INTERNATIONAL PACIFIC HALIBUT COMMISSION

Assessment of the Pacific halibut (*Hippoglossus stenolepis*) stock at the end of 2020

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PURPOSE

To provide the Commission with a detailed report of the 2020 stock assessment analysis.

ABSTRACT

This stock assessment reports the status of the Pacific halibut (*Hippoglossus stenolepis*) resource in the International Pacific Halibut Commission (IPHC) Convention Area at the end of 2020. An overview of data sources is provided in a separate document (IPHC-2021-SA-02) on the IPHC's stock assessment webpage along with the input data files for each model included in this stock assessment. A summary of both the data and assessment results, as well as management related information is provided both on the stock assessment webpage and in the meeting materials for the IPHC's 97th Annual Meeting (AM097; IPHC-2021-AM097-08).

Coastwide mortality from all sources in 2020 was estimated to be 35.5 million pounds[1] (~16,010 t), down 11% from 2019. In addition to the estimated mortality, the assessment includes data from both fishery dependent and fishery independent sources, as well as auxiliary biological information. The 2020 modelled Fishery-Independent Setline Survey (FISS; see IPHC-2021-AM097-06 and IPHC-2021-AM097-07) detailed a coastwide aggregate Numbers-Per-Unit-Effort (NPUE) which showed a fourth consecutive year of decrease, down 1% from 2019, with individual Biological Regions ranging from a 2% increase (Regions 4 and 4B) to an 8% decrease (Region 2). The modelled coastwide FISS Weight-Per-Unit-Effort (WPUE) of legal (O32) Pacific halibut, the most comparable metric to observed commercial fishery catch rates, was 6% higher than the 2019 estimate. Individual IPHC Regulatory Areas varied from a 24% increase (IPHC Regulatory Area 3A) to a 10% decrease (Regulatory Area 2B). Preliminary commercial fishery WPUE (based on all 2020 logbook records available for this assessment) increased 2% coastwide, with mixed performance across IPHC Regulatory Areas. A bias correction (to account for additional logbooks compiled after the fishing season) resulted in in an estimate of no change coastwide from 2019. Biological information (ages and lengths) from both the commercial fishery and FISS continue to show the 2005 year-class as the largest single-age contributor (in number) to the fish encountered, with the 2011 and 2012 cohorts (8 and 9 years old in 2020) showing clearly in the fishery data for the first time. In the FISS data, the 2011 and 2012 cohorts were prominent in the 2020 data and again represented the largest proportions in some IPHC Regulatory Areas for the total catch and the largest proportions coastwide for sublegal Pacific halibut. At the coastwide level, individual size-at-age continues to be low relative to the rest of the time-series; however, increasing trends for younger ages (approximately age 13 and younger depending on the IPHC Regulatory Area) suggest some improvement over the last several years. Sex-ratio data from the commercial fishery landings in 2019 and the full time-series from the recreational fishery were incorporated into this assessment. These data extended the initial addition of sex-specific age composition data from fishery sources in the 2019 assessment, but had a relatively minor effect on model results. Updated trends indicate that population distribution (measured via the modelled FISS catch in weight of all Pacific halibut)

[1] All weights in the document are 'net' weights; head-off and entrails removed approximately 75% of round weight. Mortality estimates reported in this document were current as of 31 October 2020, reflecting the information available for the stock assessment analysis.

increased in Biological Region 3, and decreased in Biological Region 2 from 2019 to 2020; this change was driven primarily by increased FISS catch rates in IPHC Regulatory Area 3A in 2020.

This stock assessment continues to be implemented using the generalized stock synthesis software (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. Results are 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. The 2019 stock assessment represented a full re-analysis of models and data, including an external independent peer review, and a review by the IPHC's Scientific Review Board (SRB; IPHC-2019-SRB014-R, IPHC-2019-SRB015-R), The 2020 stock assessment represents an update to the 2019 analysis, adding data sources where available, but retaining the same basic model structure for each of the four component models. Incremental changes made during 2020 were documented through a two-part review by the IPHC's scientific review process (IPHC-2020-SRB016-R, IPHC-2020-SRB017-R).

The results of the 2020 stock assessment indicate that the Pacific halibut stock declined continuously from the late 1990s to around 2012. 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 192 million pounds (~87,050 t) at the beginning of 2021, with an approximate 95% credible interval ranging from 125 to 292 million pounds (~56,800-132,600 t). The recent spawning biomass estimates from the 2020 stock assessment are very consistent with previous analyses, back to 2012. Pacific halibut recruitment estimates show the large cohorts in 1999 and 2005. Cohorts from 2006 through 2010 are estimated to be much smaller than those from 1999-2005, which results in a high probability of near-term 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 through 2020, individual models in this assessment produced estimates of the 2011 and 2012 year-classes that ranged extensively: from below to above the magnitude of the 2005 year-class. Even with a third year of observation from the FISS, and now a year from the commercial fishery, these two important year-classes remain uncertain. Some of this uncertainty is due to the relatively flat index trends observed which do not clearly identify these cohorts as being above average, despite the strong representation in the age structure of the samples. The projected spawning biomass over the next 3 years includes the effects of these year classes maturing at ages 8-12.

The IPHC's interim management procedure uses a relative spawning biomass of 30% as a fishery trigger, reducing the reference fishing intensity if relative spawning biomass decreases further toward a limit reference point at 20%, where directed fishing is halted due to the critically low biomass condition. The relative spawning biomass in 2021 was estimated to be 33% (credible interval: 22-52%) down slightly from 34% in 2020, but greater than the values estimated for the previous decade. The probability that the stock is below $SB_{30\%}$ is estimated to be 41% at the beginning of 2021, with less than a 1% chance that the stock is below $SB_{20\%}$. The IPHC's current interim management procedure specifies a target level of fishing intensity of a Spawning Potential Ratio (SPR) corresponding to an $F_{43\%}$; this equates to the level of fishing that would reduce the lifetime spawning output per recruit to 43% of the unfished level given current biology, fishery characteristics and demographics. Based on the 2020 assessment, the 2020 fishing intensity is estimated to correspond to an $F_{48\%}$ (credible interval: 34-65%). Stock projections were conducted using the integrated results from the stock assessment ensemble, details of IPHC Regulatory Area-specific catch sharing plans and estimates of mortality from the 2020 directed fisheries and other sources of mortality. The projections for this assessment are slightly more optimistic than in the 2019 assessment; however, a high probability of stock decline (approximately 2/3) is estimated for the entire range of SPR values from 40-46%. 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 24.4 million pounds (~11,068 t), corresponding to a projected SPR of 58% (credible interval 39-76%). At the *status quo* TCEY (36.6 million lb, (~16,600 t), the probability of spawning biomass declines is 62 and 61% for one and three years respectively. At the reference level (a projected SPR of 43%) the probability of spawning biomass decline to 2022 is 65%, decreasing to 63% in three years, as the 2011 and 2012 cohorts mature. The one-year risk of the stock dropping below $SB_{30\%}$ ranges from 35% (at the 3-year surplus level) to 41% at the reference TCEY. Over three years these probabilities range from 29% to 44% depending on the level of mortality. A bridging analysis from the 2019 to 2020 assessment results, as well as sensitivity and retrospective analyses, and a discussion of major sources of uncertainty are also included in this document.

INTRODUCTION

The stock assessment reports the status of the Pacific halibut (*Hippoglossus stenolepis*) 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 the Salish Sea, but excludes known extremities in the western Bering Sea within the Russian Exclusive Economic Zone (Figure 1). The Pacific halibut fishery has been managed by the IPHC since 1923. Mortality limits for each of eight IPHC Regulatory Areas[2] are set each year by the Commission. The stock assessment provides a brief summary of recently collected data; a more detailed treatment of data sources included in the assessment and used for other analyses supporting harvest policy calculations is provided in a separate document (**IPHC-2021-SA-02**) on the IPHC's stock assessment webpage. Results include current model estimates of stock size and trend reflecting all available data. Specific management information is summarized via a decision table reporting the estimated risks associated with alternative management actions. Mortality tables projecting detailed summaries for fisheries in each IPHC Regulatory Area (and reference levels indicated by the IPHC's interim management procedure) can be explored via the IPHC's mortality projection tool, which is updated in early January each year to reflect end-of-year mortality estimates from all sources.

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

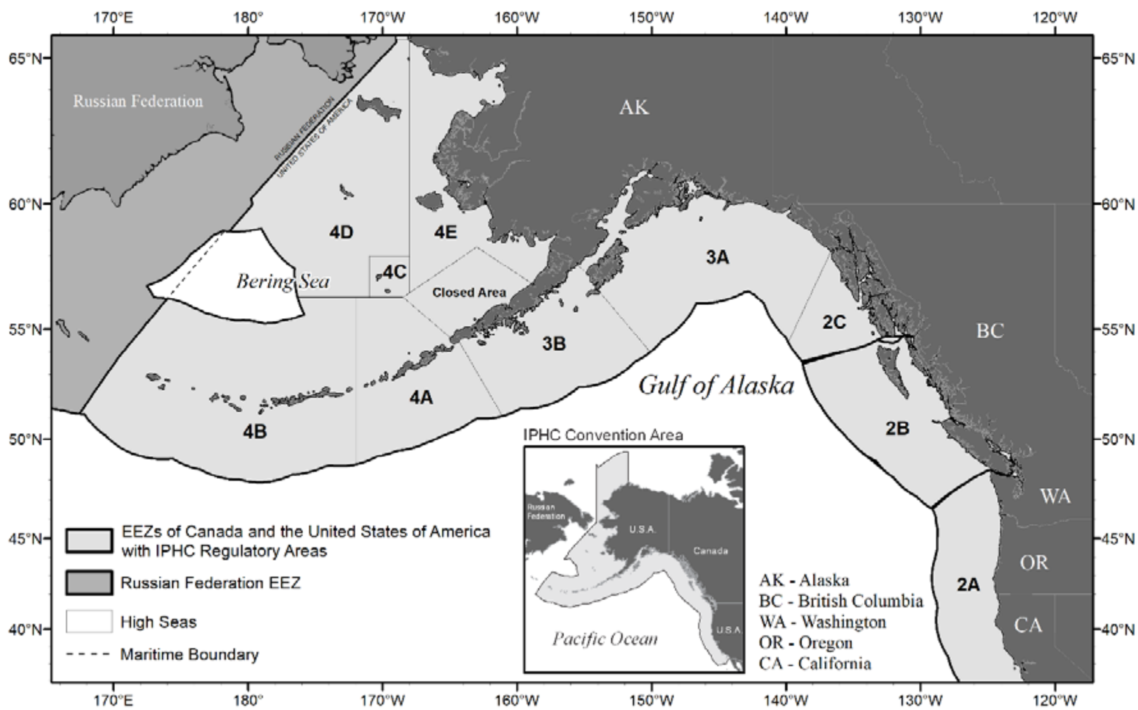

FIGURE 1. IPHC Convention Area (insert) and IPHC Regulatory Areas.

