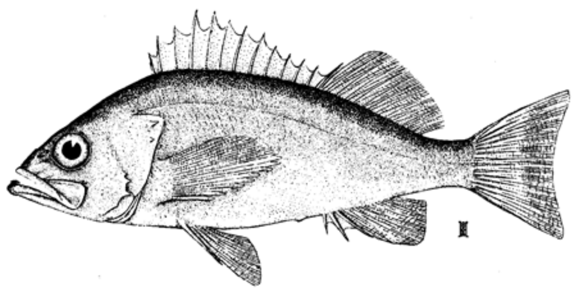
YELLOWTAIL ROCKFISH (*SEBASTES FLAVIDUS*) STOCK ASSESSMENT FOR THE COAST OF BRITISH COLUMBIA, CANADA



Yellowtail Rockfish (Sebastes flavidus). Credit: D.R. Harriott in Hart, J.L., 1973, Pacific fishes of Canada, Bull. Fish. Res. Bd. Can. 80.

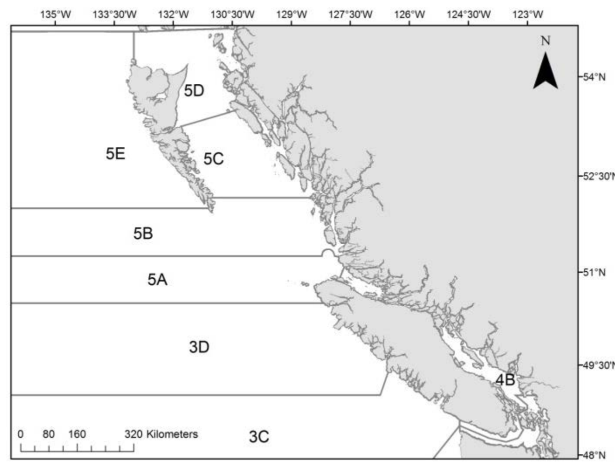


Figure 1. Pacific Marine Fisheries Commission major areas. The assessment covers area 3C (boundary stock) and areas 3D and 5A-E (coastal stock) combined. Area 4B is not assessed.

Context

Yellowtail Rockfish currently has the second largest single-species Total Allowable Catch (TAC) among rockfish species (Sebastes) under quota management along the west coast of Canada. Generally, this species is caught in equal amounts (by weight) by bottom and midwater trawl gear. Key results from the first stock assessment of Yellowtail Rockfish since 1998 are reported here. Advice on stock status and harvest level was required by the Fisheries Management Branch to inform management decisions and to evaluate consistency with the Fishery Decision-Making Framework Incorporating the Precautionary Approach.

This Science Advisory Report is from the November 18-19, 2014 Stock assessment for Yellowtail Rockfish (Sebastes flavidus) in British Columbia. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

- Yellowtail Rockfish is an important component of the multi-species and multi-gear groundfish fishery in British Columbia (BC). This species is the second-most important rockfish caught by midwater and bottom trawl gears in terms of total landings, after Pacific Ocean Perch (*Sebastes alutus*), and is also taken incidentally by the midwater trawl fishery directed at Pacific Hake (*Merluccius productus*).
- The BC population is assessed as a single stock using a two-sex statistical catch-at-age (SCA) model. Model inputs include reconstructed catches starting in 1940, one gear-type (bottom + midwater trawl), fishery-independent indices of relative biomass derived from six bottom trawl surveys spanning 40 years, and proportion-at-age data from commercial and survey sources. The model is implemented in a Bayesian framework to quantify uncertainty of estimated quantities and management parameters.
- The spawning biomass (mature females only) at the beginning of 2015 (B_{2015}) is estimated to be 0.50 (0.30-0.76) of unfished spawning biomass (B_0), where numbers denote median and (5-95 percentiles) of the Bayesian estimates of parameter uncertainty. Also, B_{2015} is estimated to be 2.20 (1.12-4.41) of the equilibrium biomass at maximum sustainable yield, B_{MSY}.
- Forecasts of stock status relative to MSY-based, unfished, minimum and current biomass outcomes are presented. These outcomes include the provisional reference points from the decision making framework (DFO 2009), namely a provisional limit reference point of $0.4B_{\mathrm{MSY}}$ and upper reference point of $0.8B_{\mathrm{MSY}}$. For the BC coast, B_{2015} is estimated to have a 1.0 probability of being greater than $0.4B_{\mathrm{MSY}}$, and a 0.995 probability of being greater than $0.8B_{\mathrm{MSY}}$ (i.e., of being in the Healthy Zone). The ratio of the exploitation rate in 2014 relative to that associated with MSY is 0.40.
- Advice to management is presented in the form of decision tables using ten year projections from 2016 to 2025 for a range of constant annual catches from 0 to 6,000 t. Annual catches at levels near the recent 5-year (2009-2013) mean of 4,333 t are predicted to cause a gradual decline of the population over the forecast period.
- Alternative model cases investigated the effects of
    - (a) separating data for bottom and midwater trawl gears,
    - (b) including the West Coast Vancouver Island shrimp trawl survey,
    - (c) increasing Yellowtail Rockfish catches during a period where actual catches were uncertain, and
    - (d) doubling the standard deviation on the prior distribution used to estimate the natural mortality parameter.

INTRODUCTION

Yellowtail Rockfish is an important component of the multi-species and multi-gear groundfish fishery in British Columbia (DFO 2014). This species was last fully assessed in 1997 and the assessment was updated in 1998 (Stanley and Haist 1997, Stanley 1998, DFO 1999). Colloquially known as “greenies”, Yellowtail Rockfish is the second-most important rockfish caught by midwater and bottom trawl gears, after Pacific Ocean Perch, and is also taken incidentally by the Pacific Hake midwater trawl fishery. Yellowtail Rockfish ranges from La Jolla, California, to Unalaska Island in the Aleutian chain; commercially fished populations range from central California northward to southern Alaska, with the centre of distribution from Oregon to BC.

