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UPDATE OF THE 2019 BOCACCIO (*SEBASTES PAUCISPINIS*) STOCK ASSESSMENT FOR BRITISH COLUMBIA IN 2024

Context

Bocaccio Rockfish (BOR, *Sebastes paucispinis*) was assessed in 2019 (Starr and Haigh 2022), and updated in 2021 (DFO 2022), using the Awatea catch-at-age stock assessment model platform tuned to six fishery-independent trawl survey series (spanning 1967–2021), a standardised commercial bottom trawl catch per unit effort (CPUE) series (1996–2012)[1], annual estimates of commercial catch from two fisheries, and age composition data from the combined commercial trawl fishery and six surveys (two historical and four synoptic).

The British Columbia (BC) outside coast model started from an assumed unfished equilibrium state in 1935. Three component base runs using a two-sex model were implemented in a Bayesian framework (using the Markov Chain Monte Carlo [MCMC] procedure) under scenarios that fixed natural mortality (M) to three levels (0.07, 0.08, 0.09) with the accumulator age (A) set to 50 years while estimating steepness of the stock-recruit function (h), catchability (q) for surveys and CPUE, and selectivity (μ) for four synoptic surveys and the commercial trawl fleet. These three runs were combined into a composite base case which explored the major axis of stock assessment uncertainty: natural mortality. The three selected M values encompassed an agreed plausible range for this parameter. A summary of the 2019 stock assessment can be found in Science Advisory Report 2020/025 and Proceedings 2021/014. Descriptions of earlier Bocaccio stock assessments (including reviews of this species by the Committee on the Status of Endangered Wildlife in Canada) can be found in Research Document 2022/001. The 2021 stock status update can be found in Science Response 2022/001.

The 2019 stock assessment depicted a coastwide BOR stock experiencing a nearly continuous decline from the start of the population reconstruction in 1935, interrupted only by a period of arrested decline spanning the years 1970–86 resulting from a few moderate recruitment events in 1969, 1976, and 1978. The decline resumed in 1987, continuing until an extremely large recruitment event occurred in 2016, estimated by the 2019 model to be 44 times the long-term average recruitment (5% and 95% quantiles: 30 times, 58 times). The 2021 update revised this recruitment event to be even larger than that estimated in 2019, with a median of 60 times the long-term average (5% and 95% quantiles: 49 times, 68 times).

The 2019 stock assessment predicted that the stock would recover (defined as being above the limit reference point, LRP = $0.4B_{MSY}$, with at least 95% probability) by the beginning of 2022. This was borne out for 2022 by the 2021 update, which also predicted that the stock would remain within the Healthy zone (defined as being above the upper stock reference, USR = $0.8B_{MSY}$, with at least 50% probability) for the next 10 years. While the 2021 update corroborated the optimism of the 2019 stock assessment, the technical working group in 2021

[1] The series was truncated at 2012 on the advice of the BOR Technical Working Group (TWG, 2019); it was felt that avoidance behaviour by the fleet would bias the indices after Total Allowable Catches were considerably reduced in 2013 in response to the COSEWIC 'Endangered' designation.

requested that another update be generated in two more years to again verify the robustness of the recovery. Within this time period, four additional synoptic survey index values became available, and new age data were also available. However, the primary empirical evidence for the progress of the large 2016 cohort remained the length frequency (LF) data. A second cohort, born in 2020, was also identified in the 2021 LF data, and evidence of its existence was flagged.

This Science Response Report results from the regional peer review of March 28, 2024 on the Update of the 2019 Bocaccio (*Sebastes paucispinis*) Stock Assessment for British Columbia in 2024.

Background

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assessed the British Columbia (BC) population of Bocaccio (BOR) as “Threatened” in 2002. In November 2013, BOR was reassessed by COSEWIC as “Endangered”. An endangered species is defined by the *Species at Risk Act* (SARA) as one that is facing imminent extirpation or extinction. In the absence of updated science advice, there was uncertainty about the risks posed to the BC BOR stock as catch levels increased (Figure 1) in response to the apparent strong recruitment event in 2016. This second stock assessment update was generated to review the expected recovery outlined in the 2019 stock status of BOR (Starr and Haigh 2022), the follow-up on its recovery two years later (DFO 2022), and to provide DFO with advice on the continued recovery for this species.

Bocaccio is ubiquitous along the BC coast, with most catches taken near the bottom in the depth range of 60–300 m. Catches appear to be greatest on the edge of the continental shelf where it slopes away, as well as along the edges of the main gullies in Queen Charlotte Sound and the more southern sections of Hecate Strait (Stanley et al. 2009). These authors noted that BOR is a schooling semi-pelagic species, leading to the observation that the adults likely do not occupy specific sites other than preferring high-relief boulder fields and rocks. The species is relatively short-lived compared to other *Sebastes* species such as Pacific Ocean Perch (*S. alutus*) or Rougheye Rockfish (*S. aleutianus*), a characteristic shared with other semi-pelagic *Sebastes* species (e.g., Widow Rockfish, *S. entomelas*; Yellowtail Rockfish, S. *flavidus*). The available age data show that BOR reaches maximum ages around 50–55 years, with one male specimen reaching age 70 and three specimens aged 60 or greater from a pool of nearly 4,000 age observations.

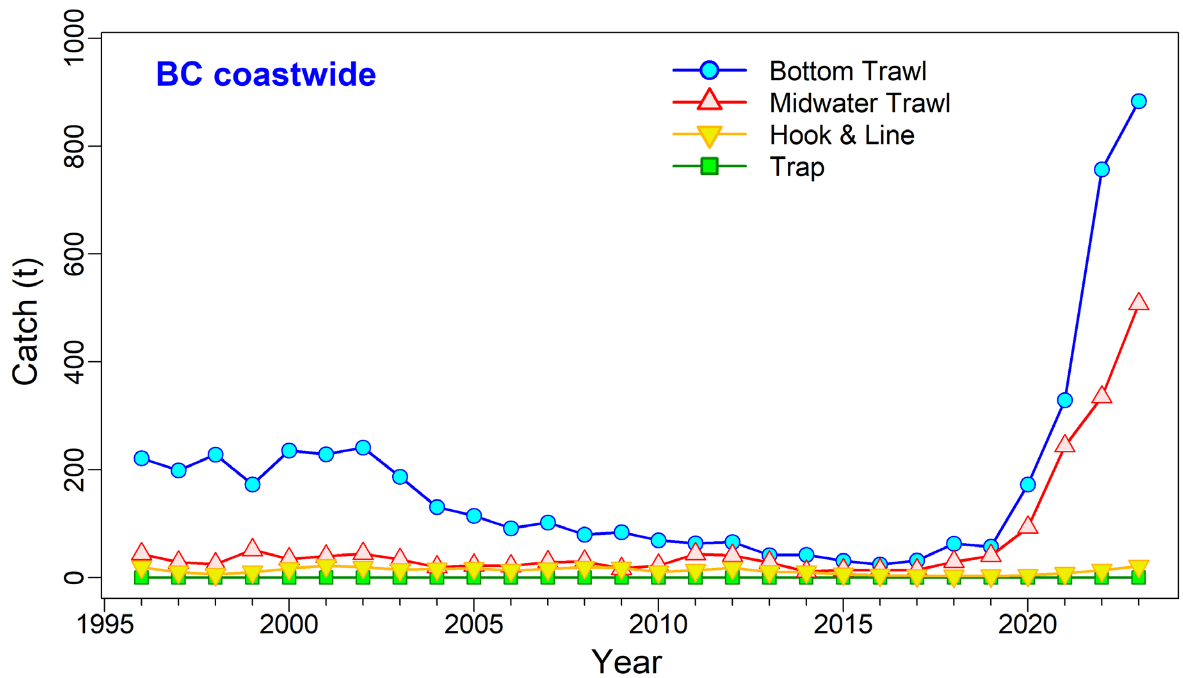

Figure 1. Reported catch (landings + released) of BOR by gear since the implementation of the trawl's onboard-observer program in 1996.

Previous Results

2019 Stock assessment

The values presented in Table 1 and Table 2 summarise MCMC medians and 90% credibility intervals in parentheses (i.e., 5% and 95% quantile values) from the 2019 Bocaccio stock assessment.

The estimated size of the initial biomass was large: 32,300 tonnes (16,500 t, 71,700 t) in order to sustain the catch history while assuming deterministic recruitment during the initial years of the reconstruction. The size of this biomass implied an estimated median maximum sustainable yield (MSY) of 1,500 t (700 t, 3,600 t), compared to the average catch over the final five years (2015–2019) of the reconstruction of only 69 t. The size of the spawning biomass relative to the unfished equilibrium spawning biomass (B_0) was very low, estimated at 0.028 (0.013, 0.058). Similarly, stock status, B_{2020} relative to equilibrium spawning biomass that would support the MSY (B_{MSY}) was 0.096 (0.042, 0.23). The 2019 female spawning biomass estimates did not include a contribution from the 2016 year class because it was assumed that the first four age classes had no mature females.

The estimated exploitation rates (u_t) throughout the time series were low: u_{2019} = 0.025 (0.021, 0.044) for the 'trawl' fishery and u_{2019} = 0.0009 (0.0005, 0.0016) for the 'other' (non-trawl) fishery. These exploitation rates were much lower than the range of natural mortality rates (0.07 to 0.09) considered plausible based on the available ageing data. Even the maximum exploitation rates estimated by the reconstruction ('trawl' = 0.06 (0.04, 0.08) and 'other' = 0.010 (0.007, 0.012) barely entered the plausible range of M. Exploitation at levels substantially less than natural mortality are thought to be sustainable, but the extremely low status of the 2020 relative spawning biomass estimated by the model (median B_{2020}/B_0 = 0.028) attested to a lack of recruitment before the advent of the 2016 year class.

2021 Stock assessment update

The values presented in Table 1 and Table 2 also summarise MCMC medians and 90% credibility intervals in parentheses (i.e., 5% and 95% quantile values) from the 2021 stock assessment update.

The estimated size of the initial biomass was large: 35,500 tonnes (19,500 t, 81,400 t) in order to sustain the catch history while assuming deterministic recruitment during the initial years of the reconstruction. The size of this biomass implied an estimated median maximum sustainable yield (MSY) of 2,100 t (1,100 t, 4,800 t), compared to the average catch over the final five years (2017–2021) of the reconstruction of only 204 t. The size of the spawning biomass relative to the unfished equilibrium spawning biomass (B_0) was 0.36 (0.18, 0.63) by year end 2021, an improvement over the final-year depletion reported in the 2019 stock assessment. Similarly, stock status, B_{2022} relative to equilibrium spawning biomass that would support the MSY (B_{MSY}) was 1.5 (0.63, 3.4). By year end 2021, the 2016 year class had profound effects on estimates of depletion and stock status.

The estimated exploitation rates (u_t) throughout the time series were low, with the 2021 exploitation rate estimated at u_{2021} = 0.030 (0.015, 0.055) for the ‘trawl’ fishery and u_{2021} = 0.0008 (0.0004, 0.0014) for the ‘other’ (non-trawl) fishery. As in the 2019 assessment, these exploitation rates were much lower than the range of natural mortality rates (0.07 to 0.09) considered plausible based on the available ageing data. The maximum exploitation rates estimated by the reconstruction (‘trawl’ = 0.06 (0.04, 0.08) and ‘other’ = 0.010 (0.007, 0.013) barely entered the plausible range of M.

Comparison

The composite base case spawning biomass at the beginning of 2020 was estimated by the 2019 assessment to be above the limit reference point (LRP) with probability $P(B_{2020} > 0.4B_{\text{MSY}})$ < 0.01, and above the upper stock reference (USR) point with probability $P(B_{2020} > 0.8B_{\text{MSY}}) = 0$ (i.e., no probability of being in the Healthy zone based on the set of MCMC posterior samples). However, two years later, $P(B_{2022} > 0.4B_{\text{MSY}})$ was estimated to be greater than 0.99 and $P(B_{2022} > 0.8B_{\text{MSY}})$ was estimated at 0.87, due to the large size of the 2016 cohort. This obviated the need for a stock rebuilding plan.

The 2019 stock assessment predicted that the stock would recover (above the LRP with at least 95% probability) by the beginning of 2022, and this was borne out by the 2021 update. This update predicted that the stock would remain in the Healthy zone (above the USR with at least 50% probability) for the next 10 years (until 2032) at all constant-catch policies up to 2,000 t/y. The increasing size of the recovering Bocaccio population constrained the capture of other target rockfish species under the existing low catch limits, so the BOR trawl total allowable catch (TAC), along with total BOR mortality caps (see DFO 2023), were increased in every year from 2019 (Table 3). The calendar year catches, used in the model, by fishing sector for the period 2019 to 2023 followed the increased catch limits closely (Table 4).

The 2019 stock assessment noted that both the Queen Charlotte Sound (QCS) and west coast Vancouver Island (WCVI) synoptic surveys provided acceptable monitoring capability for this species and suggested that corroboration of the size of the rebuild would be available when these surveys were repeated in 2020 (WCVI) and 2021 (QCS).

Table 1. Parameter estimates from 3,000 samples pooled from three MCMC posteriors for model years t = 2020 and t = 2022 from the 2019 stock assessment and 2021 assessment update, respectively. R_0 = virgin recruitment of age-1 fish (1,000s), h = steepness parameter, q_g = catchability for index series g, μ_g = age of full selectivity for females, Δ_g = shift in vulnerability for males, v_{gL} = variance parameter for left limb of selectivity curve, and subscript g = series1:6 for surveys and 7 for CPUE. Values show the medians (50th percentile, shaded columns) and 90% credibility intervals (5th and 95th percentiles).

Year (*t*)		2020			2022	
Parameter	5%	50%	95%	5%	50%	95%
R_0	703	1,713	4,633	824	1,990	5,262
h	0.503	0.671	0.846	0.683	0.810	0.93
q_1	0.019	0.0355	0.0578	0.0181	0.0332	0.0544
q_2	0.0211	0.0394	0.0647	0.0226	0.0411	0.0671
q_3	0.00195	0.00356	0.00566	0.00168	0.00304	0.00487
q_4	0.00438	0.00826	0.0136	0.00478	0.00889	0.0148
q_5	0.034	0.0573	0.091	0.0333	0.0576	0.0901
q_6	0.013	0.0221	0.0342	0.0134	0.0222	0.0344
q_7	0.000196	0.000321	0.000445	0.000199	0.000327	0.000454
μ_1	7.83	12.0	16.7	7.85	11.8	15.9
μ_2	7.60	10.0	13.1	7.29	9.62	12.7
μ_3	8.74	12.5	16.3	7.85	11.5	15.8
μ_4	9.69	13.8	17.9	8.84	12.8	17.4
μ_7	9.24	11.1	13.4	9.22	11.0	13.2
Δ_1	0.499	0.983	1.46	0.49	0.965	1.45
Δ_2	0.393	0.863	1.35	0.387	0.857	1.35
Δ_3	0.473	0.976	1.46	0.443	0.962	1.46
Δ_4	0.509	0.979	1.45	0.466	0.951	1.42
Δ_7	0.576	1.04	1.51	0.566	1.00	1.47
$\log v_{1L}$	3.72	4.59	5.35	3.52	4.42	5.21
$\log v_{2L}$	3.01	3.80	4.58	2.89	3.72	4.50
$\log v_{3L}$	2.18	3.30	4.49	2.98	4.02	4.95
$\log v_{4L}$	3.67	4.41	5.07	3.3	4.17	4.95
$\log v_{7L}$	2.97	3.55	4.14	2.85	3.44	4.02

Table 2. Derived quantities from 3,000 samples pooled from three MCMC posteriors for model years t = 2020 and t = 2022 from the 2019 stock assessment and 2021 assessment update, respectively. Definitions are: B_0 = unfished equilibrium spawning biomass (mature females), V_0 = unfished equilibrium vulnerable biomass (males and females), B_t = spawning biomass at the start of year t, V_t = vulnerable biomass in the middle of year t-1, u_{t-1} = exploitation rate (ratio of total catch to vulnerable biomass) in the middle of year t-1, u_{max} = maximum exploitation rate, B_{MSY} = equilibrium spawning biomass at MSY (maximum sustainable yield), u_{MSY} = equilibrium exploitation rate at MSY, V_{MSY} = equilibrium vulnerable biomass at MSY. All biomass values (and MSY) are in tonnes. Values show the medians (50th percentile, shaded columns) and 90% credibility intervals (5th and 95th percentiles).

