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WALLEYE POLLOCK (*THERAGRA CHALCOGRAMMA*) STOCK ASSESSMENT FOR BRITISH COLUMBIA IN 2017

Walleye Pollock (Theragra chalcogramma). Credit: Washington Department of Fish and Wildlife.

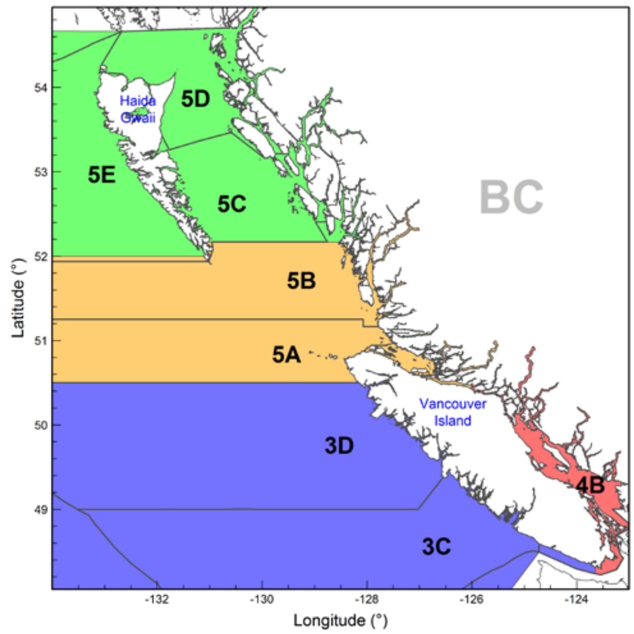

Figure 1. Walleye Pollock assessment areas comprising Pacific Marine Fisheries Commission (PMFC) major and minor areas – green for 5CDE, orange for 5AB + minor area 12, blue for 3CD + minor area 20, and red for 4B less minor areas 12 and 20. The Groundfish Management Unit area boundaries, which differ from PMFC area, are superimposed for comparison. This assessment is for areas called 'North' (5CDE, green) and 'South' (5AB3CD, orange + blue).

Context:

Walleye Pollock (Theragra chalcogramma) is caught by the trawl fishery, primarily as a target species in midwater tows (~92% of the catch) and secondarily as bycatch in bottom tows (~8% of the catch). Previous assessments identified four primary spawning grounds along the BC coast; however, in this assessment two stocks, dubbed BC North and BC South, are identified on the outer coast based on mean weight differences and are assessed separately. Annual BC offshore total allowable catch (TAC) limits were first set in 1995 for PMFC areas 5CDE and 5AB (initially 4650 t combined) and is currently 3110 t. A quantitative population dynamics model has not previously been used to assess this species. The Fisheries Management Branch of Fisheries and Oceans Canada (DFO) requested that the Walleye Pollock stock be assessed relative to reference points that are consistent with the DFO Precautionary Approach (DFO 2009), and that probabilistic decision tables be produced that forecast the effect of a range of fixed annual harvest levels on stock status.

This Science Advisory Report is from the November 14-15, 2017 regional peer review on Walleye Pollock (Theragra chalcogramma) stock assessment for British Columbia in 2017. Additional publications from this meeting will be posted on the [Fisheries and Oceans Canada (DFO) Science Advisory Schedule](#) as they become available.

SUMMARY

- A new stock assessment is presented for two British Columbia (BC) stocks of Walleye Pollock (*Theragra chalcogramma*), with the BC North stock encompassing the three most northerly Pacific Marine Fisheries Commission (PMFC) major areas (5C, 5D, 5E) and the BC South stock including the remaining four outside PMFC major areas (3C, 3D, 5A, 5B plus minor areas 12 & 20).
- Stock definitions were selected on the basis of a difference in observed mean weights, with the BC North mean weights estimated near 1.0 kg/fish while the BC South mean weights averaged near 0.5 kg/fish.
- A delay-difference production model was used to assess each stock, using data from fishery-independent surveys, a CPUE series derived from bottom trawl commercial catch rates, and an annual mean weight series derived from unsorted commercial catch samples from each area.
- The available age data from BC were inadequate to derive growth models specific to BC; therefore, survey age samples from the Gulf of Alaska were used to specify growth for the BC North stock while a published Walleye Pollock growth model from the Asian Sea of Okhotsk was used for the BC South stock.
- Each assessment explored a range of plausible natural mortality values as well as a range of ages for the knife-edge selectivity assumption because the biomass indices and the mean weight data used in the delay-difference model were not informative for these parameters.
- The stock assessment was conducted in a Bayesian framework. Twelve model runs were made for the BC North stock and 11 for the BC South stock. Model-averaged scenarios were used to represent each stock based on model runs selected with criteria established at the peer review meeting.
- The two model-averaged scenarios were evaluated against reference points based on the biomass trajectory. The average spawning biomass from 1967-2016 (B_{avg}), was used as a proxy for B_{MSY}, while B_{min}, the minimum spawning biomass from which the stock subsequently recovered to B_{avg}, was used as the Limit Reference Point (LRP), in place of a provisional LRP of $0.4B_{MSY}$ (DFO 2009). The Upper Stock Reference (USR) was defined as 2 x B_{min}, in place of a provisional USR of $0.8B_{MSY}$ (DFO 2009). An Average Removal Rate, calculated as the estimated average fishing mortality for the period 1967-2016 (u_{avg}), was used in place of u_{MSY}.
- The model-averaged BC North stock was evaluated as being above the USR after 2000. The probabilities that the estimated spawning biomass at the beginning of 2017 (B_{2017}) was greater than the limit reference point (B_{min}), and greater than the upper stock reference point ($2B_{min}$) are 0.99 and 0.62, respectively. The probability that B_{2017} was greater than B_{avg} is 0.27. The estimated harvest rate in the final year (u_{2016}) has a probability of 0.74 of being greater than the estimated average harvest rate (u_{avg}), which means that the current harvest rate is likely above the average removal rate.
- The model-averaged BC South stock was evaluated as being above the USR for most of the period after 2008. The probabilities that the estimated spawning biomass at the beginning of 2017 (B_{2017}) is greater than the LRP and the USR are 1.00 and 0.96, respectively. The probability that B_{2017} is greater than B_{avg} is 0.34. The estimated harvest rate in the final year (u_{2016}) has a probability of 0.05 of being greater than the estimated

average harvest rate (u_{avg}), which means that current harvest is likely below the average removal rate.

