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Pacific Region

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Science Advisory Report 2024/012

PACIFIC OCEAN PERCH (*SEBASTES ALUTUS*) STOCK ASSESSMENT FOR BRITISH COLUMBIA IN 2023

CONTEXT

This Science Advisory Report is from the November 6–7, 2023 regional peer review on the Pacific Ocean Perch (*Sebastes alutus*) stock assessment for British Columbia in 2023. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

Pacific Ocean Perch (POP, *Sebastes alutus*) is a commercially important species of rockfish that inhabits marine canyons along the coast of British Columbia. Of the current annual Total Allowable Catch (TAC) of rockfish on the west coast of Canada, POP has the second largest single-species quota after Yellowtail Rockfish (*S. flavidus*). Key results from the stock assessment for subareas 5ABC, 3CD, and 5DE at the start of 2024 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.

SCIENCE ADVICE

Results below are reported as medians (with 90% credibility intervals in parentheses).

Status

- The probability that the female spawning stock biomass (B) at the beginning of 2024 is greater than the limit reference point (LRP, $0.4B_{\mathrm{MSY}}$, which is equilibrium biomass at maximum sustainable yield) and upper stock reference (USR, $0.8B_{\mathrm{MSY}}$) is > 0.99 for all three Pacific Ocean Perch subareas (5ABC, 3CD, and 5DE), placing all three stocks in the Healthy zone.
- Current stock status ($B_{2024}/B_{\mathrm{MSY}}$) is 2.0 (1.1, 3.5) in 5ABC, 2.8 (1.3, 5.8) in 3CD, and 2.9 (1.5, 5.7) in 5DE. Stock status for 3CD has greater uncertainty than for the other two stocks.
- The probability that the exploitation rate (u) in 2023 was below the exploitation rate at maximum sustainable yield was greater than 0.96 for all three stocks. Therefore, the exploitation rate in all three areas is below the maximum removal reference rate of u_{MSY}.

Trends

- Annual stock status (B_t/B_{MSY}) for Pacific Ocean Perch has been fluctuating above the USR from 2014 to 2024 in 5ABC, has been trending upward above the USR from 2007 to 2024 in 3CD, and trending strongly upward above the USR from 2014 to 2024 in 5DE.
- Stock size in the beginning of 2024 relative to unfished female spawning biomass (B_{2024}/B_0) is estimated to be 0.50 (0.33, 0.77) for 5ABC, 0.71 (0.36, 1.3) in 3CD, and 0.72 (0.43, 1.3) in 5DE.

Canada

Ecosystem and Climate Change Considerations

- A low-recruitment worst-case projection was made by simulating an arbitrary 50% recruitment reduction for over 20 years from 2015 to 2034. This simulation showed little difference from the base run projections at the levels of catch investigated.

Stock Advice

- All constant-catch policies tested showed very low risk ($P < 0.01$) of breaching the equilibrium reference points based on maximum sustainable yield (MSY) (LRP, USR, Removal Reference) over the next 10 years for the base run.
- Decision tables based on B_0 reference criteria showed a probability $P(B_{2034} > 0.2B_0)$ of 0.93 at the highest catch evaluated in each subarea, and $P(B_{2034} > 0.4B_0)$ exceeded 0.5 in 3CD and 5DE for all catch policies and exceeded 0.5 in 5ABC for catches at 2,550 tonnes per year or lower.
- The probability of projected spawning biomass being greater than current spawning biomass, $P(B_t > B_{2024})$, indicated that, for all years from 2025 to 2034, the projection probabilities vary among the three stocks. 5ABC is projected to increase while 3CD is projected to decline, even at zero catch, and 5DE is projected to remain constant at all evaluated catch levels.

BASIS FOR ASSESSMENT

Assessment Details

Year Assessment Approach was Approved

2023 Terms of Reference

Assessment Type

Full Assessment: Full peer-reviewed stock assessment

Most Recent Assessment Dates

1. Last Full Assessment:
   POP 5ABC in 2017, Haigh et al. (2018)
   POP 3CD in 2012, Edwards et al. (2014b)
   POP 5DE in 2012, Edwards et al. (2014a)
2. Last Interim Year Update: N/A

Assessment Approach

1. Stock assessment model
2. Statistical catch-at-age (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 POP from 1935 to the end of 2023 using NOAA's Stock Synthesis 3 model platform (v.30.20, Methot et al. 2022). Ages were tracked from 1 to 60, where 60 acted as an accumulator age category. The population was assumed to be in equilibrium with average recruitment and with no fishing at the beginning of the reconstruction (in 1935). Outputs are estimates from Bayesian posteriors estimated from Markov Chain Monte Carlo (MCMC) runs.

Stock Structure Assumption

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

- three stocks by subarea, corresponding to Pacific Marine Fisheries Commission (PMFC) boundaries[1] 5ABC, 3CD, and 5DE, each of which have their own reference points;
- the three stocks shared a single Beverton-Holt stock-recruitment function (with one estimated steepness parameter, h), sex-specific coastwide parameters, and a shared coastwide recruitment that was apportioned to each subarea; and
- nine fleets—three commercial fisheries, one in each subarea, and six fishery-independent surveys (three synoptic bottom trawl surveys and three historical bottom trawl surveys).

Both PMFC and Groundfish Management Unit (GMU) areas account for the 5C wraparound at the southern end of Moresby Island specific to POP; however, small differences remain between the two areas, primarily inshore. It is not expected that these differences will cause a mismatch in advice between the assessed and managed areas.

Reference Points

The reference points are adopted from DFO's provisional defaults (DFO 2009). Estimates used for analysis and decisions for each stock are derived from a Bayesian analysis that yields a posterior set of at least 2,000 samples.

- 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);
- Target (TRP): (if developed) not developed or used by managers.

