5th Meeting of the Scientific Committee
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SC5-INF03

A CPUE based stock assessment of the Louisville Central orange roughy stock

P. Cordue, New Zealand High Seas Fishing Group

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New Zealand High Seas Fisheries Group Incorporated
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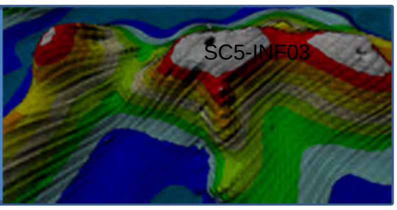

South Pacific Regional Fisheries Management Organisation

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A CPUE based stock assessment of the Louisville Central orange roughy stock

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On behalf of New Zealand High seas group

10 September 2017

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Executive summary

For the Louisville Central orange roughy stock, Roux and Edwards (2017) used a biomass dynamic model (BDM), a catch history, and a CPUE time series to estimate stock status in 2015 at 19% of the virgin level with a 95% CI of 14–25%. This was in contrast to the catch-history based assessment of Cordue (2017) which showed that the minimum biomass that was necessary to support the historical catches implied that the stock status in 2015 was very unlikely to be below 24% of the virgin level. Roux and Edwards (2017) acknowledge the limitations, for orange roughy, of the simple population dynamics of the BDM that they used. In this paper the much more appropriate dynamics of an age-structured model are used to fit the CPUE time series. Bayesian estimation was used.

It was found that the steep decline in the CPUE time series was inconsistent with an orange population when natural mortality (*M*) was greater than or equal to 0.04. For this reason *M* was estimated within the model together with virgin biomass (B_0). Three model runs were performed. Two of these used the full CPUE time series with alternative biological parameters from New Zealand EEZ stocks of orange roughy (ESCR and ORH7A). The third run used the ESCR biological parameters with a shortened CPUE time series. The shortened time series included only those years where catches from at least four vessels contributed to the index.

The assessment results using the full CPUE time series showed that the use of the BDM was responsible for the low estimated stock status of Roux and Edwards (2017). The age-structured models estimated 2015 stock status at 26% B_0 with only a 7–8% chance of it being below 20% B_0 and a 21–24% chance of it being above 30% B_0. This is qualitatively very different to the BDM estimate of 19% B_0 with more than a 50% chance of being below 20% B_0 and no chance of being above 30% B_0.

The use of the full CPUE time series is extremely hard to justify given the sparsity of suitable data. The results from the assessment using the shorter time series are more defensible though probably still very conservative. That model run estimated 2015 stock status at 29% B_0 with a 95% CI of 20–41% B_0. Projection results, taken at face value, suggest that annual catches of 300–350 t will allow the stock to slowly increase over the next few years. This paper is intended to help inform the SC working group .

1. Introduction

The Louisville Central stock was estimated by Roux and Edwards (2017) to be at 19% of the virgin level in 2015 with a 95%CI of 14-25% when they fitted a CPUE time series using a BDM. This was contrary to the catch-history based assessment of Cordue (2017) which showed that the minimum biomass that was necessary to support the historical catches implied that the stock status in 2015 was very unlikely to be below 24% of the virgin level. Roux and Edwards (2017) acknowledge the limitations of the simple population dynamics of the BDM that they used. In this paper the much more appropriate dynamics of an age-structured model are used to fit the CPUE time series.

2. Methods

The catch history (Figure 1) and CPUE time series (Figure 2) for Louisville Central are from Roux and Edwards (2017). The CPUE time series was fitted as mid-spawning season biomass in the age-structured model used by Cordue (2017). It assumes a single-area, single-sex population where fish are categorised by age and maturity state (immature or mature). A single spawning season fishery was assumed at the end of the year. Biological parameters were borrowed from the ESCR stock and in a sensitivity test the ORH7A stock (Cordue 2014). ORH7A has the smallest mean weight-at-age and the youngest maturity of the five orange roughy stocks that have been assessed in New Zealand's EEZ. Deterministic recruitment was assumed with a Beverton-Holt stock-recruitment relationship (steepness = 0.75).

The CPUE time series when taken to be a biomass index is very problematic. There were only 2 vessels and 15 tows in the first year of the index (1993) and from 2007 onwards spatial management came into force with closed, open, and "move-on" areas. A shortened CPUE time series was fitted in an alternative run where only those years with at least 4 vessels were included. The full time series spanned the period 1993-2015 and the shortened time series runs from 1994 to 2006 (Figure 2).

