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Pacific Region

Canadian Science Advisory Secretariat
Science Advisory Report 2015/055

ARROWTOOTH FLOUNDER (*ATHERESTHES STOMIAS*) STOCK ASSESSMENT FOR THE WEST COAST OF BRITISH COLUMBIA

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

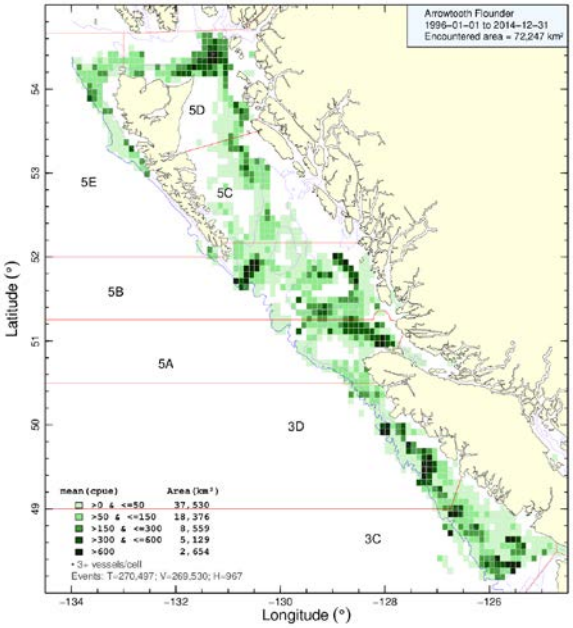

Figure 1. CPUE for Arrowtooth Flounder from bottom trawl fishery summed over 1996 to 2014 in grid cells 0.1 longitude by 0.075 latitude (approximately 58.6 km^2 each). The Pacific Marine Fisheries Commission major areas are outlined by red lines. The 2015 stock assessment for Arrowtooth Flounder was coastwide and included all areas labelled here.

Context:

Arrowtooth Flounder (Atheresthes stomias) is a significant species within the groundfish trawl fishery. Since 2006 the fishery has been subject to a coastwide trawl Total Allowable Catch of 15 000 mt. The Fisheries Management Branch of Fisheries and Oceans Canada requested advice on the status of Arrowtooth Flounder coastwide, and harvests consistent with DFO policy (Fishery Decision-Making Framework Incorporating The Precautionary Approach).

This Science Advisory Report is from the May 12-13, 2015 regional peer review on Coastwide Assessment of Arrowtooth Flounder (Atheresthes stomias) in 2014 and recommendations for 2015. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

- Arrowtooth Flounder (*Atheresthes stomias*) is a commercially important flatfish species in British Columbia, which occurs throughout the entire coast. It is caught primarily using bottom trawl gear, with a mean annual coastwide catch (landings + at-sea releases) of 8,532 t between 2010 and 2014.
- All areas of Canada's Pacific coast, excluding waters between Vancouver Island and the British Columbia mainland, were assessed as a single stock, using an annual female-only catch-at-age model, implemented in a Bayesian framework to quantify uncertainty of estimated quantities.
- The model was fit to catch and survey data from 1996 to 2014. Catch data prior to 1996 were not used in the assessment due to unknown levels of releasing at sea prior to the introduction of Total Allowable Catches (TACs).
- The median spawning biomass (mature females only) at the beginning of 2015 (B_{2015}) is estimated to be 296,271 t (95% credibility interval: 146,337-760,905 t).
- Decision tables are presented using two sets of reference points:
    (i) the provisional DFO Limit Reference Point (LRP) $0.4B_{MSY}$ and Upper Stock Reference (USR) Point $0.8B_{MSY}$ (DFO 2009); and
    (ii) alternative LRP′ = $0.2B_0$ and USR′ = $0.4B_0$.
- Advice to management is presented in the form of decision tables, using a one-year projection for a range of catches up to 50,000 t/year (average coastwide catch over 2010-2014 was 8,532 t). The probability of dropping below the LRP at the beginning of 2016 is estimated to be zero for all catches tested. The probability of dropping below the USR at the beginning of 2016 is estimated to be close to zero. Stock size is not likely to decrease at any of the projected catch levels tested.
- All model-based results are expressed in terms of female Arrowtooth Flounder. Where appropriate, catch advice is scaled up using an average proportion of females caught by fishery and survey.
- The magnitude of at-sea releases prior to 1996 is a major source of uncertainty in this assessment. Reconstruction of historical releases based on advice from the fishing industry is recommended.
- There was uncertainty in the estimated age composition of the population, given the current availability of age data. There remain unaged samples from the commercial fleet and some surveys, and it is recommended that these samples, particularly those from the freezer trawl fleet, be aged before the next assessment of this species.