Year (*t*)		2020			2022	
Derived Quantity	5%	50%	95%	5%	50%	95%
B_0	16,460	32,289	71,710	19,534	37,530	81,442
V_0 (trawl)	27,930	55,089	123,319	33,050	63,675	140,538
V_0 (other)	27,286	53,564	119,116	32,380	62,317	135,280
B_t	552	899	1,655	7,348	13,080	25,740
V_t (trawl)	3,046	5,703	12,273	13,119	24,332	48,673
V_t (other)	2,582	4,709	9,812	11,575	20,457	39,984
B_t / B_0	0.0132	0.0278	0.0578	0.176	0.357	0.633
V_t / V_0 (trawl)	0.0496	0.104	0.213	0.188	0.382	0.706
V_t / V_0 (other)	0.0426	0.0875	0.175	0.165	0.336	0.598
u_{t-1} (trawl)	0.0121	0.025	0.0441	0.0149	0.030	0.0551

Year (t) Derived Quantity	2020 5%	2020 50%	2020 95%	2022 5%	2022 50%	2022 95%
u_{t-1} (other)	0.000467	0.00093	0.00161	0.000402	0.000781	0.00137
$u_{\max}$ (trawl)	0.0369	0.0588	0.0792	0.0377	0.0599	0.0808
$u_{\max}$ (other)	0.00654	0.00968	0.0124	0.00667	0.00985	0.0127
MSY	703	1,461	3,623	1,067	2,118	4,818
B_{MSY}	4,134	9,462	22,469	3,814	8,948	21,622
$0.4B_{\text{MSY}}$	1,653	3,785	8,988	1,525	3,579	8,649
$0.8B_{\text{MSY}}$	3,307	7,570	17,976	3,051	7,159	17,298
B_t / B_{MSY}	0.0417	0.0963	0.234	0.625	1.500	3.42
B_{MSY} / B_0	0.225	0.291	0.353	0.183	0.238	0.286
V_{MSY}	7,858	17,554	41,876	7,470	16,959	41,936
V_{MSY} / V_0 (trawl)	0.252	0.319	0.378	0.211	0.269	0.319
V_{MSY} / V_0 (other)	0.253	0.328	0.396	0.212	0.275	0.335
u_{MSY}	0.054	0.085	0.133	0.09	0.124	0.176
u_{t-1} / u_{MSY} (trawl)	0.116	0.291	0.664	0.106	0.240	0.487
u_{t-1} / u_{MSY} (other)	0.00421	0.0109	0.0258	0.00266	0.00623	0.0134

Table 3. Total allowable catch (TAC) for Bocaccio by the trawl fleet and total mortality allowed by all sectors (commercial groundfish trawl, commercial groundfish hook and line, commercial salmon troll, recreation, and FSC fisheries). Values extracted from five annual IFMPs. FSC = food, social, and ceremonial by First Nations.

First day of fishing year	Trawl TAC (tonnes)	Total mortality cap (tonnes)
Feb 21, 2019	80	–
Feb 21, 2020	300	363
Feb 21, 2021	414	500
Feb 21, 2022	1,486	1,800
Feb 21, 2023	1,799	2,180

Table 4. Fishery sector catches, by calendar year, used in the stock assessment model.

Model year	Trawl catch (tonnes)	Other catch (tonnes)	Total catch (tonnes)
2019	113	3	116
2020	280	4	285
2021	578	8	587
2022	1,094	14	1,108
2023	1,393	21	1,414

Data Used for 2024 Update

The updated stock assessment in 2024 extended the 2021 analysis by evaluating a BC coastwide population harvested by two commercial fisheries: (1) a trawl fishery that combined bottom and midwater trawl gear (Figure 2, top), and (2) an ‘other’ fishery that combined Halibut longline, Sablefish trap, Dogfish/Lingcod longline, and offshore rockfish hook and line catches (Figure 2, bottom). Each fishery had updated catch information (landings and discards summed, Figure 2), but only the trawl fishery had age frequency data, which were not updated.

Four additional synoptic survey index points for Bocaccio were observed after the 2021 stock assessment update—2023 for Queen Charlotte Sound (QCS), 2022 for west coast Vancouver Island (WCVI), 2022 for west coast Haida Gwaii (WCHG), and 2023 for Hecate Strait (HS). Typically, the QCS and HS surveys occur in odd years while the WCVI and WCHG surveys occur in even years; however, due to COVID-19, the 2020 WCVI survey was delayed until 2021.

New age frequency (AF) data were available from the 2021 QCS synoptic survey; however, these data could not be used because of apparent bias in the age readings. The 2016 cohort should have been age 5 in the 2021 survey, but were aged inaccurately (mode at 8 years) with considerable imprecision. The ageing lab director communicated that ageing this species was 'extremely difficult', and mentioned that a seasoned age reader had found it difficult. Reportedly, the 2021 QCS sampled otoliths had many checks without clearly identifiable annuli. The available LF data from this survey (and all other surveys) confirmed that the LF frequency distributions were consistent with the expected growth of the 2016 cohort as age 5 Bocaccio (see discussion on page 8 below).

The Awatea model platform used in the 2019 stock assessment and the 2021 update was run using the updated catch and survey data in 2024.

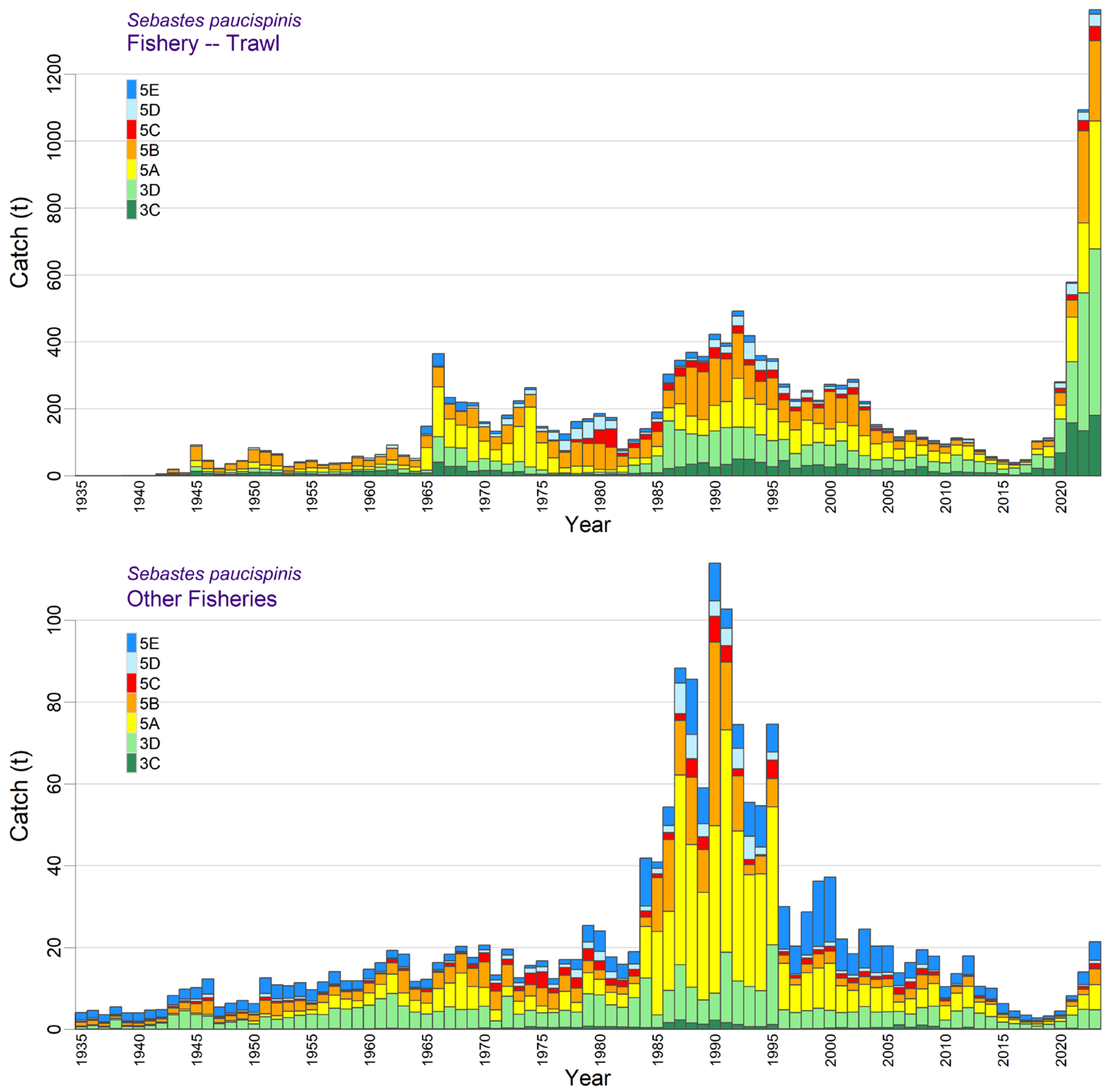

Figure 2. Catch reconstruction of Bocaccio from 1935 to 2023 for the trawl (top) and other (bottom) fisheries used in the stock assessment model. The 2023 trawl and other catches were available up until mid-December, which were used in the model for 2023.

Analysis and Response

Surveys and Lengths

The model had no difficulty in fitting each survey series, including the new 2022 and 2023 indices (Figure 3). The capacity of the model to fit the four new survey index points indicated that these new observations were consistent among each other and with the model estimates of recruitment strength for the 2016 cohort, as was also seen in the previous two model fits (in 2019 and 2021). The 2019 index value for QCS, which the model was not able to fit in the 2019 assessment nor the 2021 update, remained an outlier in the updated fits, while the 2023 index value matched the estimated stock trajectory (Figure 3). These acceptable fits to most of the survey indices were achieved in spite of the semi-pelagic behaviour of this species, which, because it spends a significant amount of time off the bottom, makes it a less than ideal species for monitoring using bottom trawl gear. An average relative error of 49.5% across 41 index values from these four synoptic surveys, conducted from 2003 to 2023, attest to the low suitability of this methodology for monitoring this species. However, the use of CPUE to track BOR abundance after 2012 has been ruled out because of the strong avoidance fishing behaviour by the trawl fleet, leaving these four surveys as the only available source of recent abundance information for this species.

The updated length frequency (LF) distribution data show that the 2016 cohort of BC BOR has remained the single dominant year class. Length frequency distributions were available from each survey, independently corroborating the presence on this cohort and demonstrating that the increased BOR abundance in each survey was entirely attributable to this cohort. The most important survey for this species (QCS synoptic) showed a steady progression in size of the cohort as the fish grew over time, although growth slowed after 2019. The available LF information indicates that the 2016 cohort increased from ~40 cm in 2019 to ~51-53 cm in 2021 and to ~56-58 cm in 2022/2023 (Figure 4). For reference, Starr and Haigh (2022) report von Bertalanffy L-infinity values of 78 and 69 for females and males, respectively, from the available survey age data. The three synoptic surveys conducted in 2021 also detected a much smaller cohort of fish measuring ~20 cm, the expected size of age-1 fish and perhaps indicative of new recruitment (Figures 4 and 5). This new cohort was also present in three of the four recent surveys (2022 for the WCVI survey and 2023 for the QCS and HS surveys). The progression of the 2016 cohort to larger sizes is very clear when all research survey data are combined (Figure 6). The continued presence of the 2016 cohort is also corroborated in the available commercial LFs, although there are no 2021 data from the commercial fisheries (Figure 6). The 2020 cohort would not be seen in the 2021 commercial data due to their small size and the use of larger sizes of net mesh in the cod-end which avoid catching small fish. The 2020 cohort might be visible in commercial fishery samples from 2022 or 2023 but there are no data available from these years at this time.

Bocaccio female maturity stages in the six synoptic surveys that operated after 2019 are summarised in Table 5. These summaries, truncated at the indicated lengths to restrict the analysis to the 2016 year class, show that 5% or less of the staged BOR from this year class were judged to be 'Immature' or 'Maturing' in all six surveys. Because the maturity ogive used in the model assumed that 30% of the age-5 BOR and 57% of the age-7 BOR were mature, it is possible that the estimates of mature BOR were biased low and that the true levels of BOR spawning females were greater than indicated by this stock assessment. However, this conclusion should be tempered by the observation that the values in Table 5 might be misleading, because these are visually staged fish and, in some cases, fish judged as 'Resting' should have been in the 'Maturing' category.

Table 5. Unweighted percentage of female Bocaccio (≥30 cm in total length in 2021 and ≥45 cm in 2022 and 2023) at each recorded maturity stage from the three synoptic surveys that operated in 2021, 2022 and 2023 (QCS, HS, and WCVI; trip IDs shown).

	Queen Charlotte Sound		Hecate Strait		West Coast Vancouver Island	
Year→	2021	2023	2021	2023	2021	2022
Trip ID→	85990	86850	85930	86910	85950	86390
Immature	0.0	0.4	0.0	0.0	0.0	0.0
Maturing	3.9	2.9	2.3	1.9	5.4	5.6
Mature	7.3	12.4	14.8	17.0	10.4	11.2
Spent	18.0	9.1	8.0	17.0	30.0	8.7
Resting	70.8	75.2	75.0	64.2	54.2	74.5
Total	100.0	100.0	100.0	100.0	100.0	100.0

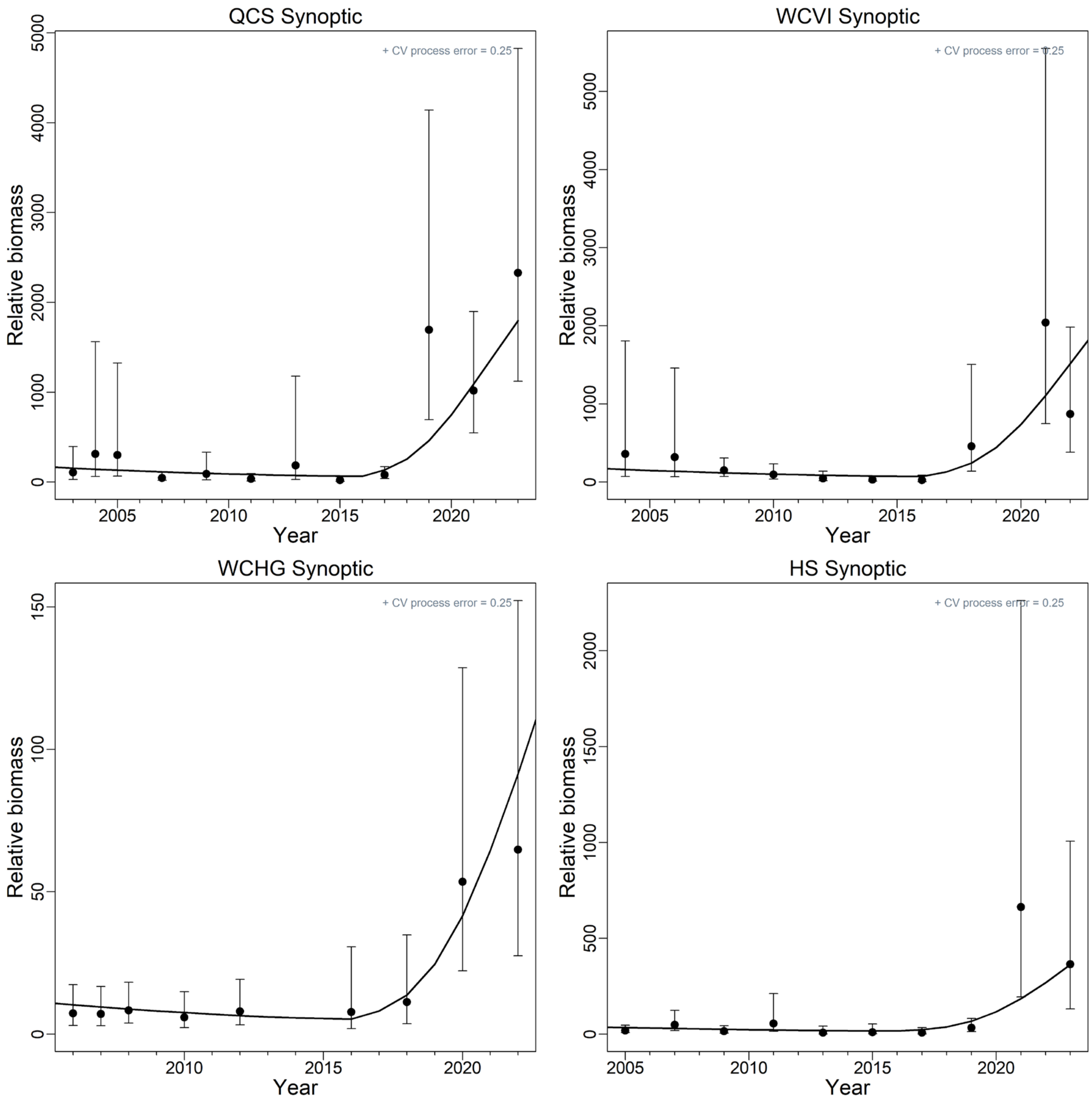

Figure 3. Central run (M = 0.08): survey index values (points) with 95% confidence intervals (bars) and MPD model fits (curves) for the synoptic survey series.