- For each stock, the assessment provides a decision table which evaluates the probability of the model-averaged case staying above the five reference points across a range of 22 constant catches. The delay-difference model used in this stock assessment is less capable of making reliable multi-year projections than an age-structured model because it has no latent age structure to inform predictions and the stock-recruitment function is poorly determined. Projections longer than one or two years were considered less reliable; only one-year projections are presented in the SAR.

INTRODUCTION

Biology and Distribution

Walleye Pollock (WAP, *Theragra chalcogramma*) occur along the North Pacific rim, ranging from the Sea of Japan, extending north into Russian and Alaskan waters, and south through BC to southern California. The species primarily hugs the coastline in this range, but forms two large population centres in the Sea of Okhotsk and the Bering Sea. In BC, there are four primary spawning grounds – Dixon Entrance/northern Hecate Strait, Queen Charlotte Sound, SW Vancouver Island, and the Strait of Georgia (Saunders et al. 1989). The bulk (98%) of the commercial harvest from the BC North population is captured between depths of 55 m and 457 m, while harvest from BC South is captured between 90 m and 401 m in 5AB, and between 64 m and 470 m in 3CD.

Mean weight over the period 1973 to 2016 for the BC North stock was estimated to be 1.056 kg/fish and growth was derived from survey data for the eastern Gulf of Alaska where Walleye Pollock achieve similar weights. Mean weight over the period 1972 to 2016 for the BC South stock was estimated to be 0.521 kg/fish and growth was assumed to be equivalent to that for Walleye Pollock in the Sea of Okhotsk to the west of the Bering Sea where length distributions are similar to those for pollock in southern BC waters (see Assessment section). Natural mortality for the BC coast was assumed to be near 0.30, based on information in Alaskan stock assessments.

Fishery

Walleye Pollock is encountered mainly by midwater and bottom trawl gears in BC's integrated groundfish fishery, with negligible catches by the groundfish hook and line fishery (percentage of catch from 1996 to 2015: midwater trawl = 92.5%, bottom trawl = 7.5%, hook & line = negligible). In trawl tows that captured at least one Walleye Pollock between 62 m and 448 m coastwide, WAP accounted for 24.6% of the catch, followed by Arrowtooth Flounder (*Atheresthes stomias*, 15.7%), Pacific Ocean Perch (*Sebastes alutus*, 14.4%) and Pacific Hake (*Merluccius productus*, 12.5%) (Figure 2).

Annual TACs (total allowable catches) for this species were introduced in 1981 for the Gulf region (Strait of Georgia) and in 1995 for the offshore region; starting at 2900 t in area 5CDE, and 1750 t in 5AB. Since 1999, TACs have remained at 1115 t in the Gulf, 1320 t in 5CDE, and 1790 t in 5AB. In area 3CD, no TAC has been set except for 270 t in 1997. No TAC is allocated to the hook and line fisheries.

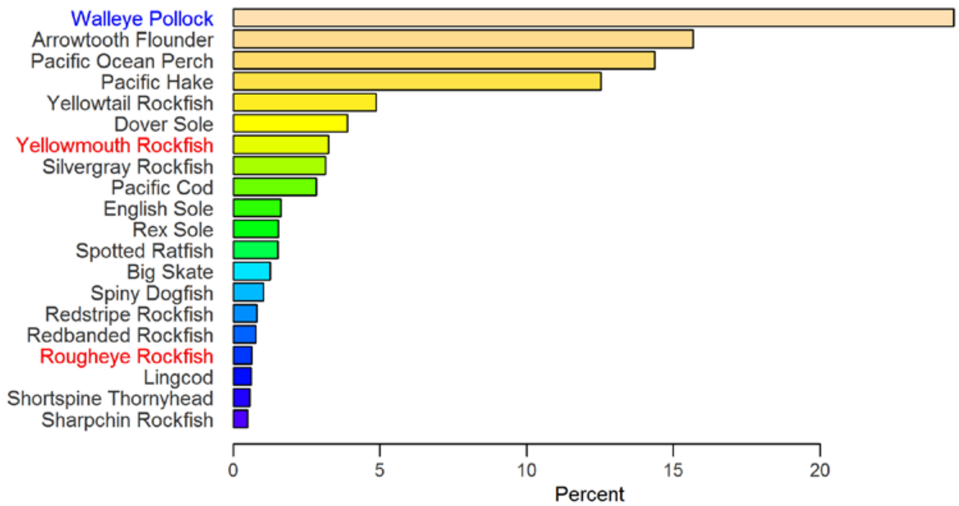

Figure 2. BC Offshore – Distribution of catch weights between February 1996 to January 2017 for important finfish species in bottom and midwater trawl tows that caught at least one Walleye Pollock coastwide. Tows were selected over a depth range between 62 and 448 m (the 1% and 99% quantile range). Relative concurrence is expressed as a percentage by species relative to the total catch weight summed over all finfish species in the specified period. Walleye Pollock is indicated in blue on the y-axis; species of interest to SARA (Species at Risk Act) are indicated in red.

