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UPDATE OF THE 2019 BOCACCIO (*SEBASTES PAUCISPINIS*) STOCK ASSESSMENT FOR BRITISH COLUMBIA IN 2021

Context

Bocaccio rockfish (BOR) was assessed in 2019 (DFO 2020) using the Awatea catch-at-age stock assessment model platform, tuned to six fishery-independent trawl survey series (covering 1967-2019), 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 four of the six surveys. The British Columbia (BC) outside coast model started from an assumed 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 surveys and the commercial trawl fleet. These three runs were combined into a composite base case which explored the major axis of uncertainty (M) in the stock assessment. A summary of the 2019 stock assessment as well as 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 the Science Advisory Report 2020/025.

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 model to be 44 times the long-term average recruitment (5% and 95% quantiles: 30 times, 58 times).

The estimated size of the initial biomass was large (median = 32,300 tonnes; 5% and 95% quantiles: 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 1,461 tonnes (703, 3,623), compared to the average catch over the final five years (2015-2019) of the reconstruction of only 69 tonnes. The size of the spawning biomass at the end of the final year (2019) relative to the unfished equilibrium spawning biomass (B_{2020}/B_0) was very low, estimated at 0.028 (0.013, 0.058), and B_{2020} relative to equilibrium spawning biomass that would support the MSY (B_{2020}/B_{MSY}) was 0.096 (0.042, 0.23). Neither of these estimates included a contribution from the 2016 year class because it was assumed that the first four age classes had no mature females. The equivalent ratio at the end of 2019 for the biomass vulnerable to trawl gear (V_{2020}/V_0) was 0.10 (0.050, 0.21). This ratio is higher than for the spawning biomass because the vulnerable biomass was determined by the selectivity function without reference to maturity status and, consequently, included a fractional contribution from the large 2016 cohort.

[1] The series was truncated at 2012 on the advice of the BOR Technical Working Group (TWG); 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.

The estimated exploitation rates (u_t) throughout the time series were low, with the 2019 exploitation rate estimated at u_{2019} = 0.025 (0.021, 0.044) for the 'trawl' fishery and u_{2019} = 0.0097 (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 (median for 'trawl' = 0.06 and 'other' = 0.01) barely entered the plausible range of M. Exploitation at levels substantially less than natural mortality are often thought to be sustainable, but the extremely low status of the 2019 relative biomass estimated by the model attested to the lack of recruitment as well as the success by management to keep exploitation to a minimum level in a mixed species trawl fishery.

The composite base case spawning biomass at the beginning of 2020 was estimated 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, a very quick recovery was projected based on the extremely large size of the 2016 cohort.

The 2019 stock assessment predicted that there would be a quick rebound in the spawning biomass starting in 2021 because, even though only a small proportion of the 5-year old fish would be mature, the large size of the 2016 cohort should contribute a detectable increase to the spawning population. Model projections predicted that, by the beginning of 2022 and assuming a constant catch of 200 tonnes/year or a harvest rate of 0.04/year, the BOR stock would move into the Cautious zone (i.e., the median was near the USR of $0.8B_{\text{MSY}}$). The stock assessment further projected that the probability of the spawning biomass exceeding the LRP, i.e. $P(B_t > 0.4B_{\text{MSY}})$, was greater than 95% in one more year (i.e. at the beginning of 2023). As a sensitivity analysis, the projections were repeated based only on the lowest 5% of the posterior distribution of the composite base case, resulting in rebuild predictions that were only delayed by 2-3 years. Finally, the 2019 stock assessment noted that both the Queen Charlotte Sound (QCS) and west coast Vancouver Island (WCVI) synoptic surveys showed good 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[2] and in 2021.

Because of the apparent demonstrated capacity of the synoptic surveys to monitor Bocaccio, the 2019 Regional Peer Review (RPR) meeting agreed that it would be feasible to check the progress of the rebuild through an update of the 2019 stock assessment once the 2020 and 2021 information from the synoptic surveys[3] used in the model became available (DFO 2020). These observations, once processed through the agreed stock assessment, should corroborate the progress of the rebuild. The 2019 RPR also noted that, although no new age data would be available in 2021, it was likely that the 2016 cohort would be identifiable from the length frequency data in the three surveys, given the large relative size of this cohort. It also noted that there was a possiblity that new recruitment, if sufficiently large, would also be identifiable in these data.

This Science Response results from the Science Response Process of October 28, 2021 on the Stock Assessment Update of Bocaccio Rockfish (*Sebastes paucispinis*) for British Columbia in 2021.

[2] The 2020 WCVI synoptic survey was postponed due to the COVID-19 pandemic. However, it was repeated May 14-Jun 11, 2021, aboard the F/V *Nordic Pearl*.

[3] WCHG (Aug 25-Sep 23, 2020) , WCVI (May 14-Jun 11, 2021), HS (May 18-Jun 14, 2021), QCS (Jul 5-Aug 13, 2021)

Background

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assessed the British Columbia (BC) population of Bocaccio 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 is uncertainty about the risks posed to the BC BOR stock as catch levels would likely increase in response to the apparent strong recruitment event. This stock assessment update was generated to review the expected recovery outlined in the 2019 stock status of BOR (DFO 2020) and to inform DFO rebuilding plans 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*). 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.

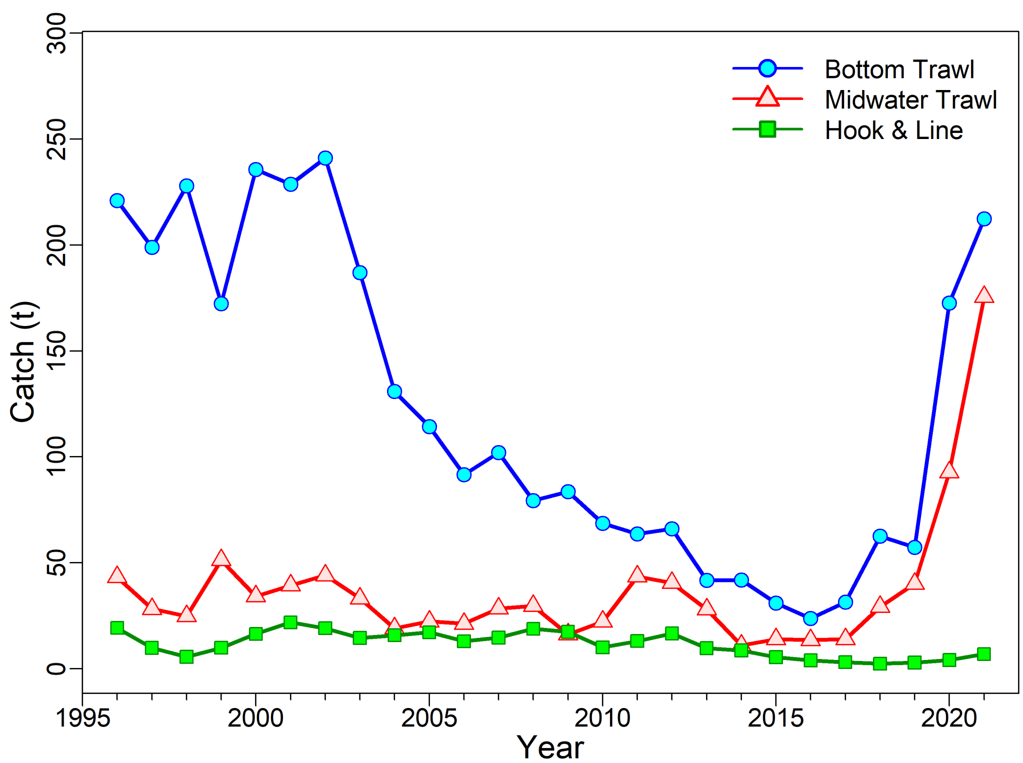


Figure 1. Reported catch (landings + released) by gear of BOR since the implementation of the trawl's onboard-observer program in 1996.

This updated stock assessment extends the 2019 analysis by evaluating a BC coastwide population harvested by two commercial fisheries: (1) trawl fishery that uses bottom and midwater trawl gear (Figure 1), and (2) ‘other’ fishery, comprising halibut longline, sablefish trap, lingcod longline, inshore longline, and salmon troll. Each fishery has updated catch information (reconstructed landings and discards summed, Figure 2), but only the trawl fishery has age frequency data, which have not been updated. Four additional synoptic survey index points for Bocaccio have accumulated since the 2019 stock assessment – 2020 for west coast Haida Gwaii (WCHG) and 2021 for Queen Charlotte Sound (QCS), west coast Vancouver Island (WCVI), and 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 WCVI survey was delayed until 2021.

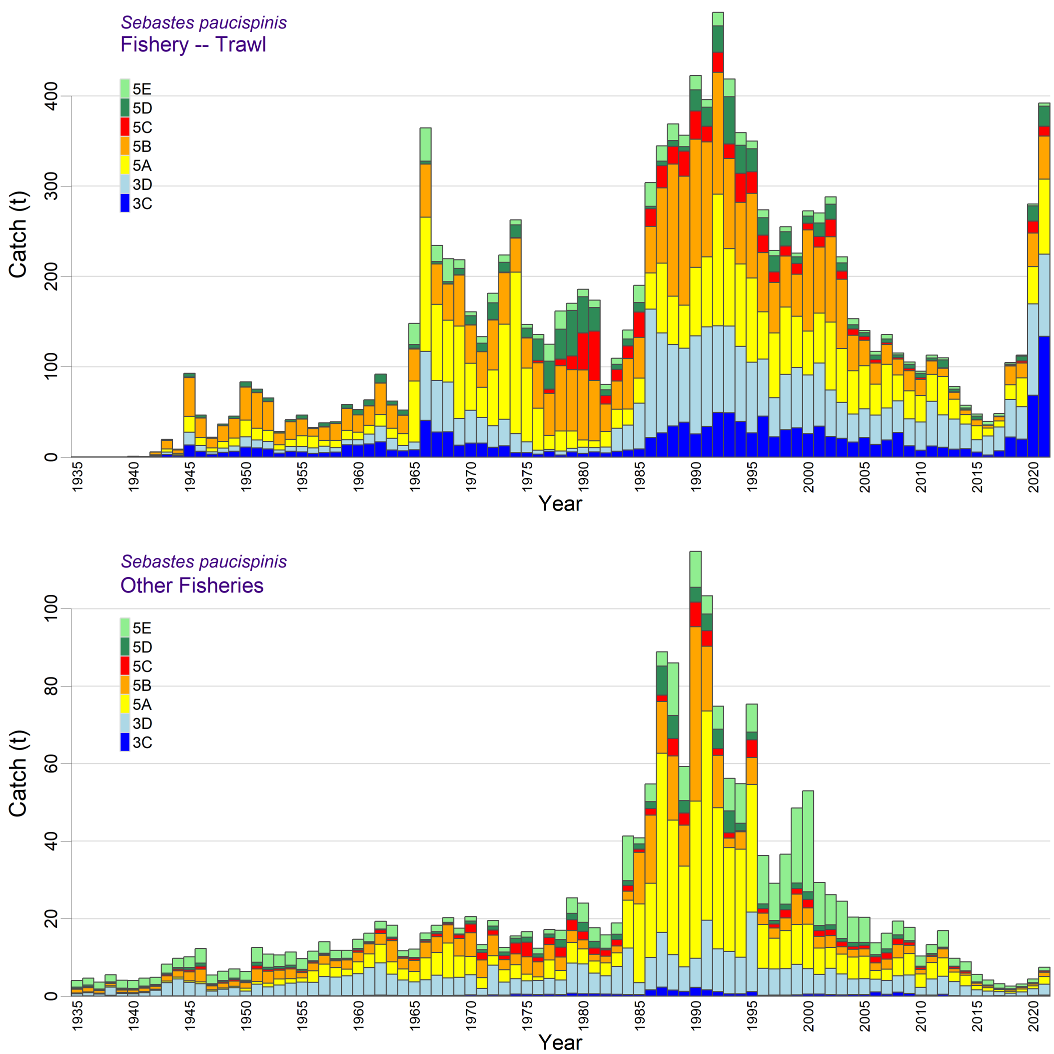


Figure 2. Catch reconstruction of Bocaccio from 1935 to 2021 (up to Oct 14) for the trawl (top) and other (bottom) fisheries used in the stock assessment model. The 2021 trawl and other catches were adjusted to 450 and 10 tonnes, respectively, after consultation with industry.

Analysis and Response

Surveys and Lengths

The updated model had no difficulty in fitting each survey series, including the new 2020 and 2021 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. The 2019 index value for QCS, which the model was not able to fit in the 2019 assessment, still remains an outlier in the updated fits while the 2021 index value matches the overall stock trajectory. These reasonable fits to most of the survey indices have been achieved in spite of the semi-pelagic behaviour of this species, which spends a significant amount of time off the bottom, making it a less than ideal species for monitoring using bottom trawl gear. An average relative error of 51% across 37 index values from these four synoptic surveys, conducted from 2003 to 2021, attest to the apparent low suitability of this methodology for monitoring this species.

