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Catch-history based stock assessments of seven SPRFMO Orange roughy stocks

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Executive summary

A data-poor stock assessment method is presented and applied to seven orange roughy SPRFMO stocks. The method uses an age-structured population model, with a single fishery on mature fish, and biological parameters borrowed from stock assessments of five New Zealand EEZ orange roughy stocks. The focus of the method is on B_{min} which is the minimum virgin biomass that would allow the historical catches to be taken assuming a maximum exploitation rate of 67% (a considered value that has been used in New Zealand orange roughy stock assessments for more than 20 years).

For each SPRFMO stock, five different assessments were performed using the biological parameters and year class strengths estimated for each of the assessed EEZ stocks in New Zealand. Bayesian estimation of B_0 was used to provide posterior distributions for virgin biomass, current stock status, long term yield, and recent exploitation rates. The risk of current biomass (2015) being below a limit reference point of 20% B_0 was also considered. A single summary assessment was also produced combining across the five alternative assessments with equal weight.

The method was tested by taking each of the five EEZ stocks in turn and assessing them using the remaining four EEZ stocks. The test results showed, provided the actual fisheries primarily removed mature fish, that the lower limit on 95% credibility intervals (CIs) for B_0, stock status, and long term yield were good indicators of the same value for the actual stock assessments. The estimated probability of being below 20% B_0 was also reasonably well predicted by the method. This is not a surprising result as the use of a maximum exploitation rate in age-structured models is often one of the main determinates of the minimum virgin biomass and minimum current stock status.

It was shown that the YCS patterns of the EEZ stocks in combination with their biological parameters are neutral or negative with regard to stock status in 2015 (the final year of the available SPRFMO catch histories). Therefore the use of these five models is precautionary relative to an average model (e.g., one with deterministic recruitment). A uniform prior on B_0 in log space was used because it is neutral (in log space) or precautionary (in linear space, relative to a uniform prior). It was also demonstrated that the lower limit of the 95% CIs and the estimated probabilities are relatively insensitive to the choice of B_{max} (which defines the upper limit on B_0). Of course the focus on the lower limit of 95% CIs is also highly precautionary.

The assessment results indicate that in 2015 five of the seven SPRFMO stocks assessed are very likely to be above the limit reference point (LRP) of 20% B_0 used in this paper and most of them are probably above 30% B_0. The recent exploitation rates for these stocks are not excessive (being zero in some cases). However, there is an indication that North West Challenger and Lord Howe Rise may both be below the LRP and that recent exploitation rates could be very high.

The assessment results are conditional on the stock hypotheses being approximately correct. Sensitivity runs using alternative stock hypotheses are yet to be performed.

A pragmatic method of choosing catch limits is illustrated which could be used as an interim measure until age frequencies and acoustic biomass estimates from the spawning populations are available (which would allow definitive stock assessments).

1. Purpose of paper

This paper provides SC-05 with preliminary stock assessment estimates for seven SPRFMO orange roughy stocks. Estimates of virgin biomass (B_0), current stock status (2015), the probability of being below a Limit Reference Point (LRP) of 20% B_0, exploitation rates, and long-term yield are provided with a suggested method for choosing precautionary catch limits.

This paper contains no recommendations for the Scientific Committee. Instead, this paper should be read in conjunction with two separate papers describing different approaches (BDM models by Roux and Edwards and a delay difference model by Edwards and Roux) and another comparing the results of the two approaches and making recommendations to the committee.

2. Introduction

A stock assessment method using CPUE and Biomass Dynamic Models (BDMs) has been developed in New Zealand and applied to SPRFMO orange roughy stocks (a separate paper by Roux & Edwards is submitted to SC-05). That approach assumes that the catch and effort analysis provides reliable biomass indices and that the simple population dynamics of a BDM are adequate for orange roughy.

The approach described in this paper and the consequent assessment results do not rely on either assumption. The method uses the catch history and an assumption on maximum annual exploitation rate to derive a minimum virgin biomass (B_{min}). The biological parameters and the recruitment patterns are borrowed from five New Zealand orange roughy stock assessments (stocks within the New Zealand EEZ).

3. Methods

Each of seven SPRFMO stocks were assessed using its catch history (data from separate paper by Roux & Edwards) and an assumption of a maximum annual exploitation rate of 67%. A single area, single sex, age structured model (1-100 years with a plus group) was used with Bayesian estimation of virgin biomass (B_0). In addition to age, fish were also classified by maturity (immature or mature). A single fishery was assumed to occur at the end of the year on mature fish only. Natural mortality (M) was fixed at 0.45 and a Beverton-Holt stock recruitment relationship was assumed with h = 0.75 (both standard and long-running assumptions for New Zealand orange roughy). The model was implemented in CASAL (Bull et al. 2012).

For each SPRFMO stock, five Bayesian stock assessments were performed using alternative biological parameters and year class strengths (YCS) obtained from the five existing orange roughy stock assessments in the New Zealand EEZ (ESCR, NWCR, MEC, ORH7A – Cordue 2014b, and Puysegur – Cordue, in press). The posterior distributions of the five assessments were then combined (with equal weight) to produce single posterior distributions for each (derived) parameter of interest.

The only free parameter in the models was B_0 which was estimated with a prior constrained on the low side by B_{min} and on the high side by B_{max} (described below). The prior was uniform on $\log(B_0)$.

B_{min} was calculated for each assessment by running the model over a range of values of B_0 to find the lowest value that allowed the historical catch history to be taken without exceeding an annual exploitation rate of 67%. B_{max} was calculated using a similar manual search over B_0 for the value corresponding to a maximum exploitation rate of 5% in any year. This puts an upper limit on B_0 as at higher values the maximum exploitation rate drops below 5%. One of the SPRFMO stocks (Louisville Central) had a very high spike in catches in one year and a value of 10% was used for this stock (rather than 5%).

The posterior for B_0 was estimated using MCMC runs with some thinning and a burn-in for a final sample size of 2000. This was not strictly necessary as the posterior was just the prior. However, the MCMC runs only took 5 minutes each and this allowed the files to be generated in the correct format for the generation of posteriors for derived parameters (using CASAL). This method was modified when it was found that some of the *tails* of the posterior distributions were not well defined. The sample size was increased to 50,000 and the generation of B_0 values was done within the statistical package R. The corresponding estimates of current biomass were also calculated within R, for the SPRFMO stocks, using the linear relationship between current biomass (in the terminal year) and virgin biomass (see Section 3.1 below).

Posterior distributions were produced for: B_0, stock status in 2015 ($ss = B_{15}/B_0$), and long term yield (being 1.4% of B_0 – a median proportion estimated in Cordue 2014a). Point estimates were made using the median of the posterior and a 95% credibility interval (95% CI) was calculated. Also, the posterior on stock status was used to estimate the probability of the 2015 spawning biomass being below 20% B_0 or above 30% B_0 (respectively the Limit Reference Point (LRP) and the lower bound of the target biomass range for New Zealand EEZ stocks – see Cordue 2014a).

3.1 Current biomass as a linear function of virgin biomass

The only free parameter in the model is B_0 so current biomass (in the terminal year which is 2015 for the SPRFMO stocks) can be viewed as a function of B_0. It is an interesting and little known result that (within an age-structured model) current biomass is essentially a linear function of B_0. This result is easily proven by induction and requires that the accumulated catch history is negligible in the years that recruited cohorts were spawned (which is the case for all of the SPRFMO stocks in combination with the EEZ-stock maturity parameters) and that $B_0 \geq B_{min}$ (at lower values the catches that are removed are reduced because they exceed the maximum exploitation rate and so the linear relationship breaks down).

A consequence of this result is that stock status is a hyperbolic function of B_0.
Suppose that

$$B_{cur} = aB_0 - c$$

for some known constants *a* and *c*.

Then

$$ss = \frac{B_{cur}}{B_0} = a - \frac{c}{B_0}$$

This result has important consequences. Because of the shape of the hyperbolic function which asymptotes to a, stock status will typically increase rapidly in the region just above B_{min}. Also, for large B_0 stock status will increase slowly as B_0 increases.

By noting that a is an asymptote it becomes clear that it is independent of the catch history and that c is a function of the biological parameters and the catches. The value of a depends primarily on the pattern of YCS and also the biological parameters. It is a measure of whether a particular model (catch history excluded) is neutral or otherwise with regard to stock status in the terminal year. A neutral model will have $a = 1$ (i.e., for extremely large B_0 the stock status is 100% B_0 in the terminal year). A "positive" model we will define to be: $a > 1$. A "negative" model will be: $a < 1$.

The constant c will be positive and of the same scale as B_{min}. For a neutral model $c < B_{min}$.

3.2 Testing of the assessment method

The assessment method has each SPRFMO stock borrowing biological parameters and YCS from each of the five EEZ assessments in turn. The hope is that a good range estimate can be obtained for B_0, stock status, and long term yield from the posterior distributions. To test whether this was true or not each of the five EEZ stocks were subjected to the same procedure using the remaining four EEZ stocks. The results were then compared to the known assessment results. Since the EEZ stocks had all experienced periods of intense fishing a minimum maximum exploitation rate of 10% was used to define B_{max}.

3.2 Sensitivity runs

For the Louisville Central stock (which has had the largest accumulated catch taken of the seven stocks considered) a number of sensitivity runs were performed to show the effect of alternative assumptions.