In BC waters, Fisheries and Oceans Canada (DFO) manages Yellowtail Rockfish as two stock areas. A coastal stock is defined from central Vancouver Island northwards (Pacific Marine Fisheries Commission [PMFC], areas 3D, 5A-E, Figure 1), while the boundary stock includes waters off southern Vancouver Island (PMFC area 3C, Figure 1). There is no known biological basis for a stock boundary at central Vancouver Island; this division was set to facilitate management. Consequently the 2014 assessment treats the BC population as a single stock unit. The PMFC major areas used in the stock assessment are similar to those used by the Groundfish Management Unit (GMU) within Fisheries and Oceans Canada (DFO).

The mean annual coastwide catches (averaged over 2009-2013) are 1,041 t for the boundary stock, 3,291 t for the coastal stock, and 4,333 t coastwide (Figure 2). The annual Total Allowable Catches (TACs) in these areas have been 1,006 t, 3,464 t, and 4,471 t, respectively, from 2006 to 2014. Currently, the trawl sector is allocated 98.91% of the annual quota of Yellowtail Rockfish and the ZN hook and line sector is allocated the remaining 1.09%.

The depth distribution of Yellowtail Rockfish, expressed as 90% of commercial bottom/midwater tows capturing this species, is similar among coastal regions – 3CD (bottom gear: 102-247 m, midwater gear: 128-653 m), 5ABC (bottom gear: 93-258 m, midwater gear: 137-296 m), 5DE: (bottom gear:70-274 m, midwater gear: 122-231 m). Reported midwater trawl gear depth ranges are often confounded by deep-water tows that capture the species of interest when nets are deployed/retrieved rather than at the intended tow depth

The primary challenge to the assessment of Yellowtail Rockfish in both Canadian and US waters is the lack of reliable indices of stock abundance. This species usually resides near the bottom but is often found in the water column and, therefore, may not be reliably represented in the various bottom trawl surveys conducted coastwide. Survey sampling error for relative biomass estimates is typically large, with coefficients of variation often exceeding 50% and reaching as high as 90%. Alternative survey gears (e.g., longline hook and trap) are inefficient for catching Yellowtail Rockfish, and there is no available midwater trawl survey or time-series derived from acoustic measurements suitable for indexing the abundance of this species.

ASSESSMENT

An annual, two-sex statistical catch-at-age (SCA) model was applied to

(i) reconstructed catches starting in 1940,

(ii) fishery-independent indices of relative biomass derived from six bottom trawl surveys spanning 48 years from 1967 to 2014, and

(iii) proportion-at-age data from commercial and survey sources spanning 34 years from 1980 to 2013.

A Bayesian approach was used to allow the modelled uncertainty to be characterized by a Markov Chain Monte Carlo (MCMC) approximation to the posterior probability distribution of leading and derived model parameters. The leading parameters estimated by the model include stock-recruitment parameters, natural mortality (independently for females and males), catchability coefficients for the six survey series, and sex-specific selectivity parameters for the commercial fishery data and for the three survey series for which age data are available. Fixed inputs to the model include growth and maturity information and the selectivity parameters for the remaining three survey series.

Estimates of the leading model parameters were used to reconstruct derived quantities annually from 1940 to 2014, including the vulnerable biomass (the biomass that is vulnerable to capture by the fishery), the spawning stock biomass (mature females only), the mid-year exploitation rate, and the population age structure. Reference points related to the unfished equilibrium biomass, current stock biomass, minimum stock biomass and the biomass at maximum sustainable yield (MSY) were used to evaluate current and future stock status. Forecasts from 2016 to 2025 (10 years) were performed for a fixed range of constant annual catches to estimate the probabilities that the spawning biomass will exceed the reference points in each future year. The uncertainty associated with parameter estimates and forecast performance was calculated using 1000 draws from five million MCMC samples from the Bayes posterior probability distribution, and presented as the median and a 90% credible interval (i.e., the 5th, 50$^{th\ and}$ 95th percentiles).

Alternative model cases were explored to investigate the effects of (a) separating data for bottom and midwater trawl gears, (b) including the West Coast Vancouver Island (WCVI) shrimp trawl survey, which is the longest time series available for rockfish on the BC west coast, (c) increasing Yellowtail Rockfish catches during a period of potential misreporting, and (d) doubling the standard deviation on the prior used to estimate the natural mortality parameter. A reference case based on a single trawl gear fishery (i.e., combined bottom and midwater trawl gears) and indices of stock abundance derived from six groundfish surveys was used as the basis for harvest advice.