Data

The main data inputs to the SS3 multi-area model included:

- catch time series (1935 to 2023) for each of the three subareas (5ABC, 3CD, 5DE);
- abundance index series from six surveys (no commercial CPUE index series were used);
- fisheries (3 fleets) and survey (5 fleets) composition data from proportions-at-age data (called 'age frequencies' or AF);
- an ageing error vector of smoothed standard deviations derived from CVs of observed lengths-at-age;
- fixed biological parameters (allometry, growth, maturity) estimated externally on a coastwide population.

[1] PMFC 5C was modified to include a portion of 5E south of 52°20′ (Anthony Island) and Moresby Gully from 5B to accommodate the management of POP (and Yellowmouth Rockfish) only. The net effect on the 5ABC area is the inclusion of Anthony Island at the expense of 5DE. PMFC areas differ slightly from GMU management regions, which are based on DFO statistical areas. This 1997 change was made to more closely reflect the POP fishery.

ASSESSMENT

Historical and Recent Stock Trajectory and Trends

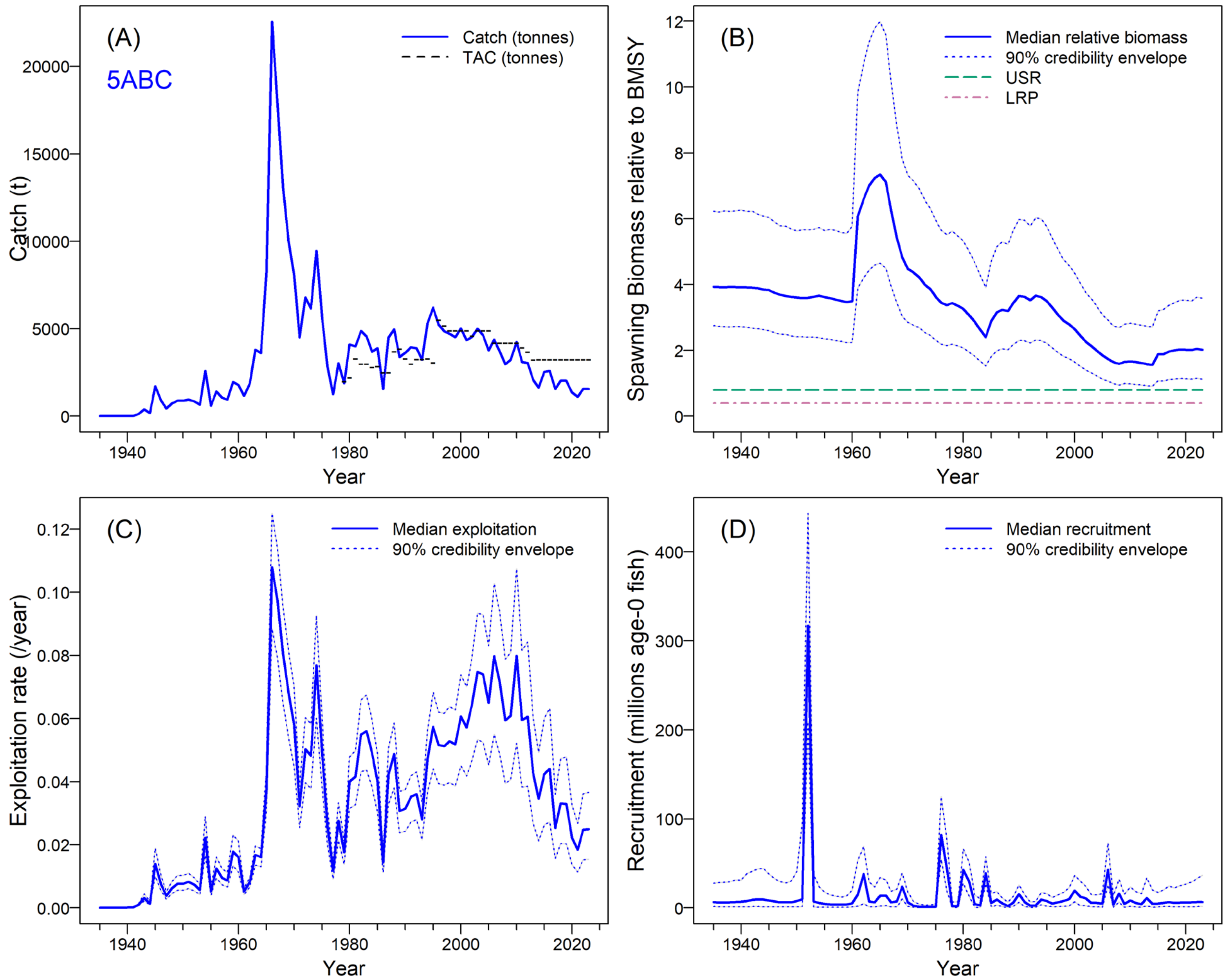

Figure 1. Subarea 5ABC: (A) catch (solid blue line) and total allowable catch (black dashes); (B) female spawning biomass relative to equilibrium biomass at MSY (B_t/B_{MSY}) with Limit Reference Point (LRP = $0.4B_{MSY}$, dashed-dot red line) and Upper Stock Reference (USR = $0.8B_{MSY}$, dashed green line); (C) exploitation rate (u_t, per year t); (D) recruitment (R_t, millions of age-0 fish). Median values in panels A-C appear as solid blue lines and the 90% credibility envelopes are delimited by dotted blue lines.

