Summary of the data, stock assessment, and harvest decision table for Pacific halibut (*Hippoglossus stenolepis*) at the end of 2019

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PURPOSE

To provide the Commission with a summary of the data, stock assessment, and harvest decision table at the end of 2019.

INTRODUCTION

In 2019 the International Pacific Halibut Commission (IPHC) undertook its annual coastwide stock assessment of Pacific halibut (*Hippoglossus stenolepis*), which included a full re-evaluation of all data sources and models contributing to the assessment. The assessment was conducted in two phases: first, a preliminary assessment underwent an external independent peer review, and a two-part review by the IPHC's Scientific Review Board (SRB; IPHC-2019-SRB014-R, IPHC-2019-SRB015-R), second the preliminary assessment was updated to include all data through 2019. This process included five steps to update from the 2018 stock assessment to the preliminary results for 2019 (Stewart and Hicks 2019) and the final estimates reported here:

1) Add the newly available sex-ratio data from the 2017 commercial fishery landings and estimate male selectivity scale parameters.
2) Extend the time series (for the two short models) from 1996 to 1992 and add a stock-recruitment function to these models.
3) Replace the modelled FISS time-series with the series corrected for whale depredation.
4) Regularize and tune each model to be reliable and internally consistent given all the changes that had been made.
5) Add the 2018 sex-ratio data, estimates of 2019 mortality and extend all data sources through 2019 for the final assessment.

Overall, the inclusion of the 2017 sex-ratio data resulted in higher spawning biomass for all models, and the updated whale depredation data made little difference to the results. Extending the time-series back to 1992 in the two short models resulted in higher estimates of recruitment for 1994 and 1995. Regularizing and tuning the series had different effects on each model. The 2019 data revised the estimates of the 2012 year-class upward slightly, but had little effect on the overall time-series, and the 2018 sex-ratio data was very similar to the 2017 information included in the preliminary analysis and therefore produced little additional change. In aggregate, the historical female spawning biomass estimated from the stock assessment ensemble was slightly larger than that estimated in previous assessments at the end of the time series, and considerably larger prior to the early 2000s, although the trend remains very similar in recent years using these updated data sources.

This document provides an overview of the final data sources available for the 2019 Pacific halibut stock assessment including the population trends and distribution among Regulatory Areas based on the modelled IPHC fishery-independent setline survey (FISS), directed commercial fishery data, and results of the stock assessment including all data available through 2019.

STOCK AND MANAGEMENT

The stock assessment reports the status of the Pacific halibut resource in the IPHC Convention Area. 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 (Figure 1).

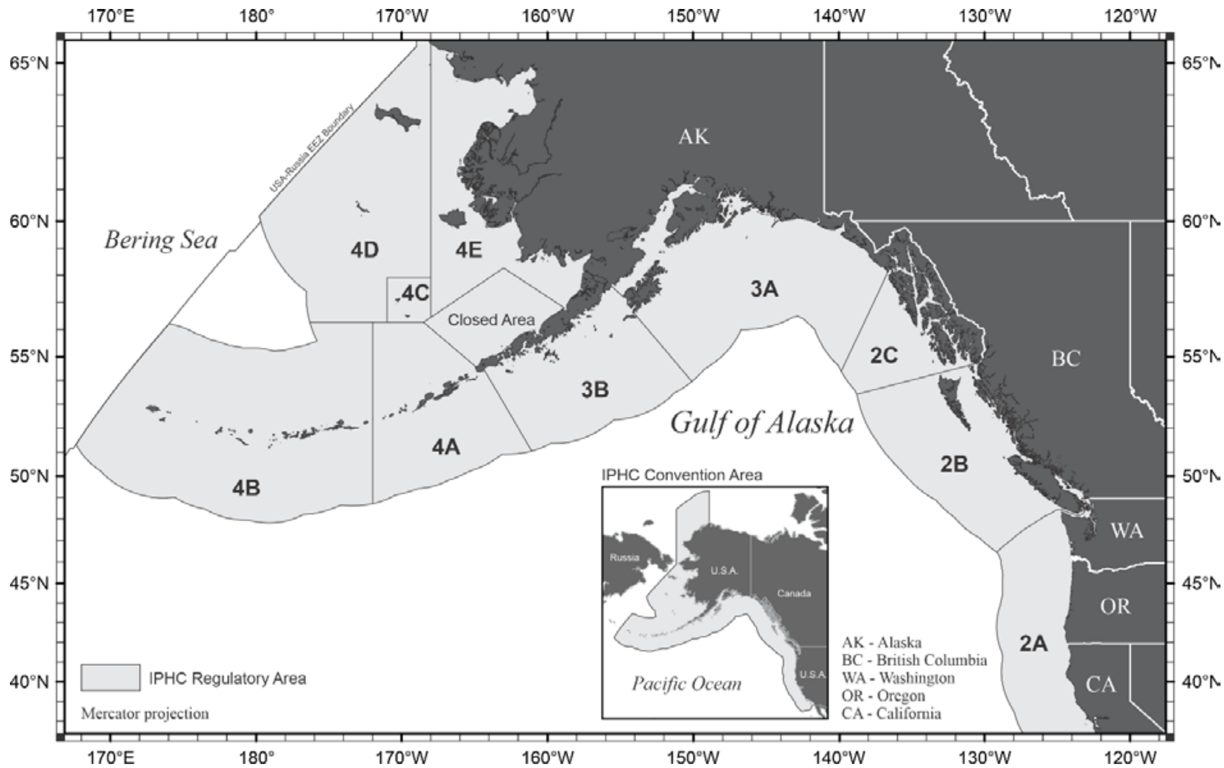

FIGURE 1. IPHC Convention Area (insert) and IPHC Regulatory Areas.

The Pacific halibut fishery has been managed by the IPHC since 1923. Catch limits for each of eight IPHC Regulatory Areas[1] are set each year by the Commission. The stock assessment provides a summary of recently collected data, and 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 projecting the level of mortality for fisheries in each Regulatory Area indicated by the IPHC's interim management procedure, as well as other alternatives.

DATA

Historical mortality

Known Pacific halibut mortality consists of target commercial fishery landings and discard mortality (including research), recreational fisheries, subsistence, and discard mortality in fisheries targeting other species ('non-directed' fisheries where Pacific halibut retention is prohibited). Over the period 1920-2019 mortality has totaled 7.2 billion pounds (~3.3 million metric tons, t), ranging annually from 34 to 100 million pounds (16,000-45,000 t) with an annual average of 63 million pounds (~29,000 t; Figure 2). Annual mortality was above this long-term

[1] The IPHC recognizes sub-Areas 4C, 4D, 4E and the Closed Area for use in domestic catch agreements but manages the combined Area 4CDE.

average from 1985 through 2010, and has averaged 41 million pounds (~18,500 t) from 2016-19.

