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Pacific Region

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Science Advisory Report 2022/XXX

Arrowtooth Flounder (Atheresthes stomias) Stock Assessment for the West Coast of British Columbia in 2021

Arrowtooth Flounder (Atheresthes stomias). Source: Kristina Anderson, DFO.

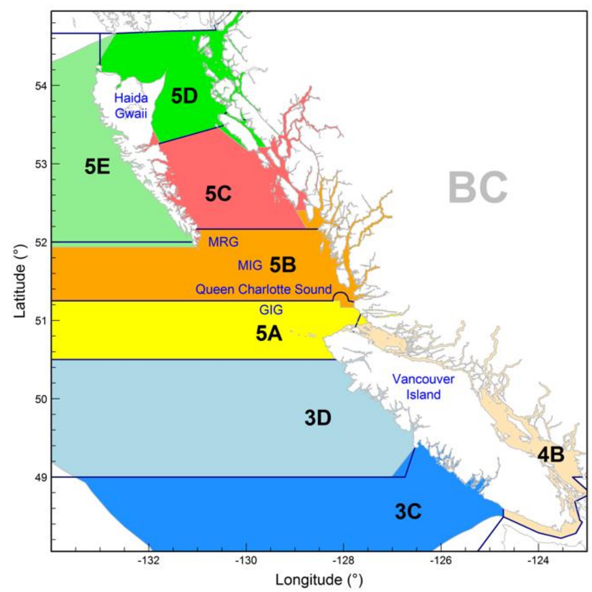

Figure 1. Arrowtooth flounder assessment areas comprising Pacific Marine Fisheries Commission (PMFC) major areas outlined with solid lines and used in this assessment. The Groundfish Management Unit area boundaries, based on [Pacific Fisheries Management Areas](), are superimposed as coloured polygons for comparison. This assessment is for all offshore areas combined (3CD5ABCDE, excludes 4B).

Context:

Arrowtooth Flounder (Atheresthes stomias, Turbot) are an important component of the bottom trawl fishery in British Columbia. They are managed as a coastwide stock. Prior to the introduction of freezer trawlers in the mid-2000s, most of the historical catch of Arrowtooth Flounder is understood to have been discarded at sea. This was largely due to proteolysis, which occurs in the muscle tissue of this species a short time after it is caught, making the flesh unpalatable. In the past decade, markets have been established for fillets that have been frozen at sea, and the freezer trawl fleet has taken an increasing proportion of the coastwide catch.This assessment was done using a two-sex two-fleet Bayesian age-structured model to catch, survey, and age-composition data from the years 1996–2021 for management areas 3CD (West Coast Vancouver Island), 5AB (Queen Charlotte Sound), 5CD (Hecate Strait), and 5E (West Coast Haida Gwaii) combined. The harvest advice is expected to be compliant with DFO's Decision-making Framework Incorporating the Precautionary Approach.

This Science Advisory Report is from the October 19-20, 2022 regional peer review on the Arrowtooth Flounder (Atheresthes stomias) Stock Assessment for the West Coast of British Columbia, 2022. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

- A single Arrowtooth Flounder stock (AF) has been identified along the BC coast, based on no observable differences in mean weight, observed length, or growth models between North (5ABCDE) and South (3CD) and among three regional areas (5DE, 5ABC, 3CD).
- The AF stock was assessed using a two-fleet, two-sex catch-at-age model, implemented in a Bayesian framework to quantify uncertainty of estimated quantities.
- The median (with 5th and 95th percentiles of the Bayesian results) spawning biomass at the beginning of 2022 (B_{2022}) is estimated to be 0.37 (0.26, 0.53) of unfished spawning biomass (B_0).
- There is an estimated probability of 1 that $B_{2022} > 0.2B_0$ and a probability of 0.34 that $B_{2022} > 0.4B_0$ (i.e. of being in the Healthy zone).
- Advice to management is presented in the form of a decision table using the provisional reference points from the DFO Decision Making Framework Incorporating the Precautionary Approach (DFO 2009). The decision table provides one year projection of the stock across a range of constant catches up to 50,000 tonnes.
- The F_{MSY} (and consequently, U_{MSY}) estimates are unrealistically large in this model due to the selectivity estimates being larger than maturity. This creates a situation where vulnerable biomass can theoretically all be harvested without impacting the stock because there is a large number of fish invulnerable to the fishery sustaining the stock through spawning. This disparity between maturity and selectivity causes the B_{MSY}-based reference points to be roughly one quarter the size of the B_0-based reference points; consequently, advice to management relative to reference points based on 0.2 and 0.4 of B_0 are presented in the Research Document.
- It is recommended that this stock assessment be updated with new data in approximately two years when one additional survey will have been been run in each area of the coast.