The IPHC's stock assessment and review process has developed from the first *ad hoc* meeting held in 2012 (Stewart et al. 2013) to a formal and documented process involving the SRB (https://www.iphc.int/the-commission/structure-of-the-commission) and periodic external independent peer review (https://www.iphc.int/management/science-and-research/stock-assessment). The IPHC's SRB meets two times per year: in June to review stock assessment development, and in September to review progress in response to the June review and to finalize the model structure and methods to be used in conducting the year's stock assessment. Within this annual review process two types of stock assessments are produced: 1) updated assessments where new data are added but the methods and model structures remain largely unchanged, and 2) full stock assessments occurring every three years in which model structure and methods are revised to reflect new data, approaches and comments from SRB and independent review. The 2015 (Stewart and Martell 2016; Stewart et al. 2016), and the 2019 (Stewart and Hicks 2019; Stewart and Hicks 2020) stock assessments were full analyses. The 2020 stock assessment represents an update retaining the same basic structure as 2019. Changes, new data, and extensions to existing time-series for 2020 include:

1) Update the version of stock synthesis used for the analysis (3.30.15.09).
2) Add sex-specific recreational age composition data from IPHC Regulatory Area 3A (and allow for sex-specific differences in selectivity) where previously only sexes-aggregated age compositions were available.
3) Include newly available sex-ratios-at-age for the 2019 commercial fishery (building on the 2017 and 2018 sex-ratios used in the 2019 stock assessment).
4) New modelled trend information from the 2020 fishery-independent setline survey (FISS) including predictions covering both sampled and unsampled (but informed by covariates and the temporal correlation parameters) IPHC Regulatory Areas.
5) Age, length, individual weight, and average weight-at-age estimates from the 2020 FISS for all sampled IPHC Regulatory Areas.

6) 2020 (and a small amount of 2019) commercial fishery logbook trend information from all IPHC Regulatory Areas.
7) 2020 commercial fishery biological sampling (age, length, individual weight, and average weight-at-age) from all IPHC Regulatory Areas.
8) Biological information (lengths and/or ages) from non-directed discards (all IPHC Regulatory Areas) and the recreational fishery (IPHC Regulatory Area 3A only) from 2019.
9) Updated mortality estimates from all sources for 2019 (where preliminary values were used) and estimates for all sources in 2020.

Incremental changes made during 2020 were documented through a two-part review by the IPHC's scientific review process (IPHC-2020-SRB016-R, IPHC-2020-SRB017-R).

DATA SOURCES

Each year, the data sources used to support this assessment are updated to include newly available information, and refined to reflect the most current and accurate information available to the IPHC. Major reprocessing and development of supplementary data sources was conducted in 2013, 2015, and again in 2019 (Stewart and Hicks 2019). All available information for the 2020 stock assessment was finalized on 31 October 2020 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 the year. These include commercial fishery WPUE, commercial fishery age composition data, and 2020 mortality estimates for all fisheries still operating after 31 October. All preliminary data series in this analysis will be fully updated as part of the 2021 stock assessment.

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. 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-2021-AM097-07; based on the FISS (in numbers and weight) and other surveys), commercial fishery Catch-Per-Unit-Effort (weight), and biological summaries from both sources (length-, weight-, and age-composition data). In aggregate, the historical time series of data available for this assessment represents a considerable resource for analysis. The range of relative data quality and geographical scope are also considerable, with the most complete information available only in recent decades (Figure 2). A detailed summary of input data used in this stock assessment can be found in **IPHC-2021-SA-02** on the IPHC's stock assessment webpage.

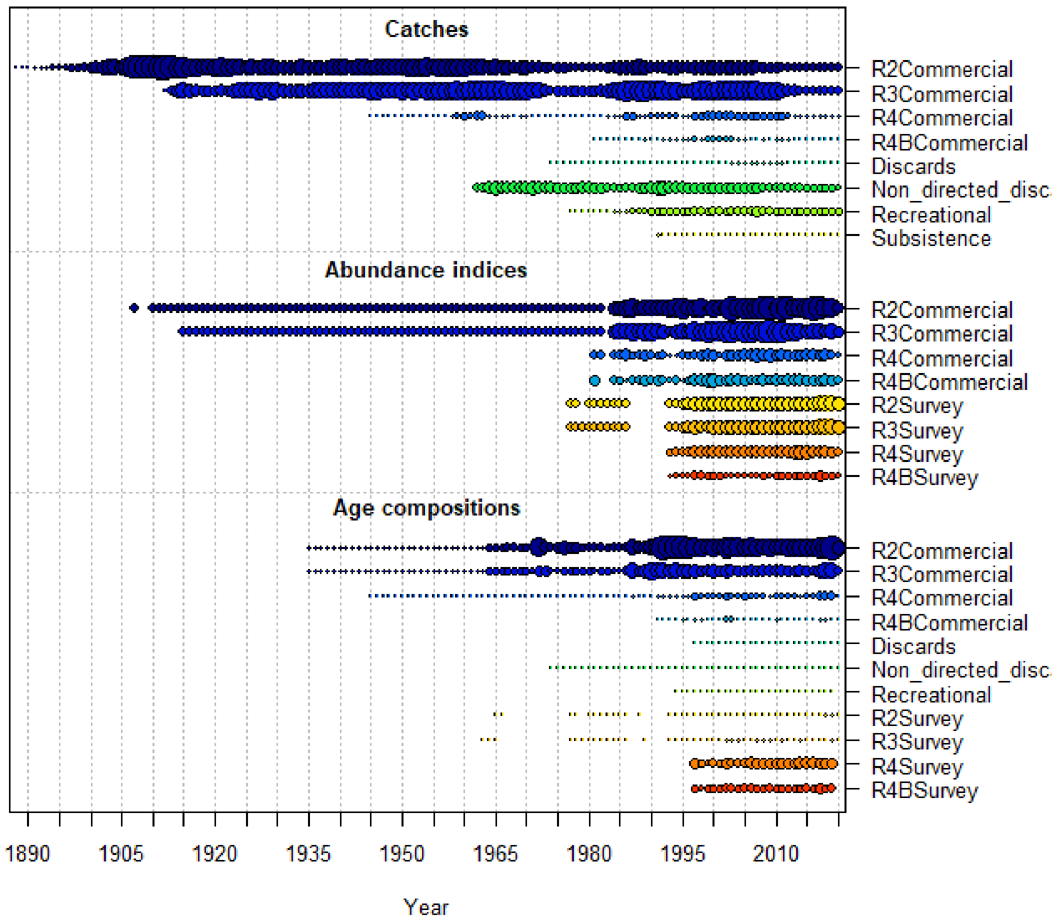

FIGURE 2. Overview of data sources. Circle areas are proportional to magnitude (mortality/catches) or the relative precision of the data (larger circles indicate greater precision for indices of abundance and age composition data).

Briefly, known Pacific halibut mortality consists of directed/target commercial fishery landings and discard mortality (including research), recreational fisheries, subsistence, and non-directed discard mortality ('bycatch') in fisheries targeting other species and where Pacific halibut retention is prohibited. Over the period 1921-2020 mortality has totaled 7.3 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). Annual mortality was above this long-term average from 1985 through 2010, and has averaged 40 million pounds (~18,000 t) from 2016-20. Coastwide commercial Pacific halibut fishery landings (including research landings) in 2020 were approximately 22.7 million pounds (~11,400 t), down 6% from 2019. Discard mortality in non-directed fisheries was estimated to be 5.0 million pounds in 2020 (~2,280 t)[3], down 23% from 2019 and representing the smallest estimate in the time-series. The total recreational mortality (including estimates of discard mortality) was estimated to be 6.0 million pounds (~2,700 t) down 15% from 2019 due to several sectors not reaching the full regulatory limit or projected level. Mortality from all sources decreased by 11% to an estimated 35.5 million pounds (~16,100 t) in 2020.

[3] The IPHC receives preliminary estimates of the current year's non-directed discard mortality from the National Marine Fisheries Service Alaska Regional Office, Northwest Fisheries Science Center, and Fisheries and Oceans Canada in late October.

The 2020 modelled FISS results detailed a coastwide aggregate NPUE which decreased by 1% from 2019 to 2020, the fourth consecutive year of a decreasing trend. Biological Region 2 declined by 8% to the lowest estimate in the time-series, while Biological Region 3 increased by 1%. Although not directly sampled in 2020, Biological Regions 4, and 4B were projected to go up slightly; uncertainty intervals were correspondingly large. The 2019 modelled coastwide WPUE of legal (O32) Pacific halibut, the most comparable metric to observed commercial fishery catch rates, increased by 6% from 2019 to 2020. This positive trend relative to that for NPUE indicates that somatic growth, primarily of O32 Pacific halibut is contributing more to current stock productivity than incoming recruitment. Individual IPHC Regulatory Areas varied from a 24% increase (Regulatory Area 3A) to a 10% decrease (Regulatory Area 2B) in O32 WPUE. Uncertainty was greater in IPHC Regulatory Areas that were not directly sampled in 2020 (2A, 4A, 4B, and 4CDE), but still comparable with the recent time-series due to the spatial and temporal correlations in the data that are captured in the space-time modelling. Preliminary commercial fishery WPUE estimates from 2020 logbooks increased by 2% at the coastwide level. The bias correction to account for additional logbooks compiled after the fishing season resulted in an estimate of no change coastwide. Trends varied among IPHC Regulatory Areas and gears, with generally positive trends observed in IPHC Regulatory Areas 2A, 2C, 3B, 4C and 4D. The largest decreases were observed in IPHC Regulatory Areas 2B and 4B, and these are likely to be even larger when 2020 logbook records are complete.

Biological information (ages and lengths) from the commercial fishery continue to show the 2005 year-class as the largest coastwide contributor (in number) to the fish encountered. In the 2020 fishery, for the first time the 2011 and 2012 year-classes were clearly present, indicating that their individual growth rates have moved them partially above the current 32 inch (81.3 cm) minimum size limit. The age data collected by the FISS observed the 2011 and 2012 cohorts (now 8 and 9 years old), for the third consecutive year. These cohorts represented the largest proportions in the total catch for some IPHC Regulatory Areas. Recognizing that no sampling occurred in IPHC Regulatory Areas 2A, 4A, 4B and 4CDE in 2020, historical cohorts have generally been widely and relatively uniformly distributed by ages 8-10. Individual size-at-age appears to be increasing for younger ages (<14) in some IPHC Regulatory Areas (particularly notable in 3A). Size-at-age trends tend to take years to change appreciably, so it may be some time before strong conclusions can be drawn regarding whether recent observations represent a change in long-term trends or annual variability. Direct estimates of the sex-ratio at age for the directed commercial fishery were first available for 2017 and 2018 in the 2019 stock assessment. For 2020, the 2019 observations (identified via genetic assays of samples from the commercial landings) again indicated a high percentage of female Pacific halibut in the landings (78% coastwide) and a slight downward trend over the three years with data (from 82% in 2017).