ASSESSMENT

The modelling approach uses a delay-difference model previously developed to assess Pacific Cod (*Gadus macrocephalus*) by Forrest et al. (2015) and Shortspine Thornyhead (*Sebastolobus alascanus*) by Starr and Haigh (2017). The delay-difference model structure tracks the effects of recruitment, survival, and growth on biomass, and represents an intermediate option between a simple surplus production model and an age- or length-structured model. Four fishery-independent bottom trawl surveys in the North and three in the South were used to describe the relative abundance of Walleye Pollock over time in the stock assessment model. These surveys span a period from 1967 to 2016, which is the same period included in the delay-difference stock assessment model. The trawl surveys are:

- GB Reed Rockfish (1967-1995), covering Goose Island Gully (GIG) [BC North and South];
- HS Assemblage (1984-2003), covering Hecate Strait [BC North];
- HS Synoptic (2005-2015), covering all of Hecate Strait and extending into Dixon Entrance and across the top of Graham Island [BC North];
- WCHG Synoptic (2006-2016), covering the west coast of Graham Island in Haida Gwaii and western part of Dixon Entrance [BC North];
- WCVI Synoptic (2004-2016), covering the west coast of Vancouver Island [BC South];
- QCS Synoptic (2003-2015), covering all of Queen Charlotte Sound [BC South].

Commercial catch and effort data (CPUE) from the bycatch of Pollock in bottom trawls were used to generate an annual index series of abundance for each stock. This approach was taken to add a long-term continuous abundance series for use in this data-poor model. The bottom trawl CPUE index series were assumed to track biomass with the expectation that they would be relatively unaffected by economic considerations, given that Walleye Pollock caught in bottom trawls are not targeted (non-directed catch).

The available age data from BC were inadequate to derive growth models specific to either BC North or BC South populations, with few BC structures aged and the majority of ages determined using pectoral fin rays, a potentially biased methodology. Length-age data randomly selected (n = 847) from eastern Gulf of Alaska surveys between 2005 and 2015 (Martin Dorn, Research Fish Biologist, NOAA Fisheries, Sand Point, Seattle) were used to estimate a growth model for the BC North stock. These fish had all been aged from otoliths prepared using the “break & burn” method, and the growth model for the BC North stock adequately fit the observed mean weight data for three knife-edge ages (k) that determine selectivity to the fishery as well as maturity of 3, 4, and 5 years. The BC North stock may belong to a larger stock that includes Dixon Entrance, northern Hecate Strait, and waters off of Southeast Alaska (Gustafson et al. 2000).

The growth model used for the BC North stock was not used for the BC South stock because fish sampled from Dixon Entrance were, on average, twice as large as those sampled from southern BC waters, and consequently did not fit the available mean weight data. For the BC South stock, no satisfactory growth model based on data from the west coast of North America could be found to fit the observed mean weight indices. However, a growth model for Walleye Pollock in the central Sea of Okhotsk (Janusz and Horbowy 1997) was adopted because it provided satisfactory fits to the observed BC South mean weight data for knife-edge ages of selectivity to the fishery of 3, 4 and 5 years. There is no reason to believe that the Sea of Okhotsk relationship represents BC South other than the estimated Sea of Okhotsk growth (1991-94) was consistent with the observed BC South mean weight indices.

Annual mean weights are used in delay-difference models as absolute estimates of population mean weight, with the time series of mean weight indices providing information for estimating recruitment deviations. An additive General Linear Model (GLM) was fit to observed Walleye Pollock fish weights (estimated from lengths), sampled from unsorted commercial catch samples, to estimate an index series of annual mean weights. The GLM model corrected for trends due to minor Pacific Marine Fisheries Commission (PMFC) area for each sample, with the remaining explanatory factors having no impact on the observed indices. The geometric means of the observed annual mean weights (1.06 kg/fish in the North and 0.52 kg/fish in the South) were used to scale the indices of standardized mean weights.

Three values of natural mortality (M=0.25, 0.30, 0.35) were evaluated in this stock assessment to reflect the difficulty of ageing Walleye Pollock and values published in the literature. This range of natural mortality values is centred on M=0.30 because M=0.30 is the value used in stock assessments for Walleye Pollock in Alaska (Dorn et al. 2015).

Reference Points

The Sustainable Fisheries Framework (DFO 2009) established provisional reference points to guide management and assess harvest in relation to sustainability. The provisional reference points are the Limit Reference Point (LRP, limit below which biological harm occurs) of $0.4B_{\mathrm{MSY}}$ and the upper stock reference point (USR, a threshold below which management needs to consider conservation action) of $0.8B_{\mathrm{MSY}}$. Estimates of reference points based on maximum sustainable yield (MSY) were sensitive to model assumptions as were estimates of unfished biomass (B_0) and B_{MSY}. Consequently, this assessment adopted the following reference points based on the estimated biomass trajectory: B_{avg} (average spawning biomass from 1967-2016) in place of B_{MSY}, and B_{min} (spawning biomass in the year when the reconstructed biomass reached a minimum from which it subsequently recovered to B_{avg}) as the LRP, in place of $0.4B_{\mathrm{MSY}}$. The

USR was defined as $2B_{min}$ instead of the $0.8B_{MSY}$ provisional reference point. Therefore, the following reference points are used:

- Current spawning biomass: B_{2017}
- Limit Reference Point (LRP): B_{min}
- Upper Stock Reference (USR): $2B_{min}$
- B_{MSY} proxy: B_{avg} (average spawning biomass over the years 1967-2016)
- Average Removal rate: u_{avg} (average harvest rate over the years 1967-2016)

Model Results

Twelve model runs were made for the BC North stock and eleven for the BC South stock, representing pairings of values for M and k, two parameters that cannot be reliably estimated in a delay-difference model. The exclusion of some biomass indices was also explored in these runs. The meeting participants selected three of the BC North runs and six of the BC South runs to construct model-averaged composite scenarios to provide advice to fishery managers (Table 1). Run selection criteria were: 1- no more than one year (of 50) with implausibly high fishing mortality (defined as the maximum median $F > 2$) and 2- having credible MCMC diagnostics. The model-averaged scenarios were constructed by pooling the Bayes posterior probability distributions calculated for each of the selected model runs using Markov Chain Monte Carlo (MCMC) sampling. Pooling these results, effectively giving each selected model run equal weight, creates an average composite model that reflects the underlying uncertainty in this stock assessment.