INTRODUCTION

AF is ubiquitous along the BC coast, with most catches taken near the bottom in the depth range of 18-950 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 eastern portion of Dixon Entrance. The available age data show that this species reaches maximum ages around 25 years, with the maximum age for sampled females and males being 27 and 23 years respectively. AF exhibit sexual dimorphism. After sexual maturity, females grow faster than males and reach a larger maximum size. The maximum length of sampled female and male AF are 61.8 and 47.2 cm respectively.

This stock assessment evaluates a BC coastwide population harvested by two commercial bottom trawl fleets (1=Freezer trawlers; 2=Shoreside) each with pooled catches and with separate age data.

ASSESSMENT

The catch-at-age model used for the stock assessment was tuned to four fishery-independent trawl survey series and one fishery-based discard series (covering 1996-2021), annual estimates of commercial catch from two fleets, and age composition data from the two commercial fleets and three of the four surveys. Years prior to 1996 could not be used in the assessment due to unreported discards of AF, many times whole tows being discarded without report. This large unreported discarding made any attempt at a catch reconstruction impossible due to the uncertainty involved.

The model started from an assumed equilibrium state in 1996. The base model for this assessment was implemented in a Bayesian framework (using the Markov Chain Monte Carlo procedure) with natural mortality (M) fixed at 0.2 for females and 0.35 for males. An accumulator age (A) of 20 years was used while estimating steepness of the stock-recruit function (h), catchability (q) for each survey and the discard CPUE index, and selectivity (μ) for the three synoptic surveys and the commercial fleets.

All calculations were made using the Bayesian Markov Chain Monte Carlo (MCMC) procedure to quantify parameter uncertainty. Ten million simulations were sampled every 5,000th to yield 2,000 MCMC samples (reduced to 1,000 after dropping the first 1000 samples as ‘burn-in’) from the posterior distributions for estimated parameters. Estimates of various quantities are presented as the median (with 2.5th and 97.5th percentiles to specify uncertainty). Calculated probabilities in the decision table are based on the full MCMC posterior distributions.

Advice to managers is presented as a decision table that provides probabilities of being below reference points (LRP=0.2B_0; USR=0.4B_0) as well as the relative spawning biomass in 2023 being less than the 2022 relative spawning biomass for a range of constant catch levels from zero up to 50,000 tonnes.

Figure 2 shows the estimated annual relative spawning biomass for the coastwide stock. The coastwide AF stock has experienced a nearly continuous decline since 2010 with a flattening trend from 2020-2022. This flattening trend in the trajectory coincides with the reduction in TAC (and consequently catch, Figure 3) in 2020 from 14,000 t to 5,000 t. The estimated current–year spawning biomass (B_{2022}) relative to equilibrium unfished biomass, B_{2022}/B_0 = 0.37 (0.26, 0.53).