The updated length frequency (LF) distribution data show that the 2016 cohort of Bocaccio 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 Bocaccio 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 aged, although growth seemed to slow from 2019 to 2021, increasing from $\sim$40 cm to $\sim$50 cm (Figure 4). For reference, Starr and Haigh (2022) report von Bertalanffy L-infinity values of 71 and 69 for females and males, respectively. The three synoptic surveys conducted in 2021 detected a smaller cohort of fish measuring $\sim$20 cm, the expected size of age-1 fish and perhaps indicative of new recruitment (Figures 4 and 5). 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 LF, although there are no 2021 data (Figure 6).

Boccacio maturity stages in the three 2021 synoptic surveys were summarised in Table 1. This summary shows that, on average, less than 5% of the staged BOR were judged to be ‘Immature’ or ‘Maturing’, likely indicating that the maturity ogive used in the model underestimated the proportion of mature BOR because that ogive assumed that only 30% of the age-5 BOR were mature. The values in Table 1 might be somewhat misleading, because these are visually staged fish and, in some cases, fish judged as ‘Resting’ should have been in the ‘Maturing’ category. However, the two unambiguous stages (‘Mature’ and ‘Spent’) account for an average of over 30% of the staged observations. This total, combined with what is likely to be a reasonably large fraction of the ‘Resting’ category, indicates that the maturity ogive used in the model may have underestimated the size of the spawning population, making it even larger.

Table 1. Percentage of female Bocaccio (>30cm in total length) at each recorded maturity stage from the three synoptic surveys that operated in 2021 (QCS, HS, and WCVI; trip IDs shown in parentheses).

Maturity Stage	QCS (85990)	HS (85930)	WCVI (85950)	Total
Immature	0	0	0	0
Maturing	3.86	2.27	5.41	4.31
Mature	7.30	14.77	10.04	9.66
Fertilised	0	0	0	0
Embryos/Larvae	0	0	0	0
Spent	18.03	7.95	30.12	21.90
Resting	70.82	75	54.44	64.14
Total	100	100	100	100

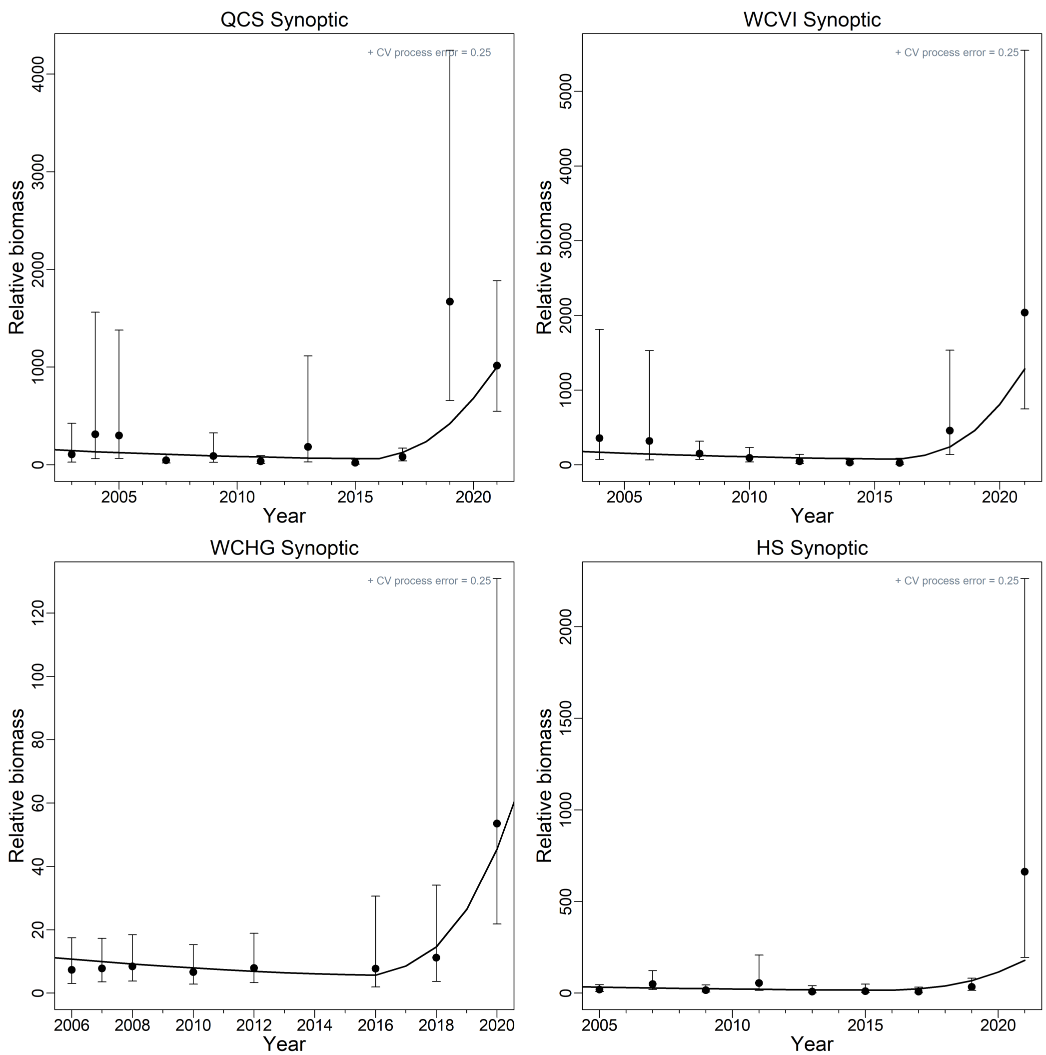


Figure 3. Central run: survey index values (points) with 95% confidence intervals (bars) and MPD model fits (curves) for the synoptic survey series.

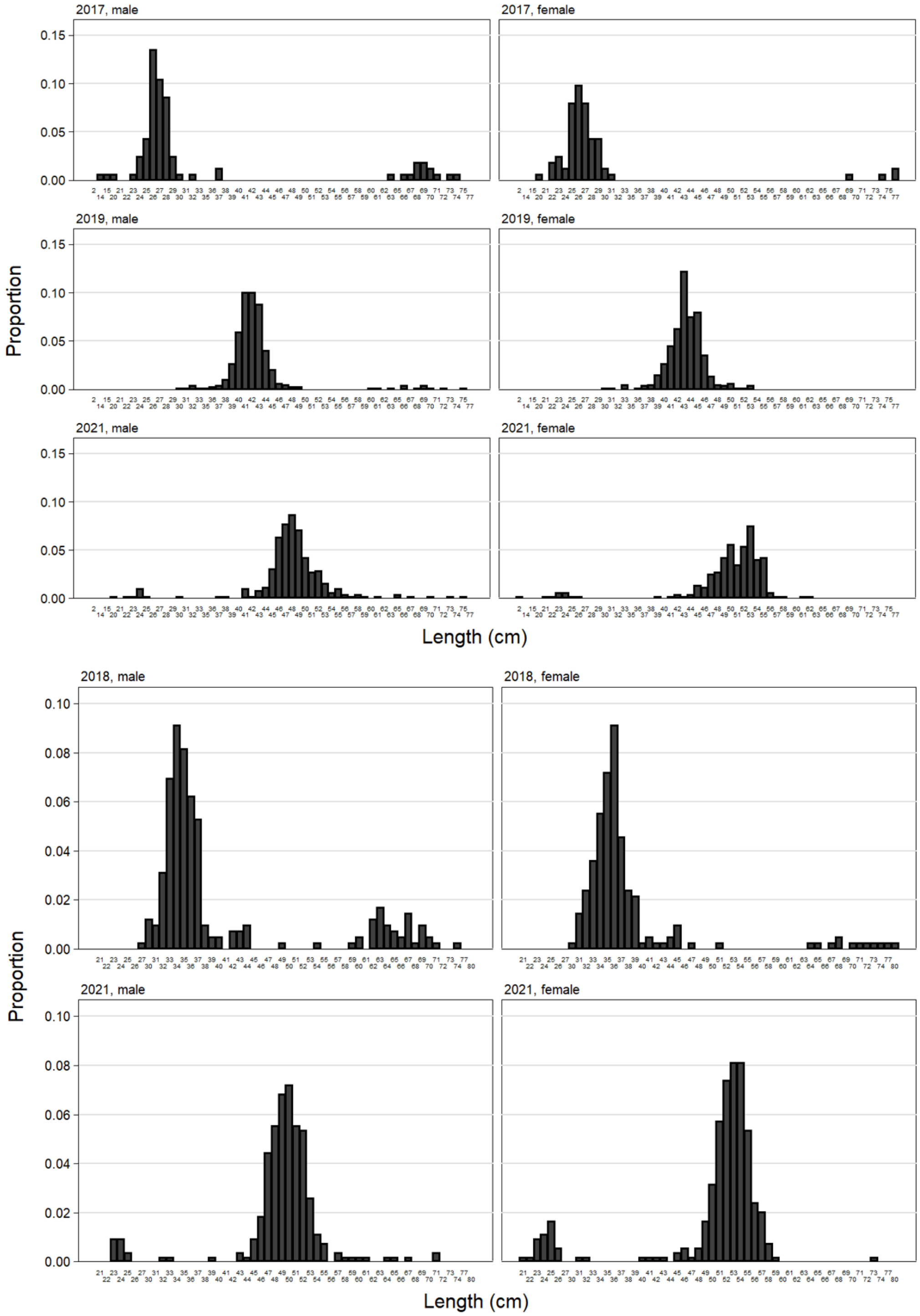


Figure 4. Length frequency distributions observed by year and sex in the Queen Charlotte Sound (top) and west coast Vancouver Island (bottom) synoptic surveys series.

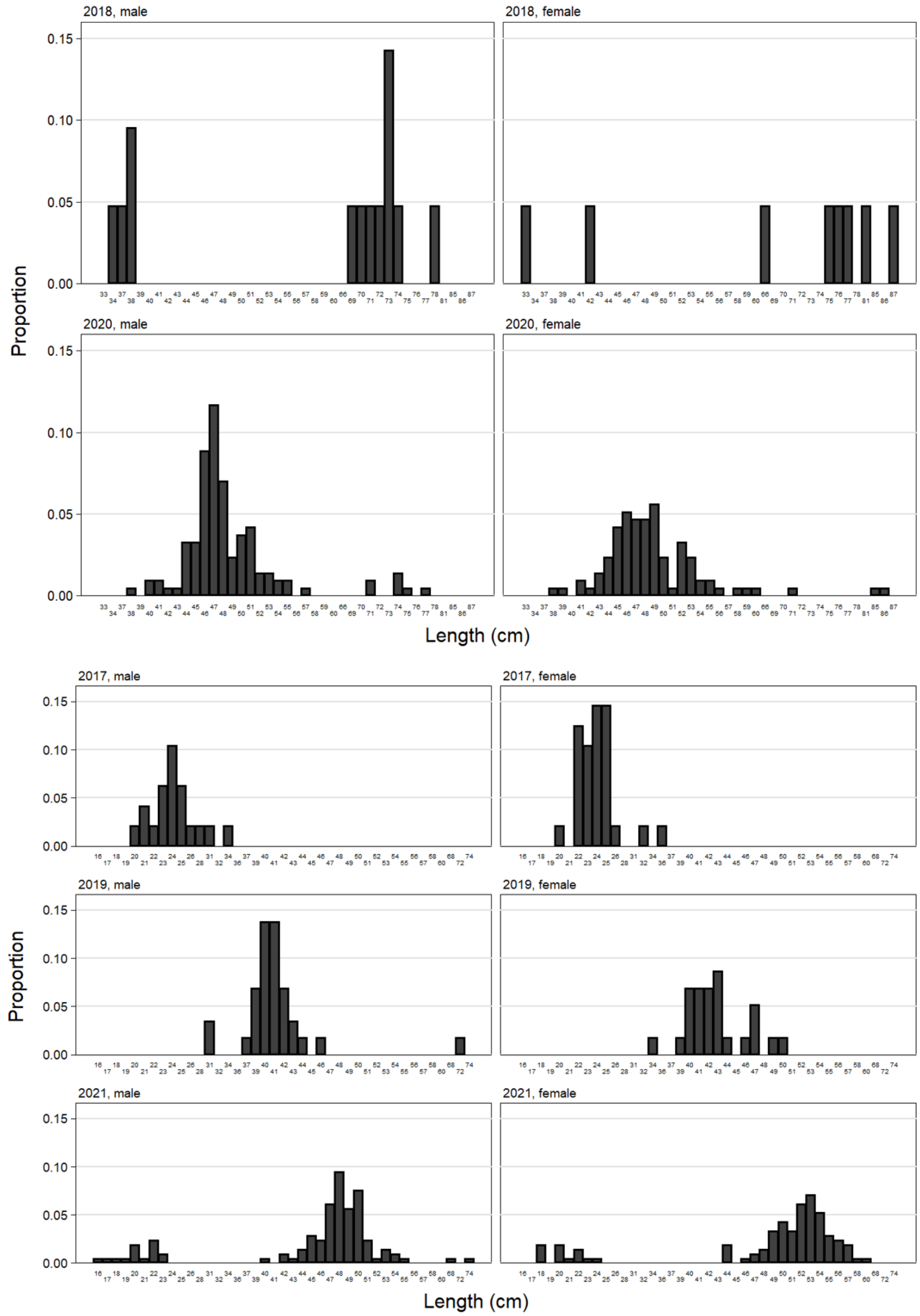


Figure 5. Length frequency distributions observed by year and sex in the west coast Haida Gwaii (top) and Hecate Strait (bottom) synoptic surveys series.

