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Pacific Region

Canadian Science Advisory Secretariat
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.

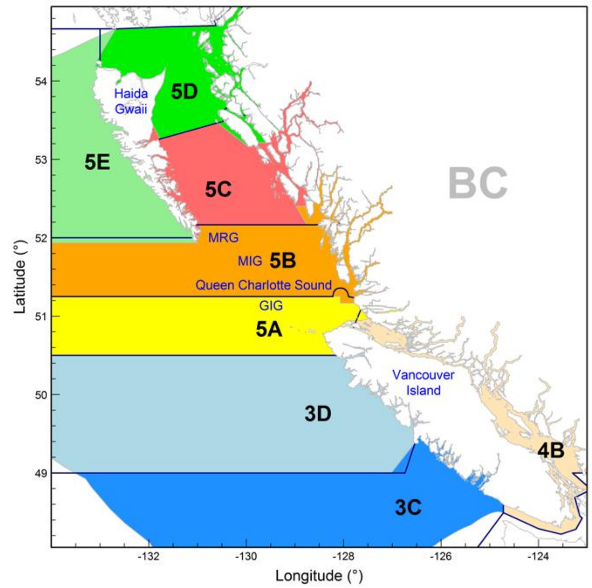

Figure 1. Arrowtooth flounder assessment areas comprising Pacific Marine Fisheries Commission (PMFC) major areas outlined with solid lines and used in this assessment. The Groundfish Management Unit area boundaries, based on [Pacific Fisheries Management Areas](), are superimposed as coloured polygons 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 0.24 (0.16, 0.34) of unfished spawning biomass (B_0).
- There is an estimated probability of 0.85 that $B_{2022} > 0.2B_0$ and a probability of 0.02 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 5000th to yield 2000 MCMC samples (reduced to 1000 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 5th and 95th 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 only a slight upward trend from 2020-2022. This upward 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 = 0.24 (0.16, 0.34).

