and in the spawning plume and northeast hills on the north Chatham Rise, New Zealand, July 2006. 91 p. (Unpublished report held by Fisheries New Zealand, Wellington).
- Hampton, I.; Soule, M.; Nelson, J. (2005). Acoustic survey of orange roughy on Graveyard Hill and in spawning plume, north Chatham Rise, and on Puysegur Bank, New Zealand, June/July 2005. 98 p. (Unpublished report held by Fisheries New Zealand, Wellington).
- Kloser, R.J.; Macaulay, G.; Ryan, T.; Lewis, M. (2011). Improving acoustic species identification and target strength using frequency difference and visual verification: example for a deep-sea fish orange roughy. DWWG 2011-52. (Unpublished report held by Fisheries New Zealand, Wellington).
- Mace, P.M.; Fenaughty, J.M.; Coburn, R.P.; Doonan, I.J. (1990). Growth and productivity of orange roughy (*Hoplostethus atlanticus*) on the north Chatham Rise, *New Zealand Journal of Marine and Freshwater Research*, 24: 105–119.
- Ryan, T.E.; Tilney, R.L. (2016). Biomass surveys of orange roughy and oreo species using a net-attached acoustic optical system for New Zealand ORH7B and ORH3B Puysegur management zones in June, July 2015. 67 p. (Copy held at CSIRO Marine and Atmospheric Research, Hobart.)

APPENDIX 1: MCMC residuals for the preliminary base model

A full set of MCMC residual plots were produced for the preliminary base model and these will be almost identical to those for the final base model because there was only a minor change (with the effective sample size for the 2015 age frequency changed from 50 to 60). The plots for the preliminary base model are given below.

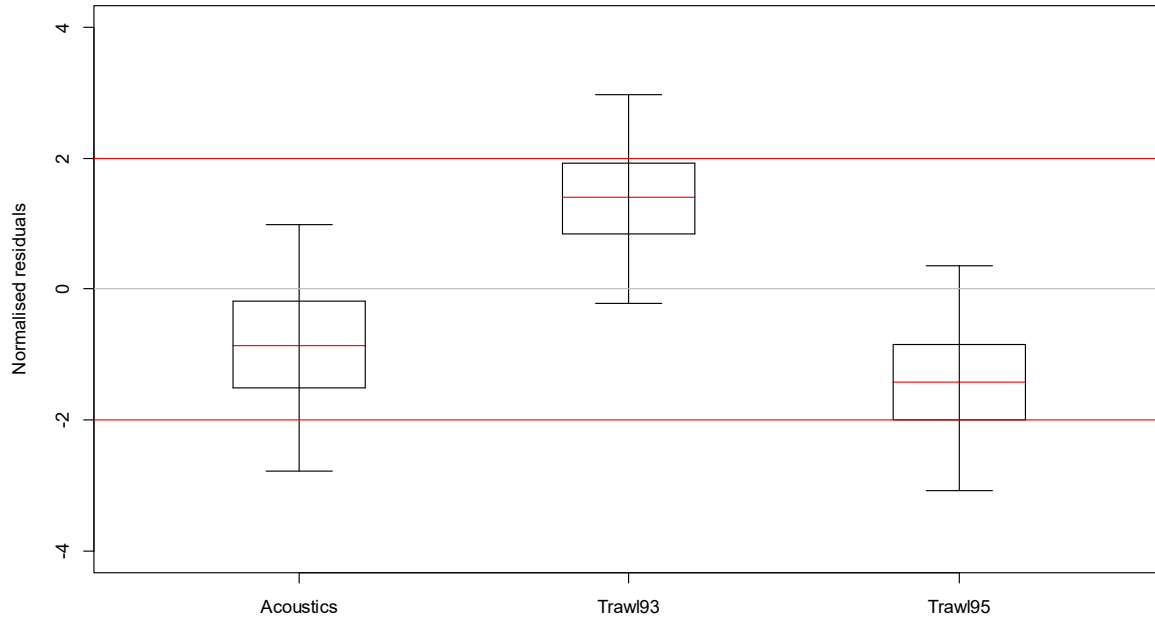


Figure A1: Preliminary base model: box and whiskers plot for the normalised residuals of the biomass indices. Boxes cover the middle 50% of the distribution and the whiskers extend to 95% of the distribution.