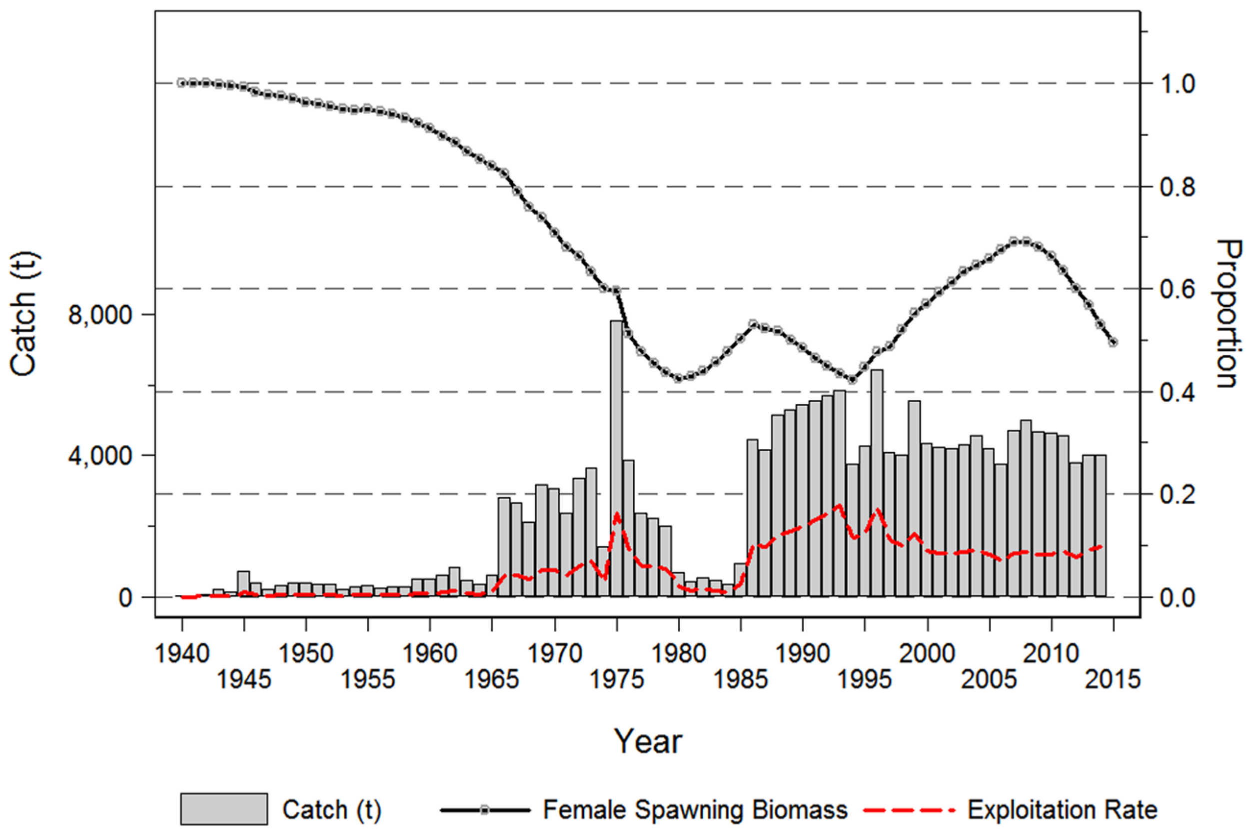


Figure 2. Annual commercial catch (tonnes, vertical bars scaled to left-hand axis) and median estimates for B_t/B_0 (female spawning biomass in year t relative to that in 1940) and exploitation rate u_t (ratio of total annual catch to the vulnerable biomass in the middle of the year) scaled to the right-hand axis. These results are based on the reference case.

Figure 2 shows the time series of the median estimate of female spawning biomass in year *t* relative to the unfished female spawning biomass in 1940 (B_t/B_0), median exploitation rate (u_t), and the reconstructed historical catches. The results show that the spawning biomass dropped by almost 60% from 1940 to 1980, recovered to 0.5B_0 during a period of low catches in the early

1980s, and then declined again as the Canadian fishery increased in the latter half of the 1980s with the development of a targeted midwater trawl fishery. Beginning in the mid 1990s, catches have remained fairly stable near 4000 t/y, with the reconstructed biomass increasing up to 2008 driven by above average recruitment observed during the 1990s. Spawning biomass declined after 2008 due to poor recruitment in the early 2000s and reached a median value of $0.5B_0$ in 2015.

Key model parameter estimates and quantities of management interest for the reference case are given in Table 1. In particular, the estimate for B_{2015}/B_0, the ratio of current spawning biomass (B_{2015}) to B_0, is 0.495 (0.298-0.755), which means that the current fished population is about 50% of the estimated equilibrium unfished population assumed to have been present in 1940. Exploitation rates have remained constant since 2000, with the exploitation rate for 2014 (the final year of the stock reconstruction), u_{2014}, estimated to be 0.098 (0.054-0.174). The maximum sustainable yield (MSY) is estimated to be 4,299 t (3,131-6,430 t).

Table 1. Percentiles of 1,000 samples from the MCMC posterior of the reference case for selected model states and management parameters. The vulnerable biomass and harvest rate represent the commercial fisheries. All biomass values (and MSY) are in metric tonnes. For reference, the average catch over the last five years (2009-2013) is 4,333 t. Definitions: B_0 – unfished equilibrium spawning biomass (mature females), V_0 – unfished equilibrium mid-year vulnerable biomass (males + females), B_{2015} – spawning female biomass at the start of 2015, V_{2014} – vulnerable biomass in the middle of 2014, u_{2014} – exploitation rate (ratio of total catch to vulnerable biomass) in the middle of 2014, u_{max} – maximum exploitation rate from 1940-2014, B_{MSY} – equilibrium spawning biomass at MSY (maximum sustainable yield), u_{MSY} – equilibrium exploitation rate at B_{MSY}, V_{MSY} – equilibrium vulnerable biomass at B_{MSY}.

	Reference Case Percentiles		
Value	**5%**	**50%**	**95%**
B_0	31,256	36,787	46,282
V_0	68,984	81,500	101,725
B_{2015}	9,901	18,390	33,677
V_{2014}	20,023	37,526	69,071
B_{2015}/B_0	0.298	0.495	0.755
V_{2014}/V_0	0.275	0.464	0.714
u_{2014}	0.054	0.098	0.174
u_{max}	0.134	0.182	0.23
MSY	3,131	4,299	6,430
B_{MSY}	4,989	8,293	12,984
$0.4B_{MSY}$	1,996	3,317	5,194
$0.8B_{MSY}$	3,991	6,635	10,387
B_{MSY}/B_{2015}	1.120	2.199	4.406
B_{MSY}/B_0	0.140	0.226	0.315
V_{MSY}	9,684	17,722	28,396
V_{MSY}/V_0	0.116	0.220	0.310
u_{MSY}	0.128	0.245	0.582
u_{2014}/u_{MSY}	0.139	0.402	1.004

Reference Points

Advice to managers is presented as a set of decision tables and associated figures (Tables 2-5 and Figures 3 and 4) that provide probabilities of exceeding a suite of reference points: the DFO-specified Lower Reference Point (LRP) and Upper Reference Point (USR), biomass at maximum sustainable yield (B_{MSY}), the unfished equilibrium spawning biomass (B_0), the exploitation rate at B_{MSY}, the historical biomass minimum (B_{min}) and the biomass at the end of the reconstruction (B_{2015}) – for 2016 through 2025 at a range of constant annual catch levels.