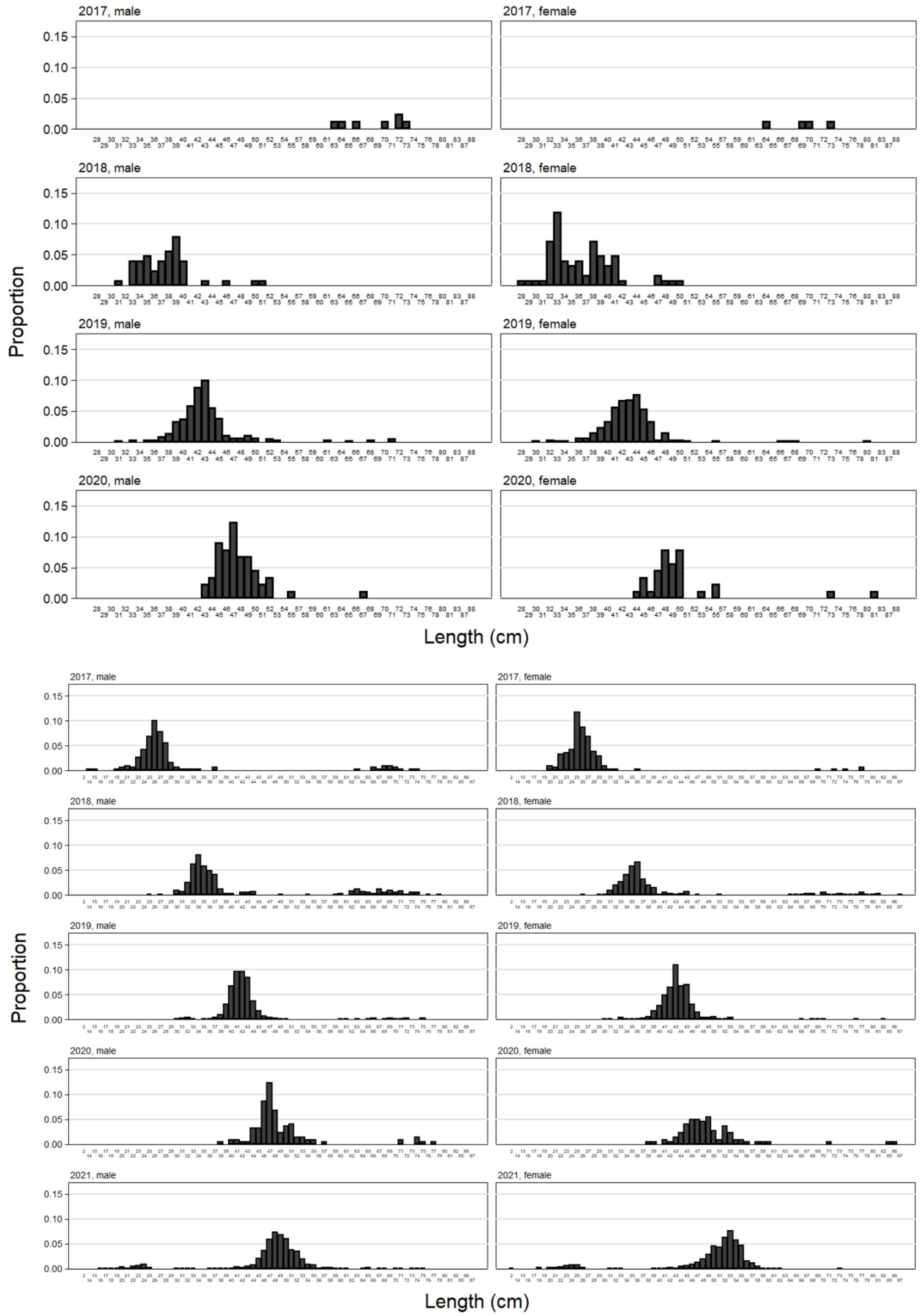


Figure 6. Length frequency distributions observed by year and sex in the commercial trawl fisheries (top) and combined research surveys (bottom).

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, 1000 MCMC samples were pooled to provide an average stock trajectory for population status and advice to managers. The stock assessment reviewed in 2019 concluded that estimating M was not possible given the uninformative nature of the data, with the mode of the posterior density (MPD) estimates not shifting from the prior means. Furthermore, runs that estimated M exhibited unstable MCMC behaviour without convergence.

The updated composite base case median parameter estimates appear in Table 2, and derived quantities at equilibrium and associated with maximum sustainable yield (MSY) appear in Table 3. 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.

Various model trajectories and final stock status for the composite base case appear in these figures:

- Figure 12 – estimates of spawning biomass B_t (tonnes) from pooled model posteriors;
- 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 (1935-2022) and projected (2023-2032) recruitment R_t (1000s 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 19 – BOR stock status at beginning of 2022.

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, which have not been repeated in this update.

The three component runs outlined above converged with acceptable MCMC diagnostics. Figures 7 to 9 show diagnostics for the R_0 parameter in each of the three component runs showing convergence for all three runs and minimal autocorrelation. Figure 10 shows the posterior distribution of the estimated parameters for each component 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 2, parameter definitions in Appendix E of Starr and Haigh 2022) and derived quantities at equilibrium and those associated with MSY (Table 3). The composite base case population trajectory from 1935 to 2022 and projected biomass to 2032 (Figure 12), assuming a constant catch policy of 500 t/y, indicates that the median stock biomass exceeded the upper stock reference (USR) in 2022, which was sooner than predicted by the 2019 assessment.

Plots of the vulnerable biomass for each fishery show a strong response to the presence of the 2016 cohort (Figure 13). The exploitation rate plot for the trawl fishery shows that the exploitation rate while low (less than 0.04) has recently increased slightly in the trawl fishery (Figure 14). Figure 15 shows the immense size of the 2016 cohort, relative to all previous year classes and to the projection recruitments.

A phase plot of the time-evolution of spawning biomass and exploitation rate in the two modelled fisheries in MSY space (Figure 16) suggests that the stock has been in the critical zone since the late 1990s, but has now moved into a current (2022) position that lies well inside the Healthy zone at B_{2022}/B_{MSY} = 1.499 (0.625, 3.416), $u_{2021(\text{trawl})}/u_{\text{MSY}}$ = 0.24 (0.106, 0.487), and $u_{2021(\text{other})}/u_{\text{MSY}}$ = 0.006 (0.003, 0.013).

Table 2. The 0.05, 0.5, and 0.95 quantiles for pooled model parameters (defined in Appendix E) from MCMC estimation of three base model runs.

Parameter	5%	50%	95%
R_0	824	1,990	5,262
h	0.683	0.810	0.930
q_1	0.0181	0.0332	0.0544
q_2	0.0226	0.0411	0.0671
q_3	0.00168	0.00304	0.00487
q_4	0.00478	0.00889	0.0148
q_5	0.0333	0.0576	0.0901
q_6	0.0134	0.0222	0.0344
q_7	0.000199	0.000327	0.000454
μ_1	7.85	11.8	15.9
μ_2	7.29	9.62	12.7
μ_3	7.85	11.5	15.8
μ_4	8.84	12.8	17.4
μ_7	9.22	11.0	13.2
Δ_1	0.490	0.965	1.45
Δ_2	0.387	0.857	1.35
Δ_3	0.443	0.962	1.46
Δ_4	0.466	0.951	1.42
Δ_7	0.566	1.00	1.47
$\log v_{1L}$	3.52	4.42	5.21
$\log v_{2L}$	2.89	3.72	4.50
$\log v_{3L}$	2.98	4.02	4.95
$\log v_{4L}$	3.30	4.17	4.95
$\log v_{7L}$	2.85	3.44	4.02

Table 3. The 0.05, 0.5, and 0.95 quantiles of MCMC-derived quantities from 3000 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_{2022} – spawning biomass at the start of 2022, V_{2022} – vulnerable biomass in the middle of 2022, u_{2021} – exploitation rate (ratio of total catch to vulnerable biomass) in the middle of 2021, u_{max} – maximum exploitation rate (calculated for each sample as the maximum exploitation rate from 1935-2021), 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 (2017-2021) was 204 t.

Quantity	5%	50%	95%
B_0	19,534	37,530	81,442
V_0 (trawl)	33,050	63,675	140,538
V_0 (other)	32,380	62,317	135,280
B_{2022}	7,348	13,080	25,740
V_{2022} (trawl)	13,119	24,332	48,673
V_{2022} (other)	11,575	20,457	39,984
B_{2022}/B_0	0.176	0.357	0.633
V_{2022}/V_0 (trawl)	0.188	0.382	0.706
V_{2022}/V_0 (other)	0.165	0.336	0.598
u_{2021} (trawl)	0.0149	0.0300	0.0551
u_{2021} (other)	0.000402	0.000781	0.00137
u_{max} (trawl)	0.0377	0.0599	0.0808
u_{max} (other)	0.00667	0.00985	0.0127
MSY	1,067	2,118	4,818
B_{MSY}	3,814	8,948	21,622
$0.4B_{MSY}$	1,525	3,579	8,649
$0.8B_{MSY}$	3,051	7,159	17,298
B_{2022}/B_{MSY}	0.625	1.50	3.42
B_{MSY}/B_0	0.183	0.238	0.286
V_{MSY}	7,470	16,959	41,936
V_{MSY}/V_0 (trawl)	0.211	0.269	0.319
V_{MSY}/V_0 (other)	0.212	0.275	0.335
u_{MSY}	0.0900	0.124	0.176
u_{2021}/u_{MSY} (trawl)	0.106	0.240	0.487
u_{2021}/u_{MSY} (other)	0.00266	0.00623	0.0134

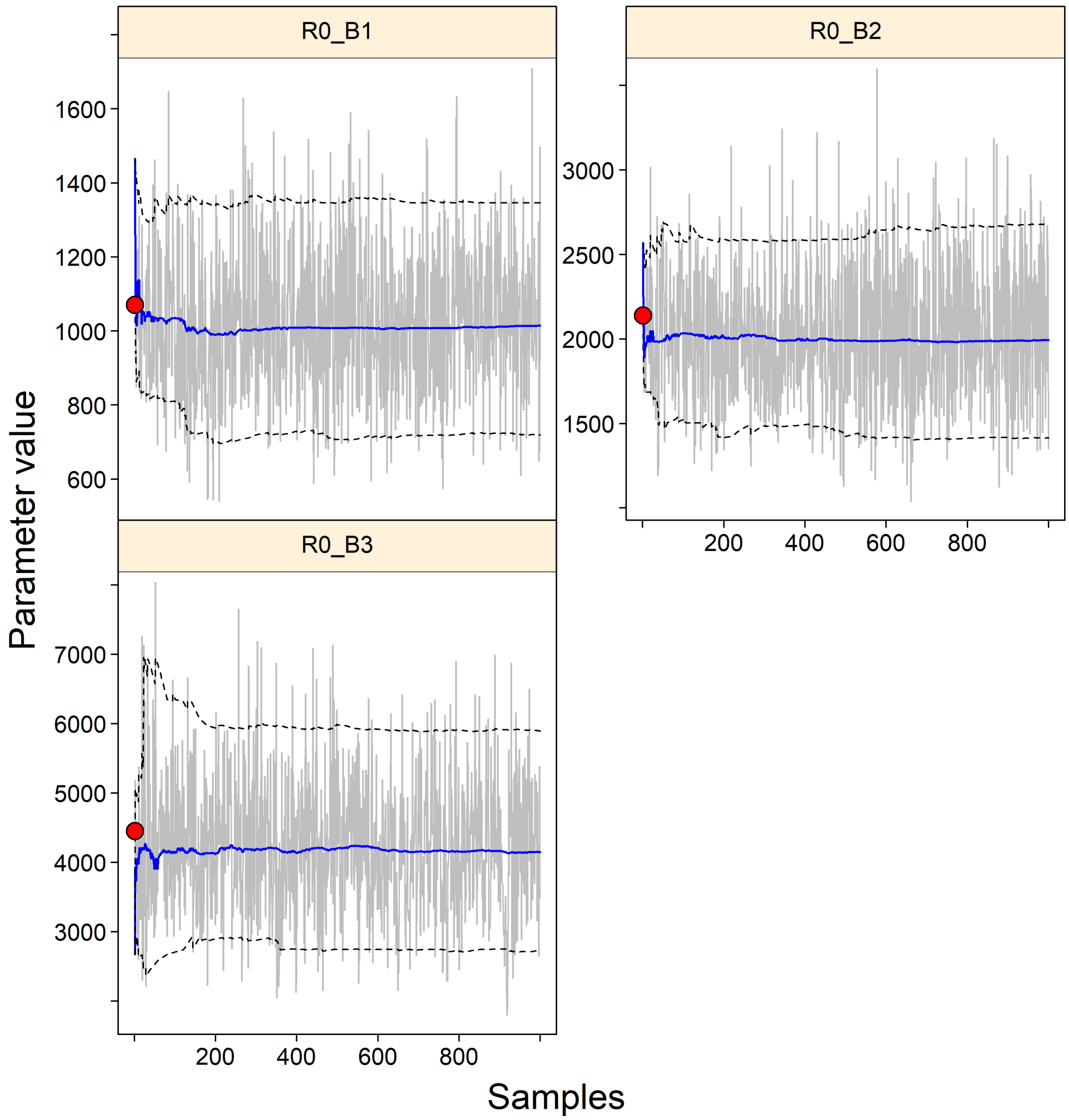


Figure 7. Component base: MCMC traces of R_0 for the three component base runs. Grey lines show the 1000 samples for the R_0 parameter, solid lines show the cumulative median (up to that sample), and dashed lines show the cumulative 0.05 and 0.95 quantiles. Red circles are the MPD estimates.