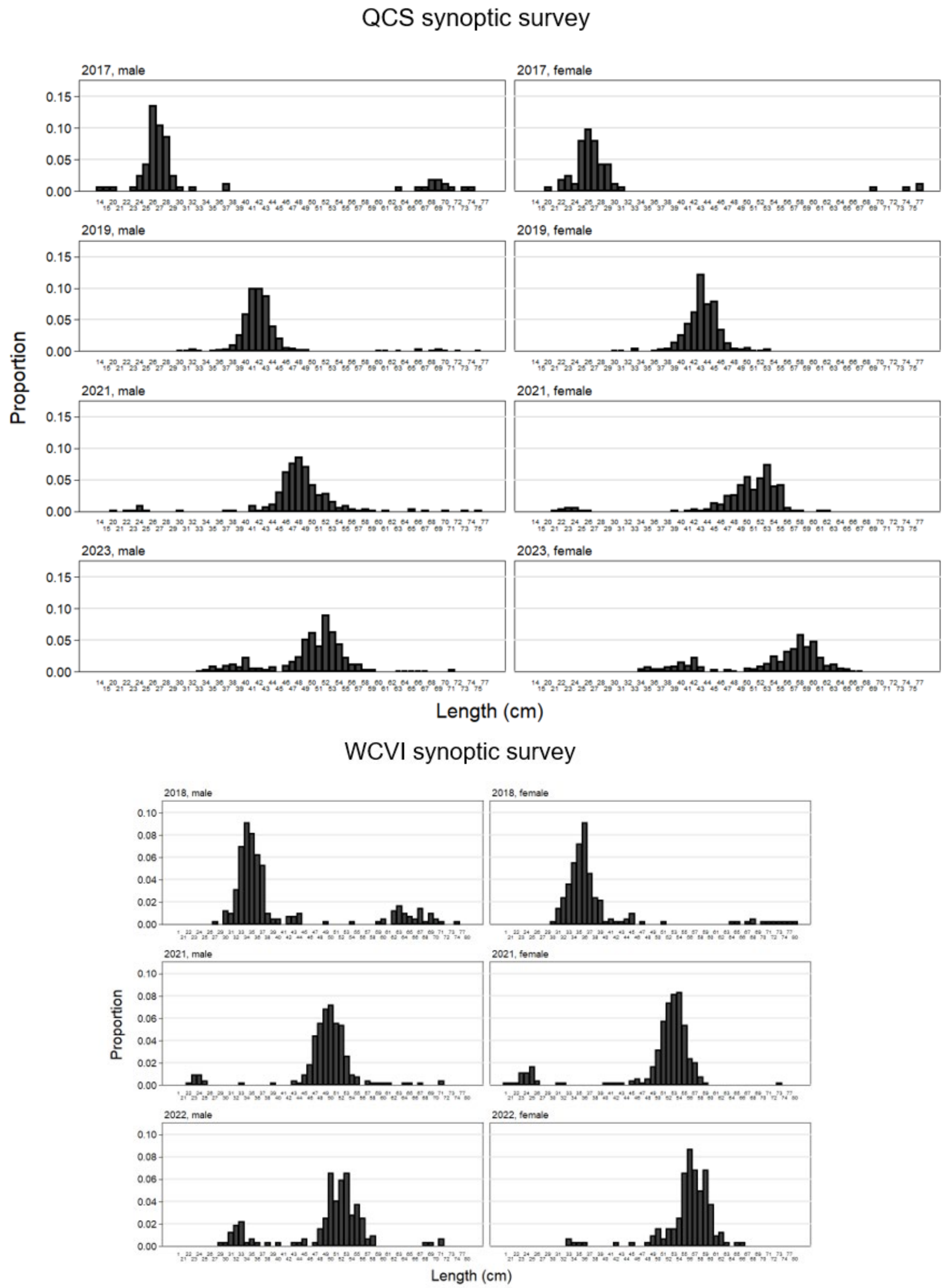

Figure 4. Unweighted length frequency distributions observed by year and sex in the Queen Charlotte Sound (top) and west coast Vancouver Island (bottom) synoptic surveys series.

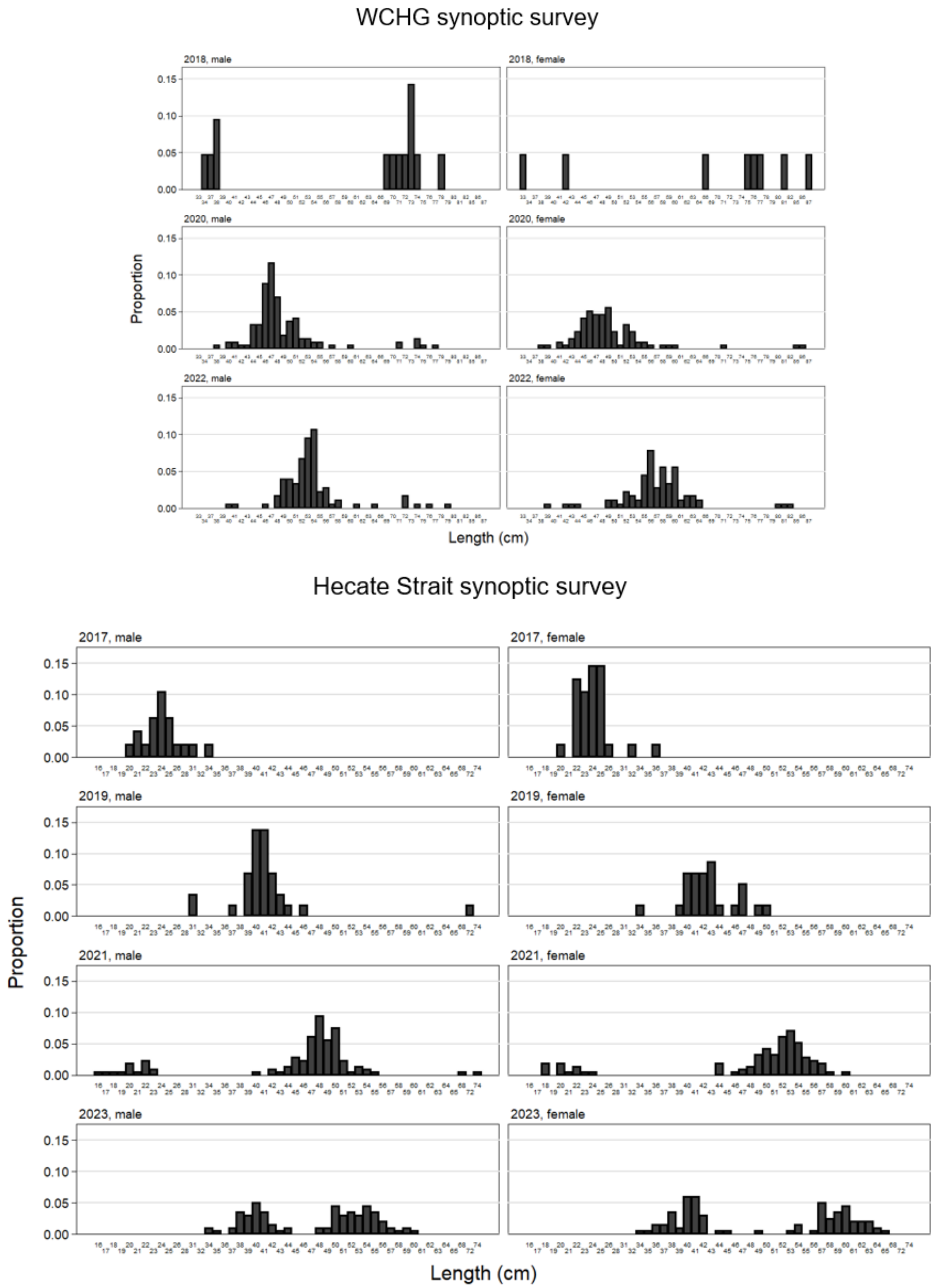

Figure 5. Unweighted length frequency distributions observed by year and sex in the west coast Haida Gwaii (top) and Hecate Strait (bottom) synoptic surveys series.

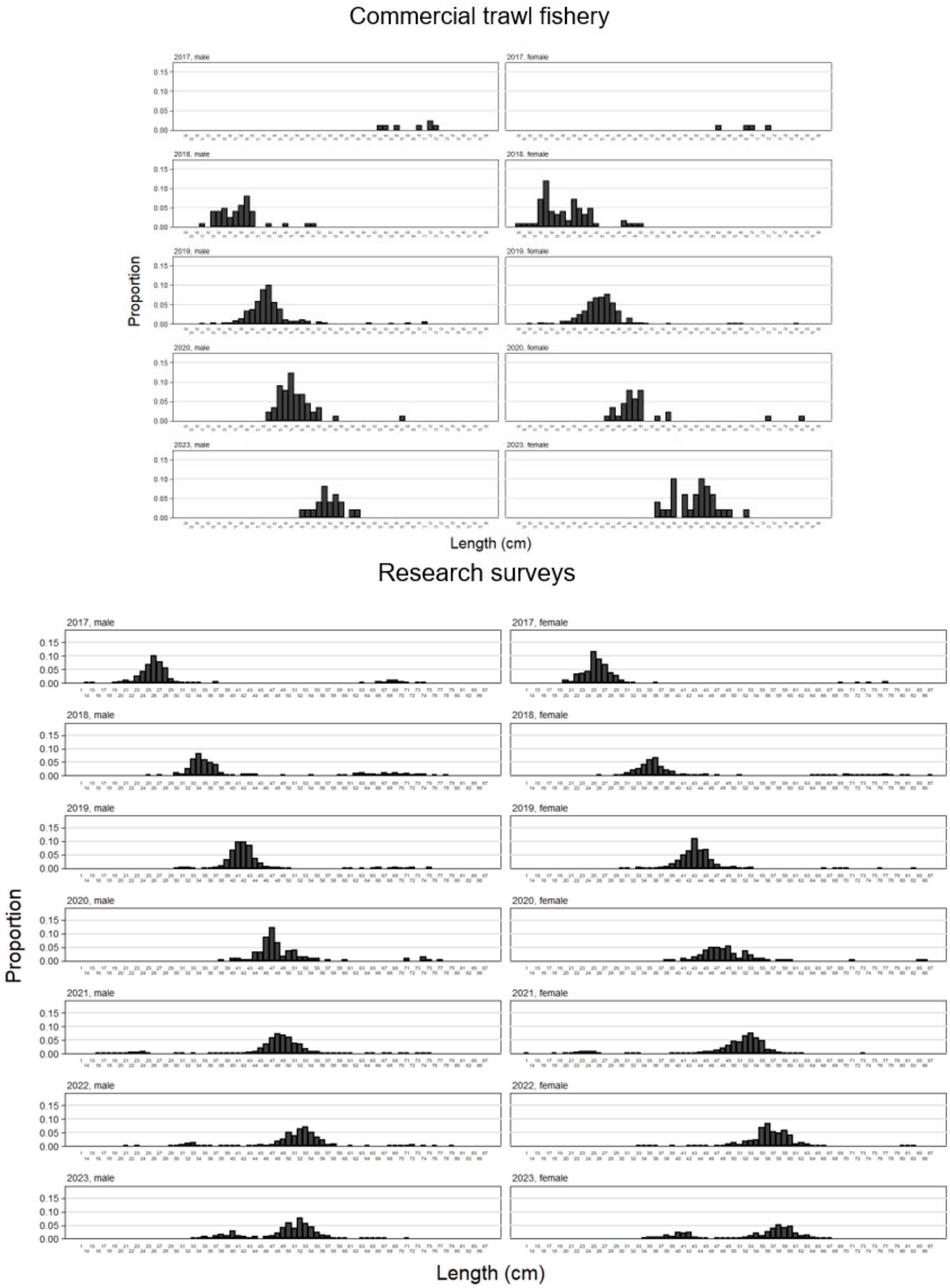

Figure 6. Unweighted length frequency distributions observed by year and sex in the commercial trawl fisheries (top) and combined research surveys (bottom).

Composite Base Case

This update of the 2019 Bocaccio composite base case comprised three runs which spanned one major axis of uncertainty (*M*) for this stock assessment:

- **B1** (Run01) – fixed M = 0.07 for both sexes and set A = 50;
- **B2** (Run02) – fixed M = 0.08 for both sexes and set A = 50;
- **B3** (Run03) – fixed M = 0.09 for both sexes and set A = 50.

For each run, 1,000 MCMC samples were pooled (for 3,000 samples) to provide an average stock trajectory for population status and advice to managers. The 2019 stock assessment concluded that estimating *M* was not possible given the uncertainty in the age data and the survey biomass indices, with the mode of the posterior density (MPD) estimates not shifting from the prior means. Furthermore, runs that estimated *M* exhibited unstable MCMC behaviour with poor convergence diagnostics.

The updated composite base case median parameter estimates appear in Table 6, and derived quantities at equilibrium and associated with maximum sustainable yield (MSY) appear in Table 7. The differences among the component base runs are summarised by various figures:

- Figure 7 – MCMC traces of R_0 (unfished equilibrium recruitment) for the three component base runs;
- Figure 8 – three chain segments for each component R_0 posterior;
- Figure 9 – autocorrelation plots for each component R_0 posterior;
- Figure 10 – quantile plots of parameter estimates from three component base runs;
- Figure 11 – quantile plots of selected derived quantities from three component base runs.

Model trajectories and final stock status for the composite base case appear in the following figures:

- Figure 12 – estimates of spawning biomass relative to B_{MSY} (B_t/B_{MSY}) from pooled model posteriors, including 10 year projections at four catch levels;
- Figure 13 – estimates of vulnerable biomass V_t (tonnes) from pooled model posteriors;
- Figure 14 – estimates of exploitation rate u_t from pooled model posteriors;
- Figure 15 – estimates of reconstructed (1935–2024) and projected (2025–2034) recruitment R_t (1,000s age-1 fish) from pooled model posteriors;
- Figure 16 – phase plot through time of median B_t/B_{MSY} and u_{t-1}/u_{MSY} relative to DFO's Precautionary Approach (PA) reference points;
- Figure 17 – comparison of spawning stock depletion (B_t/B_0) from the stock assessment updates (2024, 2021) to that estimated in the 2019 stock assessment;
- Figure 18 – comparison of recruitment estimates for age-1 fish in 2017 from the Awatea fits in 2019, 2021, and 2024;
- Figure 19 – BOR stock status at beginning of 2024 for 2024 update, 2022 for 2021 update, and 2020 for 2019 stock assessment.

The 2019 stock assessment considered uncertainty in *M* to be the most important component of uncertainty in this stock assessment, particularly when it was not possible to reliably estimate this parameter. Additional sources of uncertainty were explored through sensitivity runs (Starr and Haigh 2022), which have not been repeated in this update.

The three component runs outlined above converged with acceptable MCMC diagnostics. Figures 7–9 show diagnostics for the R_0 parameter for each component run, with good sample traces and minimal autocorrelation in each run. The component runs had very similar posterior distributions for the selectivity parameters (Figure 10) while the R_0, h and q parameters varied with M, with R_0 increasing and h and q estimates decreasing with increasing M.