Decision tables reported here are based on the reference case and give the probability of exceeding specified outcomes of interest to fishery managers:

- probability that future spawning biomass, B_t, is greater than 40%, 80%, and 100% of B_{MSY} $\text{P}(B_t > \{0.4, 0.8, 1.0\}B_{\text{MSY}})$ for $2016 \leq t \leq 2025$ (Table 2);
- probability that future exploitation, u_t, is greater than u_{MSY} $\text{P}(u_t > u_{\text{MSY}})$ for $2015 \leq t \leq 2025$ (Table 3);
- probability that future spawning biomass, B_t, is greater than 20% and 40% of B_0 $\text{P}(B_t > \{0.2, 0.4\}B_0)$ for $2016 \leq t \leq 2025$ (Table 4);
- The probability that future spawning biomass, B_t, is greater than B_{min} $\text{P}(B_t > B_{\text{min}})$ for $2016 \leq t \leq 2025$ (Table 5); and
- The probability that future spawning biomass, B_t, is greater than B_{2015} $\text{P}(B_t > B_{2015})$ for $2016 \leq t \leq 2025$ (Table 5).

Figure 3 shows the median estimates and 90% credibility intervals for B_t/B_0, together with the reference points described above. For the reference model (single gear, groundfish surveys only), the stock at the beginning of 2015 is estimated to be above the DFO (2009) provisional limit reference point with probability $\text{P}(B_{2015} > 0.4B_{\text{MSY}}) = 1$, and above the provisional upper stock reference point with probability $\text{P}(B_{2015} > 0.8B_{\text{MSY}}) = 0.995$ (Table 2).

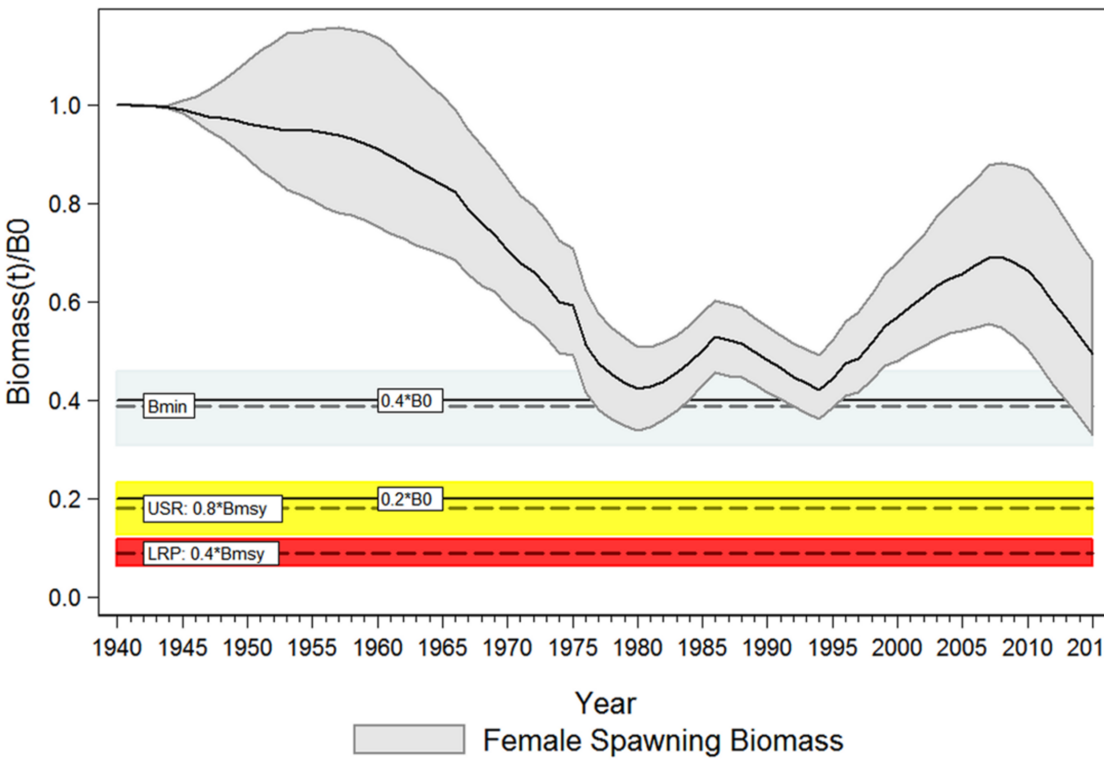


Figure 3. Posterior median estimates and 80% credibility intervals for female spawning biomass (B_t) by year relative to B_0 for Yellowtail Rockfish (grey envelope with black line median). Also shown relative to B_0 are posterior median estimates (dashed lines) and 80% credibility intervals for the MSY-based reference points (LRP: Limit Reference Point = $0.4B_{MSY}$ in red; USR: Upper Reference Point = $0.8B_{MSY}$ in yellow) and the minimum biomass reference point (B_{min}) from the MCMC posterior of B_t. The reference levels of $0.2B_0$ and $0.4B_0$ appear as solid black lines in B_0 space.

A second component of the provisional harvest rule of DFO (2009) concerns the relationship of the exploitation rate (u_t) relative to that associated with B_{MSY} under equilibrium conditions (u_{MSY}).

The rule specifies that the exploitation rate should not exceed u_{MSY} when the stock is in the Healthy Zone. Catches should be reduced when in the Cautious Zone, and be kept to the lowest level possible when in the Critical Zone. For the reference case the estimated ratio of $u_{2014}/u_{\mathrm{MSY}}$ (Table 1), which should be less than 1, is 0.40 (0.14-1.00). The probability that the current exploitation rate exceeds that associated with B_{MSY} is $P(u_{2014} > u_{\mathrm{MSY}}) = 0.052$ (Table 5).

Forecast Results and Decision Tables

Spawning stock biomass is forecast for a period of 10 years from 2016 to 2025, subject to a constant annual catch policy (Figure 4). Annual catches are applied in increments of 500 t from 0 to 6,000 t. Uncertainty in the forecasts is generated from 1,000 samples for each model parameter drawn from the MCMC posterior distribution, which are used to calculate spawning biomass estimates for each year (2016-2025) subject to the catch policy starting from the biomass and age structure calculated for 2015 (the estimated biomass from the final model reconstruction year). This procedure produces 1,000 realizations of forecast spawning biomass, that is, an approximation of the posterior distribution of spawning biomass in each year from 2016 to the beginning of 2025. For most of the forecast period, the recruitments are dependent on fish spawned prior to 2015. Annual catches of 4,500 t or greater are predicted to result in a decline in spawning stock biomass over the forecast period (Figure 4).