Updated trends indicate that population distribution (measured via the modelled FISS catch in weight of all Pacific halibut) has largely been decreasing in Biological Region 3 since 2004, and increasing in Biological Regions 2 and 4. However, in 2020 there was a notable increase in Biological Region 3 and a decrease in Biological Region 2. Biological Region 4 remained near the historical high, with the caveat that the 2020 value represents a space-time model prediction in the absence of direct sampling. Survey data are insufficient to estimate stock distribution prior to 1993. It is therefore unknown how historical distributions or the average distribution in the absence of fishing mortality may compare with recent observations.

STOCK ASSESSMENT

Creating robust, stable, and well-performing stock assessment models for the Pacific halibut stock has historically proven to be problematic due to the highly dynamic nature of the biology, distribution, and fisheries (Stewart and Martell 2014). The stock assessment for Pacific halibut has evolved through many different modeling approaches over the last 30 years (Clark 2003). These changes have reflected improvements in fisheries analysis methods, changes in model assumptions, and responses to recurrent retrospective biases and other lack-of-fit metrics (Stewart and Martell 2014). Although recent modelling efforts have created some new alternatives, no single model satisfactorily approximates all aspects of the available data and scientific understanding. For 2020, an ensemble of four stock assessment models was again used to explore the range of plausible current stock estimates. The ensemble approach recognizes that there is no "perfect" assessment model, and that a robust risk assessment can be best achieved via the inclusion of multiple models in the estimation of management quantities and the uncertainty about these quantities (Stewart and Martell 2015; Stewart and Hicks 2018b). This stock assessment is based on the approximate probability distributions derived from an 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.

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 (Areas-As-Fleets; AAF). AAF models are commonly applied when biological differences among areas or sampling programs make coastwide summary of data sources problematic (Waterhouse et al. 2014). AAF models continue to treat the population dynamics as a single aggregate stock, but fit to each of the spatial datasets individually, allowing for differences in selectivity and catchability of the fishery and survey among regions. In addition, the AAF models more easily accommodate temporal and spatial trends in where and how data have been collected, and fishery catches have occurred. This is achieved through explicitly accounting for missing information in some years, rather than making assumptions to expand incomplete observations to the coastwide level.

This combination of models included a broad suite of structural and parameter 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), fishery and survey selectivity (by region in the AAF models) and other model parameters. These sources of uncertainty have historically been very important to the understanding of the stock, as well as the annual assessment results (Clark and Hare 2006; Clark et al. 1999; Stewart and Hicks 2020; Stewart and Martell 2016). The benefits of the long time-series models include historical perspective on recent trends and biomass levels; however, these benefits come at a computational and complexity cost. The short time-series models make fewer assumptions about the properties of less comprehensive historical data, but they suffer from much less information in the short data series as well as little context for current dynamics.

Each of the four models in the ensemble was equally weighted, and 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.

COMPARISON WITH PREVIOUS ASSESSMENTS

The transition from the 2019 stock assessment to the final 2020 models was performed in a stepwise manner. To illustrate the relative effect of several key changes, a 'bridging' analysis is provided which included the following steps, beginning from the final 2019 models:

1) Update to the stock synthesis software version used for 2020 (3.30.15.09).
2) Add recreational sex-ratio-at-age data, and allow recreational selectivity-at-age for males and females to differ.
3) Add 2019 commercial fishery sex-ratio-at-age data.
4) Add the rest of the updated data for 2020 and reweight the sample sizes to be consistent with the model fit, as recommended by the SRB (IPHC 2020).

Each of these four steps is included in the bridging analysis provided in Figures 3-6. The new software version produced nearly identical result to that used for the 2019 stock assessment. The inclusion of the recreational and 2019 directed commercial sex-ratio-at-age data had little effect on the model results. The most important addition was the 2020 data, which informed the 2011+ recruitment estimates for all models and in the case of the AAF long model affected the scale of the time-series. Specifically, in the AAF long model, the estimate value for natural mortality increased from values of 0.178 (females) and 0.159 (males) to values of 0.189 (females) and 0.168 (males) in the 2020 model. This corresponded to a reduction in the estimates of relative commercial fishery selectivity for male Pacific halibut, and illustrated the remaining sensitivity to uncertainty in the historical sex ratios of the commercial fishery (see discussion below). The sequential effects of the most recent several years of data on the terminal recruitment estimates can be even more clearly observed via the retrospective analyses reported below. In aggregate, the updates from 2019 to 2020 did not appreciably change the model results for all but the AAF long model.

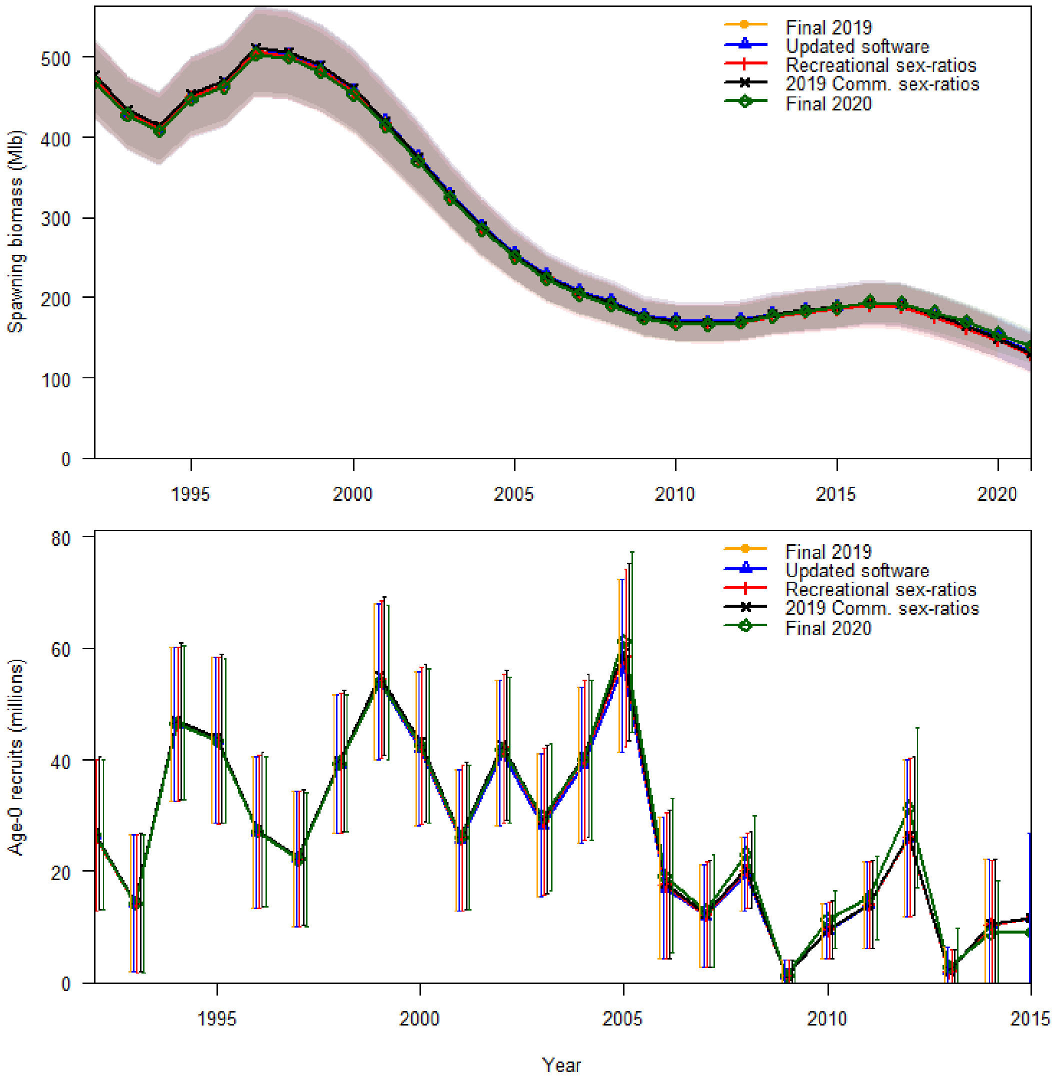

FIGURE 3. Bridging analysis showing the four steps between the 2019 and 2020 stock assessment model estimates of spawning biomass (upper panel) and recruitment (lower panel) for the short coastwide model.

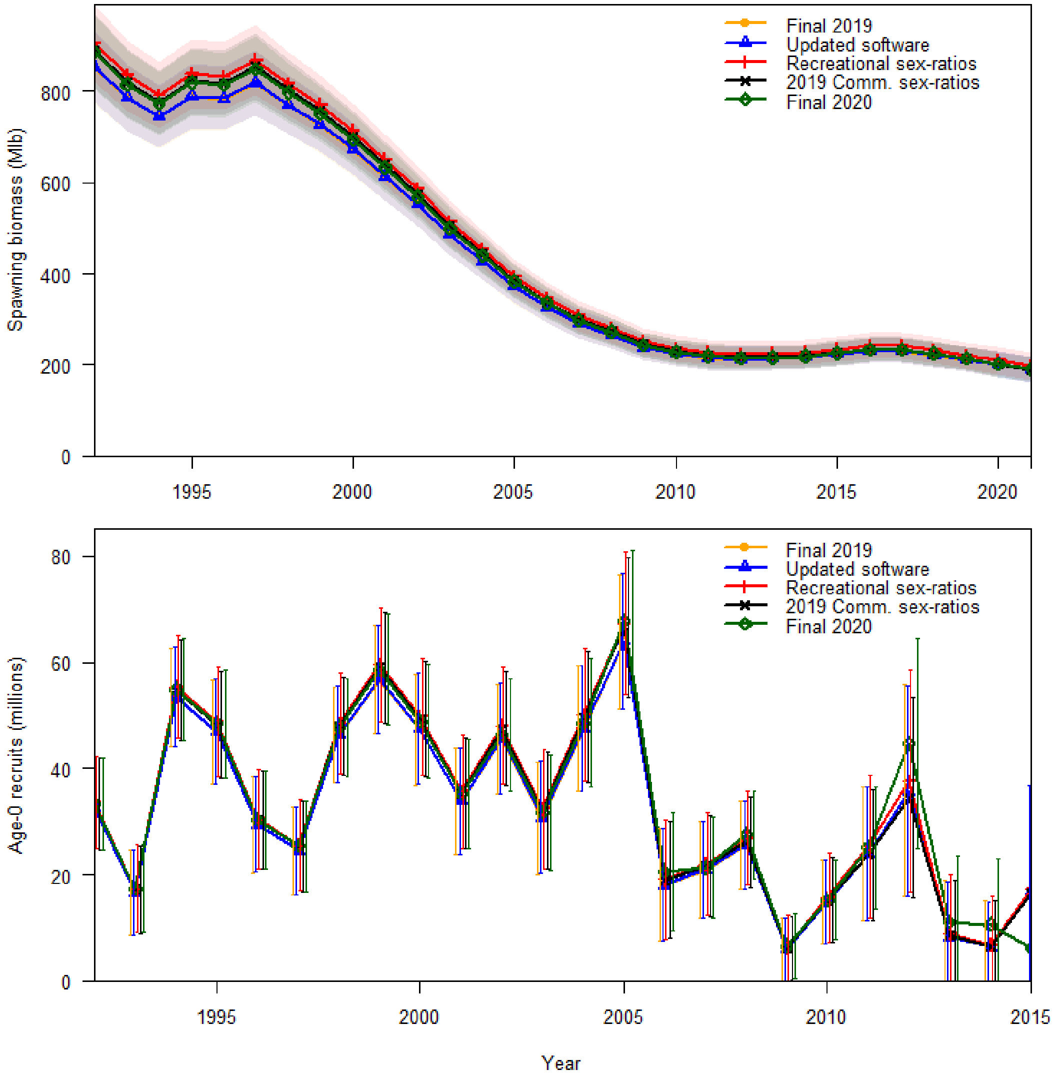

FIGURE 4. Bridging analysis showing the four steps between the 2019 and 2020 stock assessment model estimates of spawning biomass (upper panel) and recruitment (lower panel) for the short AAF model.