These runs were done using the ORH7A biological parameters and YCS because it gave the highest estimated risk (for Louisville Central) of the five alternatives. The runs were:

- 20% more catch assumed in each year
- M = 0.04 (M=0.045 in the base)
- M = 0.05
- A logistic fishery selectivity: a_{50} = 25 years, a_{to95} = 5 years (mature fish only in the base)
- YCS from 1930 to 1990 estimated with a lognormal prior (sigmaR = 0.6)
- B_{max} defined by U=5% or U=15% (U=10% in the base)
- A "strong" pattern of YCS: 1930-1959 = 0.5, 1960-1989=1.5 (YCS S)
- A neutral pattern of YCS (all equal to 1 which is deterministic(YCS N)
- A "weak" pattern of YCS: 1930-1959 = 1.5, 1960-1989=0.5 (YCS W). Three variations with the B_{max} from U=10% and then double that B_{max} and then four times that B_{max}.

3.3 The SPRFMO catch histories

Eight biological stocks of orange roughy have been defined for stock assessment purposes in the SPRFMO area:

- Louisville North (Louis N)
- Louisville Central (Louis C)
- Louisville South (Louis S)
- Lord Howe Rise (LHR)
- Lord Howe North (LHN)
- North West Challenger (NWC)
- South Tasman Rise (STR)
- West Norfolk Ridge (WNR)

The largest annual catch of about 9000 t was recorded in Louis C in 1995 (Figure 1). The catches in LHN have been minor and the stock can be assumed to be near virgin levels (it is not considered further in this paper).

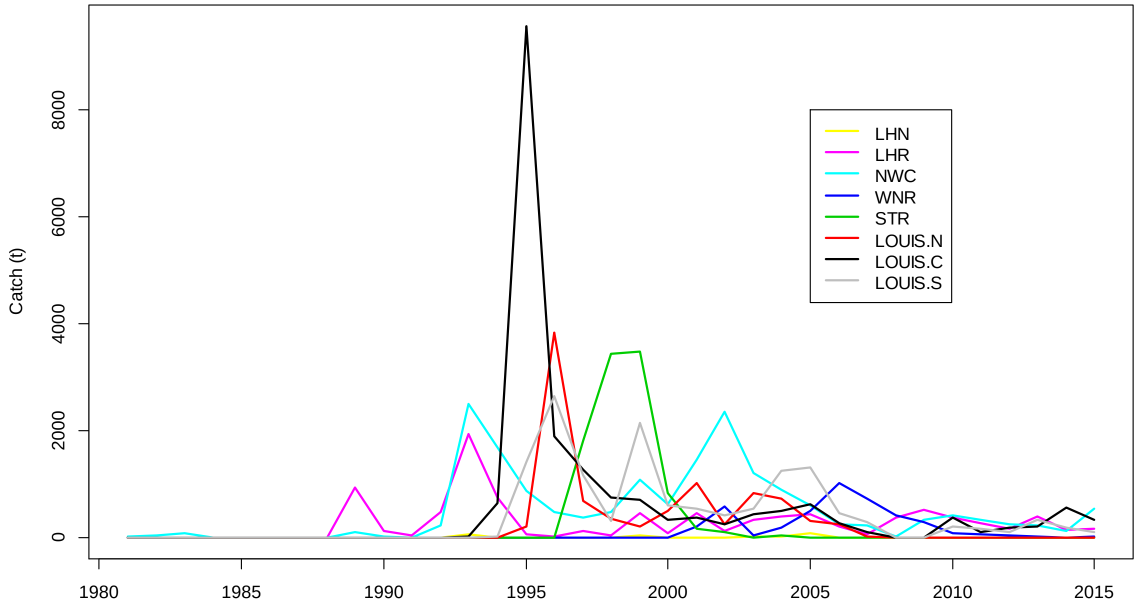

Figure 1: The catch histories for the eight defined orange roughy stocks in the SPRFMO area.

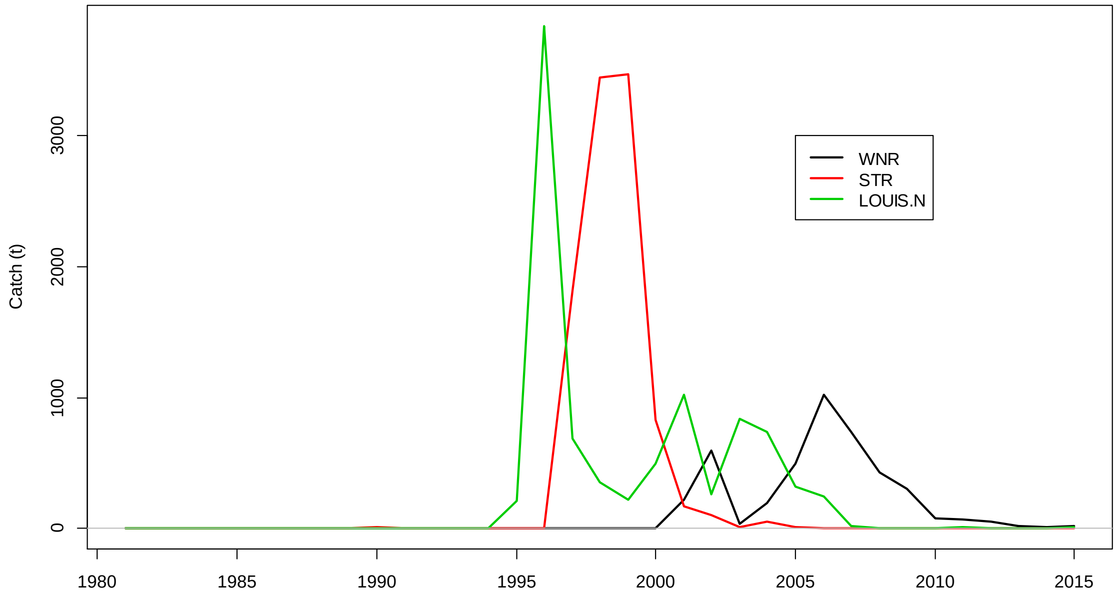

Figure 2: The catch histories for the three orange roughy stocks in the SPRFMO area with little catch in the last 7-12 years.

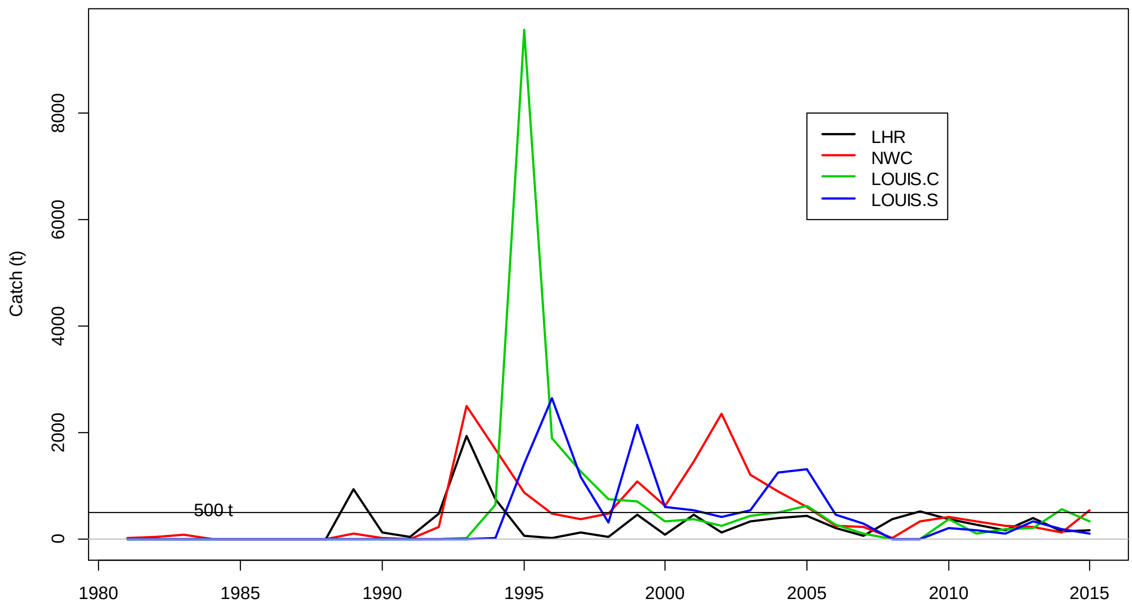

Figure 3: The catch histories for the four orange roughy stocks in the SPRFMO area with low to moderate catch in the last 15 years.

The remaining seven stocks can be split into two groups. Those with very little catch in the last 7-12 years (WNR, STR, and Louis N; see Figure 2) and those with low to moderate catch in the last 15 years (Figure 3). The stocks in the first group are very likely to have reasonable current stock status because, on average, virgin recruitment has been feeding into the stocks for about a decade with little catch being taken.

3.4 The EEZ YCS estimates

The median estimates from the posterior distributions were used as known YCS in each of the five EEZ alternative models. The growth and maturity parameters can be found in the stock assessment FARs (Cordue 2014b, in press).

The median YCS estimates are quite spikey (Figure 4) but the general pattern for each stock can be seen in the smoothed versions of the estimates (Figure 5). For all but NWCR, there is a pattern of above average YCS followed below average YCS although the timing of the switch from above average to below average does vary from about 1940 (MEC) to about 1955 (Puysegur)(Figure 5). Also the magnitude and the duration of the reduction in YCS is very different between the stocks with MEC being most extreme. NWCR essentially has average recruitment throughout.

The pattern of above average recruitment followed by below average recruitment is important for the estimation of B_{min}. It means that the early part of a catch history is supported by above average recruitment which allows *lower* values of B_{min} to be estimated than would otherwise be possible.