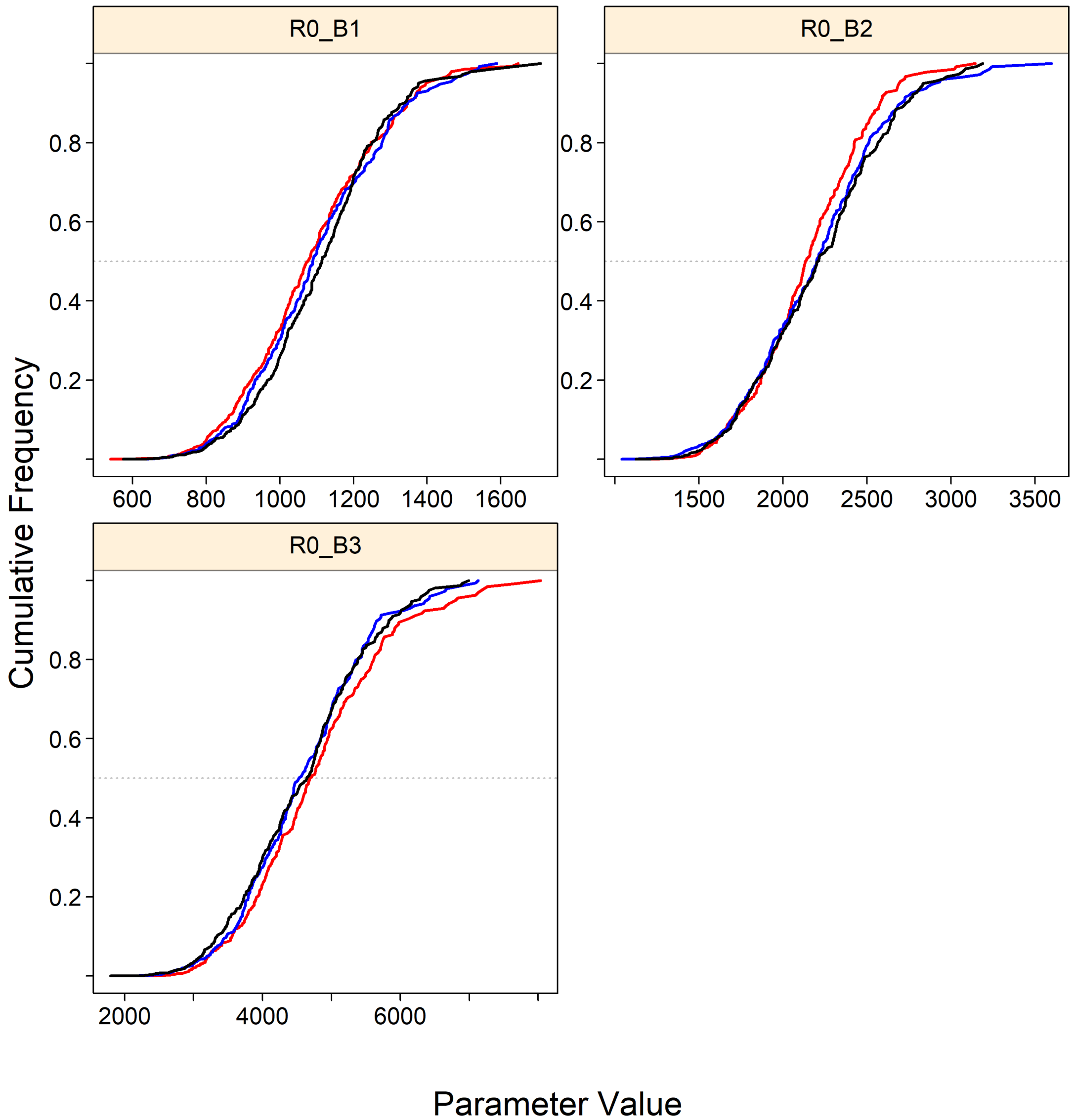


Figure 8. Component base: diagnostic plots obtained by dividing the R_0 MCMC chains of 1000 MCMC samples into three segments, and overplotting the cumulative distributions of the first segment (red), second segment (blue) and final segment (black).

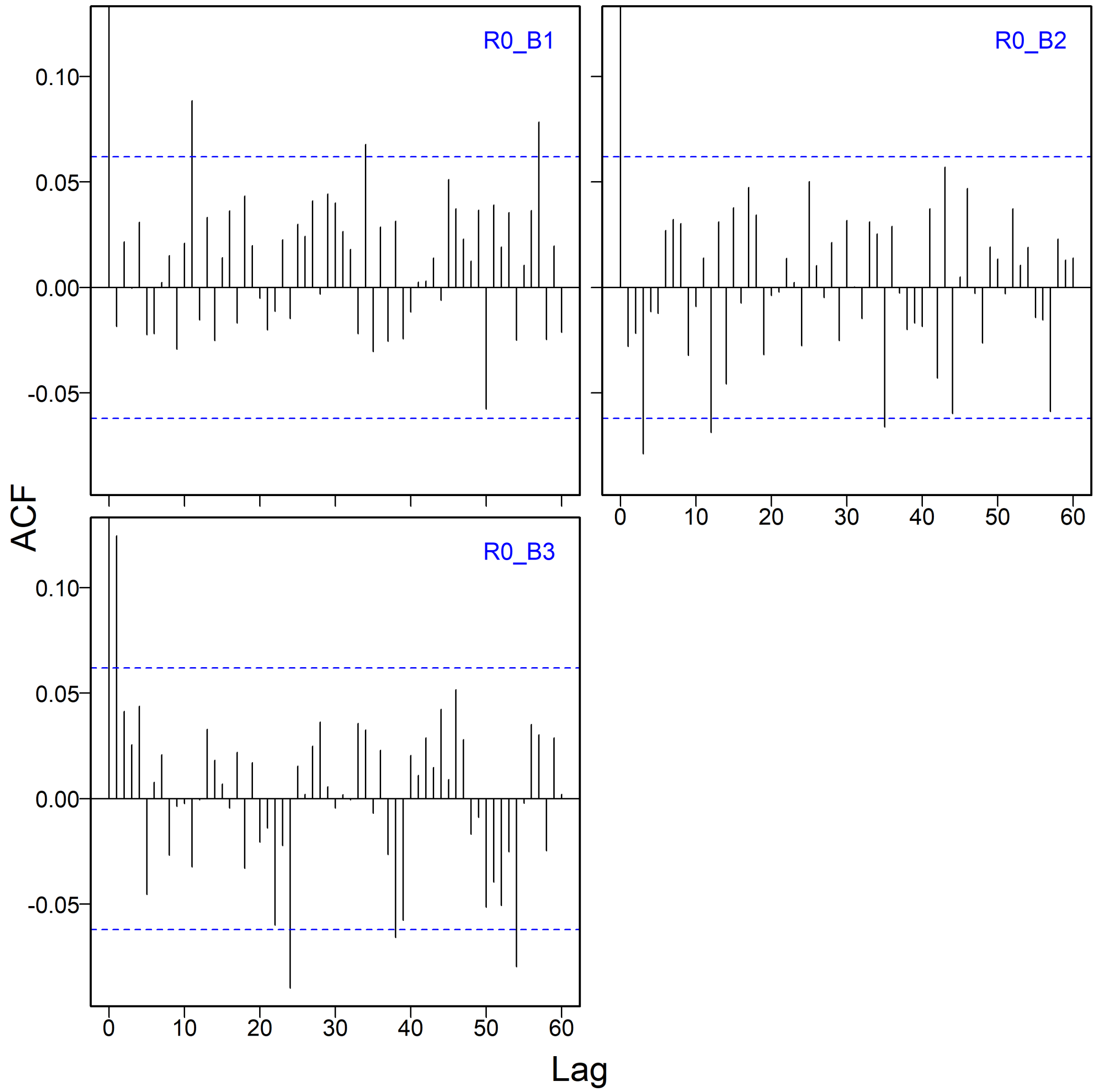


Figure 9. Component base: autocorrelation plots for the component base R_0 parameters from the MCMC output. Horizontal dashed blue lines delimit the 95% confidence interval for each parameter's set of lagged correlations.

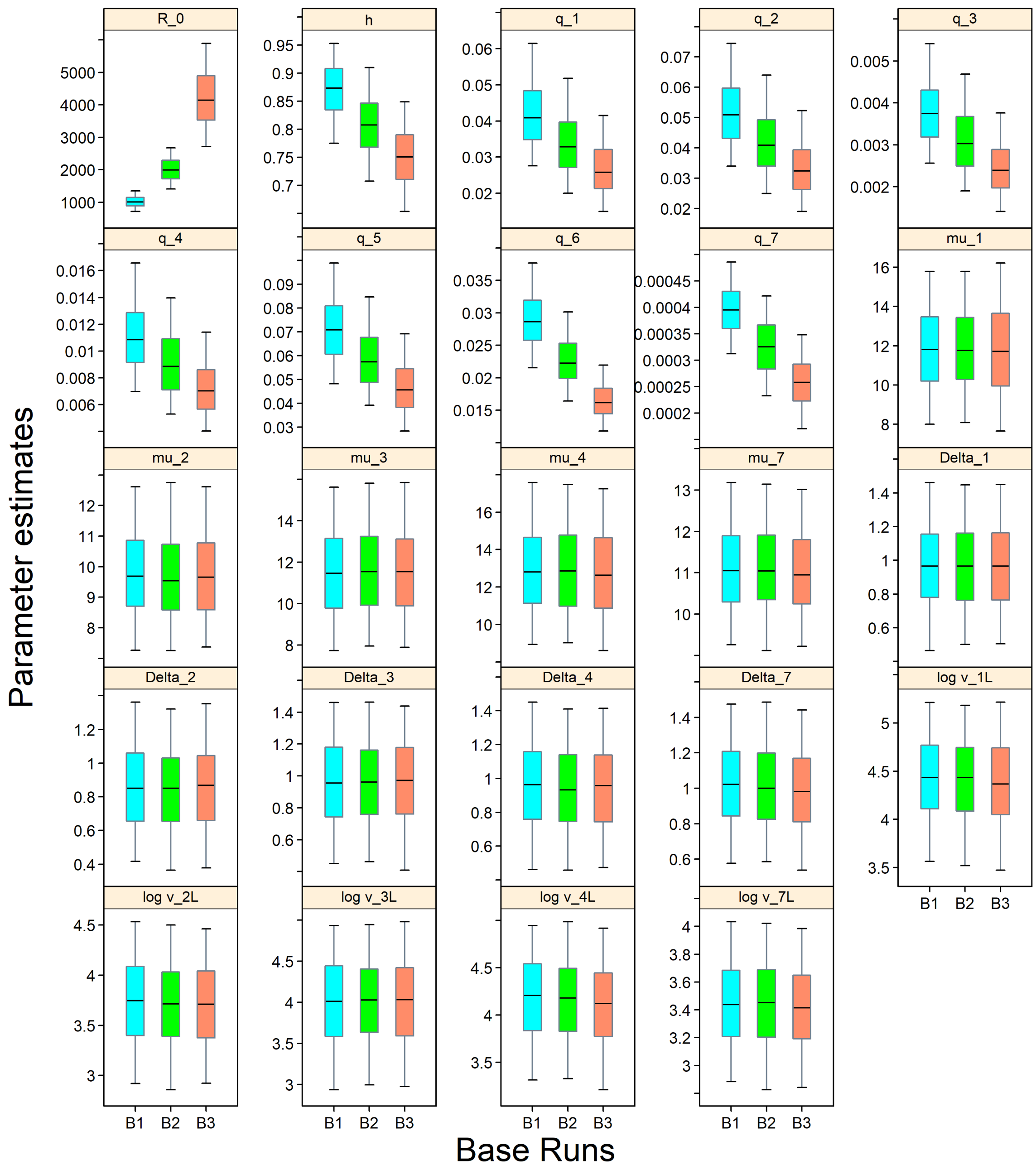


Figure 10. Component base: quantile plots of the parameter estimates from three component runs of the base case, where blue boxes denote M=0.07, green boxes denote M=0.08, red boxes denote M=0.09. The boxplots delimit the 0.05, 0.25, 0.5, 0.75, and 0.95 quantiles.

