Stock assessment (2016) and Draft harvest decision table (2017)

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PURPOSE

To provide the Commission with an opportunity to consider the results of the 2016 IPHC stock assessment for Pacific halibut within the Convention Area, and the IPHC draft harvest decision table for 2017.

BACKGROUND

Each year, the IPHC staff undertake an assessment of the status of the Pacific halibut *Hippoglossus stenolepis*) resource in the north-eastern Pacific Ocean, including the territorial waters of the United States of America and Canada. As in recent stock assessments, the resource is modelled as a single stock extending from northern California to the Aleutian Islands and Bering Sea, including all inside waters of the Strait of Georgia and Puget Sound, but excludes known extremities in the western Bering Sea within the Russian Exclusive Economic Zone.

Subsequent to the stock assessment, projections of spawning stock biomass are undertaken in tandem with the development of a draft IPHC harvest decision table, for the Commission's consideration. The harvest decision table provides a comparison of the relative risk (in times out of 100), using stock and fishery metrics (columns), for a range of alternative harvest levels for 2017. A full description of how to interpret the draft IPHC harvest decision Table is provided in paper IPHC-2016-IM092-INF01.

DISCUSSION

An executive summary of the stock assessment and the associated draft IPHC harvest decision table is provided at Appendix A.

RECOMMENDATION/S

That the Commission:

1) **NOTE** paper IPHC-2016-IM092-06 which provided the Commission with an opportunity to consider the results of the 2016 IPHC stock assessment for Pacific halibut within the Convention Area, and the IPHC draft harvest decision table for 2017.

APPENDICES

Appendix I: Executive Summary - Assessment of the Pacific halibut (*Hippoglossus stenolepis*) stock at the end of 2016.

APPENDIX I
Assessment of the Pacific halibut (*Hippoglossus stenolepis*) stock at the end of 2016

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Executive summary for the Interim Meeting (29-30 November, 2016)

Stock and management

The stock assessment reports the status of the Pacific halibut *Hippoglossus stenolepis*) resource in the northeastern Pacific, including the territorial waters of the United States of America and Canada. As in recent stock assessments, the resource is modeled as a single stock extending from northern California to the Aleutian Islands and Bering Sea, including all inside waters of the Strait of Georgia and Puget Sound, but excludes known extremities in the western Bering Sea within the Russian Exclusive Economic Zone (Fig. 1).

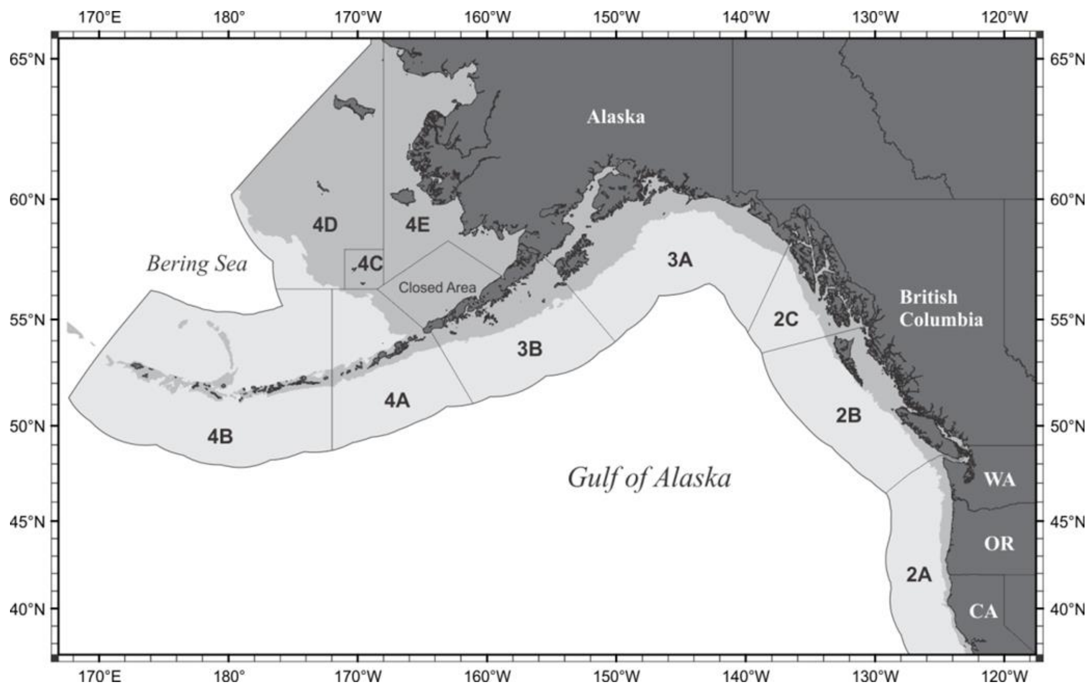

Figure 1. IPHC Regulatory Areas, and Pacific halibut range within the territorial waters of the United States of America and Canada.

The Pacific halibut fishery has been managed by the International Pacific Halibut Commission (IPHC) since 1923. Catch limits for each of eight regulatory areas are set each year by six Commissioners from the United States of America and Canada. The stock assessment provides a summary of recently collected data, model estimates of stock size and trend. Specific management information is summarized via a decision table reporting the estimated risks associated with alternative management actions and catch tables illustrating the level of harvest in each Regulatory Area indicated by the IPHC's current harvest policy (the Blue Line; see Stewart 2016 for a detailed explanation).

Data

Known Pacific halibut removals consist of target fishery landings and discards (wastage), bycatch in non-target fisheries, research (included with fishery landings), sport, and personal use. Over the period 1917-2016 removals have totaled 7.1 billion lbs (3.2 million mt; all weights in this document are reported as 'net' weights, head and guts removed; this is approximately 75% of the round weight), ranging annually from 34 to 100 million lbs (16,000-45,000 mt) with an annual average of 63 million lbs (~29,000 mt; Fig. 2). Annual removals were above average from 1985 through 2010 and have decreased annually from a peak in 2004 in response to management measures.