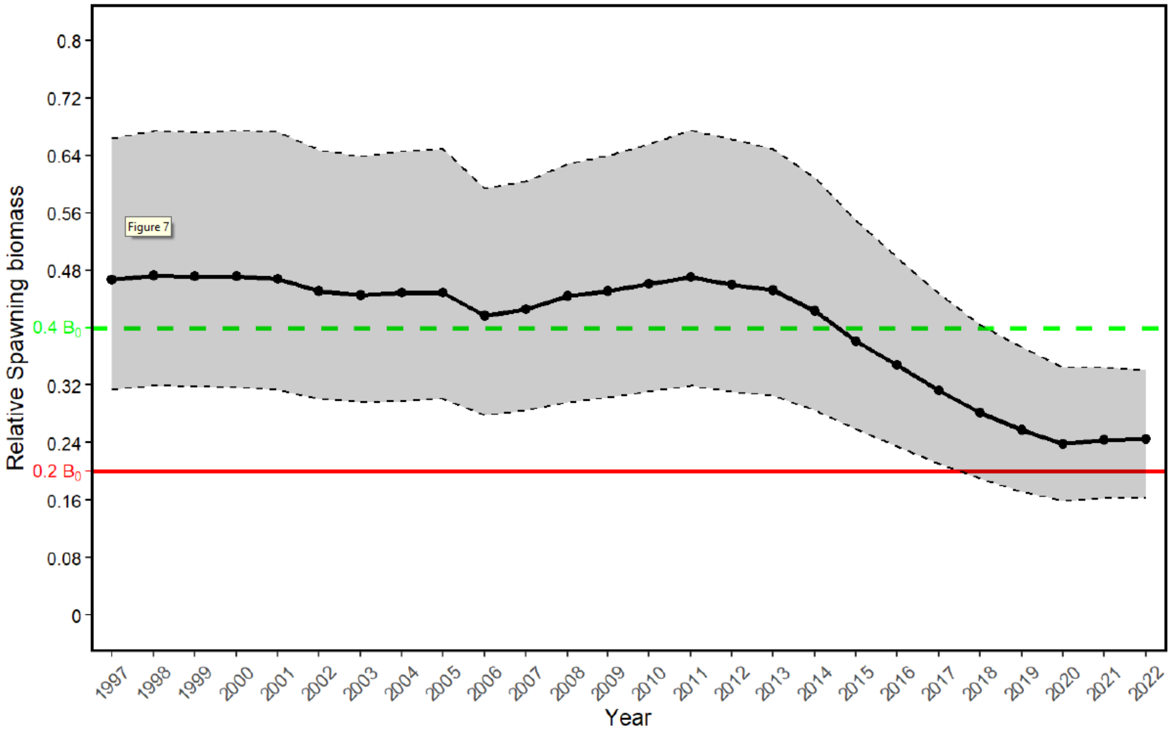

Figure 2. Relative spawning biomass for the base model. The shaded area represents the 95% credible interval. Horizontal lines indicate the 0.2B_0 (solid, red) and 0.4B_0 (dashed, green) reference points. Because the ribbon represents relative spawning biomass (depletion) and the reference points are 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.

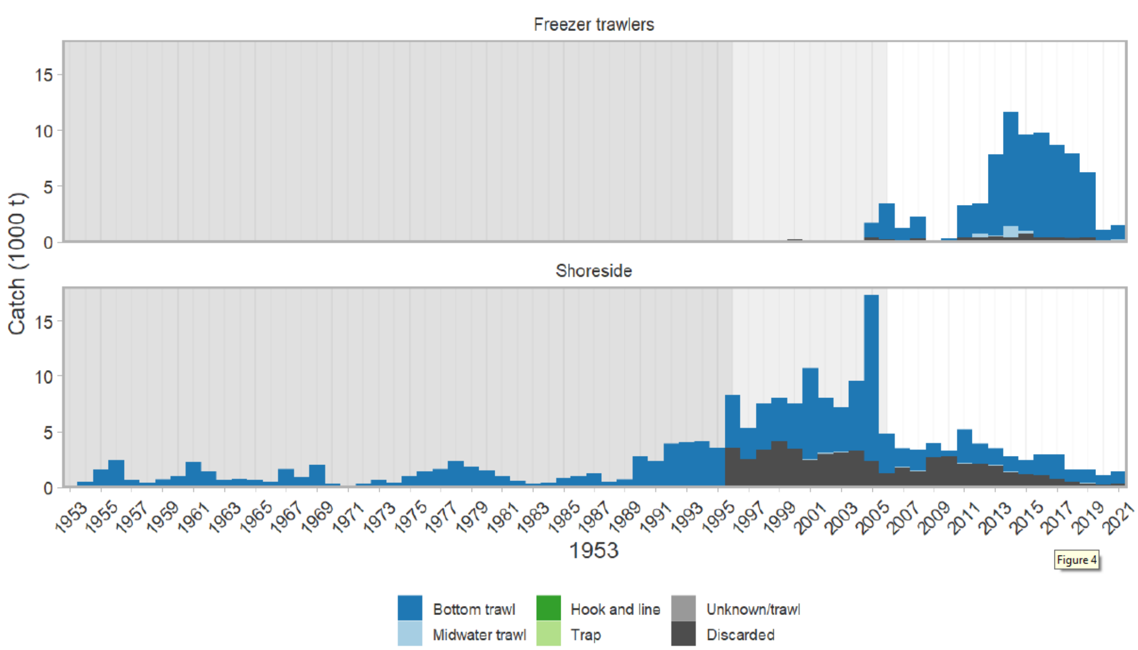

Figure 3. Commercial catch of Arrowtooth Flounder by fleet. Each year of catch starts on Feb. 21 and ends on Feb. 20.