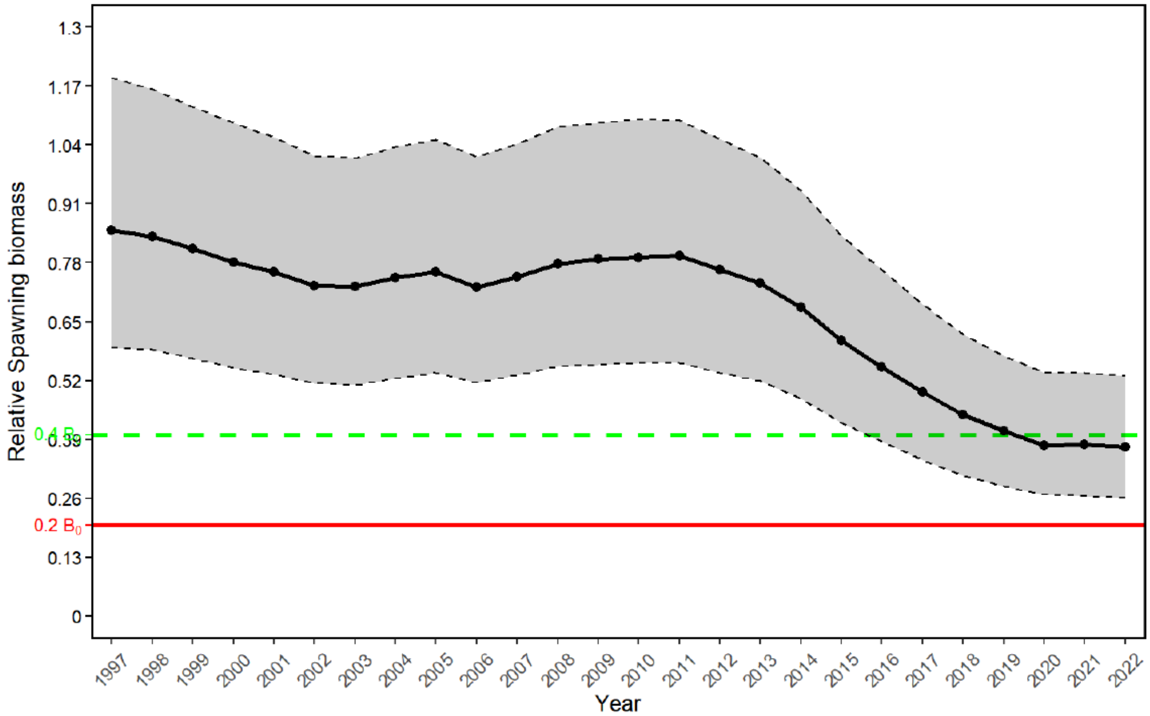

Figure 2. Relative spawning biomass for the base model. The shaded area represents the 95% credible interval. Horizontal lines indicate the $0.2B_0$ (solid, red) and $0.4B_0$ (dashed, green) reference points. Because the ribbon represents relative spawning biomass (depletion) and the reference points are with respect to B_0, all uncertainty about the ratio of the spawning biomass to the reference points is captured in the ribbon and the reference points are shown without uncertainty.

