RECOVERY POTENTIAL ASSESSMENT FOR YELLOWMOUTH ROCKFISH (*SEBASTES REEDI*) ALONG THE PACIFIC COAST OF CANADA

Figure 1: Yellowmouth Rockfish (Sebastes reedi). Credit: Terri Bonnet

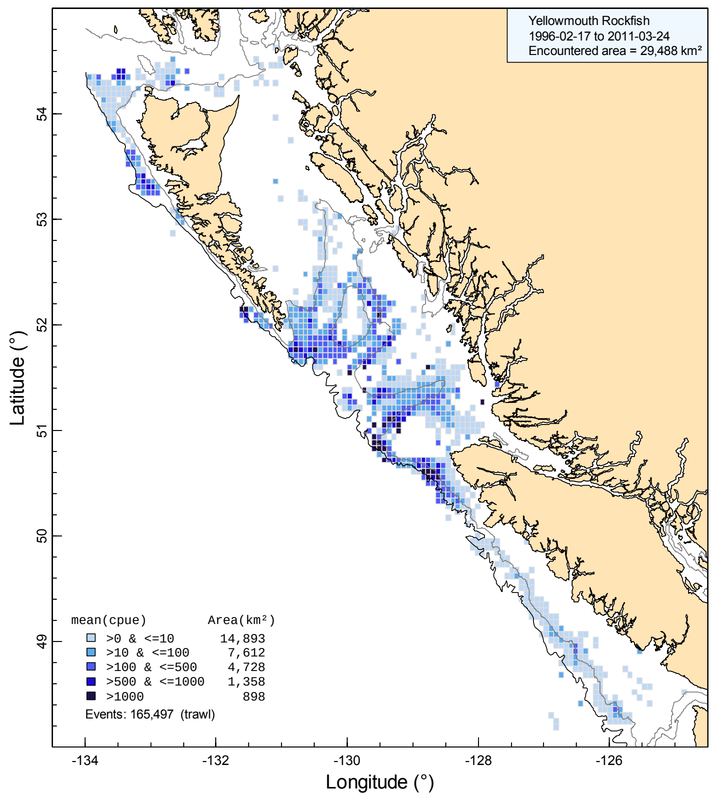

Figure 2

Figure 2: Assessment area is the Pacific coast of Canada. Shaded cells show mean catch per unit effort (kg/h) of Yellowmouth Rockfish in cells 0.075° longitude by 0.055° latitude (roughly 32 km²) from Feb 1996 to Mar 2011. These give an approximation of the area where Yellowmouth Rockfish was caught by fishing events from the groundfish trawl fishery. Contours are 200 m and 1000 m isobaths.

Context

In 2010, Yellowmouth Rockfish along the Pacific coast of Canada was designated as Threatened by the Committee on the Status of Endangered Wildlife in Canada, with commercial fishing identified as the primary threat. This designation means that Fisheries and Oceans Canada, as the responsible jurisdiction under the Species at Risk Act, is required to undertake a number of actions. Many of these actions require scientific information on the current status of the species, threats to its survival and recovery, and the feasibility of its recovery.

This Science Advisory Report has resulted from a Fisheries and Oceans Canada, Canadian Science Advisory Secretariat, Pacific Regional Advisory Process meeting held on May 30, 2011, on Stock Assessment and Recovery Potential Assessment for Yellowmouth Rockfish (Sebastes reedi) Along the Pacific Coast of Canada. Additional publications from this process will be posted as they become available on the DFO Science Advisory Schedule at http://www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm.

SUMMARY

- The assessment considered Yellowmouth Rockfish along the Pacific coast of Canada as a single stock. Over the last 15 years, the British Columbia trawl fleet has encountered Yellowmouth Rockfish over an estimated 29,500 km^2.
- A two-sex, age-structured model was used to estimate biomass from 1940 to 2011, and to make projections under a range of constant catch scenarios. Model results are reported for the two accepted model runs (the first estimated natural mortality, *M*, and the second kept it fixed); values are the medians followed by the 5-95% credible intervals derived from Bayesian output.
- The results imply a slow-growing population that experienced relatively long periods of low recruitment punctuated by occasional episodes of high recruitment, one in the early 1960s and another in the early 1980s.
- Estimates for the ratio of spawning biomass (mature females only) at the beginning of 2011 to the unfished equilibrium spawning biomass are 0.61 (0.43-0.83) and 0.41 (0.29-0.55) for runs ‘Estimate *M*’ and ‘Fix *M*’ respectively.
- Exploitation rates for 2010 are estimated to be 0.020 (0.010-0.036) for run ‘Estimate *M*’ and 0.038 (0.026-0.059) for run ‘Fix *M*’, compared to respective historic highs of 0.090 (0.059-0.123) and 0.130 (0.110-0.154) estimated for 1966 during intense fishing by foreign fleets.
- Current and projected probabilities of the status of the population are given with respect to (i) the DFO *Sustainable Fisheries Framework* provisional reference points, (ii) reference points of $0.2B_0$ and $0.4B_0$ (where B_0 is the equilibrium unfished spawning biomass), and (iii) reference criteria given by COSEWIC assessment indicators A1 and A2.
- Projections are presented for up to three generations (90 years) for both model runs. For each level of constant catch, these give probabilities of future population status with respect to the above reference points and reference criteria, as well as estimates of the time taken to attain them (with different levels of confidence).

INTRODUCTION

Yellowmouth Rockfish (*Sebastes reedi*) is an important commercial species in British Columbia (BC), often caught along with Pacific Ocean Perch (*S. alutus*). Its common name stems from yellow-black blotches in the mouth. The body sports a mixture of colours – red, orange, yellow – and features a thin pink-red strip along the lateral line and dusky saddles along the back.

The life history of Yellowmouth Rockfish remains largely unknown, but probably follows similar patterns to other *Sebastes* species, with release of larvae that spend months as free-swimming pelagic larvae before settling to the bottom as juveniles. In BC waters, larval release occurs from February to June. Males achieve 50% maturity at 37 cm, females at 38 cm. Lengths reach a maximum of approximately 54 cm.

Yellowmouth Rockfish ranges from the Gulf of Alaska southward to northern California near San Francisco, typically at depths between 180 and 275 m (Love et al. 2002). In BC, the apparent area of highest concentration occurs in Queen Charlotte Sound (middle of Figure 2) with isolated hotspots around Haida Gwaii (top-left quarter of Figure 2). This species occurs along the west coast of Vancouver Island (bottom-right quarter of Figure 2), but its density appears to be low there. Adults occur on the bottom and in midwater above high-relief rocks, and have been aged up to 99 years. This species has been encountered by the BC trawl fleet over an estimated 29,500 km^2 (based on a roughly 32 km^2 grid size and tow start positions in the commercial fishery), and the bulk of the population lies between depths of 110 m and 437 m.

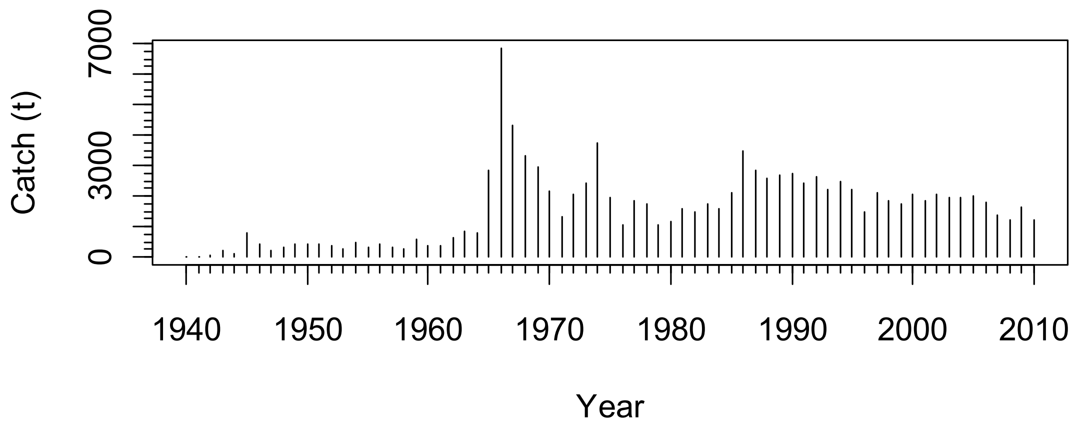

Figure 3. Reconstructed commercial catch data (tonnes) of Yellowmouth Rockfish along the west coast of Canada, constituting input to the model.