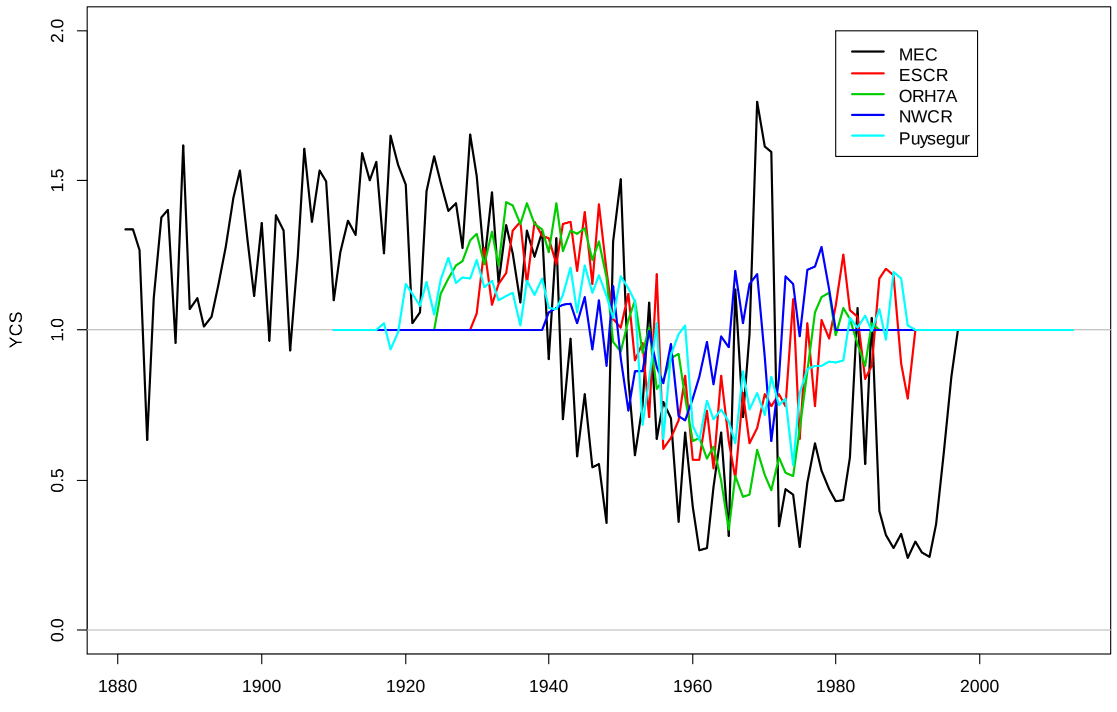

Figure 4: The estimated YCS for each of the New Zealand EEZ orange roughy stocks (median of posterior).

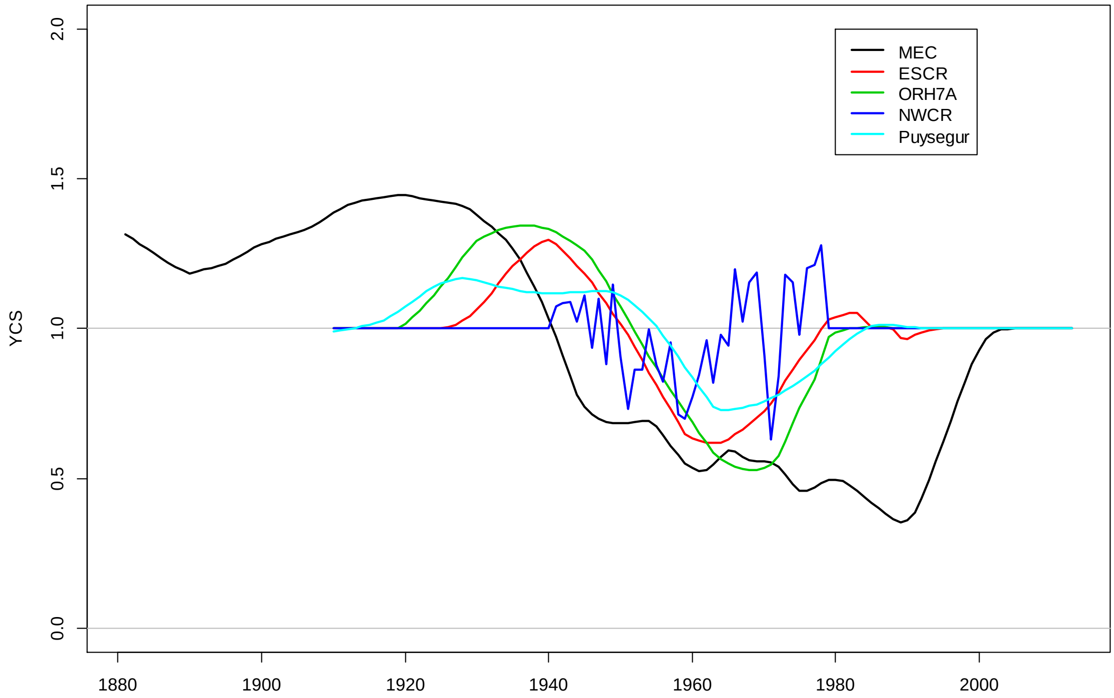

Figure 5: Estimated YCS for each of the New Zealand EEZ orange roughy stocks (smoothed using a Lowess smoother).

The nature of the EEZ models was examined by calculating the 2015 stock status asymptotes as it is important to know if they are supporting higher or lower stock status for SPRFMO stocks in 2015 compared to a neutral model (e.g., a model with all YCS = 1).

4. Results

4.1 The EEZ models are neutral or negative

For stock status in 2015, the terminal year for the SPRFMO catch histories, the EEZ models have asymptotic values for stock status that are equal to or less than 1 (Table 1). For each EEZ model, across the SPRFMO stocks, these asymptotes agreed to 2 decimal places (small differences because of minor catches in some early years for some stocks).

The artificial YCS patterns (weak, neutral, and strong) used in conjunction with ORH7A were respectively negative, neutral, and positive in regard to stock status in 2015 (Table 1). This supports the argument that a pattern of above average recruitment followed by below average recruitment induces lower stock status in 2015 compared to the opposite pattern.

Table 1: The 2015 stock status asymptotes for the EEZ stocks and three artificial stocks (which were used in sensitivity tests – see Section 3.2 for a description of the YCS patterns).

EEZ stock	2015 stock status asymptote	Artificial stock (ORH7A with a YCS pattern)	2015 stock status asymptote
MEC	1.00	Weak YCS	0.88
NWCR	1.00	Neutral YCS	1.00
ESCR	0.93	Strong YCS	1.12
ORH7A	0.91		
Puysegur	0.95		

4.2 Test results for the EEZ stocks

For the ESCR stock the four alternative assessments (using each of the other EEZ stocks in turn) provide similar (or smaller) estimates for the lower bound of the 95% CIs (Table 2). The estimated probabilities of being below the LRP (20% B_0) vary a lot between the stocks (but are not large compared to the zero risk of the real assessment) and the estimated probabilities of being above the lower bound of the target biomass range (30% B_0) are all much higher than that estimated in the assessment (Table 2).

The results are as expected and are very encouraging in terms of estimating *minimum* biomass, stock status, and long term yield. The catch-history based estimates are essentially the real assessment results *before* any observations are added – they provide estimates of what is known from just the catch history and the biological parameters of EEZ-type orange roughy. Therefore, we would expect the real assessment results to fall within the range of the catch-history based estimates and in general this is true. They agree most closely at the "low end".

Table 2: ESCR test results with the actual assessment results (last row). Estimates were obtained using each of the remaining EEZ stock models to provide biological parameters and YCS. Point estimates are in grey as they are unreliable being driven by the value of B_{max}.

	B_0 (000 t)	95% CI	ss_{14}	95% CI	P(ss < 20)	P(ss > 30)	Yield (t)	95% CI
MEC	370	270-480	41	19-56	5	78	5100	3800-6800
NWCR	440	330-590	48	27-61	0	98	6200	4600-8300
ORH7A	400	300-520	34	14-48	16	66	5600	4300-7300
Puysegur	400	290-530	39	17-54	7	76	5500	4100-7400
Assess	320	280-350	30	25-34	0	43	4400	4000-4900

A similar result is seen for the NWCR and ORH7A stocks (Tables 3 and 4). For the Puysegur stock the results are not so close with minimum stock size, stock status, and long term yield being consistently over estimated (Table 5). The reason for this is that most of the Puysegur catch was taken outside of the spawning season and the fish appear to be much younger than the spawning fish (see Cordue in press). As a consequence, minimum virgin biomass is over estimated because all of the catch has wrongly been attributed to spawning fish. The over estimation of B_0 of course flows into an over estimation of stock status and long term yield (Table 5).

Table 3: NWCR test results with the actual assessment results (last row). Estimates were obtained using each of the remaining EEZ stock models to provide biological parameters and YCS. Point estimates are in grey as they are unreliable being driven by the value of B_{max}.

	B_0 (000 t)	95% CI	ss_{14}	95% CI	P(ss < 20)	P(ss > 30)	Yield (t)	95% CI
MEC	66	51-85	40	20-54	3	79	920	710-1200
ESCR	75	55-100	40	19-54	4	80	1000	770-1400
ORH7A	75	60-93	35	20-47	3	77	1000	830-1300
Puysegur	74	55-100	41	20-56	3	83	1000	770-1400
Assess	66	61-76	37	30-46	0	96	920	850-1100

Table 4: ORH7A test results with the actual assessment results (last row). Estimates were obtained using each of the remaining EEZ stock models to provide biological parameters and YCS. Point estimates are in grey as they are unreliable being driven by the value of B_{max}.

