YELLOWTAIL ROCKFISH (*SEBASTES FLAVIDUS*) STOCK ASSESSMENT FOR BRITISH COLUMBIA IN 2024

CONTEXT

Yellowtail Rockfish (*Sebastes flavidus*) is a commercially important species of rockfish that exhibits pelagic schooling behaviour, frequently swimming off the bottom in the thousands along steep rocky substrata or above rocky reefs along the coast of British Columbia. Yellowtail Rockfish has the largest single-species quota among the current annual Total Allowable Catch (TAC) of rockfish on the west coast of Canada. Key results from the stock assessment for coastal BC (3CD5ABCDE) at the start of 2025 are reported here. Harvest advice is required to determine if current harvest levels are sustainable and compliant with DFO's Decision-making Framework Incorporating the Precautionary Approach.

This Science Advisory Report is from the September 10–11, 2024 regional peer review on the Yellowtail Rockfish (*Sebastes flavidus*) Stock Assessment for British Columbia in 2024. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SCIENCE ADVICE

Status

- The probability that the female spawning stock biomass at the beginning of 2025 (B_{2025}) was greater than the limit reference point (LRP, $0.4B_{MSY}$; B_{MSY} is the equilibrium female spawning biomass at maximum sustainable yield) was >99%.
- The probability that B_{2025} was greater than the upper stock reference (USR, $0.8B_{MSY}$) was >99%, placing the coastwide stock in the Healthy zone.
- At the beginning of 2025, the stock status relative to B_{MSY} (B_{2025}/B_{MSY}) was 2.31. The 90% credibility interval for this estimate was 1.25 to 4.59.
- At the beginning of 2025, the ratio of biomass relative to unfished female spawning biomass (B_{2025}/B_0) was estimated to be 0.56. The 90% credibility interval for this estimate was 0.33 to 0.91.
- Fourteen sensitivity analyses that tested alternative assessment assumptions all showed the coastwide stock to be in the Healthy zone.
- The probability that the exploitation rate in 2024 (u_{2024}) was below the removal reference (RR) exploitation rate at maximum sustainable yield (u_{MSY}) was 94%.

Trends

- Annual median stock status (B_t/B_{MSY}) trended down from 4.0 times B_{MSY} in 1935 to 2.0 times B_{MSY} in 1983 and then fluctuated between values of 1.7 and 2.8 times B_{MSY} until 2025. Since

2015, there has been an increasing trend in stock status. At no time did the 90% credibility envelope breach the USR.

- Since 2005, recruitment remained relatively stable compared to other Sebastes species, with more frequent strong recruitment years compared to longer lived species in the Sebastes genus. Exploitation rate has remained stable since 2000 with total annual catches between 3,500 and 5,000 t/y.

Ecosystem and Climate Change Considerations

- Six large-scale environmental index series and one local upwelling series were used as independent variables to predict recruitment.
- Overall, these environmental series had low predictive power because of the considerable associated uncertainty and the relatively small amount of contrast across the range of available observations. Further work is required before these indices are capable of providing predictive power for recruitment in future stock assessments.

Stock Advice

- Advice to managers was presented in the form of decision tables with ten-year projections using constant-catch policies up to 7,000 t/year.
- The stock was projected to remain above the LRP and USR with a probability of 99% and 93%, respectively, over the next 10 years at current levels of catch (4,000 t/year).
- The stock was projected to remain below the RR with a probability of >50% over the next 10 years at catches of 5,500 t/y or less.

BASIS FOR ASSESSMENT

Assessment Details

Year Assessment Approach was Approved

2024 Terms of Reference

Assessment Type

Full Assessment: peer-reviewed stock assessment

Most Recent Assessment Dates

1. Last Full Stock Assessment:
   Yellowtail Rockfish in 2014, DFO (2015)
2. Previous Stock Assessments:
   Shelf rockfish in 1998, Stanley (1999)
   Shelf rockfish in 1997, Stanley and Haist (1997)
3. Last Interim-Year Update: N/A

Assessment Approach

1. Statistical catch-at-age stock assessment model (fitted to data using the Stock Synthesis 3 model platform).

A two-sex, age-structured, stochastic model was used to reconstruct the population trajectory of Yellowtail Rockfish from 1935 to the end of 2024 using NOAA's Stock Synthesis 3 model platform (v3.30.22.01, Methot et al. 2023). Ages were tracked up to age 45, where 45 acted as an accumulator age category. Recruitment deviations were estimated from 1935 to the end of 2024 with mean recruitment estimated over the period 1935 to 2015. The population was assumed to be in equilibrium with average recruitment and no fishing at the beginning of the reconstruction (in 1935). The assessment employed a Bayesian framework using a Markov Chain Monte Carlo (MCMC) search procedure along with prior distributions on the parameters to estimate the parameter posterior distributions. These distributions were used to derive the biomass and exploitation rate quantities used to provide management advice, with the posterior distributions providing the basis for the uncertainty associated with each model run.

Stock Assessment Assumptions

The main assumptions for the base run of the stock assessment model included:

- one stock coastwide, corresponding to Groundfish Management Unit (GMU) areas 3CD5ABCDE (excluding the inside waters, 4B) with a set of derived parameters, including reference points;
- a Beverton-Holt stock-recruitment function with estimated parameters for equilibrium coastwide recruitment and steepness;
- one commercial fishery (>99% trawl, <1% H&L), and six fishery-independent surveys (four synoptic bottom trawl surveys and two historical bottom trawl surveys), with each survey assumed to monitor the coastwide Yellowtail Rockfish population using estimated and fixed (depending on the survey) sex-specific selectivity functions;
- separately estimated natural mortalities by sex;
- von Bertalanffy growth models and length-weight relationships for males and females, estimated outside the model to account for different growth by sex;
- female maturity estimated outside the model with fecundity assumed to be proportional to weight; and
- an ageing error vector of smoothed standard deviations derived from CVs of observed lengths-at-age.