Yellowmouth Rockfish supports the third largest rockfish fishery in BC (after Pacific Ocean Perch and Yellowtail Rockfish), with an annual coastwide TAC (total allowable catch) of 2,444 t. The time series of reconstructed historical catch (Figure 3), used as input for the assessment model, shows a peak catch of 6,843 t in 1966 (during a period of intense fishing by foreign fleets) and a recent average (2006-2010) of 1,442 t. The total Canadian catch of Yellowmouth Rockfish had a landed value of approximately $1.5 million for the 2007-2008 fishing season (COSEWIC 2010). The trawl fishery accounts for 97% of the coastwide TAC, with the rest allocated to the hook and line fishery. Appendix 8 of the 2011-2013 Department of Fisheries and Oceans (DFO) Integrated Fisheries Management Plan reports the coastwide *trawl* TAC for Yellowmouth at 2,365 t, which has not changed since 2001.

Yellowmouth Rockfish along the Pacific coast of Canada has been designated as *Threatened* (defined as likely to become *Endangered* if nothing is done to reverse the factors leading to its extirpation or extinction) by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), with commercial fishing identified as the primary threat (COSEWIC 2010). The present document summarises the Stock Assessment and Recovery Potential Assessment that formulates the scientific information developed in response to that designation. DFO (2007) listed 17 tasks that should be addressed in a Recovery Potential Assessment – these are explicitly listed and addressed here at the end, with the assessment model results being used to address most of the points. Haigh and Starr (2008) summarised the available data for Yellowmouth Rockfish along the Pacific coast of Canada, and that information was subsequently used by COSEWIC (2010) to reach its designation.

ASSESSMENT

Model Methods

Given the absence of population genetic studies of Yellowmouth Rockfish, COSEWIC (2010) considered all individuals within Canadian Pacific waters as a single population; thus the assessment also treated the population as a single stock.

The assessment used an annual two-sex, age-structured, stochastic model tuned to five fishery-independent survey series, annual estimates of commercial catch since 1940, six years of age composition data from two survey series, and 18 years of age composition data from the commercial fishery. The model started from an assumed unfished equilibrium state in 1940, and the survey data cover the period 1967 to 2010 (although not all years are represented). Ages from 1 to 60 were tracked, with 60 being an accumulator age category. The two-sex model was implemented in a Bayesian framework (using the Markov Chain Monte Carlo, MCMC, procedure) under two scenarios, in which natural mortality was either estimated or fixed (termed 'Estimate *M*' and 'Fix *M*', respectively).

Growth parameters were estimated from Yellowmouth length and age data using research samples collected from 1978 to 2009. The model estimated parameters from a stock-recruitment function, catchability coefficients for the survey series, and selectivity parameters for the commercial fishery and the two survey series for which age data are available. For run 'Estimate *M*', natural mortality was also estimated (independently for females and males).

The MCMC procedure resulted in 1,000 samples, which were used to generate estimates (marginal posterior distributions) for the parameters and quantities of interest, including stock sizes and the probabilities of being above reference points.

The model was used to estimate the past and present vulnerable biomass, spawning stock biomass and age structure. Estimated parameters were then used to calculate maximum sustainable yield (MSY) and stock status relative to reference points. Projections assuming constant catch levels and random recruitment deviations were then performed to estimate probabilities of the spawning biomass being greater than the reference points and the reference criteria for up to three generations (90 years) in the future.

Abundance and Trends

Both presented model runs ('Estimate *M*' and 'Fix *M*') had similar credible fits to the data, with neither demonstrating a noticeably better fit. The MCMC results showed the same pattern for both runs, although differing in absolute magnitude and the level of uncertainty. Estimates of various quantities of interest are given in Table 1. In particular, the median (and 5-95% credible interval) ratio of current spawning biomass (mature females only) to the unfished equilibrium level (B_{2011} / B_0), is 0.614 (0.431-0.829) for run 'Estimate *M*' and 0.409 (0.289-0.547) for run 'Fix *M*'.

The vulnerable biomass is estimated to be greater for run 'Estimate *M*' than for run 'Fix *M*', resulting in a greater relative impact from fishing on the population for run 'Fix *M*' than for run 'Estimate *M*' (Figure 4). Both runs showed a steady decline with the onset of fishing in the mid-1940s, a further sharp drop during the heavy fishing by foreign fleets in the mid-1960s, followed by a few years of recovery, another decrease and then a large recovery (reaching unfished levels for run 'Estimate *M*') from new recruitment and then a decline to the present day.

The model attributes the two periods of biomass recovery to strong recruitment (Figure 5), based on information contained in the commercial and research age composition data. There are relatively long periods of low recruitment punctuated by occasional episodes of good recruitment, one in the early 1960s and another in the early 1980s. Such episodic large recruitment events appear to be characteristic of North Pacific rockfish populations (Love *et al*., 2002).

Estimated exploitation rates (Figure 6) peaked in the mid-1960s due to the large catches, and peaked again (though not as high) in the late 1980s to early 1990s.

Table 1. The 5th, 50th and 95th percentiles of MCMC-derived quantities from the 1000 samples of the MCMC posterior for runs 'Estimate M' and 'Fix M'. Definitions are: B_0 – unfished equilibrium spawning biomass (mature females), V_0 – unfished equilibrium vulnerable biomass (males and females), B_{2011} – spawning female biomass at the start of 2011, V_{2011} – vulnerable biomass in the middle of 2011, u_{2010} – exploitation rate (ratio of total catch to vulnerable biomass) in the middle of 2010, u_{max} – maximum exploitation rate from 1940-2010, B_{MSY} – equilibrium spawning biomass at MSY (maximum sustainable yield), u_{MSY} – equilibrium exploitation rate at MSY, V_{MSY} – equilibrium vulnerable biomass at MSY. All biomass values (and MSY) are in tonnes. For reference, the average catch over the last five years (2006-2010) is 1,442 t.

	Estimate *M*			**Fix *M***		
Quantity▼	5%	50%	95%	5%	50%	95%
B_0	35,684	46,295	70,317	33,497	37,290	42,418
V_0	74,412	95,978	145,837	65,591	73,252	83,543
B_{2011}	15,866	28,425	57,052	9,727	15,239	22,718
V_{2011}	32,043	57,528	115,834	19,073	29,849	44,596
B_{2011}/B_0	0.431	0.614	0.829	0.289	0.409	0.547
V_{2011}/V_0	0.425	0.601	0.806	0.288	0.407	0.542
u_{2010}	0.010	0.020	0.036	0.026	0.038	0.059
$u_{\max}$	0.059	0.090	0.123	0.110	0.130	0.154
$0.4B_{MSY}$	2,590	4,304	6,863	2,170	3,254	4,532
$0.8B_{MSY}$	5,180	8,608	13,725	4,340	6,507	9,065
B_{MSY}	6,475	10,760	17,156	5,425	8,134	11,331
B_{MSY}/B_0	0.149	0.233	0.314	0.147	0.216	0.298
B_{2011}/B_{MSY}	1.606	2.685	4.573	1.085	1.922	3.204
MSY	1,717	2,567	4,297	1,236	1,693	2,108
u_{MSY}	0.061	0.109	0.201	0.056	0.100	0.167
u_{2010}/u_{MSY}	0.070	0.180	0.433	0.191	0.383	0.872
V_{MSY}	14,841	23,693	37,241	11,831	17,044	23,400
V_{MSY}/V_0	0.163	0.245	0.323	0.163	0.232	0.309

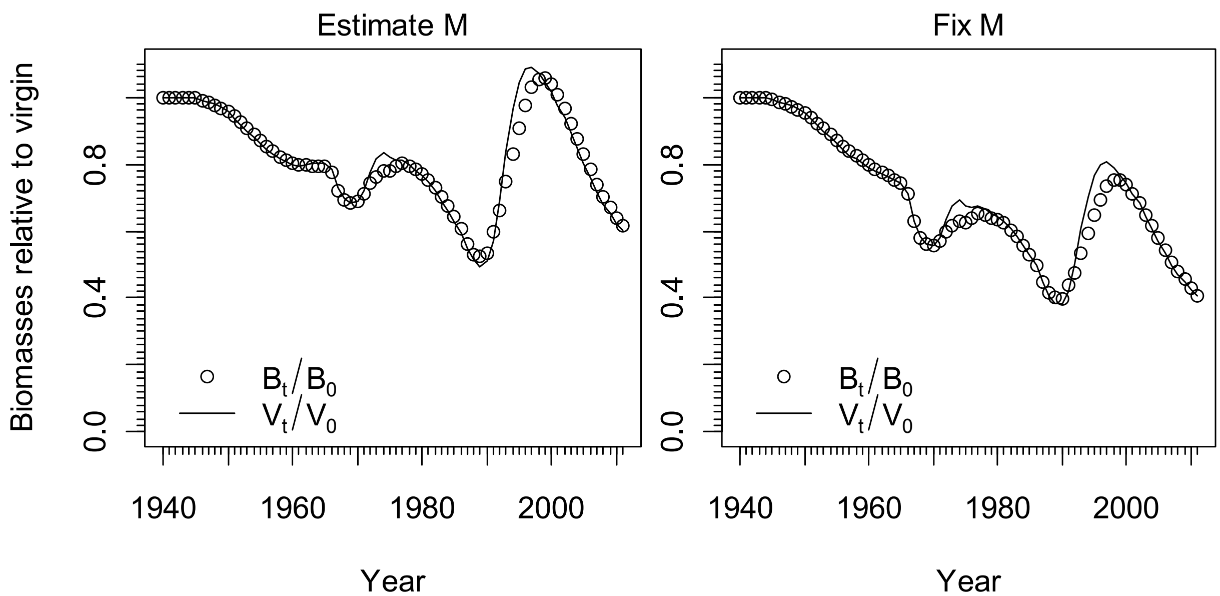

Figure 4. Changes in B_t/B_0 and V_t/V_0 (spawning and vulnerable biomass relative to unfished equilibrium levels) over time for runs 'Estimate M' and 'Fix M', shown as the medians of the MCMC posteriors.