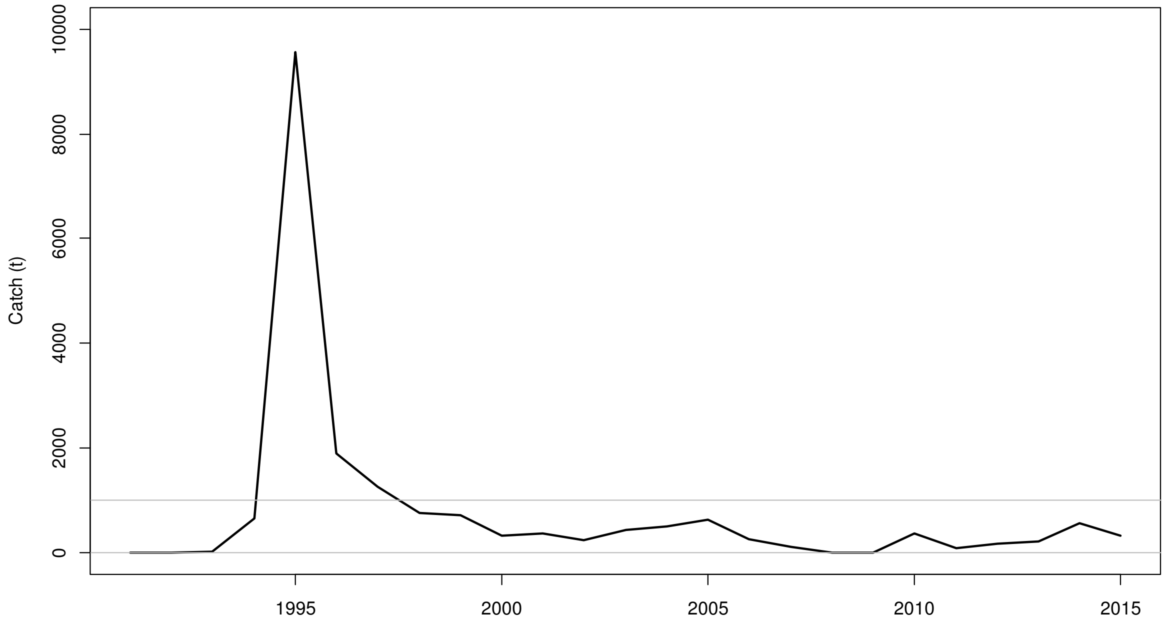

Figure 1: The catch history for Louisville Central by calendar year from Roux and Edwards (2017). A horizontal line is marked at 1000 t.

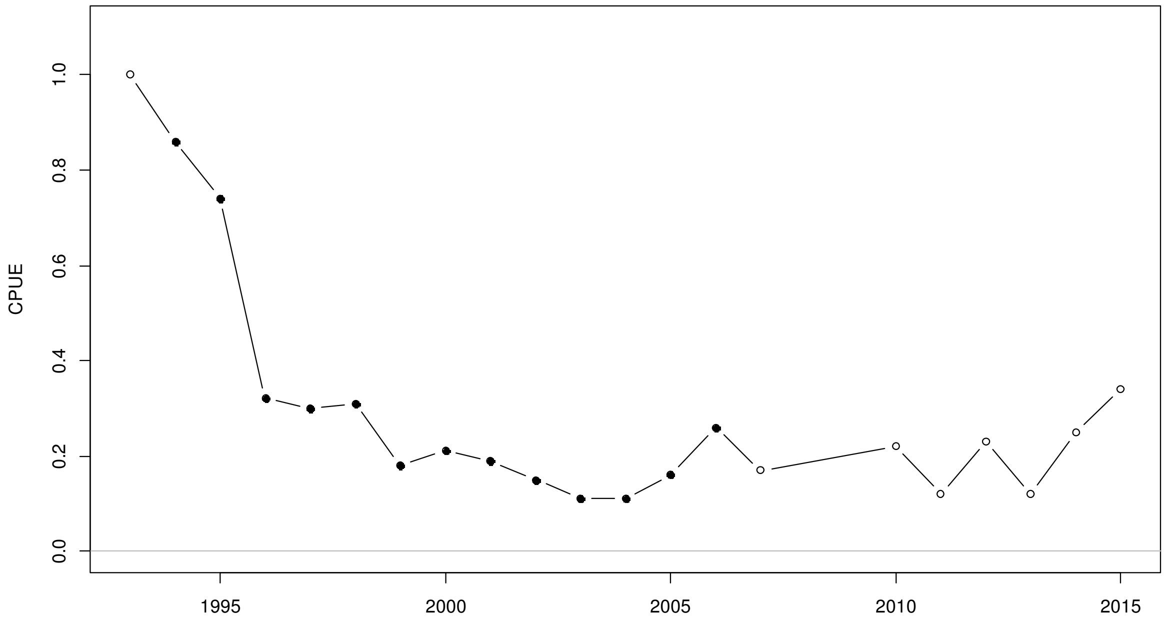

Figure 2: The full CPUE time series from Roux and Edwards (2017) and the shortened CPUE time series (solid dots) which is supported by at least 4 vessels fishing in each year.

Bayesian estimation was used with three free parameters: virgin biomass (B_0), natural mortality (*M*), and the proportionality constant for the CPUE time series (*q*). Natural mortality was estimated because the steep decline in the CPUE time series was inconsistent with M = 0.045 (which is the estimate for New Zealand EEZ stocks). Uninformed priors were used for B_0 (uniform in log space) and the CPUE *q* (uniform). For *M* a normal prior with mean of 0.045 and a CV of 15% was used. A maximum exploitation rate of 67% was assumed and a penalty was applied to discourage parameter estimates that would cause the limit to be reached (see Bull et al. 2012 and the Appendix which contains the CASAL input files). Three MCMC chains were done for each model. The chains were run to a length of 3 million with every thousandth sample retained. A burn-in of 200 samples was used and the three chains were compared to ensure they each had almost identical medians and very similar distributions (see the Appendix for some chains and convergence diagnostics).

The CPUE indices were initially fitted with a CV of 20% on each point and a constant *M* to see if the steep downward trend could be fitted adequately (in MPD runs which just look at the Mode of the Posterior Distribution). It was apparent from the normalised residuals that a CV of 20% was too low and additional variance was estimated as “process error”. This is implemented in CASAL as a constant CV which is added to the existing observation error in each year to produce a total CV for each year ($CV_{y,tot}^2 = CV_{y,obs}^2 + CV_{proc}^2$). The MCMC runs were done with a fixed process error added to the observation error. For the run with the shortened CPUE time series, process error was re-estimated.

Projections were performed for the shortened CPUE stock assessment run. They were performed for constant catches with deterministic recruitment to find the catch level that would maintain model biomass at or just above its 2015 level.