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	80.47	115.37	170.32
h	–	–	1996-2021	0.69	0.88	0.98
M_1	–	male	1996-2021	0.20	0.20	0.20
M_2	–	female	1996-2021	0.35	0.35	0.35
$\overline{R}$	–	–	1996-2021	69.00	78.64	89.51
$\overline{R}_{\text{init}}$	–	–	1996-2021	25.40	34.56	44.86
B_0	–	–	1996-2021	122.29	175.33	258.84
SB_0	–	–	1996-2021	169.72	243.33	359.24
B_{MSY}	–	–	1996-2021	13.53	29.06	63.78
MSY_1	Freezer trawlers	–	1996-2021	3.04	4.61	6.69
F_{MSY_1}	Freezer trawlers	–	1996-2021	0.21	1.03	5.56
U_{MSY_1}	Freezer trawlers	–	1996-2021	0.19	0.64	1.00
MSY_2	Shoreside	–	1996-2021	5.48	8.31	12.06
F_{MSY_2}	Shoreside	–	1996-2021	0.51	3.15	26.59
U_{MSY_2}	Shoreside	–	1996-2021	0.40	0.96	1.00
q_1	QCS Synoptic	–	1996-2021	0.10	0.11	0.14
q_2	HS Multi	–	1996-2021	0.14	0.17	0.19
q_3	HS Synoptic	–	1996-2021	0.11	0.14	0.19
q_4	WCVI Synoptic	–	1996-2021	0.08	0.09	0.11
q_5	Discard CPUE	–	1996-2021	1.51	1.80	2.08
$\hat{a}_{1,f,1}$	Freezer trawlers	female	1996-2021	5.92	6.38	6.90
$\hat{\gamma}_{1,f,1}$	Freezer trawlers	female	1996-2021	0.66	0.81	0.98
$\hat{a}_{1,m,1}$	Freezer trawlers	male	1996-2021	9.53	10.14	10.89
$\hat{\gamma}_{1,m,1}$	Freezer trawlers	male	1996-2021	1.06	1.20	1.36
$\hat{a}_{2,f,1}$	Shoreside	female	1996-2021	6.72	7.13	7.56
$\hat{\gamma}_{2,f,1}$	Shoreside	female	1996-2021	0.77	0.89	1.04
$\hat{a}_{2,m,1}$	Shoreside	male	1996-2021	10.65	11.34	12.32
$\hat{\gamma}_{2,m,1}$	Shoreside	male	1996-2021	1.04	1.17	1.30
$\hat{a}_{3,f,1}$	QCS Synoptic	female	1996-2021	2.70	3.70	5.05
$\hat{\gamma}_{3,f,1}$	QCS Synoptic	female	1996-2021	0.76	1.25	2.12
$\hat{a}_{3,m,1}$	QCS Synoptic	male	1996-2021	9.43	11.35	14.67
$\hat{\gamma}_{3,m,1}$	QCS Synoptic	male	1996-2021	1.72	2.08	2.59
$\hat{a}_{4,f,1}$	HS Multi	female	1996-2021	9.00	9.00	9.00
$\hat{\gamma}_{4,f,1}$	HS Multi	female	1996-2021	0.50	0.50	0.50
$\hat{a}_{4,m,1}$	HS Multi	male	1996-2021	9.00	9.00	9.00
$\hat{\gamma}_{4,m,1}$	HS Multi	male	1996-2021	0.50	0.50	0.50
$\hat{a}_{5,f,1}$	HS Synoptic	female	1996-2021	5.01	6.33	8.06
$\hat{\gamma}_{5,f,1}$	HS Synoptic	female	1996-2021	1.49	1.96	2.65
$\hat{a}_{5,m,1}$	HS Synoptic	male	1996-2021	12.73	14.54	16.99
$\hat{\gamma}_{5,m,1}$	HS Synoptic	male	1996-2021	1.91	2.14	2.39
$\hat{a}_{6,f,1}$	WCVI Synoptic	female	1996-2021	5.04	5.68	6.34
$\hat{\gamma}_{6,f,1}$	WCVI Synoptic	female	1996-2021	0.76	0.96	1.20
$\hat{a}_{6,m,1}$	WCVI Synoptic	male	1996-2021	10.80	12.02	13.74
$\hat{\gamma}_{6,m,1}$	WCVI Synoptic	male	1996-2021	1.38	1.58	1.80
$\hat{a}_{7,f,1}$	Discard CPUE	female	1996-2021	9.00	9.00	9.00
$\hat{\gamma}_{7,f,1}$	Discard CPUE	female	1996-2021	0.50	0.50	0.50
$\hat{a}_{7,m,1}$	Discard CPUE	male	1996-2021	9.00	9.00	9.00
$\hat{\gamma}_{7,m,1}$	Discard CPUE	male	1996-2021	0.50	0.50	0.50