INTRODUCTION

Arrowtooth Flounder (*Atheresthes stomias*, Family Pleuronectidae), also locally called Turbot, is a species of flatfish that occurs in the offshore waters of British Columbia (BC). Arrowtooth Flounder is primarily taken by the groundfish bottom trawl fishery (Figure 1), although it is also encountered in small amounts by hook and line fisheries, particularly those targeting Pacific Halibut (*Hippoglossus stenolepis*). Since 1996, catches have typically been more than 70% female. Prior to the introduction of freezer trawlers in the BC groundfish fleet in the mid-2000s, most of the historical catch of Arrowtooth Flounder is understood to have been released at sea, due to the low value commanded by the species. Proteolysis occurs in the muscle tissue of this

species a short time after it is caught, making the flesh mushy and unpalatable. In the past five years, strong markets in Asia have been established for products derived from Arrowtooth Flounder, cleaned and frozen at sea as soon as possible, to reduce proteolysis

In 2005, as the new market in Asia became available, fishing increased (Figure 2). However, problems with product deterioration, as described above, resulted in greatly reduced fishing the following year (Figure 2). Since 2010, four freezer trawlers have joined the fishery, and have increased their proportion of total catch each year. The stock was last assessed by Fargo and Starr (2001), who presented empirical summaries of catch, commercial and survey catch-per-unit-effort (CPUE), and biological data. This stock assessment covers the combined Pacific Marine Fisheries Commission (PMFC) major areas 3CD and 5ABCDE off the west coast of BC (Figure 1).

ASSESSMENT

This report summarizes the key results from a quantitative stock assessment for coastwide Arrowtooth Flounder. An annual, female-only model was applied and tuned to four series of fishery-independent trawl survey data, annual estimates of commercial catch since 1996, and age composition data from the commercial fishery and from three of the four survey series. The last four years of the time series were used to calculate the mean proportion of females in the commercial catch; the proportion of females in surveys used all years available (Table 1).

The model estimates stock-recruitment parameters, natural mortality, catchability coefficients for the survey series, selectivity parameters for the commercial fishery and those survey series for which age data are available (three synoptic surveys), and a time series of recruitment deviations from the predicted stock-recruitment function. Estimated parameters were used to calculate maximum sustainable yield (MSY) and associated reference points. All calculations were made using the Bayesian Markov Chain Monte Carlo (MCMC) procedure to quantify the uncertainty associated with parameter estimation. Posterior estimates of various quantities are presented here as median values of the posterior sample (with 2.5-97.5% percentiles). Uncertainty associated with data and model assumptions was explored through sensitivity runs.

Figure 2 shows time series of the estimated median depletion (B_{2015}/B_0), median exploitation rates, and the reconstructed historical catches. Figure 3 shows the estimated median depletion with a 95% credibility interval. The results show that the reconstructed spawning biomass has remained relatively stable, with a moderate increasing trend over the time series. Catches declined from 2005 to 2010 and biomass increased over this period up to the present. Stock status was determined using two sets of reference points:

(i) the provisional DFO limit reference point (LRP) $0.4B_{MSY}$ and upper stock reference (USR) point $0.8B_{MSY}$ (DFO 2009); and

(ii) alternative LRP′ = $0.2B_0$ and USR′ = $0.4B_0$ (Table 2). The estimate of B_{2015}/B_0, the ratio of coastwide female spawning biomass at the start of 2015 (B_{2015}) to that for unfished conditions (B_0) is also given in Table 2.