The composite base case, comprising three pooled MCMC runs, was used to calculate a set of parameter estimates (Table 6, parameter definitions in Appendix E of Starr and Haigh 2022) and derived quantities at equilibrium and those associated with MSY (Table 7). The composite base case population trajectory from 1935 to 2024 and projected biomass to 2034 indicated that the median stock biomass and the 5% credibility limit exceeded the upper stock reference (USR) in 2024, and would remain in the Healthy zone for the next 10 years over all projected catch levels (Figure 12).

Plots of the vulnerable biomass for each fishery showed a strong response to the presence of the 2016 cohort (Figure 13). The plot of annual exploitation rates by the trawl fishery showed that exploitation increased from a modern period (1996–2023) low of u_{2016} = 0.023 (0.013, 0.035) to u_{2023} = 0.043 (0.020, 0.076), which is still mostly below u_{msy}. The 2016 cohort was estimated to be much larger than all previous year classes (Figure 15). Over the reconstruction period (1935–2023), the median number of one-year old fish in 2017 was estimated to be 60 times (50x, 68x) more abundant than the average annual recruitment[2].

A phase plot of the time-evolution of spawning biomass and exploitation rate in the two modelled fisheries in MSY space suggested that the stock was in the Critical zone from the late 1990s, but transitioned quickly into the Healthy zone in 2021 once the large 2016 cohort was able to contribute to the female spawning biomass (Figure 16). The current (2024) stock status lies well inside the Healthy zone at B_{2024}/B_{MSY} = 2.54 (1.14, 6.43), $u_{2023(\text{trawl})}/u_{\text{MSY}}$ = 0.35 (0.16, 0.72), and $u_{2023(\text{other})}/u_{\text{MSY}}$ = 0.006 (0.003, 0.013) (see Table 7).

[2] Equations

$$\begin{cases} \bar{R}_x = \dfrac{1}{N}\displaystyle\sum_{t=1935}^{2023} R_{xt} & \text{where } x = \text{MCMC sample, } N = 2023 - 1935 + 1 \\ r_x = R_{x,2017} \big/ \bar{R}_x & \text{where } r_x = \text{sample ratios of 2016 recruitment to average recruitment} \end{cases}$$

Table 6. The 0.05, 0.5, and 0.95 quantiles for pooled model parameters (see Table 1 caption details) from MCMC estimation of three base model runs.

Parameter	5%	50%	95%
R_0	835	2,099	5,116
h	0.683	0.792	0.923
q_1	0.0192	0.0363	0.0581
q_2	0.0214	0.0398	0.0645
q_3	0.00160	0.00298	0.00482
q_4	0.00485	0.00940	0.0158
q_5	0.0334	0.0601	0.0946
q_6	0.0132	0.0222	0.0352
q_7	0.000197	0.000338	0.000456
μ_1	7.40	10.9	15.3
μ_2	7.72	10.2	13.7
μ_3	8.25	11.7	15.9
μ_4	8.49	12.1	16.6
μ_7	9.26	11.1	13.3
Δ_1	0.463	0.945	1.43
Δ_2	0.410	0.879	1.37
Δ_3	0.471	0.964	1.46
Δ_4	0.446	0.939	1.43
Δ_7	0.555	1.01	1.47
$\log v_{1L}$	3.37	4.30	5.12
$\log v_{2L}$	3.11	3.91	4.76
$\log v_{3L}$	3.14	4.10	4.98
$\log v_{4L}$	3.18	4.06	4.81
$\log v_{7L}$	2.87	3.44	4.05

Table 7. The 0.05, 0.5, and 0.95 quantiles of MCMC-derived quantities from 3,000 samples pooled from three MCMC posteriors. Definitions are: B_0 – unfished equilibrium spawning biomass (mature females), V_0 – unfished equilibrium vulnerable biomass (males and females), B_{2024} – spawning biomass at the start of 2024, V_{2024} – vulnerable biomass in the middle of 2023, 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, V_{MSY} – equilibrium vulnerable biomass at MSY. All biomass values (and MSY) are in tonnes. For reference, the average catch over the last 5 years (2019–2023) was 702 t.

Quantity	5%	50%	95%
B_0	19,784	39,328	79,227
V_0 (trawl)	33,466	66,950	135,819
V_0 (other)	32,795	65,285	131,597
B_{2024}	13,549	23,789	48,165
V_{2024} (trawl)	23,951	43,158	90,618
V_{2024} (other)	21,801	37,838	75,800
B_{2024}/B_0	0.315	0.627	1.22
V_{2024}/V_0 (trawl)	0.333	0.670	1.36
V_{2024}/V_0 (other)	0.302	0.601	1.18
u_{2023} (trawl)	0.0202	0.0429	0.0763
u_{2023} (other)	0.000381	0.000761	0.00130
u_{max} (trawl)	0.0374	0.0635	0.0884
u_{max} (other)	0.00658	0.0103	0.0126
MSY	1,072	2,185	4,609
B_{MSY}	3,943	9,828	21,400
$0.4B_{MSY}$	1,577	3,931	8,560
$0.8B_{MSY}$	3,154	7,862	17,120
B_{2024}/B_{MSY}	1.14	2.54	6.43
B_{MSY}/B_0	0.187	0.246	0.287
V_{MSY}	7,636	18,474	41,232
V_{MSY}/V_0 (trawl)	0.215	0.274	0.319
V_{MSY}/V_0 (other)	0.217	0.279	0.335
u_{MSY}	0.0920	0.120	0.167
u_{2023}/u_{MSY} (trawl)	0.155	0.352	0.722
u_{2023}/u_{MSY} (other)	0.00269	0.00628	0.0129

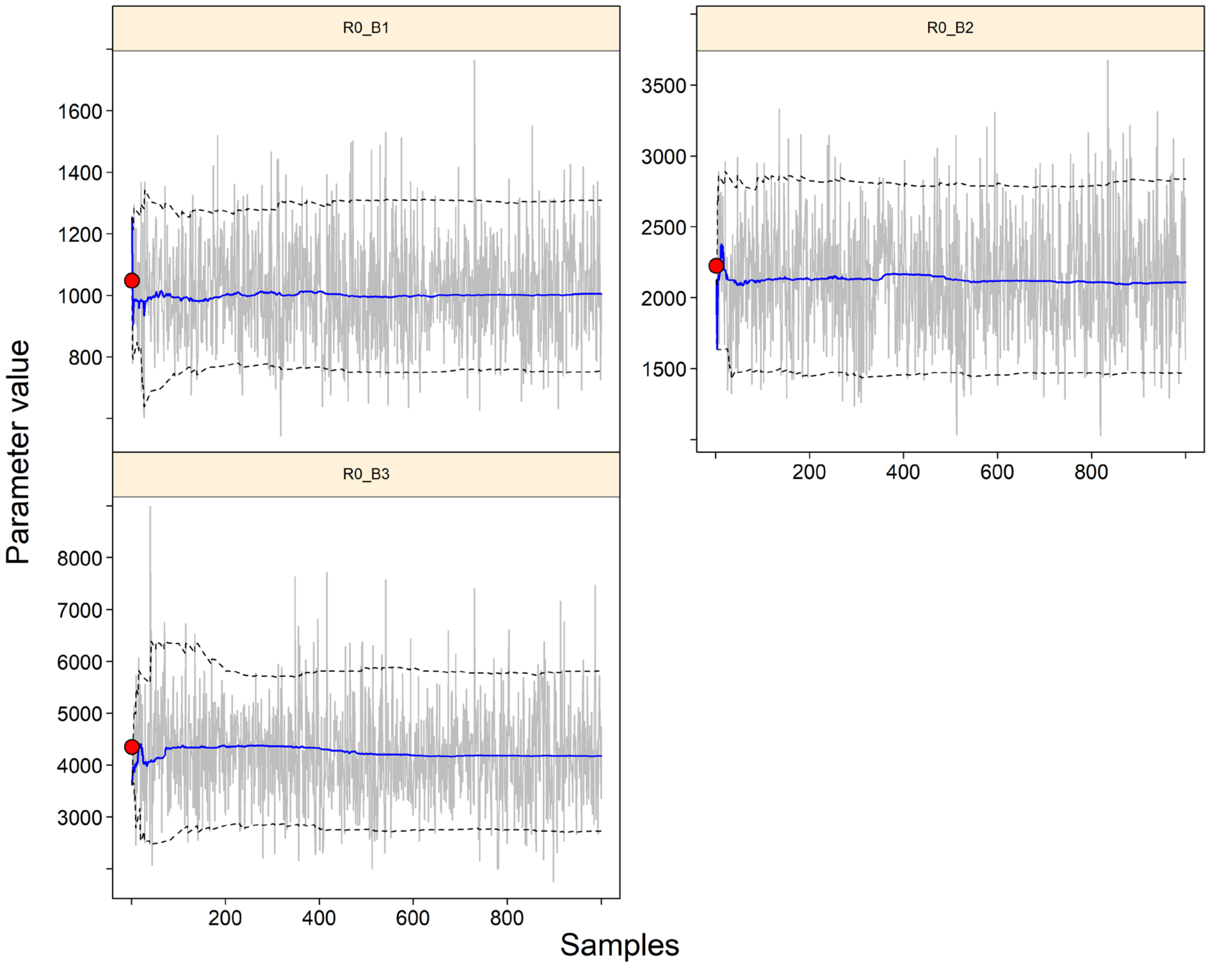

Figure 7. Component base: MCMC traces of R_0 for the three component base runs. Grey lines show the 1,000 samples for the R_0 parameter, solid lines show the cumulative median (up to that sample), and dashed lines show the cumulative 0.05 and 0.95 quantiles. Red circles are the MPD estimates.

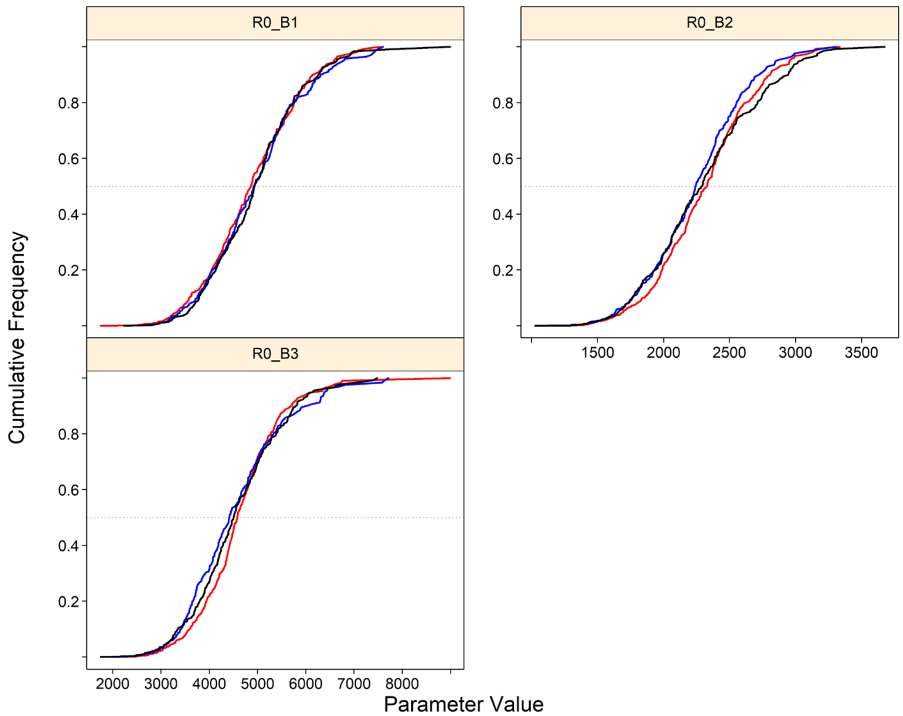

Figure 8. Component base: diagnostic plots obtained by dividing the R_0 MCMC chains of 1,000 MCMC samples into three segments, and plotting the cumulative distributions of the first segment (red), second segment (blue) and final segment (black).

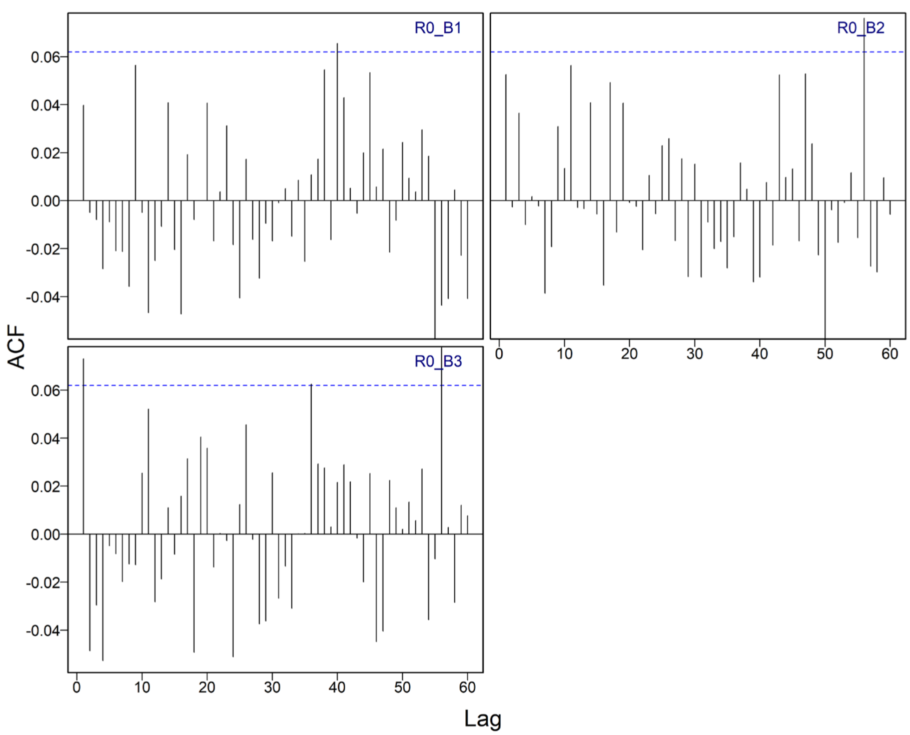

Figure 9. Component base: autocorrelation plots for the component base R_0 parameters from the MCMC output. Horizontal dashed blue lines delimit the 95% confidence interval for each parameter's set of lagged correlations.

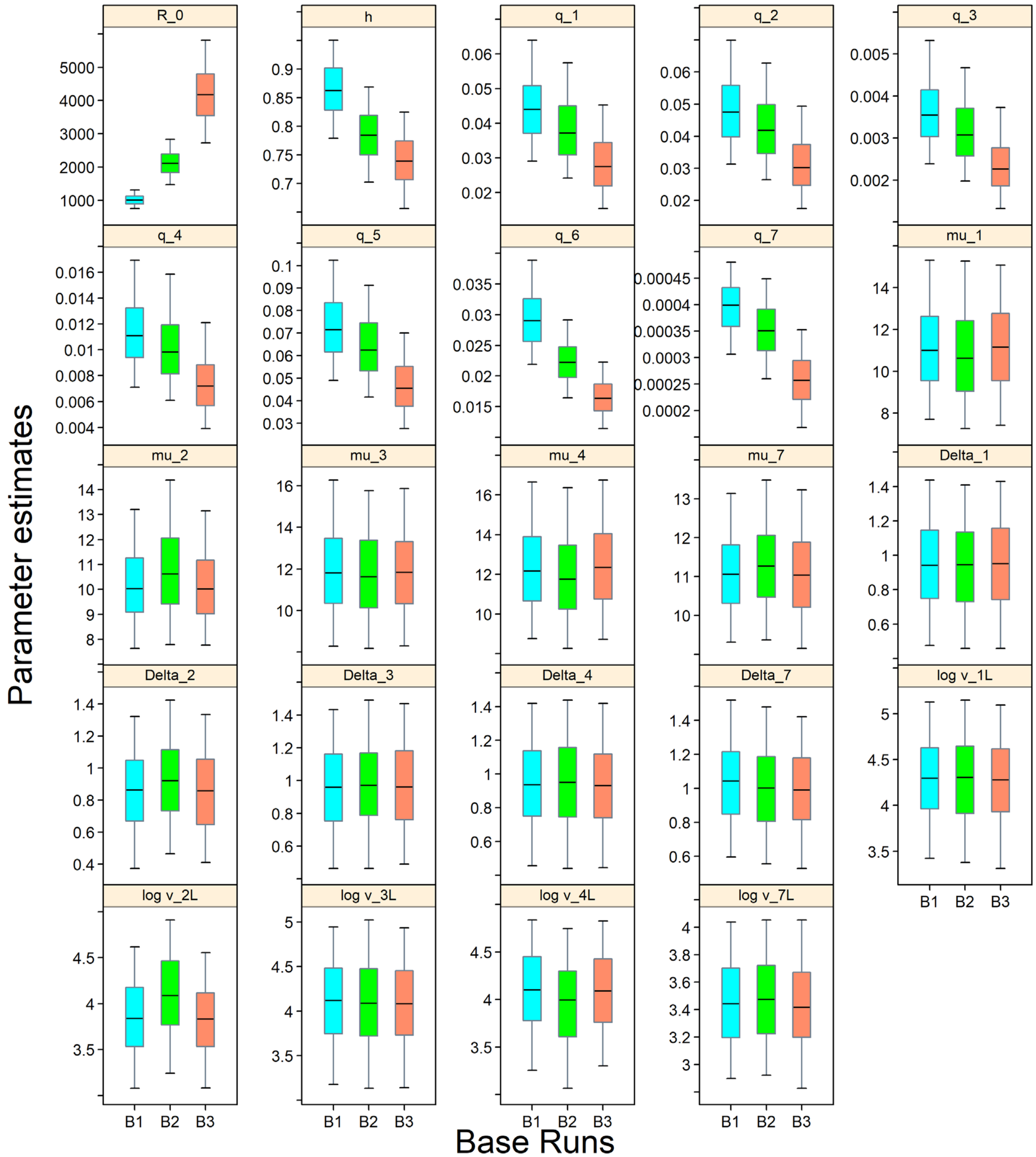

Figure 10. Component base: quantile plots of the parameter estimates from three component runs of the base case, where blue boxes denote M = 0.07, green boxes denote M = 0.08, red boxes denote M = 0.09. The boxplots delimit the 0.05, 0.25, 0.5, 0.75, and 0.95 quantiles.