TODO: Continue from here. From here on is old Bocaccio stuff

From model output

Value	5%	50%	95%
B_0	16,460	32,289	71,710
V_0 (trawl)	27,930	55,089	123,319
V_0 (‘other’)	27,286	53,564	119,116
B_{2019}	552	899	1,655
V_{2020} (trawl)	3,046	5,703	12,273
V_{2020} (‘other’)	2,582	4,709	9,812
B_{2020} / B_0	0.0132	0.0278	0.0578
V_{2020} / V_0 (trawl)	0.0496	0.104	0.213
V_{2020} / V_0 (‘other’)	0.0426	0.0875	0.175
u_{2019} (trawl)	0.0121	0.025	0.0441
u_{2019} (‘other’)	0.000467	0.000930	0.00161
$u_{\max}$ (trawl)	0.0369	0.0588	0.0792
$u_{\max}$ (‘other’)	0.00654	0.00968	0.0124

MSY-based quantities

Value	5%	50%	95%
MSY	703	1,461	3,623
B_{MSY}	4,134	9,462	22,469
$0.4B_{MSY}$	1,653	3,785	8,988
$0.8B_{MSY}$	3,307	7,570	17,976
B_{2020} / B_{MSY}	0.0417	0.0963	0.2340
B_{MSY} / B_0	0.225	0.291	0.353
V_{MSY}	7,858	17,554	41,876
V_{MSY} / V_0 (trawl)	0.252	0.319	0.378
V_{MSY} / V_0 (‘other’)	0.253	0.328	0.396
u_{MSY}	0.054	0.085	0.133
u_{2019} / u_{MSY} (trawl)	0.116	0.291	0.664
u_{2019} / u_{MSY} (‘other’)	0.00421	0.0109	0.0258

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 $0.4B_{MSY}$ and $0.8B_{MSY}$ 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 $P(B_{2020} > 0.4B_{MSY}) < 0.01$, and above the upper stock reference (USR) point with probability $P(B_{2020} > 0.8B_{MSY}) = 0$ (i.e., no probability of being in the Healthy zone based on the set of MCMC posterior samples).

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 $u_{2019}/u_{\mathrm{MSY}}$ = 0.29 (0.12, 0.66) (Table 1). The probability that the current exploitation rate is below that associated with MSY is P($u_{2019} < u_{\mathrm{MSY}}$) = 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.