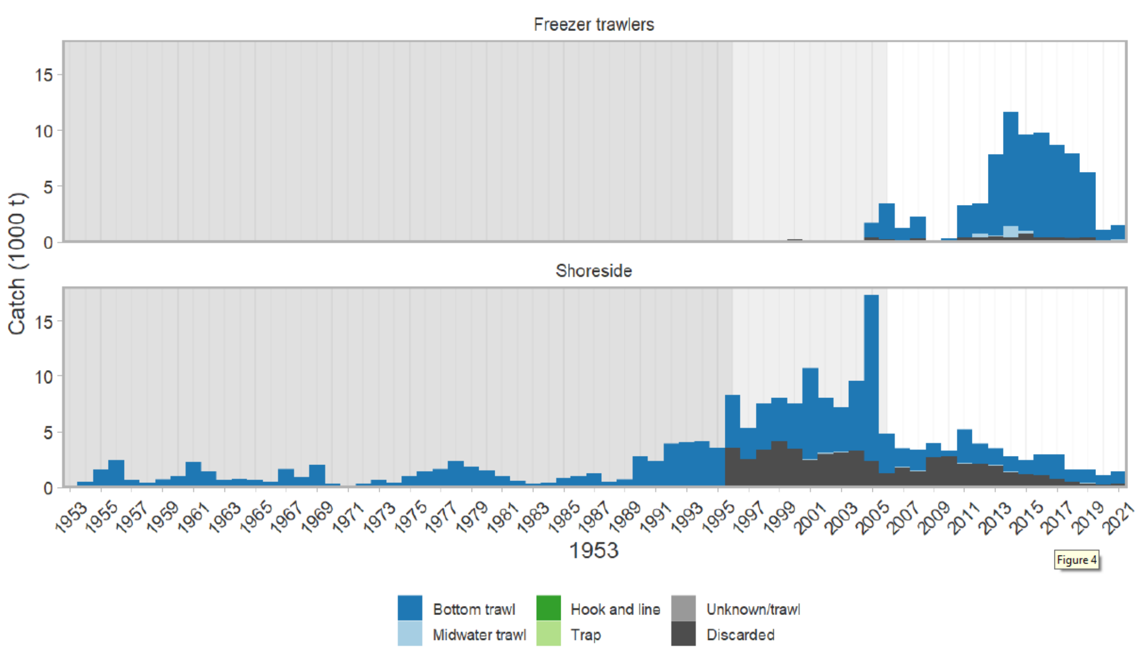

Figure 3. Commercial catch of Arrowtooth Flounder by fleet. Each year of catch starts on Feb. 21 and ends on Feb. 20.

Table 1. Quantiles from the 1000 samples of the MCMC posteriors for the base model. Definitions: R_0 – Initial recruitment (age 1), h – steepness of stock-recruitment relationship, M – natural mortality, $\bar{R}$ – average recruitment (age 1), $\bar{R}_{init}$ – average recruitment in 1995 (age 1), B_0 – Average biomass, SB_0 – unfished spawning biomass, B_{MSY} – equilibrium spawning biomass at MSY (maximum sustainable yield), MSY – Maximum sustainable yield for each fleet, F_{MSY} – Fishing mortality at MSY for each fleet. U_{MSY} – exploitation rate at MSY for each fleet, q – catchability for each gear, $\hat{a}$ – age at 50% selectivity, $\hat{\gamma}$ – standard deviation at 50% selectivity. For the $\hat{a}$ and $\hat{\gamma}$ parameters, the subscripts are 1st=gear, 2nd=sex, 3rd=time block (all 1 because there is no time-varying selectivity in the base model).