	B_0 (000 t)	95% CI	ss_{14}	95% CI	P(ss < 20)	P(ss > 30)	Yield (t)	95% CI
MEC	120	76-170	65	44-76	0	100	1600	1100-2400
ESCR	130	83-190	59	41-71	0	100	1800	1200-2700
NWCR	140	93-210	69	51-79	0	100	2000	1300-2900
Puysegur	130	85-190	63	44-74	0	100	1800	1200-2700
Assess	88	82-96	42	35-49	0	100	1200	1100-1300

Table 5: Puysegur test results with the actual assessment results (last row). Estimates were obtained using each of the remaining EEZ stock models to provide biological parameters and YCS. Point estimates are in grey as they are unreliable being driven by the value of B_{max}.

	B_0 (000 t)	95% CI	ss_{17}	95% CI	P(ss < 20)	P(ss > 30)	Yield (t)	95% CI
MEC	30	15-58	73	49-84	0	100	420	220-810
ESCR	32	16-62	69	46-80	0	100	440	220-860
NWCR	35	18-67	78	56-89	0	100	490	250-940
ORH7A	33	17-62	68	46-79	0	100	460	230-870
Assess	17	13-23	49	36-62	0	100	240	180-320

For MEC there is a very bad mismatch between the catch-history based estimates and the actual assessment results (Table 6). As with Puysegur, the reasons for this are found in the nature of the real fisheries. MEC has two fisheries, one of which is almost exclusively on immature fish (see Cordue 2014). Also, in this case there is a substantial accumulated catch for this fishery which, in the catch-history based assessments, has been wrongly attributed to spawning fish. This is the reason for the bad mismatch. The exercise could be repeated for MEC with appropriate fisheries in the catch-history model and the results would be similar to the other stocks. However, such detailed knowledge of the fisheries is not necessarily available for SPRFMO stocks – so this result sounds a warning when applying the approach.

Table 6: MEC test results with the actual assessment results (last row). Estimates were obtained using each of the remaining EEZ stock models to provide biological parameters and YCS. Point estimates are in grey as they are unreliable being driven by the value of B_{max}.

	B_0 (000 t)	95% CI	ss_{14}	95% CI	P(ss < 20)	P(ss > 30)	Yield (t)	95% CI
NWCR	150	110-190	51	34-63	0	100	2100	1600-2700
ESCR	132	100-170	41	23-53	0	86	1900	1400-2400
ORH7A	130	100-170	37	20-50	3	78	1900	1400-2400
Puysegur	130	100-170	43	26-55	0	92	1900	1400-2400
Assess	95	87-104	14	9-21	96	0	1300	1200-1500

4.3 Estimates of biomass, stock status, yield, and risk for the SPRFMO stocks

For the Louisville Central stock nearly a full assessment has been performed with numerous sensitivities to test the robustness of the results and also to illustrate the (likely) general effect of alternative assumptions. For the other stocks extensive sensitivities have not yet been performed.

The results need to be interpreted carefully. The most reliable results are those that relate most closely to B_{min} (being the lower limits of the 95% CIs and P(ss < 20% B_0)). The point estimates (the median of the posterior) and the upper limits of the 95% CIs are unreliable – they indicate only a possibility that may vanish should observations become available. The estimated probability of being above the lower bound of the target biomass range may also be too optimistic – it depends on how close minimum stock status is to 30% B_0.

With the above interpretation in mind let us look at the results for Louisville Central (should such a unit stock exist).

The base results indicate that in 2015 the stock was very likely to be above the LRP and was probably in the target biomass range (Table 7). Long term yield is at least 200 t and could be much higher. The first set of sensitivities show that these conclusions are robust to a number of alternative assumptions (Table 8). The catch history is no doubt missing some catch from lack of reporting and perhaps some burst bags/incidental mortality. More catch, especially early in the series, increases B_{min} and will have a positive impact (if any) on all estimates (Table 8). Lower and higher natural mortality (M) move the results in the expected direction but even M=0.04 raises little concern (Table 8). The selection of immature fish has a similar effect to the lower M, but again a relatively large movement in parameter values does not dramatically affect the results (Table 8). In the final sensitivity in the set, the YCS were estimated and that resulted in higher estimates of stock status and lower risk (no doubt because the ORH7A YCS pattern is mainly responsible for the negative impact on 2015 stock status i.e., a = 0.91 – see Table 1).

Table 7: Louisville Central estimates of virgin biomass (B_0), stock status in 2015 (ss_{15}), the probability of being below the LRP in 2015 (P(ss < 20)), the probability of being above 30% B_0 in 2015 (P(ss > 30)), and the long term annual yield. Point estimates are in grey as they are unreliable being driven by the value of B_{max}.

	B_0 (000 t)	95% CI	ss_{15}	95% CI	P(ss < 20)	P(ss > 30)	Yield (t)	95% CI
MEC	32	14-81	69	25-87	0	94	450	190-1100
ESCR	35	15-84	64	23-81	0	92	490	210-1200
NWCR	37	16-93	73	33-89	0	99	520	220-1300
ORH7A	36	15-88	62	20-79	2	89	500	210-1200
Puysegur	32	15-86	66	25-83	0	93	450	210-1200

Table 8: Louisville Central sensitivities when using the ORH7A model. See Section 3.2 for the description of the sensitivity runs.

	B_0 (000 t)	95% CI	ss_{15}	95% CI	P(ss < 20)	P(ss > 30)	Yield (t)	95% CI
ORH7A	36	15-88	62	20-79	2	89	500	210-1200
+ catch	40	18-100	60	20-79	2	91	570	250-1500
M=0.04	36	15-88	61	17-79	5	86	500	210-1200
M=0.05	36	15-87	63	22-79	0	92	500	200-1200
Low sel.	32	14-80	60	18-78	4	87	450	190-1100
Est YCS	41	15-90	74	29-91	0	97	570	210-1300

The second set of sensitivities for Louisville Central primarily explore general effects but also show the robustness of the base results. Higher minimum maximum exploitation rates decrease B_{max} and lower the point estimates and the upper limits on the 95% CIs (Table 9). However, they had very little impact on the estimated probabilities (Table 9). This is because a large increase in B_{max} does not lead to a proportionately large increase in the maximum stock status because of the hyperbolic nature of the function between B_0 and stock status (e.g., see Figure 6).

The pattern of YCS has a potentially strong effect on the value of $B_{min.}$ If there is a consistent pattern of above average recruitment timed to support the highest catch then B_{min} can be very low compared to the opposite pattern (Table 9). With essentially what is a double regime shift (30 years of +50% recruitment followed by 30 years of -50% recruitment) the estimated probability of the Louisville Central stock being below the LRP in 2015 is just 12% (YCS W in Table 9). The relative insensitivity of the probability estimates to the “upper end” is again demonstrated when B_{max} is arbitrarily doubled and then doubled again for this “regime shift” model (last 3 rows in Table 9).

Table 9: Louisville Central more sensitivities when using the ORH7A model. See Section 3.2 for the description of the sensitivity runs.

Run	B_{min}	B_{max}	B_0	95% CI	ss_{15}	95% CI	P(ss < 20)	P(ss > 30)	Yield (t)	95% CI
U 5%	14	185	51	15-170	70	22-85	2	93	700	210-2400
U 10%	14	92	36	15-88	62	20-79	2	89	500	210-1200
U 15%	14	62	29	15-60	56	20-74	3	87	410	200-840
YCS S	20	130	51	21-124	91	62-103	0	100	710	290-1700
YCS N	15	96	38	16-92	73	35-89	0	100	540	220-1300
YCS W	12	76	30	13-73	54	7-74	12	79	420	180-1200
YCS W	12	150	42	13-140	63	8-80	9	85	590	180-2000
YCS W	12	300	60	13-280	71	9-84	7	88	840	180-3900

Finally for Louisville Central, it can be seen from just the use of B_{min} and B_{max}, without any prior or Bayesian estimation, that there is little chance that the stock is below the target biomass range (Figure 6). The purpose in using the prior is to allow different percentiles in the long term yield to be used in setting appropriate catch limits. Without a distribution, percentiles are not accessible (or they would be formed by default using a uniform distribution (by cutting up the range) which is not as precautionary as the uniform distribution in log space – which places higher density on smaller values).