The results of forecasts at a range of fixed annual catches are presented for various reference points in the form of decision tables: Table 2 for biomass at MSY, Table 3 for exploitation rate at MSY, Table 4 for unfished equilibrium spawning biomass, and Table 5 for minimum reconstructed biomass (in 1994) and estimated current biomass (beginning of 2015). The decision tables contain the probabilities of spawning biomass exceeding a given reference points in each projection year at a range of constant annual catches from 0 to 6,000 t.

As an example of how to interpret the tables, the estimated probability that the coastwide Yellowtail Rockfish stock is in the DFO provisional Healthy Zone in 2025 under a constant catch strategy of 4,500 t/year is $P(B_{2025} > 0.8B_{\mathrm{MSY}}) = 0.843$ (corresponding to row '4500' and column '2025' of Table 2). Reference points other than those based on MSY are also presented. For example, if the management objective is to avoid the historical minimum biomass at the end of 5 years (2020) with a probability of 50%, then a 4,500 t/year catch level is indicated. If the desired probability is increased to at least 90%, then annual catches of 1500 t/year are indicated.

The SCA model results suggest that the coastwide Yellowtail Rockfish stock has been in the Healthy Zone from 1940 to 2015 (Figure 3). The MSY decision tables indicate that at current catch levels (~4,300 t), there is a high probability (>86%) that the stock will remain in the Healthy Zone over the next five years (Table 2). Inspection of Table 5 indicates that the probability of the female spawning biomass in five years exceeding the current biomass is 0.21, (i.e., there is a 79% probability that B_{2020} will be lower than B_{2015}).

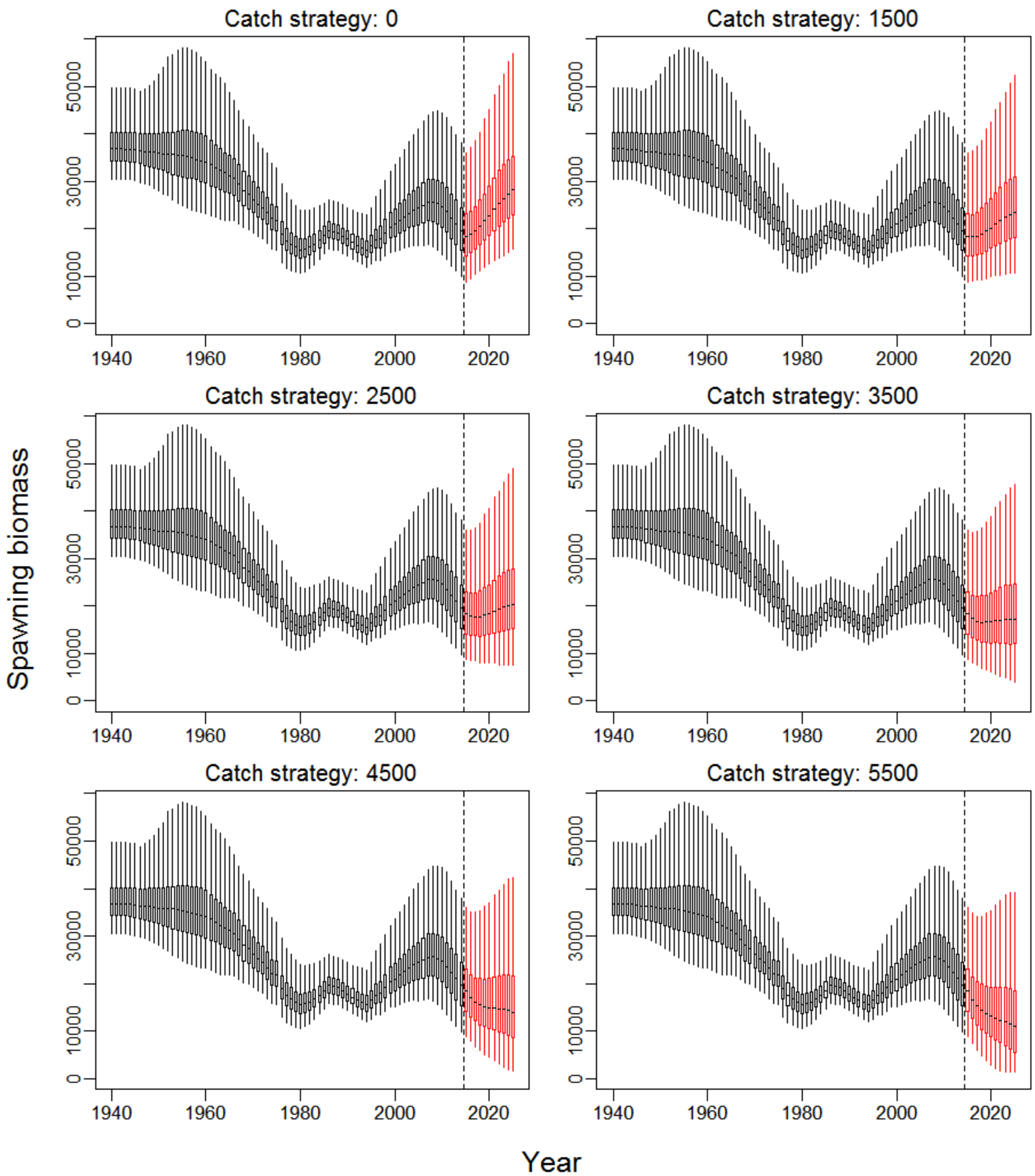


Figure 4. Forecast Yellowtail Rockfish spawning biomass (t) for selected constant annual catch (t) strategies for the reference case (single fishery, groundfish surveys only). Boxplots show the 2.5, 25, 50, 75 and 97.5 percentiles of spawning biomass based on 1,000 draws from the MCMC posterior distribution. For each of the 1,000 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 errors. For reference, the average catch over the last 5 years (2009-2013) is 4,333 t.

Table 2. Decision tables for MSY-based reference points – probability of forecasted B_t (t=2016-2025) exceeding specified proportions of B_{MSY} for a range of fixed annual catches (tonnes), where B_{2015} is the beginning year biomass at the end of the model reconstruction. The probabilities are the proportion of 1,000 draws from the MCMC posterior distribution for which spawning biomass in forecast year t exceeds the specified outcome. For reference, the average catch over the last five years (2009-2013) is 4,333 t.