3. Results and discussion

The initial MPD fits with constant *M* showed that the steep downward trend in the CPUE time series was inconsistent with *M* = 0.045 and assumed deterministic recruitment (Figure 3). The value of *M* was lowered in steps of 0.005 and it was found that as *M* decreased the fit to the CPUE indices improved substantially (Table 1). When *M* was 0.040 or 0.045 the residual pattern was extreme with 9 positive residuals at the start of the time series (Figure 3, Table 1). However, when *M* was 0.030 or 0.035 the extreme residual pattern was not present and the fit to the CPUE indices was much improved (Figure 3, Table 1). The estimated exploitation rate in 1995, when the catch peaked at over 9000 t, was at 60% or slightly higher for all values of *M* considered (Table 1).

Table 1: MPD estimates of B_0 and the exploitation rate in 1995 (U_{1995}) for decreasing fixed values of natural mortality (*M*). Also shown are the fit to the CPUE time series (negative log likelihood, NLL) and the length of the run of positive residuals for the fit (Run).

M	B_0 (000 t)	U_{1995}(%)	NLL	Run
0.045	16.0	63	3.8	9
0.040	16.0	62	-1.5	9
0.035	16.1	62	-6.1	1
0.030	16.5	60	-9.1	1

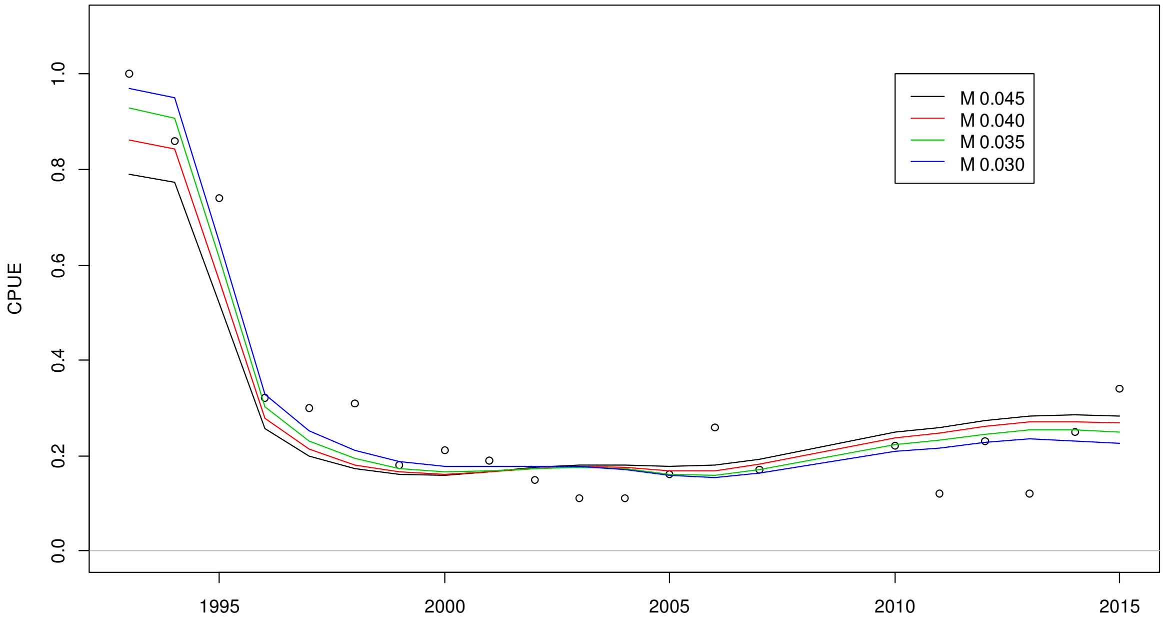

Figure 3: MPD fits to the full CPUE time series for fixed values of *M*.

The MPD estimate of *M* was 0.033 and process error was estimated at 25% which gave a total CV for each point in the time series of 32% (Table 2). Process error was slightly lower (22%) and *M* slightly higher (0.039) for the run with the shortened CPUE time series (Table 2).

Table 2: MPD estimates of *M*, B_0, and the exploitation rate in 1995 (U_{1995}) for the run using the full CPUE time series (Full) and the run using the shortened CPUE time series (Short). The estimated process error and the total CV are also given.

Run	*M*	B_0 (000 t)	U_{1995}(%)	Process CV (%)	Total CV (%)
Full	0.033	16.2	61	25	32
Short	0.039	15.7	64	22	30

The two MCMC runs which used alternative biological parameters and the full CPUE time series gave very similar estimates (Table 3). Stock status in 2015 was estimated at 26% B_0 with 7-8% risk of being below 20% B_0, and about a 20% chance of being above 30% B_0 (the lower end of the target biomass range for orange roughy in New Zealand EEZ stocks)(Table 3). The 95% CIs for *M* did not include the value of 0.045 which has been used in New Zealand EEZ stocks for many years (calculated from catch curve estimates for near virgin stocks). Virgin stock size, at 15000–19000 t, was estimated at the very low end of the 95% range of 15000–87000 t given by Cordue (2017). Stock status, at 18–38% B_0, was also at the low end. Cordue (2017) gave a 95% range of 24–87% B_0 when *M* = 0.045 and 17-79% B_0

when *M* = 0.04. There is some overlap with the estimate of Roux and Edwards (2017) at 14–25% B_0 (*K*), but qualitatively the estimates are very different as a median of 19% B_0 with a 95% CI of 14–25% B_0 gives more than a 50% risk of being below 20% B_0 and virtually no chance of being above 30% B_0.