Parameter	Gear	Sex	Year range	2.5%	50%	97.5%
R_0	–	–	1996-2021	85.98	118.69	169.38
h	–	–	1996-2021	0.67	0.89	0.98
M_1	–	female	1996-2021	0.20	0.20	0.20
M_2	–	male	1996-2021	0.35	0.35	0.35
$\overline{R}$	–	–	1996-2021	75.33	85.59	99.19
$\overline{R}_{\text{init}}$	–	–	1996-2021	46.74	63.10	81.25
B_0	–	–	1996-2021	130.66	180.38	257.41
SB_0	–	–	1996-2021	130.66	180.38	257.41
B_{MSY}	–	–	1996-2021	17.87	31.72	59.69
MSY_1	Freezer trawlers	–	1996-2021	3.74	5.47	7.77
F_{MSY_1}	Freezer trawlers	–	1996-2021	0.34	1.31	3.73
U_{MSY_1}	Freezer trawlers	–	1996-2021	0.29	0.73	0.98
MSY_2	Shoreside	–	1996-2021	6.69	9.83	14.02
F_{MSY_2}	Shoreside	–	1996-2021	0.86	4.04	14.19
U_{MSY_2}	Shoreside	–	1996-2021	0.58	0.98	1.00
q_1	QCS Synoptic	–	1996-2021	0.09	0.12	0.16
q_2	HS Multi	–	1996-2021	0.11	0.13	0.15
q_3	HS Synoptic	–	1996-2021	0.12	0.16	0.22
q_4	WCVI Synoptic	–	1996-2021	0.08	0.10	0.12
q_5	Discard CPUE	–	1996-2021	1.18	1.36	1.54
$\hat{a}_{1,\text{f},1}$	Freezer trawlers	female	1996-2021	7.34	7.97	8.60
$\hat{\gamma}_{1,\text{f},1}$	Freezer trawlers	female	1996-2021	0.85	1.02	1.20
$\hat{a}_{1,\text{m},1}$	Freezer trawlers	male	1996-2021	6.86	7.35	7.94
$\hat{\gamma}_{1,\text{m},1}$	Freezer trawlers	male	1996-2021	0.75	0.89	1.04
$\hat{a}_{2,\text{f},1}$	Shoreside	female	1996-2021	8.21	8.67	9.13
$\hat{\gamma}_{2,\text{f},1}$	Shoreside	female	1996-2021	0.93	1.06	1.21
$\hat{a}_{2,\text{m},1}$	Shoreside	male	1996-2021	7.94	8.40	8.88
$\hat{\gamma}_{2,\text{m},1}$	Shoreside	male	1996-2021	0.84	0.96	1.08
$\hat{a}_{3,\text{f},1}$	QCS Synoptic	female	1996-2021	5.55	7.25	9.61
$\hat{\gamma}_{3,\text{f},1}$	QCS Synoptic	female	1996-2021	1.78	2.46	3.50
$\hat{a}_{3,\text{m},1}$	QCS Synoptic	male	1996-2021	4.91	6.30	8.59
$\hat{\gamma}_{3,\text{m},1}$	QCS Synoptic	male	1996-2021	1.13	1.56	2.20
$\hat{a}_{4,\text{f},1}$	HS Multi	female	1996-2021	9.00	9.00	9.00
$\hat{\gamma}_{4,\text{f},1}$	HS Multi	female	1996-2021	0.50	0.50	0.50
$\hat{a}_{4,\text{m},1}$	HS Multi	male	1996-2021	9.00	9.00	9.00
$\hat{\gamma}_{4,\text{m},1}$	HS Multi	male	1996-2021	0.50	0.50	0.50
$\hat{a}_{5,\text{f},1}$	HS Synoptic	female	1996-2021	8.13	9.66	11.67
$\hat{\gamma}_{5,\text{f},1}$	HS Synoptic	female	1996-2021	2.11	2.54	3.19
$\hat{a}_{5,\text{m},1}$	HS Synoptic	male	1996-2021	8.60	10.45	12.73
$\hat{\gamma}_{5,\text{m},1}$	HS Synoptic	male	1996-2021	1.79	2.12	2.50
$\hat{a}_{6,\text{f},1}$	WCVI Synoptic	female	1996-2021	7.73	8.59	9.68
$\hat{\gamma}_{6,\text{f},1}$	WCVI Synoptic	female	1996-2021	1.34	1.59	1.95
$\hat{a}_{6,\text{m},1}$	WCVI Synoptic	male	1996-2021	6.27	6.89	7.56
$\hat{\gamma}_{6,\text{m},1}$	WCVI Synoptic	male	1996-2021	0.85	1.01	1.20
$\hat{a}_{7,\text{f},1}$	Discard CPUE	female	1996-2021	9.00	9.00	9.00
$\hat{\gamma}_{7,\text{f},1}$	Discard CPUE	female	1996-2021	0.50	0.50	0.50
$\hat{a}_{7,\text{m},1}$	Discard CPUE	male	1996-2021	9.00	9.00	9.00
$\hat{\gamma}_{7,\text{m},1}$	Discard CPUE	male	1996-2021	0.50	0.50	0.50

Reference Points

Figure 6 shows the stock status for the composite base case as well as each component run relative to the provisional DFO (2009) limit and upper stock reference points of $0.4B_{\text{MSY}}$ and $0.8B_{\text{MSY}}$ respectively (see Table 1 for B_{MSY} reference points specific to BOR). These reference points define the 'Critical', 'Cautious' and 'Healthy' zones. The composite base case spawning biomass at the beginning of 2020 is 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).