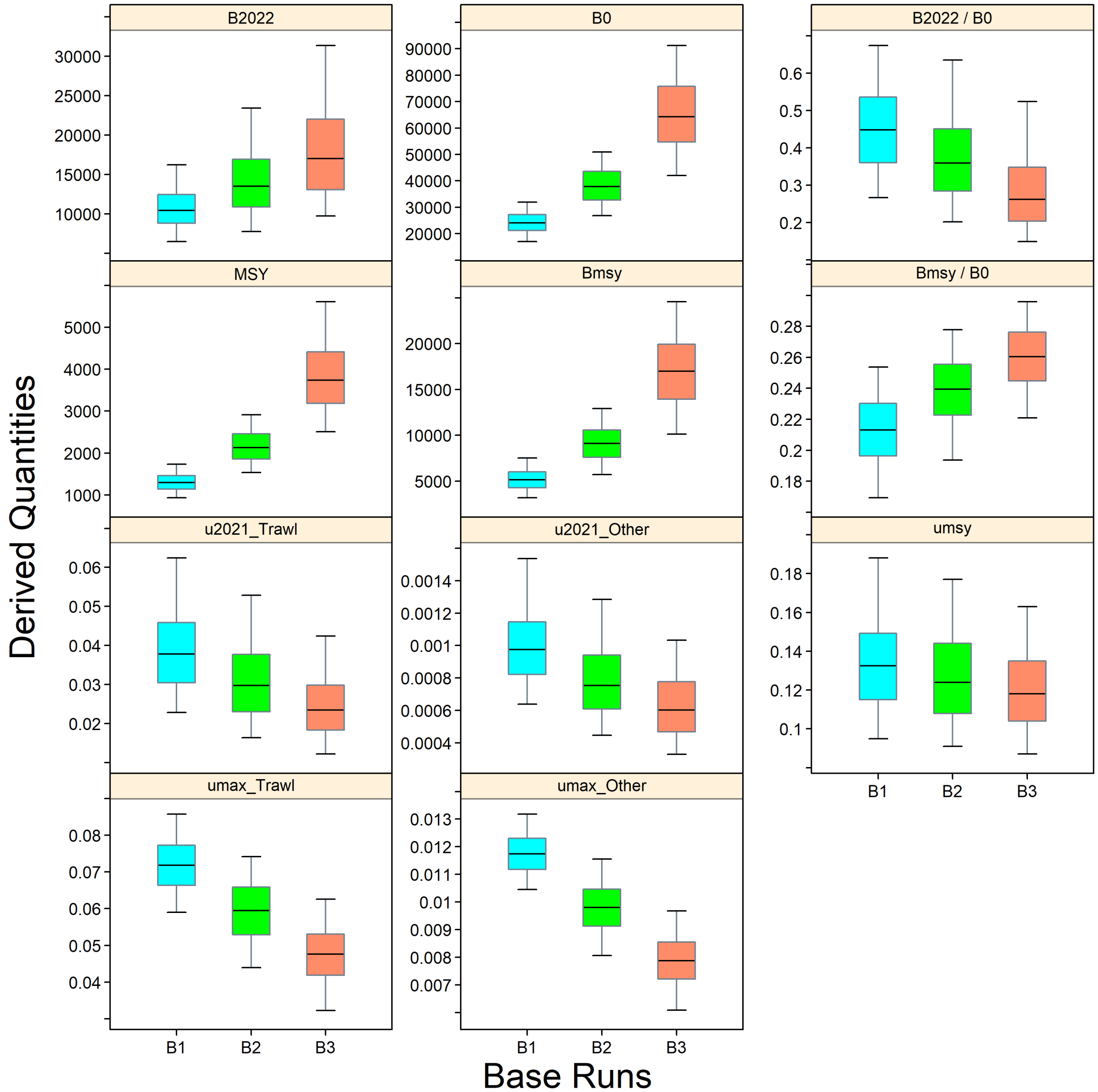


Figure 11. Component base: quantile plots of selected derived quantities (B_{2022}, B_0, B_{2022}/B_0, MSY, B_{MSY}, B_{MSY}/B_0, u_{2021}, u_{MSY}, u_{max}) from three component runs of the base case, where blue boxes denote M=0.07, green boxes denote M=0.08, red boxes denote M=0.09. The boxplots delimit the 0.05, 0.25, 0.5, 0.75, and 0.95 quantiles.

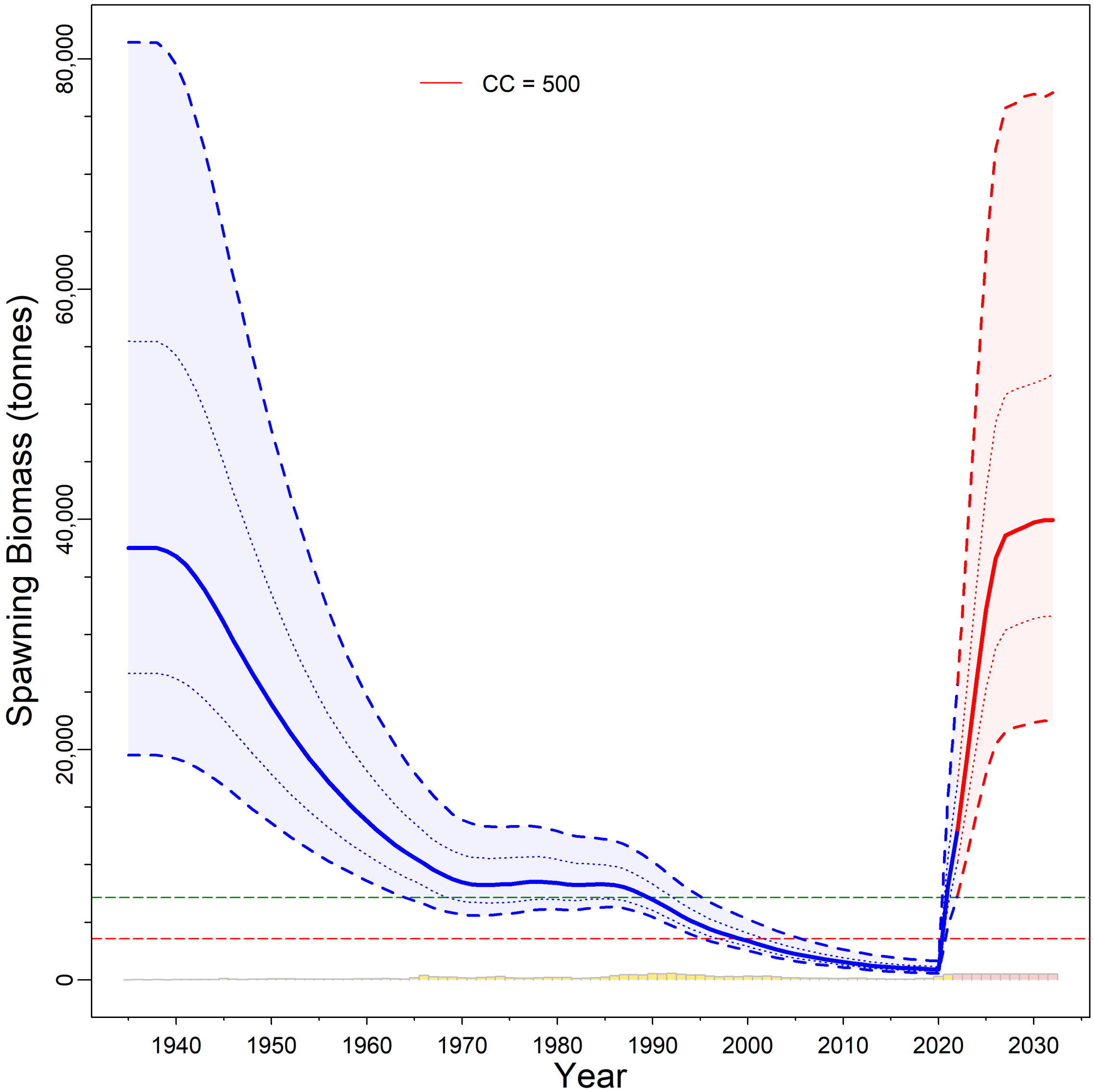
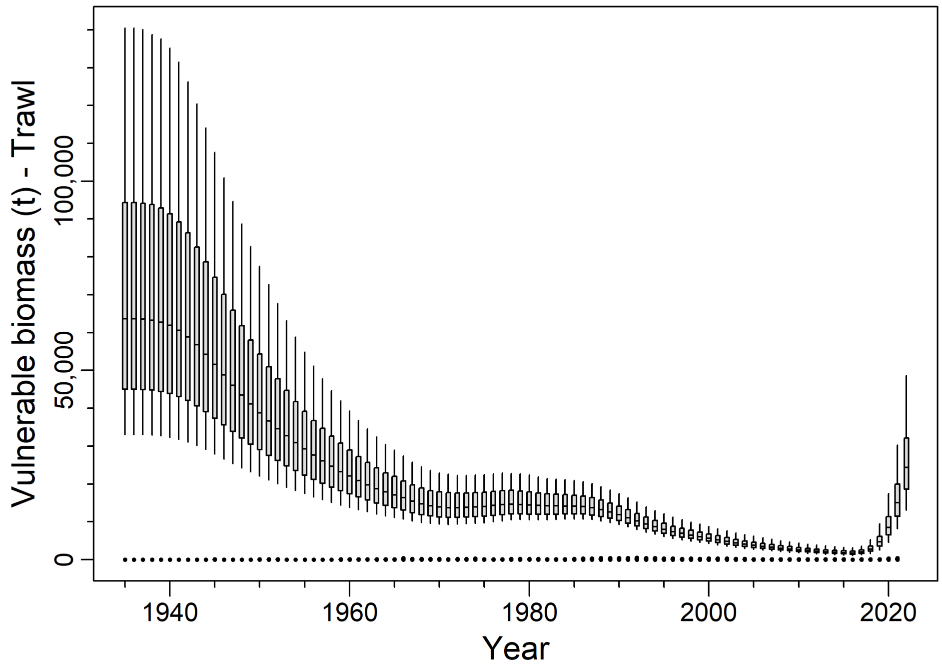


Figure 12. Composite base: estimates of spawning biomass B_t (tonnes) from pooled model posteriors. The median biomass trajectory appears as a solid curve surrounded by a 90% credibility envelope (quantiles: 0.05-0.95) in light blue and delimited by dashed lines for years t=1935:2022; projected biomass appears in light red for years t=2023:2032. Also delimited is the 50% credibility interval (quantiles: 0.25-0.75) delimited by dotted lines. The horizontal dashed lines show the median LRP and USR. Catches are represented as bars along the bottom axis and assumed catch policy appears in the legend, where CC = constant catch (t/y).



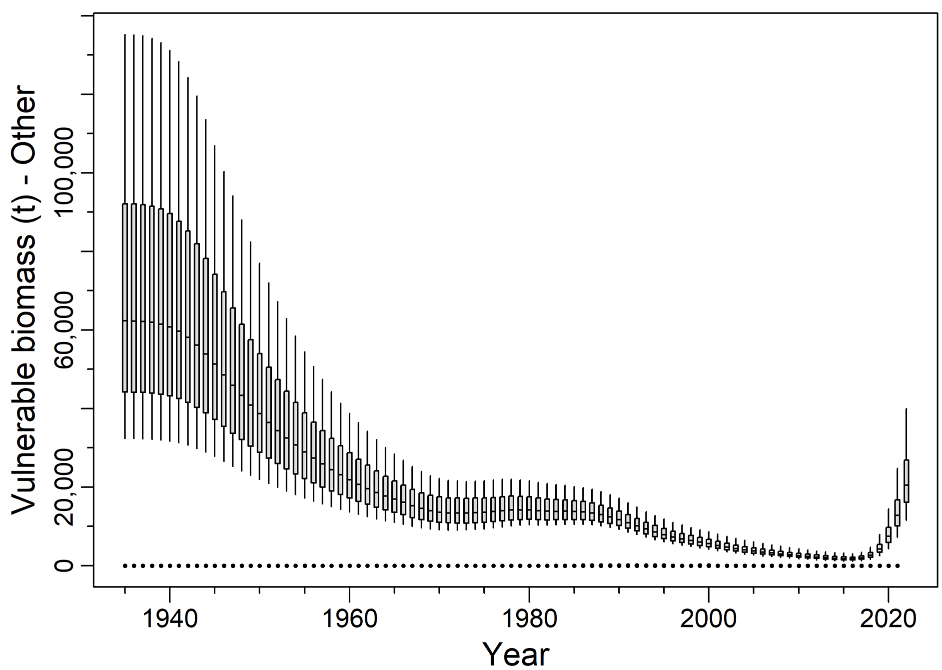
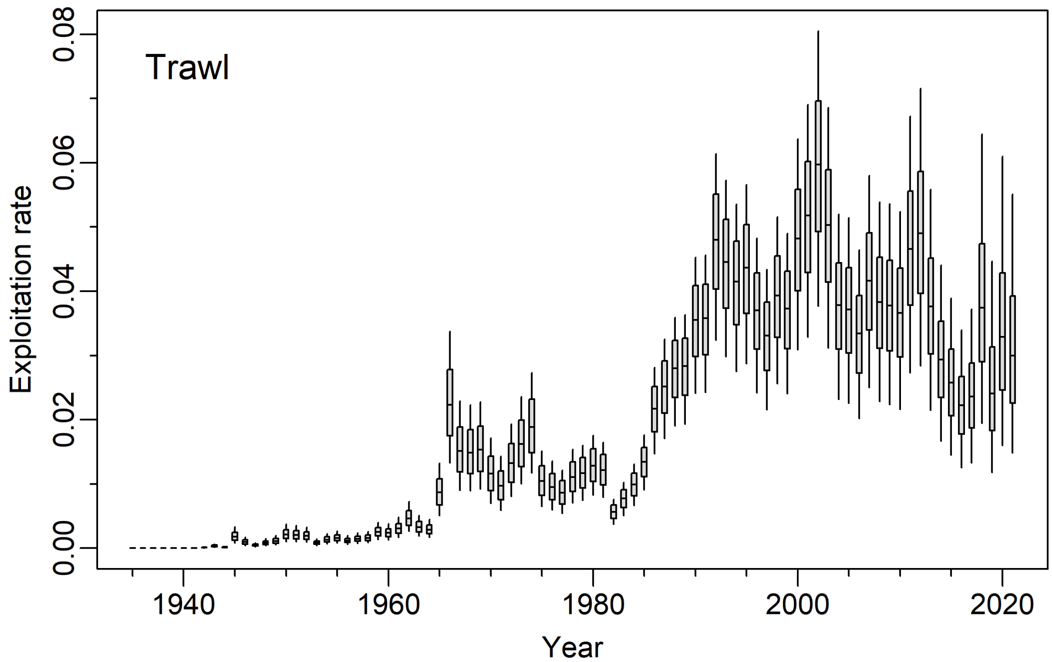


Figure 13. Composite base: estimated vulnerable biomass trajectory for two fisheries (boxplots) and commercial catch history (vertical bars), in tonnes. Boxplots show the 0.05, 0.25, 0.5, 0.75, and 0.95 quantiles from the MCMC results.