The run with the shortened CPUE time series gives lower estimates of B_0 (14000–18000 t) because it has higher estimates of *M* (0.029–0.050). Stock status in 2015 has a 95% CI of 20–41% B_0 with little chance of being below 20% B_0 and about a 45% chance of being above 30% B_0 (Figure 4, Table 3). The estimated exploitation rate in 1995 was above 60% which is difficult to believe although the fishery was year round so it is perhaps possible (Figure 5). The exploitation rate in 2014, from a catch of 571 t, was excessive according to this model (Figure 5).

Table 3: MCMC estimates of B_0, *M*, and stock status in 2015 (ss_{15}) for the runs using the full CPUE time series (Full and ORH7A) and the shortened CPUE time series (Short). Also given are the estimated probabilities of the stock status in 2015 being below 20% B_0 or above 30% B_0.

Run	B_0 (000 t)	95% CI	*M*	95% CI	ss_{15}	95% CI	P(ss < 20)	P(ss > 30)
Full	16.4	15–19	0.033	0.025–0.043	26	18–38	7	24
ORH7A	16.5	15–19	0.035	0.026–0.044	26	18–37	8	21
Short	15.7	14–18	0.039	0.029–0.050	29	20–41	3	44

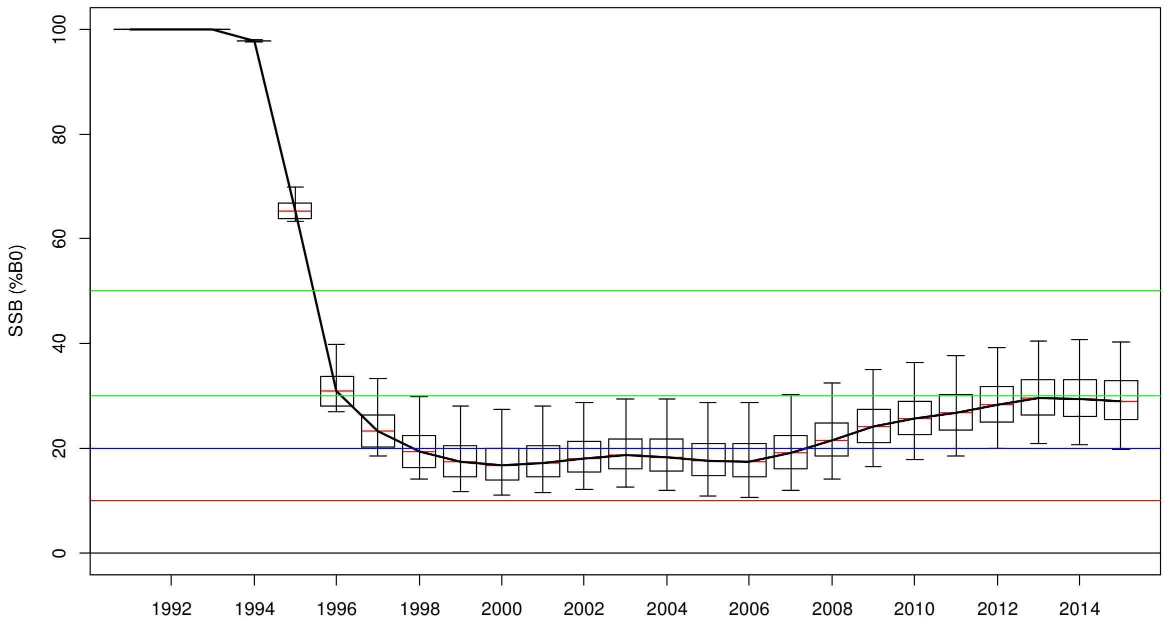

Figure 4: MCMC stock status trajectory for the shortened CPUE series run. The box includes the middle 50% of the distribution and the whiskers extend to 95%. Horizontal lines are plotted at 10%, 20%, 30% and 50% of B_0.