Table 1. Proportion of females for the trawl fishery and four surveys (QCSS = Queen Charlotte Sound Synoptic, HSMSA = Hecate Strait Multi-species Assemblage, HSS = Hecate Strait Synoptic, WCVIS =West Coast Vancouver Island Synoptic).

Year	Commercial Fishery		Surveys				
	Coast	WCVI	QCS+HS	QCSS	HSMSA	HSS	WCVIS
1996	0.854	0.860	-	-	-	-	-
1997	0.901	0.787	0.905	-	-	-	-
1998	0.778	0.635	0.789	-	0.714	-	-
1999	0.835	0.814	0.794	-	-	-	-
2000	0.834	0.787	0.950	-	0.908	-	-
2001	0.879	0.707	0.940	-	-	-	-
2002	0.857	0.869	0.855	-	0.830	-	-
2003	0.754	0.786	0.803	0.825	-	0.838	-
2004	0.868	0.850	0.866	0.812	-	-	0.838
2005	0.867	0.915	0.847	0.844	-	0.771	-
2006	0.849	0.853	0.865	-	-	-	0.897
2007	0.839	0.785	0.835	0.764	-	0.781	-
2008	0.909	0.920	0.924	-	-	-	0.822
2009	0.701	0.778	0.698	0.794	-	0.763	-
2010	0.724	0.606	0.730	-	-	-	0.813
2011	0.739	0.812	0.709	0.748	-	0.798	-
2012	0.827	0.828	0.851	-	-	-	0.786
2013	0.792	0.844	0.834	0.716	-	0.753	-
2014	0.786	0.623	0.821	-	-	-	0.777
4-y mean	0.786	0.743	0.789	-	-	-	-
All-years	0.821	0.793	0.834	0.786	0.817	0.784	0.822

Table 2. The 2.5th, 50th and 97.5th percentiles from the posterior distributions of quantities of importance derived from the model results. Definitions are: B_0 = unfished equilibrium spawning biomass (mature females), B_{2015} = spawning female biomass at the start of 2015, U_{MSY} = equilibrium exploitation rate at MSY. All biomass values and MSY are in tonnes. For reference, the average coastwide catch over the last five years (2010-2014) was 8,532 t.

	Percentiles		
	2.5	**50**	**97.5**
B_0	244,064	495,407	1,257,780
MSY	28,999	65,333	195,309
B_{MSY}	56,340	117,828	302,674
F_{MSY}	4.617	18.757	77.092
U_{MSY}	0.990	1.000	1.000
B_{2015}	146,337	296,271	760,905
B_{2015}/B_0	0.376	0.599	0.938
$0.2B_0$	48,813	99,081	251,556
$0.4B_0$	97,626	198,163	503,112
$0.4B_{MSY}$	22,536	47,131	121,070
$0.8B_{MSY}$	45,072	94,262	242,139
B_{1996}	122,058	205,747	434,021
F_{2014}	0.064	0.136	0.242