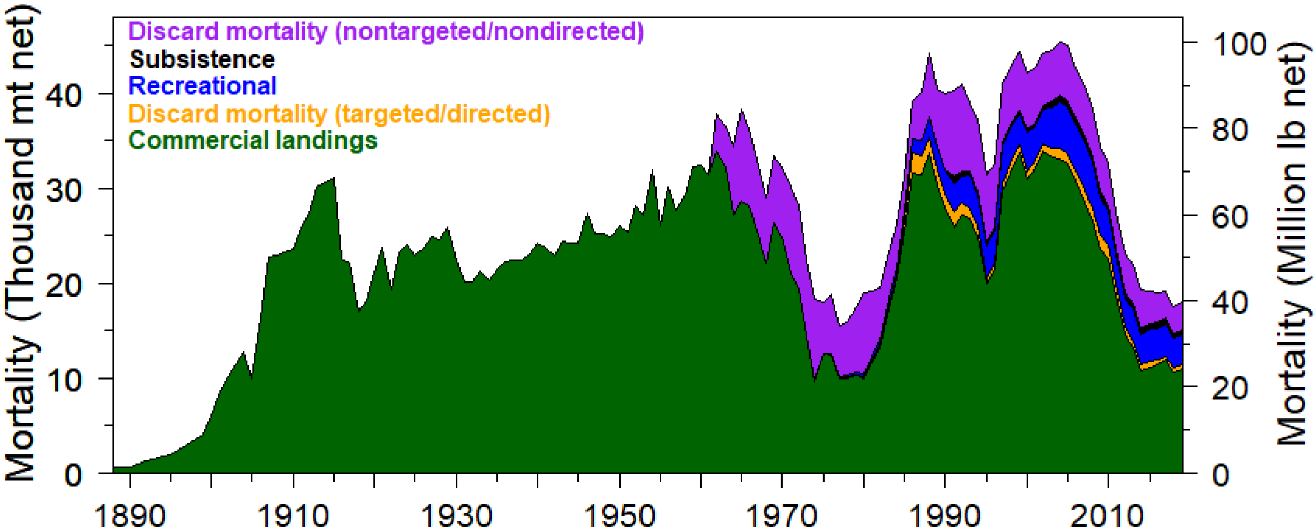

FIGURE 2. Summary of estimated historical mortality by source (colors), 1888-2019.

2019 Fishery and IPHC fishery-independent setline survey (FISS) statistics

Coastwide commercial Pacific halibut fishery landings (including research landings) in 2019 were approximately 24.3 million pounds (~11,000 t), up 3% from 2018. Discard mortality in non-directed fisheries was estimated to be 6.4 million pounds in 2019 (~2,900 t)[2], up 5% from 2018. The total recreational mortality (including estimates of discard mortality) was estimated to be 6.9 million pounds (~3,100 t), very close to the final estimate for 2018. Mortality from all sources increased by 3% to an estimated 39.7 million pounds (~18,000 t) in 2019 based on preliminary information available through 31 October 2019.

Data for stock assessment use are initially compiled by IPHC Regulatory Area, and then aggregated to four Biological Regions: Region 2 (Areas 2A, 2B, and 2C), Region 3 (Areas 3A, 3B), Region 4 (4A, 4CDE) and Region 4B and then coastwide (Figure 1). In addition to the aggregate mortality (including all sizes of Pacific halibut), the assessment includes data from both fishery dependent and fishery independent sources as well as auxiliary biological information, with the most spatially complete data available since the late-1990s. Primary sources of information for this assessment include modelled indices of abundance (IPHC-2019-IM095-07; based on the IPHC's annual fishery-independent setline survey (FISS; in numbers and weight) and other surveys), commercial Catch-Per-Unit-Effort (weight), and biological summaries from both sources (length-, weight-, and age-composition data).

All data sources are reprocessed each year to include new information from the terminal year, as well as any additional information for or changes made to the entire time-series. For 2019, there were two important improvements to the existing data sources: 1) sex-ratios at age based on genetic assays of port sampled Pacific halibut were available for commercial fishery landings made in 2017 and 2018, and 2) a revised modelled index of abundance reflecting the 2019 FISS

[2] The IPHC receives preliminary estimates of the current year's bycatch mortality in from the NOAA-Fisheries National Marine Fisheries Service Alaska Regional Office, Northwest Fisheries Science Center, and Fisheries and Oceans Canada in late October. Where necessary, projections are added to approximate the total mortality through the end of the calendar year.

sampling and expansions (in IPHC Regulatory Areas 3A and 3B). Routine updates of logbook records from the 2017-18 directed commercial fishery, as well as age-frequency observations from both commercial fishery and survey catches were also included. Since 2015, individual Pacific halibut weights collected during port sampling of commercial fishery landings are used to describe the commercial fishery. For 2019, individual weights were also collected during FISS operations such that use of the historical weight-length relationship was not necessary to calculate WPUE and stock distribution estimates. All mortality estimates (including changes to the existing time-series where new estimates have become available) were extended to include 2019. All available information was finalized on 31 October 2019 in order to provide adequate time for analysis and modeling. As has been the case in all years, some data are incomplete (i.e. commercial fishery logbook and age information), or include projections for the remainder of the year (i.e. mortality estimates for ongoing fisheries or for fisheries where final estimation is still pending).

The 2019 FISS detailed a coastwide aggregate NPUE (modelled via the space-time methodology) which showed a second consecutive year of decrease, down 4% from 2018 with 2017-19 each representing the lowest in the time-series (Figure 3). Biological Region 3 declined by 10% to the lowest estimate in the time-series while Biological Regions 2, 4, and 4B all increased slightly, but remain near historical lows. The 2019 modelled coastwide WPUE of legal (O32) Pacific halibut, the most comparable metric to observed commercial fishery catch rates, was lower (5%) than 2018, down for the third consecutive year and at the lowest value in the time series. Individual IPHC Regulatory Areas varied from a 26% increase (Regulatory Area 3B) to a 17% decrease (Regulatory Area 3A; Figure 4). The FISS sampling associated with the expansion in Biological Region 3 resulted in lower estimated catch-rates in this Region compared to the rest of the coast, and reduced the uncertainty in the index both for Region 3 and coastwide.

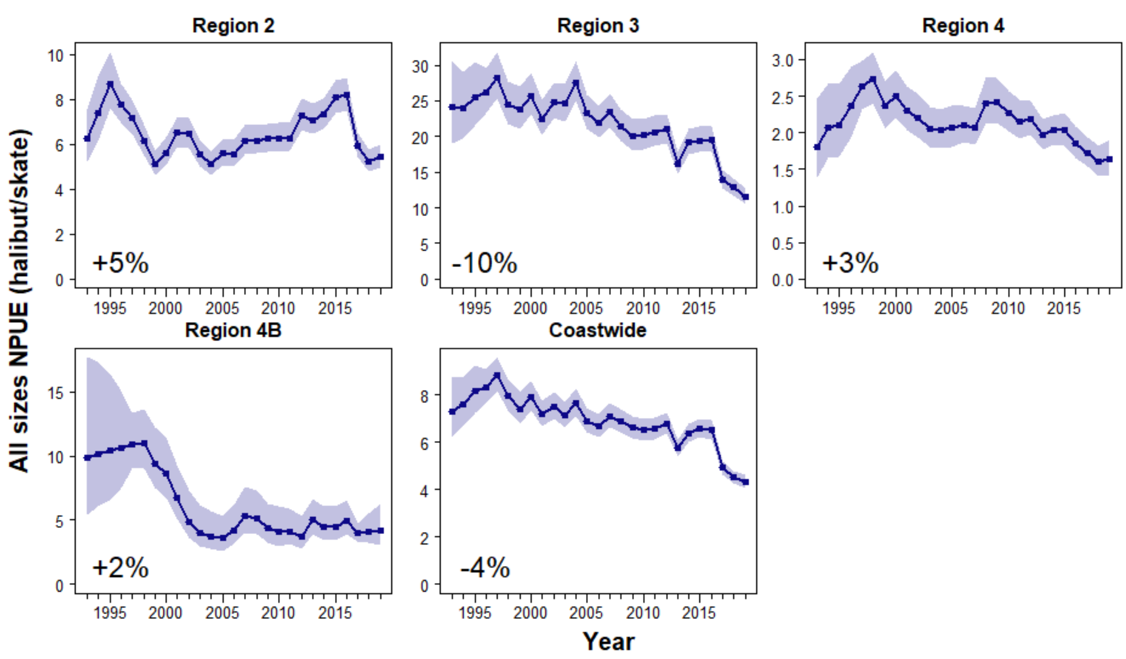

FIGURE 3. Trends in modelled FISS NPUE by Biological Region, 1993-2019. Percentages indicate the change from 2018 to 2019. Shaded zones indicate approximate 95% credible intervals.