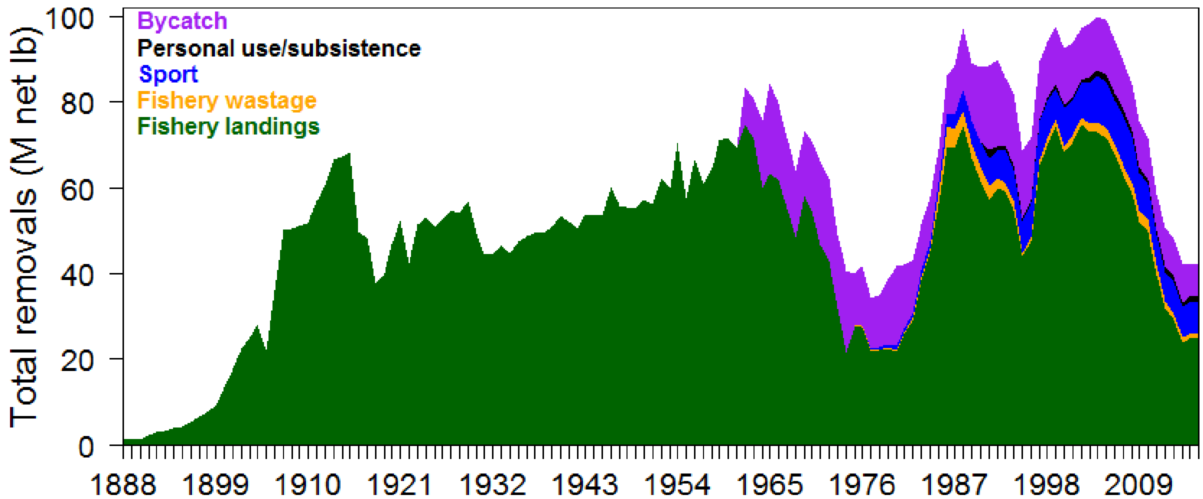

Figure 2. Summary of historical removals by source (colors).

2015-16 Fishery and survey statistics

Commercial fishery landings in 2016 were approximately 25.0 million pounds (~11,400 mt), up from a low of 23.7 million pounds (~10,700 mt) in 2014. Bycatch mortality was estimated to be 7.1 million pounds (~3,200 mt), the lowest level in the estimated time series, beginning with the arrival of foreign fishing fleets in 1962. The total sport removals was estimated to be 7.4 million pounds (~3,300 mt), down slightly from 2015. Removals from all sources in 2016 were estimated to be 41.9 million pounds (~19,000 mt), down slightly from 42.1 million pounds in 2015 (~19,100 mt).

Data are initially compiled by management area and then aggregated to the coastwide level and to four geographical regions: Area 2 (2A, 2B, and 2C), Area 3 (3A, 3B), Area 4 (4A, 4CDE) and Area 4B (Fig. 1). In addition to the removals (including all sizes of Pacific halibut), the assessment includes data from both fishery dependent and fishery independent sources as well as auxiliary biological information (Fig. 3). Primary sources of information for this assessment include indices of abundance from the annual setline survey and commercial Catch-Per-Unit-Effort (numbers and weight), and biological summaries (length-, weight-, and age-composition data).

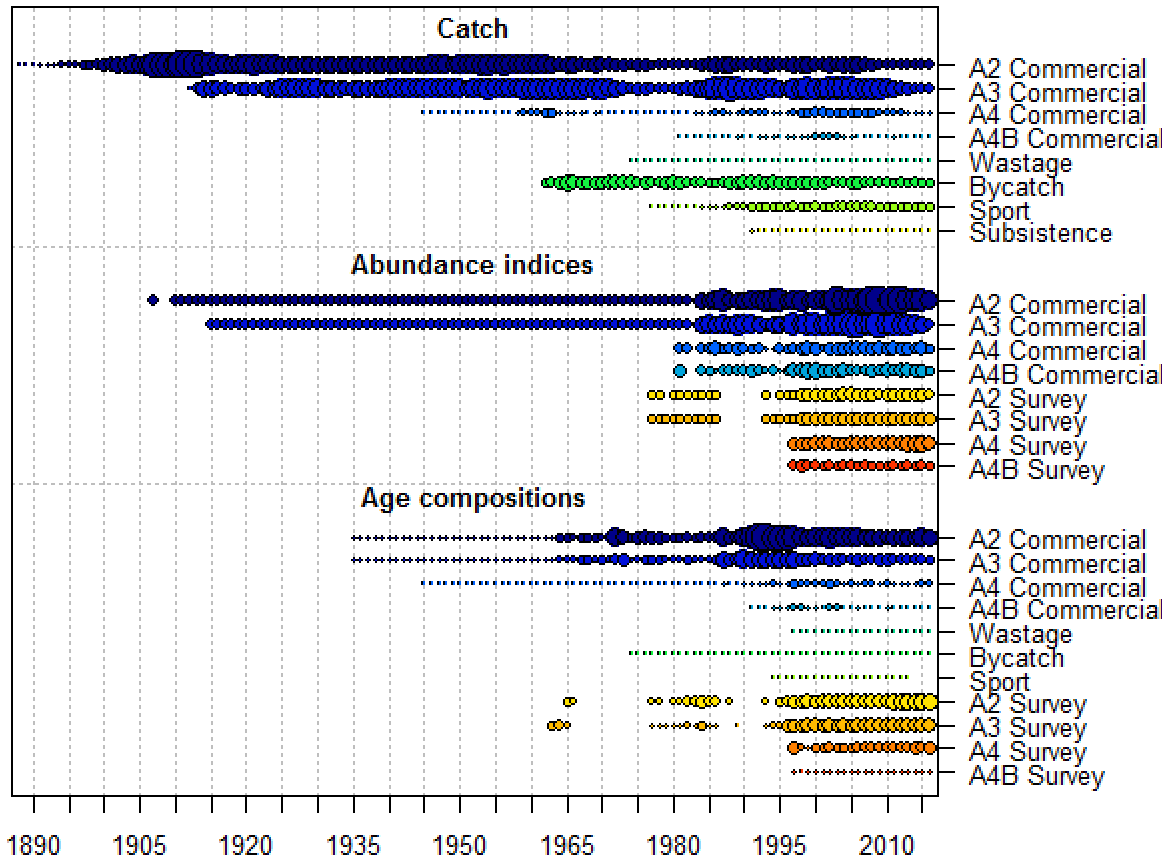

Figure 3. Overview of data sources. Circle areas are proportional to magnitude (catches) or the relative precision of the data (indices of abundance and age composition data). See Fig. 1 for Regulatory Area boundaries.