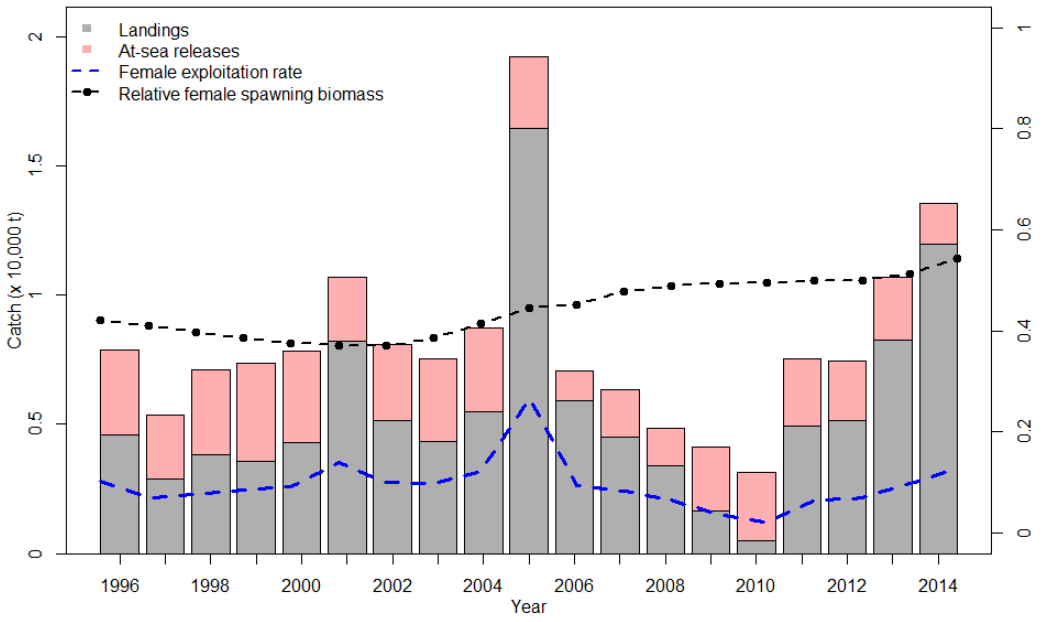

Figure 2. Annual commercial landings and at-sea-releases (vertical bars, relative to left-hand axis) and median estimates for B_t/B_0 (female spawning biomass in year t relative to that estimated to be the initial female biomass) and exploitation rate u_t (ratio of total catch to the vulnerable biomass in the middle of year t) both relative to the right-hand axis (expressed as a proportion).

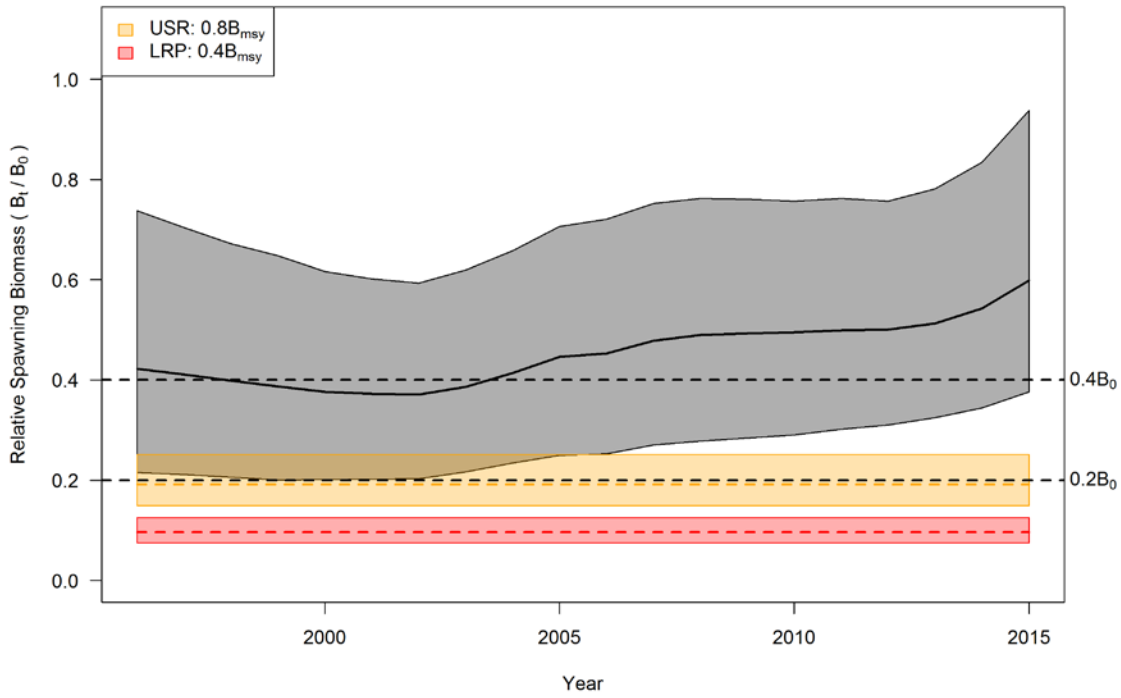

Figure 3. Median estimates and 95% credibility intervals for B_t/B_0 (female spawning biomass in year t relative to estimated initial female biomass) for Arrowtooth Flounder (solid black line and grey fill). Also shown are median estimates (dashed lines inside shaded boxes) and 95% credibility intervals for the MSY-based reference points (LRP: Limit Reference Point = $0.4B_{MSY}$; USR: Upper Stock Reference Point = $0.8B_{MSY}$) relative to B_0. The B_0-based reference points $0.2B_0$ and $0.4B_0$ are shown as dashed horizontal black lines.