Reference Points

The reference points used for analysis and decisions for this stock were those recommended in DFO's Precautionary Approach Policy (DFO 2006, 2009). These estimates were derived from a Bayesian analysis that yielded a posterior set of 2,000 samples (56 dropped due to anomalous MSY output).

- Limit Reference Point (LRP): $0.4B_{\text{MSY}}$ (40% female spawning biomass at MSY);
- Upper Stock Reference (USR): $0.8B_{\text{MSY}}$ (80% female spawning biomass at MSY);
- Removal Reference (RR): u_{MSY} (exploitation rate at MSY);

Data

The main data inputs to the SS3 coastwide model included:

- a catch time series (1935 to 2024) for the BC outer coast (3CD5ABCDE);
    - incomplete 2024 catch was assumed to be the same as 2023;
- design-based abundance index series from six fishery-independent surveys;
    - no commercial CPUE index series was used; and
- composition data from the commercial fishery and three surveys in the form of proportions--at-age (also called ‘age frequencies’ or AF).

ASSESSMENT

Historical and Recent Stock Trajectory and Trends

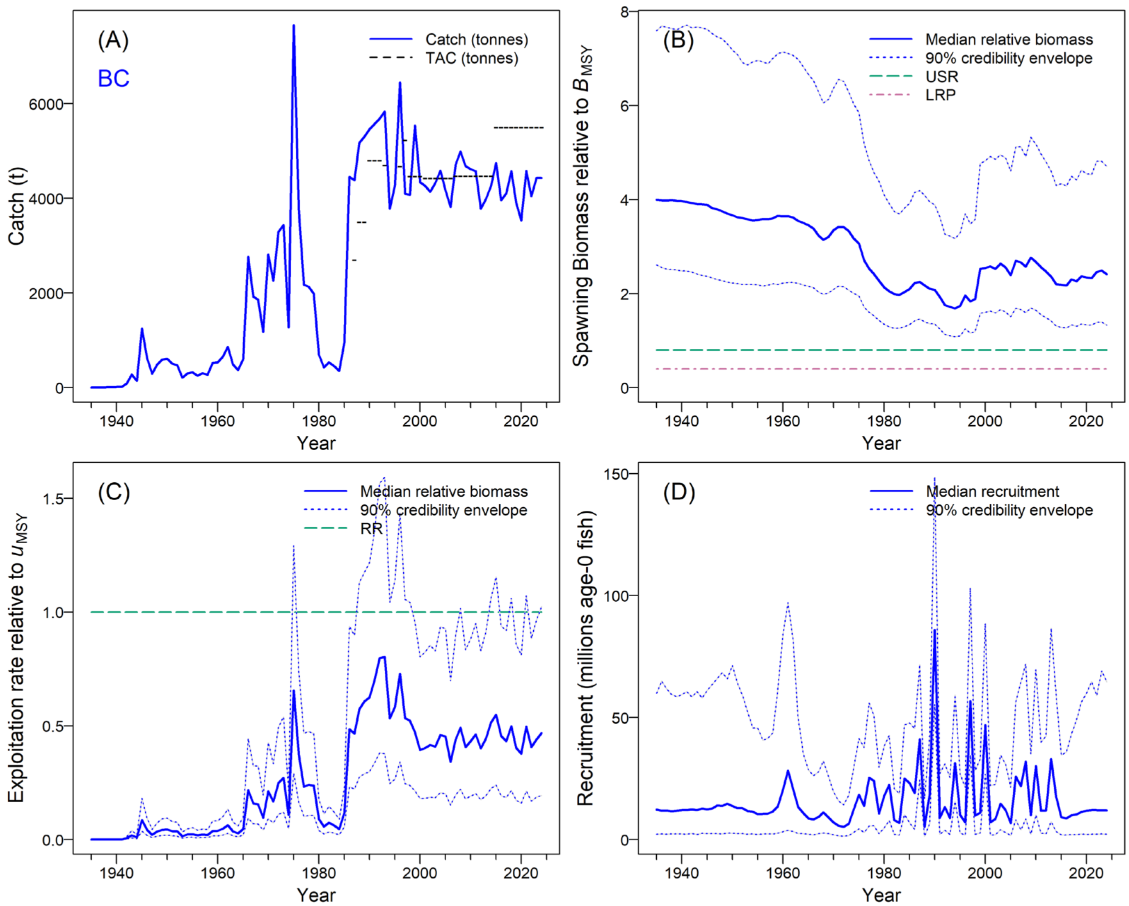

Figure 1. BC coastwide (excluding 4B): (A) catch (blue solid line) and total allowable catch (black dashes); (B) female spawning biomass relative to equilibrium biomass at MSY (B_t/B_{MSY}) with Limit Reference Point (LRP = $0.4B_{MSY}$, red-purple dot-dashed horizontal line) and Upper Stock Reference (USR = $0.8B_{MSY}$, blue-green dashed horizontal line); (C) exploitation rate relative to that at equilibrium (u_t/u_{MSY}) with Removal Reference (RR =u_{MSY}, blue-green dashed horizontal line); (D) recruitment (R_t, millions of age-0 fish). Median values in panels B, C, and D appear as blue solid lines, and the 90% credibility envelopes are delimited by blue dotted lines.