Efforts to improve the data sources included in the assessment have been ongoing since 2013. Following a complete reprocessing of all inputs in 2015, the 2016 data improvements included updating mortality estimates from all sources, extending all previously included time series and, importantly, a new approach to analyzing the setline survey data making use of a space-time model (Webster 2017; to be available for the IPHC Annual Meeting). Briefly, this method extracts more information from the survey catch rates by station through estimation of spatial and temporal correlations, as well as using covariates such as depth to more accurately infer unsampled survey stations. This approach was reviewed and endorsed by the IPHC Scientific Review Board (SRB), during June and September 2016.

All available information was finalized on 11 November 2016 in order to provide adequate time for analysis and modeling. As has been the case in all years, some data are incomplete, or include projections for the remainder of 2016. These include commercial fishery WPUE, commercial fishery age composition data, and 2016 removals for all fisheries still operating after 11 November 2016. Some of these data may therefore be revised in various documents as late-season landings and validation of data are incorporated; all preliminary series in the assessment will be fully updated in 2017.

The 2016 IPHC fishery independent setline survey detailed a coastwide aggregate legal (O32) WPUE which was 6% higher than the value observed in 2015, representing the fifth year of stable catch rates (Fig. 4). Most regulatory areas show a similar overall trend over recent years, with somewhat more positive trends observed in Area 2. Setline survey NPUE showed a much less pronounced decline from the late 1990s (only 10-15%), based on the revised survey series compared to previous analyses, and a similarly increasing trend over the last few years. Commercial fishery WPUE (based on extensive, but still incomplete logbook records available for this assessment) was unchanged at the coastwide level and showed increases in all areas except 4D from 2015 to 2016, with consistent trends observed for 2A, 4B, and 4C (Fig. 5). The largest decline, 47%, was observed in Area 2A. Age distributions in 2016 from both the survey and fishery remained similar to those observed in 2011-15, indicating a relatively stable stock, but not showing clear evidence of strong coastwide recent recruitments. At the coastwide level, individual size-at-age continues to be very low relative to the rest of the time-series, although there has been little change over the last several years.

Stock Assessment

This stock assessment is implemented using the generalized software stock synthesis (Methot and Wetzel 2013), and consists of an ensemble of four equally-weighted models; the basic approach remains unchanged since 2014.The ensemble is comprised of two long time-series models, reconstructing historical dynamics back to the beginning of the modern fishery, and two short time-series models incorporating data only from 1996 to the present when all sources of removals and surveys are available for all regions. For each time-series length there are two models: one fitting to coastwide aggregate data, and one to data disaggregated into geographic regions. This combination of models also includes uncertainty in natural mortality rates (estimated in the long time-series models, fixed in the short time-series models), environmental effects on recruitment (estimated in the long time-series models), and other model parameters.

As has been the case since 2012, this stock assessment is based on the approximate probability distributions derived from the ensemble of models, thereby incorporating the uncertainty within each model as well as the uncertainty among models. This approach reduces potential for abrupt changes in management quantities as improvements and additional data are added to individual models, and provides a more realistic perception of uncertainty than any single model, and therefore a stronger basis for risk assessment. The four models were equally weighted, as work-to-date on retrospective and predictive performance has suggested that each can be considered equally plausible. The IPHC SRB has endorsed this weighting approach pending further research. Within-model uncertainty from each model was also propagated through to the ensemble results via an asymptotic approximation. Point estimates reported in this stock assessment correspond to median values from the ensemble.