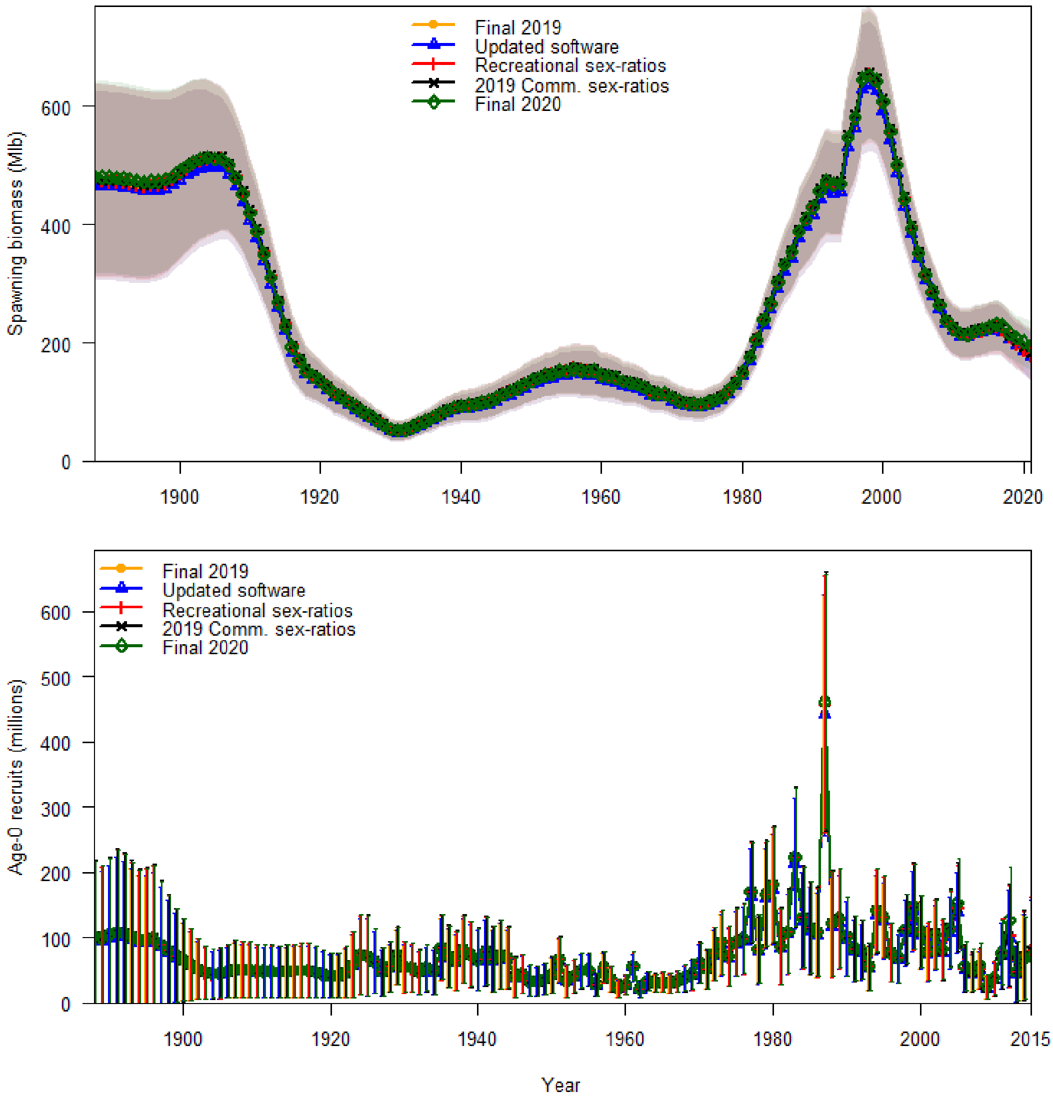

FIGURE 5. Bridging analysis showing the four steps between the 2019 and 2020 stock assessment model estimates of spawning biomass (upper panel) and recruitment (lower panel) for the long coastwide model.

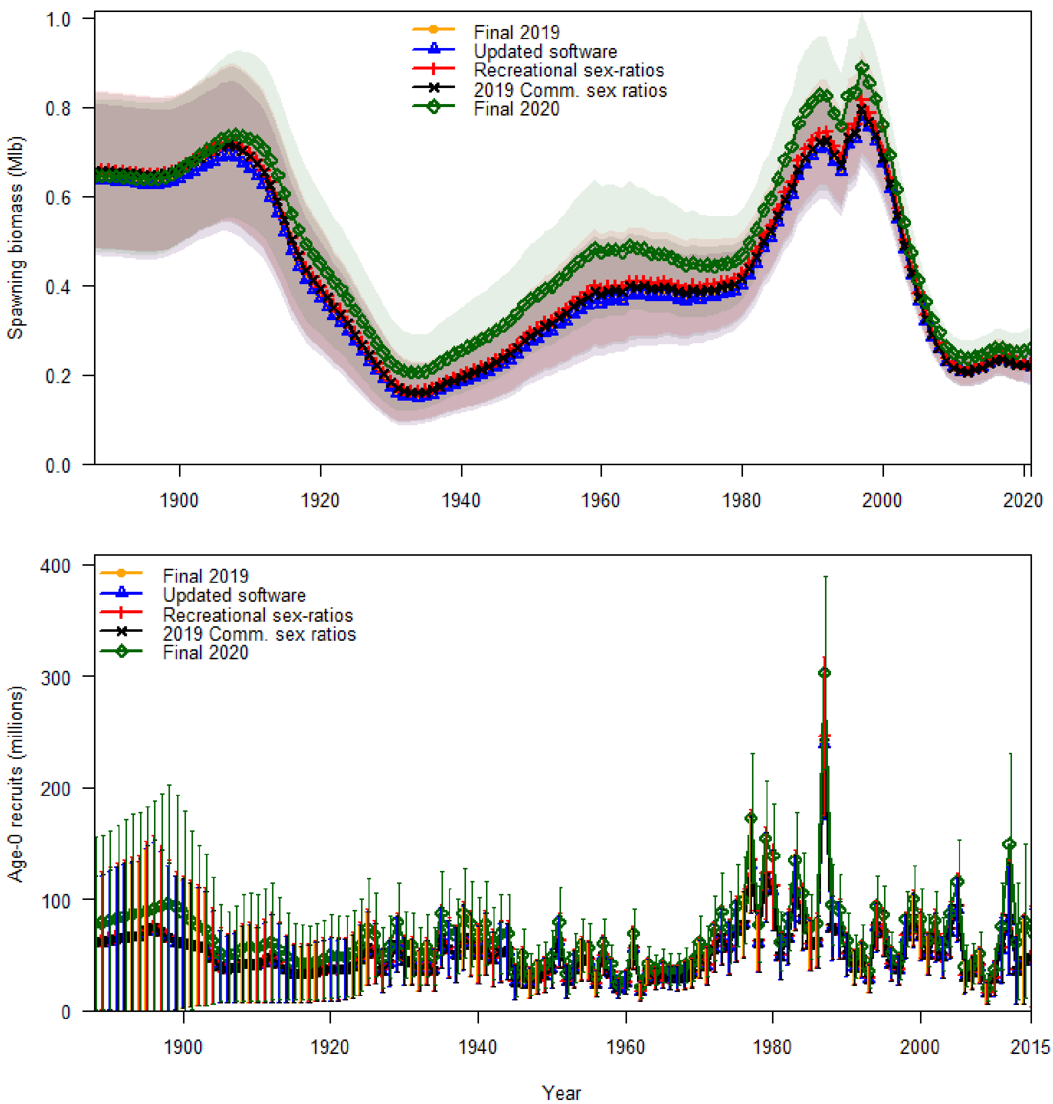

FIGURE 6. Bridging analysis showing the four steps between the 2019 and 2020 stock assessment model estimates of spawning biomass (upper panel) and recruitment (lower panel) for the long AAF model.

Comparison of this year's ensemble results with previous stock assessments indicates that the estimates of spawning biomass from the 2020 ensemble remain consistent with those from the 2012-19 assessments. Each of the previous terminal assessment values lie inside the predicted 50% interval of the current ensemble (Figure 7). The 2020 assessment estimates a slightly larger spawning biomass for the entire time-series, with the difference being more pronounced prior to around 2005. The uncertainty is much greater prior to approximately 2005 reflecting the differences among the four individual models as well as the increased uncertainty in scale resulting from the still limited time-series of sex-ratio data to inform the models.