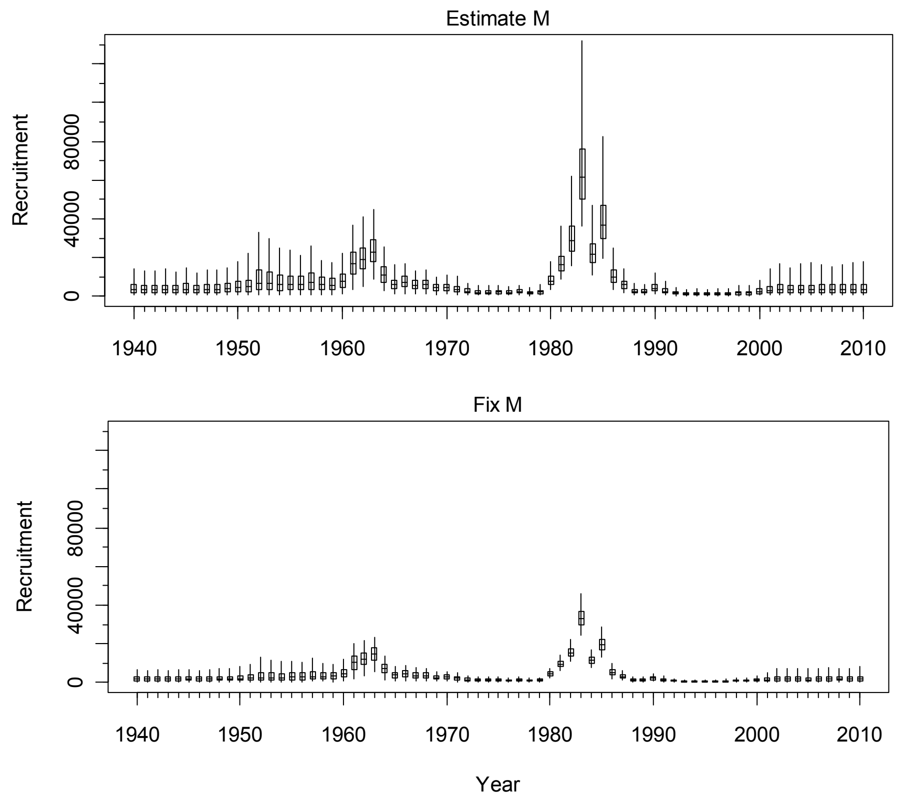

Figure 5. Marginal posterior distribution of recruitment in 1000's of age 1 fish plotted over time for run 'Estimate M' (top) and run 'Fix M' (bottom). The boxplots give the 2.5, 25, 50, 75 and 97.5 percentiles from the MCMC results.

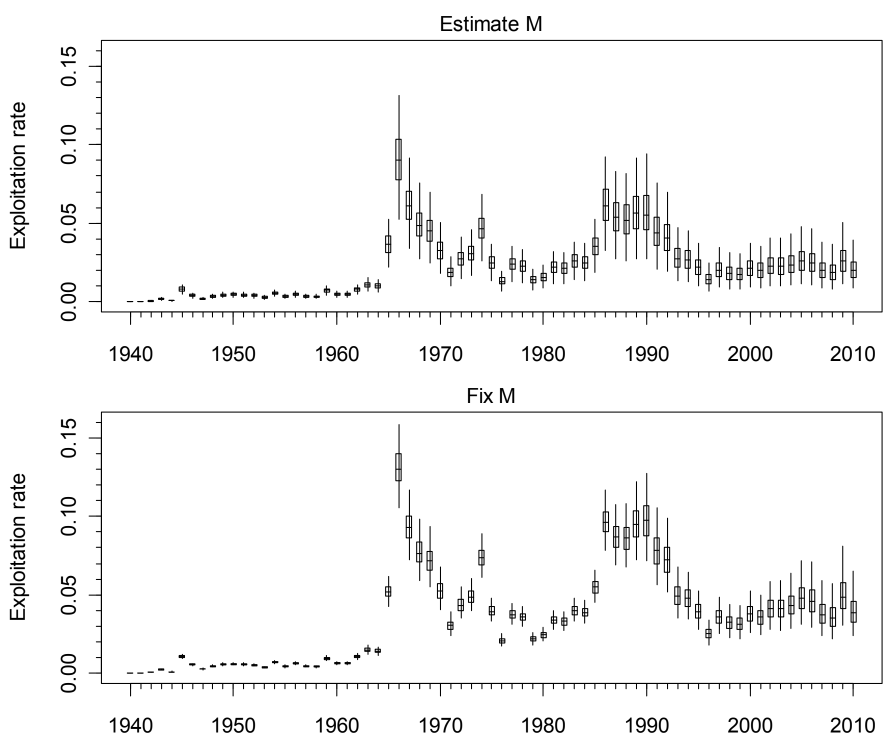

Figure 6. Marginal posterior distribution of exploitation rate (catch divided by vulnerable biomass) plotted over time for run 'Estimate M' (top) and run 'Fix M' (bottom). The boxes give the 2.5, 25, 50, 75 and 97.5 percentiles from the MCMC results.

The differences in the magnitudes of estimated recruitment (Figure 5) and spawning biomass (black boxplots in Figures 7 and 8) between the two model runs arise because run 'Estimate *M*' estimates higher natural mortality than that used for run 'Fix *M*'. The other major difference between the two model runs is the greater uncertainty (e.g. Figure 5) introduced through allowing *M* to be an estimable parameter rather than assumed to be known and fixed.

Estimates of depletion (B_{2011} / B_0) differ from that made by COSEWIC (2010), which, in addition to the surveys used in this assessment, also used the US National Marine Fisheries Service Triennial Survey in its 2010 report on Yellowmouth Rockfish. The COSEWIC determination was based on an analysis of amalgamated survey data, not on an integrated stock assessment model. The stock assessment presented here omitted the Triennial Survey because it does not monitor an area of representative abundance for this species (see Figure 2, which shows a much lower catch per unit effort below 50°N, which was the northernmost extent of the survey and was not reached in every survey year). Furthermore, the decline observed by the Triennial Survey was not consistent with the increased abundance that was estimated by the assessment model from the strong recruitment evident in the age composition data. This signal of increased abundance was very strong and persisted even when the Triennial Survey was included in the assessment as a sensitivity run.

Projections

Projections were made to evaluate potential future behaviour of the population under different levels of constant catch. To address the potential for recovery of a *Threatened* species, DFO (2007) requested that projections be made over 'three generations (or other biologically reasonable time)'. Given a 30-year generation time (which is the average age of parents) for Yellowmouth Rockfish, projections were taken to a maximum of 90 years. The projections, starting with the biomass at the beginning of 2011, were made over a range of constant catch strategies (0-3,000 t) for each of the 1,000 MCMC samples in the posterior, generating future biomass trends by assuming random recruitment deviations mediated through the assessment model's stock-recruitment function. Resulting projections of spawning biomass are shown for selected catch strategies for run 'Estimate *M*' (Figure 7) and run 'Fix *M*' (Figure 8).

Although uncertainty is built into the projections (and the overall assessment) by taking a Bayesian approach for parameter estimation, results depend heavily on model and data assumptions, particularly the average recruitment assumptions used for the projections. The projection procedure does not capture the occasional rare but very large recruitment events that have had a significant impact on the historical biomass trajectory, mainly because it is impossible to estimate the frequency and size of these events due to their rarity.

Projections also assume (as in the stock assessment model) that life-history parameters and other conditions remain stationary. Finally, the assumption that a constant catch scenario will operate continuously without feedback intervention is a strong assumption that is unlikely to persist if the stock is declining.