The model averaged biomass (B_t, Figure 3) for the BC North stock has remained below B_{avg} over most years but above the USR ($2B_{min}$) since 2001, after dropping to near B_{min} in 2000. Since then, the stock increased to well above B_{avg}, peaking in 2012 before dropping. The component model runs to the model-average scenario all show biomass trajectories that are similar in shape but differ in absolute size to the model average biomass trajectory (Figure 4). The probability that the estimated spawning biomass at the end of the final reconstruction year (B_{2017}) is greater than the LRP (B_{min}) is 0.99, greater than the USR ($2B_{min}$) is 0.62 and greater than B_{avg} is 0.27 (Table 2, Figure 6). The final year harvest rate (u_{2016}) has a probability of 0.74 of being greater than the average harvest rate (u_{avg}), indicating that the 2016 harvest rate is likely above the average removal rate. Current stock status is shown in Figure 6 for each of the three contributing scenarios to the model average, and provides the managers with a visual appreciation for the variability of the runs accepted by the peer review participants.

For the BC South stock, the model-averaged biomass (B_t, Figure 3) has remained below B_{avg} most of the time but above the USR ($2B_{min}$) since 2009, after dropping to the LRP (B_{min}) in 2008. Since then, the stock increased to levels well above both reference levels, peaking in 2014 before dropping. The model runs which contribute to the model average scenario all show biomass trajectories that are similar in shape to the model average biomass trajectory but differ considerably in absolute size (Figure 5). The probabilities that the estimated spawning biomass at the beginning of 2017 (B_{2017}) is greater than the LRP (B_{min}) is 1, greater than the USR ($2B_{min}$) is 0.96 and greater than B_{avg} is 0.34 (Table 2, Figure 6). The estimated harvest rate u_{2016} has a 0.05 probability of being greater than the estimated average harvest rate (u_{avg}), indicating that the 2016 harvest rate is likely below the average removal rate. Current stock status is shown in Figure 6 for each of the six scenarios contributing to the model average, and provides the managers with a visual appreciation for the variability of the runs accepted by the peer review participants.

Table 1. Summary of runs with acceptable MCMC diagnostics and F-values that contribute to the Model Average composite scenario. M = natural mortality, k = knife-edge recruitment age, F_t = fishing mortality in year t, F_{max} = maximum fishing mortality for all MCMC draws. All runs for the BC North stock use the eastern Gulf of Alaska growth model; all runs for the BC South stock use the Sea of Okhotsk growth model.

Stock	Case	Run ID	*M*	*k*	# Years median annual $F_t > 2$	$P(F_t>2)$	Median F_{max} from 1000 MCMCs	Year of maximum median F_t
BC North	S00	M.30+k3	0.3	3	0	0.001	0.71	1993
	S03	M.35+k3	0.35	3	0	0.000	0.51	1993
	S10	M.30+k3-GIG-CPUE	0.3	3	1	0.048	18.38	2000
BC South	S00	M.30+k3	0.3	3	0	0	0.28	2003
	S01	M.30+k4	0.3	4	1	0.025	18.30	2003
	S03	M.30+k5	0.25	3	0	0.000	0.49	2003
	S04	M.25+k3	0.25	4	1	0.024	18.29	2003
	S06	M.25+k4	0.35	3	0	0	0.12	2003
	S07	M.25+k5	0.35	4	1	0.031	14.21	2003

Harvest Advice

A decision table of probabilities for BC North (Table 3), based on the model-averaged scenario, forms the basis of the advice to managers. One-year projections show that even if no harvest occurred in 2018, the stock has a 0.77 probability of declining from current levels. The average level of total removals from BC North in the last five years (2011-2015) has been 992 t, which is similar to the constant catch policy of 1000 t listed in Table 3. At 1000 t, the probability that biomass in 2018 is greater than the LRP, $P(B_{2018} > B_{min})$, is 0.90 and the probability that biomass in 2018 is greater than the USR, $P(B_{2018} > 2B_{min})$, is 0.43. At fixed annual catches of 1000 t, the probability that the harvest rate will exceed the average removal rate, u_{avg}, is 0.70.

A decision table of probabilities for BC South (Table 4), based on the model-averaged scenario, also forms the basis of the advice to managers. One-year projections show that even if no harvest occurred in 2018, the stock has a 0.95 probability of declining from current levels. The average level of total removals from BC South in the last five years (2011-2015) has been 3256 t, which is similar to the constant catch policy of 3250 t listed in Table 4. With a catch policy of 3250 t, the probability that biomass in 2018 is greater than the LRP, $P(B_{2018} > B_{min})$, is 0.99 and the probability that biomass in 2018 is greater than the USR, $P(B_{2018} > 2B_{min})$ is 0.95. At fixed annual catches of 3250 t, the probability that the harvest rate will exceed the average removal rate, u_{avg}, is 0.85.

Note that the delay-difference model used in this stock assessment is less capable of making reliable multi-year projections than an age-structured model because it has no latent age structure to inform predictions and the stock-recruitment function is poorly determined. One and two year projections were agreed upon at the peer review meeting as longer projections were considered to be unreliable.