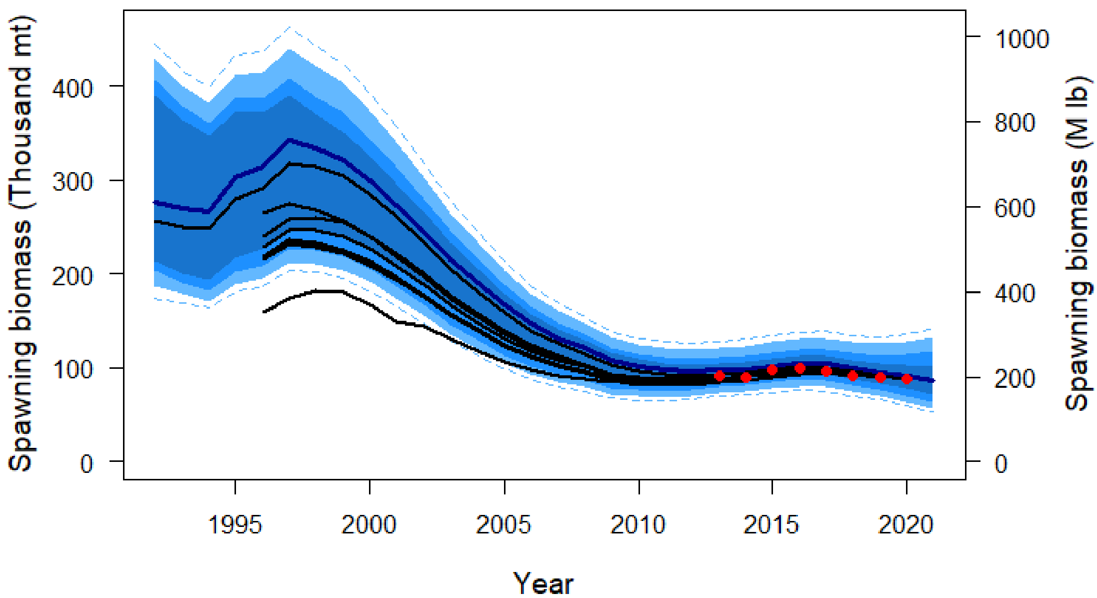

FIGURE 7. Retrospective comparison among recent IPHC stock assessments. Black lines indicate estimates of spawning biomass from assessments conducted from 2012-2019 with the terminal estimate shown as a point, the shaded distribution denotes the 2020 ensemble: the dark blue line indicates the median (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.

BIOMASS, RECRUITMENT, AND REFERENCE POINT RESULTS

Ensemble

The results of the 2020 stock assessment indicate that the Pacific halibut stock declined continuously from the late 1990s to around 2012 (Figure 7, Table 1). 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 192 million pounds (~87,050 t) at the beginning of 2021, with an approximate 95% credible interval ranging from 125 to 292 million pounds (~56,800-132,600 t; Figure 8). The differences among the individual models contributing to the ensemble are most pronounced prior to the early 2000s (Figure 9); however, current stock size estimates (at the beginning of 2020) also differ substantially among the four models (Figure 10). The differences in both scale and recent trend reflect the structural assumptions, e.g., higher natural mortality estimated in the long coastwide model and dome-shaped selectivity for Regions 2 and 3 in the AAF models.

Differences are also apparent in the recent recruitment estimates, which suggest larger recruitments in 1999 and 2005 than in subsequent years until 2012 (Figure 11, Table 1). All of these recent recruitments are much lower than the 1987 cohort, and in the two long time-series models they are at or below those in the late 1970s and early 1980s (Figure 12). 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 recent age data, this assessment estimated the 2011 and 2012 year-classes to be larger than those from 2006-10. The projected spawning biomass over the next 2-

4 years includes the effects of these year classes maturing at ages 8-13. Short-term trends in fishery yield are likely to decrease as Pacific halibut born in 2006 and later become increasingly important to the directed fisheries. The differing effects of these reduced 2006-10 recruitments on fishery yield (the effects are more delayed for spawning biomass, which largely comprises ages greater than 11) are illustrated in the estimated declines in age-8+ biomass, which start earlier and are more pronounced than those seen for spawning biomass (Table 1). Recruitment estimates after 2013 remain poorly informed by information from the fishery and survey data, and are therefore highly uncertain.

TABLE 1. Estimated recent median spawning biomass (SB; millions lbs) and fishing intensity (smaller values indicate higher fishing intensity) with approximate 95% credibility intervals, and age-0 recruitment (millions) and age-8+ biomass (millions lbs) from the individual models (CW=coastwide, AAF=Areas-As-Fleets) comprising the ensemble.

Year	SB	SB interval	Fishing intensity ($F_{XX\%}$)	Fishing intensity interval	Recruitment CW Long	CW Short	AAF Long	AAF Short	Age-8+ biomass CW Long	CW Short	AAF Long	AAF Short
1992	611	414-948	44%	30-60%	82.3	26.6	57.6	33.4	1,655	1,117	2,390	1,853
1993	597	393-882	44%	29-60%	55.9	14.2	36.3	17.4	1,554	1,061	2,202	1,701
1994	590	378-843	44%	30-60%	142.0	46.5	94.0	54.9	1,489	998	2,084	1,603
1995	669	416-910	53%	37-67%	132.5	43.3	86.2	48.4	2,076	1,322	2,594	1,936
1996	695	431-914	52%	36-66%	78.0	27.1	52.1	30.3	2,038	1,307	2,554	1,920
1997	755	470-971	46%	32-61%	70.7	22.1	45.7	25.4	2,103	1,366	2,623	1,984
1998	737	466-932	44%	31-59%	113.6	39.3	82.0	47.8	1,999	1,319	2,463	1,868
1999	708	450-890	42%	29-57%	147.8	53.9	100.5	58.6	1,840	1,227	2,256	1,718
2000	660	422-825	41%	29-57%	110.3	42.5	83.0	48.9	1,665	1,124	2,052	1,576
2001	603	385-752	38%	27-55%	79.8	26.1	63.1	35.2	1,466	994	1,820	1,402
2002	541	343-669	34%	26-51%	105.7	41.7	80.7	46.4	1,403	941	1,707	1,325
2003	476	300-586	30%	23-47%	82.9	29.6	59.8	31.7	1,339	885	1,594	1,238
2004	420	263-516	27%	22-45%	113.9	39.9	87.3	48.6	1,218	808	1,448	1,131
2005	368	230-449	26%	21-43%	152.8	61.1	116.4	67.8	1,095	721	1,299	1,014
2006	325	205-395	26%	20-43%	56.6	19.1	40.2	20.5	1,036	676	1,224	954
2007	291	187-354	25%	19-41%	50.7	12.9	41.9	21.3	1,032	669	1,195	928
2008	266	175-324	25%	18-41%	59.3	23.1	51.1	27.5	982	643	1,148	893
2009	238	159-291	25%	19-42%	25.6	1.2	21.1	6.6	887	579	1,056	820
2010	224	153-275	25%	19-42%	38.6	11.3	36.8	15.2	847	562	1,016	787
2011	215	152-266	29%	23-47%	77.4	15.3	76.1	25.1	798	534	963	743
2012	212	154-264	32%	27-51%	126.3	31.4	149.6	44.6	797	535	961	738
2013	215	162-268	34%	28-52%	49.1	2.8	62.4	11.0	849	582	1,014	779
2014	218	167-273	40%	31-56%	68.7	8.9	81.0	10.7	797	559	962	741
2015	224	172-280	41%	31-56%	72.2	9.0	71.5	6.1	748	527	921	712
2016	230	178-289	42%	31-57%	NA	NA	NA	NA	723	522	908	703
2017	229	176-289	41%	30-56%	NA	NA	NA	NA	659	472	852	655
2018	220	166-281	44%	30-59%	NA	NA	NA	NA	611	436	817	615
2019	211	155-277	43%	30-60%	NA	NA	NA	NA	633	415	871	607
2020	201	140-283	48%	34-65%	NA	NA	NA	NA	733	431	1,078	645
2021	192	125-292	NA	NA	NA	NA	NA	NA	701	378	1,093	600

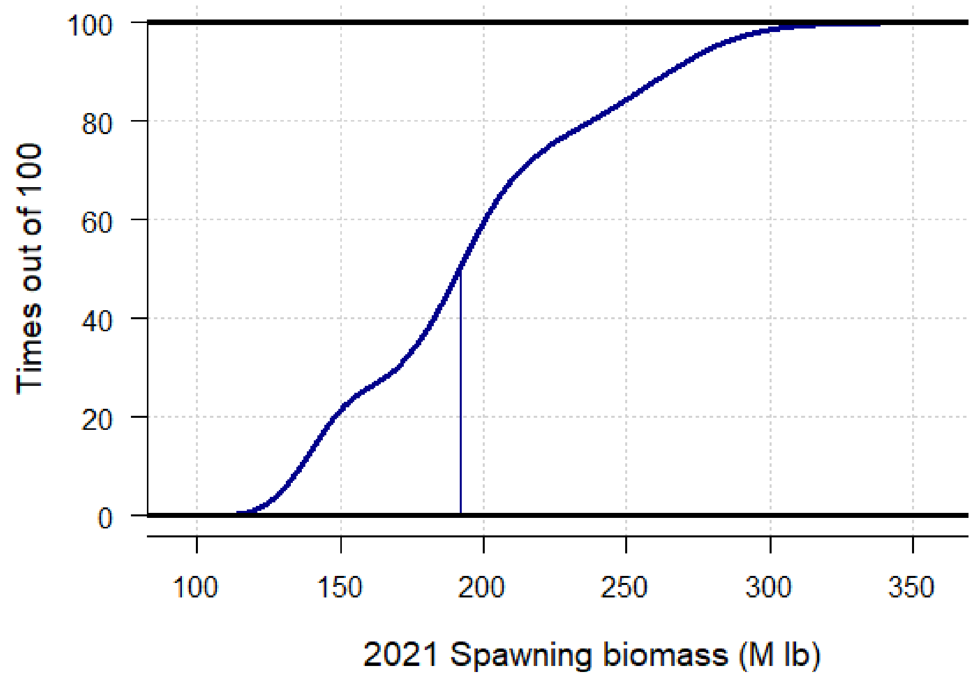

FIGURE 8. Cumulative distribution of the estimated spawning biomass at the beginning of 2021. Curve represents the estimated probability that the biomass is less than or equal to the value on the x-axis; vertical line represents the median (192 million pounds; ~87,050 t).

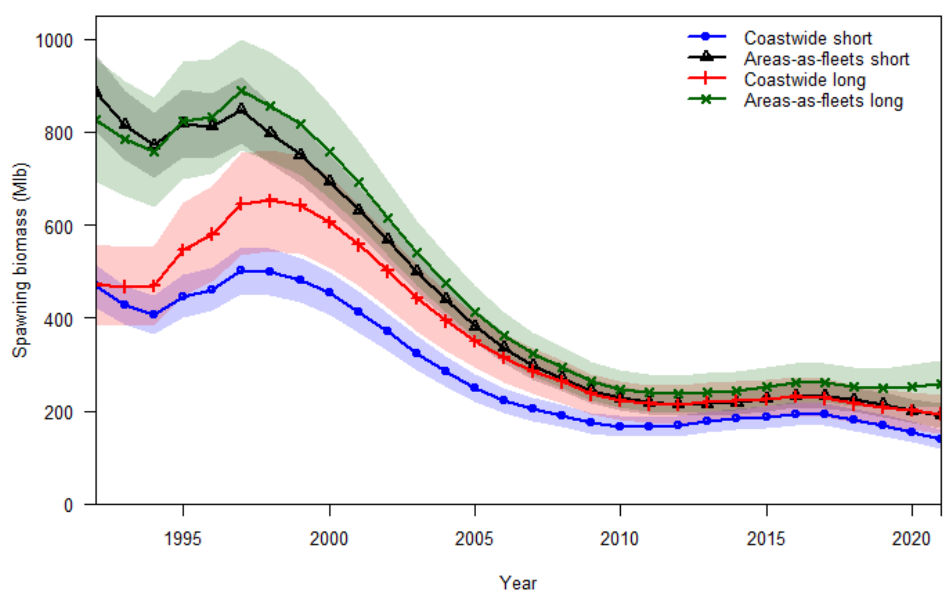

FIGURE 9. Estimated spawning biomass trends (1996-2021) based on the four individual models included in the 2020 stock assessment ensemble. Solid lines indicate the maximum likelihood estimates; shaded intervals indicate approximate 95% credible intervals.