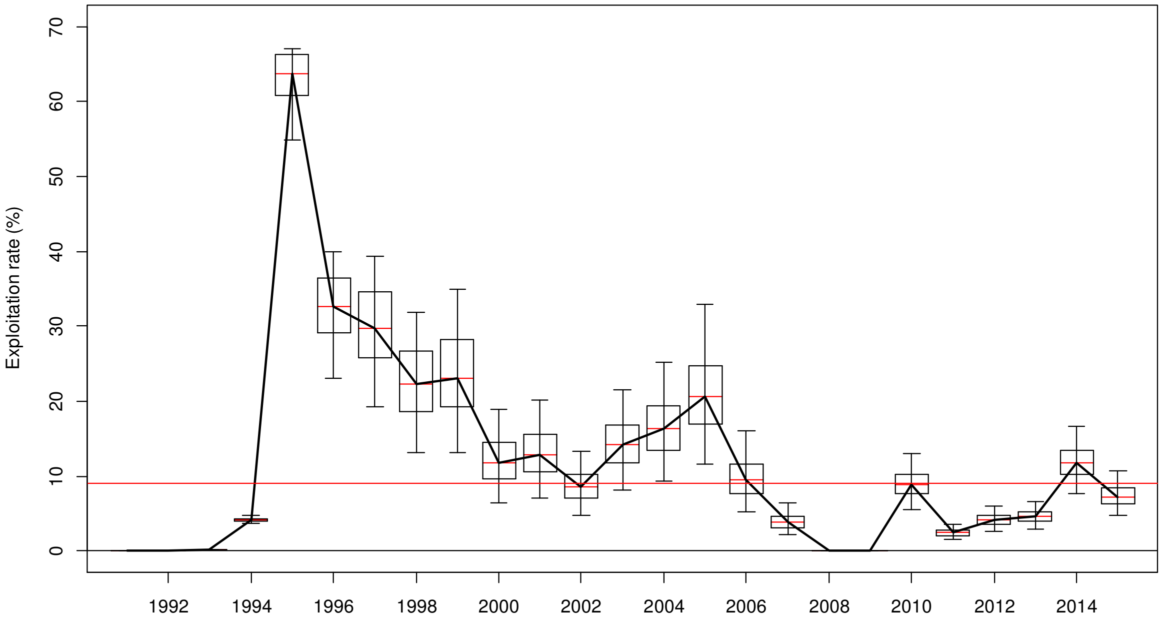

Figure 5: MCMC estimates of exploitation rates for the shortened CPUE series run. The box includes the middle 50% of the distribution and the whiskers extend to 95%. A horizontal line is plotted at 9% (an excessive exploitation rate for orange roughy).

The use of catch and effort data to construct biomass indices for orange roughy was abandoned for New Zealand EEZ stocks some years ago. Typically the indices would show a steep downward trend at the start of the fishery which was consistent with localised depletion but inconsistent with stock wide depletion. The use of spatial CPUE can in theory overcome this problem but only if there are adequate data to support the approach. Also, the data need to come from non-spawning season fisheries where it is reasonable to argue that the fish reside in a home ground (and do not move between sub areas). Catch rates in the spawning season are driven by fish availability and the way that the marks are fished rather than the level of spawning biomass. For Louisville Central, the fishery was year round in 1995 and 1996 and somewhat so in 1997 but since then has been almost entirely during the spawning season. The full CPUE series from 1993 to 2015 is not defensible because of the lack of suitable data (e.g., spawning season catches and no data in closed or move-on areas in the last 7 years). The shortened series from 1994 to 2006 is also difficult to defend but there is perhaps some validity to the sharp downward trend from 1995 to 1997 as it incorporates a non-spawning season fishery (although it could just be showing localised depletion on the seamounts as resident fish were removed).

The low estimated value of *M* for Louisville Central is very likely an artefact of a CPUE series which is not tracking biomass. It descends very steeply which is inconsistent with the level of production expected from an orange roughy stock with $M \geq 0.04$ unless there is a very unusual recruitment pattern.

The results from the run with the shortened CPUE series could be given some consideration. Stock status was estimated in 2015 at 29% B_0 with a 95% CI of 20–41% B_0 and projection results suggest that catches of 300–350 t will allow the stock to increase slowly over the next 5 years (Figure 6).

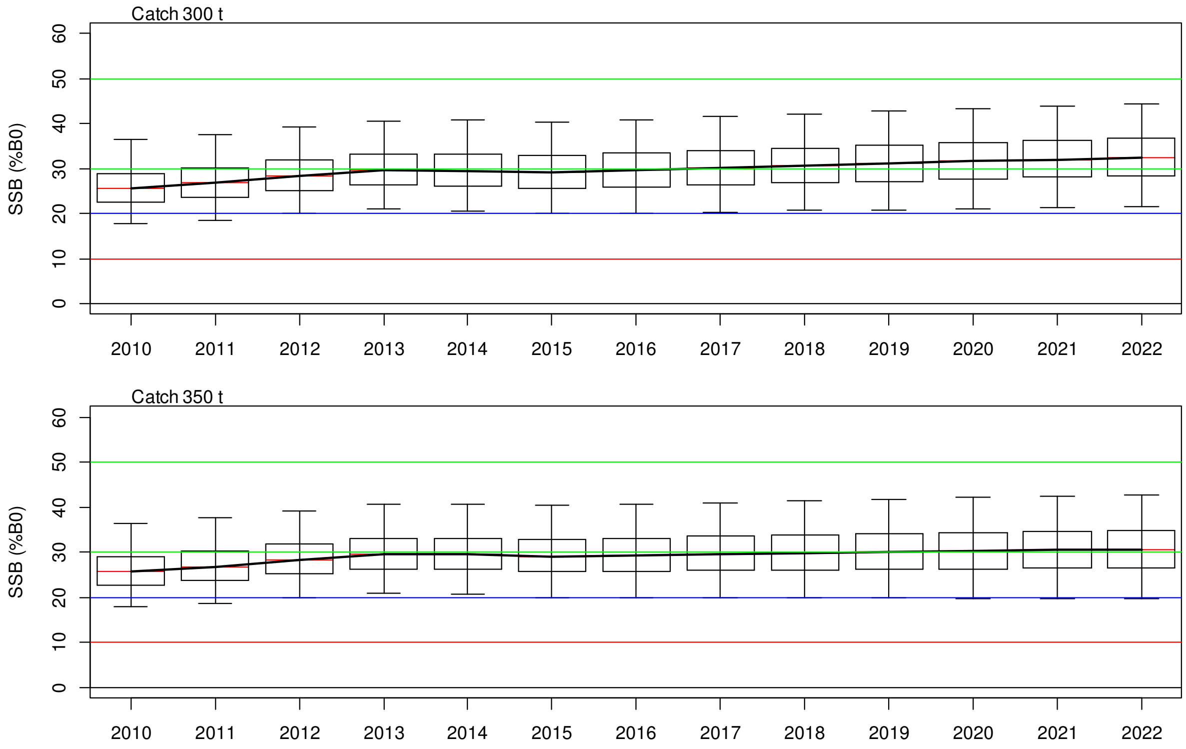

Figure 6: Deterministic MCMC projections for 2016 to 2022 at a constant catch of 300 t (top) or 350 t (bottom) for the shortened CPUE series run. The box includes the middle 50% of the distribution and the whiskers extend to 95%. Horizontal lines are plotted at 10%, 20%, 30% and 50% of B_0.