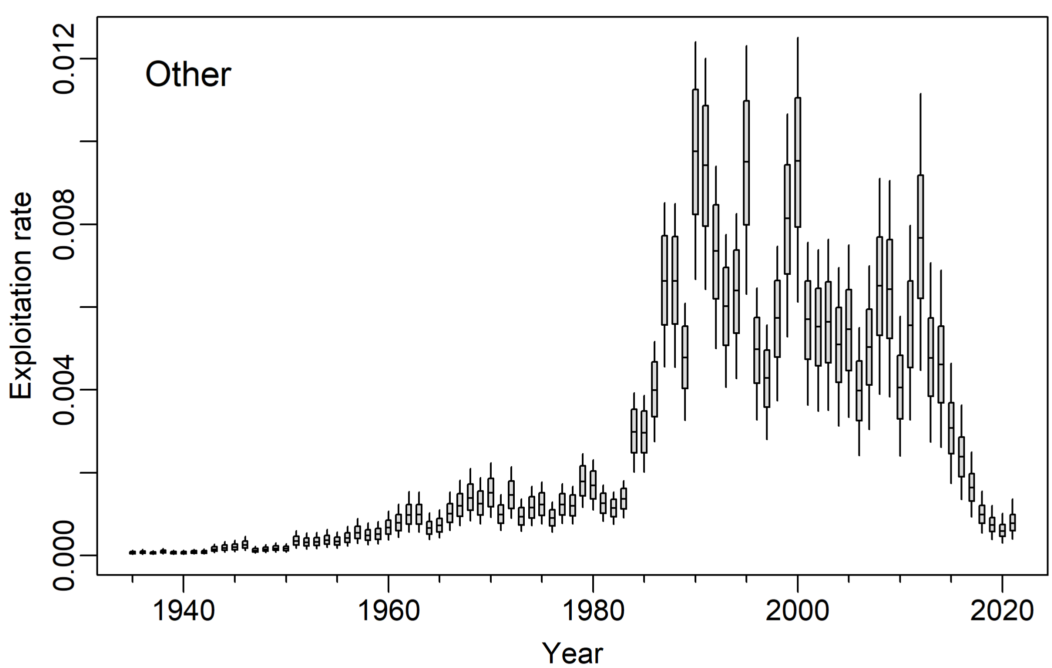


Figure 14. Composite base: marginal posterior distribution of exploitation rate trajectory for two fisheries. Boxplots show the 0.05, 0.25, 0.5, 0.75, and 0.95 quantiles from the MCMC results.

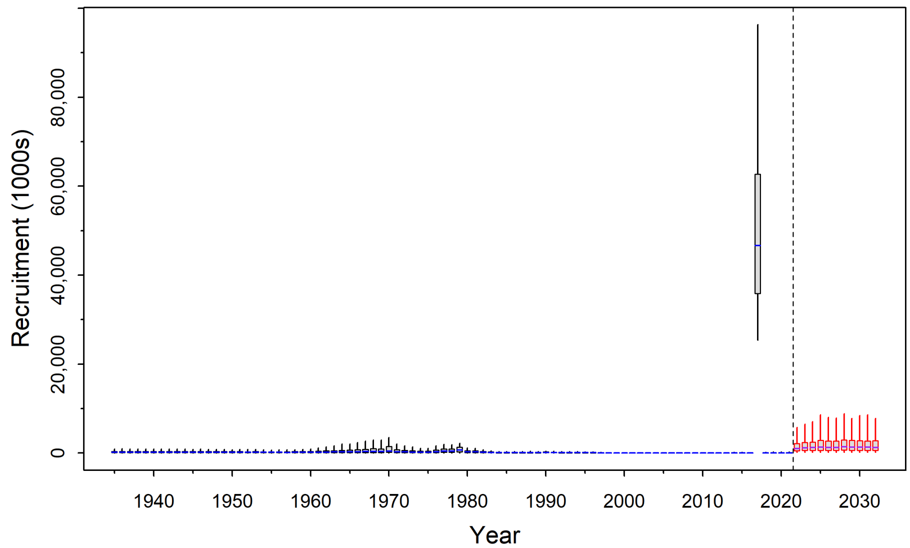


Figure 15. Composite base: marginal posterior distribution of recruitment trajectory (reconstructed: 1935-2022, projected: 2023-2032) in 1,000s of age-1 fish.

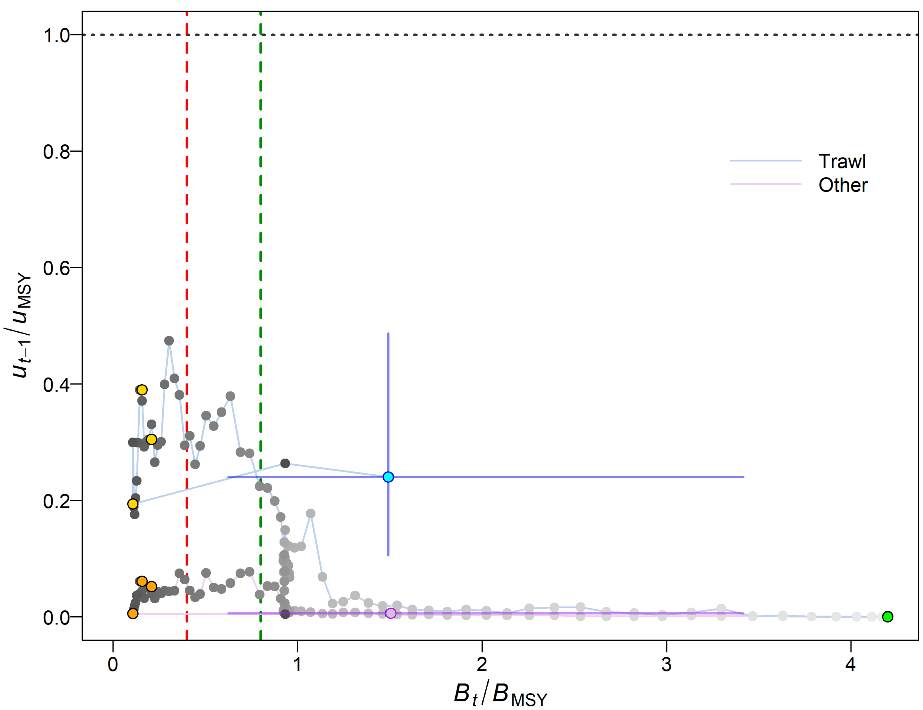


Figure 16. Composite base: phase plot through time of the medians of the ratios B_t/B_{MSY} (the spawning biomass in year t relative to B_{MSY}) and u_{t-1}/u_{MSY} (the exploitation rate in year $t-1$ relative to u_{MSY}) for two fisheries (trawl/other). The filled green circle is the starting year (1935). Years then proceed along lines gradually darkening from light blue/purple, with the final year end (2021) as a filled cyan/purple circle, and the blue/purple cross lines represent the 0.05 and 0.95 quantiles of the posterior distributions for the final year. Previous assessment years (2008, 2012, 2019) are indicated by gold/orange circles. Red and green vertical dashed lines indicate the precautionary approach limit and upper stock reference points (0.4, 0.8 B_{MSY}), and the horizontal grey dotted line indicates u at MSY.

Comparison with Previous Assessment

This updated stock assessment for Bocaccio in 2021 appeared to be even more optimistic than the assessment conducted in 2019 with respect to the recovery of the stock. A comparison of the 2019 and 2021 composite spawning biomass depletion trajectories (Figure 17) showed somewhat greater depletion over the trajectory time period but 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 two stock assessments, indicating that there is good agreement between the two analyses. The 2019 stock assessment appeared to have underestimated the recovery compared to this 2021 update, with both the 2021 and 2022 biomass estimates elevated compared to the equivalent 2019 projections, even though actual catches exceeded the projected catches. This was likely because this updated assessment has estimated an even larger 2016 cohort than did the 2019 stock assessment (indicated by age-1 fish in 2017, Figure 18): R_{2017} = 47 (25, 96) million age-1 fish vs. 25 (12, 59) million age-1 fish in the 2019 stock assessment. Previously, the BOR stock assessment projected that the median 2022 spawning biomass would lie on the boundary of the Cautious and Healthy zones (at $0.8B_{\text{MSY}}$), assuming a projected catch of 200 t/y, but this updated B_{2022}/B_{MSY} estimate places the stock firmly in the Healthy zone (Figure 19).

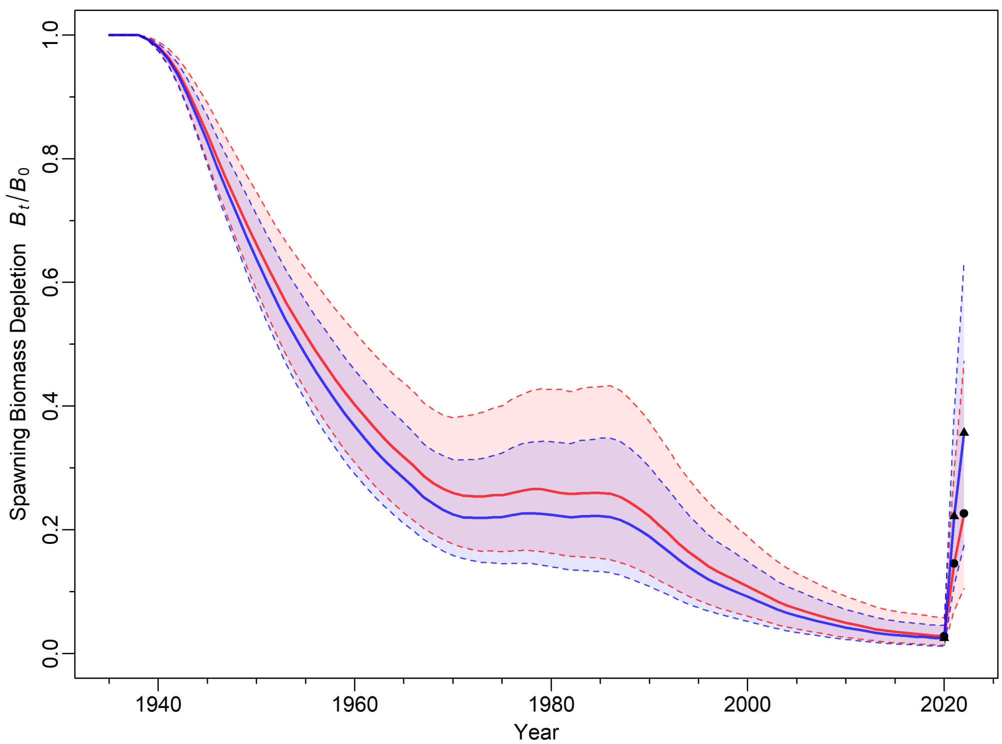


Figure 17. Composite base: comparison of MCMC estimates of spawning stock depletion (B_t/B_0) from the current (2021) stock assessment update (blue) to that estimated in the 2019 stock assessment (red). The final three model years (start year 2020 to start year 2022) are shown as triangles for the update (all model trajectories) and circles for the previous assessment (final two years were projections using a catch policy of 200 t/y). The credibility envelopes (dashed lines) delimit the 0.05 and 0.95 quantiles.

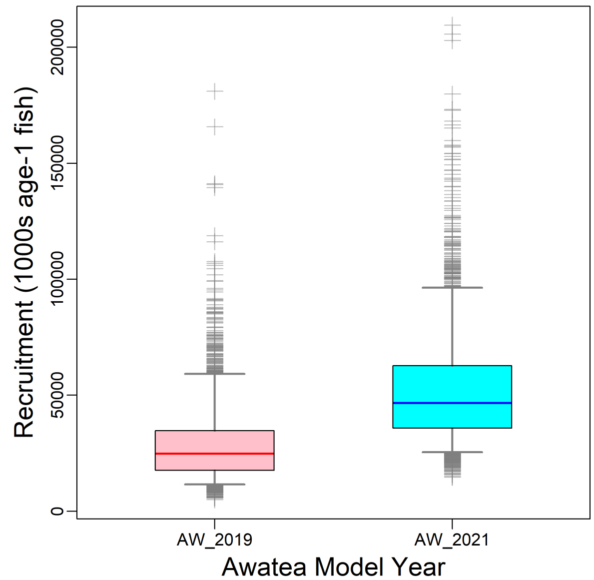


Figure 18. Composite base: comparison of MCMC recruitment estimates for age-1 fish in 2017 from the Awatea fits in 2019 (red) and 2021 (blue).