Projection Results and Decision Tables

Advice to managers is presented as a decision table (Table 3) that provide probabilities of the 2016 stock being below biomass-based reference points or exceeding exploitation reference points. The projections were made from the start of 2015 to the start of 2016 over a range of catch levels (0-30,000 t in 1,000 or 2,000 t increments). A 50,000 t projection was also included at the request of management during the review meeting. Projections were made for one year only due to large model uncertainty that stems from the lack of early catch history and the potential bias in estimated trawl selectivity.

As model results are expressed in terms of females only, the 2015 catch levels are also adjusted to total catch using two alternative methods:

(i) average proportion of females for all years 1996-2014; and

(ii) average proportion of females for the last four years (2010-2014) to account for the increased proportion of catch from freezer trawlers during this period (Table 3).

Figure 4 depicts projected 2016 stock status with respect to the B_{MSY} and B_0-based reference points. In both cases, the 95% credibility interval is projected to be entirely within the healthy zone (above the USR).

With a female catch of 12,000 t (equivalent to a total catch of 15,300 t or 14,600 t), which is approximately equal to the TAC for recent years (15,000 t), the probability of the stock entering the critical zone, $P(B_{2016} < \text{LRP})$, is zero for both the B_{MSY} and B_0-based reference points (Table 3). Stock size is expected to remain around the current level under all catch scenarios under a 30,000 t 2015 female catch, where $P(B_{2016} < B_{2015}) = 0.13$. Note that for a 50,000 t female catch, $P(B_{2016} < B_{2015})$ increases threefold to 0.425.

Uncertainty in the estimated parameters and quantities is explicitly addressed using a Bayesian approach, but reflects only uncertainty in the specified model and weights assigned to the various data components. However, results from sensitivity runs (not shown here) do not differ greatly from the base run.

Table 3. Decision tables for the coastwide Arrowtooth Flounder stock projected one year to 2016 using various reference points over a range of constant annual catch strategies. Values are the probabilities P of the spawning biomass (mature females) at the start of projection year 2016 being greater than the reference point for the given annual catch strategy. The probabilities are the proportion of the MCMC samples for which B_{2016} is greater than the respective reference point. For comparison, the average catch (landings + releases) over the last five years (2010-2014) is 8,532 t. Adj. FT Catch is the female catch policy multiplied by the inverse of the mean proportion of females from the last four years (when freezer trawlers were present). Adj. All Catch is the female catch policy multiplied by the inverse of the mean proportion of females from 1996-present.

2015 Catch (1000 t)	Adj. FT Catch (prop.♀ 0.786)	Adj. All Catch (prop.♀ 0.821)	$P(B_{2016}< B_{1996})$	$P(B_{2016}< B_{2015})$	$P(B_{2016}< 0.2B_0)$	$P(B_{2016}< 0.4B_0)$	$P(B_{2016}< 0.4B_{MSY})$	$P(B_{2016}< 0.8B_{MSY})$	$P(U_{2015}> U_{2014})$	$P(U_{2015}> U_{MSY})$
0	0	0	0.023	0	0	0.01	0	0.001	0	0
2	2.5	2.4	0.025	0	0	0.01	0	0.001	0	0
4	5.1	4.9	0.028	0	0	0.011	0	0.001	0	0
6	7.6	7.3	0.028	0	0	0.014	0	0.001	0	0
8	10.2	9.7	0.031	0	0	0.016	0	0.001	0	0
10	12.7	12.2	0.033	0	0	0.017	0	0.001	0.269	0
11	14.0	13.4	0.034	0	0	0.02	0	0.001	0.845	0
12	15.3	14.6	0.035	0	0	0.02	0	0.001	0.998	0
13	16.5	15.8	0.038	0.001	0	0.02	0	0.001	1	0
14	17.8	17.1	0.038	0.001	0	0.021	0	0.001	1	0