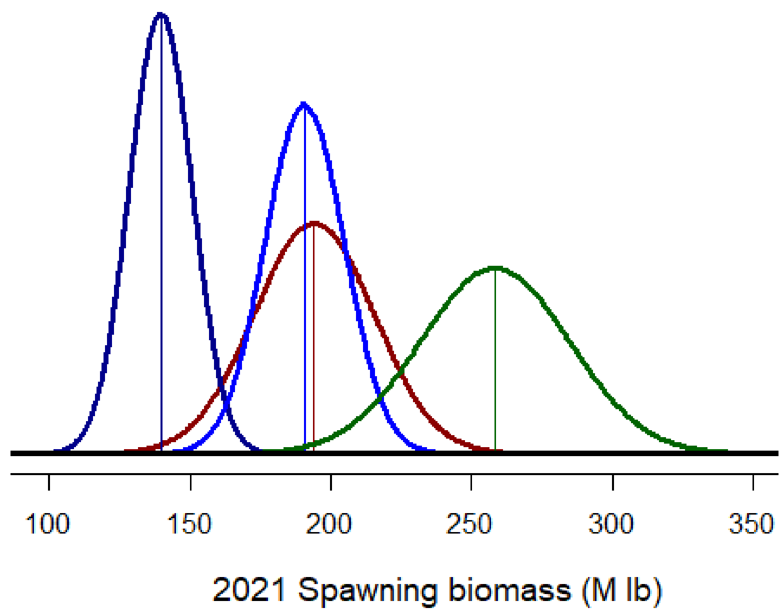

FIGURE 10. Distribution of individual model estimates for the 2020 spawning biomass. Vertical lines indicate the median values.

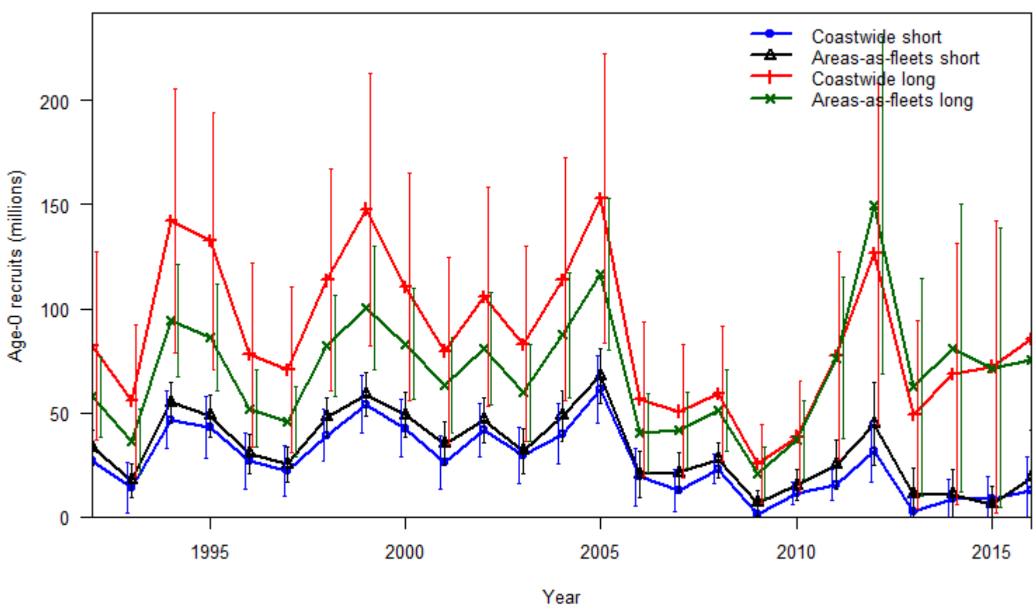

FIGURE 11. Estimated age-0 recruitment trends (1992-2016) based on the four individual models included in the 2020 stock assessment ensemble. Series indicate the maximum likelihood estimates; vertical lines indicate approximate 95% credible intervals.

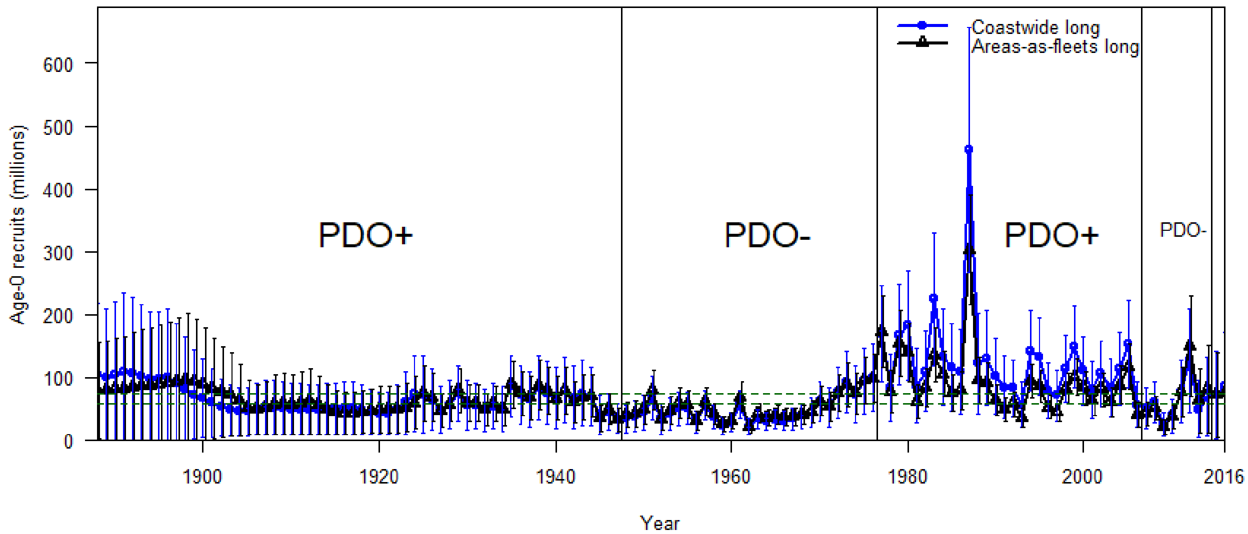

FIGURE 12. Trend in historical recruitment strengths (by birth year) estimated by the two long time-series models, including the effects of the Pacific Decadal Oscillation (PDO) regimes.

Ecosystem conditions

Average Pacific halibut recruitment is estimated to be higher (70 and 75% 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 2019 were positive, with 2020 showing negative average conditions through September. Although strongly correlated with historical recruitments, it is unclear whether recent anomalous conditions in both the Bering Sea and Gulf of Alaska (especially since 2014) are comparable to those observed in previous decades.

Reference points

The IPHC's interim management procedure uses a relative spawning biomass of 30% as a trigger, below which the target fishing intensity is reduced. At a spawning biomass limit of 20%, directed fishing is halted due to the critically low biomass condition. Beginning with the 2019 stock assessment, this calculation has been based on recent biological conditions rather than a long-term static average. By using current weight-at-age and estimated recruitments that are influencing the current stock only, the 'dynamic' calculation measures the effect of fishing on the spawning biomass. The relative spawning biomass decreased continuously over the period 1992-2012, then increased gradually to just above the $SB_{30\%}$ fishery trigger after 2015 (Figure 13. This result reflects the greater effects of reduced recruitment, rather than fishing in the last few years. The relative spawning biomass in 2021 was estimated to be 33% (credible interval: 22-52%) down slightly from 34% in 2020, but greater than the values estimated for the previous decade. The probability that the stock is below the $SB_{30\%}$ level is estimated to be 41% at the beginning of 2021, with less than a 1% chance that the stock is below $SB_{20\%}$ (Figure 14). The two long time-series models (coastwide and areas-as-fleets) show different results when comparing the current stock size to that estimated at the historical low in the 1970s. The AAF model estimates that recent stock sizes are well below those levels, and the coastwide model above. The 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.

The IPHC's current interim management procedure specifies a target level of fishing intensity of a Spawning Potential Ratio (SPR) corresponding to an $F_{43\%}$; this equates to the level of fishing that would reduce the lifetime spawning output per recruit to 43% of the unfished level given current biology, fishery characteristics and demographics. Based on the 2020 assessment, the 2020 fishing intensity is estimated to correspond to an $F_{48\%}$, less than the values estimated over the previous several years (credible interval: 34-65%; Table 1; Figures 15 and 16). This drop in fishing intensity corresponds to the reduction in mortality limits adopted for 2020 and the actual mortality of several sectors totaling less than predicted. 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 via 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 17)

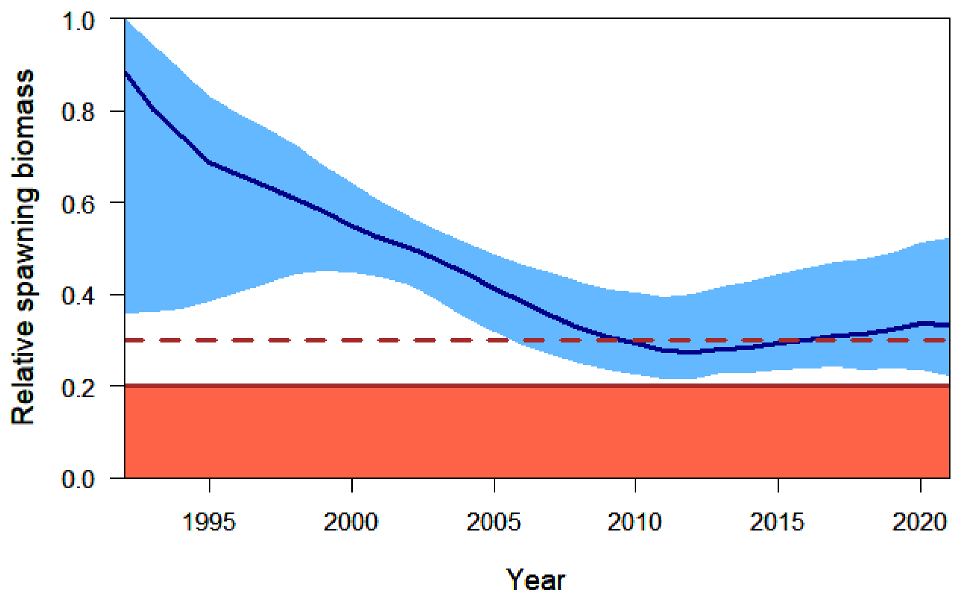

FIGURE 13. Estimated time-series of relative spawning biomass (compared to the unfished condition in each year) based on the median (dark blue line) and approximate 95% credibility interval (blue shaded area). IPHC management procedure reference points ($SB_{30\%}$ and $SB_{20\%}$) are shown as dashed and solid lines respectively, with the region of biological concern ($<SB_{20\%}$) shaded in red.