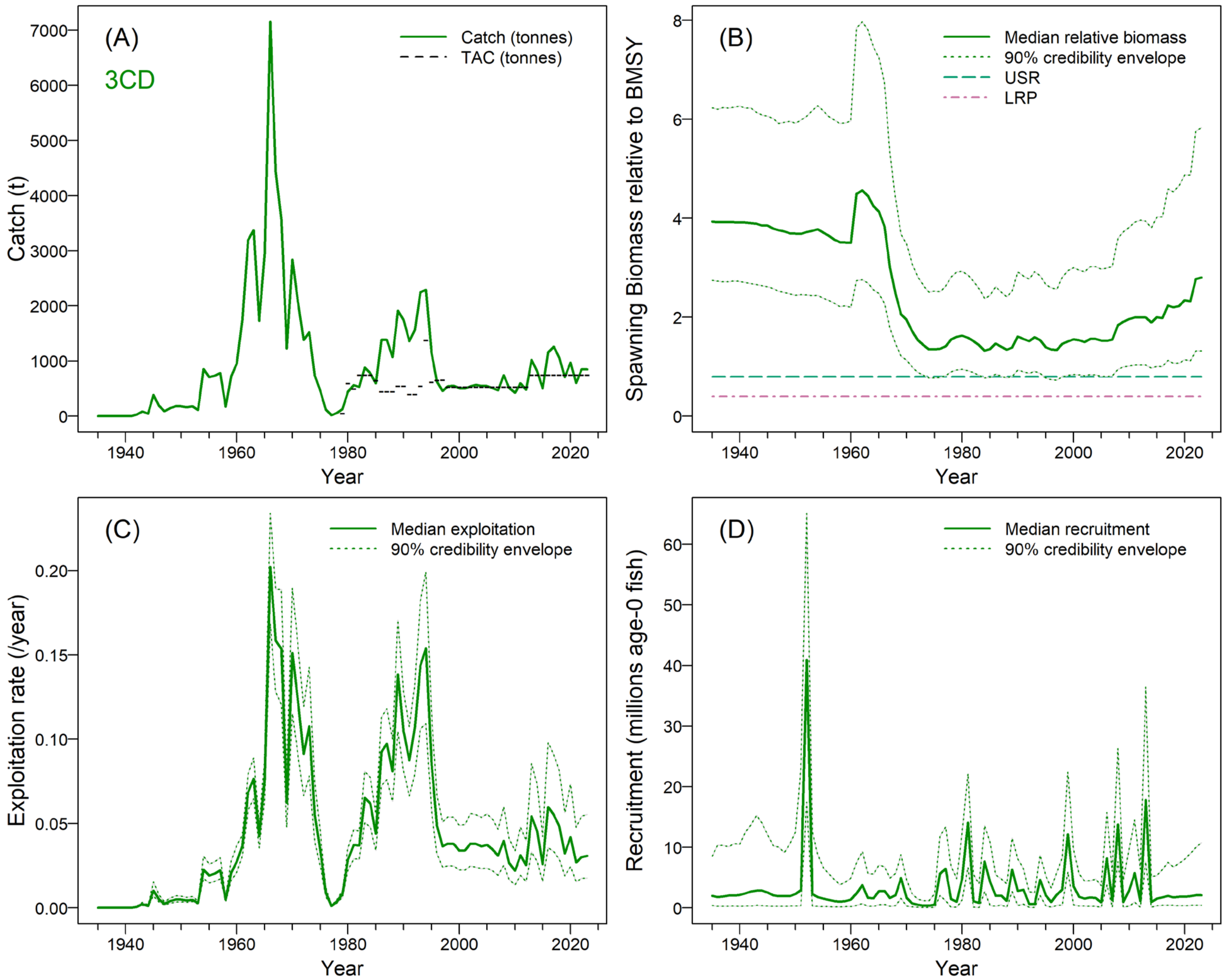

Figure 2. Subarea 3CD: (A) catch and total allowable catch; (B) female spawning biomass relative to equilibrium biomass at MSY (B_t/B_{MSY}) with LRP and USR; (C) exploitation rate (u_t); (D) recruitment (R_t). See Figure 1 caption for details.