Table 2. Reference points and values of interest from the base model. Medians and credible intervals represent 1,000 samples of the MCMC posteriors for the base model. Definitions: SB_0 - Spawning biomass (both sexes), $0.2B_0$ - 20% of SB_0, $0.4B_0$ - 40% of SB_0, SB_{2021} - Spawning biomass in 2021, SB_{2022} - Spawning biomass in 2022, F_{MSY1} - Fishing mortality for the Freezer trawler fleet, F_{MSY2} - Fishing mortality for the Shoreside fleet, B_{MSY} - Biomass at MSY, $0.4B_{MSY}$ - 40% of B_{MSY}, $0.8B_{MSY}$ - 80% of B_{MSY}, MSY_1 - Maximum sustainable yield for the Freezer trawler fleet, MSY_2 - Maximum sustainable yield for the Shoreside fleet, F_{20211} - Fishing mortality in 2021 for the Freezer trawler fleet, F_{20212} - Fishing mortality in 2021 for the Shoreside fleet, U_{MSY1} - Harvest rate for the Freezer trawler fleet, U_{MSY2} - Harvest rate for the Shoreside fleet.

Reference point	Median	Credible interval
SB_0	180.38	130.66-257.41
$0.2B_0$	36.08	26.13-51.48
$0.4B_0$	72.15	52.26-102.96
SB_{2021}	68.70	56.84-84.11
SB_{2022}	67.77	54.99-85.38
F_{MSY_1}	1.31	0.34-3.73
F_{MSY_2}	4.04	0.86-14.19
B_{MSY}	31.72	17.87-59.69
$0.4B_{\text{MSY}}$	12.69	7.15-23.87
$0.8B_{\text{MSY}}$	25.38	14.30-47.75
MSY_1	5.47	3.74-7.77
MSY_2	9.83	6.69-14.02
F_{2021_1}	0.06	0.05-0.08
F_{2021_2}	0.04	0.03-0.05
U_{MSY_1}	0.73	0.29-0.98
U_{MSY_2}	0.98	0.58-1.00

Starting in 2021, there is a quick rebound in spawning biomass because a small proportion of the 5-year old fish have become mature. Due to the large estimated size of the 2016 cohort, the recovery of the spawning stock biomass is rapid and the probability of this biomass exceeding the LRP, i.e. P($B_t > 0.4B_{MSY}$), exceeds 95% in year t =2023 (Table 2). Figure 6 demonstrates the rapidity of this rebound by showing projected stock status in two years (at the beginning of 2022), assuming a constant catch of 200 tonnes/year or a harvest rate of 0.04/year. In this short time, spawning biomass has moved into the Cautious zone (i.e., the median lies near the USR of $0.8B_{MSY}$).

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., New Zealand Ministry of Fisheries 2011). Therefore, the reference points of $0.2B_0$ and $0.4B_0$ are also presented in Appendix F of the Research Document. These reference points 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 provisional DFO Sustainable Fisheries Framework while a ‘target’ biomass is not specified.

A second component of the provisional harvest rule (DFO 2009) concerns the relationship of the exploitation rate relative to that associated with MSY under equilibrium conditions (u_{MSY}). The rule specifies that the exploitation rate should not exceed u_{MSY} when the stock is in the Healthy zone. Catches should be reduced when in the Cautious zone, and be kept to the lowest level possible when in the Critical zone. Because of the strong management measures in place to protect BOR, exploitation rates are already well below u_{MSY}, with the estimated ratio of u_{2019}/u_{MSY} = 0.29 (0.12, 0.66) (Table 1). The probability that the current exploitation rate is below that associated with MSY is P($u_{2019} < u_{MSY}$) = 0.99 for the trawl fishery and 1 for the ‘other’ fishery. A phase plot of the time-evolution of spawning biomass and exploitation rate for the two modelled fisheries in MSY space (Figure 5) shows that the stock has been in the Cautious zone from 1989 to 1998 and in the Critical zone since 1999.

Projection Results and Decision Tables

The stock was projected for one year, starting with the biomass at the beginning of 2022. Alternative 2022 catch levels are presented from zero t to 50,000 t. Catches are shown in 2,000 t increments from zero to 10,000 t; then in 1,000 t increments between 10,000 t and 20,000 t; and then in 2,000 t increments from 22,000 t to 30,000 t. A catch level of 50,000 t is also shown in the table for reference purposes as it was included in the last assessment (Figure 4 and Table 3).