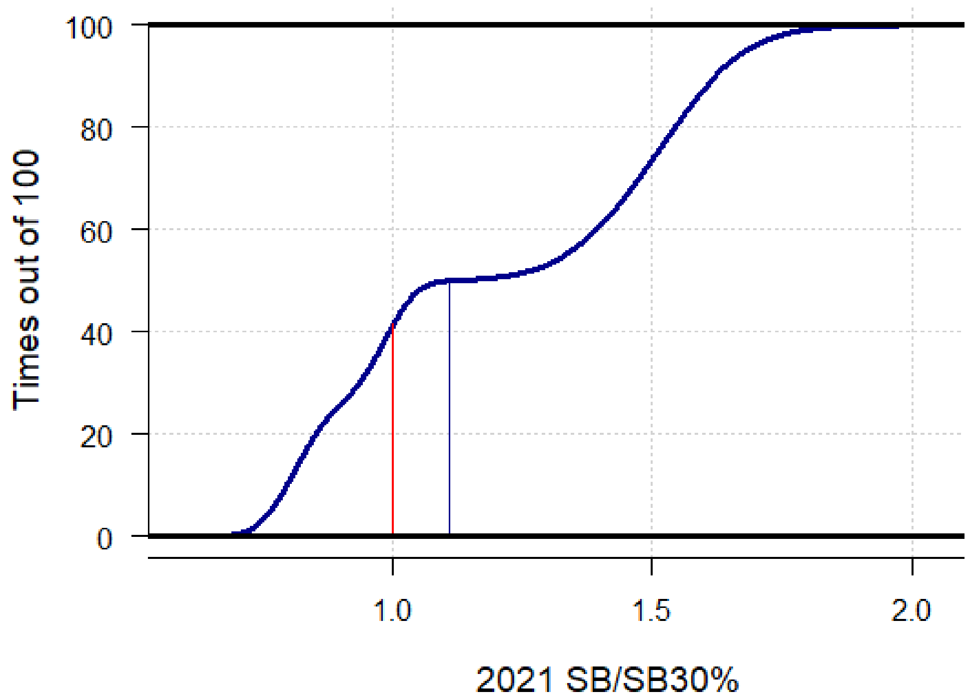

FIGURE 14. Cumulative distribution of ensemble 2021 spawning biomass estimates relative to the $SB_{30\%}$ reference point. Curve represents the estimated probability that the biomass is less than or equal to the value on the x-axis. Vertical lines denote the values corresponding to the fishery threshold in the IPHC's harvest policy (red; $SB_{30\%}$), and the median (blue; 33%).

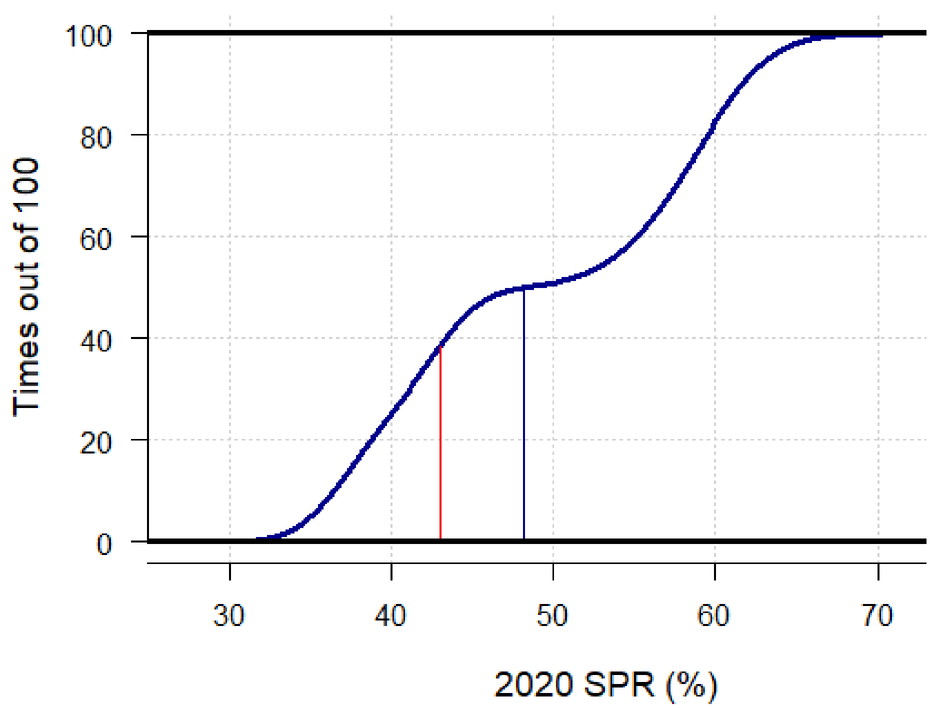

FIGURE 15. Cumulative distribution of the estimated fishing intensity (based on the Spawning Potential Ratio) estimated to have occurred in 2019. Curve represents the estimated probability that the fishing intensity is less than or equal to the value on the x-axis. Vertical lines indicates the reference ($F_{43\%}$; red) and the median value ($F_{48\%}$; blue).

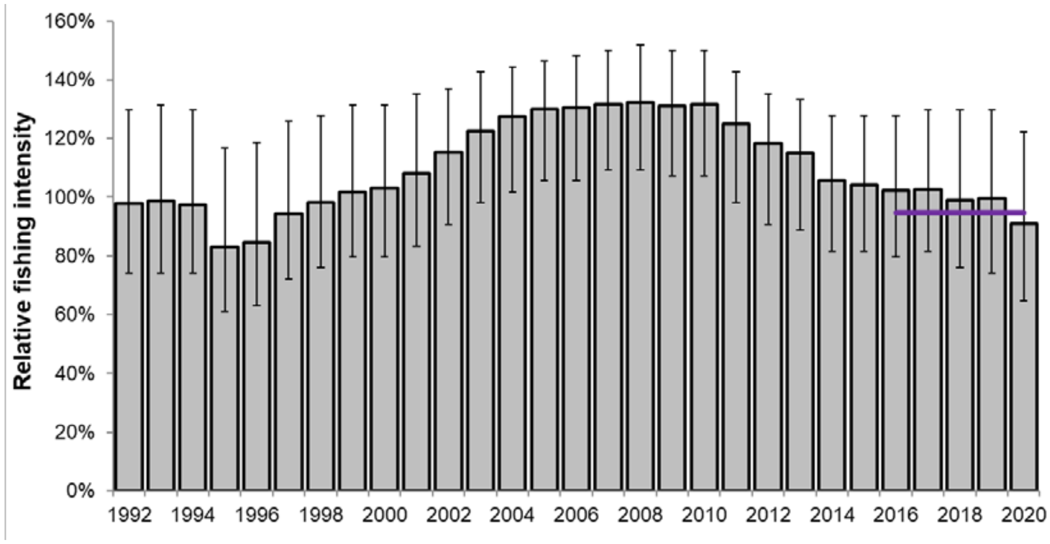

FIGURE 16. Recent estimated fishing intensity (1992-2019; based on the Spawning Potential Ratio) relative to the SPR=43% reference level (horizontal line indicates the SPR-46% reference in place during 2016-2020). Vertical lines indicate approximate credible intervals from the stock assessment ensemble.

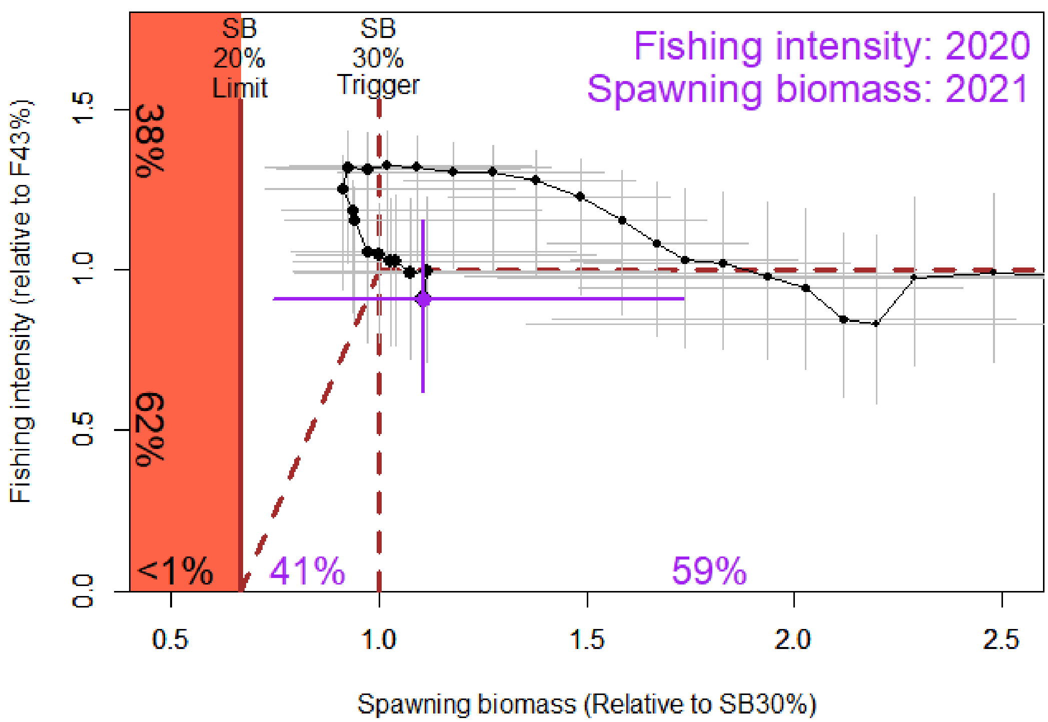

FIGURE 17. Phase plot showing the time-series (1992-2021) of estimated spawning biomass and fishing intensity relative to the reference points specified in the IPHC's interim management procedure. Dashed lines indicate the current $F_{43\%}$ (horizontal) reference fishing intensity, with linear reduction below the $SB_{30\%}$ (vertical) trigger, the red area indicates relative spawning biomass levels below the $SB_{20\%}$ limit. 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 2020 and spawning biomass at the beginning of 2021 shown as the largest point (purple). Percentages along the y-axis indicate the probability of being above and below $F_{43\%}$ in 2020; 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 2021.

Long time-series models

The two long time-series models provided different perceptions of current vs. historical stock sizes (Figure 18). The two long time-series models (coastwide and areas-as-fleets) show different results when comparing the current stock size to that estimated at the historical low in the 1970s. The AAF model estimates that recent stock sizes are below those levels, and the coastwide model above. Relatively large 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. Recent differences are likely attributable to the separation of signals from each Biological Region (particularly Region 2, with the longest time-series of data), and allowance for different properties in each region's fishery and survey. Historical differences appear to be due to the differing assumptions regarding connectivity between Regions 2-3 and Regions 4-4B during the early part of the 1900s when there are no data available from Regions 4-4B (Stewart and Martell 2016).