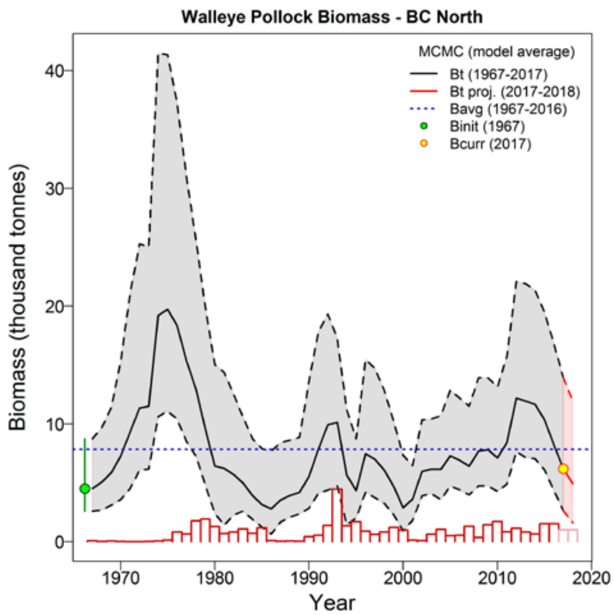

Figure 3. [left] BC North, [right] BC South. Median estimates (solid black line) and 90% credibility intervals (black dashed lines, grey fill) for the model-average B_t (biomass in year t in tonnes) for Walleye Pollock. Also shown are the initial biomass B_{1967} (green circle), current biomass B_{2017} (yellow circle), one-year projection B_{2018} (pink fill), the median of average biomass B_{avg} (blue dotted line), the historical catch (red bars) and the catch strategy (pink bars, 1000 t for BC North and 3250 t for BC South).

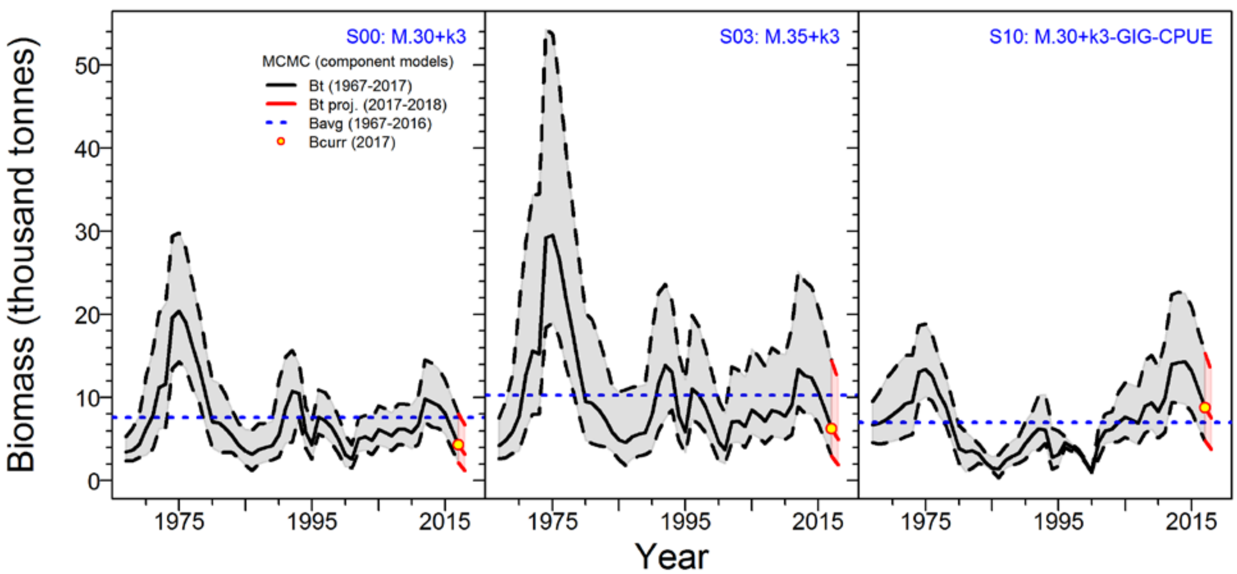

Figure 4. Biomass trajectory for each of the three component runs (Table 1) in the model averaged scenario for the BC North stock.