P(B_t > 0.4B_{MSY})											
Catch	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
0	1	1	1	1	1	1	1	1	1	1	1
500	1	1	1	1	1	1	1	1	1	1	1
1000	1	1	1	1	1	1	1	1	1	1	1
1500	1	1	1	1	1	1	1	1	1	1	1
2000	1	1	1	1	1	1	1	1	1	1	1
2500	1	1	1	1	1	1	1	1	1	1	0.999
3000	1	1	1	1	1	1	0.999	0.997	0.996	0.995	0.994
3500	1	1	1	1	1	0.998	0.996	0.993	0.991	0.990	0.987
4000	1	1	1	1	0.998	0.994	0.991	0.989	0.985	0.977	0.968
4500	1	1	1	0.998	0.996	0.990	0.986	0.977	0.965	0.951	0.944
5000	1	1	1	0.998	0.989	0.985	0.970	0.957	0.940	0.926	0.910
5500	1	1	0.999	0.993	0.984	0.969	0.948	0.931	0.909	0.885	0.863
6000	1	1	0.999	0.991	0.974	0.951	0.928	0.903	0.877	0.837	0.799

P(B_t > 0.8B_{MSY})											
Catch	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
0	0.995	0.999	1	1	1	1	1	1	1	1	1
500	0.995	0.999	1	1	1	1	1	1	1	1	1
1000	0.995	0.998	1	1	1	1	1	1	1	1	1
1500	0.995	0.996	0.997	0.998	0.997	0.997	0.997	0.997	0.998	0.998	0.998
2000	0.995	0.994	0.995	0.993	0.994	0.994	0.993	0.993	0.993	0.993	0.992
2500	0.995	0.994	0.991	0.990	0.990	0.989	0.989	0.988	0.987	0.986	0.983
3000	0.995	0.993	0.986	0.984	0.981	0.984	0.985	0.982	0.977	0.972	0.967
3500	0.995	0.990	0.982	0.977	0.971	0.969	0.957	0.953	0.955	0.943	0.936
4000	0.995	0.987	0.978	0.967	0.960	0.946	0.942	0.933	0.921	0.904	0.891
4500	0.995	0.985	0.972	0.961	0.941	0.928	0.915	0.892	0.874	0.857	0.843
5000	0.995	0.983	0.969	0.948	0.922	0.903	0.872	0.849	0.836	0.803	0.776
5500	0.995	0.981	0.960	0.929	0.905	0.868	0.833	0.810	0.771	0.736	0.708
6000	0.995	0.981	0.949	0.910	0.876	0.829	0.790	0.741	0.702	0.666	0.637

P(B_t > B_{MSY})											
Catch	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
0	0.977	0.984	0.990	0.997	0.999	1	1	1	1	1	1
500	0.977	0.983	0.983	0.991	0.994	0.996	0.998	0.999	0.999	0.999	0.999
1000	0.977	0.981	0.981	0.988	0.990	0.993	0.994	0.996	0.997	0.998	0.998
1500	0.977	0.977	0.976	0.980	0.984	0.988	0.990	0.990	0.990	0.989	0.990
2000	0.977	0.975	0.973	0.972	0.972	0.979	0.982	0.985	0.983	0.980	0.979
2500	0.977	0.968	0.967	0.967	0.965	0.964	0.962	0.970	0.970	0.966	0.964
3000	0.977	0.966	0.966	0.959	0.951	0.950	0.947	0.948	0.943	0.939	0.933
3500	0.977	0.964	0.956	0.947	0.939	0.928	0.927	0.919	0.903	0.896	0.890
4000	0.977	0.960	0.946	0.928	0.913	0.903	0.881	0.874	0.855	0.852	0.842
4500	0.977	0.955	0.932	0.905	0.894	0.866	0.852	0.830	0.810	0.797	0.773
5000	0.977	0.954	0.916	0.886	0.859	0.831	0.806	0.779	0.754	0.724	0.703
5500	0.977	0.949	0.902	0.864	0.825	0.795	0.756	0.715	0.681	0.653	0.632
6000	0.977	0.941	0.887	0.838	0.784	0.744	0.695	0.650	0.623	0.593	0.565

Table 3. Decision table for the probability of forecasted u_t (t=2015-2025) exceeding specified proportions of u_{MSY} for a range of fixed annual catches (tonnes), where u_{2015} is the mid-year biomass after the end of the model reconstruction. See Table 2 for further details.

$P(u_t > u_{MSY})$											
Catch	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
0	0	0	0	0	0	0	0	0	0	0	0
500	0	0	0	0	0	0	0	0	0	0	0
1000	0	0	0	0	0	0	0	0	0	0	0
1500	0	0	0	0	0	0	0	0	0	0	0
2000	0.004	0.004	0.006	0.005	0.002	0.002	0.003	0.003	0.004	0.006	0.007
2500	0.015	0.019	0.021	0.021	0.020	0.017	0.015	0.015	0.016	0.016	0.018
3000	0.030	0.038	0.038	0.042	0.040	0.038	0.040	0.037	0.042	0.048	0.054
3500	0.051	0.062	0.073	0.072	0.076	0.081	0.086	0.092	0.095	0.107	0.120
4000	0.076	0.105	0.120	0.129	0.131	0.139	0.151	0.160	0.168	0.183	0.189
4500	0.107	0.145	0.174	0.206	0.215	0.211	0.226	0.236	0.252	0.263	0.294
5000	0.142	0.203	0.251	0.273	0.293	0.311	0.322	0.327	0.346	0.369	0.380
5500	0.194	0.275	0.311	0.348	0.367	0.390	0.406	0.421	0.438	0.460	0.469
6000	0.247	0.318	0.382	0.420	0.450	0.471	0.486	0.501	0.521	0.538	0.572

Table 4. Decision tables for reference points based on unfished spawning biomass – probability of forecasted B_t (t=2016-2025) exceeding $0.2B_0$ and $0.4B_0$ for a range of fixed annual catches (tonnes), where B_{2015} is the beginning year biomass at the end of the model reconstruction. See Table 2 for further details.