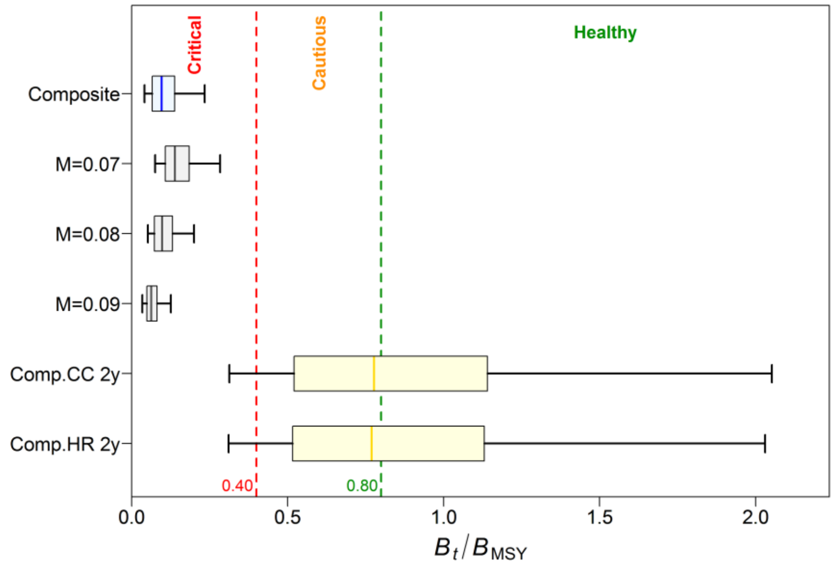

Figure 6. Status of the coastal BOR stock relative to the DFO Precautionary Approach (PA) provisional reference points of 0.4B_{MSY} and 0.8B_{MSY} for the t=2020 composite base case and the component base runs that are pooled to form the composite base case. Also shown are projected stock status for the composite base case at the beginning of 2022 after fishing at a constant catch=200 tonnes/year or a constant exploitation rate of 0.04/year. 2022 is the second year that the 2016 cohort is assumed to contribute to the spawning population. Boxplots show the 0.05, 0.25, 0.5, 0.75 and 0.95 quantiles from the MCMC posterior.

Projection Results and Decision Tables

Ten-year projections, starting with the biomass at the beginning of 2020, were made over a range of constant catch levels (0-600 tonnes in 50 tonne increments) and harvest rates (0-0.12/year in 0.01/year increments, available in the Research Document). This time frame was considered adequate for advice to managers before the next stock assessment of this species, especially given that these projections are dominated by the 2016 cohort, which is by far the primary contributor to any short-term biomass increase. Note that the uncertainty in rebuilding increases the further forward in time they are projected. While all projections should be treated with caution, projections beyond 10 years should be treated with additional caution. The decision table (Table 2) gives the probabilities of the spawning biomass exceeding the biomass reference points and of being below u_{MSY} in each projected year for each catch level. Note that these tables assume that catches are held constant, so there is no consequent reduction of the exploitation rate in the projections if a stock reaches the Cautious or Critical zones.

At all levels of evaluated catch, Table 2 shows that a manager would be ≥ 99% certain that both B_{2025} and B_{2030} are above the LRP of 0.4B_{MSY}, ≥89% certain that B_{2025} and ≥93% certain that B_{2030} are above the USR of 0.8B_{MSY}, and ≥98% certain that u_{2025} and u_{2030} are below u_{MSY} for the composite base case. The preferred catch and risk levels used in managing the BOR stock are management choices. For example, it may be desirable to be 95% certain that B_{2025} exceeds an LRP whereas exceeding a USR might only require a 50% probability. Assuming this risk profile, all the catch policies in Table 2 would satisfy the specified LRP and USR constraints. Assuming that u_{MSY} is a limit exploitation rate, all the catch policies in Table 2 beginning in 2021 define harvest rates that would be less than u_{MSY} with a probability of at least 95%.

Table 2. Decision tables for the reference points $0.4B_{MSY}$, $0.8B_{MSY}$, and u_{MSY} for 1-10 year projections for a range of constant catch policies (in tonnes) using the composite base case. Values are the probability (proportion of 3000 MCMC samples) of the female spawning biomass at the start of year t being greater than the B_{MSY} reference points, or the exploitation rate of vulnerable biomass in the middle of year t being less than the u_{MSY} reference point. For reference, the average annual catch over the last 5 years (2015-2019) was 69 tonnes.

P(B_t >0.4B_{MSY})

Catch		Projection year									
policy	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
0	<0.01	0.66	0.88	0.97	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
50	<0.01	0.66	0.88	0.97	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
100	<0.01	0.66	0.88	0.97	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
150	<0.01	0.66	0.88	0.97	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
200	<0.01	0.65	0.87	0.97	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
250	<0.01	0.65	0.87	0.97	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
300	<0.01	0.65	0.87	0.96	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
350	<0.01	0.65	0.86	0.96	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
400	<0.01	0.64	0.86	0.96	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
450	<0.01	0.64	0.86	0.96	0.99	0.99	>0.99	>0.99	>0.99	>0.99	>0.99
500	<0.01	0.64	0.86	0.96	0.99	0.99	>0.99	>0.99	>0.99	>0.99	>0.99
550	<0.01	0.64	0.85	0.96	0.98	0.99	>0.99	>0.99	>0.99	>0.99	>0.99
600	<0.01	0.64	0.85	0.95	0.98	0.99	0.99	>0.99	>0.99	0.99	0.99