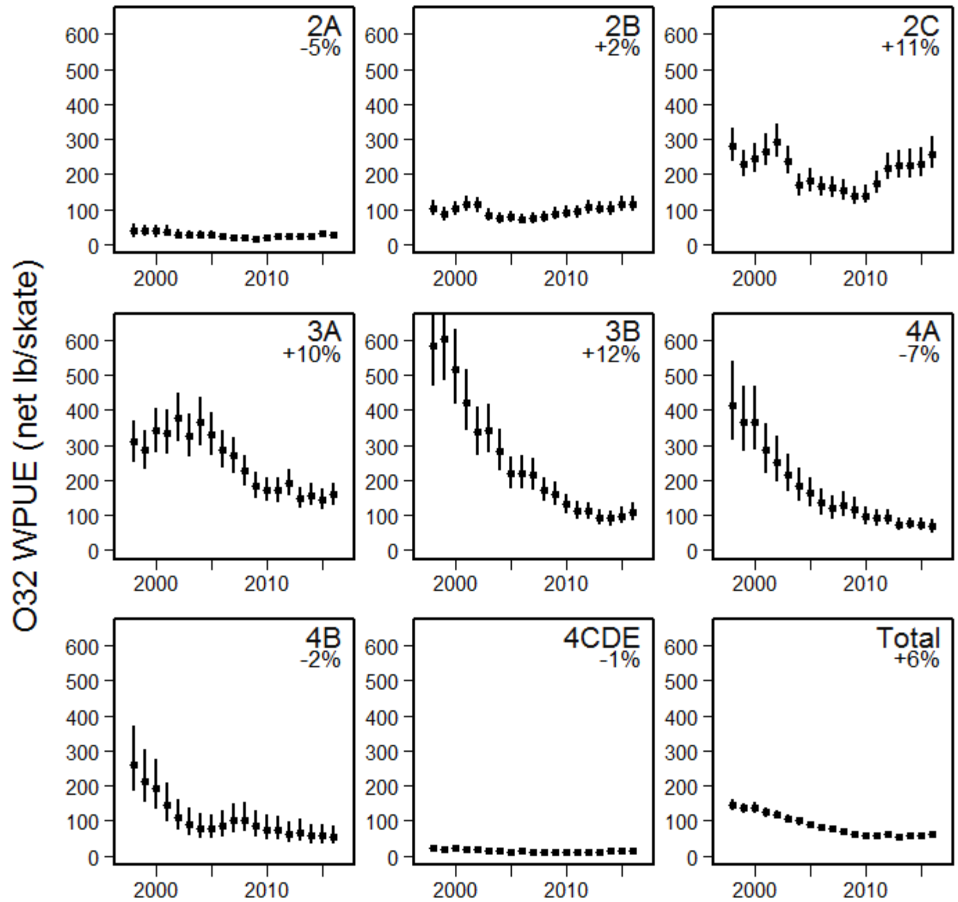

Figure 4. Trends in setline survey legal (O32) WPUE by regulatory area, 1998-2016. Percentages indicate the change from 2015 to 2016. Vertical lines indicate approximate 95% confidence intervals.

Biomass and recruitment trends

The results of the 2016 stock assessment indicate that the Pacific halibut stock declined continuously from the late 1990s to around 2010 (Fig. 6). That trend is estimated to have been largely a result of decreasing size-at-age, as well as somewhat weaker recruitment strengths than those observed during the 1980s. Since the estimated female spawning biomass (SB) stabilized near 200 million pounds (~90,100 mt) in 2010, the stock is estimated to have been increasing gradually. Comparison with previous stock assessments indicates that the 2016 results are very consistent with estimates from 2012 through 2015, all of which lie inside the 50% interval (Fig. 7; Table 1). The SB at the beginning of 2017 is estimated to be 212 million pounds (~96,200 mt), with an approximate 95% confidence interval ranging from 153 to 286 million pounds (~69,400-129,700 mt; Fig. 8).

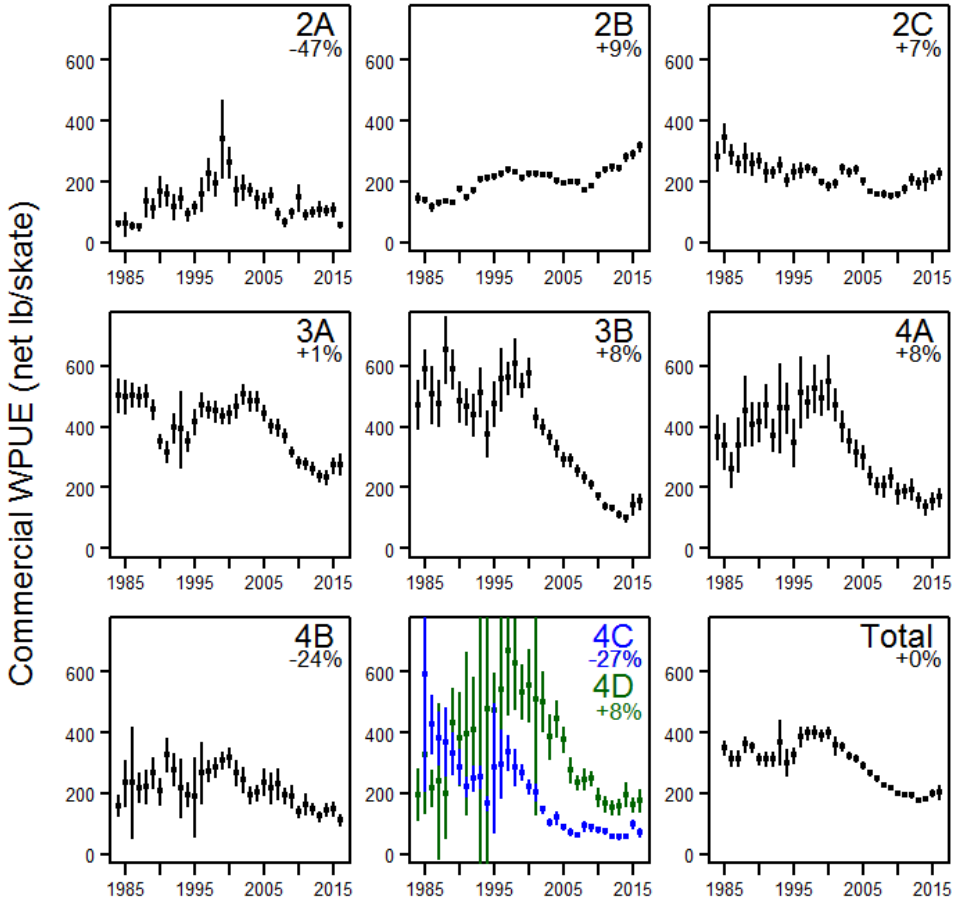

Figure 5. Trends in commercial fishery WPUE by regulatory area, 1985-2016. Percentages indicate the change from 2015 to 2016. Vertical lines indicate approximate 95% confidence intervals.

Based on the two long time-series models, average Pacific halibut recruitment is estimated to be higher (38 and 70% for the coastwide and AAF models respectively) during favorable Pacific Decadal Oscillation (PDO) regimes, a widely used indicator of productivity in the north Pacific. Historically, these regimes included positive conditions prior to 1947, poor conditions from 1947-77, positive conditions from 1978-2006 and poor conditions from 2007-13. Average conditions from 2014 through October 2016 have been positive; however, many other environmental indicators, current and temperature patterns have been anomalous relative to historical periods. Recruitment estimates show the largest recent cohorts in 1999 and 2005, and there is little information on the relative strength of subsequent cohorts, which will be the most important for stock productivity over the next decade.

Table 1. Comparison of 2016 biomass point estimates (median ensemble value; millions of net pounds) from the 2015 and 2016 ensemble assessments.