4. Future directions

Assessments which use CPUE to provide biomass indices must be treated with great caution. The main possibility for refinement lies in more careful analysis of the catch and effort data to provide more defensible biomass indices (e.g., like the shortened CPUE series used here). Definitive stock assessments for SPRFMO orange roughy stocks will require that biological data, including age frequencies, are collected and that acoustic surveys of spawning biomass are undertaken.

5. Acknowledgments

This additional work was funded by the New Zealand High Seas Group Ltd and was not able to go through the New Zealand working group process. Thanks to NIWA for the use of their stock assessment package CASAL.

6. References

Bull, B; Francis, R.I.C.C; Dunn, A.; Gilbert, D.J.; Bian, R.; Fu, D. (2012). CASAL (C++ algorithmic stock assessment laboratory): CASAL User Manual v2.30-2012/03/21. *NIWA Technical Report* 135. 280 p.

Cordue, P.L. (2014). The 2014 orange roughy stock assessments. *New Zealand Fisheries Assessment Report 2014/50*. 135 p.

Cordue, P.L. (2017). Catch-history based stock assessments of seven SPRFMO orange roughy stocks. Paper for the Scientific Committee of the South Pacific Regional Fisheries Management Organisation, Shanghai, 23-28 August 2017.

Roux, M.J.; Edwards, C. T. T. (2017). A data-limited approach for assessing small-scale fisheries for orange roughy *Hoplostethus atlanticus* in the South Pacific Regional Fisheries Management Organisation Convention Area (SPRFMO). Paper for the Scientific Committee of the South Pacific Regional Fisheries Management Organisation, Shanghai, 23-28 August 2017.

7. Appendix: MCMC chains, convergence diagnostics, and CASAL input files

This appendix contains figures showing some MCMC chains and diagnostics for the run fitting the shortened CPUE time series. It also includes the two important CASAL input files for the run (population.csl and estimation.csl).

The chains for B_0 and M were well mixed showing no long term systematic trends or shifts (e.g., Figure A1). Short term correlations are not an issue provided the chains are of adequate length. Three chains were run and they delivered very similar marginal posterior distributions with almost identical medians (Figures A2, A3, and A4).

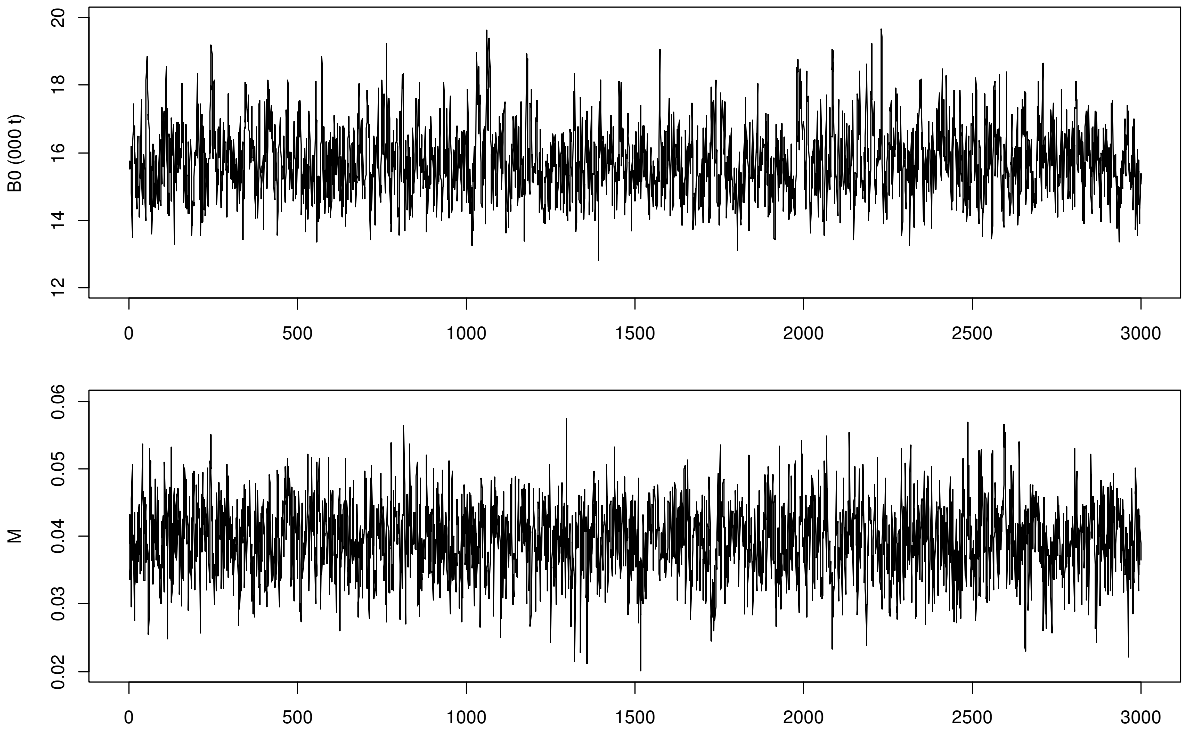

Figure A1: The first MCMC chain for the run with the shortened CPUE time series. Retained estimates are shown for B_0 (top) and M (bottom).