P(B_t >0.8B_{MSY})

Catch		Projection year									
policy	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
0	0	0.21	0.49	0.73	0.87	0.94	0.96	0.97	0.97	0.97	0.98
50	0	0.20	0.49	0.73	0.87	0.93	0.96	0.97	0.97	0.97	0.97
100	0	0.20	0.49	0.73	0.86	0.93	0.96	0.97	0.97	0.97	0.97
150	0	0.20	0.48	0.72	0.85	0.93	0.96	0.96	0.96	0.97	0.97
200	0	0.20	0.48	0.72	0.85	0.92	0.95	0.96	0.96	0.96	0.97
250	0	0.20	0.48	0.72	0.85	0.92	0.95	0.96	0.96	0.96	0.96
300	0	0.20	0.48	0.71	0.85	0.92	0.94	0.95	0.96	0.96	0.96
350	0	0.20	0.47	0.71	0.84	0.91	0.94	0.95	0.95	0.96	0.96
400	0	0.19	0.47	0.70	0.84	0.91	0.94	0.95	0.95	0.95	0.95
450	0	0.19	0.46	0.70	0.83	0.90	0.93	0.94	0.94	0.95	0.95
500	0	0.19	0.46	0.70	0.83	0.90	0.93	0.94	0.94	0.94	0.94
550	0	0.19	0.46	0.69	0.82	0.89	0.93	0.93	0.93	0.93	0.94
600	0	0.19	0.45	0.68	0.82	0.89	0.92	0.93	0.93	0.93	0.93

P(u_t <u_{MSY})

Catch		Projection year									
policy	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
0	1	1	1	1	1	1	1	1	1	1	1
50	1	1	1	1	1	1	1	1	1	1	1
100	>0.99	>0.99	1	1	1	1	1	1	1	1	1
150	0.98	>0.99	>0.99	1	1	1	1	1	1	1	1
200	0.95	0.99	>0.99	>0.99	>0.99	1	1	1	1	1	1
250	0.89	0.97	0.99	>0.99	>0.99	>0.99	1	1	1	1	1
300	0.81	0.94	0.99	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
350	0.72	0.91	0.97	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
400	0.63	0.86	0.96	0.99	0.99	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99
450	0.56	0.82	0.93	0.97	0.99	0.99	0.99	>0.99	>0.99	0.99	0.99
500	0.49	0.76	0.91	0.96	0.98	0.99	0.99	0.99	0.99	0.99	0.99
550	0.42	0.71	0.88	0.95	0.97	0.98	0.99	0.99	0.99	0.99	0.99
600	0.36	0.65	0.85	0.93	0.96	0.98	0.98	0.98	0.98	0.98	0.98

The associated Research Document (RD) also provides tables for rebuilding out to three generations; however, the current base case shows that a full recovery (with 95% probability) above the LRP will occur in three years and above the USR in six years, assuming catch policy does not exceed 250 tonnes/year (Table 2). Further, the stock will remain above the LRP for the next three generations under constant catch polices with a high probability (Table F.21, RD). Only under harvest rate scenarios greater than 0.08 does the spawning stock biomass begin to decline such that the probability of remaining above the LRP falls below 95% (Table F.22, RD).

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. These intervals and probabilities are only valid for the specified model using the weights assigned to the various data components across the three runs comprising the composite base case. The Bayesian approach also relies on the prior belief about each input parameter. In particular, the Technical Working Group noted that natural mortality (*M*) was a key uncertainty for this species, especially as it could not be estimated given the available data. Using a plausible range of *M* values helped to capture this uncertainty in model results.

Other uncertainties were explored through sensitivity runs. These included:

- productivity assumptions – changing standard deviation of recruitment residuals, using an alternative growth model;
- abundance – decreasing/increasing historical catch, removing the CPUE signal, dropping the historical surveys;
- composition – narrowing ageing error, using a full maturity ogive.