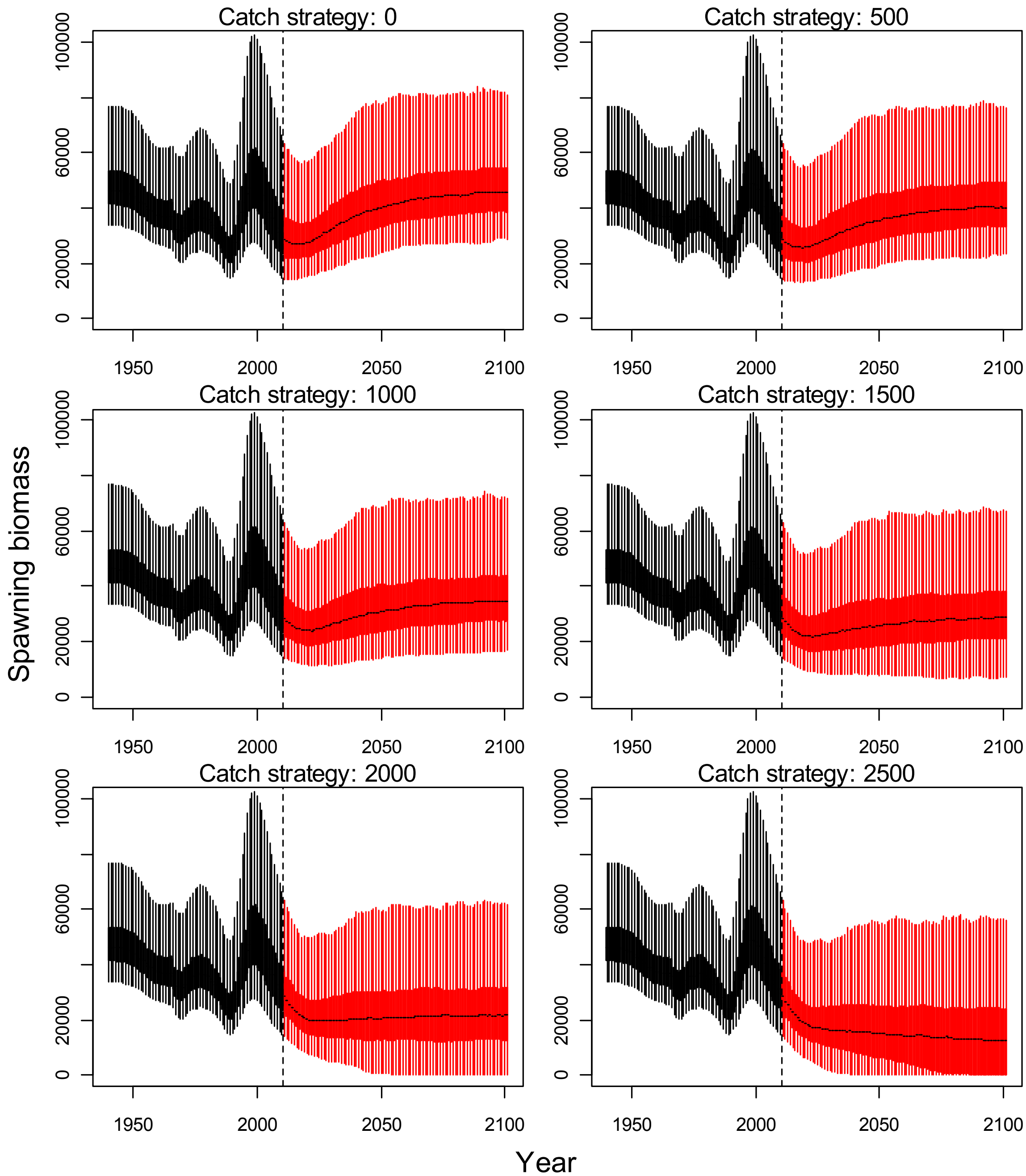

Figure 7. Projected spawning biomass (t) under different constant catch strategies (t) for run 'Estimate M' (boxplots show the 2.5, 25, 50, 75 and 97.5 percentiles from the MCMC results; given the large number of years the boxes appear as bolder regions). Black boxplots are estimates for 1940-2011. For each of the 1000 samples from the MCMC posterior, the model was run forward in time (red, with medians in black) with a constant catch, and recruitment was simulated from the stock-recruitment function with lognormal error. For reference, the average catch over the last five years (2006-2010) is 1,442 t.

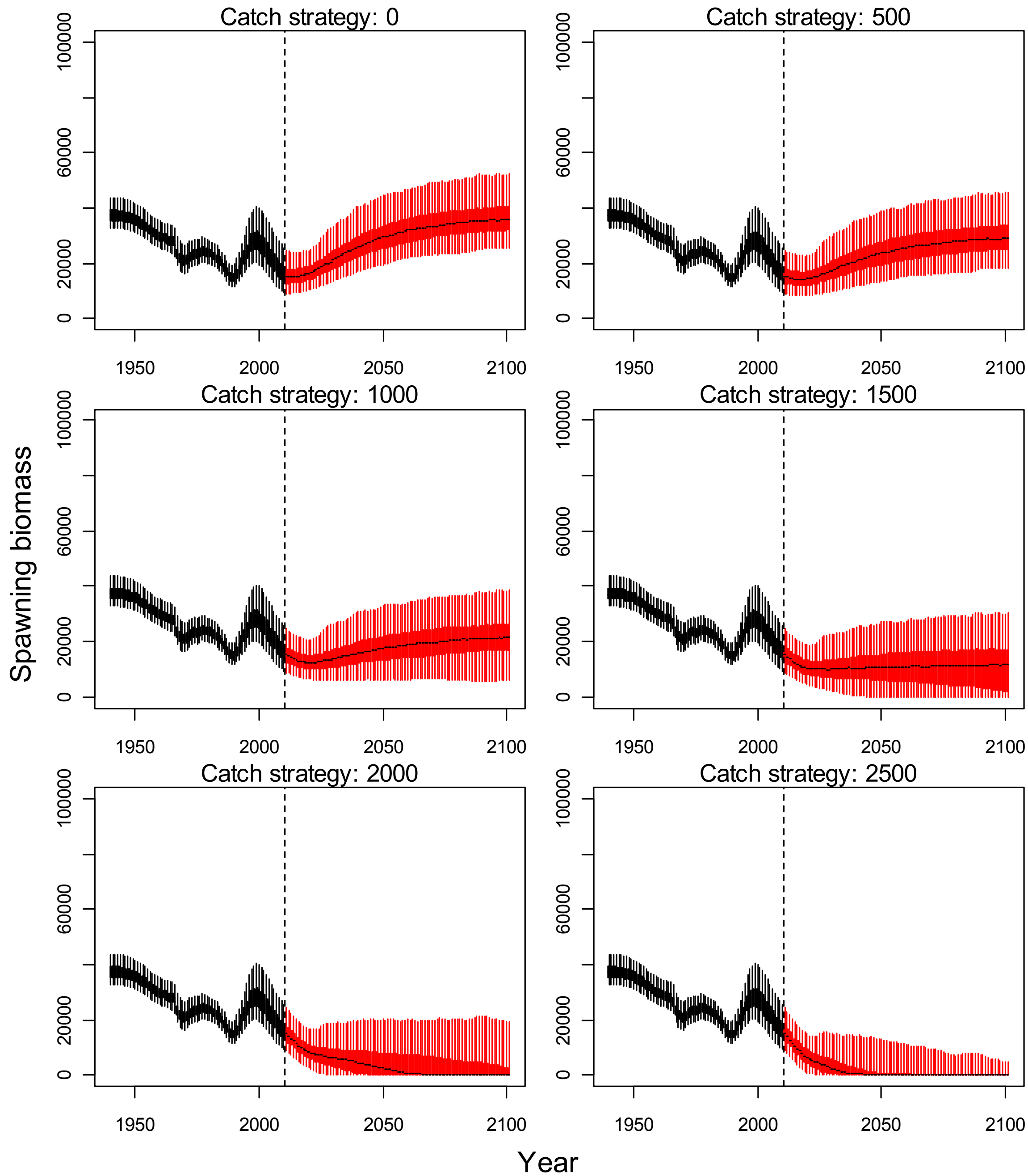

Figure 8. As for Figure 7 but for run 'Fix M'.