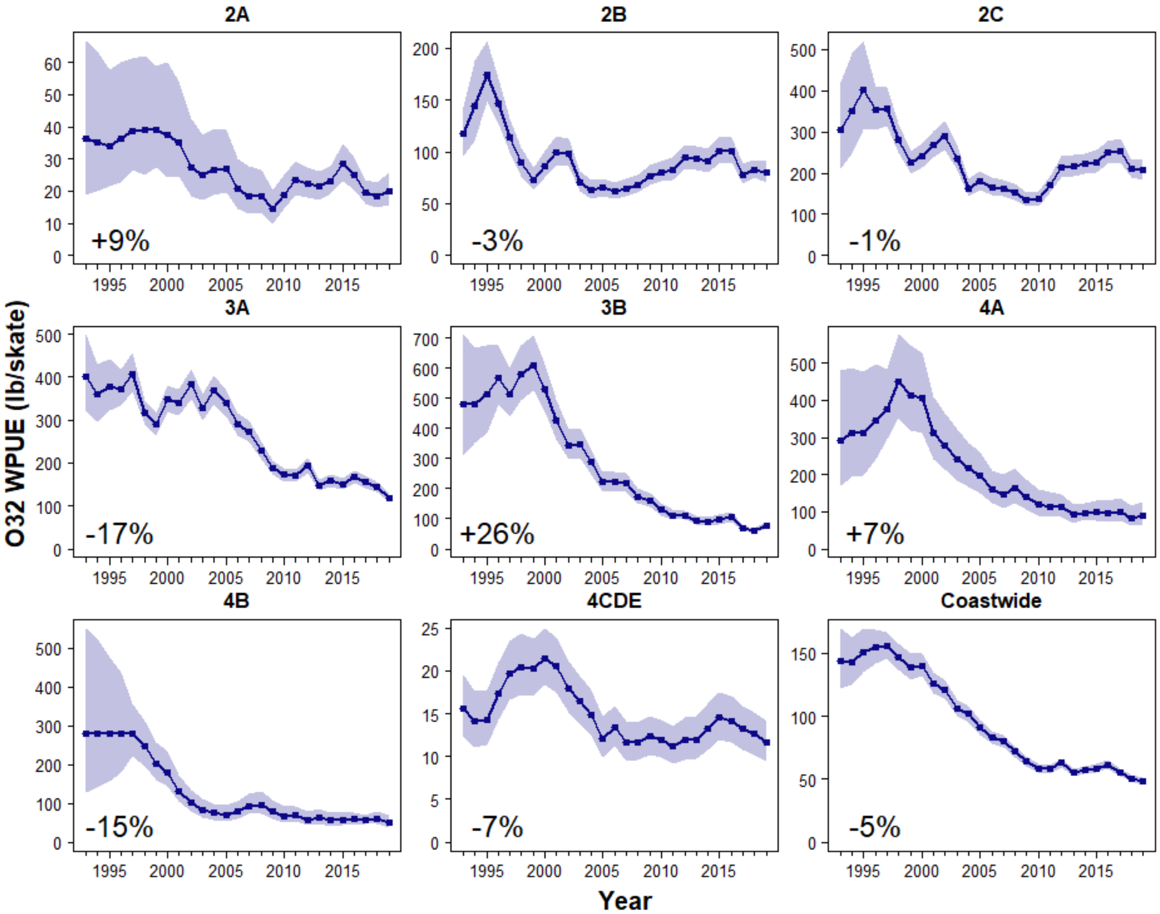

FIGURE 4. Trends in modelled FISS legal (O32) WPUE by IPHC Regulatory Area, 1993-2019. Percentages indicate the change from 2018 to 2019. Shaded zones indicate approximate 95% credible intervals.

Commercial fishery WPUE (based on extensive, but incomplete logbook records available for this assessment) increased 4% coastwide, with mixed performance across IPHC Regulatory Areas (Figure 5). A bias correction (to account for additional logbooks compiled after the fishing season, standard practice in recent years) resulted in an estimate of a 1% increase coastwide. As in 2018, fisheries and gear types are reported separately to allow more detailed evaluation of fishery performance (Figure 5).

Biological information (ages and lengths) from the commercial fishery continue to show the 2005 year-class as the largest contributor (in number) to the fish encountered. In the FISS age-frequency data, 2011 and 2012 cohorts (7 and 8 years old, following a series of weak cohorts from 2006-10) represented the largest proportions in some IPHC Regulatory Areas for the total catch, and the largest proportions coastwide for sublegal female Pacific halibut. At the coastwide level, individual size-at-age continues to be very low relative to the rest of the time-series and there has been no clear trend across ages over the last several years. For the first time, direct estimates of the sex-ratio at age for the directed commercial fishery were available for the IPHC's stock assessment. Data from sampled Pacific halibut in 2017 indicated a very high proportion female coastwide (82%), and a range from 65% in Biological Region 4B to 92% in Biological Region 4. Data from 2018 reflected very similar patterns, with females comprising 80% of the coastwide commercial landings (by number).

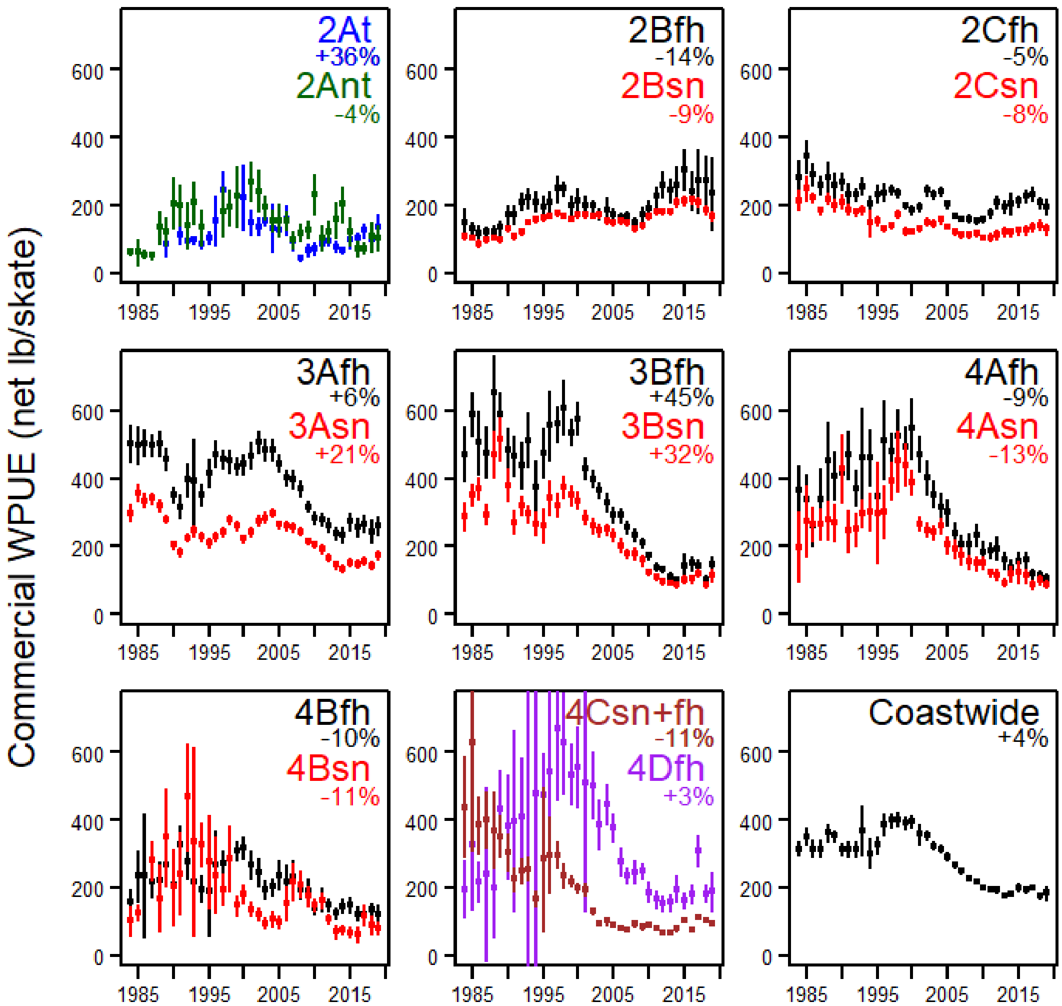

FIGURE 5. Trends in commercial fishery WPUE by IPHC Regulatory Area and fishery or gear, 1984-2019. The tribal fishery in 2A is denoted by "2At", nontribal by "2Ant", fixed hook catch rates by "fh" and snap gear catch rates by "sn" for IPHC Regulatory Areas 2B-4D. Percentages indicate the change from 2018 to 2019 uncorrected for bias due to incomplete logbooks (see text above). Vertical lines indicate approximate 95% confidence intervals.