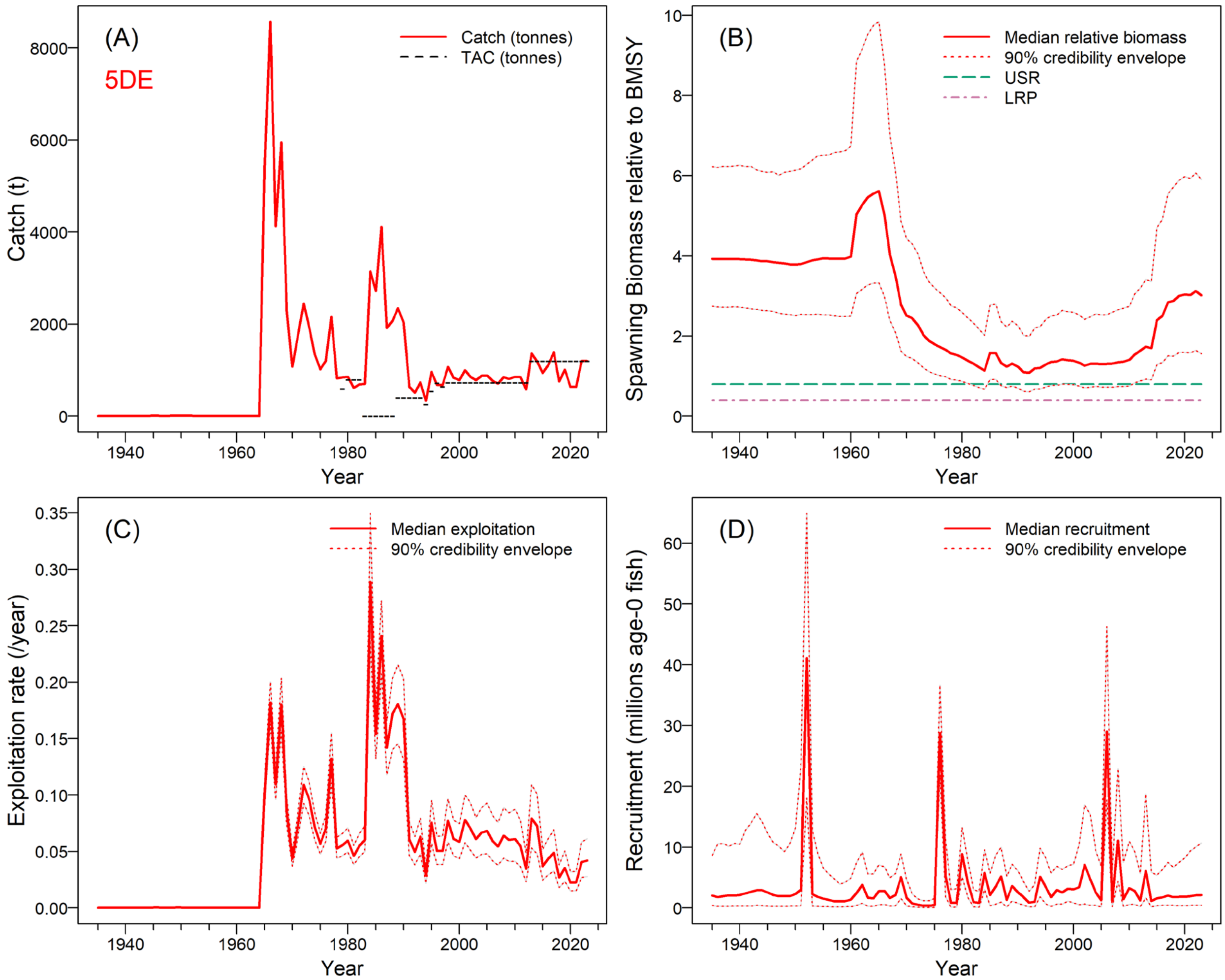

Figure 3. Subarea 5DE: (A) catch and total allowable catch; (B) female spawning biomass relative to equilibrium biomass at MSY (B_t/B_{MSY}) with LRP and USR; (C) exploitation rate (u_t); (D) recruitment (R_t). See Figure 1 caption for details.

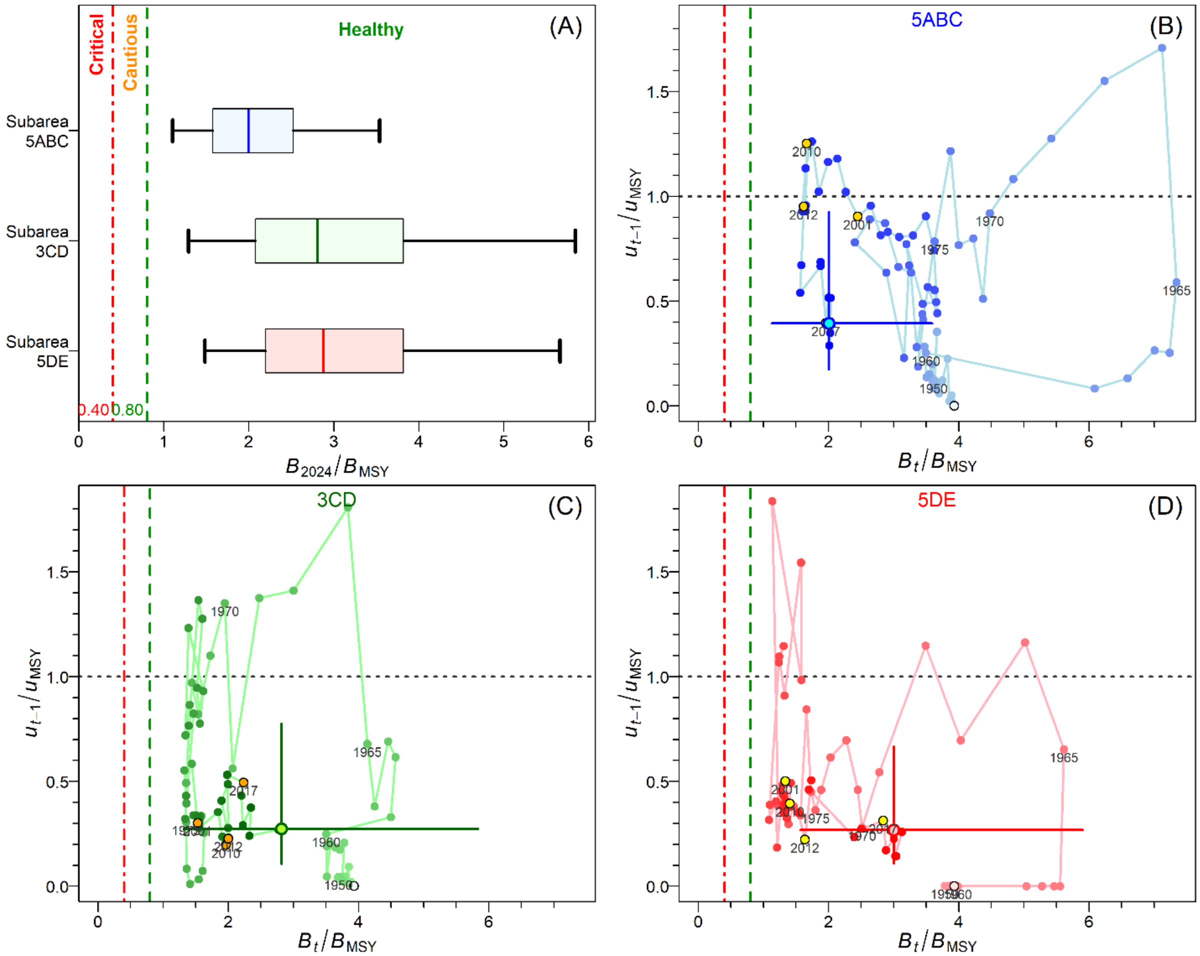

Figure 4. (A) Stock status (B_t/B_{MSY}) at beginning of 2024 for the coastwide model three component subareas relative to the DFO PA provisional reference points of $0.4B_{MSY}$ and $0.8B_{MSY}$ for the base run. Boxplots show the 0.05, 0.25, 0.5, 0.75 and 0.95 quantiles from the MCMC posterior. (B-D) Phase plots of u_{t-1}/u_{MSY} vs. B_t/B_{MSY} for subareas 5ABC, 3CD, and 5DE, respectively.

Productivity Parameters

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

Table 1. Quantiles of the posterior distribution based on 2,000 MCMC samples for the main estimated model parameters for the base run POP stock assessment. M = natural mortality. BH = Beverton-Holt. R = recruitment.