This one-year projection was considered adequate for advice to managers before the next stock assessment of this species, in two years.

The model-predicted probability of the 2023 spawning biomass being below the 2022 spawning biomass ranged from 0.007 under zero 2022 catch to 0.978 under 10,000 t of catch, which is double the current total TAC. At 50,000 t, the probability is 1.000. The TAC that is closest to 0.5 probability of the biomass declining from 2022 to 2023 (while still being below 0.5) is 2,000 t, at a probability of 0.189. The probability of being below the USR of $0.4B_0$ was from 0.491 to 1 over the range of catch levels considered; the probability of being below the LRP of $0.2B_0$ for the same catch range was from 0 to 0.953. All catch levels (except zero) had a probability of greater than 0.5 of the 2023 biomass being under the $0.4B_0$ reference point.

Table 3. Decision table for the reference points $0.2B_0$, $0.4B_0$, and probability of the spawning biomass declining for a 1-year projection for a range of constant catch policies (in tonnes) using the base model. Values are the probability (proportion of 1,000 MCMC samples) of the spawning biomass at the start of 2023 being less than the B_0 reference points.

Catch (thousand t)	$P(B_{2023} < 0.2B_0)$	$P(B_{2023} < 0.4B_0)$	$P(B_{2023} < B_{2022})$
0	0.000	0.491	0.007
2	0.000	0.583	0.189
4	0.000	0.676	0.627
6	0.000	0.749	0.863
8	0.000	0.810	0.952
10	0.003	0.870	0.978
11	0.008	0.892	0.985
12	0.009	0.914	0.991
13	0.014	0.932	0.992
14	0.021	0.938	0.993
15	0.030	0.951	0.995
16	0.039	0.959	0.996
17	0.056	0.966	0.998
18	0.067	0.971	0.998
19	0.084	0.977	0.998
20	0.108	0.978	0.998
22	0.156	0.987	0.998
24	0.211	0.988	0.999
26	0.273	0.990	0.999
28	0.334	0.990	0.999
30	0.418	0.994	1.000
50	0.953	1.000	1.000

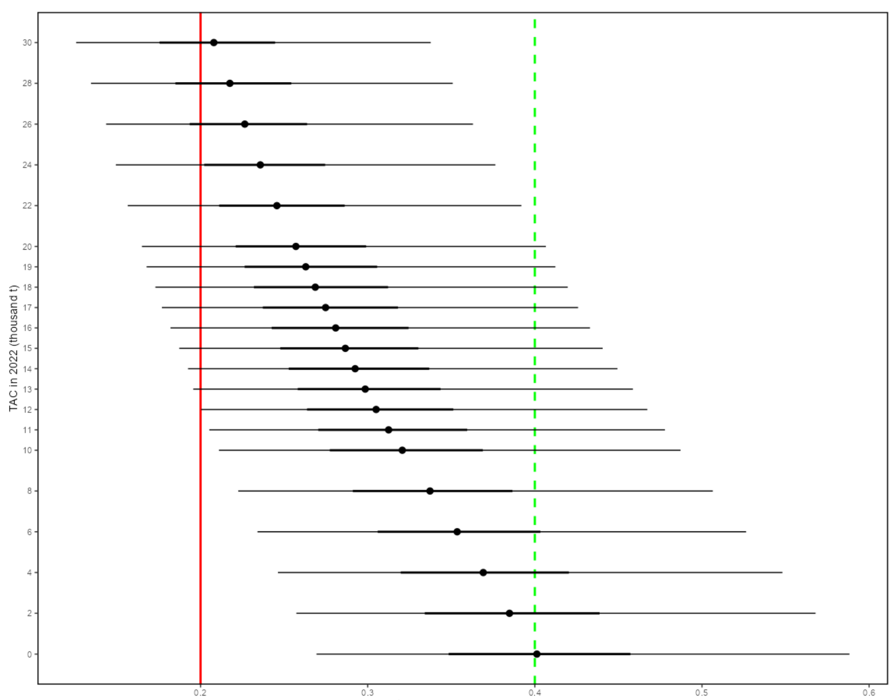

Figure 4. Projected 2023 relative spawning biomass by TAC level chosen for 2022 catch. The thin horizontal lines are the 95% CI (2.5%-97.5%), the thicker lines are the 50% CI (25%-75%), and the points are the medians. The solid red vertical line represents the $0.2B_0$ reference point, the dashed green line represents the $0.4B_0$ reference point.