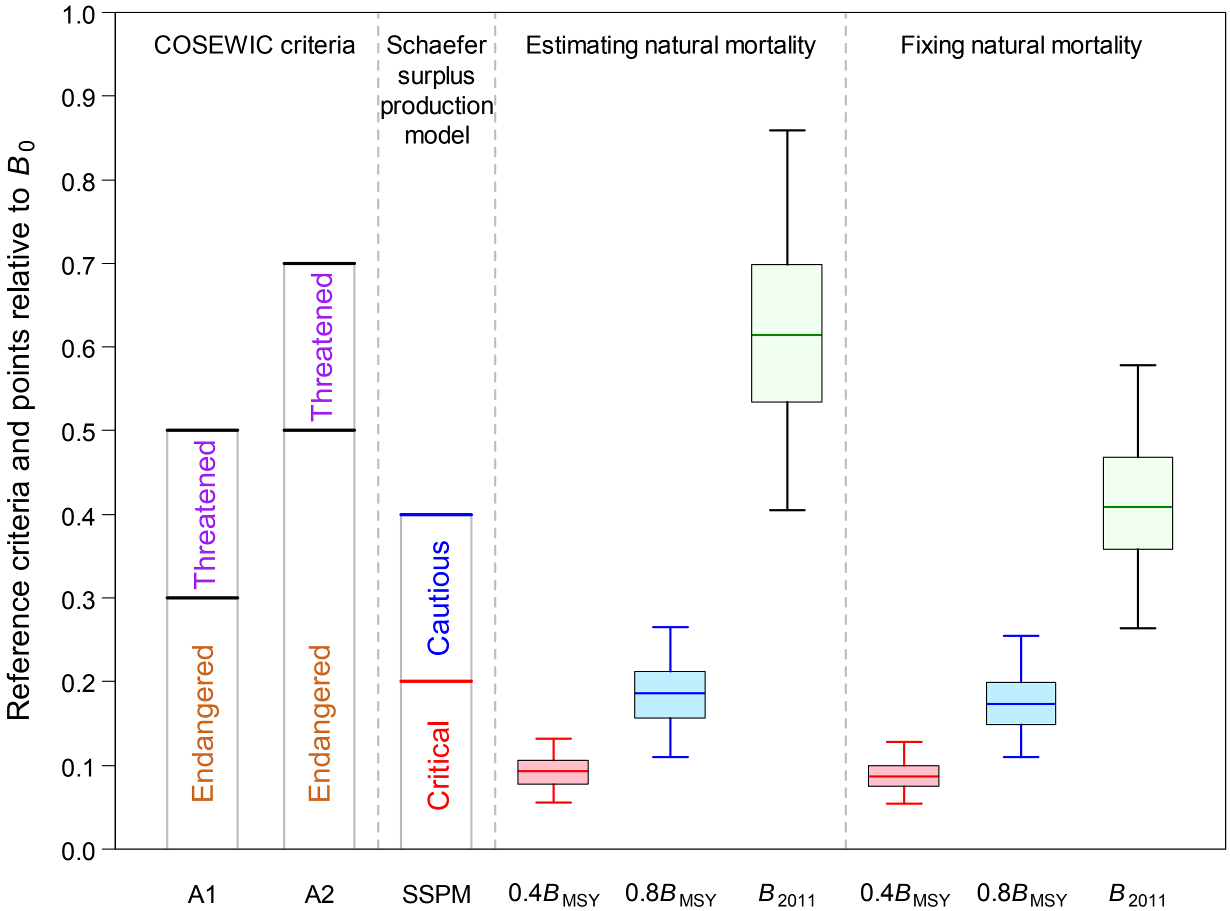

Figure 9. Reference criteria (for 2011), reference points and stock sizes as proportions of the unfished equilibrium spawning biomass (mature females), B_0. COSEWIC criteria A1 and A2 are defined in terms of percentage declines over three generations (90 years). Therefore the indicators A1 and A2 become fixed proportions of B_0 in 2011 because the model starts less than three generations ago. For a Schaefer surplus production model (SSPM), by definition $B_{MSY}=0.5B_0$; hence the provisional DFO Sustainable Fisheries Framework reference points of $0.4B_{MSY}$ and $0.8B_{MSY}$ lie at $0.2B_0$ (red bar) and $0.4B_0$ (blue bar), respectively. Thus, for this model the population could be simultaneously in the healthy zone ($>0.8B_{MSY}=0.4B_0$) with respect to the DFO Sustainable Fisheries Framework, but be considered Endangered ($<0.5B_0$) with respect to COSEWIC indicator A2. For the Yellowmouth Rockfish age-structured model, the relationship between B_{MSY} and B_0 is determined by the biological parameters of the model rather than external fixed assumptions. The resulting estimates of $0.4B_{MSY}$ (red boxplots) and $0.8B_{MSY}$ (blue boxplots) are shown for the two model runs (horizontal bars are medians, boxes are the 25-75 percentiles and whiskers extend to the 2.5 and 97.5 percentiles). Green boxplots show the present estimated spawning biomass, B_{2011}.

Reference Points and Criteria

Decision tables are presented with respect to three sets of reference points or reference criteria. Each set is based on either B_{MSY} (the estimated equilibrium spawning biomass (mature females only) that will support the maximum sustainable yield, MSY), B_0 (the estimated unfished equilibrium spawning biomass) or $B_{t\text{-3Gen}}$ (the spawning biomass three generations before B_t, the spawning biomass at the beginning of year t). Figure 9 summarizes the relationship between the reference points and criteria that are defined below. *Reference criteria* are defined here in terms of a changing reference biomass, whereas *reference points* are based on fixed biomass values.

As part of the Sustainable Fisheries Framework, DFO (2009) suggested provisional reference points to guide management and assess harvest in relation to sustainability. Because reference points for Canadian west coast groundfish species have not yet been specified by policy, the suggested provisional DFO limit and upper stock reference points of $0.4B_{\mathrm{MSY}}$ and $0.8B_{\mathrm{MSY}}$ have been used here. Figure 9 shows these reference points relative to B_0 for the two accepted model runs, showing that the distribution of $0.8B_{\mathrm{MSY}}$ lies $<0.5B_0$ (which would be considered *Endangered* in 2011 under COSEWIC indicator A2). This contradiction was highlighted in DFO (2005, p10).

Internationally, 'proxy' reference points that are expressed in terms of B_0 rather than B_{MSY} are used (e.g. New Zealand Ministry of Fisheries, 2007), because B_{MSY} is often poorly estimated as it is dependent on estimated parameters and a consistent fishery. Therefore, the reference points of $0.2\mathrm{B}_0$ and $0.4\mathrm{B}_0$ are reported which are values used in New Zealand for a 'soft' limit (below which management action needs to be taken) and 'target' biomass (a mean around which the biomass is expected to vary).

The reference criteria used here to assess COSEWIC recovery are defined by the COSEWIC indicators A1 and A2 for species that have been assessed as *Threatened* (http://www.cosewic.gc.ca/eng/sct0/assessment_process_e.cfm, updated August 2010). The indicators are based on a decline in the total number of mature individuals over the most recent 10 years or 3 generations, whichever is longer. Because the generation time for Yellowmouth Rockfish is estimated to be 30 years, three generations (90 years) has been used as the period over which to calculate the decline. Indicator A1 is reserved for those species where the causes of the reduction are clearly reversible, understood, and ceased. Indicator A2 is used when the population reduction may not be reversible, may not be understood, or may not have ceased. COSEWIC (2010) designated Yellowmouth Rockfish in Canada as *Threatened* under criterion A2b (where the '*b*' indicates that the designation was based on "an index of abundance appropriate to the taxon").

Under A1, a species is considered *Threatened* if the decline has been between 50 and 70% over three generations; under A2, the decline thresholds for the *Threatened* designation are between 30 and 50%. Therefore, since COSEWIC designated Yellowmouth Rockfish under A2, the recovery reference criteria become $0.5B_{t\text{-3Gen}}$ (a 50% decline) and $0.7B_{t\text{-3Gen}}$ (a 30% decline), where $B_{t\text{-3Gen}}$ is the biomass three generations previous to the biomass in year t. For the initial 19 years of the projection, $B_{t\text{-3Gen}}$ is set to B_0 because the reconstructed population from 1940 to 2011 is less than 3 generations; therefore, the COSEWIC criteria are expressed in terms of B_0 (as in Figure 9) for the first 19 years of the projections. From year 20 of the projections, $B_{t\text{-3Gen}}$ moves forward in time as a 90-year long moving window; for example, the projected spawning biomass in 2048, B_{2048}, is compared with that 90 years earlier, $B_{t\text{-3Gen}} = B_{2048\text{-}90} = B_{1958}$.

The estimated current spawning biomass, B_{2011} (Figure 9), lies mostly in the COSEWIC A2 *Threatened* region when estimating natural mortality, and mostly in the COSEWIC A2 *Endangered* region when fixing natural mortality, yet is $>0.8B_{\mathrm{MSY}}$ for both model runs and thus lies in the healthy zone of the DFO Sustainable Fisheries Framework.