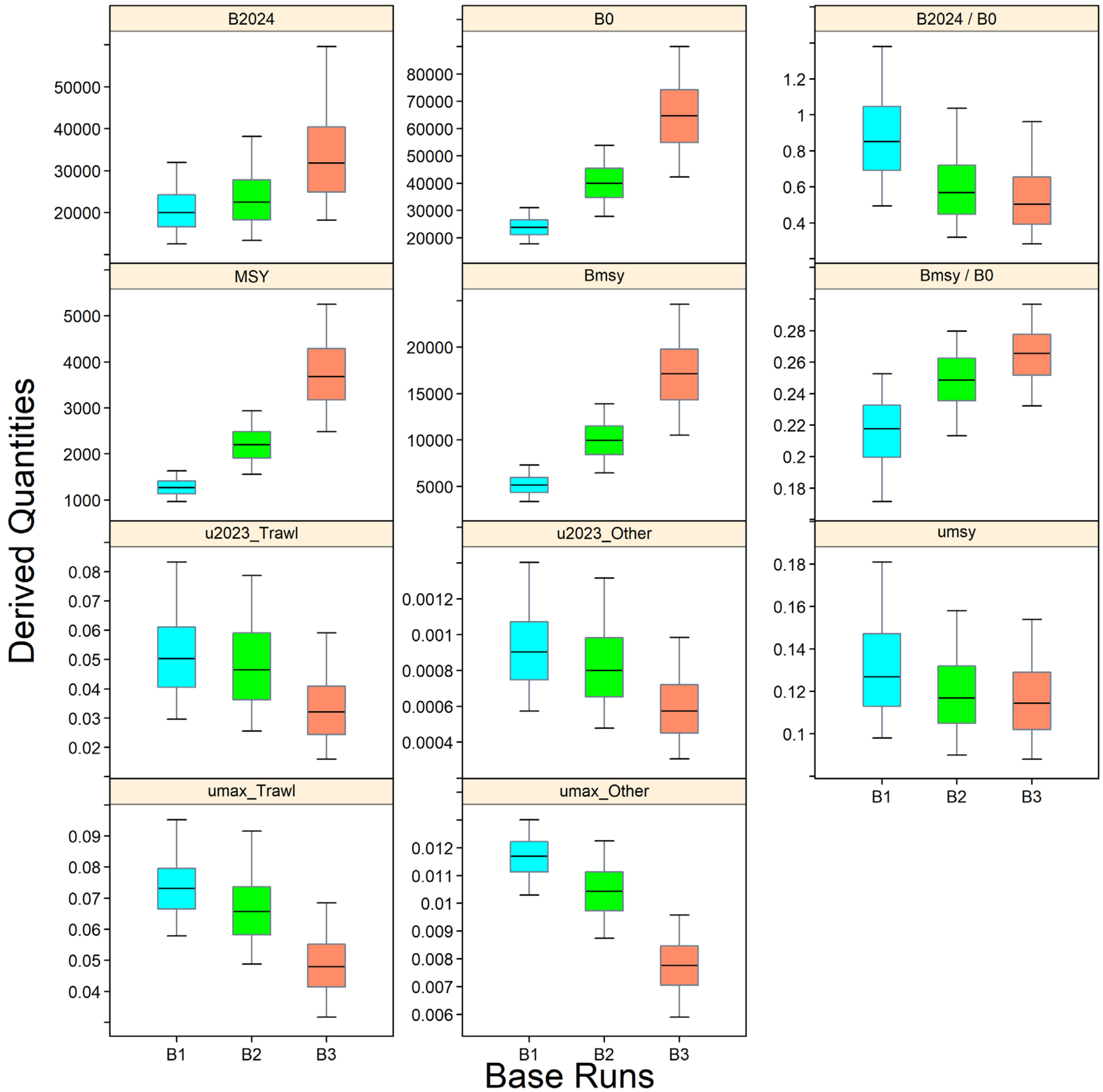

Figure 11. Component base: quantile plots of selected derived quantities (B_{2024}, B_0, B_{2024}/B_0, MSY, B_{MSY}, B_{MSY}/B_0, u_{2023}, u_{MSY}, u_{max}) from three component runs of the base case, where blue boxes denote M = 0.07, green boxes denote M = 0.08, red boxes denote M=0.09. The boxplots delimit the 0.05, 0.25, 0.5, 0.75, and 0.95 quantiles.

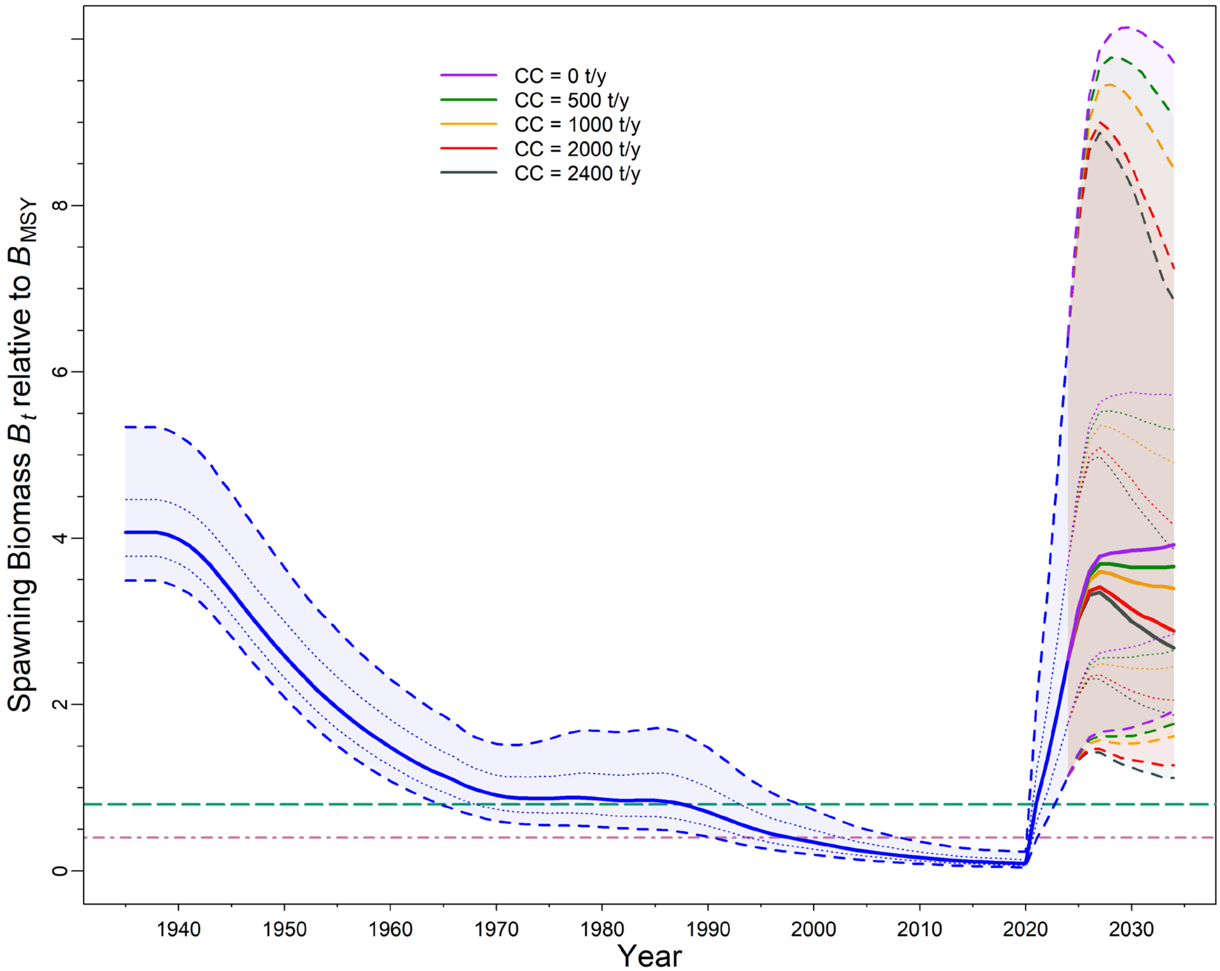

Figure 12. Composite base: estimates of spawning biomass B_t relative to B_{MSY} from pooled model posteriors. The median biomass trajectory appears as a solid curve surrounded by a 90% credibility envelope (quantiles: 0.05–0.95) in light blue and delimited by dashed lines for years t = 1935:2024; projected biomass for years t = 2025:2034 appear as colours specified in the legend. Also shown is the 50% credibility interval (quantiles: 0.25–0.75), delimited by dotted lines. The horizontal lines show the LRP (0.4B_{MSY}, dash-dot) and the USR (0.8B_{MSY}, dash). Assumed catch policies appear in the legend, where CC = constant catch (tonnes/year).

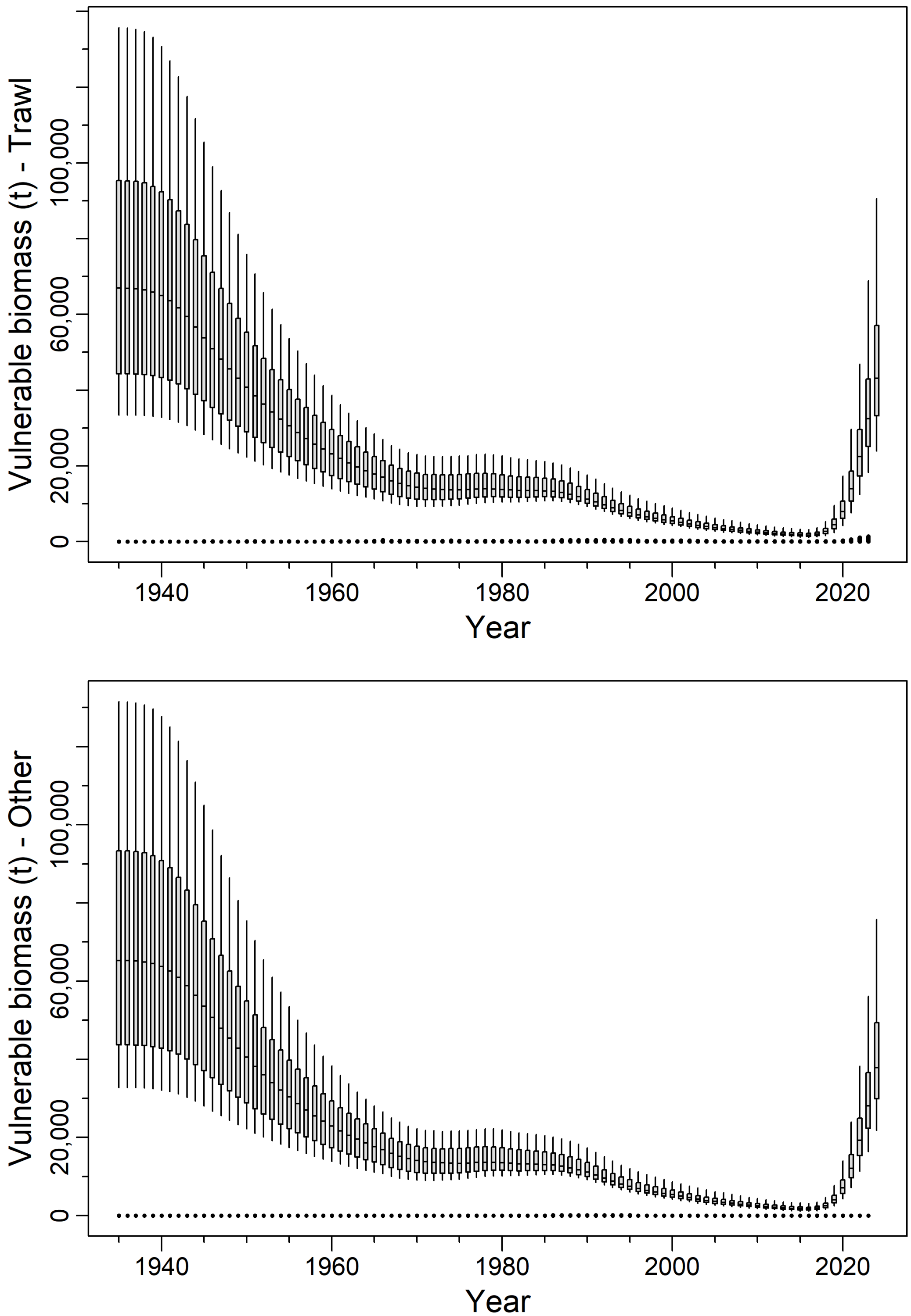

Figure 13. Composite base: estimated vulnerable biomass trajectory for two fisheries (boxplots) and commercial catch history (vertical bars), in tonnes. Boxplots show the 0.05, 0.25, 0.5, 0.75, and 0.95 quantiles from the MCMC results.