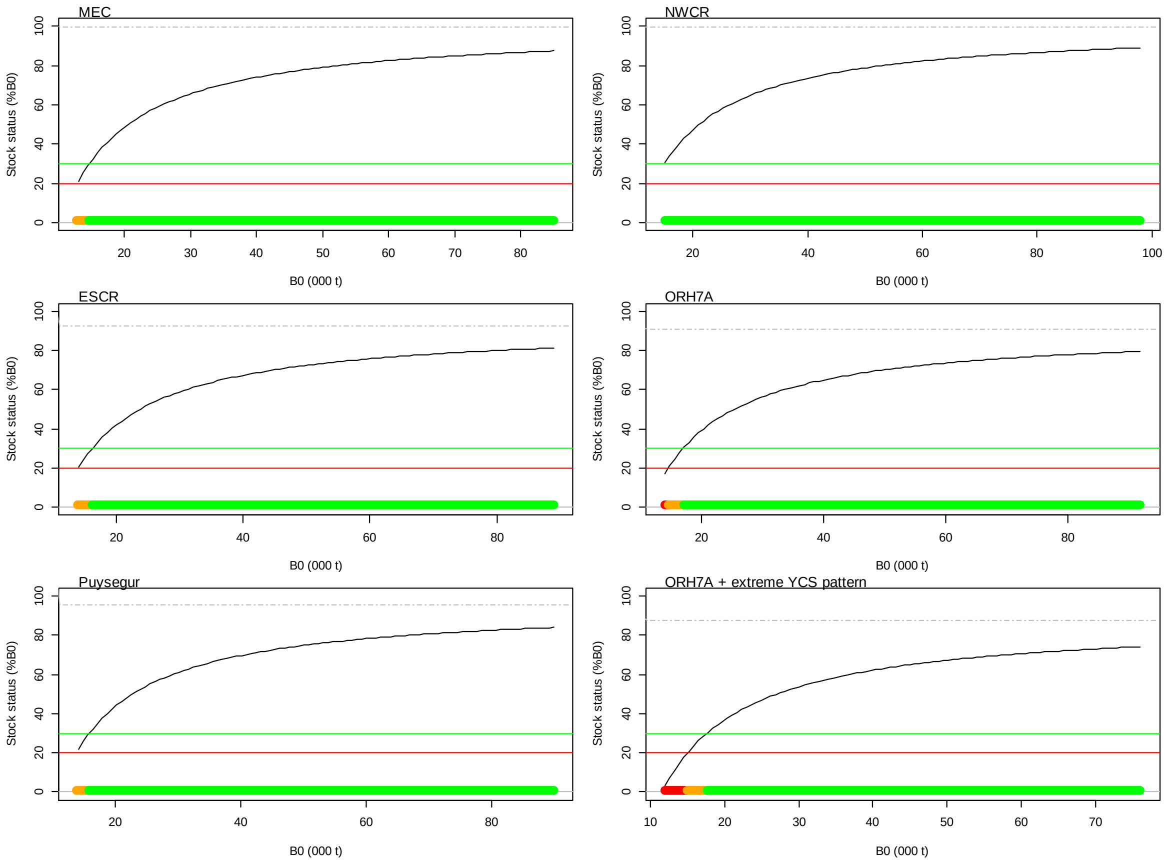

Figure 6: Louisville Central stock status in 2015 as a function of B_0 for six scenarios. The red region (where it exists) goes from B_{min} to $B_{ss20\%}$ (the B_0 that maps to a stock status of 20%B_0), the orange region from $B_{ss20\%}$ to $B_{ss30\%}$ (the B_0 that maps to a stock status of 30%B_0), and the green region from $B_{ss30\%}$ to B_{max}. The grey dashed line is the stock status asymptote (approached as B_0 approaches infinity). The extreme YCS pattern is "YCS W" (see Section 3.2).

The results for Louisville North (should such a unit stock exist) indicate that in 2015 the stock was almost certainly above the LRF and very likely in the target biomass range (Table 10). Long term yield is at least 100 t and may be much higher. Of course, should the fishery actually be taking lots of immature fish then these results would be unreliable.

Table 10: Louisville North estimates of virgin biomass (B_0), stock status in 2015 (ss_{15}), the probability of being below the LRP in 2015 (P(ss < 20)), the probability of being above 30% B_0 in 2015 (P(ss > 30)), and the long term annual yield. Point estimates are in grey as they are unreliable being driven by the value of B_{max}.

	B_0 (000 t)	95% CI	ss_{15}	95% CI	P(ss < 20)	P(ss > 30)	Yield (t)	95% CI
MEC	23	7-66	78	32-92	0	99	320	100-930
ESCR	24	8-68	72	31-85	0	98	330	110-950
NWCR	25	8-75	80	34-93	0	100	360	110-1000
ORH7A	25	9-71	71	31-84	0	98	350	120-990
Puysegur	24	8-69	74	32-88	0	99	330	110-970

For Louisville South the results are not so clear cut as the estimated probabilities of the stock being below the LRP range vary from 2-7% (Table 11). These are still low and there are few values of B_0 above B_{min} which result in stock status less than 20% B_0 (Figure 7).

Table 11: Louisville South estimates of virgin biomass (B_0), stock status in 2015 (ss_{15}), the probability of being below the LRP in 2015 (P(ss < 20)), the probability of being above 30% B_0 in 2015 (P(ss > 30)), and the long term annual yield. Point estimates are in grey as they are unreliable being driven by the value of B_{max}.

	B_0 (000 t)	95% CI	ss_{15}	95% CI	P(ss < 20)	P(ss > 30)	Yield (t)	95% CI
MEC	22	10-47	62	20-82	2	89	310	140-660
ESCR	23	10-48	57	14-76	7	84	320	150-670
NWCR	25	12-53	66	26-84	0	94	350	160-740
ORH7A	24	11-50	57	18-74	4	86	340	160-700
Puysegur	22	10-49	59	16-78	6	85	310	145-680

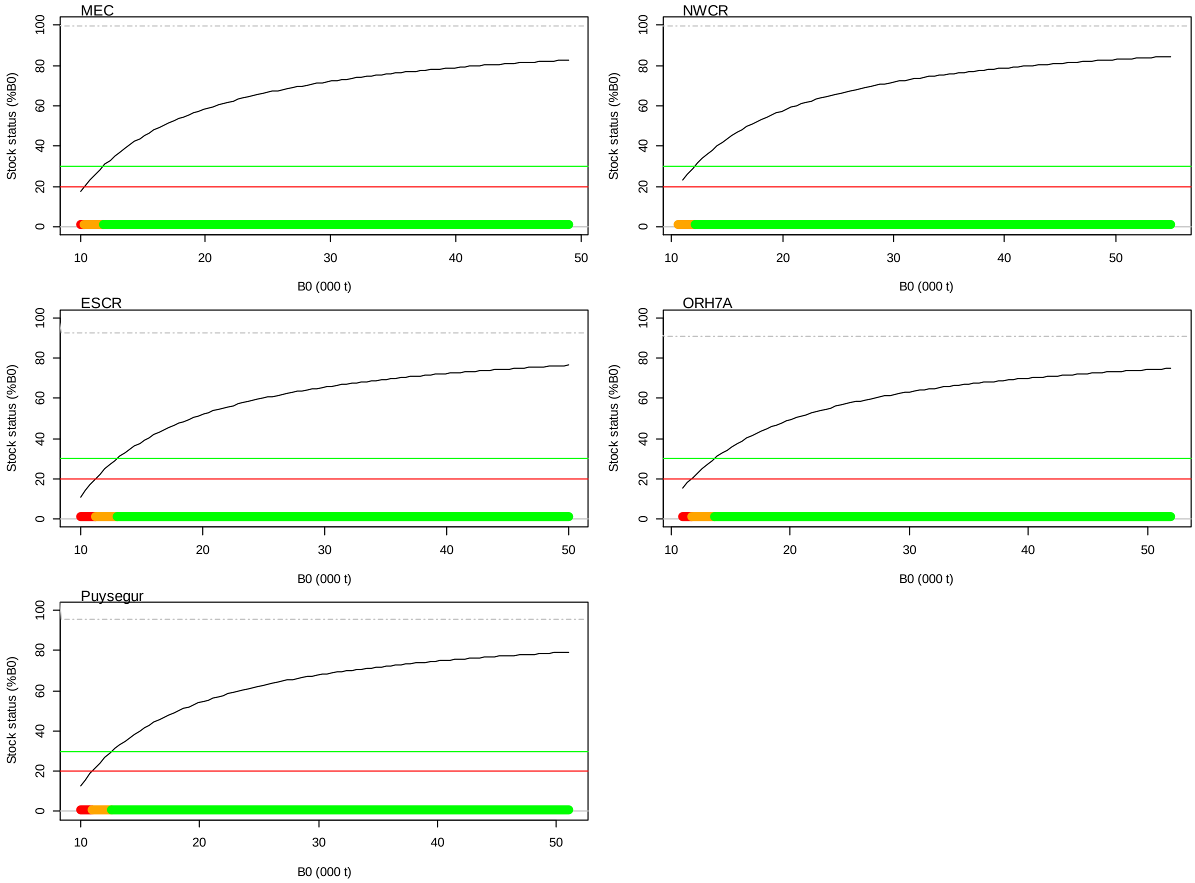

Figure 7: Louisville South stock status in 2015 as a function of B_0 for five scenarios. The red region (where it exists) goes from B_{min} to $B_{ss20\%}$ (the B_0 that maps to a stock status of 20%B_0), the orange region from $B_{ss20\%}$ to $B_{ss30\%}$ (the B_0 that maps to a stock status of 30%B_0), and the green region from $B_{ss30\%}$ to B_{max}. The grey dashed line is the stock status asymptote (approached as B_0 approaches infinity).

The results for South Tasman Rise (should such a unit stock exist) indicate that the stock is well into the target biomass range and that long term yield is at least 130 t and may be much higher (Table 12). For North West Challenger and especially Lord Howe Rise there must be some concern that the stock status in 2015 may have been below the LRP (Tables 13 and 14). North West Challenger is probably the larger stock of the two with a long term yield of at least 160 t while Lord Howe Rise has a long term yield of at least 80 t (Tables 13 and 14). West Norfolk Ridge appears to be a small stock which is probably above the LRP but with a minimum long term yield of only 50 t (Table 15).

Table 12: South Tasman Rise estimates of virgin biomass (B_0), stock status in 2015 (ss_{15}), the probability of being below the LRP in 2015 (P(ss < 20)), the probability of being above 30% B_0 in 2015 (P(ss > 30)), and the long term annual yield. Point estimates are in grey as they are unreliable being driven by the value of B_{max}.

	B_0 (000 t)	95% CI	ss_{15}	95% CI	P(ss < 20)	P(ss > 30)	Yield (t)	95% CI
MEC	24	10-64	79	46-91	0	100	340	130-900
ESCR	25	9-67	72	40-85	0	100	350	130-940
NWCR	28	10-72	81	49-92	0	100	390	150-1000
ORH7A	28	10-72	72	41-83	0	100	390	150-1000
Puysegur	25	9-67	75	42-88	0	100	350	130-940

Table 13: North West Challenger estimates of virgin biomass (B_0), stock status in 2015 (ss_{15}), the probability of being below the LRP in 2015 (P(ss < 20)), the probability of being above 30% B_0 in 2015 (P(ss > 30)), and the long term annual yield. Point estimates are in grey as they are unreliable being driven by the value of B_{max}.