Most sensitivity runs remained primarily in the Critical zone. Explorations of alternative model runs that dropped abundance indices (CPUE, historical surveys) improved perceived stock status relative to B_0; however, these runs had either poor or unacceptable MCMC diagnostics. Using a full maturity ogive also increased perceived stock status, because small proportions of fish aged 1-4 were included in the spawning stock.

Uncertainty in the strength of the 2016 cohort was explored through a projection sensitivity run which used only the lowest 5th percentile of the 2016 recruitment posterior distribution to estimate future stock status. These projections extended the time required to rebuild biomass above the LRP and the USR by only 2 years.

Although the coastwide population of BOR might comprise multiple stocks, these could not be separated given the data available at the time of the stock assessment. Future assessments might adopt spatially distinct stocks if additional data support subdivision.

Ecosystem Considerations and Climate Change

DFO groundfish fisheries managers have worked in consultation with science, industry and non-government organisations to implement measures in the commercial trawl fishery to protect bottom habitat, foster biodiversity, and ensure that these fisheries remain sustainable. These actions, described below, will benefit all species impacted by this fishery, including Bocaccio.

In 2012, measures were introduced to reduce and manage the bycatch of corals and sponges by the BC groundfish bottom trawl fishery. These measures were developed jointly by industry and environmental non-governmental organisations, which include: limiting the footprint of groundfish bottom trawl activities to manage the trawl fishery impacts on significant ecosystem components such as corals and sponges, establishing a combined bycatch conservation limit for corals and sponges, and establishing an encounter protocol. These measures also restrict access by bottom trawling to less than one-half of the available benthic habitat (stratified by area and depth) on the BC coast, thus providing protection for areas frequented by juvenile groundfish of many species as well as juvenile and adult BOR. These measures have been incorporated into DFO's Pacific Region Groundfish Integrated Fisheries Management Plan.

To further mitigate ecosystem risk, all BC commercial Groundfish fisheries are subject to the following management measures: 100% at-sea monitoring, 100% dockside monitoring, individual vessel accountability for all retained and released catch, individual transferable quotas and reallocation of these quotas between vessels and fisheries to cover catch of non-directed species (see aforementioned Management Plan). These measures ensure that impacts on non-target species, 'Endangered, Threatened and Protected' (ETP) species and biogenic habitat components (coral and sponge) are well monitored.

In addition to the fishery dependant ecosystem and fishery monitoring, DFO, in collaboration with industry partners, conduct a suite of fishery independent random depth-stratified surveys (using bottom trawl, demersal hook and line, and trap gears), which provide comprehensive coast wide coverage biennially of most offshore benthic habitats between the depths of 50 and 500 m. This suite of surveys provides an important layer of information with very high specificity ensuring that ecosystem components vulnerable to fishing gears are monitored.

While assessments and harvest options for groundfish species in the Pacific region are provided on a single species basis, the fishery is managed in a multi-species context wherein many single species quotas are managed simultaneously. Additionally, freezing the footprint of the trawl fishery reduces the likelihood of impacts from the activities of the commercial bottom trawl fleet expanding into new benthic habitats.

It is not known how climate change will affect this species or the conclusions made by this stock assessment. Although there is agreement that warmer temperature regimes and changes to other environmental variables such as dissolved oxygen will affect marine species, the exact nature of these effects is poorly understood. Previous attempts at incorporating climate variables into stock assessments such as this one have proved unsuccessful, largely due to low contrast in the introduced series, a too-short time series, or overly simplistic (or unrealistic) functional models. Warmer temperatures may affect recruitment processes, natural mortality, and growth, any of which may affect stock resilience, productivity, and status relative to reference points which may in turn alter the perception of consequences associated with varying harvest levels relative to stock status. As well, reference points which rely on equilibrium conditions will shift because changing temperature regimes imply a change in productivity and consequently a different equilibrium level. Understanding the effect of climate change in a marine context will require additional monitoring and analyses.