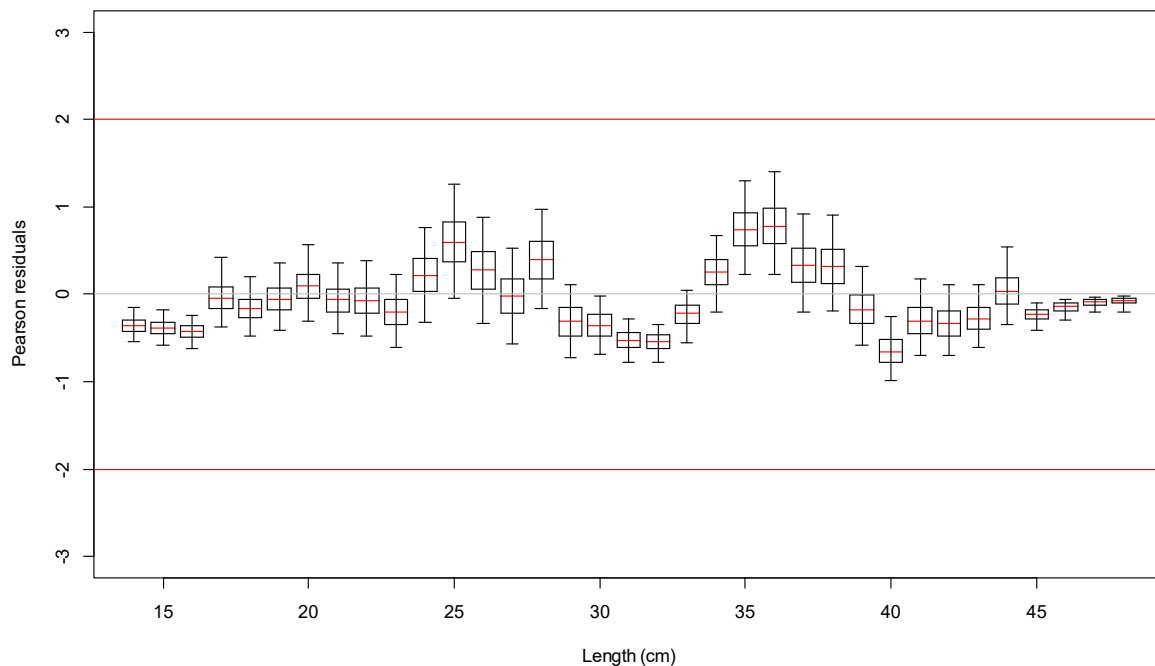


Figure A2: Preliminary base model: box and whiskers plot for the Pearson residuals for the 1992 trawl survey length frequency. Boxes cover the middle 50% of the distribution and the whiskers extend to 95% of the distribution.