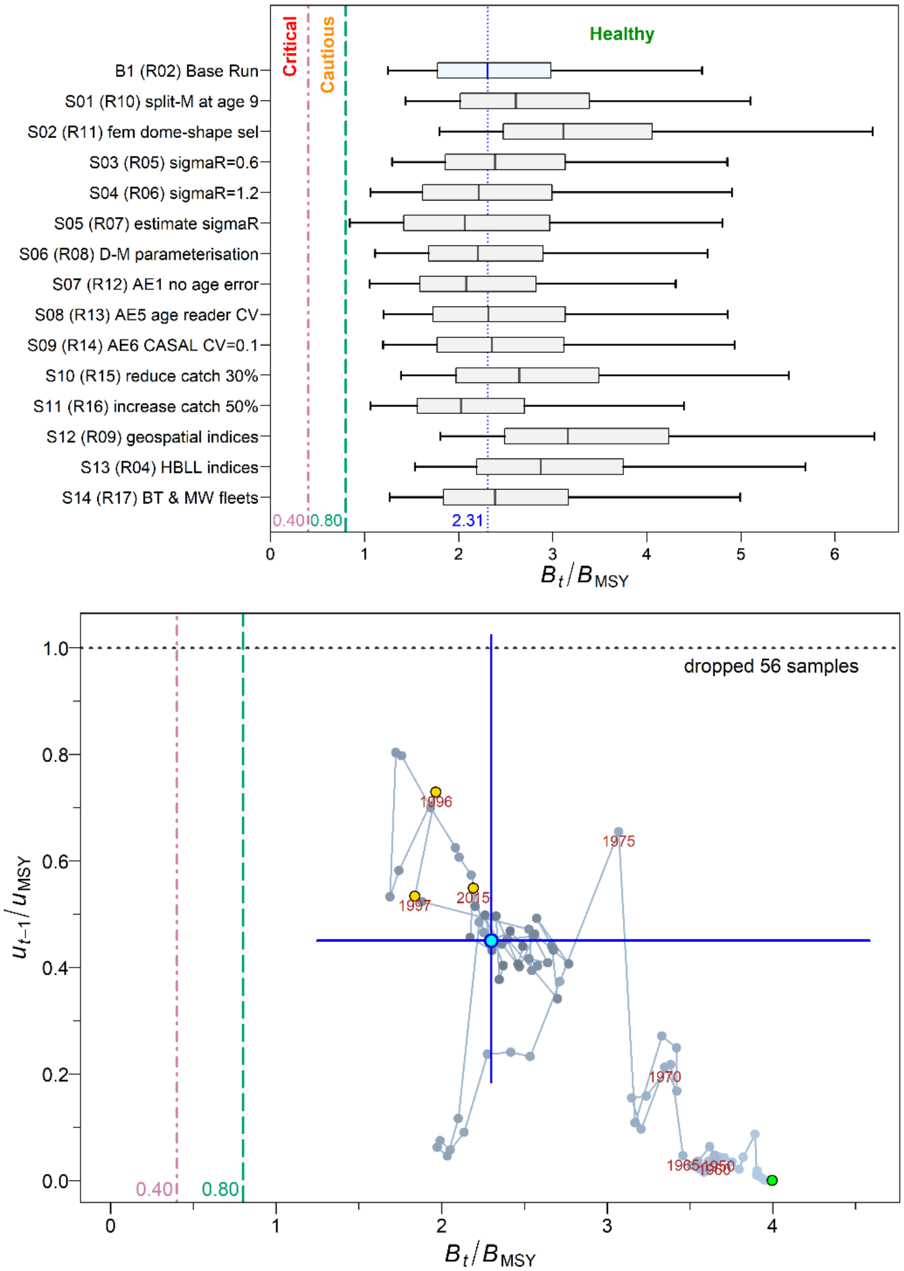

Figure 2. (top) Stock status (B_t/B_{MSY}) at beginning of 2025 for the coastwide model relative to the DFO PA provisional reference points of $0.4B_{MSY}$ (red-purple dot-dashed vertical line) and $0.8B_{MSY}$ (blue-green dashed vertical line) for the base run and 14 sensitivity runs. Boxplots show the 0.05, 0.25, 0.5, 0.75 and 0.95 quantiles from the MCMC posterior. Blue dotted vertical line shows the median B_t/B_{MSY} of the base run. (bottom) Phase plot of median u_{t-1}/u_{MSY} vs. B_t/B_{MSY} for the base model, showing the provisional reference points of $0.4B_{MSY}$ (red-purple dash-dotted vertical line) and $0.8B_{MSY}$ (blue-green dashed vertical line), and the RR (black dotted horizontal line). Blue solid horizontal and vertical lines represent the 90% credibility ranges for the final year. Note: 56 MCMC samples yielded anomalous (non-finite) MSY-based quantities and were excluded.

Productivity Parameters

The base run was used to calculate a set of coastwide parameter estimates (subset in Table 1) and derived quantities at equilibrium and those associated with MSY (Table 2), all based on the posterior parameter distributions generated by the MCMC search procedure.

Table 1. Quantiles of the posterior distribution based on 2,000 MCMC samples for the main estimated model parameters for the base run Yellowtail Rockfish stock assessment. M = natural mortality for sex 1=females and 2=males; BH = Beverton-Holt steepness h; R_0 = recruitment at unfished equilibrium. Shaded column (labelled '50%') highlights median values.