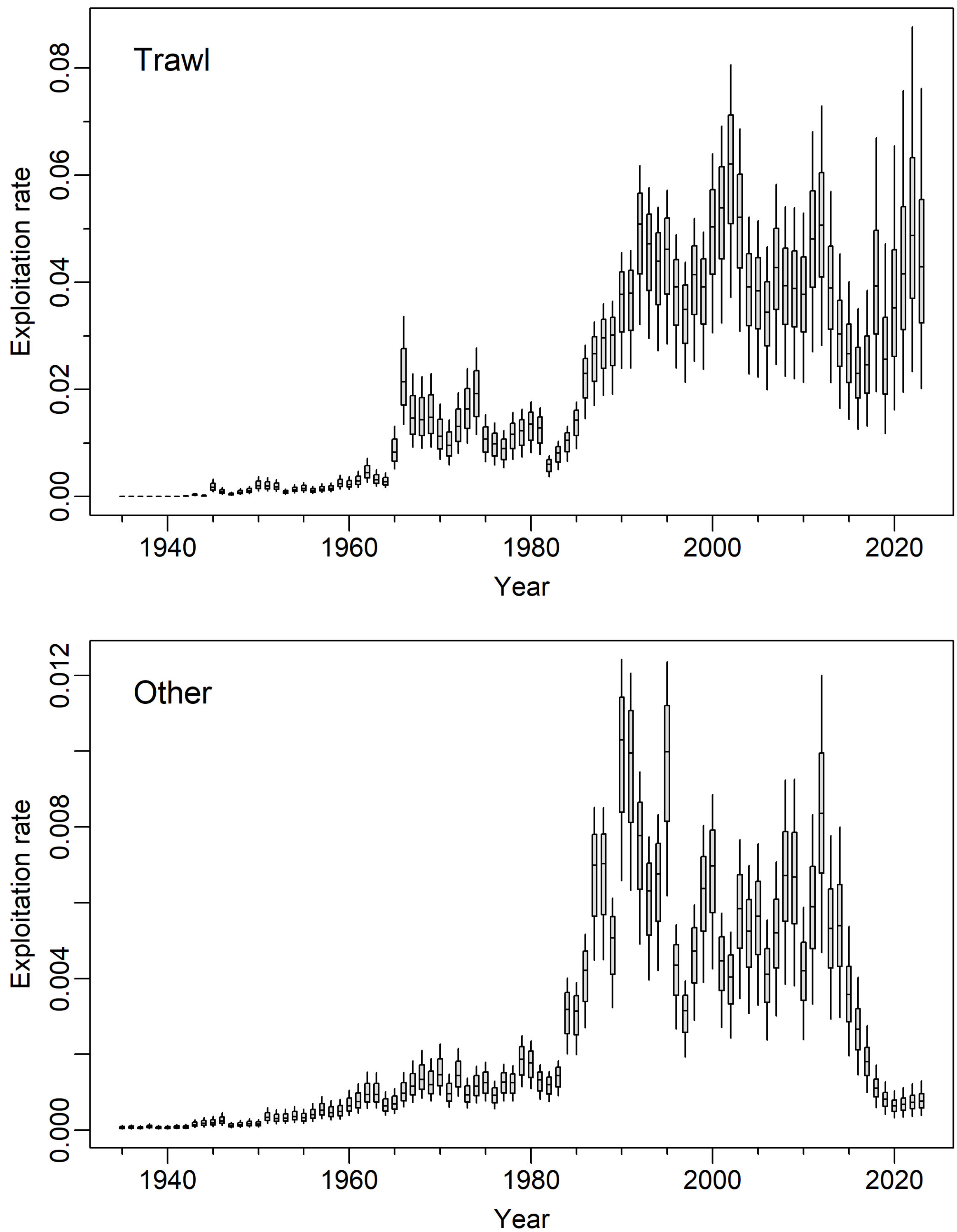

Figure 14. Composite base: posterior distributions of exploitation rate trajectory for two fisheries by year. Boxplots show the 0.05, 0.25, 0.5, 0.75, and 0.95 quantiles from the MCMC results.

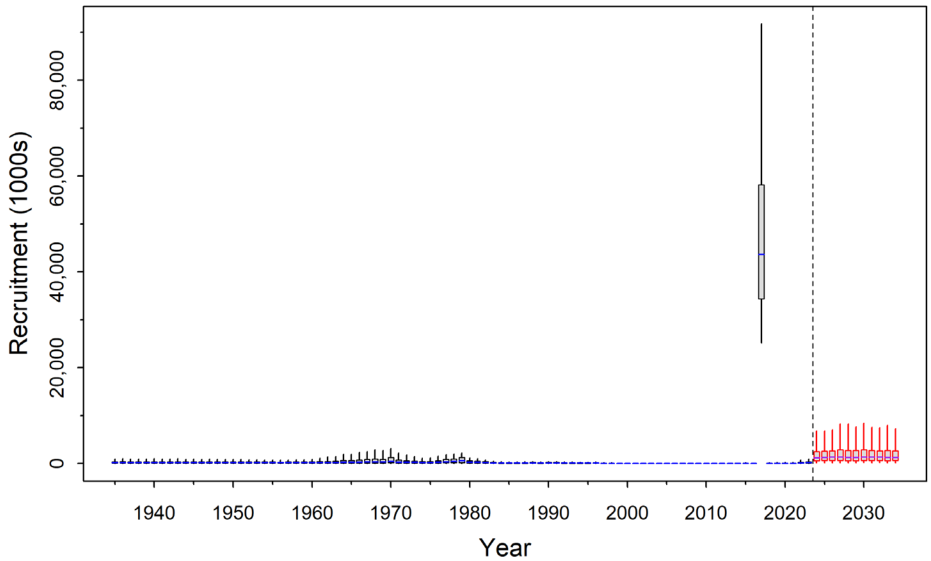

Figure 15. Composite base: posterior distributions of recruitments by year (reconstructed: 1935–2024, projected: 2025–2034) in 1,000s of age-1 fish.

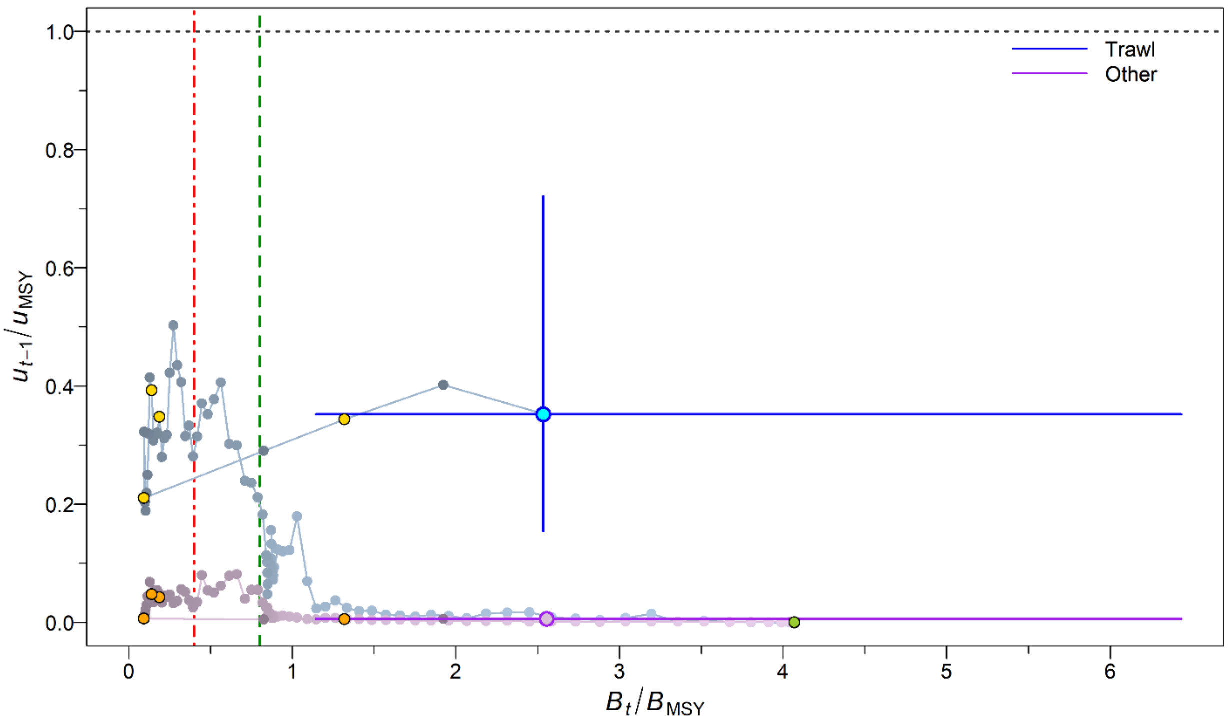

Figure 16. Composite base: phase plot through time of the medians of the ratios B_t/B_{MSY} (the spawning biomass in year t relative to B_{MSY}) and u_{t-1}/u_{MSY} (the exploitation rate in year t-1 relative to u_{MSY}) for two fisheries (trawl and other). The filled green circle is the starting year (1935). Years then proceed along lines gradually darkening from light blue/purple, with the final year end (2024) as a filled cyan/purple circle, and the blue/purple cross lines represent the 0.05 and 0.95 quantiles of the posterior distributions along both axes for the final year. Model years from previous assessments (2008, 2012, 2020, 2022) are indicated by gold/orange circles. Red and green vertical dashed lines indicate the precautionary approach limit and upper stock reference points (0.4, 0.8B_{MSY}), and the horizontal grey dotted line indicates u at MSY.

Comparison with Previous Assessments

The 2024 update of the 2019 Bocaccio stock assessment estimated lower levels of stock depletion (B_t/B_0) than did the 2021 update for the same years, but remained at levels greater than those estimated by the original assessment (Figure 17). A comparison of the composite spawning biomass depletion trajectories from three assessments showed slightly greater depletion over the reconstruction period by the two updates (2021, 2024) compared to the original assessment (2019), but all three trajectories converged by 2020 with the introduction of the 2016 cohort into the spawning population. Note that there is a good overlap in the posterior credibility envelopes from the three stock assessments, indicating that there is strong agreement among the three analyses.

The two updates were nearly identical to each other in the overlapping years, although the 2024 update estimated a lower level of stock depletion for the beginning of 2024 than did the 2021 update because the actual removals in 2022 and 2023 exceeded the projected 500 t/y used for the 2021 update in Figure 17 (Table 4). Given the results from the 2021 and 2024 updated stock assessments, the 2019 stock assessment appeared to have underestimated the actual rate of recovery. This was because both updates estimated a larger 2016 cohort than did the 2019 stock assessment (indicated by millions of age-1 fish in 2017, Figure 18): 2024 R_{2017} = 44 (25, 92), 2021 R_{2017} = 47 (25, 96), and 2019 R_{2017} = 25 (12, 59) million age-1 fish.

In 2019, the BOR stock assessment projected that the 2022 and 2024 spawning biomass would be in the Healthy zone (>0.8B_{MSY}) with 48% and 85% probabilities, respectively, at a constant projected catch of 200 t/y from 2020 to 2023. Note that the actual catches in those years were much higher than those used for the 2019 projections (Table 4). The 2021 update estimated the 2022 spawning biomass to have a probability of 87% to be the Healthy zone, and projected the 2024 biomass (at catch = 500 t/y) to have a probability of >99% to be the Healthy zone. However, the actual 2022 and 2023 catches were much higher than the 500 t/y used in that projection (Table 4). Nevertheless, in spite of the higher catches observed in 2022 and 2023, the 2024 update estimated that the 2024 spawning biomass had a probability of 99% to be in the Healthy zone (Table 9, Figure 19).

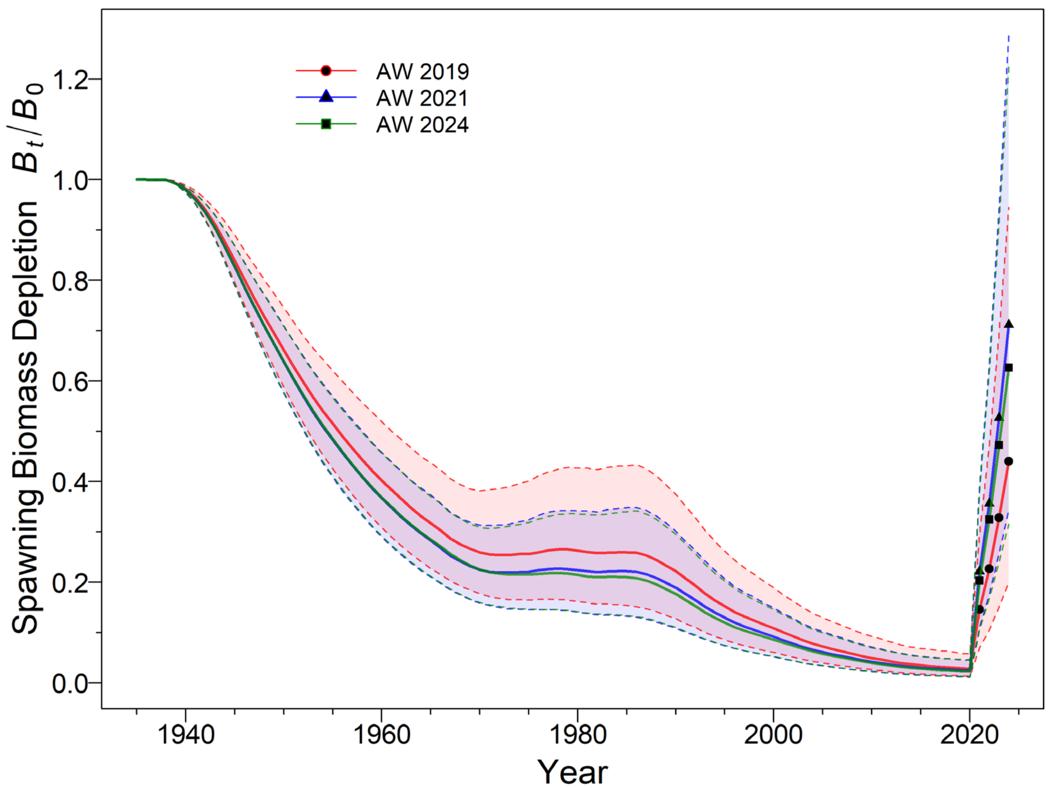

Figure 17. Composite base: comparison of MCMC estimates of spawning stock depletion (B_t/B_0) from 1935 to 2024 for the stock assessment updates in 2024 (green) and 2021 (blue) and the 2019 stock assessment (red). The final four model years (2021 to 2024) are shown as squares for the 2024 update, triangles for the 2021 update (includes two projection years at 500 t/y), and circles for the 2019 assessment (includes four projection years at 200 t/y). The credibility envelopes (dashed lines) delimit the 0.05 and 0.95 quantiles.

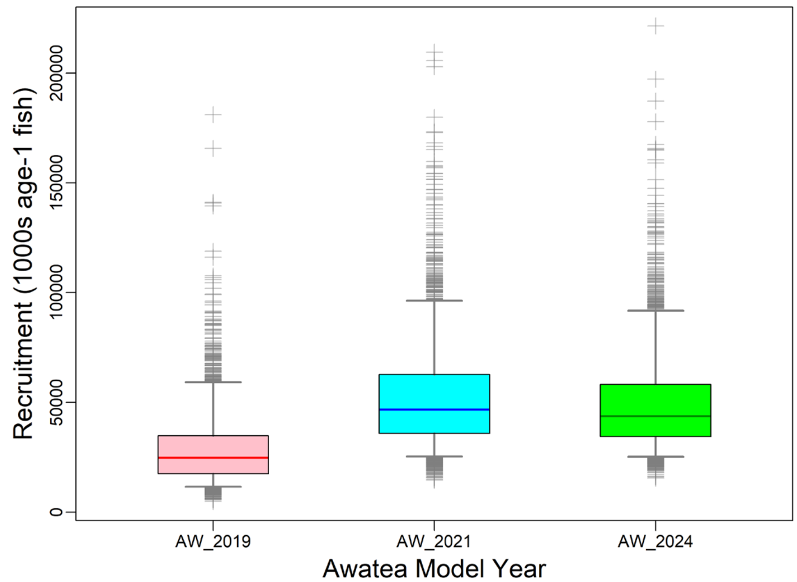

Figure 18. Composite base: comparison of MCMC recruitment estimates for age-1 fish in 2017 from the Awatea fits in 2019 (red), 2021 (blue), and 2024 (green).