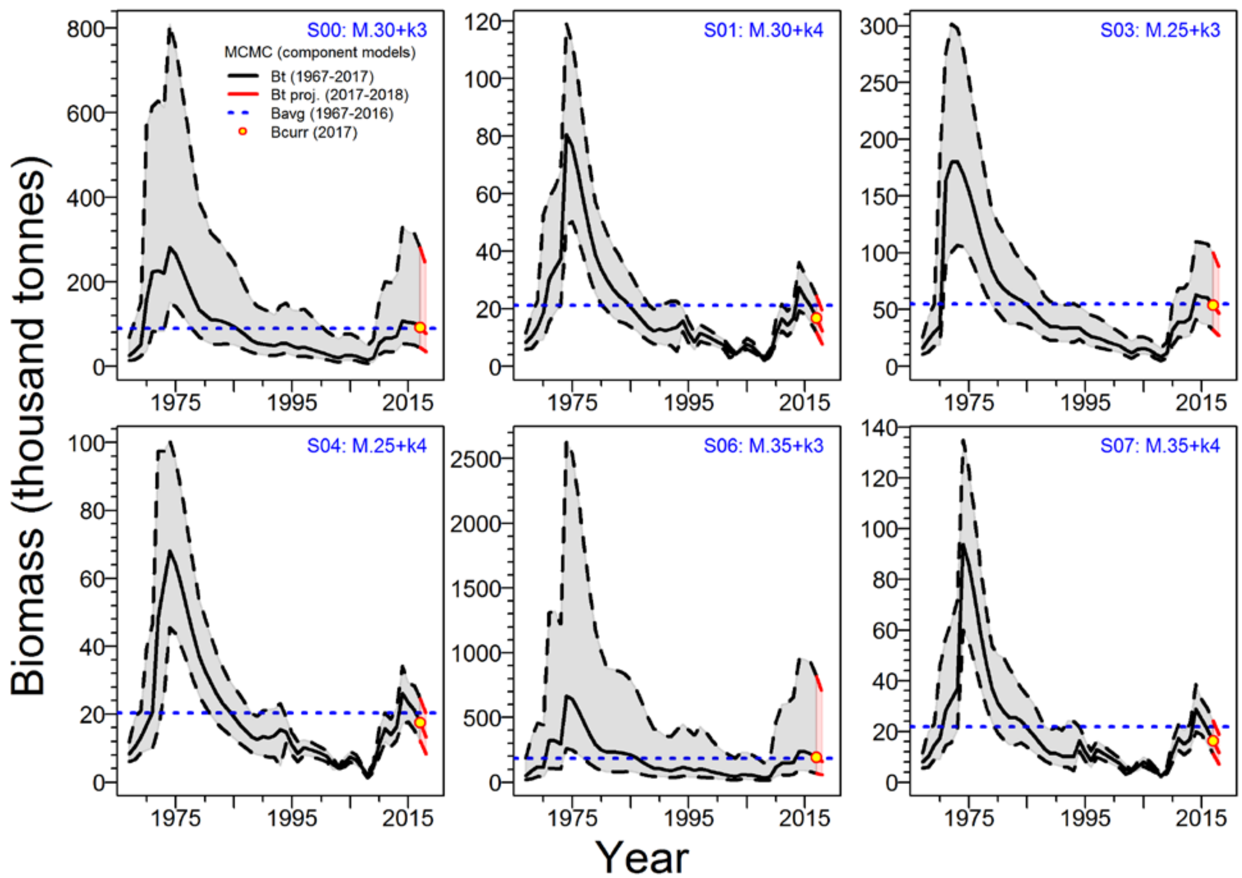

Figure 5. Biomass trajectory for each of the six component runs (Table 1) in the model averaged scenario for the BC South stock.

Table 2. Biomass values (B, in thousand tonnes*), exploitation rates (u), and current levels of depletion for the BC North and BC South stocks, showing the 5%, median and 95% percentiles from the posterior distribution of the model-averaged scenario for each quantity. Probabilities of selected outcomes for the model-averaged scenario are also shown.*

	BC North Stock			**BC South Stock**		
-	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**
B_{2017}	2621	6185	13927	12737	28923	317629
B_{avg}	5634	7837	14626	16938	33487	292976
B_{2017} / B_{avg}	0.385	0.683	1.62	0.589	0.899	1.35
u_{2016}	0.106	0.214	0.406	0.00787	0.0829	0.171
u_{avg}	0.0744	0.150	0.234	0.0113	0.119	0.195
u_{2016} / u_{avg}	0.602	1.79	2.52	0.589	0.772	1
P(B_{2017} > LRP)	-	0.99	-	-	1	-
P(B_{2017} > USR)	-	0.62	-	-	0.96	-
P(B_{2017} > B_{avg})	-	0.27	-	-	0.34	-
P(u_{2016} > u_{avg})	-	0.74	-	-	0.05	-

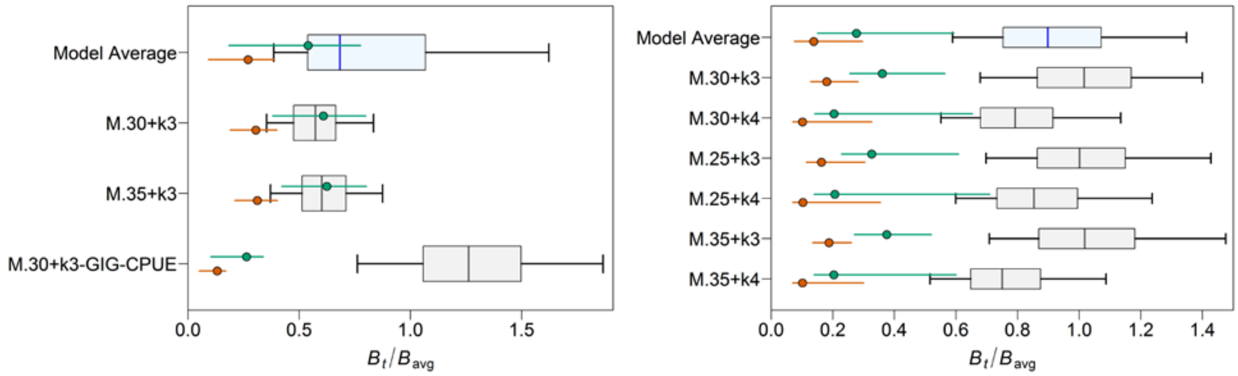

Figure 6. [left] BC North, [right] BC South. Status of the current stock B_{2017} relative to B_{avg} with the circles showing median biomass reference points (B_{min}/B_{avg} [orange], $2B_{min}/B_{avg}$ [green]), where B_{avg} is a proxy for B_{MSY}, B_{min} is the limit reference point (LRP), and $2B_{min}$ is the upper stock reference point (USR). The 5-95% quantile range is shown for the LRP and USR. Stock status is shown for the Model Average Composite scenario comprising pooled model runs: three for BC North and six for BC South (see Table 1 for definitions of these model runs). Box plots show the 5, 25, 50, 75 and 95 quantiles from the MCMC posteriors. M = instantaneous natural mortality (y^{-1}); k = age (y) at knife-edge recruitment.