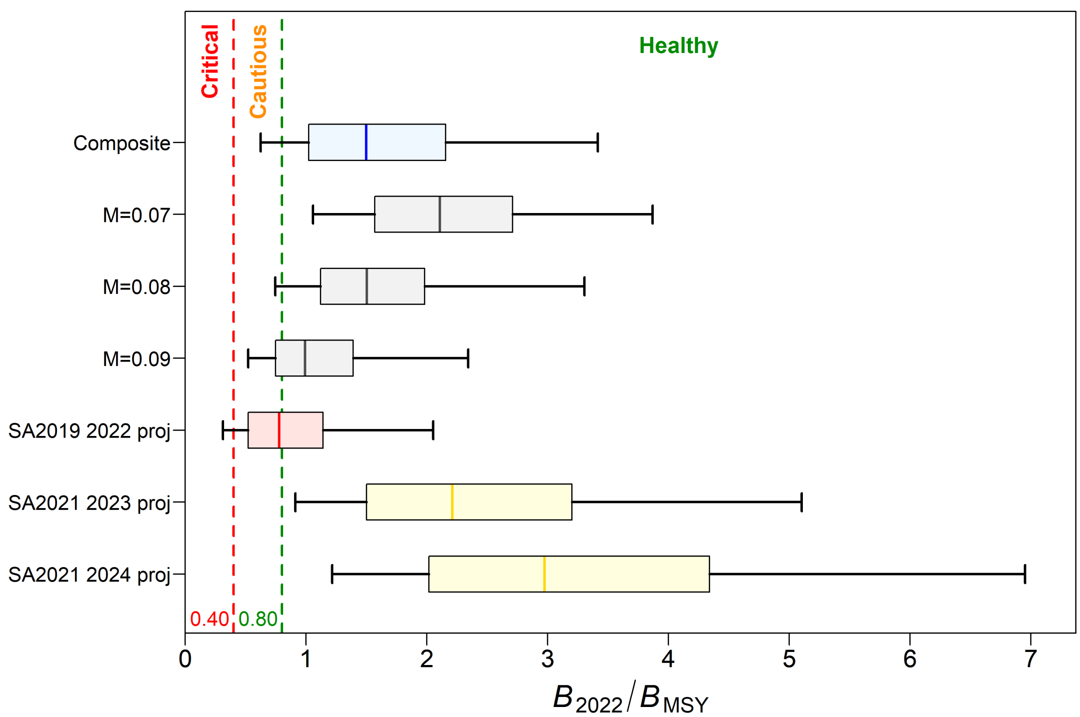


Figure 19. Composite base: status at beginning of 2022 of the Bocaccio stock relative to the PA reference points of 0.4B_{MSY} and 0.8B_{MSY} for a base case comprising three model runs. The top quantile plot shows the composite distribution and below are the three contributing runs. Also shown are projected stock status for the composite base case in the 2019 stock assessment (red, assuming constant catch = 200 t/y) and for the current composite base case at the beginning of 2023 and 2024 (yellow, constant catch = 500 t/y). 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 extracting samples from the composite posterior that corresponded to the lowest 5th percentile of the age-1 recruitment estimates for R_{2017} in order to test the robustness of the projected rebuild by using the least productive component of the posterior distribution. This resulted in 150 samples: 118 samples from run B1 (M=0.07), 29 samples from run B2 (M=0.08), and three samples from run B3 (M=0.09). The reduced set of posterior samples reduced the R_{2017} median estimate to 23 (17, 25) million recruits from 47 (25, 96) million using the full posterior, a drop of over one-half of the expected recruitments (see upper panel, Figure 20). When this subset of the posterior distribution was projected forward at 500 t/y constant catch (lower panel, Figure 20), the rebuild was only delayed by one year, with more than 90% of the distribution of B_{2023}/B_{MSY} lying in the Healthy zone at the beginning of 2023.

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 of potential data. 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.

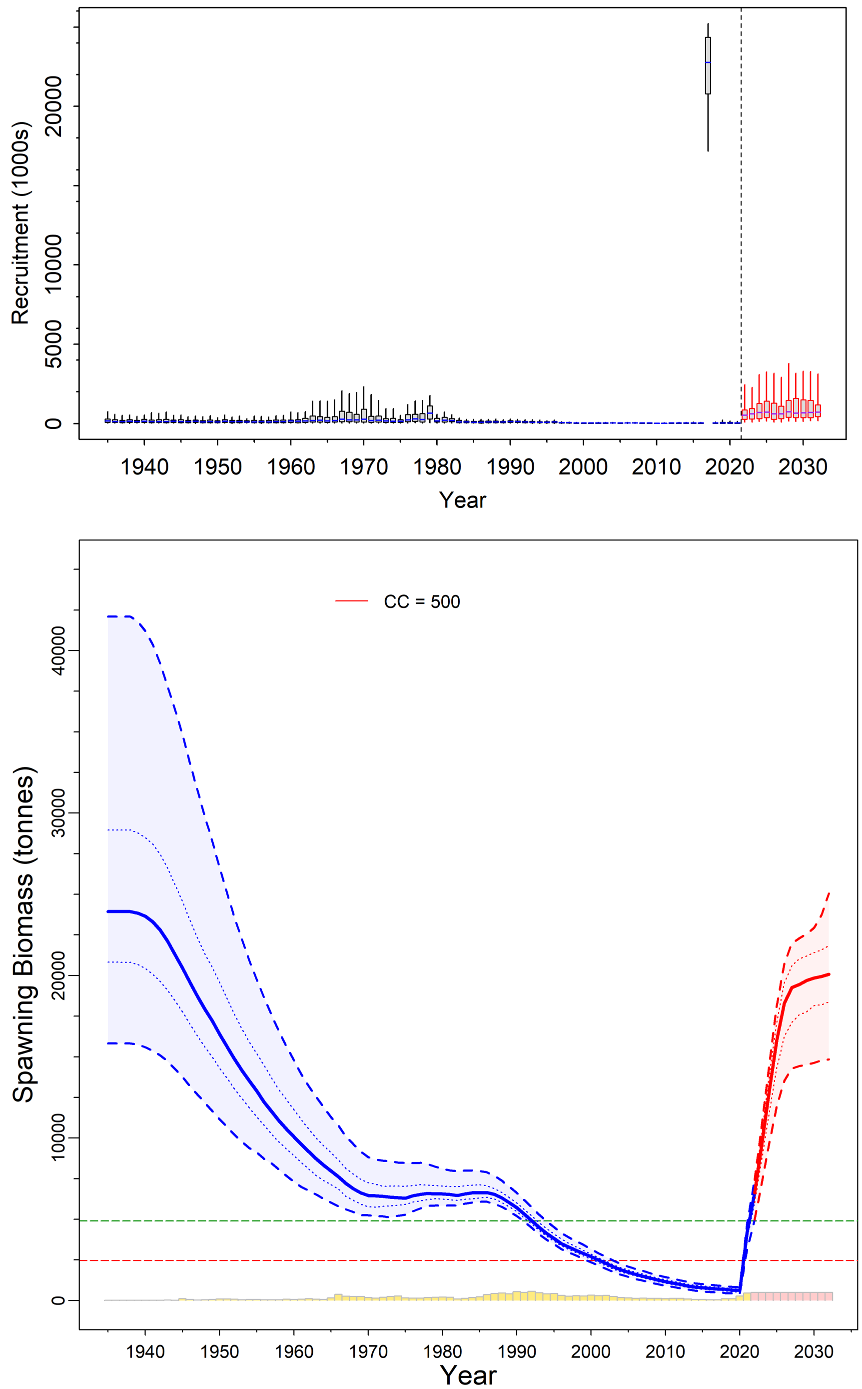


Figure 20. Low recruitment extraction: (top) marginal posterior distribution of recruitment trajectory in 1,000s of age-1 fish (see Figure 15 caption for further details); (bottom) estimates of spawning biomass B_t (tonnes) from 150 of the pooled model posteriors that represent the samples with the lowest 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 ($t = 2022, ..., 2032$) 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 ($\sim$mid-year). To interpret the decision tables with respect to DFO's LRP ($0.4B_{\text{MSY}}$) and USR ($0.8B_{\text{MSY}}$), 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 4 – probability of B_t exceeding the LRP: P$(B_t > 0.4B_{\text{MSY}})$;
- Table 5 – probability of B_t exceeding the USR: P$(B_t > 0.8B_{\text{MSY}})$;
- Table 6 – probability of B_t exceeding biomass at MSY: P$(B_t > B_{\text{MSY}})$;
- Table 7 – probability of u_t falling below harvest rate at MSY: P$(u_t < u_{\text{MSY}})$;
- Table 8 – probability of B_t exceeding current-year biomass: P$(B_t > B_{2022})$;
- Table 9 – probability of u_t falling below current-year harvest rate: P$(u_t < u_{2021})$;
- Table 10 – probability of B_t exceeding a non-DFO 'soft limit': P$(B_t > 0.2B_0)$;
- Table 11 – probability of B_t exceeding a non-DFO 'target' biomass: P$(B_t > 0.4B_0)$.

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. Additionally, results are provided comparing projected biomass to B_{MSY} and to current spawning biomass B_{2022}, and comparing projected harvest rate to current harvest rate u_{2021}.

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 YMR 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 12 – probability of B_t exceeding 'Endangered' status: (P$(B_t > 0.5B_0)$);
- Table 13 – probability of B_t exceeding 'Threatened' status: (P$(B_t > 0.7B_0)$).

Table 4. 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 3000 MCMC samples for which $B_t > 0.4B_{MSY}$. For reference, the average catch over the last 5 years (2017-2021) was 204 t.

CC	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
0	>0.99	1	1	1	1	1	1	1	1	1	1
100	>0.99	1	1	1	1	1	1	1	1	1	1
200	>0.99	1	1	1	1	1	1	1	1	1	1
300	>0.99	1	1	1	1	1	1	1	1	1	1
400	>0.99	1	1	1	1	1	1	1	1	1	1
500	>0.99	1	1	1	1	1	1	1	1	1	1
600	>0.99	1	1	1	1	1	1	1	1	1	1
700	>0.99	1	1	1	1	1	1	1	1	1	1
800	>0.99	1	1	1	1	1	1	1	1	1	1
900	>0.99	1	1	1	1	1	1	1	1	1	1
1000	>0.99	1	1	1	1	1	1	1	1	1	1
1200	>0.99	1	1	1	1	1	1	1	1	1	1
1400	>0.99	1	1	1	1	1	1	1	1	1	1
1600	>0.99	1	1	1	1	1	1	1	1	1	1
1800	>0.99	1	1	1	1	1	1	1	1	1	1
2000	>0.99	1	1	1	1	1	1	1	1	1	1

Table 5. 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 (2017-2021) was 204 t.

CC	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
0	0.87	0.98	>0.99	>0.99	1	1	1	1	1	1	1
100	0.87	0.98	>0.99	>0.99	1	1	1	1	1	1	1
200	0.87	0.98	>0.99	>0.99	1	1	1	1	1	1	1
300	0.87	0.98	>0.99	>0.99	1	1	1	1	1	1	1
400	0.87	0.97	>0.99	>0.99	1	1	1	1	1	1	1
500	0.87	0.97	>0.99	>0.99	1	1	1	1	1	1	1
600	0.87	0.97	>0.99	>0.99	1	1	1	1	1	1	1
700	0.87	0.97	>0.99	>0.99	1	1	1	1	1	1	1
800	0.87	0.97	>0.99	>0.99	1	1	1	1	1	1	1
900	0.87	0.97	>0.99	>0.99	1	1	1	1	1	1	1
1000	0.87	0.97	>0.99	>0.99	1	1	1	1	1	1	1
1200	0.87	0.97	0.99	>0.99	>0.99	1	1	>0.99	1	>0.99	1
1400	0.87	0.97	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	1
1600	0.87	0.97	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
1800	0.87	0.97	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
2000	0.87	0.97	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99

Table 6. Decision table (BC Coast) concerning the reference point B_{MSY} for 1-10-year projections-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 (2017-2021) was 204 t.

CC	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
0	0.76	0.93	0.98	>0.99	>0.99	>0.99	>0.99	>0.99	1	1	1
100	0.76	0.93	0.98	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	1	1
200	0.76	0.93	0.98	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	1	1
300	0.76	0.93	0.98	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	1
400	0.76	0.93	0.98	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	1
500	0.76	0.93	0.98	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	1
600	0.76	0.93	0.98	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
700	0.76	0.93	0.98	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
800	0.76	0.92	0.98	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
900	0.76	0.92	0.98	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
1000	0.76	0.92	0.98	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
1200	0.76	0.92	0.98	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
1400	0.76	0.92	0.98	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
1600	0.76	0.92	0.98	0.99	>0.99	>0.99	0.99	0.99	0.99	0.99	>0.99
1800	0.76	0.92	0.97	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
2000	0.76	0.92	0.97	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99

Table 7. 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 (2017-2021) was 204 t.