Quantity	2015 Assessment	2016 Assessment
2016 Exploitable biomass	185	174
2016 Spawning biomass	219	207

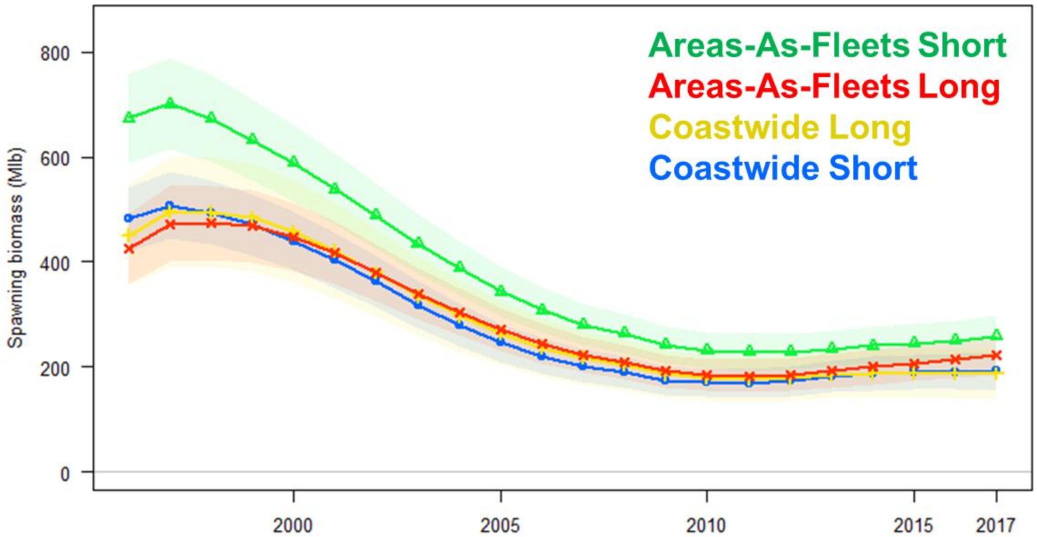

Figure 6. Trend in spawning biomass estimated from each of the four models included in the 2016 stock assessment ensemble. Series indicate the maximum likelihood estimates; shaded intervals indicate approximate 95% confidence intervals.

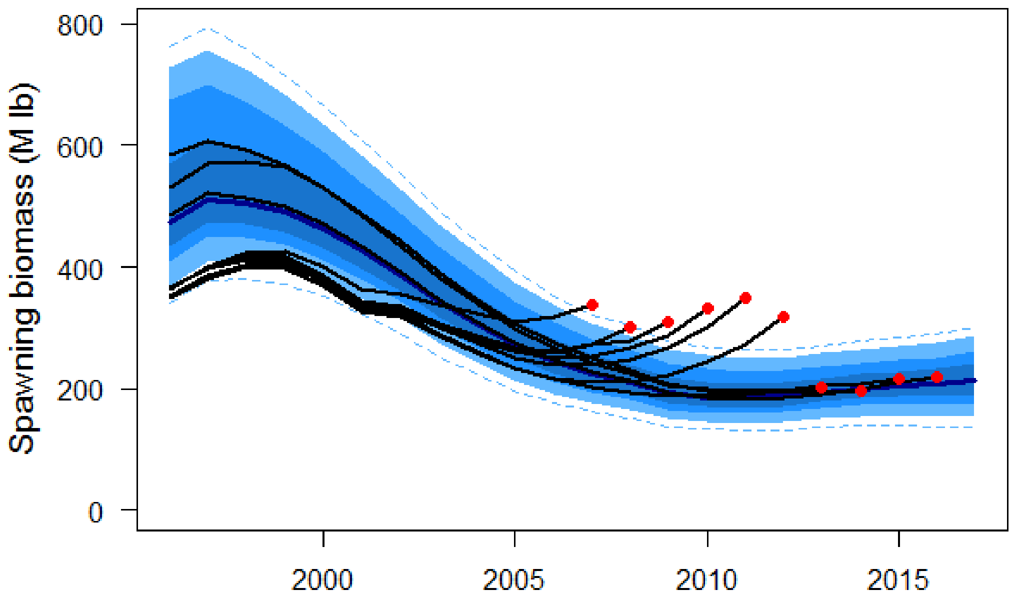

Figure 7. Retrospective comparison among recent IPHC stock assessments. Black lines indicate estimates of spawning biomass from assessments conducted from 2006-15 with the terminal estimate shown as a point, the shaded distribution denotes the 2016 ensemble: the dark blue line indicates the median (or "50:50 line") with an equal probability of the estimate falling above or below that level; colored bands moving away from the median indicate the intervals containing 50/100, 75/100, and 95/100 estimates; dashed lines indicating the 99/100 interval.

Harvest policy and other reference points

A comparison of the median current ensemble SB to reference levels specified by the current harvest policy suggests that the stock is currently at 41% of equilibrium unfished levels); however, the probability distribution indicates considerable uncertainty ranging from a 5/100 (5%) probability the stock is below the $SB_{30\%}$ level, to 90/100 (90%) at slightly more than $SB_{50\%}$. Consistent with the current harvest policy, estimates of spawning biomass are compared to equilibrium values representing poor recruitment regimes and relatively large size-at-age. The two long time-series models also provide a comparison with SB levels estimated to have occurred during the historically low stock sizes of the mid to late 1970s. In that case, the AAF model suggests that recent stock sizes may have been much closer to 1970s levels (121% of the minimum) than the coastwide model (231% of the minimum; Fig. 9). These differences reflect both the uncertainty in historical dynamics as well as the importance of spatial patterns in the data and population processes, for which both models represent only simple approximations.