While occasional large recruitment events can be considered to be typical among species of *Sebastes*, such events tend to occur every 10 to 25 years in other species of this genus that have been assessed. Bocaccio appears to be an outlier species, with only one large cohort observed in over 60 years of potential data. While the existence of the large 2016 cohort is welcome information that is predicted to lead to recovery, it is noted that the southern California population of BOR has had several good recent recruitments that have led to recovery in that population.

There was considerable discussion amongst the peer review participants of possible linkages between environmental variables, BOR recruitment, and rockfish recruitment more generally as there have been a number of significant recruitment events for BOR as well as other rockfish species along the Pacific coast of North America over the last decade. Such recruitment events, while likely driven by environmental events, are difficult to evaluate because of their rarity and the indirect causality associated with these events. For example, it is possible that the coincident timing of a marine heat wave in the NE Pacific Ocean (2014-15), coined the 'The Blob', and the current strong BC BOR recruitment event are linked, but the intermediate causation steps are poorly understood

CONCLUSIONS AND ADVICE

In common with other BC rockfish stock assessments, this stock assessment depicts a slow-growing, low productivity stock. However, what is unusual about this stock assessment is that this stock appears to be even less productive than would be expected for the apparent rate of natural mortality suggested by the available ageing information. The exploitation rates estimated by the model, which reach their highest point at around 0.06/y, a level much lower than that seen in other recent rockfish stock assessments, should result in catches below replacement levels and allow the population to increase. But such increases had not been observed until evidence began to accumulate from the large 2016 cohort. The number of good recruitment events appear to be few for BOR, which has steadily declined over the period 1935–2020, in spite of the low exploitation rates stemming from management actions that have reduced recent removals to 100 tonnes or less per year. These results corroborate the findings in previous stock assessments of BOR. However, what distinguishes this stock assessment from the previous ones is the signal of new recruitment in the form of the strong 2016 year class, which is estimated by the composite base model to be 44 times (median estimate; 5-95% range: 30–58) the long-term average recruitment.

The RPR meeting participants recommended biennial updates of the current assessment to track progress of the strong 2016 cohort. The two-year interval is the minimum elapsed time required to obtain a complete cycle of bottom trawl survey results. This set of survey observations will provide a coast wide view of BOR abundance, which is needed to update this stock assessment, including revised decision tables.

Scheduling of the next full assessment depends on the actual strength of the recruiting 2016 year class, as it develops in the coming years. If it continues to show a strength consistent with the evaluation in this stock assessment, then coastal BOR should rebuild to levels above the USR in 3–5 years, and the need to re-evaluate this stock assessment can be postponed for a few years. The existing synoptic trawl surveys, particularly the Queen Charlotte Sound (QCS) and west coast Vancouver Island (WCVI) surveys, should provide adequate monitoring of this year class in the coming years. The next full stock assessment should be scheduled in 2025 (or possibly later), such that there will be at least two new indices from both the QCS and WCVI synoptic surveys. Regardless of when a new stock assessment is scheduled, technicians need 6-12 months to process and read new ageing structures before assessment scientists can begin the reconstruction of a population trajectory. Advice for interim years is explicitly included in the decision tables and managers can select another line on the table if stock abundance appears to have changed or if greater certainty of staying above the reference point is desired.

Advice to management is provided in the form of decision tables. These tables assume the composite base case model is valid and there will be no management interventions if stock status falls below accepted reference points at any level of constant catch.

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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.

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THIS REPORT IS AVAILABLE FROM THE:

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ISSN 1919-5087

Correct Citation for this Publication:

DFO. 2022. Arrowtooth Flounder (Atheresthes stomias) Stock Assessment for the West *Coast of British Columbia in 2021. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2022/nnn*

Aussi disponible en français :

MPO. 2022. Évaluation du stock de la plie à dents de flèche (Atheresthes stomias) sur la côte ouest de la Colombie-Britannique pour 2021. Secr. can. de consult. sci. du MPO, Avis sci. 2022/nnn.