	B_0 (000 t)	95% CI	ss_{15}	95% CI	P(ss < 20)	P(ss > 30)	Yield (t)	95% CI
MEC	24	11-49	58	11-79	9	82	340	160-690
ESCR	26	12-53	55	12-74	9	82	370	170-740
NWCR	26	13-55	61	17-81	5	86	370	180-770
ORH7A	28	14-56	54	15-73	7	84	390	190-780
Puysegur	26	13-52	56	14-76	8	83	360	180-720

Table 14: Lord Howe Rise estimates of virgin biomass (B_0), stock status in 2015 (ss_{15}), the probability of being below the LRP in 2015 (P(ss < 20)), the probability of being above 30% B_0 in 2015 (P(ss > 30)), and the long term annual yield. Point estimates are in grey as they are unreliable being driven by the value of B_{max}.

	B_0 (000 t)	95% CI	ss_{15}	95% CI	P(ss < 20)	P(ss > 30)	Yield (t)	95% CI
MEC	14	6-33	60	5-83	12	80	190	81-470
ESCR	14	6-35	56	6-77	12	79	200	88-480
NWCR	15	6-39	64	11-86	8	85	210	88-550
ORH7A	15	7-35	55	9-75	11	80	210	95-490
Puysegur	14	6-36	59	8-80	11	79	190	88-500

Table 15: West Norfolk Ridge estimates of virgin biomass (B_0), stock status in 2015 (ss_{15}), the probability of being below the LRP in 2015 (P(ss < 20)), the probability of being above 30% B_0 in 2015 (P(ss > 30)), and the long term annual yield. Point estimates are in grey as they are unreliable being driven by the value of B_{max}.

	B_0 (000 t)	95% CI	ss_{15}	95% CI	P(ss < 20)	P(ss > 30)	Yield (t)	95% CI
MEC	9	4-20	65	18-85	4	88	120	52-280
ESCR	9	4-21	61	20-79	3	89	130	57-300
NWCR	9	4-21	67	23-85	0	91	130	56-300
ORH7A	10	4-21	63	19-81	3	88	130	56-300

Puysegur	9	4-21	63	19-81	3	88	130	56-300

The results for each of the seven SPRFMO stocks where equal weight is given to each EEZ scenario show a very similar picture to that of the individual EEZ-stock based results (Table 16). Some concern for North West Challenger and especially Lord Howe Rise. No concerns for any of the other stocks.

Table 16: Combined results for each SPRFMO stock giving the five individual models equal weight. Estimates of virgin biomass (B_0), stock status in 2015 (ss_{15}), the probability of being below the LRP in 2015 (P(ss < 20)), the probability of being above 30% B_0 in 2015 (P(ss > 30)), and the long term annual yield. Point estimates are in grey as they are unreliable being driven by the value of B_{max}.

	B_0 (000 t)	95% CI	ss_{15}	95% CI	P(ss < 20)	P(ss > 30)	Yield (t)	95% CI
Louis N	24	8-69	74	32-92	0	99	340	110-970
Louis C	34	15-87	66	24-87	1	93	480	200-1200
Louis S	23	11-49	60	18-82	5	87	320	150-690
STR	26	10-69	75	42-91	0	100	360	140-970
NWC	26	12-53	56	13-79	8	83	360	170-750
LHR	14	6-36	57	7-83	11	81	200	87-500
WNR	9	4-21	63	19-84	3	89	130	56-300

4.4 Estimates of exploitation rates for the SPRFMO stocks

The model results can be used to estimate exploitation rates in each year. Of course, high exploitation rates are expected in early years with B_{min} derived from an assumed exploitation rate of 67% in the year of highest exploitation. If there are potentially very high exploitation rates in recent years then there must be a concern about the level of recent catches.

The results are presented as a series of box and whiskers plots showing the posterior distribution of exploitation rates for each year. A reference line is plotted at 9% in red because it is obviously an excessive exploitation rate for orange roughy (being twice the value of M=4.5%). If, in recent years, most of the distribution lies below that line then recent exploitation rates are not excessive.

For Louisville Central, almost all of the estimated exploitation rates are below the reference line since 1998 (Figure 8). The same is true for Louisville South since 2010 (Figure 9) and there has been almost no catch in Louisville North since 2006 (Figure 10). The same is true for South Tasman Rise (Figure 11) and recent catches on West Norfolk Ridge are very low (Figure 12).

The 2015 catch on North West Challenger of 550 t may correspond to a very high exploitation rate and there is an estimated 23% chance that the exploitation rate is above 9% (Figure 13). Likewise, recent catches on Lord Howe Rise are indicative of possible very high exploitation rates (Figure 14). The catch of 393 t in 2013 has an estimated 30% chance of being above the reference line of 9%.

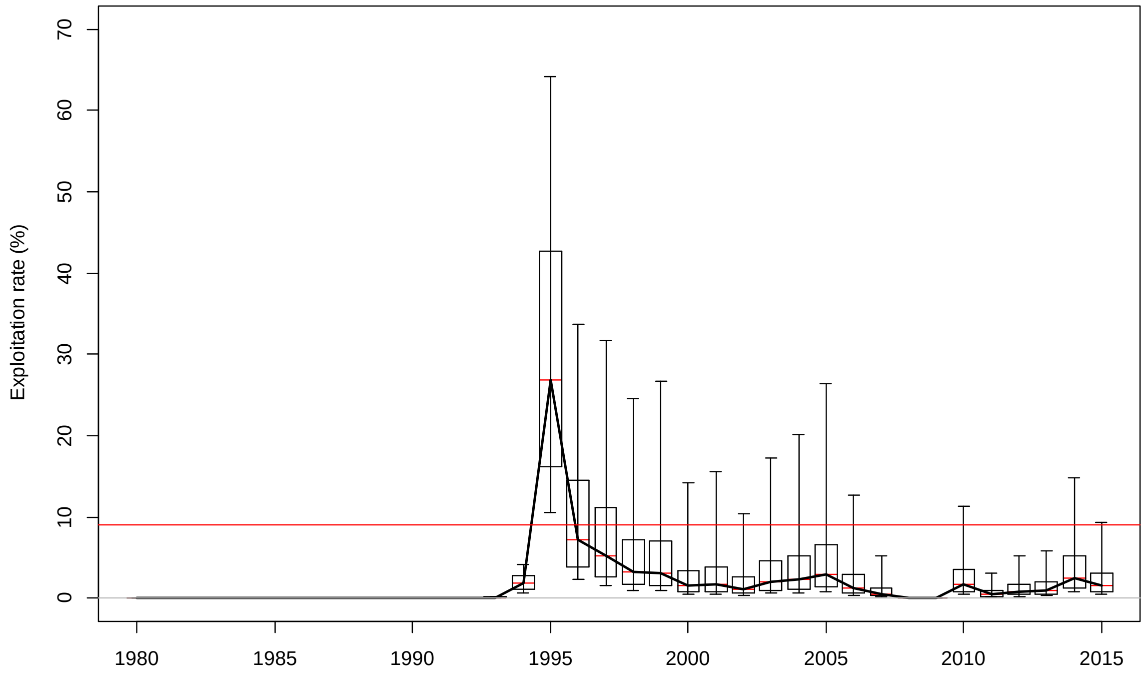

Figure 8: Estimated exploitation rates for Louisville Central (combined model). Each box covers the middle 50% of the posterior distribution with the whiskers extending to the 95% CIs. The red line is plotted at 9%.

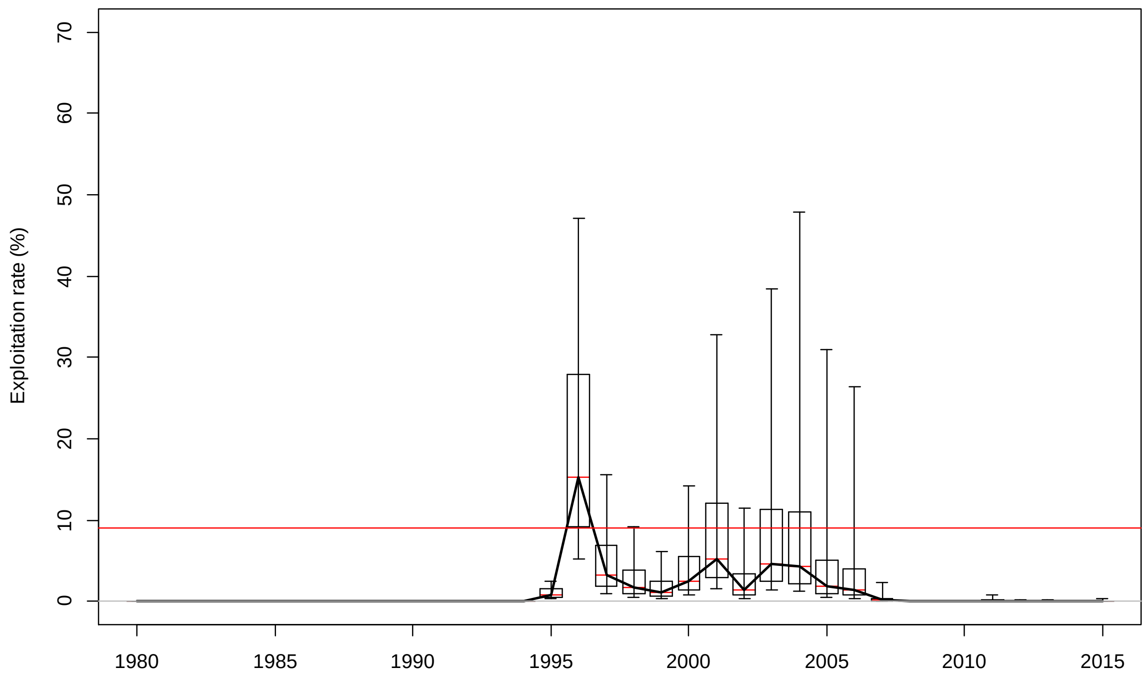

Figure 9: Estimated exploitation rates for Louisville North (combined model). Each box covers the middle 50% of the posterior distribution with the whiskers extending to the 95% CIs. The red line is plotted at 9% (which is 2M for NZ orange roughy).