CC	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
0	1	1	1	1	1	1	1	1	1	1	1
100	1	1	1	1	1	1	1	1	1	1	1
200	1	1	1	1	1	1	1	1	1	1	1
300	1	1	1	1	1	1	1	1	1	1	1
400	1	1	1	1	1	1	1	1	1	1	1
500	1	1	1	1	1	1	1	1	1	1	1
600	1	1	1	1	1	1	1	1	1	1	1
700	>0.99	1	1	1	1	1	1	1	1	1	1
800	>0.99	1	1	1	1	1	1	1	1	1	1
900	>0.99	1	1	1	1	1	1	1	1	1	1
1000	0.99	>0.99	1	1	1	1	1	1	1	1	1
1200	0.98	>0.99	1	1	1	1	1	1	1	1	>0.99
1400	0.96	0.99	>0.99	1	1	1	1	>0.99	>0.99	>0.99	>0.99
1600	0.92	0.98	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
1800	0.88	0.97	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	0.99	0.99	0.99
2000	0.82	0.95	0.98	0.99	0.99	0.99	0.99	0.99	0.99	0.98	0.98

Table 8. Decision table (BC Coast) comparing the projected biomass to current biomass for a range of constant catch strategies, given by probabilities P($B_t > B_{2022}$). For reference, the average catch over the last 5 years (2017-2021) was 204 t.

CC	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
0	0	1	1	1	1	1	1	1	1	1	1
100	0	1	1	1	1	1	1	1	1	1	1
200	0	1	1	1	1	1	1	1	1	1	1
300	0	1	1	1	1	1	1	1	1	1	1
400	0	1	1	1	1	1	1	1	1	1	1
500	0	1	1	1	1	1	1	1	1	1	1
600	0	1	1	1	1	1	1	1	1	1	1
700	0	1	1	1	1	1	1	1	1	1	1
800	0	1	1	1	1	1	1	1	1	1	1
900	0	1	1	1	1	1	1	1	1	1	1
1000	0	1	1	1	1	1	1	1	1	1	1
1200	0	1	1	1	1	1	1	1	1	1	1
1400	0	1	1	1	1	1	1	1	1	1	1
1600	0	1	1	1	1	1	1	1	1	1	1
1800	0	1	1	1	1	1	1	1	1	1	>0.99
2000	0	1	1	1	1	1	1	1	1	>0.99	>0.99

Table 9. Decision table (BC Coast) comparing the projected exploitation rate to that in 2021 for a range of constant catch strategies, such that values are P($u_t < u_{2021}$). For reference, the average catch over the last 5 years (2017-2021) was 204 t.

CC	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
0	1	1	1	1	1	1	1	1	1	1	1
100	1	1	1	1	1	1	1	1	1	1	1
200	1	1	1	1	1	1	1	1	1	1	1
300	1	1	1	1	1	1	1	1	1	1	1
400	1	1	1	1	1	1	1	1	1	1	1
500	1	1	1	1	1	1	1	1	1	1	1
600	0.99	1	1	1	1	1	1	1	1	1	1
700	0.41	1	1	1	1	1	1	1	1	1	1
800	0.03	0.98	1	1	1	1	1	1	1	1	1
900	0	0.80	>0.99	1	1	1	1	1	1	1	1
1000	0	0.51	0.97	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
1200	0	0.09	0.73	0.94	0.98	0.99	0.99	0.99	0.98	0.97	0.97
1400	0	<0.01	0.37	0.76	0.88	0.91	0.91	0.90	0.88	0.86	0.84
1600	0	0	0.13	0.48	0.68	0.74	0.74	0.72	0.69	0.66	0.63
1800	0	0	0.03	0.26	0.46	0.54	0.53	0.50	0.45	0.42	0.39
2000	0	0	0.01	0.11	0.26	0.34	0.34	0.30	0.27	0.24	0.22

Table 10. 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 (2017-2021) was 204 t.

CC	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
0	0.90	0.99	>0.99	1	1	1	1	1	1	1	1
100	0.90	0.99	>0.99	1	1	1	1	1	1	1	1
200	0.90	0.99	>0.99	1	1	1	1	1	1	1	1
300	0.90	0.99	>0.99	1	1	1	1	1	1	1	1
400	0.90	0.99	>0.99	1	1	1	1	1	1	1	1
500	0.90	0.99	>0.99	1	1	1	1	1	1	1	1
600	0.90	0.99	>0.99	1	1	1	1	1	1	1	1
700	0.90	0.99	>0.99	1	1	1	1	1	1	1	1
800	0.90	0.99	>0.99	1	1	1	1	1	1	1	1
900	0.90	0.99	>0.99	1	1	1	1	1	1	1	1
1000	0.90	0.99	>0.99	1	1	1	1	1	1	1	1
1200	0.90	0.99	>0.99	1	1	1	1	1	1	1	1
1400	0.90	0.99	>0.99	1	1	1	1	1	1	1	1
1600	0.90	0.98	>0.99	1	1	1	1	1	1	1	1
1800	0.90	0.98	>0.99	>0.99	1	1	1	1	1	1	>0.99
2000	0.90	0.98	>0.99	>0.99	1	1	1	>0.99	>0.99	>0.99	>0.99

Table 11. 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 (2017-2021) was 204 t.

CC	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
0	0.40	0.74	0.90	0.96	0.99	0.99	0.99	0.99	>0.99	>0.99	>0.99
100	0.40	0.74	0.90	0.96	0.98	0.99	0.99	0.99	0.99	>0.99	>0.99
200	0.40	0.73	0.90	0.96	0.98	0.99	0.99	0.99	0.99	>0.99	>0.99
300	0.40	0.73	0.90	0.96	0.98	0.99	0.99	0.99	0.99	0.99	>0.99
400	0.40	0.73	0.90	0.96	0.98	0.99	0.99	0.99	0.99	0.99	>0.99
500	0.40	0.73	0.90	0.96	0.98	0.99	0.99	0.99	0.99	0.99	0.99
600	0.40	0.73	0.89	0.96	0.98	0.99	0.99	0.99	0.99	0.99	0.99
700	0.40	0.73	0.89	0.96	0.98	0.98	0.98	0.99	0.99	0.99	0.99
800	0.40	0.73	0.89	0.95	0.98	0.98	0.98	0.98	0.98	0.99	0.99
900	0.40	0.72	0.89	0.95	0.98	0.98	0.98	0.98	0.98	0.99	0.99
1000	0.40	0.72	0.88	0.95	0.97	0.98	0.98	0.98	0.98	0.98	0.99
1200	0.40	0.72	0.88	0.95	0.97	0.98	0.98	0.98	0.98	0.98	0.98
1400	0.40	0.71	0.87	0.95	0.97	0.97	0.97	0.97	0.97	0.98	0.98
1600	0.40	0.71	0.87	0.94	0.96	0.97	0.97	0.97	0.96	0.96	0.97
1800	0.40	0.71	0.87	0.94	0.96	0.96	0.96	0.96	0.96	0.96	0.96
2000	0.40	0.70	0.87	0.93	0.96	0.96	0.95	0.95	0.95	0.94	0.94

Table 12. 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 (2017-2021) was 204 t.

CC	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
0	0.19	0.56	0.79	0.90	0.95	0.96	0.96	0.97	0.97	0.98	0.98
100	0.19	0.56	0.79	0.90	0.95	0.96	0.96	0.97	0.97	0.98	0.98
200	0.19	0.55	0.78	0.90	0.94	0.95	0.96	0.96	0.97	0.97	0.98
300	0.19	0.55	0.78	0.89	0.94	0.95	0.96	0.96	0.97	0.97	0.98
400	0.19	0.55	0.78	0.89	0.94	0.95	0.95	0.96	0.96	0.97	0.97
500	0.19	0.55	0.78	0.88	0.94	0.95	0.95	0.96	0.96	0.96	0.97
600	0.19	0.55	0.78	0.88	0.93	0.94	0.95	0.95	0.96	0.96	0.97
700	0.19	0.54	0.78	0.88	0.93	0.94	0.95	0.95	0.95	0.96	0.96
800	0.19	0.54	0.77	0.88	0.93	0.94	0.94	0.95	0.95	0.95	0.96
900	0.19	0.54	0.77	0.88	0.92	0.94	0.94	0.94	0.95	0.95	0.95
1000	0.19	0.54	0.77	0.87	0.92	0.94	0.94	0.94	0.94	0.94	0.95
1200	0.19	0.53	0.76	0.87	0.91	0.93	0.93	0.93	0.93	0.93	0.94
1400	0.19	0.53	0.75	0.86	0.90	0.92	0.92	0.92	0.92	0.92	0.92
1600	0.19	0.53	0.75	0.86	0.90	0.91	0.91	0.91	0.91	0.91	0.91
1800	0.19	0.52	0.74	0.85	0.89	0.90	0.90	0.90	0.89	0.89	0.89
2000	0.19	0.52	0.73	0.84	0.88	0.89	0.89	0.88	0.88	0.88	0.87

Table 13. 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 (2017-2021) was 204 t.

CC	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
0	0.02	0.25	0.53	0.71	0.80	0.83	0.84	0.85	0.86	0.87	0.88
100	0.02	0.25	0.53	0.70	0.79	0.83	0.84	0.84	0.86	0.86	0.87
200	0.02	0.25	0.53	0.70	0.79	0.82	0.83	0.84	0.85	0.86	0.87
300	0.02	0.24	0.52	0.70	0.78	0.82	0.83	0.83	0.84	0.85	0.86
400	0.02	0.24	0.52	0.69	0.78	0.81	0.82	0.83	0.83	0.84	0.85
500	0.02	0.24	0.52	0.69	0.78	0.81	0.82	0.82	0.83	0.84	0.84
600	0.02	0.24	0.51	0.68	0.77	0.80	0.81	0.81	0.82	0.83	0.83
700	0.02	0.24	0.51	0.68	0.77	0.79	0.80	0.81	0.81	0.82	0.83
800	0.02	0.24	0.50	0.67	0.76	0.79	0.79	0.80	0.80	0.81	0.82
900	0.02	0.24	0.50	0.67	0.76	0.78	0.79	0.79	0.80	0.80	0.81
1000	0.02	0.23	0.50	0.66	0.75	0.78	0.78	0.78	0.79	0.79	0.80
1200	0.02	0.23	0.49	0.66	0.74	0.77	0.76	0.77	0.77	0.77	0.78
1400	0.02	0.23	0.48	0.65	0.73	0.75	0.75	0.75	0.75	0.76	0.75
1600	0.02	0.23	0.47	0.64	0.72	0.74	0.74	0.74	0.74	0.73	0.73
1800	0.02	0.22	0.47	0.63	0.71	0.73	0.72	0.71	0.71	0.71	0.70
2000	0.02	0.22	0.46	0.62	0.70	0.71	0.70	0.70	0.69	0.68	0.67

Conclusion

While the estimated size of the 2016 year class seems unprecedented, particularly because it was spawned by a stock at a very low level of mature females, this is the response demanded by the data given the consistent increase in the four survey estimates (Figure 3) attributable entirely to this cohort (Figures 4–6). There is little doubt about the reality of the biomass increase, while there remains some uncertainty in its absolute magnitude. This situation is similar to that confronted by the RPR participants in 2019, who provisionally accepted the stock assessment subject to an update of the model using new survey data in 2021. This update confirms and extends the conclusions presented by the previous stock assessment, given that observations from all four surveys were consistent with those from the 2019 stock assessment. Furthermore, Table 1 shows that a larger percentage of females from the 2016 cohort are mature in 2021 than was assumed in the model's maturity ogive, which means that the update may be underestimating the size of the 2022 female spawning population. This updated stock assessment suggests that a considered outcome would be to accept these results and recommend that the assessment be again updated in 2023 when four new survey index values become available, thus continuing the validation of the size of the 2016 cohort. This recommendation is made notwithstanding the high survey CVs associated with the semi-pelagic behaviour of this species.

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Sources of Information

DFO. 2009. A fishery decision-making framework incorporating the Precautionary Approach.

DFO. 2020. Bocaccio (*Sebastes paucispinis*) stock assessment for British Columbia in 2019, including guidance for rebuilding plans. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2020/025. 17 p.

Edwards, A.M., Haigh, R. and Starr, P.J. 2012. Stock assessment and recovery potential assessment for Yellowmouth Rockfish (*Sebastes reedi*) along the Pacific coast of Canada. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/095. iv + 188 p.

Forrest, R.E., Holt, K.R. and Kronlund, A.R. 2018. Performance of alternative harvest control rules for two Pacific groundfish stocks with uncertain natural mortality: bias, robustness and trade-offs. Fish. Res. 206. 259–286.

N.Z. Min. Fish. 2011. Operational Guidelines for New Zealand's Harvest Strategy Standard. Ministry of Fisheries, New Zealand.

Stanley, R.D., McAllister, M., Starr, P. and Olsen, N. 2009. Stock assessment for bocaccio (*Sebastes paucispinis*) in British Columbia waters. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/055. xiv + 200 p.

Starr, P.J. and Haigh, R. 2022. Bocaccio (*Sebastes paucispinis*) stock assessment for British Columbia in 2019, including guidance for rebuilding plans. DFO Can. Sci. Advis. Sec. Res. Doc. *In press*.

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