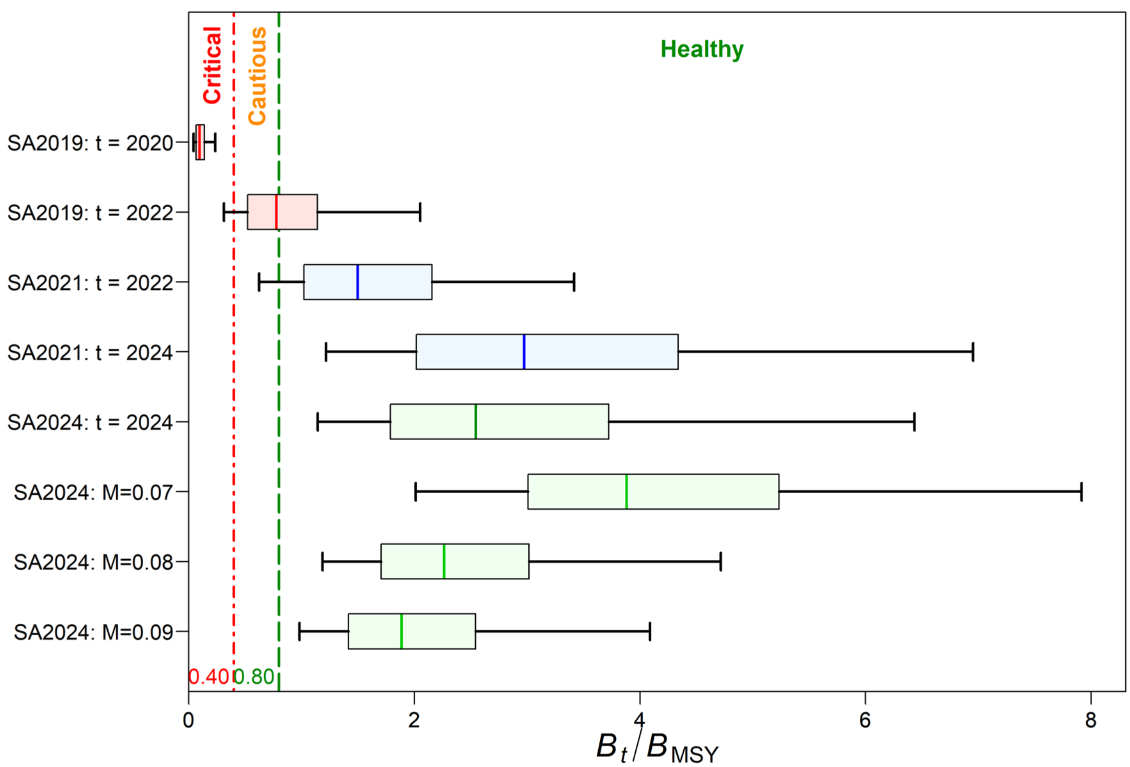

Figure 19. Composite base case: stock status at beginning of model years t = 2020 in the 2019 stock assessment (SA) (bar 1), 2022 in the 2021 SA (bar 3), and 2024 in the 2024 SA (bar 5). Two-year projections for SA 2019 at 200 t/y (bar 2) and SA 2021 at 500 t/y (bar 4) are displayed to compare with base case estimates in SA 2021 and SA 2024, respectively. The last three bars show stock status for the component runs of SA 2024 that contribute to the base case (bar 5). Quantile plots show the 0.05, 0.25, 0.5, 0.75, and 0.95 quantiles from the MCMC posteriors.

Low Recruitment Projections

Uncertainty in the strength of the 2016 cohort was explored by the 2019 stock assessment by extracting samples from the composite posterior that corresponded to the lowest 5th percentile of the age-1 recruitment estimates for R_{2017} to test the robustness of the projected rebuild by using the least productive component of the posterior distribution. This low recruitment projection was repeated by the 2024 update assessment. This resulted in 150 samples: 109 samples from run B1 (M = 0.07), 39 samples from run B2 (M = 0.08), and two samples from run B3 (M =0.09). This set of low productivity posterior samples, with an effective M lying between 0.07 and 0.08, reduced the R_{2017} median estimate to 23 (19, 25) million recruits from 44 (25, 92) million using the full posterior, a drop of about one-half of the expected recruitments (see upper panel, Figure 20). When this subset of the posterior distribution was projected forward for 10 years at 0, 500, 1,000 and 2,000 t/y constant catch (lower panel, Figure 20), the stock continued to increase in 2025 and 2026 (except for the 2,000 t/y trajectory which showed a slight decline in 2026). The trajectories diverged after 2026, with the 0 t/y trajectory continuing to increase, the 500 t/y trajectory remaining flat and the remaining three trajectories decreasing to the end of the projection period. Note, however, that the 5th percentile of the 2,000 t/y projection remained in the Healthy zone at the end of the projection period (Figure 20).

Occasional large recruitment events are typical among deep-water species of *Sebastes*; such events have been observed to occur every 10 to 25 years in other species of this genus. Bocaccio appears to be an outlier species, with only one large cohort observed in over 60 years. According to this model update, the large 2016 cohort has led to full recovery of the coastwide BOR population, even though model estimates of the status in the latter part of the 2010s indicated that the population was at less than 5% of the unfished equilibrium biomass. Similarly, the southern California population of Bocaccio has had several good recent recruitments that have led to recovery in that population (Starr and Haigh 2022).

Anecdotal reports of young Bocaccio appearing in 2016 were reported previously in Starr and Haigh (2022), but bear repeating here. Amateur fishers and members of the commercial fishing fleet noticed juvenile BOR appearing in 2016 and 2017. Commercial fishers increasingly complained that this new BOR recruitment was making it difficult to stay within the allotted catch caps while fishing for other species. Additionally, independent young-of-year surveys along the central BC coast (Alejandro Frid, Central Coast Indigenous Resource Alliance, pers. comm. 2019) and along the California coast (John Field, Southwest Fisheries Science Center, NOAA, pers. comm. 2019) had detected a substantial number of juvenile BOR in 2016 and in following years. In 2023, Bocaccio was being caught in substantial numbers, comparable to those for major rockfish species, in a newly-implemented commercial biosampling program (Norm Olsen, Pacific Biological Station, DFO, pers. comm. 2024).

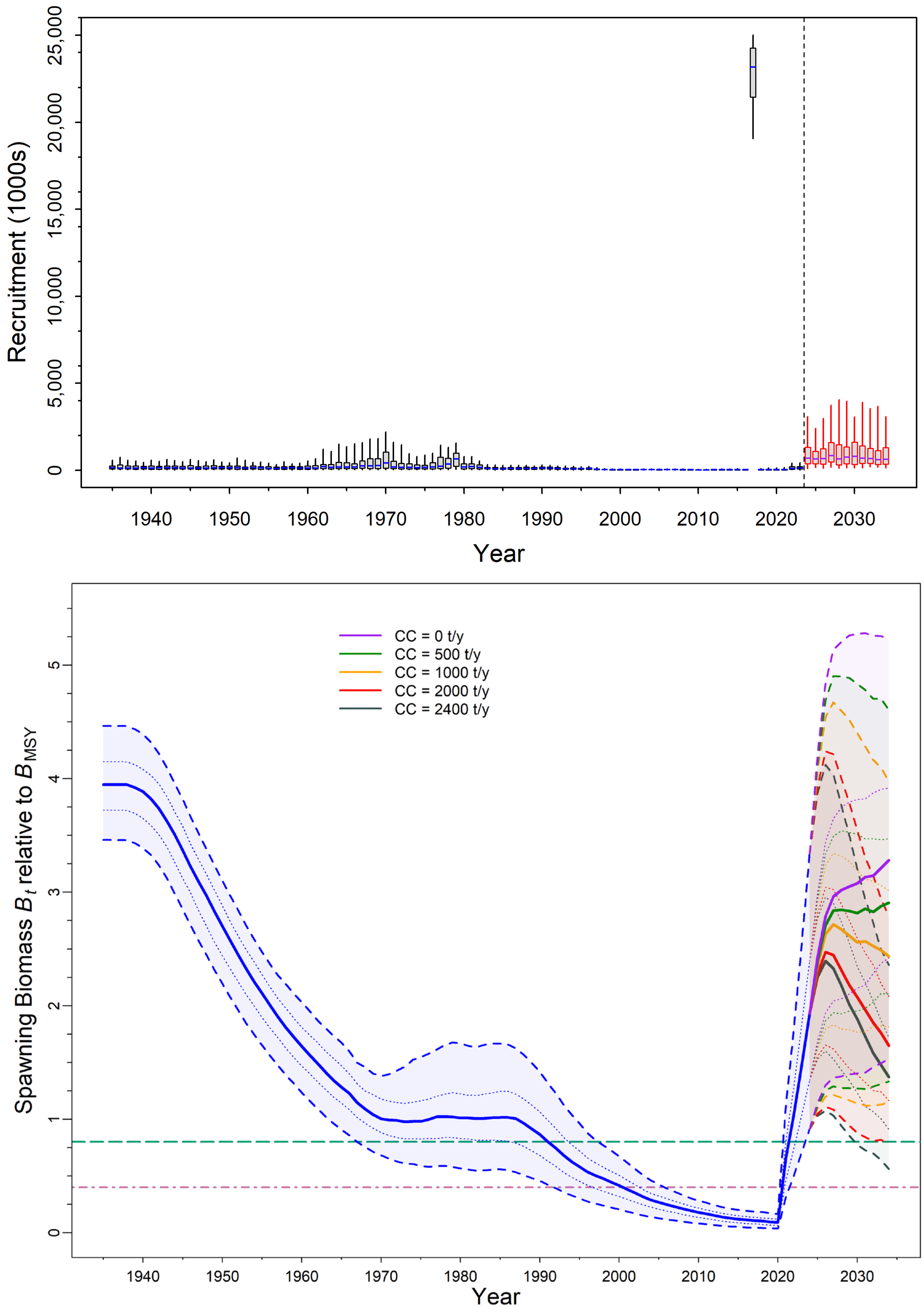

Figure 20. Low recruitment extraction: (top) marginal posterior distribution of recruitment trajectory in 1,000s of age-1 fish (see Figure 15 caption for further details); (bottom) estimates of spawning biomass B_t relative to B_{MSY} from 150 of the pooled model posteriors that represent the samples with the lowest R_{2017} age-1 recruitment estimates (see Figure 12 caption for further details).

Indicators of Stock Status

Decision tables for the composite base case provide advice to managers as probabilities that current and projected biomass B_t (t = 2024, ..., 2034) will exceed biomass-based reference points (or that projected exploitation rate u_t will fall below harvest-based reference points) under constant catch (CC) policies. Note that years for biomass-based reference points refer to the start of years, whereas years for harvest-based reference points refer to years prior to the start (~mid-year). To interpret the decision tables with respect to DFO's LRP ($0.4B_{MSY}$) and USR ($0.8B_{MSY}$), the probability of being (i) in the Healthy zone is P(B_t > USR), (ii) in the Cautious zone is P(B_t > LRP) − P(B_t > USR), and (iii) in the Critical zone is 1 − P(B_t > LRP). Decision tables in the document (all under a constant catch policy) include:

- Table 8 – probability of B_t exceeding the LRP: P($B_t > 0.4B_{MSY}$);
- Table 9 – probability of B_t exceeding the USR: P($B_t > 0.8B_{MSY}$);
- Table 10 – probability of B_t exceeding biomass at MSY: P($B_t > B_{MSY}$);
- Table 11 – probability of u_t falling below harvest rate at MSY: P($u_t < u_{MSY}$);
- Table 12 – probability of B_t exceeding current-year biomass: P($B_t > B_{2024}$);
- Table 13 – probability of u_t falling below current-year harvest rate: P($u_t < u_{2023}$);
- Table 14 – probability of B_t exceeding a non-DFO 'soft limit': P($B_t > 0.2B_0$);
- Table 15 – probability of B_t exceeding a non-DFO 'target' biomass: P($B_t > 0.4B_0$).

In addition to tables based on the LRP and the USR, results are provided comparing projected biomass to B_{MSY} and to current spawning biomass B_{2024}, and comparing projected harvest rate to current harvest rate u_{2023}.

MSY-based reference points estimated within a stock assessment model can be highly sensitive to model assumptions about natural mortality and stock recruitment dynamics (Forrest et al. 2018). As a result, other jurisdictions use reference points that are expressed in terms of B_0 rather than B_{MSY} (e.g., N.Z. Min. Fish. 2011), because B_{MSY} is often poorly estimated as it depends on estimated parameters and a consistent fishery (although B_0 shares several of these same problems). Therefore, the reference points of $0.2B_0$ and $0.4B_0$ are also presented here.

These are default values used in New Zealand respectively as a 'soft limit', below which management action needs to be taken, and a 'target' biomass for low productivity stocks, a mean around which the biomass is expected to vary. The 'soft limit' is equivalent to the upper stock reference (USR, $0.8B_{MSY}$) in the DFO Sustainable Fisheries Framework (SFF, DFO 2009) while a 'target' biomass is not specified by the DFO SFF.

COSEWIC indicator A1 is reserved for those species where the causes of the reduction are clearly reversible, understood, and ceased. Indicator A2 is used when the population reduction may not be reversible, may not be understood, or may not have ceased. The 2011 Yellowmouth Rockfish recovery potential analysis (Edwards et al. 2012) placed Yellowmouth Rockfish into category A2b (where the 'b' indicates that the designation was based on 'an index of abundance appropriate to the taxon'). Under A2, a species is considered Endangered or Threatened if the decline has been >50% or >30% below B_0, respectively.

Additional short-term tables for COSEWIC's A2 criterion:

- Table 16 – probability of B_t exceeding 'Endangered' status: (P($B_t > 0.5B_0$);
- Table 17 – probability of B_t exceeding 'Threatened' status: (P($B_t > 0.7B_0$).

Table 8. Decision table (BC Coast) concerning the limit reference point $0.4B_{MSY}$ for 1–10-year projections for a range of constant catch strategies (in tonnes). Values are $P(B_t > 0.4B_{MSY})$, i.e. the probability of the spawning biomass (mature females) at the start of year t being greater than the limit reference point. The probabilities are the proportion (to two decimal places) of the 3,000 MCMC samples for which $B_t > 0.4B_{MSY}$. For reference, the average catch over the last 5 years (2019–2023) was 702 t, and the 2023 commercial trawl TAC was 1,800 t.

CC	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
0	1	1	1	1	1	1	1	1	1	1	1
500	1	1	1	1	1	1	1	1	1	1	1
1,000	1	1	1	1	1	1	1	1	1	1	1
1,200	1	1	1	1	1	1	1	1	1	1	1
1,300	1	1	1	1	1	1	1	1	1	1	1
1,400	1	1	1	1	1	1	1	1	1	1	1
1,500	1	1	1	1	1	1	1	1	1	1	1
1,600	1	1	1	1	1	1	1	1	1	1	1
1,700	1	1	1	1	1	1	1	1	1	1	1
1,800	1	1	1	1	1	1	1	1	1	1	1
1,900	1	1	1	1	1	1	1	1	1	1	1
2,000	1	1	1	1	1	1	1	1	1	1	1
2,100	1	1	1	1	1	1	1	1	1	1	1
2,200	1	1	1	1	1	1	1	1	1	>0.99	>0.99
2,300	1	1	1	1	1	1	1	1	1	>0.99	>0.99
2,400	1	1	1	1	1	1	1	1	>0.99	>0.99	>0.99

Table 9. Decision table (BC Coast) concerning the upper stock reference point $0.8B_{MSY}$ for 1–10-year projections for a range of constant catch strategies (in tonnes), such that values are $P(B_t > 0.8B_{MSY})$. For reference, the average catch over the last 5 years (2019–2023) was 702 t, and the 2023 commercial trawl TAC was 1,800 t.

CC	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
0	0.99	>0.99	>0.99	>0.99	>0.99	1	1	1	1	1	1
500	0.99	>0.99	>0.99	>0.99	>0.99	1	>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
1,200	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
1,300	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
1,400	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
1,600	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
1,700	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
1,800	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
1,900	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
2,000	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99
2,100	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99
2,200	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.99
2,300	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.99	0.99
2,400	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.98	0.98

Table 10. Decision table (BC Coast) concerning the reference point B_{MSY} for 1–10-year projections for a range of constant catch strategies (in tonnes), such that values are $P(B_t > B_{MSY})$. For reference, the average catch over the last 5 years (2019–2023) was 702 t, and the 2023 commercial trawl TAC was 1,800 t.

CC	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
0	0.97	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
500	0.97	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
1,000	0.97	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
1,200	0.97	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
1,300	0.97	0.99	>0.99	>0.99	>0.99	0.99	0.99	>0.99	>0.99	>0.99	>0.99
1,400	0.97	0.99	0.99	>0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
1,500	0.97	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
1,600	0.97	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
1,700	0.97	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
1,800	0.97	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.98	0.98
1,900	0.97	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.98	0.98	0.98
2,000	0.97	0.99	0.99	0.99	0.99	0.99	0.99	0.98	0.98	0.98	0.98
2,100	0.97	0.99	0.99	0.99	0.99	0.99	0.99	0.98	0.98	0.98	0.98
2,200	0.97	0.99	0.99	0.99	0.99	0.99	0.98	0.98	0.98	0.98	0.97
2,300	0.97	0.99	0.99	0.99	0.99	0.99	0.98	0.98	0.98	0.97	0.97
2,400	0.97	0.99	0.99	0.99	0.99	0.99	0.98	0.97	0.97	0.97	0.96

Table 11. Decision table (BC Coast) comparing the projected exploitation rate to that at MSY for a range of constant catch strategies, such that values are $P(u_t < u_{MSY})$, i.e. the probability of the exploitation rate in the middle of year t being less than that at MSY. For reference, the average catch over the last 5 years (2019–2023) was 702 t, and the 2023 commercial trawl TAC was 1,800 t.