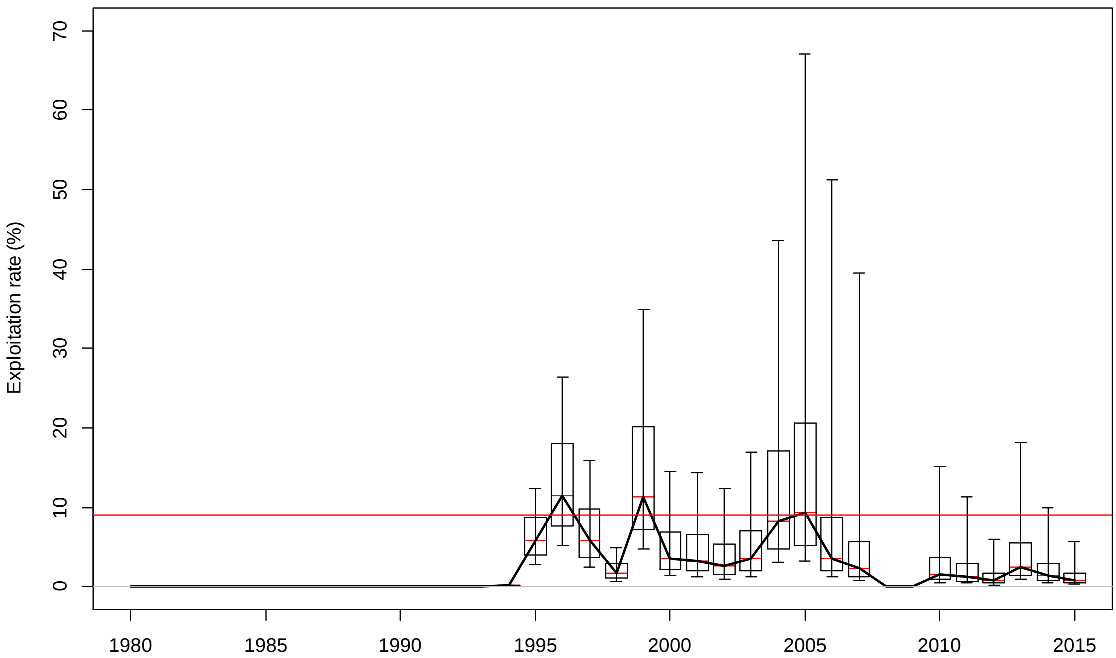

Figure 10: Estimated exploitation rates for Louisville South (combined model). Each box covers the middle 50% of the posterior distribution with the whiskers extending to the 95% CIs. The red line is plotted at 9%.

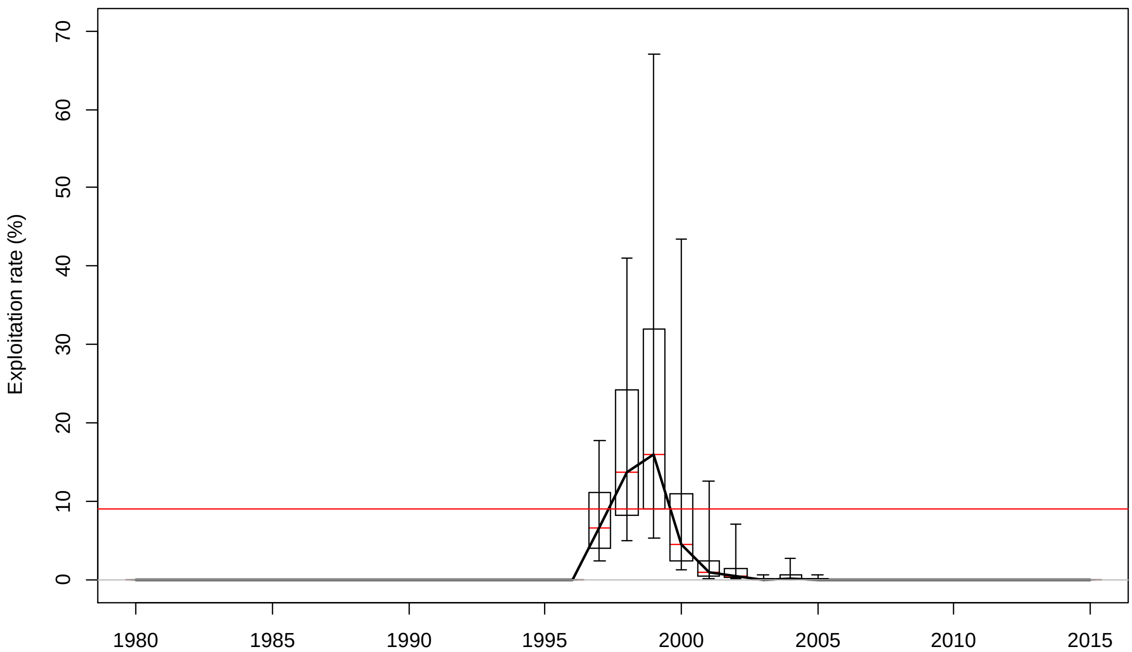

Figure 11: Estimated exploitation rates for South Tasman Rise (combined model). Each box covers the middle 50% of the posterior distribution with the whiskers extending to the 95% CIs. The red line is plotted at 9%.

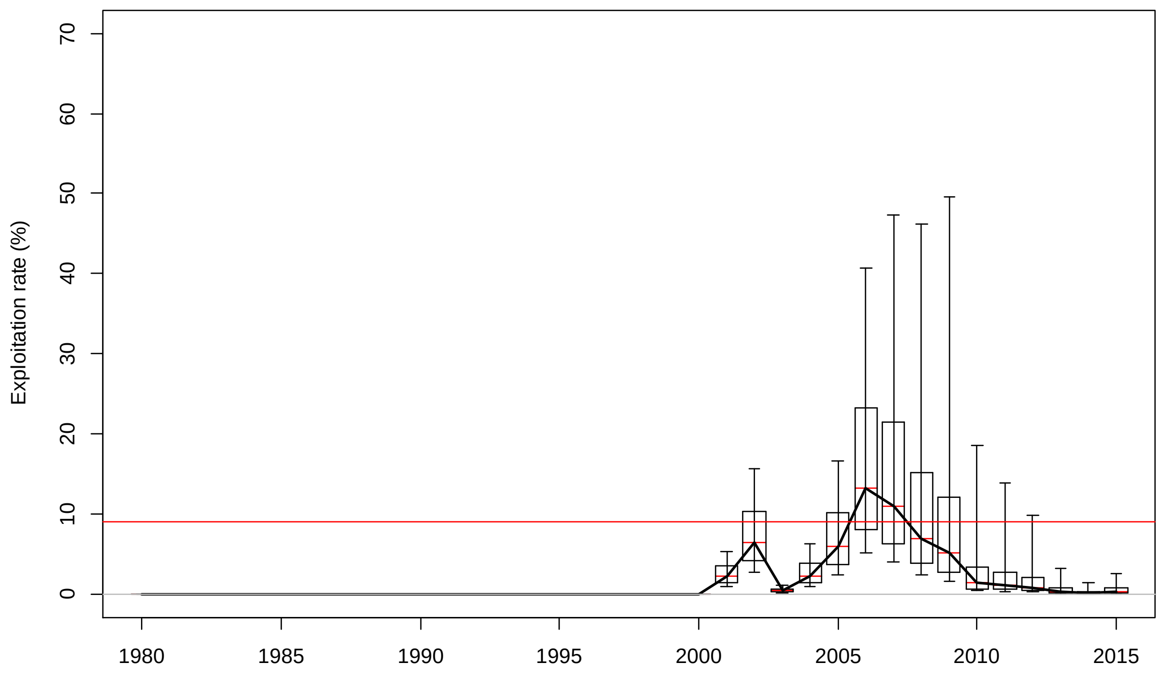

Figure 12: Estimated exploitation rates for West Norfolk Ridge (combined model). Each box covers the middle 50% of the posterior distribution with the whiskers extending to the 95% CIs. The red line is plotted at 9%.