Table 3. BC North: Decision table for the Model Average Composite scenario for 5 reference points: the starting-year spawning biomass B_{2017}, the limit reference point B_{min}, the upper stock reference $2B_{min}$, the average spawning stock biomass from 1967 to 2016 B_{avg}, and the average harvest rate over the same time period u_{avg}; for the projected starting-year biomass B_{2018} and mid-year harvest rate u_{2017} for a range of constant catch strategies (in tonnes). Each value is the probability that projected biomass or harvest rate is greater than the indicated reference point. The probabilities are the proportion of MCMC samples from 3 pooled scenarios chosen for their acceptable fishing mortality estimates and MCMC diagnostics. For reference, the average catch over the last 5 years (2011-2015) is 992 t. Probabilities of 0 and 1 are due to rounding.

Catch (t)	P(B_{2018} > B_{2017})	P(B_{2018} > B_{min})	P(B_{2018} > $2B_{min}$)	P(B_{2018} > B_{avg})	P(u_{2017} > u_{avg})
0	0.23	0.99	0.58	0.26	0
100	0.17	0.99	0.56	0.26	0
200	0.13	0.98	0.54	0.25	0
300	0.10	0.98	0.53	0.25	0.01
400	0.08	0.97	0.51	0.24	0.08
500	0.07	0.96	0.50	0.23	0.24
600	0.06	0.95	0.49	0.22	0.45
700	0.05	0.94	0.47	0.22	0.59
800	0.04	0.93	0.46	0.21	0.65
900	0.03	0.91	0.45	0.21	0.68
1000	0.03	0.90	0.43	0.20	0.70
1200	0.02	0.87	0.42	0.19	0.74
1400	0.01	0.84	0.40	0.18	0.80
1600	0.01	0.80	0.39	0.16	0.85
1800	0.01	0.76	0.38	0.15	0.90
2000	0.01	0.71	0.37	0.13	0.93
2500	0	0.62	0.35	0.11	0.98
3000	0	0.54	0.34	0.09	0.99
3500	0	0.48	0.32	0.07	1
4000	0	0.43	0.30	0.05	1
4500	0	0.40	0.28	0.04	1
5000	0	0.37	0.26	0.03	1

Table 4. BC South: Decision table for the Model Average Composite scenario for 5 reference points: the starting-year spawning biomass B_{2017}, the limit reference point B_{min}, the upper stock reference $2B_{min}$, the average spawning stock biomass from 1967 to 2016 B_{avg}, and the average harvest rate over the same time period u_{avg}; for the projected starting-year biomass B_{2018} and mid-year harvest rate u_{2017} for a range of constant catch strategies (in tonnes). Each value is the probability that projected biomass or harvest rate is greater than the indicated reference point. The probabilities are the proportion of MCMC samples from 6 pooled scenarios chosen for their acceptable fishing mortality estimates and MCMC diagnostics. For reference, the average catch over the last 5 years (2011-2015) is 3256 t. Probabilities of 0 and 1 are due to rounding.

Catch (t)	$P(B_{2018} > B_{2017})$	$P(B_{2018} > B_{min})$	$P(B_{2018} > 2B_{min})$	$P(B_{2018} > B_{avg})$	$P(u_{2017} > u_{avg})$
0	0.05	1	0.96	0.20	0
500	0.03	1	0.95	0.19	0
1000	0.02	1	0.95	0.18	0
1500	0.01	1	0.95	0.17	0
1750	0.01	1	0.95	0.16	0.02
2000	0.01	1	0.95	0.16	0.07
2250	0.01	1	0.95	0.15	0.20
2500	0.01	1	0.95	0.15	0.38
2750	0.01	0.99	0.95	0.15	0.56
3000	0	0.99	0.95	0.14	0.73
3250	0	0.99	0.95	0.14	0.85
3500	0	0.99	0.95	0.13	0.93
4000	0	0.99	0.95	0.13	0.99
4500	0	0.99	0.94	0.12	1
5000	0	0.98	0.94	0.11	1
5500	0	0.98	0.94	0.11	1
6000	0	0.98	0.94	0.11	1
6500	0	0.98	0.93	0.10	1
7000	0	0.97	0.93	0.10	1
8000	0	0.97	0.91	0.09	1
9000	0	0.96	0.87	0.09	1
10000	0	0.94	0.82	0.08	1

Sources of Uncertainty

Uncertainty due to natural mortality, the age of knife-edged selectivity, and the exclusion of some abundance index series was evaluated by running a range of model scenarios for each stock, with a subset selected to be included in the model-averaged scenario. The initial range of explored values included natural mortality with three options (M = 0.25, 0.30, 0.35), three ages at knife-edge selectivity (k = 3, 4, 5 y), and the removal of the Goose Islands Gully survey for the BC North stock, and the CPUE index series for both stocks. Some of these model runs resulted in implausible levels of fishing mortality because the observed levels of catch matched or exceeded the size of the vulnerable population estimated by the model. This result frequently occurred when k>3, which is interpreted to mean that an appreciable proportion of the catch was age 3, at least in some years. These high estimates of F may be the result of implicit model misspecification, given the requirement that the delay-difference model set selectivity using a knife-edge assumption rather than the more gradual proportion by age that is usually estimated in age-structured models. Removing select index series (GIG and CPUE in the North and CPUE in the South) changed stock status in some instances, sometimes appreciably, but the effect of these sensitivities was to some extent confounded with the high estimated F values. Although

CPUE provides a stabilizing long-term series that links the other disparate series, there are many caveats when using a commercial fishery index, the primary one being fishing behaviour in response to management regulations (e.g., TACs, area closures, catch restrictions on species at risk).