Biological stock distribution

Updated trends indicate that population distribution (measured via the modelled FISS catch in weight of all Pacific halibut) has been decreasing in Biological Region 3 since 2004, and increasing in Biological Regions 2 and 4 (Figure 6; recent years in Table 1). Survey data are insufficient to estimate stock distribution prior to 1993. It is therefore unknown how historical distributions, and the average distribution likely to occur in the absence of fishing mortality may compare with recent observations.

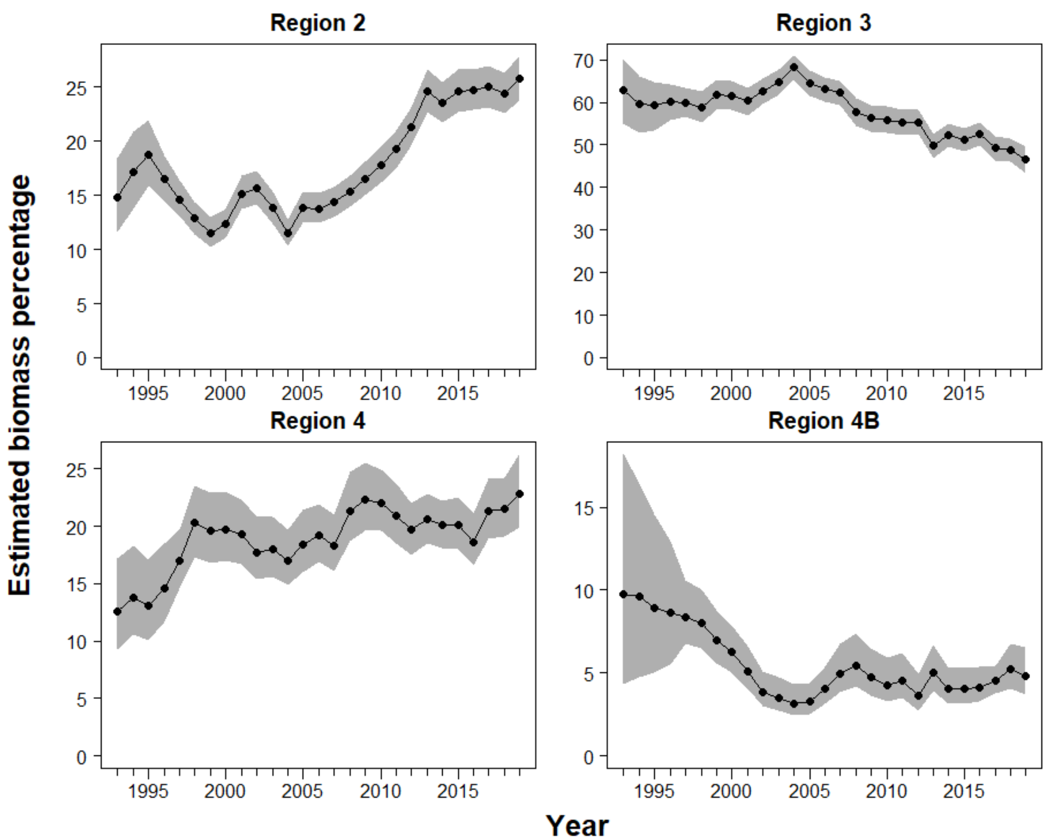

FIGURE 6. Estimated stock distribution (1993-2019) based on modelled survey catch of all sizes of Pacific halibut. Shaded zones indicate approximate 95% credible intervals.

TABLE 1. Recent stock distribution estimates by Biological Region based on modelling of all Pacific halibut captured by the FISS.

Year	Region 2 (2A, 2B, 2C)	Region 3 (3A, 3B)	Region 4 (4A, 4CDE)	Region 4B
2015	24.6%	51.3%	20.1%	4.0%
2016	24.7%	52.5%	18.7%	4.1%
2017	25.0%	49.2%	21.3%	4.5%
2018	24.4%	48.9%	21.5%	5.2%
2019	25.8%	46.5%	22.8%	4.8%

STOCK ASSESSMENT

This stock assessment continues to be implemented using the generalized software stock synthesis (Methot and Wetzel 2013). The analysis consists of an ensemble of four equally weighted models: 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 1992 to the present, a time-period for which estimates of all sources of mortality and survey indices are available for all regions. For each time-series length, there are two models: one fitting to coastwide aggregate data, and one fitting to data disaggregated into the four geographic regions. This combination of models includes uncertainty in the form of alternative hypotheses about several important axes of uncertainty, including: 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.

The 2019 stock assessment included a complete re-evaluation of all data sources and modelling choices. Although the basic ensemble approach and four structural models remain consistent with previous analyses, several key improvements were made including: extending the short time-series models back to 1992 to utilize the full modelled FISS index (beginning in 1993), additional flexibility in modelling fishery selectivity enabled by newly available sex-ratio at age data, and re-weighting the contributions of each type of data to the stock assessments based on the goodness of fit to index and age frequencies. The sex-ratio data were critically important to this assessment, as they allowed for direct estimation of parameters describing the scale of male selectivity in each of the individual models.

As has been the case since 2012, the results of this stock assessment are based on the approximate probability distributions derived from the ensemble of models, thereby incorporating the uncertainty within each model (parameter or estimation uncertainty) as well as the uncertainty among models (structural uncertainty). This approach reduces the 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. For 2019, the four models were again equally weighted. Within-model uncertainty from each model was propagated through to the ensemble results via the maximum likelihood estimates and an asymptotic approximation to their variance. Point estimates in this stock assessment correspond to median values from the ensemble: with the simple probabilistic interpretation that there is an equal probability above or below the reported value.

BIOMASS AND RECRUITMENT TRENDS

The results of the 2019 stock assessment indicate that the Pacific halibut stock declined continuously from the late 1990s to around 2012 (Figure 7). 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. The spawning biomass (SB) is estimated to have increased gradually to 2016, and then decreased to an estimated 194 million pounds (~87,850 t) at the beginning of 2020, with an approximate 95% confidence interval ranging from 133 to 248 million pounds (~60,500-112,500 t; Figure 8). Comparison with previous stock assessments indicates that over the last decade the 2019 results are very close to estimates from the 2012 through 2018 assessments. Prior to that period, the current 2019 assessment indicates a high probability of larger biomass than estimated in previous assessments (Figure 9); this is largely the result of the new sex-ratio information for the directed commercial landings indicating more females than in past analyses. All assessments since 2015 have indicated a decreasing spawning biomass in the terminal year.