Decision tables give the probabilities of exceeding the reference points or reference criteria in specified years, calculated by counting the proportion of MCMC samples that satisfied the reference points or reference criteria. They are given for the reference points in Table 2 ('Estimate *M*') and Table 3 ('Fix *M*'), and then for the reference criteria in Table 4 ('Estimate *M*') and Table 5 ('Fix *M*').

Table 2. Decision tables for four reference points (RP) $0.4B_{MSY}$, $0.8B_{MSY}$, $0.2B_0$ and $0.4B_0$, projected from 2011 for 90 years over a range of constant catch strategies (in tonnes), for run 'Estimate M'. Value P(B_t > *RP*) *is the probability of the spawning biomass at the beginning of year t being greater than the reference point. The probabilities are based on the MCMC posterior distributions of B_t and B_{MSY} or B_0.*

Annual catch strategy	Projection Year 0	5	10	15	30	45	60	75	90
P(B_t > 0.4B_{MSY})									
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
500	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1000	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1500	1.00	1.00	1.00	1.00	1.00	0.99	0.99	0.98	0.98
2000	1.00	1.00	1.00	0.99	0.97	0.94	0.90	0.88	0.86
2500	1.00	1.00	0.99	0.97	0.87	0.78	0.71	0.67	0.63
P(B_t > 0.8B_{MSY})									
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
500	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1000	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1500	1.00	1.00	1.00	0.98	0.98	0.97	0.97	0.97	0.97
2000	1.00	1.00	0.98	0.95	0.90	0.87	0.85	0.83	0.82
2500	1.00	0.99	0.95	0.88	0.74	0.67	0.62	0.60	0.58
P(B_t > 0.2B_0)									
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
500	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1000	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1500	1.00	1.00	0.99	0.99	0.98	0.98	0.97	0.97	0.97
2000	1.00	1.00	0.98	0.96	0.90	0.87	0.86	0.84	0.83
2500	1.00	0.99	0.95	0.87	0.74	0.65	0.61	0.59	0.56
P(B_t > 0.4B_0)									
0	0.98	0.99	0.99	0.99	1.00	1.00	1.00	1.00	1.00
500	0.98	0.96	0.96	0.97	1.00	1.00	1.00	1.00	1.00
1000	0.98	0.92	0.88	0.88	0.94	0.97	0.98	0.99	0.99
1500	0.98	0.87	0.76	0.72	0.77	0.83	0.84	0.86	0.88
2000	0.98	0.81	0.61	0.57	0.58	0.59	0.59	0.61	0.62
2500	0.98	0.76	0.47	0.41	0.39	0.36	0.37	0.35	0.34

Table 3. As for Table 2 but for run 'Fix M'.

Annual catch strategy	Projection Year 0	5	10	15	30	45	60	75	90
P(B_t > 0.4B_{MSY})									
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
500	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1000	1.00	1.00	1.00	0.99	0.99	0.99	0.99	0.98	0.98
1500	1.00	1.00	0.99	0.96	0.89	0.83	0.78	0.76	0.74
2000	1.00	0.99	0.93	0.82	0.57	0.42	0.34	0.29	0.24
2500	1.00	0.98	0.79	0.56	0.23	0.12	0.08	0.05	0.04
P(B_t > 0.8B_{MSY})									
0	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
500	0.99	0.99	0.99	0.98	1.00	1.00	1.00	1.00	1.00
1000	0.99	0.97	0.95	0.95	0.95	0.96	0.96	0.96	0.96
1500	0.99	0.94	0.85	0.80	0.75	0.72	0.69	0.68	0.67
2000	0.99	0.89	0.67	0.55	0.39	0.31	0.27	0.23	0.20
2500	0.99	0.82	0.45	0.29	0.13	0.08	0.06	0.03	0.02
P(B_t > 0.2B_0)									
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
500	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1000	1.00	0.99	0.97	0.96	0.96	0.97	0.97	0.97	0.97
1500	1.00	0.96	0.84	0.76	0.71	0.68	0.66	0.66	0.65
2000	1.00	0.89	0.59	0.44	0.31	0.25	0.21	0.19	0.16
2500	1.00	0.79	0.34	0.19	0.09	0.05	0.03	0.03	0.01
P(B_t > 0.4B_0)									
0	0.55	0.58	0.77	0.92	1.00	1.00	1.00	1.00	1.00
500	0.55	0.42	0.44	0.62	0.92	0.98	0.99	0.99	0.99
1000	0.55	0.27	0.19	0.29	0.58	0.70	0.78	0.82	0.87
1500	0.55	0.15	0.07	0.10	0.22	0.28	0.30	0.32	0.34
2000	0.55	0.09	0.01	0.04	0.06	0.06	0.06	0.05	0.05
2500	0.55	0.05	0.00	0.01	0.02	0.01	0.00	0.00	0.00

Table 4. Decision tables for run 'Estimate M' for two reference criteria (RC=0.5$B_{t\text{-}3Gen}$ and RC=0.7$B_{t\text{-}3Gen}$), where $B_{t\text{-}3Gen}$ is the spawning biomass 3 generations (90 years) before year t. Value P(B_t > *RC*) *is the probability of the spawning biomass at the beginning of year t satisfying (being greater than) the reference criterion RC, based on the MCMC posterior samples. $B_{t\text{-}3Gen}$=B_0 if t<2030 because the model start year is <90 years beforehand. The criterion RC=0.5$B_{t\text{-}3Gen}$ corresponds to a 50% decline over 3 generations, and RC=0.7$B_{t\text{-}3Gen}$ corresponds to a 30% decline over three generations, which are the respective COSEWIC A2 criteria for Endangered and Threatened. Values are shown over a range of constant catch strategies (in tonnes).*

Annual catch	Projection Year						
strategy	0	15	30	45	60	75	90
P(B_t >0.5$B_{t\text{-}3Gen}$)							
0	0.84	0.94	1.00	1.00	1.00	1.00	1.00
500	0.84	0.79	0.98	1.00	1.00	0.99	1.00
1000	0.84	0.61	0.84	0.97	0.99	0.95	1.00
1500	0.84	0.44	0.63	0.84	0.87	0.75	0.96
2000	0.84	0.29	0.44	0.60	0.63	0.42	0.75
2500	0.84	0.19	0.28	0.40	0.39	0.17	0.43
P(B_t >0.7$B_{t\text{-}3Gen}$)							
0	0.25	0.31	0.86	1.00	1.00	0.95	1.00
500	0.25	0.19	0.64	0.95	0.98	0.84	1.00
1000	0.25	0.11	0.42	0.79	0.87	0.61	0.99
1500	0.25	0.06	0.25	0.55	0.63	0.29	0.86
2000	0.25	0.04	0.14	0.34	0.37	0.10	0.54
2500	0.25	0.02	0.08	0.18	0.18	0.04	0.23

Table 5. As for Table 4 but for run 'Fix M'.

Annual catch	Projection Year						
strategy	0	15	30	45	60	75	90
P(B_t >0.5$B_{t\text{-}3Gen}$)							
0	0.14	0.54	0.99	1.00	1.00	1.00	1.00
500	0.14	0.23	0.79	0.99	1.00	1.00	1.00
1000	0.14	0.07	0.38	0.80	0.90	0.90	0.98
1500	0.14	0.03	0.12	0.37	0.48	0.40	0.64
2000	0.14	0.01	0.03	0.09	0.12	0.07	0.14
2500	0.14	0	0.01	0.02	0.01	0.01	0.01
P(B_t >0.7$B_{t\text{-}3Gen}$)							
0	0	0.03	0.63	1.00	1.00	1.00	1.00
500	0	0.01	0.25	0.87	0.98	0.97	1.00
1000	0	0	0.07	0.46	0.71	0.67	0.96
1500	0	0	0.02	0.15	0.26	0.16	0.52
2000	0	0	0	0.03	0.05	0.02	0.08
2500	0	0	0	0	0	0	0

The interpretation of reference criteria is more difficult than for reference points, because the reference biomass is not constant over time. For instance, Tables 4 and 5 show that, for a catch of 1,000 t, the probabilities increase from 15 to 30 to 45 to 60 years, but then decrease (or stay constant) for year 75, even though the projected biomass is still increasing (Figure 7). This is because the biomass 90 years beforehand underwent a large increase (Figure 7), and so the reference criteria of 0.5$B_{t\text{-}3Gen}$ and 0.7$B_{t\text{-}3Gen}$ become higher (and therefore harder to meet). However, in Tables 2 and 3, the reference biomass levels remain fixed through time.