Parameter	5%	25%	50%	75%	95%
M_1 (female)	0.1126	0.1228	0.1305	0.1383	0.1504
M_2 (male)	0.08954	0.09949	0.1071	0.1149	0.1263
BH (h)	0.4884	0.6407	0.7469	0.8387	0.9369
log R_0	9.349	9.662	9.884	10.13	10.52

Estimated productivity parameters appear in Table 1. Median natural mortality for females was notably higher than that for males, a feature that stems from the disappearance of older females (compared to the maximum age in males) in the data (as was observed for Canary Rockfish [*S. pinniger*], Starr and Haigh 2023). Three hypotheses were put forward to explain the lack of older females:

1. different sex-based natural mortality;
2. increased age-dependent natural mortality for female Yellowtail Rockfish (i.e., senescence) after reaching maturity; and
3. different selectivity at older ages for female Yellowtail Rockfish (i.e., size or age-based selectivity), creating a population of older females that was less vulnerable to the fishery.

The base run chose the first hypothesis as it was the most parsimonious model (fewer parameters and fewer assumptions) while still fitting the data. The steepness posterior was similar to the prior, likely because the coastwide population had not declined below $0.2B_0$ (the population size below which recruitment is assumed to be notably reduced).

Biomass

Estimated 2025 median spawning biomass B_t relative to B_0 (also called depletion) for the coastwide model was 0.56 (0.33, 0.91), and the estimated 2025 stock status (B_{2025}/B_{MSY}) was 2.31 (1.25, 4.59), fluctuating above the USR (in DFO's Precautionary Approach Healthy zone) since 1935.

Female spawning biomass at the beginning of 2025 (B_{2025}) was estimated to be above the limit reference point biomass (LRP = $0.4B_{\text{MSY}}$), and above the upper stock reference biomass (USR = $0.8B_{\text{MSY}}$; Table 2). The ratio of the estimated exploitation rate u_{2024} to u_{MSY} (where u_{MSY} is the maximum Removal Reference [RR] for the Healthy zone), was below the RR: 0.45 (0.19, 1.02; Table 2).

Recruitment

Coastwide recruitment estimates were generally stable, with recruitment excursions greater than the mean occurring more often than once per decade. The largest recruitment event occurred in 1990 with 5.3 times the mean of annual medians (Figure 1). Notable recruitment events were more frequent than the occasional large recruitment events exhibited by longer-lived *Sebastes* species like Pacific Ocean Perch (*Sebastes alutus*) and Rougheye Rockfish (*S. aleutianus*).

Table 2. Derived parameter quantiles from the 2,000 samples[1] of the MCMC posterior of the Yellowtail Rockfish base run coastwide. Definitions: B_0 – unfished equilibrium female spawning biomass, B_{2025} – spawning biomass at the start of 2025, u_{2024} – exploitation rate (ratio of total catch to vulnerable biomass) in the middle of 2024, u_{max} – maximum exploitation rate (calculated for each sample as the maximum exploitation rate from 1935-2024), B_{MSY} – equilibrium spawning biomass at MSY (maximum sustainable yield), u_{MSY} – equilibrium exploitation rate at MSY. All biomass values (including MSY) are in tonnes. The average catch over the last 5 years (2019-2023) was 4,099 t. Shaded column (labelled '50%') highlights median values.

Quantity	5%	25%	50%	75%	95%
B_0	27,565	34,168	39,535	46,680	62,586
B_{2025}	13,163	17,816	22,300	27,602	40,388
B_{2025} / B_0	0.3302	0.4523	0.5649	0.6908	0.9147
u_{2024}	0.03932	0.05591	0.06872	0.08475	0.1137
u_{max}	0.09433	0.1134	0.1263	0.1396	0.1568
MSY	2,840	3,745	4,556	5,551	7,416
B_{MSY}	5,225	7,746	9,807	12,262	16,099
$0.4B_{MSY}$	2,090	3,099	3,923	4,905	6,440
$0.8B_{MSY}$	4,180	6,197	7,846	9,809	12,879
B_{2025} / B_{MSY}	1.246	1.772	2.306	2.98	4.585
B_{MSY} / B_0	0.1317	0.1981	0.2502	0.304	0.3836
u_{MSY}	0.08202	0.1177	0.1521	0.1945	0.2933
u_{2024} / u_{MSY}	0.185	0.3204	0.4509	0.6379	1.024

History of Harvest and Total Allowable Catch (TAC)

Yellowtail Rockfish catch in BC was reconstructed back to 1918, but the assessment model started from assumed equilibrium conditions in 1935 (because commercial catches prior to this year were minimal). Table 3 presents annual catches since the implementation of an onboard observer program in 1996, with the full catch history available in the Research Document (Starr and Haigh, in prep.[2]). Total Allowable Catch in fishing year 2024 (Feb 21, 2024 to Feb 20, 2025, Trawl + Hook & Line) was 1,238 t in 3C, 4,263 t in 3D5ABCDE, and 5,500 t coastwide.

Table 3. Reconstructed calendar-year catches (in tonnes, landings + releases) of Yellowtail Rockfish for 'Trawl' (bottom + midwater), 'Bottom Trawl', 'Midwater Trawl', and 'Other' fisheries (non-trawl: Halibut, Sablefish, Dogfish/Lingcod, and H&L Rockfish). The 'Total' column shows catches used in the population model (Trawl + Other). Catches for 2024 were set to values in 2023. Column labelled 'TAC' shows Total Allowable Catch by fishing year[3] for Trawl + ZN fisheries. Column labelled 'pMW' shows proportions used to separate Total catch into catches for bottom and midwater fleets.