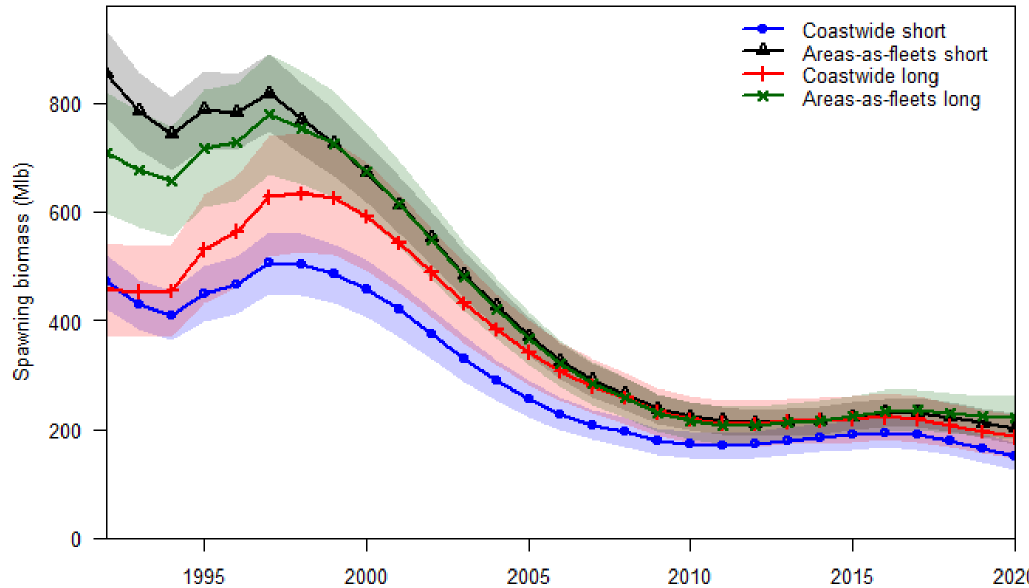

FIGURE 7. Estimated spawning biomass trends (1992-2020) based on the four individual models included in the 2019 stock assessment ensemble. Series indicate the maximum likelihood estimates; shaded intervals indicate approximate 95% credible intervals.

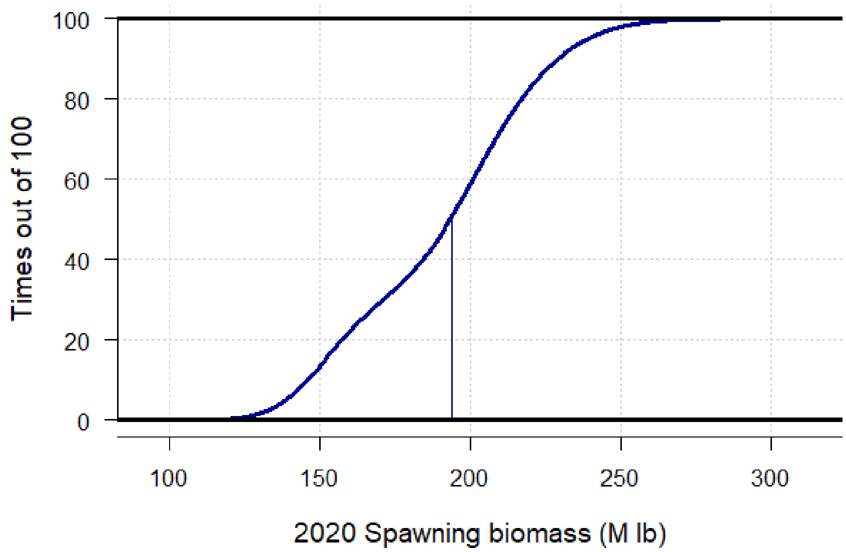

FIGURE 8. Cumulative distribution of the estimated spawning biomass at the beginning of 2020. Curve represents the estimated probability that the biomass is less than or equal to the value on the x-axis; vertical line represents the median (194 million pounds, ~87,850 t).

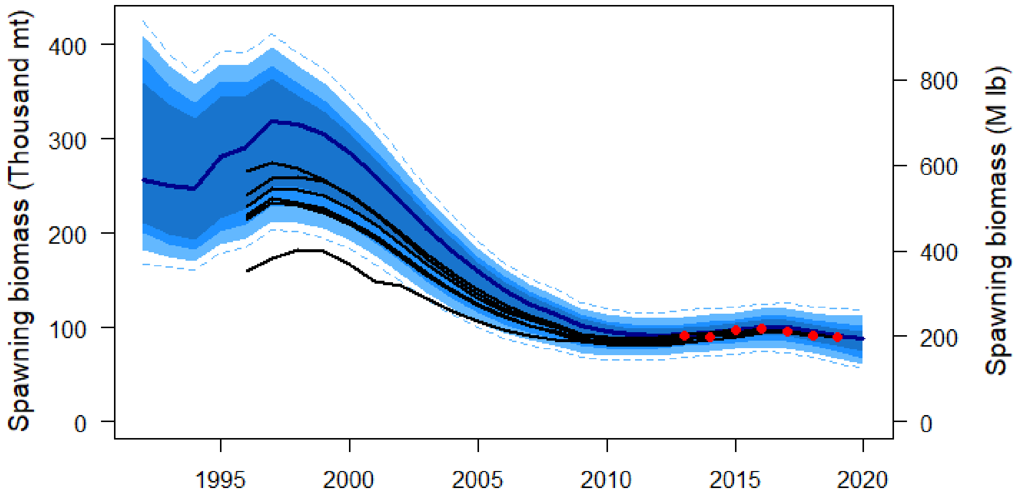

FIGURE 9. Retrospective comparison among recent IPHC stock assessments. Black lines indicate estimates of spawning biomass estimated by assessments conducted from 2012-2018 with the terminal estimate shown as a point, the shaded distribution denotes the 2019 ensemble: the dark blue line indicates the 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.

Average Pacific halibut recruitment is estimated to be higher (69 and 76% 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. Annual averages from 2014 through September 2019 have been positive; however, over this period many other environmental indicators, current and temperature patterns have been anomalous. Therefore, historical patterns of productivity related to the PDO may not be relevant to the most recent few years, and it will be years or decades before this can be verified via observed recruitment strengths. Pacific halibut recruitment estimates show the largest recent cohorts in 1999 and 2005 (Figure 10). Cohorts from 2006 through 2010 are estimated to be much smaller than those from 1999-2005 which results in a high probability of decline in both the stock and fishery yield as these low recruitments become increasingly important to the age range over which much of the harvest and spawning takes place. Based on age data from the 2019 survey, this assessment estimated the 2011 and 2012 year-classes to be similar to those in 2000-04. This is consistent with the appearance of these cohorts in the 2018 assessment, although they remain below the level of the 1999 and 2005 year-classes even with second year of observation. The projected spawning biomass over the next 2-4 years includes the effects of these year classes maturing at ages 8-13.

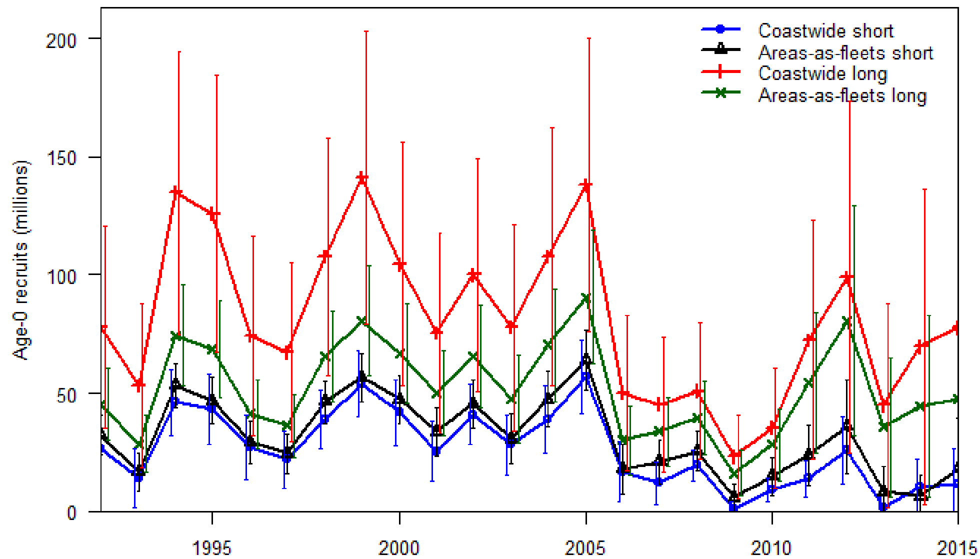

FIGURE 10. Estimated age-0 recruitment trends (1992-2015) based on the four individual models included in the 2019 stock assessment ensemble. Series indicate the maximum likelihood estimates; vertical lines indicate approximate 95% credible intervals.