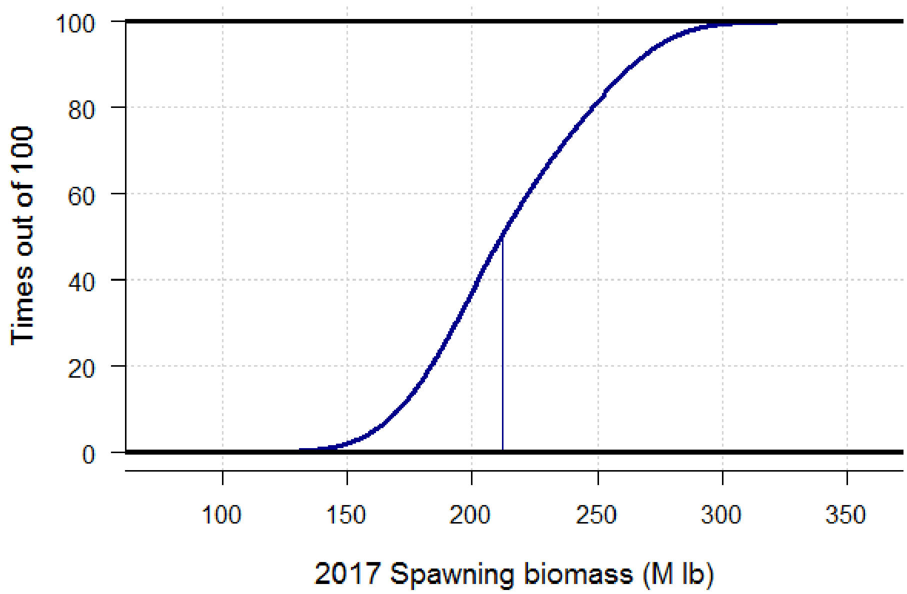

Figure 8. Cumulative distribution of the estimated spawning biomass at the beginning of 2017. Curve represents the estimated probability that the biomass is less than or equal to the value on the x-axis. Vertical line represents the median.

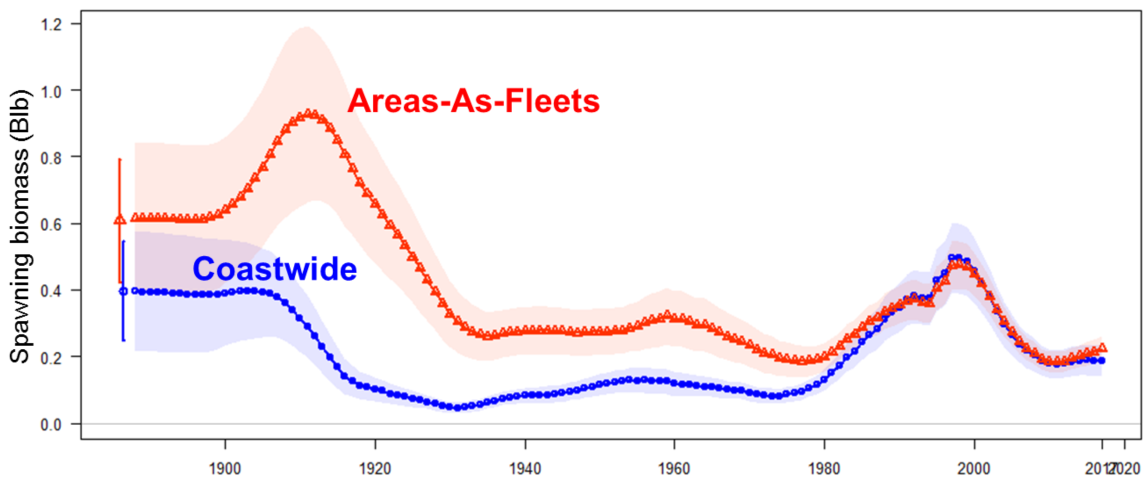

Figure 9. Estimated spawning biomass time-series from the two long time-series models (of four total) included in the 2016 ensemble.

Major sources of uncertainty

This stock assessment includes substantial uncertainty associated with estimation of model parameters, treatment of the data sources (e.g., short and long time-series), natural mortality (fixed vs. estimated), approach to spatial structure in the data, and other differences among the models included in the ensemble. Although this is a substantial improvement over the use of a single assessment model, there are important sources of uncertainty that are not included.

Two primary uncertainties continue to hinder our current understanding of the Pacific halibut resource:

1) The sex-ratio of the commercial catch (not sampled due to the dressing of fish at sea), which serves to set the scale of the estimated female abundance in tandem with assumptions regarding natural mortality. Ongoing efforts to test methods for direct marking of male and female fish at sea will continue in 2017 via voluntary marking in all regulatory areas along with collection of genetic samples for determining the accuracy and precision of the marking program;
2) The treatment of spatial dynamics and movement rates among Regulatory Areas, which are represented via the coastwide and AAF approaches, and have very strong implications for the current stock trend. In addition, movement rates for adult and younger halibut (roughly ages 0-6, which were not well-represented in the PIT-tagging study), particularly to and from Area 4, are necessary for parameterizing a spatially explicit stock assessment. Current understanding of these rates has now been summarized, but remains uncertain.

Other important contributors to assessment uncertainty and potential bias include recruitment, size-at-age, and fishery removals. The link between Pacific halibut recruitment strengths and environmental conditions remains poorly understood, and there is no guarantee that observed correlations will continue in the future. Therefore, recruitment variability remains a substantial source of uncertainty in current stock estimates due to the lag between birth year and direct observation in the fishery and survey data (6-10 years). Reduced size-at-age relative to levels observed in the 1970s is the most important driver of recent stock trends, but its cause remains unknown. The historical record suggests that size-at-age changes relatively slowly; therefore, although projection of future values is highly uncertain, near-term values are unlikely to be substantially different than those currently observed. Data suggest that the decreasing trend in size-at-age has slowed and coastwide values have been relatively stable over the last decade. Like most stock assessments, estimated removals from the stock are assumed to be accurate. Therefore uncertainty due to bycatch estimation (observer sampling and representativeness), discard mortality rates, and any other unreported sources of removals in either directed or non-directed fisheries could create significant bias in this assessment. Ongoing research on these topics may help to inform our understanding of these processes in the long-term, but in the near-future it appears likely that a high degree of uncertainty in both stock scale and trend will continue to be an integral part of the annual management process.