Year	Trawl	Bottom Trawl	Midwater Trawl	Other	Total	TAC	pMW
1996	6,440	1,400	5,040	8.21	6,448	4,675	0.7823
1997	4,086	2,118	1,968	10.1	4,096	5,233	0.4811
1998	4,058	1,816	2,242	12.7	4,071	4,464	0.5520

[1] 56 MCMC samples yielded anomalous (non-finite) MSY-based and harvest-based quantities. B_0 and B_{2025} were available for all 2,000 samples.
[2] Starr, P.J. and Haigh, R. In prep. Yellowtail Rockfish (*Sebastes flavidus*) Stock Assessment for British Columbia in 2024. DFO Can. Sci. Advis. Sec. Res. Doc.
[3] Fishing year currently spans 21 Feb 2024 to 20 Feb 2025.

Year	Trawl	Bottom Trawl	Midwater Trawl	Other	Total	TAC	pMW
1999	5,522	2,072	3,450	11.1	5,533	4,464	0.6245
2000	4,329	1,802	2,527	10.6	4,339	4,464	0.5832
2001	4,257	2,149	2,107	8.35	4,265	4,422	0.4947
2002	4,130	2,168	1,962	8.11	4,138	4,422	0.4745
2003	4,312	2,456	1,856	8.85	4,321	4,422	0.4299
2004	4,577	2,684	1,893	11.3	4,588	4,422	0.4130
2005	4,155	2,559	1,596	14.6	4,170	4,422	0.3835
2006	3,810	2,037	1,772	7.13	3,817	4,422	0.4644
2007	4,706	2,153	2,553	4.36	4,710	4,471	0.5420
2008	4,990	2,434	2,556	4.69	4,994	4,471	0.5117
2009	4,679	2,948	1,731	4.46	4,684	4,471	0.3697
2010	4,613	2,533	2,080	5.30	4,618	4,471	0.4505
2011	4,566	2,402	2,164	5.59	4,571	4,471	0.4733
2012	3,779	2,081	1,698	3.93	3,783	4,471	0.4489
2013	3,980	1,910	2,070	3.63	3,983	4,471	0.5196
2014	4,253	2,138	2,115	3.31	4,257	4,471	0.4969
2015	4,741	3,000	1,742	3.80	4,745	5,500	0.3671
2016	3,949	2,351	1,598	7.86	3,957	5,500	0.4039
2017	4,099	2,076	2,023	4.54	4,103	5,500	0.4931
2018	4,569	2,107	2,462	4.38	4,573	5,500	0.5384
2019	3,909	1,426	2,483	4.36	3,913	5,500	0.6346
2020	3,527	1,161	2,365	3.04	3,530	5,500	0.6701
2021	4,576	901	3,675	2.08	4,578	5,500	0.8027
2022	4,041	1,053	2,988	1.82	4,043	5,500	0.7391
2023	4,429	936	3,493	1.62	4,431	5,500	0.7884
2024	4,429	936	3,493	1.62	4,431	5,500	0.7884

Projections or Simulations

The Yellowtail Rockfish population was projected forward for each base run MCMC sample to the end of 2034 (beginning of 2035) using stochastic recruitment deviations selected from the mean of the period 1935 to 2015 and which assumed a standard deviation of 0.9. Decision tables for the base run provided advice to managers as probabilities that the projected biomass B_t (t = 2026, ..., 2035) exceeded biomass-based reference points, or that projected exploitation rate u_t (t = 2025, ..., 2034) fell below the harvest-based reference point under a range of constant-catch policies. That is, the tables present probabilities that projected B_t, using the base model run, exceeded the LRP (Table 4) and the USR (Table 5) or was less than the RR (exploitation rate at MSY, Table 6). All decision tables (including those for alternative reference levels) for the base run can be found in Starr and Haigh (In prep.[2]).

Assuming that a coastwide catch of 4,000 t (close to the recent 5-y mean) will be taken for each year over the next 10 years, a manager could be at least 99% certain that both B_{2030} and B_{2035} would lie above the LRP of 0.4B_{MSY} (Table 4), 97% and 93% certain that B_{2030} and B_{2035} would lie above the USR of 0.8B_{MSY} (Table 5), and 87% and 83% certain that u_{2029} and u_{2034} would lie below u_{MSY} (Table 6) for the base run. Generally, it is up to managers to choose the preferred catch levels or harvest levels using their preferred risk levels. For example, it may be desirable to be 95% certain that B_{2035} exceeded the LRP whereas exceeding the USR might only require a 50% probability. Assuming this risk profile, catch policies ≤ 5,000 t/y would satisfy the LRP constraint in Table 4, and all catch policies would satisfy the USR constraint (Table 5). Assuming that u_{MSY} is the RR, all catch policies ≤ 2,500 t/y have a probability greater than 95%

of the harvest rate remaining below u_{MSY} in 10 years, whereas catch policies ≤5,500 t/y would have a probability greater than 50% (Table 6).

Figure 3 shows the impact on the spawning biomass caused by projections at three catch levels (none = 0 t/y, current 5-yr average = 4,000 t/y, high = 6,000 t/y). At no catch, projected biomass is expected to increase over the next 10 years. At current average exploitation, projected biomass will decline until it levels out after about five years (because 4,000 t/y is close to the estimated annual median MSY of 4,556 tonnes, Table 2). At high exploitation levels, projected biomass will decline over the next 10 years, with the lower tails of the posterior distribution of the female mature biomass breaching both the USR and the LRP.