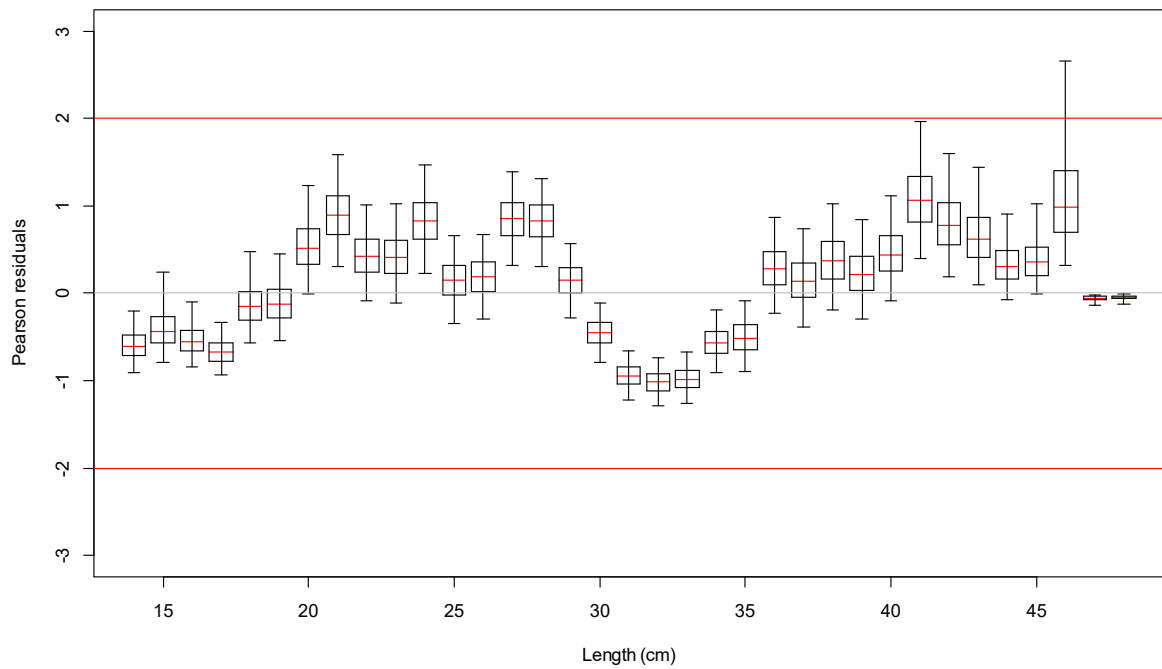


Figure A3: Preliminary base model: box and whiskers plot for the Pearson residuals for the 1994 trawl survey length frequency. Boxes cover the middle 50% of the distribution and the whiskers extend to 95% of the distribution.

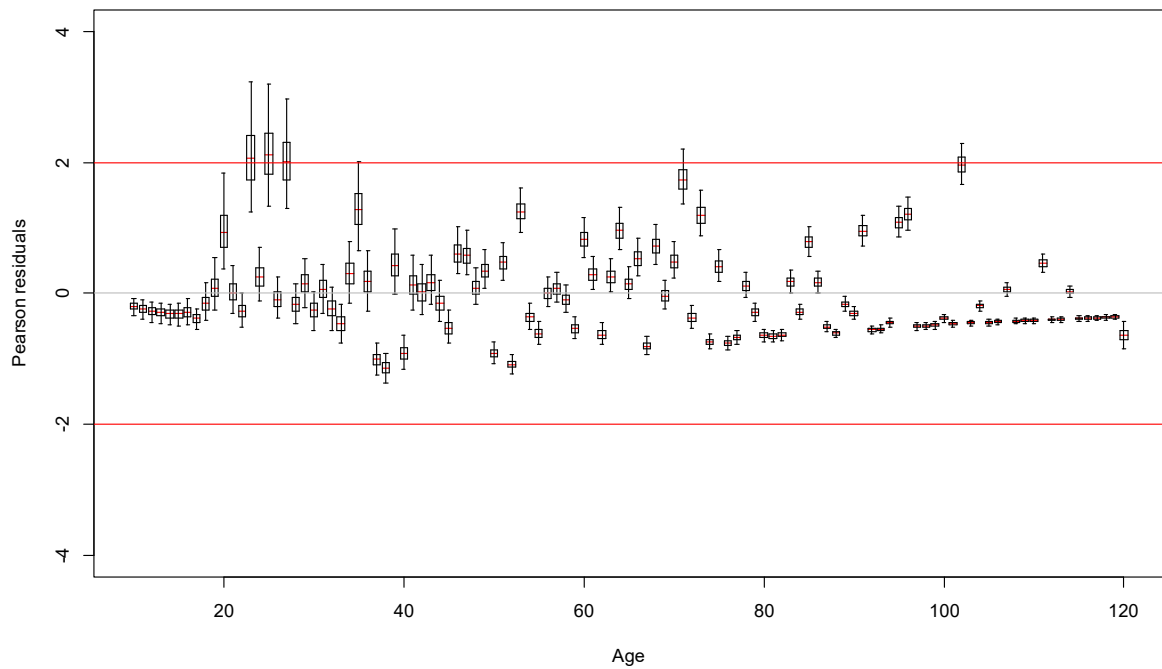


Figure A4: Preliminary base model: box and whiskers plot for the Pearson residuals for the 1992 age frequency. Boxes cover the middle 50% of the distribution and the whiskers extend to 95% of the distribution.