Parameter	5%	25%	50%	75%	95%
M_1 (female)	0.0436	0.0485	0.0523	0.0557	0.0615
M_2 (male)	0.0505	0.0557	0.0594	0.0631	0.0690
BH (h)	0.474	0.638	0.754	0.848	0.943
log R_0	9.448	9.680	9.845	10.01	10.26
prop R_0 (5ABC)	0.543	0.589	0.619	0.649	0.690
prop R_0 (3CD)	0.152	0.174	0.190	0.206	0.229
prop R_0 (5DE)	0.156	0.176	0.191	0.207	0.229

Estimated productivity parameters appear in Table 1. Median natural mortality for females was lower than that for males, and steepness was not well-defined, likely because none of the subarea populations had breached $0.2B_0$. The estimated proportion of recruitment in 3CD did not move far from the initial value of zero in log space, and so its proportion did not differ greatly from that in 5DE, which was fixed at zero during the estimation routine. Consequently, the outlying populations (3CD and 5DE) were estimated to have similar biomass magnitudes to the base run.

Biomass

Estimated 2024 median spawning biomass B_t relative to B_0 (also called depletion) for the multi-area model were:

- 0.50 (0.33, 0.77) in 5ABC,
- 0.71 (0.36, 1.3) in 3CD, and
- 0.72 (0.43, 1.3) in 5DE.

Estimated 2024 stock status (B_{2024}/B_{MSY}) was:

- 2.0 (1.1, 3.5) in 5ABC, fluctuating above the USR since 2015,
- 2.8 (1.3, 5.8) in 3CD, trending upward above the USR since 2015, and
- 2.9 (1.5, 5.7) in 5DE, trending strongly upward above the USR since 2015.

The coastwide POP model estimated that all three subareas were firmly in DFO's Precautionary Approach Healthy zone (medians > 1) in 2024.

Female spawning biomass at the beginning of 2024 (B_{2024}), maximum sustainable yield (MSY), the limit reference point biomass (LRP = $0.4B_{MSY}$), and the upper stock reference biomass (USR = $0.8B_{MSY}$) are also reported in Table 2, as are various metrics for exploitation rate. The ratio of estimated exploitation rate u_{2023} to u_{MSY} (where u_{MSY} was the adopted Removal Reference in the Healthy zone), did not exceed 1:

- 0.39 (0.18, 0.93) in 5ABC,
- 0.27 (0.11, 0.78) in 3CD, and
- 0.27 (0.11, 0.67) in 5DE.

Recruitment

Coastwide recruitment estimates were fairly modest (mean of annual medians from 1935 to 2014 = 22 million age-0 fish), with one big recruitment event in 1952 of 401 million age-0 fish (18x the mean), which sustained the early fisheries by the foreign fleets in the late 1960s and the 1970s (Figure 1). The single-area models for 5ABC and 5DE had good-recruitment years in 1952, 1976, and 2006 (see Starr and Haigh In prep.[2]); however, the single-area 3CD model saw modest recruitment upticks in 1981, 1999, 2008, and 2013 (see Starr and Haigh In prep.[2]). A feature of the multi-area stock assessment model was that it retained area-specific recruitment events, but also "borrowed" recruitment information from the more data-rich 5ABC data set. Consequently, both outlying stocks (3CD and 5DE) showed good recruitment from the 1952

[2] Starr, P.J. and Haigh, R. Pacific Ocean Perch (*Sebastes alutus*) stock assessment for British Columbia in 2023. DFO Can. Sci. Advis. Sec. Res. Doc. In prep.

year class, even though the age frequency from the 3CD stock did not extend that far back while the 5DE stock showed a lower level of increased recruitment in that year.

Table 2. Derived parameter quantiles from the 2,000 samples of the base run MCMC posterior for three subareas from the coastwide multi-area model. Definitions: B_0 – unfished equilibrium spawning biomass, B_{2024} – spawning biomass at the start of 2024, u_{2023} – exploitation rate (ratio of total catch to vulnerable biomass) in the middle of 2023, u_{max} – maximum exploitation rate (calculated for each sample as the maximum exploitation rate from 1935-2023), 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 (2018–2022) was 1,618 t in 5ABC, 840 t in 3CD, and 848 t in 5DE. Note: quantiles are not additive.

Area	Quantity	5%	25%	50%	75%	95%
5ABC	B_0	47,759	57,364	65,469	74,842	90,531
	B_{2024}	21,853	27,195	32,243	38,669	52,341
	B_{2024} / B_0	0.328	0.420	0.495	0.594	0.770
	u_{2023}	0.015	0.021	0.025	0.029	0.037
	u_{max}	0.089	0.100	0.108	0.115	0.125
	MSY	1,803	2,418	2,993	3,618	4,744
	B_{MSY}	9,681	13,364	16,311	20,390	27,164
	$0.4B_{MSY}$	3,872	5,346	6,524	8,156	10,866
	$0.8B_{MSY}$	7,745	10,691	13,049	16,312	21,731
	B_{2024} / B_{MSY}	1.101	1.574	1.994	2.522	3.537
	B_{MSY} / B_0	0.161	0.214	0.254	0.298	0.364
	u_{MSY}	0.029	0.046	0.064	0.083	0.118
	u_{2023} / u_{MSY}	0.176	0.281	0.394	0.563	0.925
3CD	B_0	13,298	17,039	20,370	23,856	29,456
	B_{2024}	7,700	11,088	14,105	17,904	24,562
	B_{2024} / B_0	0.356	0.540	0.710	0.922	1.316
	u_{2023}	0.018	0.024	0.031	0.039	0.055
	u_{max}	0.168	0.190	0.202	0.214	0.234
	MSY	514	740	918	1,131	1,482
	B_{MSY}	2,829	4,028	5,048	6,290	8,652
	$0.4B_{MSY}$	1,132	1,611	2,019	2,516	3,461
	$0.8B_{MSY}$	2,264	3,222	4,039	5,032	6,922
	B_{2024} / B_{MSY}	1.291	2.078	2.806	3.817	5.843
	B_{MSY} / B_0	0.161	0.214	0.254	0.298	0.364
	u_{MSY}	0.051	0.080	0.112	0.152	0.228
	u_{2023} / u_{MSY}	0.106	0.185	0.274	0.407	0.777
5DE	B_0	13,238	17,157	20,513	23,831	30,002
	B_{2024}	9,819	12,305	14,491	17,157	22,138
	B_{2024} / B_0	0.426	0.583	0.715	0.899	1.263
	u_{2023}	0.028	0.036	0.042	0.049	0.061
	u_{max}	0.238	0.267	0.289	0.311	0.350
	MSY	518	749	921	1,138	1,483
	B_{MSY}	2,860	4,056	5,123	6,334	8,676
	$0.4B_{MSY}$	1,144	1,623	2,049	2,534	3,470
	$0.8B_{MSY}$	2,288	3,245	4,098	5,067	6,941
	B_{2024} / B_{MSY}	1.482	2.198	2.876	3.819	5.661
	B_{MSY} / B_0	0.161	0.214	0.254	0.298	0.364
	u_{MSY}	0.072	0.113	0.156	0.214	0.325
	u_{2023} / u_{MSY}	0.110	0.187	0.268	0.389	0.666