The IPHC's interim management procedure uses a relative spawning biomass of 30% as a trigger, to begin reducing the target fishing intensity to a limit at 20%, where directed fishing is halted due to the critically low biomass condition. The relative spawning biomass has historically been calculated based on an arbitrary choice of 'good' weight-at-age and 'poor' recruitment levels estimated decades ago. The 2019 assessment, after Scientific Review Board and external review, and following the developments in the IPHC's Management Strategy Evaluation (MSE) process, has updated this calculation to include recent biological conditions. By using current weight-at-age and estimated recruitments influencing the current stock only, the 'dynamic' calculation measures the effect of fishing on the spawning biomass. This avoids the potential situation where environmental and biological conditions could be conflated with fishing effects. The 'historical' static relative spawning biomass was declining rapidly (although estimated to be higher in the 2018 assessment), where the dynamic calculation has been lower (estimated to be 32% in 2020; approximate credible interval: 22-46%) but more stable (Table 2). This result reflects the greater effects of reduced recruitment, rather than fishing in the last few years. The probability that the stock is below the $SB_{30\%}$ level is estimated to be 46% at the beginning of 2020, with less than a 1% chance that the stock is below $SB_{20\%}$. The two long time-series models provide a comparison with spawning biomass levels estimated to have occurred during the low stock sizes estimated for the 1970s: the AAF model suggests that recent stock sizes are at 61% of those levels, and the coastwide model at 207%. The large relative differences among models reflect both the uncertainty in historical dynamics as well as the importance of spatial patterns in the data and population processes, for which all of the models represent only simple approximations.

TABLE 2. Comparison of ‘historical’ and ‘dynamic’ relative spawning biomass estimates from the 2018 and current 2019 stock assessments. Percentage indicates the relative spawning biomass estimated for that year with approximate 95% credible intervals in parentheses; $P(SB<SB_{XX\%})$ indicates the probability that the relative spawning biomass in that year is below the reference point (either 20 or 30%).

Year	**2018 Assessment** (‘Historical’ relative *SB*)	**2019 Assessment** (‘Dynamic’ relative *SB*)
2019	43% (27-63%) *P(SB<SB30*%) = 11% *P(SB<SB20%)* = <1%	32% (23-46%) *P(SB<SB30*%) = 44% *P(SB<SB20%)* = <1%
2020	38% (22-51%) *P(SB<SB30*%) = 25% *P(SB<SB20%)* = <1%	32% (22-46%) *P(SB<SB30*%) = 46% *P(SB<SB20%)* = <1%

The IPHC’s Interim management procedure specifies a target level of fishing intensity of a Spawning Potential Ratio (SPR) corresponding to an $F_{46\%}$; this equates to the level of fishing that would reduce the lifetime spawning output per recruit to 46% of the unfished level given current biology, fishery characteristics and demographics. Based on the 2019 assessment, and including the higher proportion of females in the directed commercial landings than previously understood, the 2019 fishing intensity is estimated to correspond to an $F_{42\%}$ (credible interval: 29-57%; Table 3). Comparing the relative spawning biomass and fishing intensity over the recent historical period provides for an evaluation of trends conditioned on the currently defined reference points; this type of comparison is commonly called a ‘phase’ plot. The phase plot for Pacific halibut shows that the relative spawning biomass decreased as fishing intensity increased through 2010, then increased as the fishing intensity decreased through 2016, and has been relatively stable since then (Figure 11).

TABLE 3. Status summary of Pacific halibut in the IPHC Convention Area at the end of 2019.

Indicators	Values	Trends	Status
Total mortality 2019: Retained catch 2019: Average removals 2015–19:	39.67 MLBS, 17,996 T[1] 32.21 MLBS, 14,608 T 40.93 MLBS, 18,567 T	MORTALITY INCREASED FROM 2018 TO 2019	**2019 MORTALITY NEAR 100-YEAR LOW**
SPR_{2019}: P(SPR<46%): P(SPR<limit):	42% (29-57%)[2] 59% LIMIT NOT SPECIFIED	FISHING INTENSITY INCREASED FROM 2018 TO 2019	**FISHING INTENSITY ABOVE REFERENCE LEVEL[3]**
SB_{2020} (Mlb): SB_{2020}/SB_0: $P(SB_{2020}<SB_{30})$: $P(SB_{2020}<SB_{20})$:	194 MLBS (133–248) 32% (22-46%) 46% <1%	SB DECREASED FROM 2016 TO 2020	**NOT OVERFISHED[4]**
Biological stock distribution:	SEE TABLES AND FIGURES	REGION 3 DECREASING	**REGION 2 AND 4 AT HISTORICAL HIGHS**

[1] Weights in this document are reported as 'net' weights, head and guts removed; this is approximately 75% of the round (wet) weight.
[2] Ranges denote approximate 95% credible intervals from the stock assessment ensemble.
[3] Status determined relative to the IPHC's interim reference Spawning Potential Ratio level of 46%.
[4] Status determined relative to the IPHC's interim management procedure biomass limit of $SB_{20\%}$.

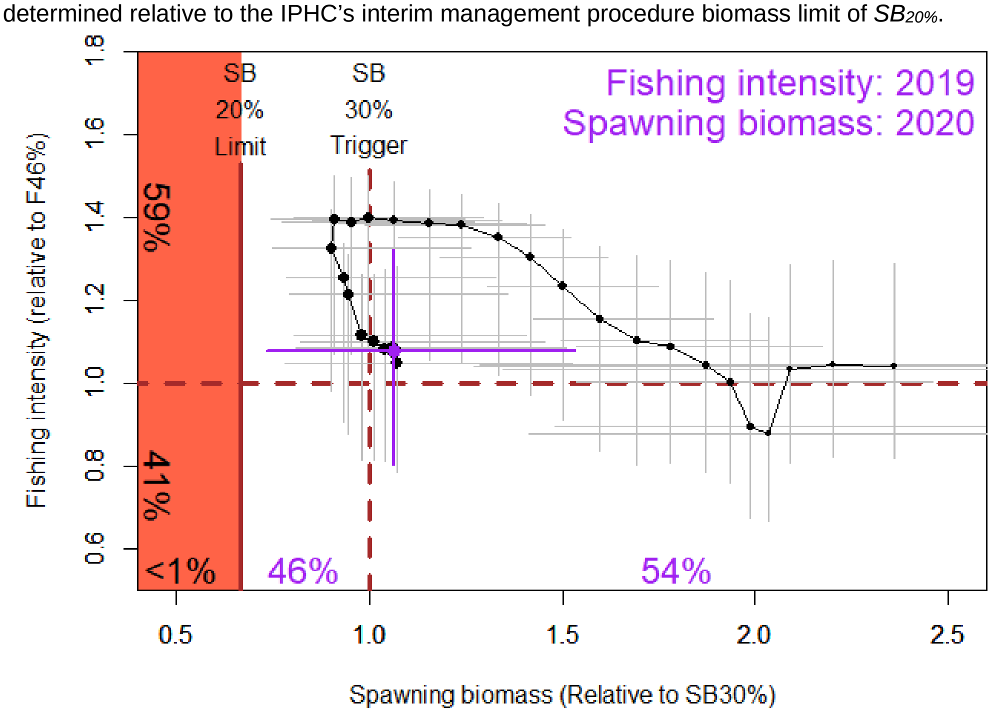

FIGURE 11. Phase plot showing the time-series (1992-2020) of estimated spawning biomass and fishing intensity relative to the reference points specified in the IPHC's interim management procedure. Dashed lines indicate the $F_{46\%}$ (horizontal) and $SB_{30\%}$ (vertical) values, red area indicates relative spawning biomass levels below the $SB_{20\%}$ threshold. Each year of the time series is denoted by a solid point (credible intervals by horizontal and vertical whiskers), with the relative fishing intensity in 2019 and spawning biomass at the beginning of 2020 shown as the largest point (purple). Percentages along the y-axis indicate the probability of being above and

below $F_{46\%}$ in 2019; percentages on the x-axis the probabilities of being below $SB_{20\%}$, between $SB_{20\%}$ and $SB_{30\%}$ and above $SB_{30\%}$ at the beginning of 2020.