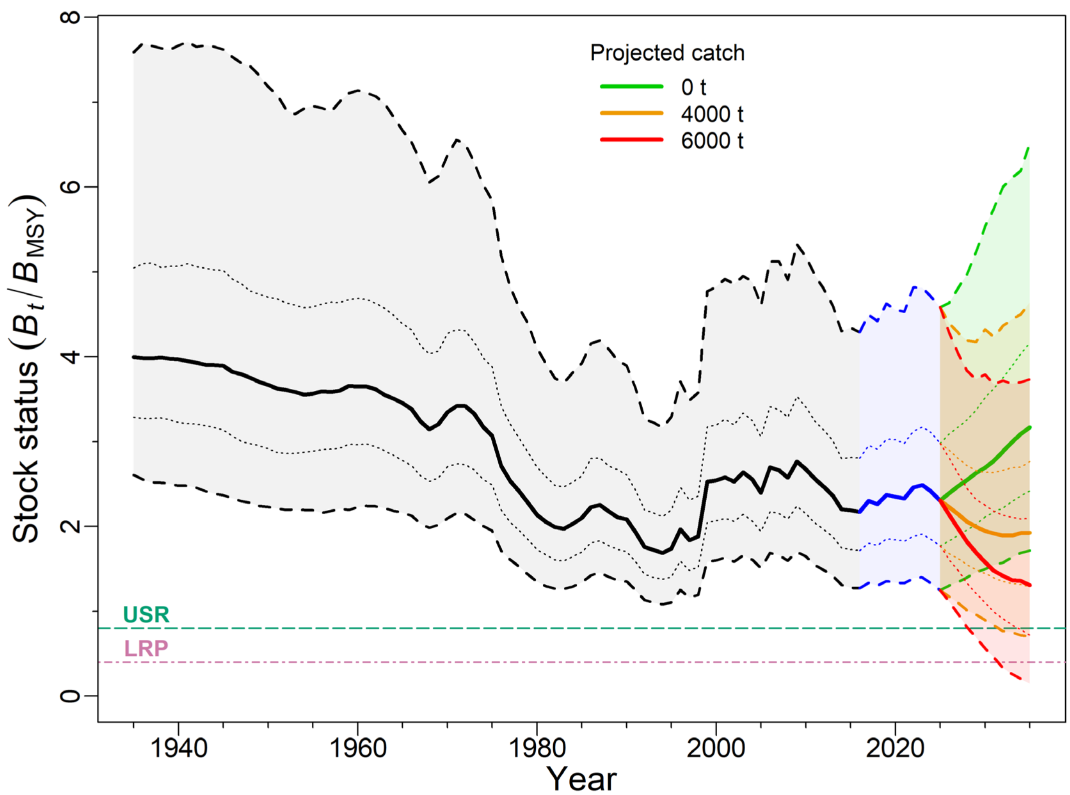

Figure 3. Reconstructed spawning biomass trajectories for the BC coastwide Yellowtail Rockfish population, showing projections at three levels: (a) no catch (green); (b) average catch (orange); (c) high catch (red). Solid lines are the posterior median, and the shaded areas encompass the 90% credibility envelopes. Blue-green dashed horizontal line marks the USR ($0.8B_{MSY}$) and red-purple dot-dashed horizontal line marks the LRP ($0.4B_{MSY}$).

Table 4. Base run: decision table for the limit reference point (LRP = $0.4B_{MSY}$) for 1-10 year projections for a range of constant catch policies (in tonnes) using the base run (B1). Values are the probability (proportion of 1,944 MCMC samples[4]) of the female spawning biomass at the start of year t being greater than the LRP. For reference, the average catch over the last 5 years (2019-2023) was 4,099 t.

CC(t/y)	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
0	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
1,000	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
2,500	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99

[4] 56 MCMC samples yielded anomalous (not a number) MSY-based quantities.

CC(t/y)	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
4,000	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99
4,500	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.98	0.98	0.97
5,000	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.98	0.97	0.96	0.95
5,500	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.98	0.96	0.95	0.93	0.92
6,000	>0.99	>0.99	>0.99	>0.99	0.99	0.98	0.96	0.94	0.92	0.90	0.87
6,500	>0.99	>0.99	>0.99	0.99	0.99	0.96	0.94	0.91	0.89	0.85	0.83
7,000	>0.99	>0.99	>0.99	0.99	0.98	0.95	0.91	0.87	0.84	0.80	0.77

Table 5. Base run: decision table for the upper stock reference (USR = 0.8B_{MSY}) for 1-10 year projections for a range of constant catch policies (in tonnes) using the base run (B1). Values are the probability (proportion of 1,944 MCMC samples) of the female spawning biomass at the start of year t being greater than the USR. For reference, the average catch over the last 5 years (2019-2023) was 4,099 t.

CC(t/y)	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
0	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
1,000	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
2,500	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
4,000	>0.99	>0.99	0.99	0.99	0.98	0.97	0.96	0.94	0.94	0.94	0.93
4,500	>0.99	>0.99	0.99	0.98	0.97	0.95	0.94	0.92	0.92	0.90	0.89
5,000	>0.99	0.99	0.99	0.97	0.95	0.93	0.91	0.89	0.87	0.85	0.83
5,500	>0.99	0.99	0.98	0.96	0.95	0.91	0.88	0.86	0.82	0.79	0.78
6,000	>0.99	0.99	0.98	0.96	0.92	0.88	0.84	0.81	0.77	0.74	0.71
6,500	>0.99	0.99	0.97	0.94	0.90	0.85	0.80	0.75	0.71	0.68	0.65
7,000	>0.99	0.99	0.97	0.93	0.88	0.81	0.76	0.69	0.65	0.62	0.59

Table 6. Base run: decision table for the removal reference (RR = u_{MSY}) for 1-10 year projections for a range of constant catch policies (in tonnes) using the base run (B1). Values are the probability (proportion of 1,944 MCMC samples) of the exploitation rate at the middle of year t being less than the RR. For reference, the average catch over the last 5 years (2019-2023) was 4,099 t.