History of Harvest and Total Allowable Catch (TAC)

BC POP catch was reconstructed back to 1918 but the assessment model started from assumed equilibrium conditions in 1935. Table 3 shows catches since the implementation of an onboard observer program in 1996. Total Allowable Catch in 2023 (Feb 21, 2023 to Feb 20, 2024) was 1,687 t in 5AB, 1,555 t in 5C, 750 t in 3CD, 1,200 t in 5DE, and 5,192 t coastwide.

Table 3. History of recent catches (in tonnes, landings + releases) of POP by calendar year in three PMFC regions (5ABC, 3CD, 5DE) from trawl (bottom + midwater) and non-trawl fisheries (Halibut, Sablefish, Dogfish/Lingcod, and H&L Rockfish). The final three columns show catches used in the population model. Area catches for 2023 were set to values in 2022.

	TRAWL			OTHER			TOTAL		
Year	5ABC	3CD	5DE	5ABC	3CD	5DE	5ABC	3CD	5DE
1996	5,249	625	682	1.06	0.603	0.411	5,250	626	683
1997	4,851	459	678	0.979	0.912	0.380	4,852	460	679
1998	4,706	541	1,071	1.43	0.658	0.515	4,708	542	1,072
1999	4,516	555	838	1.28	0.750	0.253	4,517	556	838
2000	5,016	511	784	1.83	0.564	2.84	5,018	512	787
2001	4,352	501	998	1.26	0.486	0.476	4,353	502	999
2002	4,545	543	855	0.922	0.531	0.201	4,546	543	855
2003	5,004	569	783	0.434	0.351	0.182	5,004	569	783
2004	4,626	549	880	0.498	0.600	0.153	4,626	550	880
2005	3,765	546	881	0.351	1.03	0.079	3,766	547	881
2006	4,377	509	771	0.902	0.216	0.078	4,378	509	771
2007	3,714	467	713	0.621	0.300	0.092	3,714	468	713
2008	2,969	742	853	0.343	0.198	0.062	2,970	742	853
2009	3,214	513	813	0.153	0.085	0.156	3,215	513	813
2010	4,248	426	858	0.187	0.887	0.295	4,248	427	858
2011	3,095	598	852	0.260	0.240	0.131	3,096	598	853
2012	3,045	483	581	0.188	0.244	0.121	3,045	484	581
2013	2,073	1,020	1,362	0.085	0.110	0.060	2,073	1,020	1,362
2014	1,642	814	1,194	0.096	0.042	0.119	1,642	814	1,194
2015	2,544	504	936	0.318	0.191	0.164	2,545	505	936
2016	2,593	1,155	1,101	0.502	0.144	0.066	2,593	1,156	1,101
2017	1,552	1,264	1,391	0.143	0.235	0.340	1,552	1,264	1,391
2018	2,024	1,066	755	0.243	0.258	0.184	2,024	1,066	755
2019	2,033	711	1,009	0.368	0.283	0.145	2,034	711	1,010
2020	1,364	970	639	0.193	0.142	0.065	1,364	970	639
2021	1,118	606	636	0.098	0.067	0.026	1,118	606	636
2022	1,551	849	1,200	0.188	0.076	0.091	1,551	849	1,200
2023	1,551	849	1,200	0.188	0.076	0.091	1,551	849	1,200

Projections or Simulations

Projections extend to the end of 2033 (beginning of 2034). Decision tables for the POP base run provide advice to managers as probabilities that projected biomass B_t (t = 2025, ..., 2034) will exceed biomass-based reference points, or that projected exploitation rate u_t (t = 2024, ..., 2033) will fall below harvest-based reference points, under constant-catch policies. That is, the tables present probabilities that projected B_t, using the base run, will exceed the LRP (Table 4) and the USR (Table 5) or will be less than the exploitation rate at MSY (Removal Reference, RR, 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 catch of 1,750 t (close to the recent 5-y mean) will be taken in 5ABC for each year over the next 10 years, Table 4 indicates that a manager would be >99% certain that both B_{2029} and B_{2034} lie above the LRP of $0.4B_{\mathrm{MSY}}$, >99% certain that both B_{2029} and B_{2034} lie above the USR of $0.8B_{\mathrm{MSY}}$, and >99% certain that both u_{2028} and u_{2033} lie below u_{MSY} for the base run.

Figure 5 shows the impact on the spawning biomass for each of the three component subareas caused by projections at three catch levels (no catch, current catch and maximum catches used in each decision table). While the 5ABC subarea is projected to increase under current levels of catch, both the 3CD and the 5DE subareas are projected to decrease at current catch levels, although they are projected to remain in the Healthy zone at these catch levels (Table 5). All three subareas are projected to decline under the maximum projection catch levels, but again they are projected to remain in the Healthy zone at these maximum catch levels (Table 5).