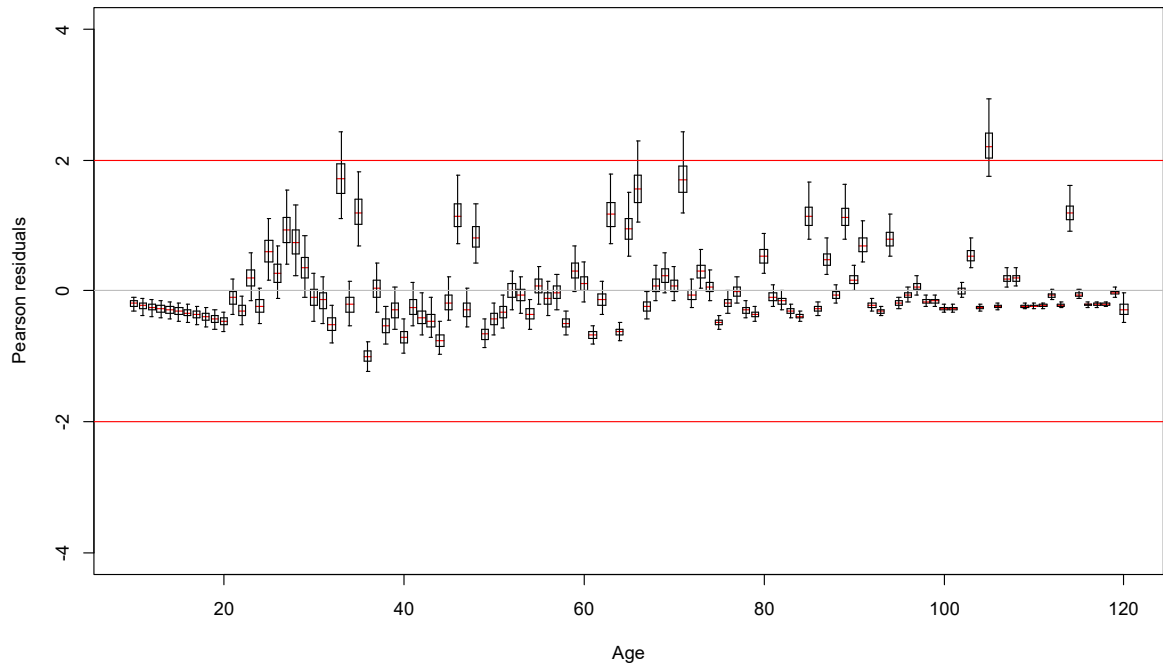


Figure A5: Preliminary base model: box and whiskers plot for the Pearson residuals for the 2015 age frequency. Boxes cover the middle 50% of the distribution and the whiskers extend to 95% of the distribution.