CC	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
0	1	1	1	1	1	1	1	1	1	1	1
500	1	1	1	1	1	1	1	1	1	1	1
1,000	1	1	1	1	1	1	1	1	1	1	1
1,200	>0.99	1	1	1	1	1	1	1	1	1	1
1,300	>0.99	1	1	1	1	1	1	1	1	1	1
1,400	>0.99	1	1	1	1	1	1	1	1	>0.99	>0.99
1,500	>0.99	>0.99	1	1	1	1	>0.99	>0.99	>0.99	>0.99	>0.99
1,600	>0.99	>0.99	1	1	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
1,700	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99
1,800	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99
1,900	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99	0.98	0.98
2,000	0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.98	0.98	0.98	0.97
2,100	0.98	0.99	>0.99	>0.99	0.99	0.99	0.99	0.98	0.97	0.97	0.96
2,200	0.98	0.99	0.99	0.99	0.99	0.99	0.98	0.97	0.96	0.96	0.95
2,300	0.97	0.99	0.99	0.99	0.99	0.98	0.97	0.96	0.96	0.94	0.93
2,400	0.96	0.98	0.99	0.99	0.98	0.97	0.96	0.95	0.94	0.93	0.92

Table 12. Decision table (BC Coast) comparing the projected biomass to current biomass for a range of constant catch strategies, given by probabilities $P(B_t > B_{2024})$. For reference, the average catch over the last 5 years (2019–2023) was 702 t, and the 2023 commercial trawl TAC was 1,800 t.

CC	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
0	0	1	1	1	1	1	1	1	1	1	1
500	0	1	1	1	1	1	1	1	1	1	1
1,000	0	1	1	1	1	1	1	1	1	1	1
1,200	0	1	1	1	1	1	1	1	>0.99	>0.99	>0.99
1,300	0	1	1	1	1	1	1	1	>0.99	>0.99	0.99
1,400	0	1	1	1	1	1	1	>0.99	>0.99	0.99	0.99
1,500	0	1	1	1	1	1	1	>0.99	>0.99	0.99	0.97
1,600	0	1	1	1	1	1	>0.99	>0.99	0.99	0.98	0.95
1,700	0	1	1	1	1	1	>0.99	0.99	0.98	0.96	0.93
1,800	0	1	1	1	1	>0.99	>0.99	0.99	0.97	0.94	0.90
1,900	0	1	1	1	1	>0.99	0.99	0.98	0.95	0.92	0.86
2,000	0	1	1	1	1	>0.99	0.99	0.97	0.94	0.88	0.82
2,100	0	1	1	1	>0.99	>0.99	0.98	0.95	0.91	0.85	0.78
2,200	0	1	1	1	>0.99	0.99	0.97	0.94	0.88	0.81	0.73
2,300	0	1	1	1	>0.99	0.99	0.96	0.92	0.85	0.76	0.68
2,400	0	1	1	1	>0.99	0.98	0.95	0.89	0.81	0.72	0.62

Table 13. Decision table (BC Coast) comparing the projected exploitation rate to that in 2023 for a range of constant catch strategies, such that values are $P(u_t < u_{2023})$. For reference, the average catch over the last 5 years (2019-2023) was 702 t, and the 2023 commercial trawl TAC was 1,800 t.

CC	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
0	1	1	1	1	1	1	1	1	1	1	1
500	1	1	1	1	1	1	1	1	1	1	1
1,000	1	1	1	1	1	1	1	1	1	1	1
1,200	1	1	1	1	1	1	1	1	1	1	1
1,300	1	1	1	1	1	1	1	1	>0.99	>0.99	>0.99
1,400	1	1	1	1	1	1	>0.99	>0.99	>0.99	0.99	0.98
1,500	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.98	0.97	0.96
1,600	0.98	>0.99	>0.99	>0.99	0.99	0.99	0.98	0.97	0.95	0.93	0.90
1,700	0.72	0.99	0.99	0.99	0.98	0.97	0.95	0.92	0.89	0.85	0.80
1,800	0.27	0.96	0.98	0.97	0.95	0.92	0.89	0.84	0.79	0.74	0.70
1,900	0.05	0.89	0.95	0.94	0.91	0.86	0.80	0.74	0.67	0.63	0.56
2,000	<0.01	0.71	0.90	0.88	0.84	0.77	0.69	0.62	0.56	0.49	0.44
2,100	<0.01	0.49	0.80	0.81	0.75	0.67	0.58	0.50	0.42	0.37	0.33
2,200	0	0.28	0.66	0.70	0.65	0.56	0.47	0.37	0.31	0.26	0.24
2,300	0	0.14	0.51	0.59	0.53	0.44	0.34	0.27	0.21	0.18	0.16
2,400	0	0.06	0.37	0.47	0.42	0.34	0.25	0.18	0.14	0.12	0.11

Table 14. Decision table for the alternative limit reference point $0.2B_0$ for 1–10-year projections for a range of constant catch strategies, such that values are $P(B_t > 0.2B_0)$. For reference, the average catch over the last 5 years (2019–2023) was 702 t, and the 2023 commercial trawl TAC was 1,800 t.

CC	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
0	>0.99	1	1	1	1	1	1	1	1	1	1
500	>0.99	>0.99	1	1	1	1	1	1	1	1	1
1,000	>0.99	>0.99	1	1	1	1	1	1	1	>0.99	1
1,200	>0.99	>0.99	1	1	1	1	1	1	>0.99	>0.99	>0.99
1,300	>0.99	>0.99	1	1	>0.99	1	1	>0.99	>0.99	>0.99	>0.99
1,400	>0.99	>0.99	1	1	>0.99	1	1	>0.99	>0.99	>0.99	>0.99
1,500	>0.99	>0.99	1	1	>0.99	1	>0.99	>0.99	>0.99	>0.99	>0.99
1,600	>0.99	>0.99	1	1	>0.99	1	>0.99	>0.99	>0.99	>0.99	>0.99
1,700	>0.99	>0.99	1	>0.99	>0.99	1	>0.99	>0.99	>0.99	>0.99	>0.99
1,800	>0.99	>0.99	1	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
1,900	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
2,000	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
2,100	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
2,200	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
2,300	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99
2,400	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99

Table 15. Decision table for the alternative upper stock reference point $0.4B_0$ for 1–10-year projections for a range of constant catch strategies, such that values are $P(B_t > 0.4B_0)$. For reference, the average catch over the last 5 years (2019–2023) was 702 t, and the 2023 commercial trawl TAC was 1,800 t.

CC	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
0	0.85	0.94	0.97	0.98	0.98	0.98	0.99	0.99	0.99	0.99	0.99
500	0.85	0.94	0.97	0.98	0.98	0.98	0.97	0.98	0.98	0.98	0.98
1,000	0.85	0.94	0.96	0.97	0.97	0.96	0.96	0.97	0.97	0.97	0.97
1,200	0.85	0.94	0.96	0.97	0.96	0.96	0.96	0.96	0.96	0.96	0.96
1,300	0.85	0.94	0.96	0.96	0.96	0.96	0.95	0.95	0.96	0.96	0.96
1,400	0.85	0.94	0.96	0.96	0.96	0.95	0.95	0.95	0.95	0.95	0.96
1,500	0.85	0.94	0.96	0.96	0.96	0.95	0.95	0.95	0.95	0.95	0.95
1,600	0.85	0.93	0.96	0.96	0.95	0.95	0.94	0.94	0.94	0.94	0.94
1,700	0.85	0.93	0.96	0.96	0.95	0.94	0.94	0.94	0.93	0.94	0.94
1,800	0.85	0.93	0.96	0.96	0.95	0.94	0.94	0.93	0.93	0.93	0.93
1,900	0.85	0.93	0.96	0.95	0.95	0.94	0.93	0.93	0.92	0.92	0.92
2,000	0.85	0.93	0.95	0.95	0.94	0.93	0.93	0.92	0.92	0.92	0.91
2,100	0.85	0.93	0.95	0.95	0.94	0.93	0.92	0.92	0.91	0.90	0.90
2,200	0.85	0.93	0.95	0.95	0.94	0.93	0.92	0.91	0.90	0.89	0.89
2,300	0.85	0.93	0.95	0.95	0.94	0.92	0.91	0.90	0.90	0.89	0.87
2,400	0.85	0.93	0.95	0.95	0.93	0.92	0.91	0.90	0.89	0.88	0.86

Table 16. Decision table for reference criterion $0.5B_0$ for 10-year projections and for a range of constant catch strategies, such that values are $P(B_t > 0.5B_0)$. For reference, the average catch over the last 5 years (2019–2023) was 702 t, and the 2023 commercial trawl TAC was 1,800 t.

CC	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
0	0.70	0.85	0.91	0.93	0.93	0.93	0.94	0.95	0.95	0.96	0.97
500	0.70	0.84	0.90	0.91	0.92	0.92	0.92	0.92	0.93	0.94	0.94
1,000	0.70	0.83	0.89	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.91
1,200	0.70	0.83	0.89	0.90	0.89	0.89	0.88	0.88	0.88	0.89	0.89
1,300	0.70	0.83	0.89	0.90	0.89	0.88	0.88	0.87	0.88	0.88	0.88
1,400	0.70	0.83	0.89	0.89	0.89	0.88	0.87	0.87	0.87	0.87	0.87
1,500	0.70	0.83	0.88	0.89	0.88	0.87	0.86	0.86	0.86	0.86	0.86
1,600	0.70	0.83	0.88	0.89	0.88	0.87	0.86	0.85	0.85	0.85	0.85
1,700	0.70	0.82	0.88	0.88	0.87	0.86	0.85	0.84	0.84	0.84	0.84
1,800	0.70	0.82	0.88	0.88	0.87	0.86	0.84	0.83	0.83	0.83	0.82
1,900	0.70	0.82	0.88	0.88	0.87	0.85	0.84	0.83	0.82	0.81	0.81
2,000	0.70	0.82	0.87	0.87	0.86	0.84	0.83	0.82	0.81	0.80	0.79
2,100	0.70	0.82	0.87	0.87	0.86	0.84	0.82	0.81	0.80	0.79	0.78
2,200	0.70	0.82	0.87	0.87	0.85	0.83	0.81	0.80	0.79	0.78	0.77
2,300	0.70	0.82	0.87	0.87	0.85	0.83	0.80	0.79	0.78	0.76	0.75
2,400	0.70	0.82	0.86	0.86	0.84	0.82	0.80	0.78	0.76	0.75	0.73

Table 17. Decision table for reference criterion $0.7B_0$ for 10-year projections and for a range of constant catch strategies, such that values are $P(B_t > 0.7B_0)$. For reference, the average catch over the last 5 years (2019–2023) was 702 t, and the 2023 commercial trawl TAC was 1,800 t.

CC	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
0	0.41	0.60	0.71	0.74	0.75	0.75	0.76	0.76	0.77	0.79	0.80
500	0.41	0.59	0.69	0.72	0.72	0.72	0.72	0.72	0.73	0.74	0.75
1,000	0.41	0.58	0.67	0.70	0.70	0.69	0.68	0.67	0.67	0.67	0.67
1,200	0.41	0.58	0.67	0.69	0.68	0.67	0.66	0.65	0.65	0.64	0.64
1,300	0.41	0.57	0.66	0.69	0.67	0.66	0.65	0.64	0.63	0.63	0.63
1,400	0.41	0.57	0.66	0.68	0.67	0.66	0.64	0.63	0.62	0.61	0.61
1,500	0.41	0.57	0.66	0.67	0.66	0.65	0.63	0.62	0.61	0.60	0.59
1,600	0.41	0.57	0.66	0.67	0.66	0.64	0.62	0.61	0.59	0.58	0.58
1,700	0.41	0.57	0.65	0.67	0.65	0.63	0.61	0.60	0.58	0.57	0.57
1,800	0.41	0.56	0.65	0.66	0.65	0.63	0.60	0.59	0.57	0.56	0.55
1,900	0.41	0.56	0.65	0.66	0.64	0.62	0.60	0.57	0.56	0.55	0.54
2,000	0.41	0.56	0.65	0.65	0.63	0.61	0.59	0.56	0.55	0.53	0.52
2,100	0.41	0.56	0.65	0.65	0.63	0.60	0.58	0.55	0.54	0.52	0.50
2,200	0.41	0.56	0.64	0.65	0.62	0.59	0.57	0.54	0.52	0.51	0.49
2,300	0.41	0.56	0.64	0.64	0.61	0.59	0.56	0.53	0.51	0.49	0.47
2,400	0.41	0.56	0.63	0.64	0.60	0.58	0.55	0.52	0.50	0.47	0.45

Conclusions

While the estimated size of the 2016 year class seems unprecedented, particularly because it was spawned by a stock with a very low level of mature females, this is the response indicated by the data given the consistent increase in the abundance signal from four synoptic surveys (Figure 3). The length frequency plots suggested that the signal was attributable entirely to the 2016 cohort (Figures 4–6). There is little doubt about the reality of the biomass increase, which has been confirmed by two stock assessment updates in 2021 and 2024. As well, systematic dockside sampling of rockfish in Ucluelet, Port Hardy and Prince Rupert from March 2023 to February 2024 indicated that BOR was present in these samples at levels similar to known abundant species such as Widow Rockfish, Canary Rockfish and Pacific Ocean Perch, providing independent confirmation that that BOR has vastly increased its apparent relative abundance (N. Olsen, DFO, pers. comm. 2024). While the regional peer review participants in 2019 were uncertain about the absolute magnitude of the biomass increase, the data continue to show a steady progression of the 2016 cohort as it ages. Some evidence exists that a notable, but likely smaller, cohort was born in 2020.

Additional age data (2021 QCS synoptic) were not used in this update due to poor accuracy and precision of the ages in the samples. The age readings centred on age 8, which contradicted the known age of 5 years in 2021. Communication with the Sclerochronology Lab (SCL) indicated that many of these otoliths were aged by inexperienced technicians. Bocaccio remains a difficult fish to age given its rapid growth. Many 'checks' (false annuli caused by interannual hyalinization, Wischniowski and Loher 2010) occur in the early life history of Bocaccio (ages 1 to 4, Audrey Ty, PBS, pers. comm. 2024). A misclassification of age in very young fish has a greater impact on observed age accuracy and precision than for older fish, assuming older ages are easier to delimit.

The discrepancy between true ages and observed ages needs to be addressed and resolved before future age readings for Bocaccio can be used in the next stock assessment. Experienced readers have retired or will be retiring soon. It is recommended that training for new personnel in the SCL be continued and their progress evaluated on a regular basis. The SCL needs more support in terms of funding, mentorship, and inter-lab exchanges to support the new personnel. In the short-term, the 2021 QCS synoptic samples should be sent to another ageing lab, preferably in the US Pacific Northwest, for validation and comparison.

Science personnel should review the availability of age samples (otoliths) collected from the commercial biosampling program and submit age requests annually rather waiting until the ageing is needed before an assessment. There needs to be a strong commitment to continue the dockside rockfish sampling that was started in 2023. This program provides systematic sampling of all important rockfish species, including Bocaccio, at the three major BC ports.

The use of length data in current stock assessment platforms, including Stock Synthesis, should be avoided. This is because these models use expected mean growth at each age to convert the length data into pseudo-age data, which is at best an approximation and does not correctly model the existence of fast and slow growing individuals in a cohort. To correctly include length data into an age-structured model requires the model to track the length structure for fast and slow growing fish outside of the expected mean growth distribution, a requirement that can be both hardware and data intensive. We note that the length data are used qualitatively to identify the 2016 cohort and possible successive cohorts (e.g., see Figure 4, Figure 5 and Figure 6).

Given the similarity of model estimates from this update to those from the 2021 update, and the continued evaluation of stock status into the Healthy zone, further updates using the Awatea platform are not recommended. Instead, the Bocaccio stock should be fully assessed on or before 2029 using the Stock Synthesis 3 (SS3) model platform, which has been adopted for the last three offshore rockfish stock assessments. The SS3 platform is better able to incorporate ageing error and provides model diagnostics unavailable in Awatea. Monitoring synoptic survey abundance indices could be used to trigger an assessment earlier than 2029 if there is evidence of credible abundance declines. An earlier assessment may be required if there is no additional recruitment and the large 2016 cohort is reduced as a result of fishing and natural mortality.

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