Sources of Uncertainty

Uncertainty in the estimated parameters is explicitly addressed using a Bayesian approach, with credibility intervals and probabilities provided for all quantities of interest.

As with all stock assessments, there are two major types of uncertainty in the advice presented in this document:

1. Uncertainty in the estimates of model parameters within the assessment
2. Structural uncertainty arising from processes and data that were not included in the assessment

The first type, parameter uncertainty, is presented in terms of posterior credible intervals for parameters and state variables such as biomass, recruitment, and fishing mortality. This uncertainty was captured in the decision tables and was further explored using sensitivity analyses.

The magnitude of catch and discards prior to 1996 is a major source of structural uncertainty in this assessment. All catch data prior to 1996 were omitted from this assessment on the recommendation of industry advisors and Technical Working Group, as was done in the 2015 assessment. Arrowtooth Flounder is known to have been discarded at sea in large quantities due to proteolysis of the flesh if catches were not landed and frozen quickly after capture. Applications of ratio estimators or models to estimate historical discard rates were rejected as analytical tools due to discarding of whole tows and changes to discarding behaviour over time.

The assessment model was able to fit all indices of abundance well with the possible exception of the Queen Charlotte Sound Synoptic Survey. Although the index has declined since 2015 (and in particular in 2021 after the initial Technical Working Group meetings), the decline has been somewhat less pronounced than the other surveys or the Discard CPUE Index. We attempted to better fit the Queen Charlotte Sound Synoptic Survey with survey-specific time-varying selectivity, but we were unable to obtain satisfactory estimates of selectivity and MCMC diagnostics on this model and so used time-invariant selectivity in the base model. It is possible Queen Charlotte Sound represents a nursery ground for Arrowtooth Flounder or factors affecting local distribution or movement (such as environmental conditions) have resulted in a moderately different index pattern in the Queen Charlotte Sound Synoptic Survey compared to the other surveys. Overall, the congruence between the coast-wide ‘stitched’ synoptic survey and the Discard CPUE Index give us some confidence that both data sources are capturing underlying biomass dynamics.

Ecosystem Considerations and Climate Change

Ecosystem and climate change data were not direct inputs into the stock assessment and are not included in the advice, which includes the decision table (Table 3). We did examine some ecosystem considerations, including prey (although we were limited to Alaskan data as we do not have stomach samples in the BC surveys) and predators. We also investigated spatio-temporal changes in body condition and found that condition ("plumpness") tended to be higher in deeper waters and that this relationship did not appear to be related to temperature. In contrast to the patterns reported from Alaska (Spies et al 2019), condition index in BC climbed steeply between 2013 and 2015, the period that includes the 2014–2016 marine heat wave. Indeed local warming was associated with increases biomass of immatures in cooler areas, but declines in biomass across maturity classes in already warmer areas (English et al. 2021). This suggests that climate-related vulnerability is likely low in the short term, but long-term impacts remain uncertain.

CONCLUSIONS AND ADVICE

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LIST OF MEETING PARTICIPANTS

Last Name	First Name	Affiliation
		DFO Science, Groundfish Section

SOURCES OF INFORMATION

This Science Advisory Report is from the December 17-18, 2019 regional peer review on the Evaluation of Bocaccio rebuilding plan objectives. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

DFO. 2009. A fishery decision-making framework incorporating the Precautionary Approach, (last reportedly modified 23 May 2009, though figures have since changed). (Accessed June 18, 2018).

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