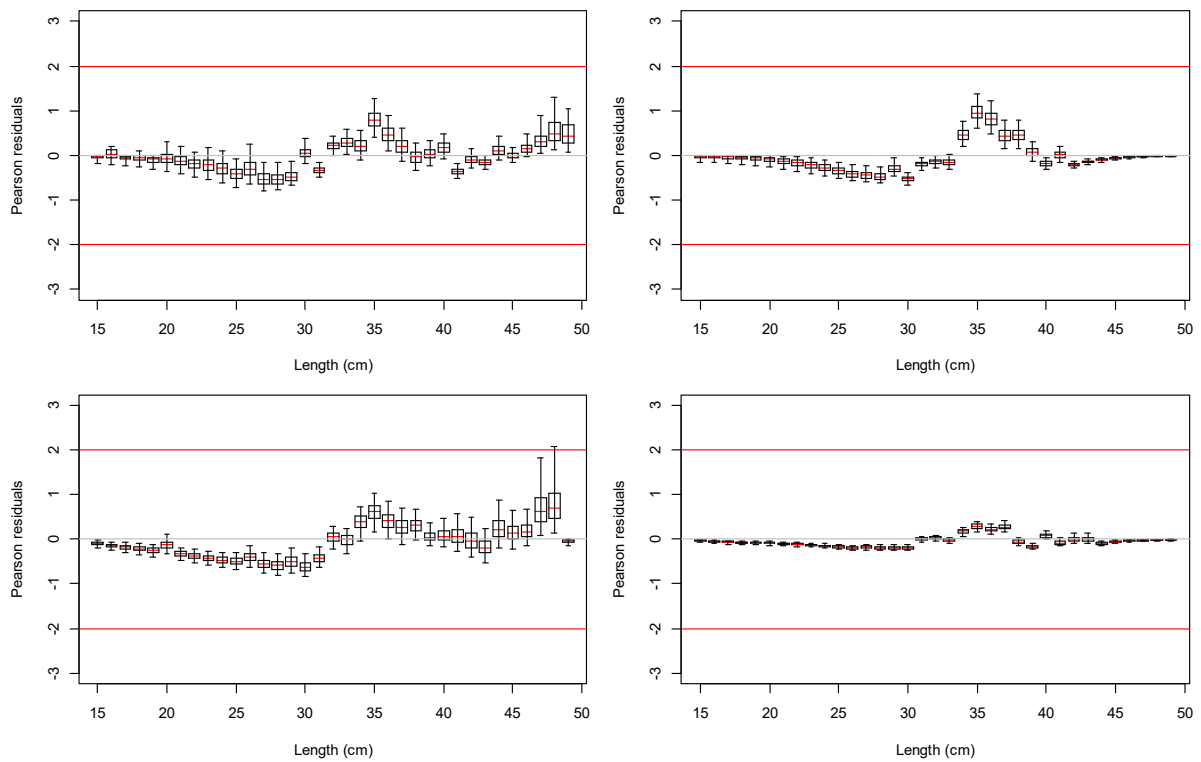


Figure A6: Preliminary base model: box and whiskers plot for the Pearson residuals for the commercial length frequencies (1st row 1994, 2nd row 1997, 1st column pre-spawning, 2nd column spawning). Boxes cover the middle 50% of the distribution and the whiskers extend to 95% of the distribution.

first_free 1917

last_free 1990

@randomisation_method lognormal

@natural_mortality

all 0.045

@fishery non

years 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

catches 150 484 6285 5018 1516 1448 709 270 0 0 7 8 0 0 1 21 0 10 0 0 0 0
0 26 0 0 0 0

future_years 2018 2019 2020 2021 2022

future_catches 0 0 0 0 0

selectivity nonsel

U_max 0.8

@fishery spawn

years 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

catches 0 366 665 182 1084 102 91 280 0 0 0 26 0 12 3 96 187 0 0 0 0 0
0 0 0 145 0 0

future_years 2018 2019 2020 2021 2022

future_catches 0 0 0 0 0

selectivity spsel

U_max 0.8

@selectivity_names spsel nonsel trawlsel93 trawlsel95

@selectivity spsel

mature constant 1

immature constant 0

@selectivity nonsel

all logistic 25 4

@selectivity trawlsel93

immature logistic 20 4

mature constant 1

@selectivity trawlsel95

immature logistic 20 4

mature constant 0.5

SIZE AT AGE From Hicks (p. 3, floor + 0.5).

@size_at_age_type von_Bert

@size_at_age_dist normal

@size_at_age

k 0.059

t0 -0.491

Linf 37.78

cv1 0.06

cv2 0.06

by_length True

SIZE WEIGHT

@size_weight

a 8.0e-8

b 2.75

@maturation
rates_all logistic_producing 10 60 37 4.56

@initialization
B0 30000

estimation.csl

ESTIMATION
@estimator Bayes
@max_iters 4000
@max_evals 4000
@grad_tol 0.001

MCMC
@MCMC
start 0.2
length 15000000
keep 1000
stepsize 0.1
proposal_t True
df 2
burn_in 1000

#-----

Acoustic estimate for Goomzy

#-----

@relative_abundance aco
step 2
proportion_mortality 0.5
biomass True
ogive spsel
years 2015
2015 4198
cv_2015 0.26
dist lognormal
q acoq