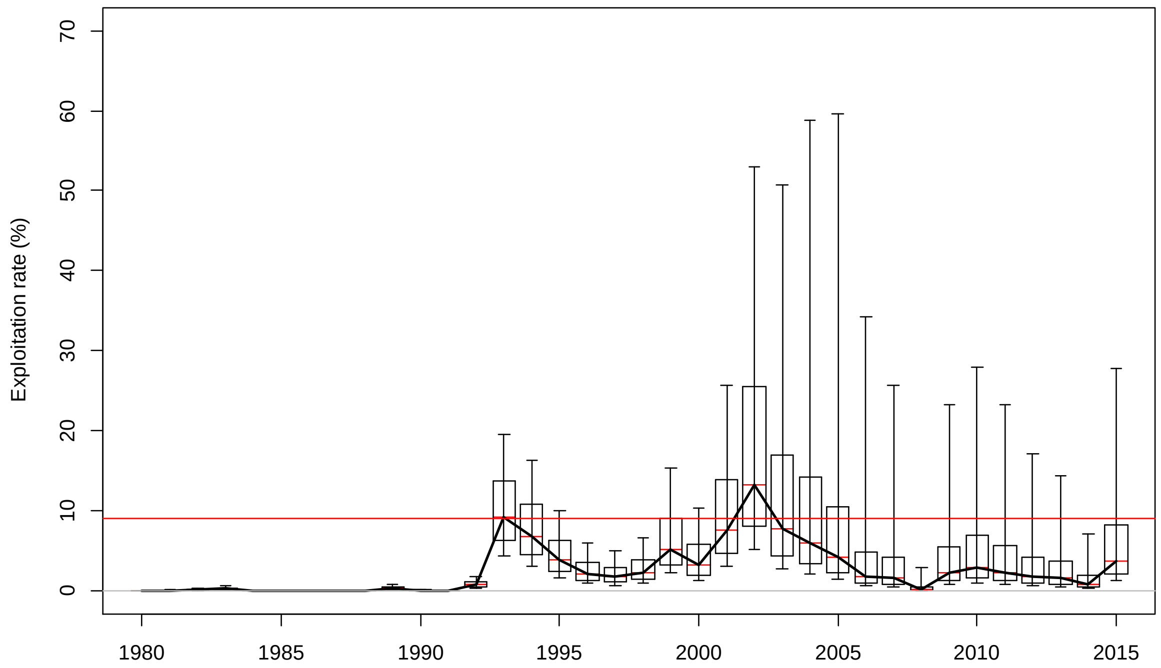

Figure 13: Estimated exploitation rates for North West Challenger (combined model). Each box covers the middle 50% of the posterior distribution with the whiskers extending to the 95% CIs. The red line is plotted at 9%.

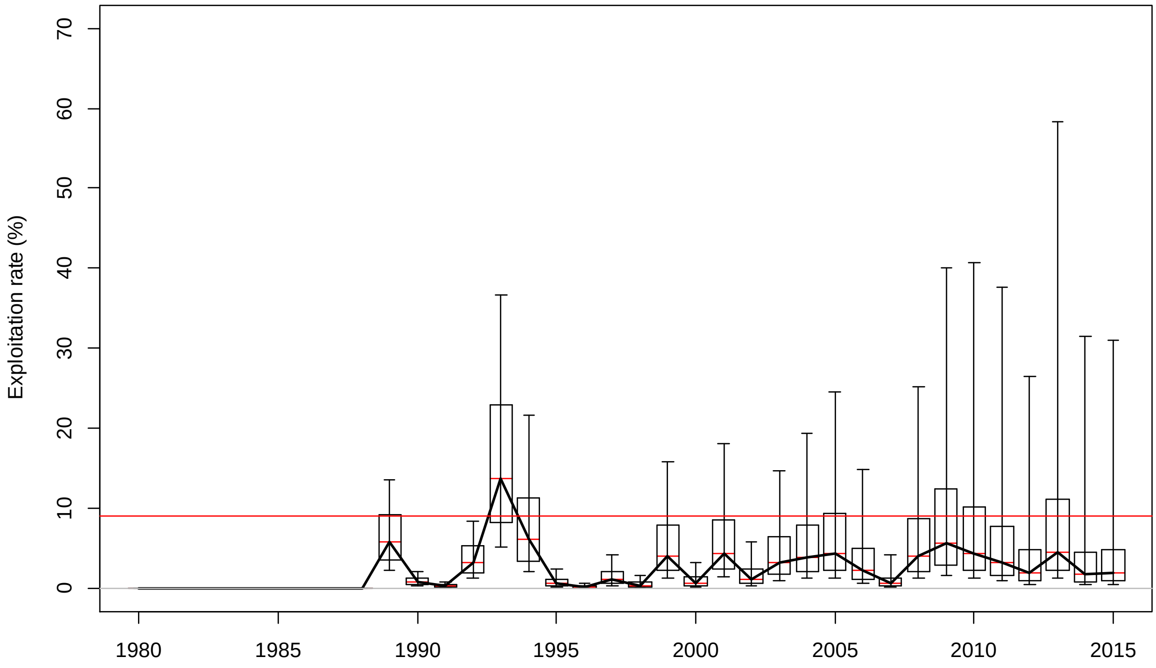

Figure 14: Estimated exploitation rates for Lord Howe Rise (combined model). Each box covers the middle 50% of the posterior distribution with the whiskers extending to the 95% CIs. The red line is plotted at 9%.

4.5 An illustrative traffic light system for setting catch limits

The catch-history based assessment gives an indication of the potential of being below the LRP through the probability estimate. Also, there are estimates of long term yield (with the focus on the low end). The two types of estimates could be used in combination to set catch limits for the stocks. The catch limits could be set on a precautionary basis to provide an incentive for new data collection.

One possibility for such a rule (for illustrative purposes only) is:

- If P(ss < 20%B_0) ≤ 0.05 then choose a catch limit from the 40-70th percentiles of long term yield, or
- If P(ss < 20%B_0) > 0.05 then choose a catch limit from the 2.5-30th percentiles of long term yield, or
- If P(ss < 20%B_0) ≥ 0.20 then set the catch limit at zero.

Table 17 gives the results of applying the illustrative rule to the SPRFMO stocks. Green shading is used for stocks that have very low estimated risk (less than or equal to 5%) and amber/orange for those with moderate risk (greater than 5% and less than 20%). Red would be used for stocks with high risk (greater than or equal to 20%).

Table 17: Traffic light yields: an illustrative example of using the estimated probability of being below the LRP to choose a range of potential catch limits (see the text for the rule).

		Percentiles of estimated long term yield (t)									
	P(ss < 20)	2.5%	20%	30%	40%	50%	60%	70%	80%	97.5%
Louis N	0.00	110	170	210	270	340	420	510	630	970
Louis C	0.01	200	280	330	400	480	580	720	870	1200
Louis S	0.05	150	200	230	270	320	380	440	520	690
STR	0.00	140	200	240	290	360	440	530	650	970
NWC	0.08	170	230	260	300	360	420	480	560	750
LHR	0.11	87	120	140	170	200	250	290	350	500
WNR	0.03	56	76	90	110	130	150	180	220	300

5. Discussion

An activity which has as its objective to estimate the size of a fish stock, its stock status, and current and long term yield is by definition a stock assessment. In data poor situations a stock assessment may involve few or no observations from the stock being assessed.

The 2014 assessments of New Zealand EEZ orange roughy stocks set a high quality threshold for observations that were fitted in the models (Cordue 2014b). This was one of the primary reasons for the success of the assessments. The approach taken in this paper is by definition a stock assessment although no observations from the stock are used. Instead, the best available information is used in the form of historical catch histories and the certain knowledge that the animals in question are orange roughy.

The population dynamics of the model are appropriate for orange roughy as are the biological parameters and the YCS patterns (as they have been estimated for orange roughy stocks). They are appropriate for the SPRFMO stocks at this stage because we have no other information on their specific biology and YCS patterns. They are undoubtedly not the same as the biological parameters and YCS patterns of the SPRFMO stocks that will be obtained when age data are collected but they are a reasonable proxy.

The growth parameters are not particularly important for the method used in this paper. Smaller fish would just result in a larger number per unit of biomass and conversely for larger fish. Similarly the length-weight relationship is not an issue. Age at maturity will be more important as the older that fish mature the larger the impact of a given catch is likely to be on the spawning biomass.

Natural mortality is of course important and if the natural mortality for a SPRFMO stock is outside of the range of 0.04-0.05 then the results of this analysis could be compromised (though only lower values are of concern).

The YCS patterns of the EEZ stocks in combination with their biological parameters are neutral or negative with regard to stock status in 2015. The use of that set of five models is precautionary relative to an average model (e.g., one with deterministic recruitment). The use of the uniform prior on B_0 in log space is also neutral or precautionary (relative to a uniform prior in linear space). Of course the focus on the lower limit of 95% CIs is also highly precautionary. It has been demonstrated that the lower limit of the 95% CIs and the estimated probabilities are relatively insensitive to the choice of B_{max} (which defines the upper limit on B_0).

The lower bound of the 95% CIs for each of the SPRFMO stocks for virgin biomass, current stock status, and long term yield can be considered reliable provided the fishery is not taking lots of juvenile fish and the true recruitment pattern is not extreme. Of the two probability estimates the risk of being below the LRP is the most reliable because it is more closely associated with B_{min}. The estimated probability of being above the lower bound of the target biomass range is less reliable unless B_{min} is close to the lower bound of the target biomass range (30% B_0).

Of course, all of the results are conditional on the stock hypothesis. No stock assessment can be considered reliable if the stock hypothesis is highly suspect. Sensitivity analysis, using alternative stock hypotheses, is an essential element of a full stock assessment in such cases. Therefore, the assessments as they stand at this time are indicative only.

The assessment results indicate that five of the seven SPRFMO stocks assessed are very likely to be above the LRP of 20% B_0 used in this paper and most of them are probably above 30% B_0. The recent exploitation rates for these stocks are not excessive (being zero in some cases). There is an indication that North West Challenger and Lord Howe Rise may be below the LRP and that recent exploitation rates could be very high.

The suggested method of choosing catch limits is a pragmatic approach which could be used as an interim measure until age frequencies and acoustic biomass estimates from the spawning populations are available (which would allow definitive stock assessments).

6. Future directions

A full range of sensitivity tests could be performed for all stocks including alternative stock hypotheses. Prospective catch limits could also be tested with projections from the lower percentiles of the posterior of B_0.

7. Acknowledgments

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8. References

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