$P(B_t > 0.2B_0)$											
Catch	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
0	1	1	1	1	1	1	1	1	1	1	1
500	1	1	1	1	1	1	1	1	1	1	1
1000	1	1	1	1	1	1	1	1	1	1	1
1500	1	1	1	1	1	0.999	0.999	0.999	0.999	0.999	0.999
2000	1	0.999	0.999	0.998	0.998	0.998	0.997	0.996	0.996	0.996	0.995
2500	1	0.999	0.998	0.998	0.998	0.995	0.992	0.989	0.987	0.987	0.984
3000	1	0.999	0.998	0.994	0.989	0.985	0.982	0.981	0.974	0.970	0.964
3500	1	0.997	0.992	0.988	0.978	0.970	0.963	0.958	0.953	0.949	0.934
4000	1	0.994	0.986	0.974	0.960	0.947	0.938	0.927	0.914	0.907	0.896
4500	1	0.991	0.980	0.957	0.939	0.921	0.908	0.888	0.880	0.852	0.826
5000	1	0.990	0.969	0.943	0.913	0.893	0.873	0.851	0.813	0.782	0.758
5500	1	0.985	0.955	0.918	0.884	0.856	0.817	0.778	0.743	0.705	0.685
6000	1	0.983	0.945	0.896	0.861	0.807	0.767	0.710	0.669	0.625	0.597
$P(B_t > 0.4B_0)$											
Catch	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
0	0.766	0.816	0.864	0.903	0.939	0.964	0.982	0.990	0.991	0.993	0.995
500	0.766	0.805	0.833	0.880	0.913	0.937	0.957	0.972	0.979	0.983	0.982
1000	0.766	0.788	0.814	0.854	0.883	0.907	0.929	0.943	0.954	0.960	0.965
1500	0.766	0.773	0.792	0.818	0.851	0.870	0.883	0.900	0.908	0.916	0.924
2000	0.766	0.757	0.752	0.777	0.797	0.821	0.841	0.858	0.864	0.872	0.875
2500	0.766	0.734	0.714	0.724	0.755	0.769	0.781	0.789	0.797	0.802	0.801
3000	0.766	0.715	0.686	0.682	0.689	0.702	0.711	0.718	0.722	0.718	0.721
3500	0.766	0.699	0.655	0.632	0.625	0.632	0.627	0.626	0.628	0.629	0.628
4000	0.766	0.680	0.621	0.583	0.566	0.552	0.557	0.558	0.562	0.555	0.551
4500	0.766	0.663	0.594	0.547	0.512	0.498	0.493	0.495	0.494	0.482	0.469
5000	0.766	0.643	0.564	0.499	0.463	0.449	0.446	0.437	0.419	0.408	0.401
5500	0.766	0.627	0.537	0.469	0.426	0.404	0.390	0.376	0.360	0.346	0.335
6000	0.766	0.610	0.508	0.430	0.380	0.368	0.344	0.329	0.311	0.300	0.285

Table 5. Decision tables for reference points based on spawning biomass – probability of forecasted B_t (t=2016-2025) exceeding B_{min} for a range of fixed annual catches (tonnes), where B_{2015} is the beginning year biomass at the end of the model reconstruction, and probability of $B_{t=2016\text{-}2025}$ exceeding B_{2015}. See Table 2 for further details.

P(B_t > B_{min})											
Catch	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
0	0.751	0.981	0.985	0.989	0.991	0.996	0.997	0.998	0.998	0.998	0.998
500	0.751	0.953	0.965	0.974	0.981	0.984	0.989	0.987	0.989	0.992	0.993
1000	0.751	0.906	0.926	0.938	0.950	0.954	0.958	0.966	0.971	0.971	0.972
1500	0.751	0.854	0.870	0.885	0.895	0.917	0.925	0.932	0.939	0.937	0.939
2000	0.751	0.801	0.814	0.825	0.837	0.854	0.863	0.874	0.887	0.893	0.899
2500	0.751	0.769	0.765	0.771	0.778	0.786	0.805	0.814	0.821	0.826	0.831
3000	0.751	0.738	0.710	0.708	0.713	0.723	0.730	0.740	0.739	0.740	0.743
3500	0.751	0.714	0.668	0.651	0.651	0.656	0.663	0.669	0.663	0.653	0.655
4000	0.751	0.700	0.633	0.602	0.586	0.574	0.572	0.574	0.583	0.571	0.560
4500	0.751	0.670	0.588	0.548	0.527	0.519	0.514	0.502	0.499	0.496	0.477
5000	0.751	0.644	0.555	0.495	0.471	0.458	0.447	0.445	0.437	0.426	0.408
5500	0.751	0.629	0.532	0.456	0.425	0.404	0.402	0.393	0.376	0.355	0.344
6000	0.751	0.612	0.499	0.425	0.384	0.363	0.358	0.332	0.316	0.294	0.281
P(B_t > B_{2015})											
Catch	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
0	---	0.821	0.850	0.879	0.905	0.924	0.934	0.947	0.955	0.956	0.957
500	---	0.725	0.773	0.815	0.849	0.869	0.893	0.909	0.915	0.922	0.925
1000	---	0.585	0.639	0.707	0.757	0.795	0.822	0.838	0.862	0.874	0.877
1500	---	0.444	0.511	0.586	0.638	0.693	0.739	0.760	0.780	0.798	0.812
2000	---	0.322	0.392	0.466	0.531	0.587	0.620	0.663	0.693	0.716	0.724
2500	---	0.226	0.306	0.373	0.432	0.482	0.535	0.560	0.579	0.609	0.619
3000	---	0.164	0.217	0.285	0.342	0.392	0.433	0.464	0.476	0.491	0.504
3500	---	0.120	0.169	0.222	0.276	0.316	0.357	0.389	0.400	0.407	0.411
4000	---	0.088	0.121	0.170	0.228	0.253	0.283	0.302	0.322	0.323	0.323
4500	---	0.065	0.095	0.129	0.166	0.210	0.232	0.249	0.260	0.269	0.265
5000	---	0.041	0.068	0.099	0.128	0.158	0.183	0.199	0.206	0.211	0.205
5500	---	0.033	0.052	0.077	0.103	0.128	0.148	0.161	0.166	0.164	0.159
6000	---	0.025	0.042	0.060	0.082	0.101	0.117	0.130	0.132	0.127	0.128