Estimated times to reach the reference points and reference criteria are given in Table 6 ('Estimate *M*') and Table 7 ('Fix *M*'). Times are given for three different levels of confidence: 50%, 80% and 95%. New Zealand Ministry of Fisheries (2011) guidelines aim to achieve a *target* with a 50% probability, given that a 50% confidence represents an equal probability of

Table 6. Decision table showing the time to reach the four reference points (RP): $0.4B_{MSY}$, $0.8B_{MSY}$, $0.2B_0$ and $0.4B_0$, and the two reference criteria (RC) of $0.5B_{t\text{-}3Gen}$ and $0.7B_{t\text{-}3Gen}$ over a range of constant catch strategies (in tonnes) for three levels of confidence for run 'Estimate M'. Values are the first year that the RP or RC is reached with the given confidence level (and the population is increasing), where 0 means that the projected population always exceeds the RP or RC and 90 means that the RP or RC is not reached within 90 years.

Annual catch	Reference Point or Reference Criterion					
strategy	$0.4B_{MSY}$	$0.8B_{MSY}$	$0.2B_0$	$0.4B_0$	$0.5B_{t\text{-}3Gen}$	$0.7B_{t\text{-}3Gen}$
50% confidence						
0	0	0	0	0	0	20
500	0	0	0	0	0	26
1000	0	0	0	0	0	32
1500	0	0	0	0	21	41
2000	0	0	0	0	34	64
2500	0	0	0	90	66	90
80% confidence						
0	0	0	0	0	0	29
500	0	0	0	0	16	34
1000	0	0	0	0	28	46
1500	0	0	0	38	39	65
2000	0	0	0	90	90	90
2500	90	90	90	90	90	90
95% confidence						
0	0	0	0	0	17	35
500	0	0	0	0	28	45
1000	0	0	0	38	40	64
1500	0	0	0	90	67	90
2000	90	90	90	90	90	90
2500	90	90	90	90	90	90

Table 7. As for Table 5, but for run 'Fix M'.

Annual catch	Reference Point or Reference Criterion					
strategy	$0.4B_{MSY}$	$0.8B_{MSY}$	$0.2B_0$	$0.4B_0$	$0.5B_{t\text{-}3Gen}$	$0.7B_{t\text{-}3Gen}$
50% confidence						
0	0	0	0	0	15	29
500	0	0	0	12	23	35
1000	0	0	0	25	34	46
1500	0	0	0	90	62	67
2000	90	90	90	90	90	90
2500	90	90	90	90	90	90
80% confidence						
0	0	0	0	12	21	33
500	0	0	0	22	31	43
1000	0	0	0	65	46	63
1500	90	90	90	90	90	90
2000	90	90	90	90	90	90
2500	90	90	90	90	90	90
95% confidence						
0	0	0	0	17	27	38
500	0	0	0	36	38	46
1000	0	27	0	90	65	89
1500	90	90	90	90	90	90
2000	90	90	90	90	90	90
2500	90	90	90	90	90	90

being above or below the target. A probability of 95% is often used in statistics to conclude statistical significance and is likely most appropriate for *limit* reference points, where a high degree of certainty is required to be above the reference point. The 80% confidence level is intermediate between 50 and 95%.

Although Yellowmouth Rockfish is characterised as a long-lived, slow growing species, this population is clearly able to make a rapid recovery from biomass levels $<0.5B_0$. For both model runs, the spawning biomass roughly doubled through the 1990s (Figure 4), with run 'Estimate *M*' peaking above B_0, and run 'Fix *M*' reaching $0.75B_0$. These observed recoveries demonstrate that large episodic recruitments, although infrequent, have the capacity to rebuild the stock to high levels.

The 17 Recovery Potential Assessment framework tasks from DFO (2007)

DFO (2007) specified that Recovery Potential Assessments should routinely address the following 17 tasks, given below (in italics) with the associated advice. In every case, the best possible science advice should be provided given the information that can be assembled, and uncertainties taken into account. Quantities are given for run 'Estimate *M*' followed by run 'Fix *M*', and, where appropriate, as medians (with 5-95% credible intervals) from the MCMC posterior distributions.

Phase I: Assess current/recent species status

1. Evaluate ***present species status*** *for abundance, range and number of populations.*

A single coastwide population of Yellowmouth Rockfish was considered by COSEWIC (2010).

The estimated ratio of current spawning biomass (mature females) to the unfished equilibrium level (B_{2011} / B_0) is 0.61 (0.43-0.83) for run 'Estimate *M*' and 0.41 (0.29-0.55) for run 'Fix *M*'. The present stock status for the two model runs with respect to the reference points and reference criteria is shown in Figure 9, with the probabilities of achieving them given in the '0 Projection Year' column of Tables 2-5.

Figure 2 shows the range of Yellowmouth Rockfish (as measured by catches from the groundfish trawl fishery over the last 15 years). This species has been encountered by the British Columbia trawl fleet over an estimated 29,500 km^2.

2. Evaluate ***recent species trajectory*** *for abundance, range, and number of populations.*

The estimated ratio of spawning biomass (mature females) to the unfished equilibrium level (B_t / B_0) over the most recent period of increase and decrease (Figure 4) are: for run 'Estimate *M*', from a low of 0.52 (median of the MCMC posterior distribution) in 1989 increasing to 1.06 in 1999 and then declining down to 0.64 at the start of 2011; and for run 'Fix *M*,' from a low of 0.40 in 1990 increasing to 0.75 in 1999 and then declining down to 0.41 at the start of 2011. The increase through the 1990s is the result of a period of very strong recruitment in the early 1980s. Evidence for this high recruitment can be seen in the proportions-at-age data from the commercial fishery and research surveys.

There is no evidence for a change in the occupied range of the population.

*3. Estimate, to the extent that information allows, the current or recent **life history parameters** for the species (total mortality [Z], natural mortality [m], fecundity, maturity, recruitment, etc.) or reasonable surrogates, and associated uncertainties for all parameters.*

For run 'Estimate *M*', the natural mortality rate was estimated to be 0.0595 (0.0544-0.0648) for females and 0.0559 (0.0507-0.0613) for males, and the current exploitation rate (ratio of total catch to vulnerable biomass in the middle of the year) was estimated to be 0.020 (0.010-0.036). The current total mortality rate (Z), calculated from $Z = M+F = M - \log(1-u)$ for mortality rate M and exploitation u, is 0.080 (0.072-0.094) for females and 0.076 (0.068-0.091) for males.

For run 'Fix *M*', natural mortality was fixed at 0.047 for females and males. Current exploitation was estimated to be 0.038 (0.026-0.059), giving an estimated total mortality rate Z of 0.086 (0.073-0.108) for both females and males.

For each model run, the estimated parameter values for the assumed Beverton-Holt stock-recruitment relationship were R_0 (unfished equilibrium recruitment of age-1 fish, in 1000s of fish): 7,342 (5,185-12,290) and 4,034 (3,624-4,589), and h (steepness): 0.807 (0.605-0.951) and 0.841 (0.640-0.957).

At age 11, 48% of females were estimated from data to be mature.

*4. Address the separate terms of reference for describing and quantifying (to the extent possible) the **habitat requirements and habitat use patterns** of the species.*

Habitat is not thought to be a limiting factor for Yellowmouth Rockfish. Maps of the catch distribution of Yellowmouth Rockfish (from 1996-2011) overlaid with the spatial distribution of surficial geology for Queen Charlotte Sound show that catches are concentrated over glacial outwash along the canyon walls of Goose Island Gully.

*5. Estimate expected **population and distribution targets** for recovery, according to DFO guidelines.*

The estimated values of expected population targets (whether based on reference points or reference criteria) can be calculated from the B_0 and B_{MSY} estimates in Table 1 (although for the reference criteria that are based on the biomass three generations prior, the target will change continuously after 2030).

*6. Project **expected population trajectories** over three generations (or other biologically reasonable time), and trajectories over **time to the recovery target** (if possible to achieve), given current population dynamics parameters and associated uncertainties using DFO guidelines on long-term projections.*

Projections over three generations (reliant on the assumptions regarding the data, the model and future management responses) under different constant catch strategies are presented in Figures 7 and 8. Probabilities of attaining reference points and reference criteria are given in Tables 2-5, and projected times to reach them are given in Tables 6 and 7.

*7. Evaluate **residence requirements** for the species, if any.*

Yellowmouth Rockfish does not have any known dwelling place similar to a den or nest during any part of its life-cycle. Therefore, the concept of residence does not apply.

Phase II: Scope for management to facilitate recovery.

8. Assess the ***probability that the recovery targets can be achieved*** *under current rates of population dynamics parameters, and* ***how that probability would vary with different mortality (****especially lower****) and productivity (****especially higher****) parameters.***

See task 6 (and Figures 7 and 8 and Tables 2-7). A range of constant catch strategies were considered in the projections, with productivity parameters estimated by the model under two accepted model runs. The effect of higher productivity was not considered. Under current levels of catch, the median spawning biomass is projected to be increasing within one generation (Figures 7 and 8). The infrequent, episodic nature of recruitment in this species should be taken into account in recovery planning.