2015 Catch (1000 t)	Adj. FT Catch (prop.♀ 0.786)	Adj. All Catch (prop.♀ 0.821)	$P(B_{2016}< B_{1996})$	$P(B_{2016}< B_{2015})$	$P(B_{2016}< 0.2B_0)$	$P(B_{2016}< 0.4B_0)$	$P(B_{2016}< 0.4B_{MSY})$	$P(B_{2016}< 0.8B_{MSY})$	$P(U_{2015}> U_{2014})$	$P(U_{2015}> U_{MSY})$
15	19.1	18.3	0.039	0.006	0	0.021	0	0.001	1	0
16	20.4	19.5	0.042	0.009	0	0.021	0	0.001	1	0
17	21.6	20.7	0.042	0.012	0	0.021	0	0.001	1	0
18	22.9	21.9	0.042	0.013	0	0.022	0	0.001	1	0
19	24.2	23.1	0.042	0.014	0	0.022	0	0.001	1	0
20	25.4	24.4	0.044	0.019	0	0.023	0	0.001	1	0
22	28.0	26.8	0.05	0.035	0	0.028	0	0.001	1	0
24	30.5	29.2	0.056	0.052	0	0.03	0	0.001	1	0
26	33.1	31.7	0.062	0.072	0	0.03	0	0.001	1	0
28	35.6	34.1	0.064	0.1	0	0.031	0	0.001	1	0
30	38.2	36.5	0.066	0.13	0	0.036	0	0.002	1	0
50	63.6	60.9	0.116	0.425	0	0.064	0	0.002	1	0

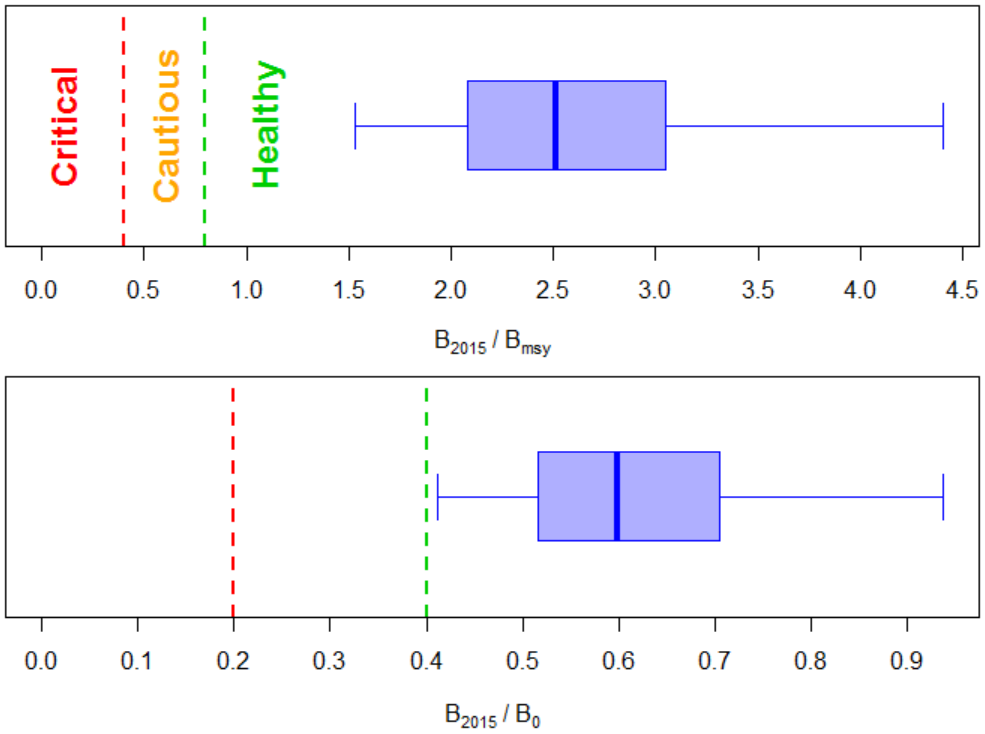

Figure 4. Status of the BC 2015 coastwide Arrowtooth Flounder stock relative to the DFO precautionary approach provisional reference points of $0.4B_{MSY}$ and $0.8B_{MSY}$ (top) and relative to alternative reference points of $0.2B_0$ and $0.4B_0$ (bottom). Boxplots show the 2.5th, 25th, 50th, 75th and 97.5th percentiles from the MCMC results. The dashed red line represents $0.4B_{MSY}$ in the top panel and $0.2B_0$ in the bottom panel; the dashed green line represents $0.8B_{MSY}$ in the top panel and $0.4B_0$ in the bottom panel.