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

@q_method free

@q acoq
q 0.8

```
#-----  
#  
# Tangaroa trawl surveys  
#  
#-----
```

```
@relative_abundance trawl93  
step 1  
proportion_mortality 0  
biomass True  
ogive trawlsl93  
years 1993  
1993 6630  
cv_1993 0.28  
dist lognormal  
q trawlq
```

```
@relative_abundance trawl95  
step 1  
proportion_mortality 0  
biomass True  
ogive trawlsl95  
years 1995  
1995 1160  
cv_1995 0.24  
dist lognormal  
q trawlq
```

```
@estimate  
parameter q[trawlq].q  
prior uniform  
lower_bound 0.05  
upper_bound 2.0
```

```
@q trawlq  
q 0.5
```

```
#-----  
#  
# Tangaroa LFs  
#  
#-----
```

```
@proportions_at tanLF93  
years 1993  
step 1  
proportion_mortality 0  
sexed False  
sum_to_one True  
at_size True  
class_mins 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37  
38 39 40 41 42 43 44 45 46 47 48  
plus_group True  
ogive trawlsl93  
1993 0 0 0 0.003056129 0.003056129 0.00506404 0.007943119 0.008120169 0.01030513 0.01126482
```

0.02121585 0.03248068 0.03239215 0.03239215 0.04827839 0.03831327 0.04415996 0.0467131
0.05344504 0.06993687 0.09079862 0.1092098 0.1071134 0.08318143 0.06816636 0.0384018
0.01483802 0.01151631 0.004798464 0.001919386 0.001919386 0 0 0 0
dist multinomial
r 0.00001
N 70

@proportions_at tanLF95
years 1995
step 1
proportion_mortality 0
sexed False
sum_to_one True
at_size True
class_mins 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37
38 39 40 41 42 43 44 45 46 47 48
plus_group True
ogive trawlsl95
1995 0 0.001810019 0.001080013 0.0004100051 0.006990097 0.009515129 0.02169533 0.03243549
0.03078546 0.03705054 0.0534158 0.04617067 0.05520084 0.08140122 0.08827134 0.07331603
0.05760586 0.04274065 0.03902559 0.03727552 0.04475564 0.04019059 0.05250077 0.03951565
0.03411554 0.02181036 0.01694529 0.01643528 0.008535133 0.004445072 0.001615028
0.0009750153 0.001360027 0 0
dist multinomial
r 0.00001
N 70

#-----

1992 trawl survey age freq (GIL)

#-----

@proportions_at AF92
years 1992
step 2
proportion_mortality 0.5
sexed False
sum_to_one True
at_size False
min_class 10
max_class 120
ageing_error True
plus_group True
ogive spsel
1992 0 2.440844e-05 0 0 0 7.322532e-05 0.0003173097 0 0.001290945 0.002806971 0.008201236
0.00324362 0.001765603 0.01864867 0.006362585 0.02148005 0.004643185 0.02295554
0.004892585 0.008394067 0.005223583 0.009359596 0.007254977 0.005633034 0.01596095
0.03020493 0.01736034 0.002055802 0.0008705972 0.02524732 0.005513782 0.02271407
0.02176493 0.02466692 0.02002374 0.01392956 0.03308269 0.0325023 0.02408652 0.02814931
0.006964778 0.02931011 0.003772588 0.04062787 0.01450995 0.01015688 0.01915314 0.01973354
0.01654135 0.009576569 0.02872971 0.02031394 0.006964778 0.01846953 0.02725701 0.01567075
0.02002374 0.002611792 0.02089433 0.01102756 0.01661457 0.0301807 0.005803981 0.02234533
0.001160796 0.01276876 0.0005803981 0.001160796 0.008415773 0.004352986 0.0008705972
0.0005803981 0.0005803981 0.007254977 0.00319219 0.01160796 0.00638438 0.0008705972 0
0.00319219 0.002031394 0.01073737 0 0 0.0005803981 0.01044717 0.01102756 0 0 0 0.0005803981

0 0.01392956 0 0.001450995 0 0 0.002611792 0 0 0 0.004352986 0 0 0.002031394 0 0 0 0 0
0.00928637
dist multinomial
r 0.00001
N 80

#-----

2015 aco survey age freq (AXP)