Sources of Uncertainty

Uncertainty in the estimated parameters and management quantities is explicitly addressed using a Bayesian approach, but reflects only the specified prior and model assumptions, and the weights assigned to the various data components. The credibility of the stock reconstruction for Yellowtail Rockfish derived from this assessment depends largely on the degree to which the relative indices from the bottom trawl surveys are linearly proportional to abundance. Model results were sensitive to the inclusion of the West Coast Vancouver Island shrimp trawl survey as an abundance index, which was excluded from the reference case. The utility of the survey indices can be examined on the basis of three factors:

1. Yellowtail Rockfish is an aggregating, mobile species that is typically distributed off bottom and therefore may not always be available to bottom trawl gear;
2. the realized annual survey relative errors are large, often exceeding 0.5 and as high as ~0.8 to 0.9; and
3. the individual groundfish bottom trawl survey series are short (no more than seven observations for the synoptic surveys) relative to the history of the fishery and longevity of Yellowtail Rockfish.

The absolute scale of the reconstructed biomass is uncertain due primarily to the uncertainty in the fishery independent biomass indices, which affects the characterization of stock status and the expected long-term yield. Biomass scale is also determined partly by natural mortality, which is a key determinant of the values of the MSY-based statistics and a measure of the overall productivity of the stock. A sensitivity analysis for natural mortality illustrated this effect both on the scale of the reconstruction, and on the estimates of B_{MSY} and B_0-based statistics. These sensitivities should be taken into account when in interpreting and applying model results.

Longer term biomass projections, particularly beyond five years, become increasingly uncertain. One reason for this is that forecasts will increasingly rely on recruitment deviations generated from average recruitment conditions using lognormal process error as the forecast period increases, instead of observed age proportions that can indicate periods of low (or high) recruitment. Furthermore, because forecasts are produced using a fixed annual catch harvest policy, there is no adjustment of the harvest based on changes in stock status and no opportunity to exploit accumulating future survey and age-structured data until the next assessment. In practice, significant changes in survey indices might initiate management intervention over a shorter time horizon than the forecast period in response to stock concerns or harvest opportunities.

ECOSYSTEM CONSIDERATIONS

In 2012, measures were introduced to reduce and manage the bycatch of corals and sponges by the British Columbia groundfish bottom trawl fishery. These measures were developed jointly by industry and environmental non-governmental organizations, and include: limiting the footprint of groundfish bottom trawl activities, establishing a combined bycatch conservation limit for corals and sponges, and establishing an encounter protocol for individual trawl tows when the combined coral and sponge catch exceeds 20 kg. These measures have been incorporated into DFO’s Pacific Region Integrated Fisheries Management Plan for Groundfish (DFO 2014).

The BC integrated groundfish fishery is also subject to the following management measures: 100% at-sea monitoring, 100% dockside monitoring, individual vessel accountability for all retained and released catch, individual transferable quotas and reallocation of these quotas between vessels and fisheries to cover catch of non-directed species (DFO 2014).

CONCLUSIONS AND ADVICE

The interpretation of Yellowtail Rockfish stock status that can be derived from the reference case (single gear, six groundfish bottom trawl survey indices) is of a population that has declined from a median spawning stock depletion of about 0.7 to about 0.49 of the unfished state over the last eight years, as a relatively strong 2001 year class is removed by fishing and natural mortality (emigration is not explicitly accounted for in the model and will appear as a higher natural mortality). Estimated spawning stock biomass remains above historical lows that occurred in 1980 and 1994, when the median depletion was below $0.4B_0$. Median exploitation rates have been near 0.1 since 1990, ending with u_{2014}=0.10 by the terminal year in the reconstruction. The population is forecast to decline modestly over the next 10 years at current harvest levels to a median depletion of about $0.4B_0$. For the history of the fishery (1940-2015) the median spawning biomass is estimated to have remained above the provisional $0.8B_{MSY}$ reference point.

Advice to management is provided in the form of decision tables. Results reported in these tables are predicated on model assumptions and the application of a constant annual catch policy with no future management intervention over the projection period in response to changes in stock status.

Catch monitoring of the commercial groundfish fisheries is presently of high quality by virtue of independent at-sea monitoring of the fishery. These catch data, together with ongoing results from fishery-independent surveys, give confidence that future assessments can continue to monitor this stock and that corrective action can be taken if required.

SOURCES OF INFORMATION

This Science Advisory Report is from the November 18-19, 2014 Stock assessment for Yellowtail Rockfish (*Sebastes flavidus*) in British Columbia. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

DFO. 1999. Yellowtail Rockfish. DFO Science Stock Status Report A6-07 (1999). (Accessed January 13, 2015)

DFO. 2009. A fishery decision-making framework incorporating the Precautionary Approach, (last reportedly modified 23 May 2009, though figures have since changed). (Accessed January 13, 2015)

DFO. 2014. Pacific Region Integrated Fisheries Management Plan for Groundfish. Effective February 21, 2014, ver. 1.0. Fisheries and Oceans Canada. (Accessed January 13, 2015)

Stanley, R. 1999. Shelf rockfish assessment for 1998 and recommended yield options for 1999. Can. Stock Assess. Sec. Res. Doc. 1999/53. 57 p. (Accessed January 13, 2015)

Stanley, R.D. and Haist, V. 1997. Shelf rockfish stock assessment for 1997 and recommended yield options for 1998. Can. Stock Assess. Sec. Res. Doc. 1997/132. 76 p. (Accessed January 13, 2015)

THIS REPORT IS AVAILABLE FROM THE:

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

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

ISSN 1919-5087

Correct Citation for this Publication:

DFO. 2015. Yellowtail Rockfish (*Sebastes Flavidus*) Stock Assessment for the Coast of British Columbia, Canada. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2015/010.

Aussi disponible en français :

MPO. 2015. Évaluation du stock de sébastes à queue jaune (sebastes flavidus) pour le littoral de la Colombie-Britannique, au Canada. Secr. can. de consult. sci. du MPO, Avis sci. 2015/010.