MAJOR SOURCES OF UNCERTAINTY

This stock assessment includes 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 an improvement over the use of a single assessment model, there are important sources of uncertainty that are not included.

The 2019 assessment utilizes two years (2017-18) of sex-ratio information from the directed commercial fishery landings. However, uncertainty in historical ratios, and the degree of variability likely present in those and future fisheries remains unknown. Additional years of data are likely to further inform selectivity parameters and cumulatively reduce uncertainty in stock size in the future. The treatment of spatial dynamics and movement rates among Biological Regions, which are represented via the coastwide and AAF approaches, has large implications for the current stock trend, as evidenced by the different results among the four models comprising the stock assessment ensemble. Further, movement rates for adult and younger Pacific halibut (roughly ages 2-6, which were not well-represented in the PIT-tagging study), particularly to and from Biological Region 4 (and especially to and from the Eastern Bering Sea), are important and uncertain components in understanding and delineating between the distribution of recruitment among biological Regions, and other factors influencing stock distribution and productivity. This assessment also does not include mortality, trends or explicit demographic linkages with Russian waters, although such linkages may be increasingly important as warming waters in the Bering Sea allow for potentially important exchange across the international border.

Additional important contributors to assessment uncertainty (and potential bias) include factors influencing recruitment, size-at-age, and some estimated components of the fishery removals. The link between Pacific halibut recruitment strengths and environmental conditions remains poorly understood, and although correlation with the Pacific Decadal Oscillation is currently useful, it may not remain so in the future. Therefore, recruitment variability remains a substantial source of uncertainty in current stock estimates due to the lack of mechanistic understanding and 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 has been the most important driver of recent decade's stock trends, but its cause also remains unknown. Like most stock assessments, mortality estimates are assumed to be accurate. Therefore, uncertainty due to discard mortality estimation (observer sampling and representativeness), discard mortality rates, and any other unreported sources of removals in either directed or non-directed fisheries (e.g., whale depredation) could create bias in this assessment.

Maturation schedules are currently under renewed investigation by the IPHC. Currently used historical values are based on visual field assessments, and the simple assumption that fecundity is proportional to spawning biomass and that Pacific halibut do not experience appreciable skip-spawning (physiologically mature fish which do not actually spawn due to environmental or other conditions). To the degree that maturity, fecundity or skip spawning may be temporally variable, the current approach could result in bias in the stock assessment trends and reference points. New information will be incorporated as it becomes available; however, it may take years to better understand these biological processes.

Due to the many remaining uncertainties in Pacific halibut biology and population dynamics, a high degree of uncertainty in both stock scale and trend will continue to be an integral part of an annual management process. Potential solutions include management procedures that utilize multi-year management approaches, which are being tested with the MSE framework.

OUTLOOK

Stock projections were conducted using the integrated results from the stock assessment ensemble in tandem with summaries of the 2019 directed fisheries and other sources of mortality. The harvest decision table (Table 4) provides a comparison of the relative risk (in times out of 100), using stock and fishery metrics (rows), against a range of alternative harvest levels for 2020 (columns). The block of rows entitled "Stock Trend" provides for evaluation of the risks to short-term trend in spawning biomass, independent of all harvest policy calculations. The remaining rows portray risks relative to the spawning biomass reference points ("Stock Status") and fishery performance relative to the approach identified in the interim management procedure. The alternatives (columns) provided include several coarsely spaced levels of mortality intended for evaluation of stock dynamics including:

- No mortality (useful to evaluate the stock trend due solely to population processes),
- A 10 million pound (~4,500 t) 2020 Total Constant Exploitation Yield (TCEY[3])
- A 50 million pound (~22,700 t) 2020 TCEY
- A 60 million pound (~27,200 t) 2020 TCEY
- The mortality at which there is a 50% chance that the spawning biomass will be smaller in three years than in 2020 ("*3-year surplus*")
- The mortality consistent with the "Reference" SPR ($F_{46\%}$) level.
- The mortality consistent with repeating the TCEYs set for 2019 (*"status quo"*).

A grid of alternative TCEY values corresponding to SPR values from 40% to 58% is also provided. For each row of the decision table, the mortality (including all sizes and sources), the coastwide TCEY and the associated level of fishing intensity projected for 2020 (median value with the 95% credible interval below) are reported.

The stock is projected to decrease with at least a 51% chance over the period from 2021-23 for all TCEYs greater than the "3-year surplus" of 18.4 million pounds (~8,350 t), corresponding to a projected SPR of 63% (credible interval 44-75%; Table 4, Figure 12). At the reference level (a projected SPR of 46%) the probability of spawning biomass decline to 2021 is 89%, decreasing to 75% in three years, as the 2011 and 2012 cohorts mature. At the *status quo* TCEYs (38.61 million lb, (~17,500 t), the probability of spawning biomass declines is 97 and 87% for one and three years respectively. The one-year risk of the stock dropping below $SB_{30\%}$ ranges from 43% (at the 3-year surplus level) to 49% at the *status quo* TCEYs. Over three years these probabilities range from 37% to 50% depending on the level of mortality.

[3] The TCEY corresponds approximately to all mortality of Pacific halibut, except non-directed discard mortality of fish less than 26 inches (66 cm) in length.

TABLE 4. Harvest decision table for 2020 mortality limits. Columns correspond to yield alternatives and rows to risk metrics. Values in the table represent the probability, in “times out of 100” (or percent chance) of a particular risk.

		2020 Alternative			3-Year Surplus				*Reference SPR=46%*						Status quo		
		Total mortality (M lb)	0.0	11.6	20.0	23.6	27.6	32.3	33.5	34.6	35.7	36.8	37.8	38.9	40.2	61.6	
		TCEY (M lb)	0.0	10.0	18.4	22.0	26.0	30.7	31.9	33.0	34.1	35.2	36.2	37.3	38.6	60.0	
		2020 fishing intensity	$F_{100\%}$	$F_{78\%}$	$F_{63\%}$	$F_{58\%}$	$F_{53\%}$	$F_{47\%}$	$F_{46\%}$	$F_{45\%}$	$F_{44\%}$	$F_{43\%}$	$F_{42\%}$	$F_{41\%}$	$F_{40\%}$	$F_{27\%}$	
		Fishing Intensity Interval	--	59-87%	44-75%	39-71%	35-67%	31-62%	30-61%	29-60%	28-59%	28-58%	27-57%	26-56%	25-56%	17-43%	
Stock Trend (spawning biomass)	In 2021	Is less than 2020	1	29	61	71	79	87	89	91	93	94	95	96	97	>99	a
		Is 5% less than 2020	<1	<1	11	23	30	42	46	50	54	58	61	64	67	98	b
	In 2022	Is less than 2020	<1	16	50	60	68	77	79	81	83	85	87	89	90	>99	c
		Is 5% less than 2020	<1	1	23	33	45	59	61	64	66	68	69	71	74	99	d
	In 2023	Is less than 2020	1	22	50	58	65	73	75	77	79	81	83	85	87	>99	e
		Is 5% less than 2020	<1	6	33	43	53	62	64	66	67	69	71	73	75	99	f
Stock Status (Spawning biomass)	In 2021	Is less than 30%	35	39	43	44	46	47	48	48	48	48	48	49	49	51	g
		Is less than 20%	<1	<1	<1	<1	<1	1	1	1	2	2	2	3	3	16	h
	In 2022	Is less than 30%	26	31	40	43	46	48	48	49	49	49	49	50	50	54	i
		Is less than 20%	<1	<1	<1	1	2	6	7	8	9	11	12	14	15	27	j
	In 2023	Is less than 30%	18	27	37	41	45	48	49	49	49	49	50	50	50	60	k
		Is less than 20%	<1	<1	<1	2	6	13	15	17	18	20	21	22	23	40	l
Fishery Trend (TCEY)	In 2021	Is less than 2020	0	<1	11	24	36	50	51	52	54	57	59	63	67	>99	m
		Is 10% less than 2020	0	<1	1	12	25	40	44	46	48	50	51	52	53	>99	n
	In 2022	Is less than 2020	0	<1	11	25	39	50	51	52	54	56	59	62	66	>99	o
		Is 10% less than 2020	0	<1	2	14	27	43	46	48	49	50	51	52	54	>99	p
	In 2023	Is less than 2020	0	<1	13	27	41	50	51	52	54	56	58	61	65	>99	q
		Is 10% less than 2020	0	<1	4	16	30	45	47	48	49	50	51	52	54	>99	r
Fishery Status (Fishing intensity)	In 2020	Is above $F_{46\%}$	0	<1	7	22	31	48	50	51	53	55	57	60	64	>99	s