#-----

@proportions_at AF15
years 2015
step 2
proportion_mortality 0.5
sexed False
sum_to_one True
at_size False
min_class 10
max_class 120
ageing_error True
plus_group True
ogive spsel
2015 0 0 0 0 0 0 0 0 0 0.004021448 0.002680965 0.009383378 0.00536193 0.01809651 0.01541555
0.02815013 0.02747989 0.0227882 0.01608579 0.01675603 0.01072386 0.05898123 0.02010724
0.0536193 0.004691689 0.03016086 0.01742627 0.02412869 0.01407507 0.02546917 0.02144772
0.019437 0.0113941 0.02412869 0.05294906 0.01876676 0.04088472 0.008042895 0.0113941
0.01206434 0.01675603 0.01407507 0.008042895 0.01407507 0.01005362 0.01072386 0.003351206
0.01407507 0.01072386 0 0.006702413 0.0227882 0 0.01876676 0.02546917 0.004021448
0.007372654 0.008713137 0.006702413 0.02345845 0.004691689 0.008042895 0.00536193 0
0.002680965 0.004021448 0.001340483 0.0006702413 0.008042895 0.002680965 0.002010724
0.0006702413 0 0.0113941 0.0006702413 0.006032172 0.002010724 0.01005362 0.003351206
0.006702413 0.0006702413 0 0.006702413 0.0006702413 0.001340483 0.002010724 0.0006702413
0.0006702413 0 0 0.001340483 0.004021448 0 0.01206434 0 0.002010724 0.002010724 0 0 0
0.0006702413 0 0.006032172 0.0006702413 0 0 0.0006702413 0.005361931
dist multinomial
r 0.00001
N 60

#-----

LF data

#-----

@catch_at nonLF
years 1994 1997
fishery non
sexed False
sum_to_one True
at_size 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
plus_group True

```

1994 0 0.0001237485 0 6.213106e-05 0 0.0003800121 0.0004093734 0.0003839735 0.001365459
0.001792842 0.001493472 0.009956169 0.006324773 0.01253294 0.0234861 0.06303177 0.04787991
0.09333896 0.1066098 0.1058107 0.1506735 0.1210585 0.09143937 0.05931761 0.04614167
0.03642465 0.004948034 0.006488438 0.001421601 0.002996051 0.0007165068 0.0009323042
0.0009323042 0.0008926317 0.0006347603
1997 0 0 0 0 0 0 0 0 0 0 0 0 0 0.003531532 0.007589204 0.03170942 0.01505956 0.05574273
0.06608582 0.06705679 0.1352088 0.1870246 0.1622731 0.1087002 0.09207393 0.04202104
0.01189213 0.01403115 0 0 0 0 0 0 0
dist multinomial
r 0.00001
N_1994 15
N_1997 6

```

```

@catch_at spawnLF
years 1994 1997
fishery spawn
sexed False
sum_to_one True
at_size 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
plus_group True
1994 0 0 7.75296e-06 2.252078e-05 0 0.0009966687 0 6.290022e-05 6.368527e-05 0.0003542378
0.00101865 0.00396034 0.004100894 0.00673656 0.01381531 0.01824563 0.03464996 0.06496028
0.07927076 0.1128195 0.1364891 0.132141 0.1189443 0.1025364 0.06815388 0.04604268
0.02742765 0.01300927 0.004310182 0.004655504 0.001838476 0.0009993902 0.001419038
0.0009382551 9.375279e-06
1997 0 0 0 0 0 0 0 0 0 0 0 0 0 0.004077376 0.006707408 0.01197192 0.01774795 0.05121754
0.06917351 0.07580392 0.1218262 0.1533486 0.1457857 0.1464057 0.07387635 0.03751652
0.04921355 0.01677251 0.01237016 0.006185081 0 0 0 0 0 0
dist multinomial
r 0.00001
N_1994 44
N_1997 3

```

```

#-----
#
# Estimated parameters
#
#-----

```

```

@estimate
parameter selectivity[nonsel].all
lower_bound 5 3
upper_bound 50 20
prior uniform

```

```

@estimate
parameter selectivity[trawlsl93].immature
same selectivity[trawlsl95].immature
lower_bound 5 3
upper_bound 50 20
prior uniform

```

```

@estimate
parameter selectivity[trawlsl95].mature
lower_bound 0.05

```