CC(t/y)	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
0	0.94	1	1	1	1	1	1	1	1	1	1
1,000	0.94	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
2,500	0.94	0.99	0.99	0.99	0.99	0.99	0.98	0.98	0.99	0.99	0.98
4,000	0.94	0.93	0.91	0.89	0.89	0.87	0.86	0.85	0.84	0.83	0.83
4,500	0.94	0.90	0.86	0.84	0.82	0.79	0.79	0.78	0.76	0.75	0.75
5,000	0.94	0.84	0.80	0.77	0.75	0.72	0.70	0.69	0.68	0.67	0.65
5,500	0.94	0.78	0.75	0.71	0.67	0.64	0.61	0.59	0.58	0.58	0.56
6,000	0.94	0.74	0.68	0.64	0.60	0.55	0.53	0.51	0.50	0.49	0.48
6,500	0.94	0.68	0.62	0.57	0.51	0.48	0.45	0.43	0.42	0.42	0.41
7,000	0.94	0.62	0.56	0.49	0.44	0.41	0.38	0.37	0.35	0.35	0.34

Ecosystem and Climate Change Considerations

The base stock assessment model MCMC posterior distribution for recruitment deviations (1960 to 2015) was used to explore the possibility that six environmental index series (Aleutian Low Pressure Index, Arctic Oscillation, Multivariate ENSO Index, North Pacific Gyre Oscillation, Pacific Decadal Oscillation, Southern Oscillation Index) and one local upwelling index series provided usable predictive correlations with the estimated recruitment deviations.

These environmental series are measures of oceanic regime changes over time, usually oscillating between a high-primary-productivity state (cooler waters, higher nutrients) and a low -primary-productivity state (warmer waters, lower nutrients). High primary production should lead to more food for pelagic larval fish, whereas warm surface waters might enhance the fecundity of females through the downwelling of oxygen-rich water.

These seven predictive models each indicated a loose association between the recruitment deviations estimated by the stock assessment model and ocean state. Overall, the seven models indicated that these environmental series had low predictive power because of the considerable associated uncertainty and the relatively small contrast across the range of available observations. However, these relationships suggested that there may be some potential predictive power in some of these data sets. Alternative measures of ocean state from BC local waters may possibly provide better predictive power for estimating BC rockfish recruitment.

While the relationships between recruitment and environmental index series were of interest, they summarised correlations only. Even though intuitive explanations can be given to explain possible mechanisms for environmental effects on Yellowtail Rockfish recruitment, there is presently no method to incorporate functional responses to environmental variables into existing population model platforms (e.g., SS3) nor is there a strong literature indicating how to link these effects within a fisheries population model.

PROCEDURE FOR INTERIM YEAR UPDATES

DFO (2016) provides guidance concerning the appropriate time interval between future stock assessments and, for the interim years between stock updates, potential indicators that could trigger a full assessment earlier than expected. However, none of the existing synoptic trawl surveys can be relied on to individually signal a major reduction in stock abundance because of the large relative errors associated with this species from each survey, resulting in the concern that apparent major shifts in abundance could be generated through random chance. Fortunately, the BC population of Yellowtail Rockfish was assessed to be well in the Healthy zone and should remain in that zone given that reasonably strong year classes were already recruited and should remain in evidence over the next 10 years.

This means that a full stock assessment is required to evaluate this population, and that it should be on a regular stock assessment cycle (within 5-10 years). A regular interval between assessments will ensure that all elements of the data will be available before an assessment is undertaken. This implies that at least 12 months lead time should be allowed for the processing of new ageing structures that will be needed for the interpretation of the population reconstruction that has occurred in the intervening years. This is particularly true for Yellowtail Rockfish because the AF data are an important component of the analysis. Advice for interim years is explicitly included in the decision tables, and managers can select another line on the table if stock abundance appears to have changed or if greater certainty of staying above the reference point is desired. During intervening years, the trend in abundance can be cautiously tracked by the fishery independent surveys used in this stock assessment. The groundfish synopsis reports (Anderson et al. 2019, 2024) summarise these trends and can be used as a tracking tool.

SOURCES OF UNCERTAINTY

Although uncertainty was built into the stock assessment and its projections by taking a Bayesian approach for parameter estimation, these results were heavily dependent on the assumed model structure, the informative priors, and underlying assumptions (particularly the average recruitment assumptions) used for the projections. Because of this limitation, uncertainty was also explored by changing some of the base model assumptions in fourteen sensitivity runs (all analysed using a Bayesian approach).

The greatest uncertainty in this stock assessment was the lack of reliable measures of Yellowtail Rockfish abundance. This is because the species often occurs off the bottom and thus may not always be consistently vulnerable across survey years to the survey net which is dragged along the bottom. This variation in vulnerability is expressed as high relative error in the survey abundance indices, reflecting a lack of precision in the observations. Despite this, the base model was able to fit the available survey series credibly, indicating that there were no strong conflicts among the four overlapping synoptic surveys in the 20+ years of operation. Additionally, the retrospective analysis showed a response by the assessment model to observed drops in the WCVI and QCS synoptic survey indices for 2022 and 2023, respectively. This shift by the model in response to the change in survey biomass indices indicated that it was able to obtain biomass trend information from the survey observations, in spite of their apparent imprecision. Finally, recent stock assessments of rockfish species which exhibit similar semi-pelagic behaviour (e.g., Widow Rockfish [*S. entomelas*], Canary Rockfish) showed an equivalent capacity to use the available synoptic survey index series to estimate credible abundance trends (Starr and Haigh 2021, 2023).