Table 4. Base run subareas: decision table for the limit reference point (LRP = $0.4B_{MSY}$) for 1–10 year projections using a range of constant catch policies (in metric tonnes). Values are the probability 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 (2018–2022) was 5ABC = 1,618 t, 3CD = 840 t, and 5DE = 848 t.

Area	Catch (t/y)	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
5ABC	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
	1,350	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	1,750	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	2,150	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	2,550	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	3,500	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99
3CD	0	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	500	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	750	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	875	>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
	1,125	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99
	1,250	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.99
5DE	0	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	700	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	900	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	1,050	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	1,200	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	1,350	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	1,500	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99

Table 5. Base run subareas: decision table for the upper stock reference (USR = $0.8B_{MSY}$) for 1–10 year projections for a range of constant catch policies (in metric tonnes). Values are the probability of the female spawning biomass at the start of year t being greater than the USR. See Table 4 caption for more details.

Area	Catch (t/y)	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
5ABC	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
	1,350	>0.99	>0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
	1,750	>0.99	>0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
	2,150	>0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.98	0.98	0.98	0.98
	2,550	>0.99	0.99	0.99	0.99	0.99	0.98	0.98	0.97	0.97	0.97	0.96
	3,500	>0.99	0.99	0.99	0.98	0.97	0.96	0.95	0.93	0.92	0.90	0.89

Area	Catch (t/y)	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
3CD	0	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	500	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
	750	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.98	0.98	0.98	0.98
	875	0.99	0.99	0.99	0.99	0.99	0.98	0.98	0.98	0.98	0.98	0.98
	1,000	0.99	0.99	0.99	0.99	0.98	0.98	0.98	0.98	0.97	0.97	0.96
	1,125	0.99	0.99	0.99	0.98	0.98	0.98	0.97	0.97	0.96	0.95	0.95
	1,250	0.99	0.99	0.99	0.98	0.98	0.97	0.96	0.96	0.95	0.94	0.93
5DE	0	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	700	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.99
	900	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.99	0.99	0.99
	1,050	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.99	0.98	0.98	0.97
	1,200	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.98	0.98	0.97	0.96
	1,350	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.98	0.97	0.96	0.96	0.95
	1,500	>0.99	>0.99	>0.99	0.99	0.99	0.98	0.98	0.96	0.95	0.94	0.92

Table 6. Base run subareas: decision table for the removal reference (RR = u_{MSY}) for 1–10 year projections for a range of constant catch policies (in metric tonnes). Values are the probability of the exploitation rate at the middle of year t being less than the RR. See Table 4 caption for more details.

Area	Catch (t/y)	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
5ABC	0	1	1	1	1	1	1	1	1	1	1	1
	1,000	>0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	>0.99	>0.99	>0.99
	1,350	0.98	0.98	0.98	0.98	0.98	0.97	0.97	0.97	0.97	0.97	0.97
	1,750	0.93	0.93	0.92	0.92	0.92	0.91	0.91	0.91	0.91	0.91	0.91
	2,150	0.86	0.85	0.85	0.84	0.83	0.83	0.82	0.82	0.82	0.81	0.81
	2,550	0.78	0.77	0.75	0.74	0.73	0.72	0.70	0.70	0.70	0.69	0.69
	3,500	0.59	0.55	0.53	0.50	0.47	0.44	0.43	0.41	0.41	0.40	0.40
3CD	0	1	1	1	1	1	1	1	1	1	1	1
	500	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.99	0.99	0.99
	750	0.98	0.98	0.98	0.98	0.98	0.98	0.97	0.97	0.97	0.97	0.97
	875	0.97	0.97	0.97	0.96	0.96	0.96	0.95	0.95	0.95	0.94	0.94
	1,000	0.96	0.96	0.95	0.94	0.94	0.93	0.92	0.91	0.91	0.90	0.90
	1,125	0.94	0.93	0.92	0.91	0.91	0.90	0.88	0.88	0.87	0.86	0.84
	1,250	0.92	0.91	0.89	0.88	0.87	0.86	0.83	0.82	0.80	0.79	0.78
5DE	0	1	1	1	1	1	1	1	1	1	1	1
	700	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
	900	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.99	0.98	0.98
	1,050	>0.99	0.99	0.99	0.99	0.98	0.98	0.98	0.97	0.97	0.96	0.96
	1,200	0.99	0.99	0.98	0.98	0.97	0.96	0.95	0.95	0.94	0.93	0.93
	1,350	0.98	0.98	0.97	0.96	0.95	0.94	0.93	0.92	0.91	0.89	0.87
	1,500	0.97	0.96	0.95	0.94	0.93	0.91	0.89	0.87	0.85	0.83	0.80