This stock assessment contains a broader representation of uncertainty in stock levels relative to those for many other species. Although the improved survey analysis and 2016 data from all sources reduced the among-model uncertainty relative to last year's projections, this considerable uncertainty can be seen in the distribution for spawning biomass estimated at the beginning of 2017 (Fig. 8), such that the small differences between the estimate from the 2016 and recent assessments (Fig. 7, Table 1) are not statistically significant.

Projections and decision-making table

Stock projections were conducted using the integrated results from the stock assessment ensemble, summaries of the 2016 fishery, and other sources of mortality, as well as the results of apportionment calculations and the target harvest rates from current IPHC harvest policy. The steps included:

1) apportioning the coastwide estimate of exploitable biomass according to the legal-sized (O32) survey catches in each regulatory area;
2) applying the area-specific target harvest rates to estimate the total CEY for each area, including all removals over 26 inches (66 cm) in length (O26) associated with a given level of harvest; and
3) calculating the total mortality and projecting the stock trends three years into the future assuming constant values for all sources of removals.

The decision table (Table 2) provides a comparison of the relative risk (in times out of 100), using stock and fishery metrics (columns), for a range of alternative harvest levels for 2017 (rows). The block of columns entitled "Stock Trend" provides for evaluation of the risks to short term trend in spawning biomass, without reference to a particular harvest policy. The remaining columns portray these risks relative to the spawning biomass reference points ("Stock Status") and fishery performance identified in the current harvest policy. The alternatives provided include:

- No mortality (useful to evaluate the stock trend due solely to population processes),
- No directed mortality (but accounting for bycatch and other removals not under direct IPHC control including recreational removals from some sources and personal use removals),
- The Blue Line (consistent with the current harvest policy and, historically, IPHC staff advice),
- The *status quo* SPR (Spawning Potential Ratio) removals (maintaining the same average fishing intensity as has been realized over the recent period of increasing stock size from 2014-2016),
- Arbitrary values (at 10 million pounds (~4,500 mt) increments) intended to foster the evaluation of the relative change in risk probability across a range of total mortality levels.

For each row of the decision table, the total mortality of all sizes and from all sources, the total coastwide fishery CEY and the associated level of fishing intensity (median value with the 95% credible range below; measured via the Spawning Potential Ratio) are reported. Fishing intensity reflects the relative reduction in equilibrium (long-term) spawning biomass per recruit from all sources and sizes of removals, reported as $F_{x\%}$, (where x = the SPR) for comparison to other management processes in both nations where harvest rate targets and limits are commonly reported in these units. As in previous years, it is expected that additional alternatives will be produced during the IPHCs annual process such that all management alternatives considered for 2017 can be directly evaluated in terms projected total mortality and risk.

The results for 2017 show somewhat more risk than those from last year's assessment: the stock is projected to increase gradually over 2018-2020 in the absence of any removals, and for removals of up to around 40 million pounds (~18,100 mt). For removals around 40 million pounds (~18,100 mt), projections are slightly decreasing. The risk of stock declines begins to increase rapidly for levels of harvest above 40 million pounds (~18,100 mt) of total mortality, becoming more pronounced by 2020 (Table 2; Fig. 10). The Blue Line (37.9 million pounds, ~17,200 mt, total removals) corresponds to a 56/100 (56%) chance of stock decline in 2018 and a 77/100 (77%) chance in 2020. However, the risk of substantial stock decline (>5%) is much lower at only 3/100 (3%) in 2018 and a 53/100 (53%) in 2019. The *status quo* SPR line (41.6 million pounds, ~18,900 mt) corresponds to a 68/100 (68%) chance of stock decline in 2018 and an 87/100 (87%) chance in 2020, again with much lower values of substantial decline.

For stock status, fishery trend and fishery status metrics based on the current harvest policy, there is a relatively small chance (<37/100; 37%) that the stock will decline below the threshold ($SB_{30\%}$) reference point in projections for all the levels of removals evaluated over three years. For removals in excess of the Blue Line, there is a greater than a 50/100 (50%) chance that the fishery CEY would be smaller in 2018-20 if the current harvest policy were applied in those years.