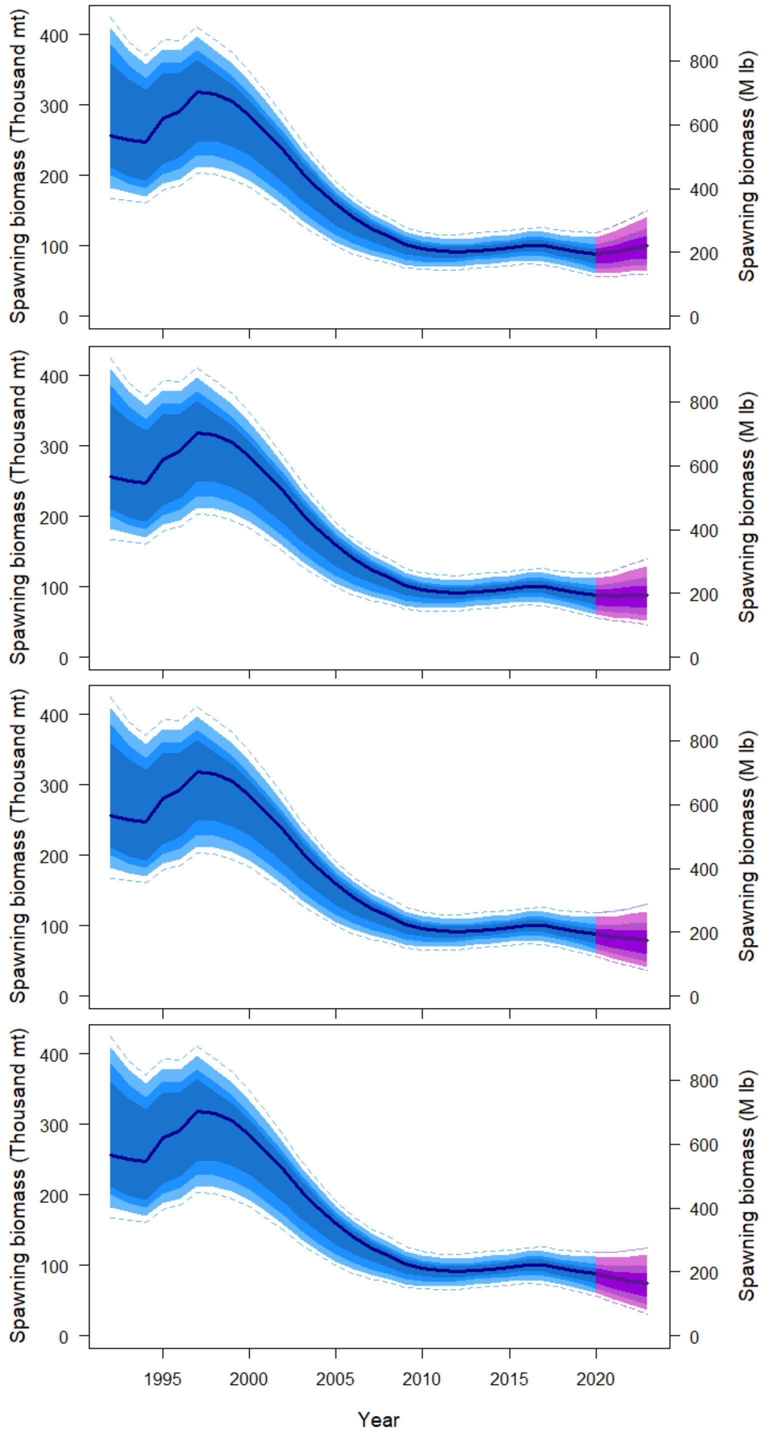

FIGURE 12. Three-year projections of stock trend under alternative levels of mortality: no fishing mortality (upper panel), the 3-year surplus (18.4 million pounds, ~8,350 t; second panel), the TCEY projected for the IPHC's Interim management procedure (31.9 million pounds, 14,500 t; third panel) and a TCEY of 38.61 million pounds (~17,500 t, the *status quo* TCEYs from 2019; lower panel).

SCIENTIFIC ADVICE

Sources of mortality: In 2019, total Pacific mortality due to fishing was up slightly to 39.67 million pounds (17,996 t) from 38.5 million pounds (17,461 t) in 2018 (updated for this assessment). Of that total, 81% comprised the retained catch, down from 82% in 2018 (Table 3).

Fishing intensity: The 2019 mortality corresponded to a point estimate of SPR = 42%; there is a 59% chance that fishing intensity exceeded the IPHC's reference level of 46% (Table 3). The Commission does not currently have a coastwide fishing intensity limit reference point.

Stock status (spawning biomass): Current female spawning biomass is estimated to be 194 million pounds (87,856 t), which corresponds to an 46% chance of being below the IPHC threshold (trigger) reference point of $SB_{30\%}$, and less than a 1% chance of being below the IPHC limit reference point of $SB_{20\%}$. The stock is estimated to have been declining since 2016 and is currently at 32% of the unfished state. Therefore, the stock is considered to be '**not overfished**'. Projections indicate that mortality consistent with the Interim management procedure reference fishing intensity ($F_{46\%}$) is likely to result in further declining biomass levels in the near future.

Stock distribution: The proportion of the coastwide stock represented by Biological Region 3 has been decreasing since 2004 (Figure 6), with Biological Regions 2 and 4 increasing. Although comprising 46.5% of the coastwide surveyed biomass in 2019, the decreasing trend suggests that surplus production has likely been exceeded in Biological Region 3 over the last 15 years to a greater degree than in other Biological Regions.

RESEARCH PRIORITIES

Research priorities for the stock assessment and related analyses have been consolidated with those for the IPHC's MSE and the Biological Research program. These ranked and categorized priorities will soon be available on the IPHC's website.

ADDITIONAL INFORMATION

Detailed information for AM096 will include any revisions to this document (IPHC-2020-AM096-08), a description of the data sources (IPHC-2020-AM096-09), and the stock assessment (IPHC-2020-AM096-10). The IPHC's website contains many new interactive tools and historical data series that allow for detailed evaluation and will replace historical static summaries.

An updated mortality projection tool will be developed prior to AM096 for use in evaluating 2020 mortality limits. This tool will be finalized in early January 2020 in order to make use of revised end-of-year 2019 discard mortality estimates in non-directed fisheries.

RECOMMENDATION/S

That the Commission:

a) **NOTE** paper IPHC-2019-IM095-09 Rev_1 which provides a summary of data, the 2019 stock assessment and the harvest decision table for 2020.

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