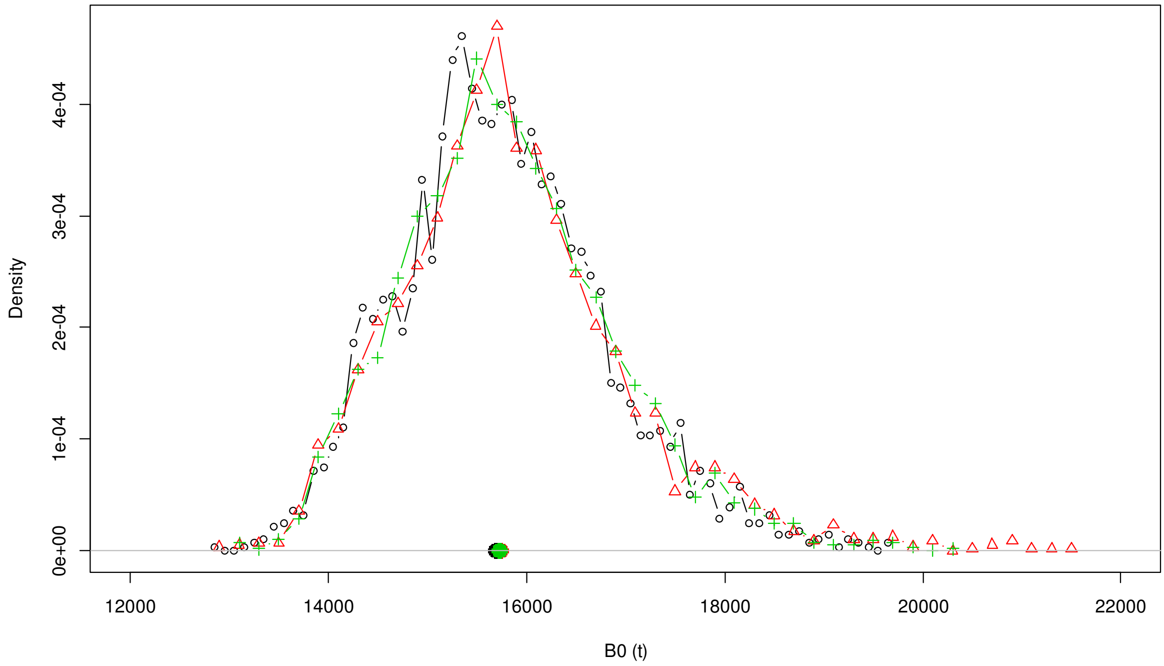

Figure A2: Marginal posterior distributions for *B_0* from the three separate chains for the run fitting the shortened CPUE time series. The medians are marked by the solid dots (all medians were equal to 15700 t).

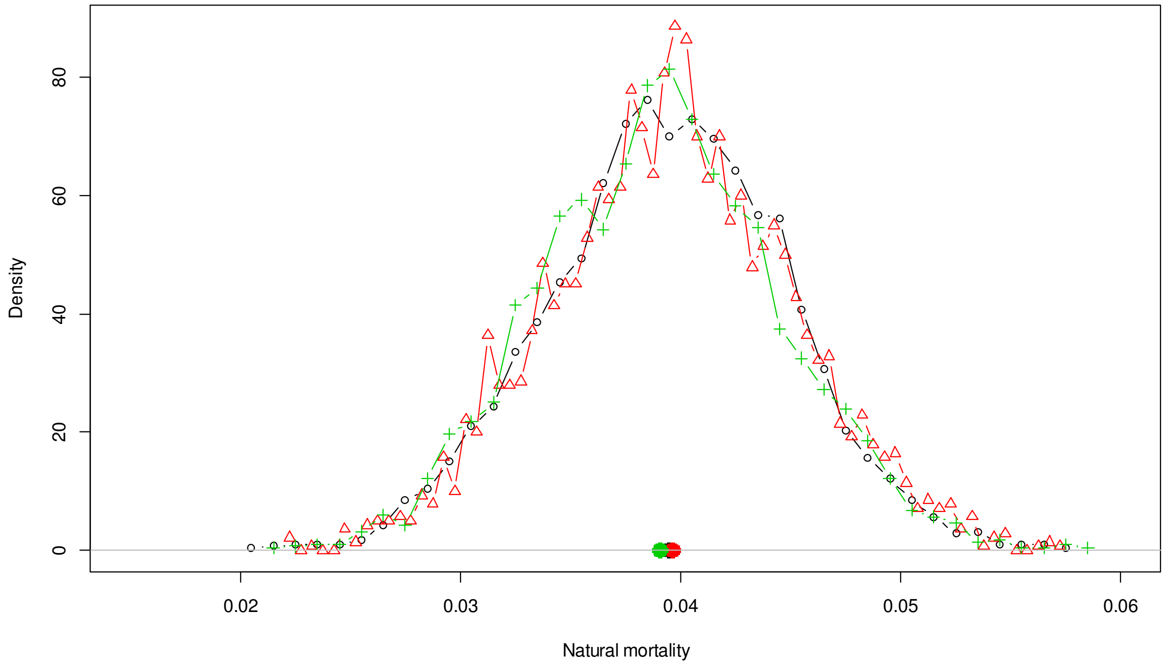

Figure A3: Marginal posterior distributions for *M* from the three separate chains for the run fitting the shortened CPUE time series. The medians are marked by the solid dots (the medians were equal to 0.0391, 0.0395, 0.0396).