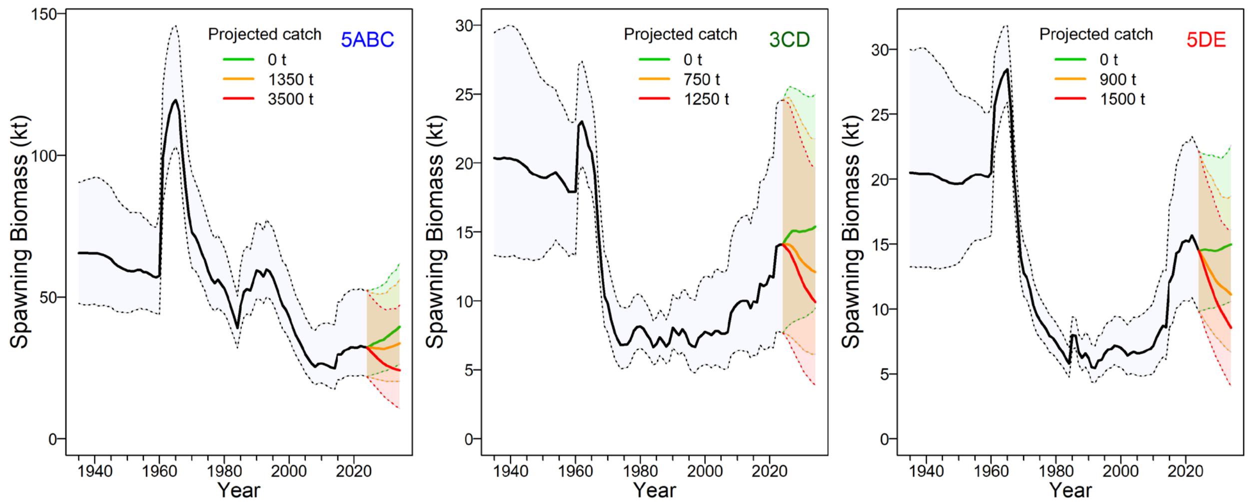

Figure 5. Reconstructed spawning biomass trajectories for the three component subareas of the BC coastwide POP population, showing projections at three levels: (a) no catch (green); (b) current catch levels (orange); (c) maximum catch projected by this study (red). Solid lines are the posterior median and the shaded area encompasses the 90% credibility envelope.

Ecosystem and Climate Change Considerations

This assessment did not incorporate an environmental index series (e.g., winter Pacific Decadal Oscillation) to predict recruitment, because a previous attempt for Canary Rockfish (Starr and Haigh 2023) found the relationship was dependent on how much relative weight was assigned to the series through added process error (i.e., the approach lacked objectivity). Instead, to simulate possible environmental impacts in this assessment, recruitment strength was reduced arbitrarily by half from the base-run forecast ($0.5R_0$). This was done for pragmatic reasons (to accommodate limitations of the SS3 assessment platform) and to represent a short-term, easily understandable “worst case” scenario.

Reduced-recruitment decision tables (in Starr and Haigh In prep.[2]) show virtually no impact on the risk of breaching the LRP ($0.4B_{\mathrm{MSY}}$), but some reduction in the predicted probabilities for exceeding the USR ($0.8B_{\mathrm{MSY}}$) at the highest catch levels in all three subareas. Exploitation rate (u_t) was predicted to remain below u_{MSY} with relativity high probability, except for 5ABC at the higher catch levels.

While lowering forecast recruitment was not a definitive test, it does indicate that, under severe and continuous recruitment failure, POP stock status will decline at high catch levels. However, such an outcome seems extreme; therefore, the exact scenarios demonstrated in Starr and Haigh (In prep.[2]) are considered unlikely to occur.

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 usual. Three of the existing synoptic trawl surveys, the QCS, WCVI, and WCHG surveys, should be capable of signaling a major reduction in stock abundance, but it will be difficult to distinguish minor changes in abundance from random observation error, given relative errors that lie in the range of 0.15 to 0.3. The next full stock assessment should be scheduled no earlier than 2034, given the currently assessed Healthy state and low exploitation rates. Recent recruitment appeared to be good, and the 2013 year class may have been quite good, if the signal in the 3CD recruitment series was credible. Regardless of when a new stock assessment is to be initiated, sufficient time is required to allow for the reading of new ageing structures that will be needed for the interpretation of the population trajectory. 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 tracked by the fishery independent surveys used in this stock assessment. The groundfish synopsis report (DFO 2022), updating Anderson et al. (2019), summarized these trends and can be used as a tracking tool.

SOURCES OF UNCERTAINTY

Although uncertainty was built into the assessment and its projections by taking a Bayesian approach for parameter estimation, these results depend heavily on the assumed model structure, the informative priors, and assumptions (particularly the average recruitment assumptions) used for the projections.

The greatest uncertainty in this stock assessment was the relative size of the three subarea stocks in the multi-area model. This uncertainty largely centered around the size of the 3CD stock, with the estimates varying depending on the choice of arbitrary underlying assumptions concerning recruitment allocation (Starr and Haigh In prep.[2]). It is advised to treat the evaluation and predictions for 3CD with caution.

The implementation of the Dirichlet-multinomial (D-M) method for weighting the age frequency data was the initial choice for this stock assessment, after having successfully used this procedure for assessing Canary Rockfish in 2022 (Starr and Haigh 2023). However, exploratory analyses using larger sample sizes resulted in a considerable downward shift in the estimated POP stock size (-38%) when using the D-M procedure, but resulted in almost no change for the stock size when using the Francis (2011) procedure (see discussion in E.6.2.3 of Starr and Haigh In prep.[2]). The findings were surprising because the choice of method to weight age frequency data appeared to be strongly affected by the magnitude of sample sizes alone in one method but not the other. Therefore, choice of weighting method for age frequency data remains a source of uncertainty.

Foreign fleet effort in 1965–76 along the BC coast targeted offshore rockfish (mainly POP), but the magnitude of the foreign fleet removals of POP remained uncertain because reporting at the time, even for total rockfish catch, was not as rigorous as now, and the uncertainty in the catch by species was also great. Another source of uncertainty in the historical catch series came from domestic landings from the mid-1980s to 1995 (pre-observer coverage) which may have misreported (inflated) lesser rockfish species to bypass quota restrictions on more desirable species like POP, leading to uncertainty in the allocation of catch by rockfish species. The sensitivity runs on catch (S07: -30%; S08: +50%) showed that catch uncertainty did not have a major effect on the model’s biomass trajectory or on the estimates of the relative stock size at the beginning of 2024. However, S08 (+50%) resulted in an increase in absolute stock size, which would imply greater productivity than was estimated by the base run, while S07 (-30%) showed a drop in stock size which implied a lowering of potential productivity.

Ageing error was applied using two alternative implementations in addition to the base run implementation; however, their impact on the model results was not large. Removing ageing error estimated a much larger stock size (60% greater B_0 and 45% greater current biomass B_{2024}), while the two other ageing error implementations resulted in much smaller differences relative to the base run. All three implementations of ageing error, as well as its removal, resulted in similar estimates for stock size relative to B_0 (B_{2024}/B_0).

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