The other major uncertainty associated with the Yellowtail Rockfish stock assessment was the relative absence of females after age 30 in comparison to the male ages which extend to near age 50. The same phenomenon was apparent in the Canary Rockfish data, and this stock assessment adopted a similar approach as was implemented by the Canary Rockfish stock assessment (Starr and Haigh 2023). Three hypotheses were proposed to explain the different age distribution by sex observed for Yellowtail Rockfish (B=base run, S=sensitivity run, Figure 2): B1: separate sex-based natural mortality, constant over the entire life span; S01: increased age-dependent natural mortality for females (i.e., senescence) after reaching maturity (age 9); and S02: decreased vulnerability to the fishery (dome-shaped selectivity) at older ages for females.

Hypothesis 1 is the simplest, involving only two parameters, and asks the question: “can this assumption provide sufficient ‘goodness of fit’ to explain the available observations?”. Hypothesis 2 was explored by sensitivity run S01 where, for each sex, one M was estimated for ages up to 9 (age of 50% female maturity), followed by a second estimated M per sex for age 10 and older. Hypothesis 3 was explored by sensitivity run S02 where trawl selectivity was allowed to estimate a descending right-hand limb for females only, thus eliminating older females from the trawl catch.

The base run (B1) fit the data acceptably and had good MCMC diagnostics. This run was selected as the base run because it was the most parsimonious in terms of model assumptions while achieving better model diagnostics compared to the other two hypotheses.

Sensitivity run S01 estimated split-M values for young fish (ages1-9) and mature fish (ages 10-45). This was reasonably successful, with the two male M medians estimated to be relatively similar (young = 0.088 and mature = 0.105), while the two median female M estimates were much further apart (young = 0.070 and mature = 0.200). However, this run failed to provide MCMC diagnostics that were as good as those for the base run and which estimated a stock status that was notably higher than that estimated by the base run (median B_{2025}/B_0 = 0.73 compared to B1 B_{2025}/B_0 = 0.56; median B_{2025}/B_{MSY} = 2.61 compared to B1 B_{2025}/B_{MSY} = 2.31). While this sensitivity run fit the data about as well as the base run, the somewhat poorer MCMC diagnostics, coupled with the strong optimism of S01 and the more complex model with two additional M parameters, suggested that this run should not be used as a replacement to the base run.

Sensitivity S02 resulted in strong dome-shaped selectivities for the trawl fleet and the three surveys which estimated selectivities. However, the MCMC simulation for this run was less acceptable than for either B1 or S01 and it estimated an enormous stock size of invulnerable mature females. The RPR noted that there was no corroborating evidence of a large cryptic population of mature female fish, thus reducing the credibility of this sensitivity run. The estimated M medians were credible, with both sexes having similar estimates (females = 0.110 and males = 0.111). However, the stock status estimate for this run was also very optimistic because of the presence of the large cryptic mature female population (median B_{2025}/B_0 = 0.81 compared to the B1 B_{2025}/B_0 = 0.56; median B_{2025}/B_{MSY} = 3.11 compared to B1 B_{2025}/B_{MSY} = 2.31). The yield from this population was also estimated to be much higher (median MSY = 7,420 t compared to the B1 MSY = 4,556 t). Again, this sensitivity run fit the data about as well as the base run, but the less acceptable MCMC diagnostics, coupled with the existence of a large cryptic but unsubstantiated mature female population suggested that this run should also not be considered as a replacement to the base run.

Two sensitivity runs which altered the abundance index assumptions resulted in higher stock status estimates compared to the base run. Using a geostatistical procedure to estimate standardised indices for the four synoptic surveys instead of the design-based indices (S12) or adding the Hard-bottom Longline (HBLL) survey series (S13) resulted in more optimistic interpretations of the data for both runs. For these two runs, the difference arose from a more optimistic model-fit trajectory through the recent survey index values, with indices over the past decade increasing more than for the base run. Further investigation into the underlying reasons that caused the divergence between the base run abundance series and the alternative abundance series would be required if these series were to be used in future Yellowtail Rockfish stock assessments.

Other sensitivity runs indicated little effect on Yellowtail Rockfish stock status (B_t/B_{MSY}) from these alternative assumptions:

- changing recruitment deviation variability (S03: reduced; S04: increased), and estimating recruitment variability (S05),
- alternative composition reweighting procedure (S06),
- using alternative ageing error assumptions (S07: no error; S08: age-reader CV; S09: constant 10% CV),
- changing catches (S10: -30%, S11: +50%) for the period between 1965 and 1995 (foreign fleets and pre-observer fisheries), and
- splitting the commercial fishery into bottom and midwater trawl fisheries (S14).

Sensitivity run S14 was particularly satisfying because this run returned results that were very similar to the base run, indicating that the considerable amount of midwater trawl AF data were in agreement with the bottom trawl AF data collected over the same 38-year period.

Research Recommendations

- Continue the coastwide coverage by fisheries independent synoptic surveys.
- Continue (and expand) the dockside (shoreside) sampling program.

- Explore best practices for choosing natural mortality priors.
- Explore the implications of using fecundity relationships that differ from the simple weight--based assumption on model output; also, whether alternative fecundity relationship should be estimated using samples from BC waters (currently only available from US waters).
- Explore and resolve the cause of the differences between geostatistical and design-based modelling approaches.
- Consider ageing additional Yellowtail Rockfish otoliths that are available from the Hecate Strait survey.
- Consider dropping the West Coast Haida Gwaii survey from model data for Yellowtail Rockfish.
- Conduct research into the different maximum ages by sex observed in Yellowtail Rockfish.
- Improve the specification of ageing error in the stock assessment model, e.g., explore the R package called ‘AgeingError’.

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