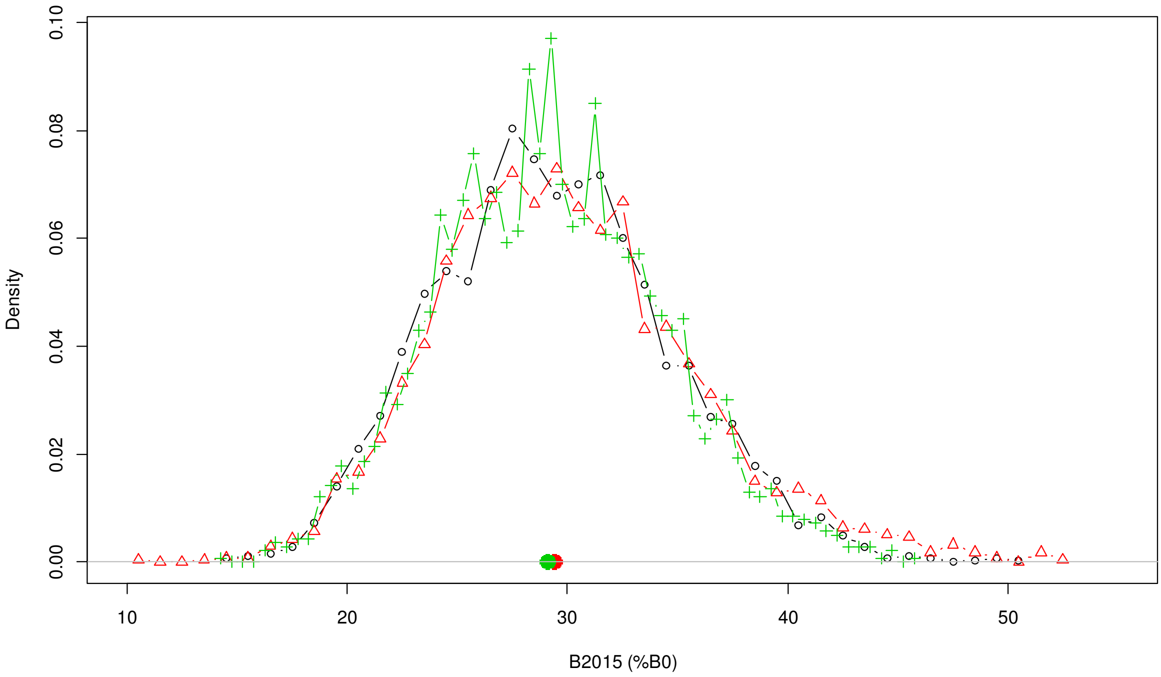

Figure A4: Marginal posterior distributions for 2015 stock status (B_{2015}/B_0) from the three separate chains for the run fitting the shortened CPUE time series. The medians are marked by the solid dots (all medians were equal to 29% B_0).

CASAL population file

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

# TIME SEQUENCE
@initial 1911
@current 2015
@final 2019

@annual_cycle
time_steps 2

# recruitment
recruitment_time 1

# spawning
spawning_time 2
spawning_part_mort 0.5
spawning_p 1

# growth and mortality
aging_time 1
M_props 1 0
baranov False

# maturation
n_maturations 1
maturation_times 1

# fishery
fishery_names SpawnFish
fishery_times    2


@y_enter 1
@standardise_YCS True
@recruitment
YCS_years    1910 1911 1912 1913 1914 1915 1916 1917 1918 1919 1920 1921 1922 1923 1924 1925
1926 1927 1928 1929 1930 1931 1932 1933 1934 1935 1936 1937 1938 1939 1940 1941 1942 1943
1944 1945 1946 1947 1948 1949 1950 1951 1952 1953 1954 1955 1956 1957 1958 1959 1960 1961
1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979
1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997
1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014
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
```

```
SR  BH
steepness 0.75
sigma_r  1.1
first_free 1930
last_free 1990

@randomisation_method none

@natural_mortality
all   0.030

@fishery SpawnFish
years     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
catches  0 0 0 0 0 0 0 0 0 0 0 0 0 25 657 9566 1889 1277 760 712.5 331.6633 371.4717 251.4187
443.464 508.6927 629.6213 271.8925 117.0078 0 0 371 101 185 215 571 341
future_years      2016 2017         2018      2019
future_catches       0    0     0     0
selectivity matsel
U_max 0.67


@selectivity_names matsel

@selectivity matsel
mature constant 1
immature constant 0

## SIZE AT AGE (ESCR)
@size_at_age_type von_Bert
@size_at_age_dist normal
@size_at_age
k 0.059
t0 -0.491
Linf 37.78
cv1 0.10
cv2 0.06
by_length True


# SIZE WEIGHT
@size_weight
a 8.0e-8
b 2.75

@maturation
rates_all logistic_producing 10 60 41 12
```

```
@initialization
B0 40000
```

CASAL estimation file (shortened CPUE series)

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

# MCMC
@MCMC
start 0.2
length 3000000
keep 1000
stepsize 0.003
proposal_t True
df 2
burn_in 200

@relative_abundance cpue
step 2
proportion_mortality 0.5
biomass True
ogive matsel
years 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006
1994 0.86
1995 0.74
1996 0.32
1997 0.30
1998 0.31
1999 0.18
2000 0.21
2001 0.19
2002 0.15
2003 0.11
2004 0.11
2005 0.16
2006 0.26
cv 0.2
cv_process_error 0.22
dist lognormal
q cpueq


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

```
#---------------------------------------------------------------------

@estimate
parameter initialization.B0
lower_bound 10e3
upper_bound 89e3
prior uniform-log

@estimate
parameter q[cpueq].q
prior uniform
lower_bound 1e-10
upper_bound 1e-3

@q_method free

@q cpueq
q 1e-5

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

{
@estimate
parameter relative_abundance[cpue].cv_process_error
prior uniform
lower_bound 0
upper_bound 0.5
}
#-----------------------------------------------------------
#
# Penalties
#
#------------------------------------------------------------

@catch_limit_penalty
label catchpen
fishery SpawnFish
multiplier 200
log_scale True
```