9. Quantify to the extent possible the ***magnitude of each major potential source of mortality*** *identified in the pre-COSEWIC RAP and considering information in the COSEWIC Status Report, from DFO sectors, and other sources.*

Commercial fishing was identified as the primary threat to Yellowmouth Rockfish (COSEWIC 2010). For run ‘Estimate *M*’, the current exploitation rate (ratio of total catch in 2010 to the vulnerable biomass in the middle of 2010) was estimated to be 0.020 (0.010-0.036), compared to total mortality rates of 0.080 (0.072-0.094) for females and 0.076 (0.068-0.091) for males. For run ‘Fix *M*’, the estimated current exploitation rate is 0.038 (0.026-0.059), compared to a total mortality rate of 0.086 (0.073-0.108) for both females and males. Exploitation rate is estimated to be below natural mortality for both model runs.

10. Quantify to the extent possible the ***likelihood that the current quantity and quality of habitat is sufficient*** *to allow population increase, and would be sufficient to support a population that has reached its recovery targets (using the same methods as in step 4).*

Habitat is not believed to be a limiting factor for Yellowmouth Rockfish, and under current levels of catch the median spawning biomass is projected to be increasing within one generation.

11. Assess to the extent possible the magnitude by which current ***threats to habitats have reduced habitat quantity and quality.***

Habitat is not believed to be a limiting factor for Yellowmouth Rockfish.

Phase III: Scenarios for mitigation and alternative to activities

12. Using input from all DFO sectors and other sources as appropriate, develop an ***inventory of all feasible measures to minimize/mitigate*** *the impacts of activities that are threats to the species and its habitat (steps 9 and 11).*

The primary threat is commercial fishing, thus changing the catch level would be a feasible measure if it is required to reduce fishing mortality.

13. Using input from all DFO sectors and other sources as appropriate, develop an inventory of all reasonable ***alternatives to the activities*** *that are threats to the species and its habitat (steps 9 and 11), but with potential for less impact. (e.g. changing gear in fisheries causing bycatch mortality, relocation of activities harming habitat).*

The primary threat is commercial fishing, thus, if necessary, the catch level could be reduced. Habitat is not believed to be a limiting factor.

14. Using input from all DFO sectors and other sources as appropriate, develop an inventory of all ***reasonable and feasible activities that could increase the productivity or survivorship parameters*** *(steps 3 and 8).*

There do not appear to be any practical means for increasing the productivity of Yellowmouth Rockfish.

15. Estimate, to the extent possible, the ***reduction in mortality rate expected*** *by each of the mitigation measures in step 12 or alternatives in step 13 and* ***the increase in productivity or survivorship*** *associated with each measure in step14.*

See Figures 7 and 8 and Tables 2-7 for the projected effects on the population of different levels of constant catch.

16. Project ***expected population trajectory*** *(and uncertainties) over three generations (or other biologically reasonable time), and to the time of reaching recovery targets when recovery is feasible; given mortality rates and productivities from 15 that are* ***associated with specific scenarios*** *identified for exploration. Include scenarios which provide as high a probability of survivorship and recovery as possible for biologically realistic parameter values.*

See Figures 7 and 8 and Tables 2-7 for the projected effects on the population of different levels of constant catch, including times to reach reference points and criteria.

17. Recommend ***parameter values for population productivity and starting mortality rates,*** *and where necessary, specialized features of population models that would be required to allow exploration of additional scenarios as part of the assessment of economic, social, and cultural impacts of listing the species.*

Parameter estimates for natural mortality and recruitment for the two model runs are summarised under Task 3 above.

Sources of Uncertainty

Although this stock is relatively data-rich compared to other shelf and slope rockfish populations in western Canadian waters, the amount of historical data available to support the interpretation of the long early catch history is relatively small. There are no biomass indices prior to 1967 and the available age composition data are all relatively recent. The earliest available age data are able to provide information on year class strengths in the 1950s and 1960s, due to the long-lived nature of the species and the precision of the ageing methodology. Prior to 1991, species identification was not rigorous, and Pacific Ocean Perch was the only rockfish routinely identified in the commercial catch. It is likely there are species identification errors, with fish identified as Pacific Ocean Perch possibly being other rockfish species such as Yellowmouth.

It is acknowledged that there will be error in the ageing of Yellowmouth Rockfish, and preliminary runs investigating the effects of ageing error were explored. These runs added uncertainty to the model output without materially affecting the results.

Unlike for Pacific Ocean Perch (DFO 2011), there are no published estimates for natural mortality, and so the fixed value for this parameter used in the run ‘Fix *M*’ was developed from a generic formula that is based only on the maximum observed age. Estimates of natural mortality from run 'Estimate *M*' are based on the full range of available data, including 18 years of age composition data, and this run incorporates more uncertainty.

The accuracy of the projections is predicated on the model being correct. Uncertainty in the parameters was explicitly addressed using a Bayesian approach, but reflected only the specified model and weights assigned to the various data components. Projection accuracy also depends on uncertain future recruitment values and the assumed lack of management intervention in the constant catch scenarios.

CONCLUSIONS AND ADVICE

The assessment portrays a slow-growing, low productivity stock that has undergone periods of high recruitment in the early 1960s and the early 1980s. The advice is given in the form of decision tables (Tables 2-7) and associated Figures 7, 8 and 9. Listing and harvest decisions depend upon the choice of reference points or criteria.

SOURCES OF INFORMATION

This Science Advisory Report is from the Fisheries and Oceans Canada, Canadian Science Advisory Secretariat, Regional Advisory Process meeting held on 30th May 2011, reviewing Working Paper 2010/035 *Stock assessment and recovery potential assessment for Yellowmouth Rockfish (Sebastes reedi) along the Pacific coast of Canada.* Additional publications from this process will be posted as they become available on the DFO Science Advisory Schedule at http://www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm.

COSEWIC. 2010. COSEWIC assessment and status report on the yellowmouth rockfish *Sebastes reedi* in Canada. 64pp. http://www.sararegistry.gc.ca/document/default_e.cfm?documentID=2099

DFO. 2005. A framework for developing science advice on recovery targets for aquatic species in the context of the *Species at Risk Act.* DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2005/054. 16 p.

DFO. 2007. Revised Protocol for Conducting Recovery Potential Assessments. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2007/039. (Revised in April 2009).

DFO. 2009. A fishery decision-making framework incorporating the Precautionary Approach, (last modified 23 May 2009). http://www.dfo-mpo.gc.ca/fm-gp/peches-fisheries/fish-ren-peche/sff-cpd/precaution-eng.htm

DFO. 2011. Stock assessment for Pacific ocean perch (*Sebastes alutus*) in Queen Charlotte Sound, British Columbia in 2010. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2011/017. 11 p.

Haigh, R. and Starr, P. 2008. A review of yellowmouth rockfish *Sebastes reedi* along the Pacific coast of Canada: biology, distribution, and abundance trends. DFO Can. Sci. Advis. Sec. Res. Doc. 2008/055, 97 pp.

Love, M.S., Yoklavich, M., and Thorsteinson, L. 2002. The Rockfishes of the Northeast Pacific. University of California Press, Berkeley and Los Angeles, California, 404 p.

New Zealand Ministry of Fisheries. 2007. Operational guidelines for New Zealand's harvest strategy standard. Unpublished manuscript. 67 p.

New Zealand Ministry of Fisheries. 2011. Operational guidelines for New Zealand's harvest strategy standard. Unpublished manuscript, June 2011, ii + 78 p.

FOR MORE INFORMATION

Contact: Dr. Andrew Edwards
Pacific Biological Station, Fisheries and Oceans Canada
3190 Hammond Bay Road, Nanaimo, British Columbia V9T 6N7
Tel: 250-756-7146
Fax: 250-756-7053
E-Mail: Andrew.Edwards@dfo-mpo.gc.ca

This report is available from the:

Centre for Science Advice Pacific
Fisheries and Oceans Canada
Pacific Biological Station
3190 Hammond Bay Road
Nanaimo, BC V9T 6N7

Telephone: 250-756-7208
Fax: 250-756-7209
E-Mail: CSAP@dfo-mpo.gc.ca
Internet address: www.dfo-mpo.gc.ca/csas-sccs

ISSN 1919-5079 (Print)
ISSN 1919-5087 (Online)

La version française est disponible à l'adresse ci-dessus.

CORRECT CITATION FOR THIS PUBLICATION

DFO. 2012. Recovery Potential Assessment for Yellowmouth Rockfish (*Sebastes reedi*) along the Pacific Coast of Canada. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2011/060.