This stock assessment is not capable of giving advice on equilibrium levels of yield, nor does it provide confidence in the absolute stock size, given that the available data can be fit reasonably well across a range of stock production hypotheses and that equilibrium calculations can vary depending on the definition of the equilibrium biomass mediated through the knife-edge selectivity assumption. Following the examples of Pacific Cod (Forrest et al. 2015), and Rock Sole (Holt et al. 2016), this assessment uses reference points based on the estimated biomass trajectory to guide managers on the sustainability of Walleye Pollock removals by the trawl fleets (bottom and midwater). There was no simulation performed to determine the suitability of these reference points, but B_{min} as a limit reference point is thought to be a reasonable benchmark because it is based on observations where the stock has declined to this level in the past and subsequently recovered.

The stock assessment projections show that recent catch levels will reduce the biomass over the next one or two years, after biomass indices are no longer available. This drop indicates that stock abundance has been maintained in the past through strong recruitment, or possibly stock productivity is too low. Projections are less reliable than stock reconstruction results, and for this reason the projection probabilities presented in Table 3 and Table 4 should be considered less reliable than the stock reconstruction presented in Figure 6.

A primary limitation of this assessment is the lack of a growth model based on stock-specific data, due to a lack of reliable ageing of this species from BC waters. This limitation increases the uncertainty with respect to the stock structure adopted by this stock assessment. While there is a clear difference in mean size between northern and southern Pollock, it is unclear how this large difference has been maintained. It is suspected that the BC North stock may be part of a larger SE Alaska stock (Gustafson et al. 2000, and references therein), which suggests that it should not be evaluated as a unit stock. This possibility should be further explored, because concepts such as stock status and long-term yields need to be evaluated for the total stock, not just the part of it that appears in BC waters. The SE Gulf of Alaska stock is lightly exploited, given the long-term prohibition of trawling in the SE Alaskan panhandle, and may possibly provide a “rescue effect” (i.e. replenishment of the BC part of the population) from this larger, less exploited parent population.

However, there are other processes which could cause this observation, including migration of older fish from south to north and differential exploitation rates. Without reliable ageing, it is not possible to rule out the first alternative hypothesis, although the NOAA survey data indicate the presence of younger age classes in the Eastern Gulf of Alaska. The hypothesis of differential harvest rates seems less likely, given the relative equivalence of the catch histories over much of the recent 25 years.

CONCLUSIONS

Three model runs for the BC North stock and six model runs for the BC South stock (see Table 1) were selected to create a model-averaged scenario for each stock from which management advice for Walleye Pollock is provided. This advice is presented in Table 2, Table 3 and Table 4, plotted in Figure 3 and in the uppermost box plot in Figure 6, and can be summarized as follows:

- Both biomass trajectories have remained below the average biomass (B_{avg}), largely due to an estimated early period (mid 1970s) of high productivity and low catches, which leads to a high level for B_{avg}.
- Current BC North stock status (beginning year biomass in 2017) has a 0.99 probability of being above the LRP, a 0.62 probability of being above the USR, and a 0.27 probability of being above B_{avg}. The probability that u_{2016} is above u_{avg} is 0.74.
- Current BC South stock status (beginning year biomass in 2017) has a 1.00 probability of being above the LRP, a 0.96 probability of being above the USR, and a 0.34 probability of being above B_{avg}. The probability that u_{2016} is above u_{avg} is 0.05.
- One-year projections for the BC North stock show that, even if annual catches were not taken, the stock is predicted to decline from current levels. Stock status at the end of the one-year projection period under a catch level equivalent to the 2011-2015 average catch (1000 t/year) has a probability of 0.90 of being above the LRP and a probability of 0.43 of being above the USR. The probability of the 2017 harvest rate being above u_{avg} is 0.70.
- One-year projections for the BC South stock show that even if annual catches were not taken, the stock is predicted to decline from current levels. Stock status at the end of the one-year projection period under a catch level equivalent to the 2011-2015 average catch (3250 t/year) has a probability of 0.99 of being above the LRP and a probability of 0.95 of being above the USR. The probability of the 2017 harvest rate being above u_{avg} is 0.85.
- Advice for catch levels other than 1000 t/y for BC North can be found in the Table 3 decision table which provides probabilities for catch levels ranging from 0 to 4000 t/year. Similarly, advice for catch levels other than 3250 t/y for BC South are presented in Table 4 for catch levels ranging from 0 to 10,000 t/y.

This assessment considers Walleye Pollock to comprise two stocks along the outer BC coast and does not provide harvest advice on a smaller scale or for the Gulf (Strait of Georgia) stock. Further exploration of the utility and potential for more spatially explicit management advice is recommended for future stock assessments.

Given the uncertainty in growth, natural mortality, and the age of knife-edge selectivity in this assessment, improvements in biological sampling and ageing of Walleye Pollock are recommended before an updated stock assessment is conducted. The following issues should be considered when planning future stock assessments and management evaluations for Walleye Pollock.

1. Determine the most reliable method for ageing Walleye Pollock in BC. While Alaskan Walleye Pollock is aged using the otolith break and burn methodology, there is uncertainty whether this procedure is suitable for BC Walleye Pollock.
2. Available BC Walleye Pollock ageing data (currently only available on paper) from the 1980s should be entered into the DFO data system.
3. Review the existing BC otolith repository and begin break-and-burn ageing if this ageing method is deemed reliable and where there are sufficient samples/specimens to yield useful stock assessment data.
4. If otolith ageing is deemed reliable, review the otolith sampling plans for Walleye Pollock in the commercial fishery and in the synoptic surveys, and adjust as needed to ensure that stocks are adequately represented.

5. Collect length-stratified biological samples from the commercial fishery and from research surveys to ensure that age structures represent the full size range of Walleye Pollock in BC.
6. Reassess the growth curves for BC Walleye Pollock stocks when reliable age-length data from BC stocks become available.

SOURCES OF INFORMATION

This Science Advisory Report is from the November 14-15, 2017 regional peer review on Walleye Pollock (*Theragra chalcogramma*) stock assessment for British Columbia in 2017. 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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