Ecosystem Considerations

In 2012, measures were introduced to reduce and manage the non-directed catch of corals and sponges by the British Columbia groundfish bottom trawl fishery. These measures were developed jointly with industry and environmental non-governmental organizations, and include: limiting the footprint of groundfish bottom trawl activities, establishing a combined non-directed catch conservation limit for corals and sponges, and establishing an encounter protocol for individual trawl tows when the combined coral and sponge catch exceeds 20 kg. These

measures have been incorporated into DFO's Pacific Region Integrated Fisheries Management Plan for Groundfish (DFO 2014).

The BC integrated groundfish fishery is also 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 (DFO 2014).

Sources of Uncertainty

Uncertainty in the estimated parameters and management quantities is explicitly addressed using a Bayesian approach, but reflects only the specified prior and model assumptions, and the weights assigned to the various data components by the model-fitting procedure. The magnitude of catch and releases prior to 1996 is a major source of uncertainty in this assessment. The technical working group recommended that catch data prior to 1996 should be omitted from this assessment until agreed-upon reconstructed catches are available. Reconstruction of the catch history, in collaboration with industry, is highly recommended to better resolve the size and productivity of this fish stock. Such a reconstruction will be difficult because it is thought that the level of releases during this early period far exceeded the level of reported landings due to the low value of the species and its poor keeping qualities.

The estimated age-at-50% selectivity for the trawl fishery was 4-5 years older than the age-at-50% maturity, implying that fish could spawn several times before becoming vulnerable to the fishery. This strongly affected estimates of reference points. Two sensitivity analyses were conducted to explore this, where trawl fishery selectivity was fixed at younger ages and age compositions for the fishery were removed from the model. These changes resulted in a much lower estimate of female spawning biomass, a reduction in u_{MSY}, and a corresponding increase in B_{MSY}. Information about fishery selectivity primarily comes from age-composition data, which had considerable uncertainty in this assessment. In particular, selectivity differences between freezer trawlers and shoreside bottom trawlers need to be refined to understand if there are differences between these two components of the fleet. To this end, the ageing of archived otoliths from the freezer trawl fleet should become a high priority. Development of a two-fleet model with the freezer trawlers represented as a separate fleet may also help to resolve uncertainties in fishery selectivity. Spatial analysis of stock structure in BC is also recommended.

CONCLUSIONS AND ADVICE

This assessment depicts a large stock. For the fishery, the estimated age-at-50% selectivity was 4-5 years higher than the estimate for age-at-50% maturity. This difference reduces the estimated vulnerable biomass to levels that suggest the vulnerable stock could be fully harvested in each year without compromising the reproductive success of the population. This is because a large component of the spawning biomass is protected from exploitation due to the commercial preference for larger fish. However, this advice should be treated with high caution, due to significant uncertainties in the assessment and the possibility that commercial selectivity could change over time.

The magnitude of released catch before 100% observer coverage was implemented in 1996 was a major source of uncertainty in this assessment. Estimates of the level of these releases would provide critical information about the scale and productivity of this stock, which is poorly estimated in this assessment. The level of releases during this early period likely far exceeded the level of reported landings due to the low value of the species and its poor keeping qualities. A reconstruction of catch for the pre-1996 years would require input from industry members who

were involved with the fishery at that time, since there are no reliable records of the at-sea releases before 1996.

Total catch in the commercial groundfish fisheries has been well recorded as a result of independent at-sea and dockside monitoring of the fishery, beginning in 1996. These data, together with on-going results from surveys, give confidence that future assessments can continue to monitor this stock and that action can be taken if required.

SOURCES OF INFORMATION

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