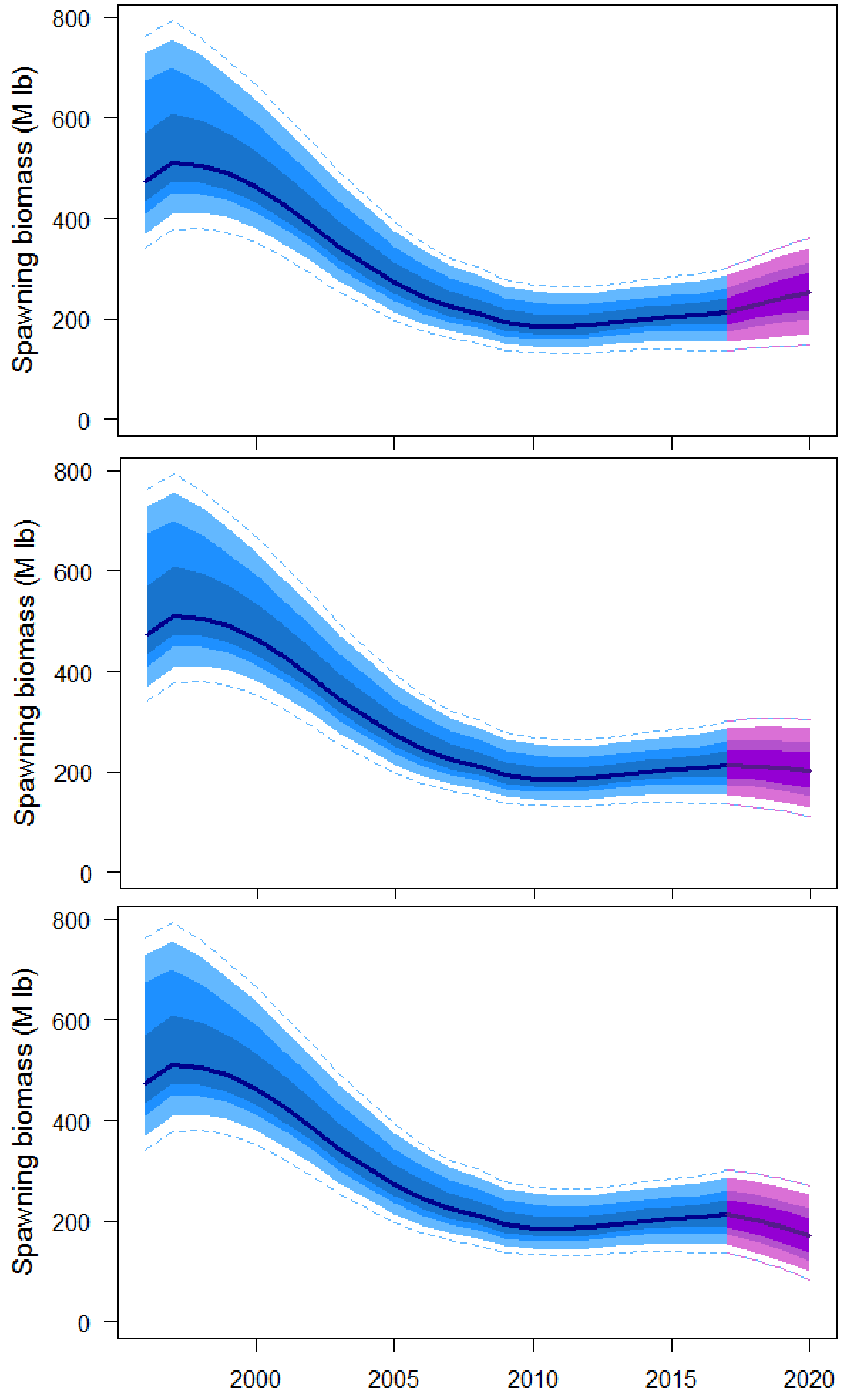

Figure 10. Three-year projections of stock trend under alternative levels of mortality: no removals (upper panel), Blue Line removals (37.9 million pounds; middle panel) and 60 million pounds of total removals (lower panel).

Table 2. Decision table of yield alternatives (rows) and risk metrics (columns). Values in the table represent the probability, in “times out of 100” of a particular risk.

				Stock Trend				**Stock Status**				**Fishery Trend**				**Fishery Status**
				Spawning biomass				**Spawning biomass**				**Fishery CEY from the harvest policy**				**Harvest rate**
				in 2018		**in 2020**		**in 2018**		**in 2020**		**in 2018**		**in 2020**		**in 2017**
2017 Alternative	**Total removals (M lb)**	**Fishery CEY (M lb)**	**Fishing intensity**	**is less than 2017**	**is 5% less than 2017**	**is less than 2017**	**is 5% less than 2017**	**is less than 30%**	**is less than 20%**	**is less than 30%**	**is less than 20%**	**is less than 2017**	**is 10% less than 2017**	**is less than 2017**	**is 10% less than 2017**	**is above target**
No removals	0.0	0.0	$F_{100\%}$	<1	<1	<1	<1	3	<1	1	<1	<1	<1	<1	<1	0
FCEY = 0	11.2	0.0	$F_{77\%}$ 61%-84%	1	<1	3	<1	3	<1	1	<1	<1	<1	<1	<1	<1
	20.0	8.6	$F_{66\%}$ 49%-75%	5	<1	20	4	4	<1	3	<1	<1	<1	<1	<1	<1
	30.0	18.4	$F_{55\%}$ 39%-67%	32	<1	53	31	5	<1	6	<1	6	3	8	4	8
Blue Line	37.9	26.1	$F_{48\%}$ 33%-62%	56	3	77	53	6	<1	12	<1	47	33	48	39	50
***status quo* SPR**	41.6	29.7	$F_{46\%}$ 32%-60%	68	6	87	64	6	<1	15	<1	57	45	57	49	61
	50.0	37.9	$F_{40\%}$ 27%-55%	92	29	98	88	7	<1	25	1	94	83	95	86	95
	60.0	47.7	$F_{35\%}$ 23%-51%	>99	52	>99	99	9	<1	37	3	>99	>99	>99	>99	>99
				a	b	c	d	e	f	g	h	i	j	k	l	m

Future research

Future research will continue to focus on topics identified in previous assessments and extensions already underway:

1) Continued expansion and/or refinement of the ensemble of models used in the stock assessment. Specifically, an explicit spatial model will continue to be developed that may allow for improved incorporation of the uncertainty due to spatial processes such as migration and recruitment distribution among regulatory areas. Longer term efforts will include explicit modelling of growth within potential assessment models.
2) Continued development of weighting approaches for models included in the ensemble, potentially including fit to the survey index of abundance, retrospective and predictive performance.
3) Continued development of methods for sampling the sex-ratio of the commercial catch. The results of the stock assessment are sensitive to the sex-ratio, and therefore this source of uncertainty is a high priority for future data collection.
4) Further investigation of the factors contributing to recruitment strength, recruitment distribution, and the information available from trawl surveys, particularly in the Bering Sea. There are several avenues of research that can be explored using a spatial model, but not with the currently available structures.
5) Explore methods for including uncertainty in wastage and bycatch estimates in the assessment (now evaluated only via alternative catch tables or model sensitivity tests) in order to better include these sources uncertainty in the decision table.
6) Bayesian methods for fully integrating parameter uncertainty may provide improved uncertainty estimates within the models contributing to the assessment, and a more natural approach for combining the individual models in the ensemble.
7) Continued integration of the assessment data and analyses with the development of the harvest policy and the Management Strategy Evaluation process.

References

Methot Jr, R.D., and Wetzel, C.R. 2013. Stock synthesis: A biological and statistical framework for fish stock assessment and fishery management. Fish. Res. 142: 86-99.

Stewart, I.J. 2016. Regulatory area harvest policy calculations and catch tables. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2016: 220-237.

Webster, R.A. 2017. Results of space-time modelling of survey WPUE and NPUE data. Report of Assessment and Research Activities 2016: XX-XX.