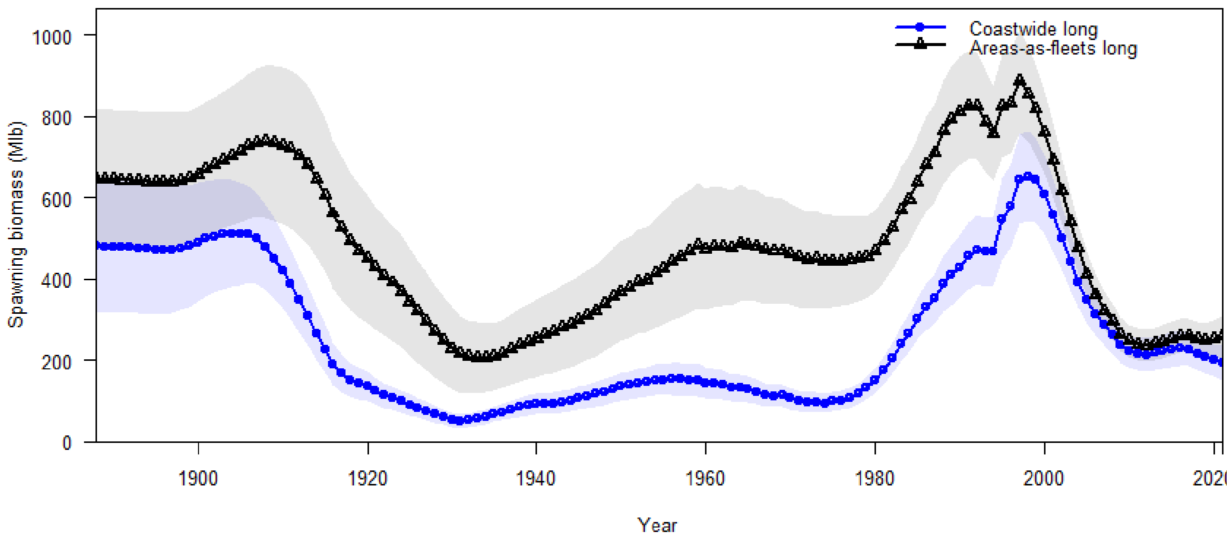

FIGURE 18. Spawning biomass estimates from the two long time-series models. Shaded region indicates the approximate 95% within-model credible interval. The black (upper) series is the Areas-As-Fleets model and the blue (lower) series is the coastwide model.

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 includes three years (2017-19) 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. Ongoing research to better understand the stock structure within the Convention Area as well as connectivity to Western North Pacific waters is ongoing. These investigations are particularly important for understanding the dynamics in IPHC Regulatory Area 4B, which is potentially the most demographically isolated of the eight Areas.

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 (8-12 years) 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 productivity, but its cause also remains unknown. Like most stock assessments, fishing 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 including the spatial and temporal variability inherent in them.

Since 2012, natural mortality has been an important source of uncertainty that is included in the stock assessment. In 2012, three fixed levels were used to bracket the plausible range of values. In 2013, the three models contributing to the ensemble included both fixed and estimated values of natural mortality. In the current ensemble, the models again span both fixed (0.15/year for female Pacific halibut) and estimated values. The female value estimated in the long AAF model (0.19) differs substantially from the value estimated in the coastwide model (0.22). Both of these estimates are highly correlated to the relative commercial fishery selectivity of males and females, which is estimated based on only the three years of available data, and remain highly uncertain. This difference contributes to the difference in scale and productivity for the two models, but is not easily reconciled at present. Although this uncertainty is directly incorporated into the ensemble results, uncertainty in female natural mortality in the two short models is not and remains an avenue for future investigation.

This stock assessment contains a broad representation of uncertainty in stock levels when compared to analyses for many other species. This is due to the inclusion of both within-model (parameter or estimation uncertainty) and among-model (structural) uncertainty. 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, which can result in variable mortality limits from year to year. Potential solutions to reduce the variability in mortality limits include management procedures that utilize multi-year management approaches, which are being tested with the MSE framework.

SENSITIVITY AND RETROSPECTIVE ANALYSES

A wide range of sensitivity analyses have been conducted during the development of the 2015 and 2019 full stock assessments (Stewart and Hicks 2019; Stewart and Martell 2016). These efforts form the primary basis for the identification of important sources of uncertainty outlined above. The most important contributors to estimates of both population trend and scale included: the sex ratio of the directed commercial fishery landings, the treatment of historical selectivity in the long time-series models, and natural mortality. Several sensitivity analyses were investigated in the 2017 and 2018 stock assessment in order to update and illustrate their importance, particularly with regard to the IPHC's research program (Stewart and Hicks 2018a). Those sensitivities included trends in spawning output (due to skip spawning or changes in maturity schedules), sex ratio of the commercial landings, and the effects of unobserved mortality of spawning biomass scale and trends. The results of those analyses illustrated the importance of ongoing research into factors influencing reproductive biology and success for Pacific halibut, the genetic analysis of commercial sex-ratios at age, as well as whale depredation and discard mortality rates.

For this year's stock assessment the focus of sensitivity analyses was in the bridging analysis (presented above) as well as effects of the most recently available data on the 2011 and 2012 recruitment estimates. To illustrate the effects of the most recent year's data separate from all other model changes and data updates, retrospective analyses were performed for each of the individual models contributing to the assessment. This exercise consists of sequentially removing the terminal year's data and rerunning the assessment model. This is commonly done for five or more years; however, the current models, restructured for the 2019 stock assessment around estimation of commercial fishery selectivity separately for males and females, rely on sex-ratios-at-age which are only available from 2017-2019. Therefore, the retrospective for this year's assessment only include 2 'peels', or three model runs including: the final 2020 model run, a run removing one year of data (2020) and a second model run removing two years of data (2019-2020). Estimates for relative selectivity parameters become less certain with reduced data, and required at least two years of data for reliable estimation. As data accumulate since this change in model structure it will be possible to extend the range of retrospective analyses further.

The retrospective analysis revealed that spawning biomass time series for each of the four stock assessment models changed very little as the terminal year's data were removed; with the highest variance in the results observed for the AAF long model (Figures 19-22; upper panels). As noted above, the AAF long model was very sensitive to the estimated values for natural mortality, which were correlated with relative male and female selectivity in the directed commercial fishery. This result highlights the need for historical estimates of the sex ratio of the commercial landings, a topic of ongoing research. The second clear result from the retrospective analysis was the effect of 2019 and 2020 data on the 2012 year-class. This cohort is strongly informed by each year's data and the estimated magnitude increased strongly across the three model runs (Figures 19-22; lower panels). Although there was a small effect on the 2011 year class, the information in the recent data are increasingly suggesting that that cohort is smaller than 2012 and closer to the magnitude of 2006-10.

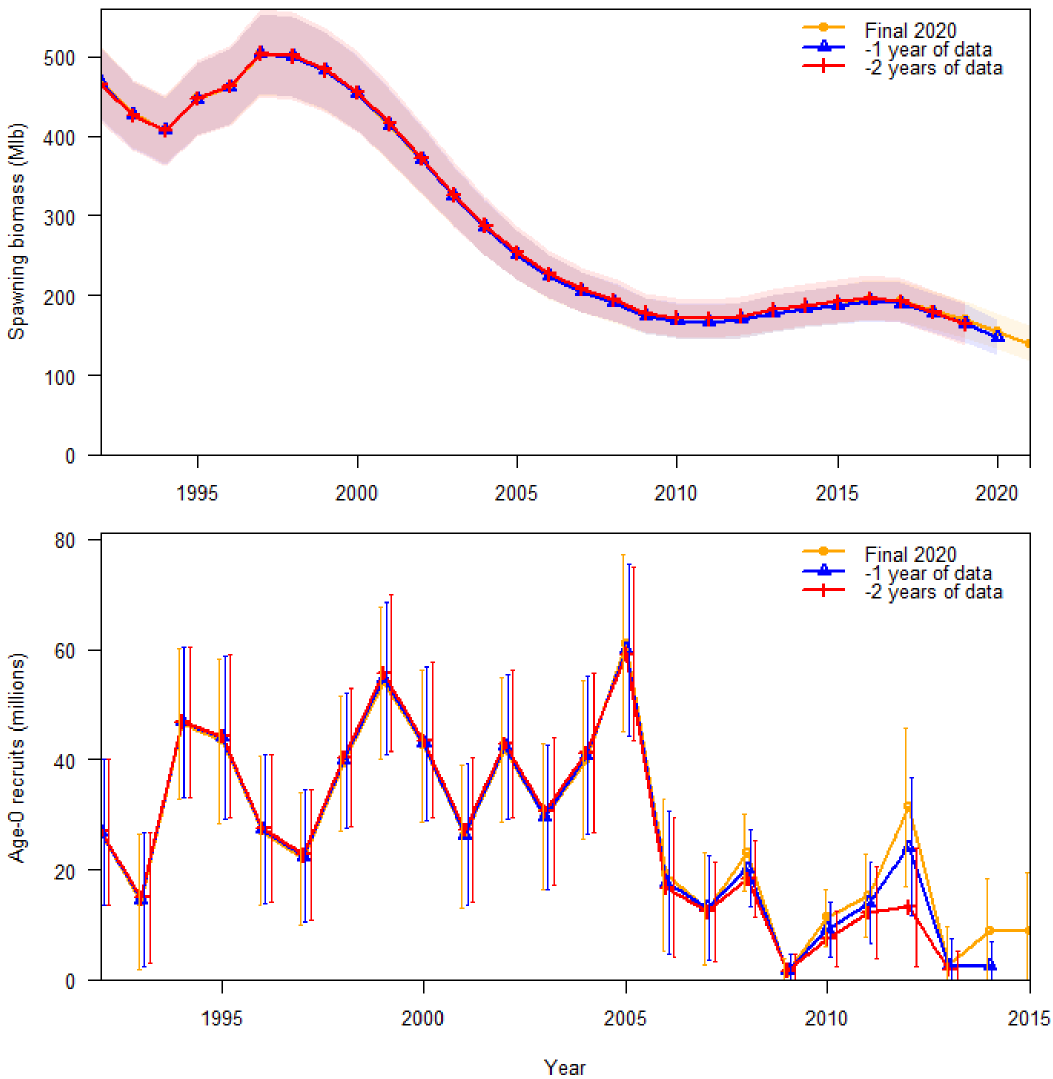

FIGURE 19. Spawning biomass (top panel) and recruitment (bottom panel) estimates from a retrospective analysis sequentially removing terminal years of data from the coastwide short model. Shaded regions and vertical whiskers indicate approximate 95% within-model credible intervals.

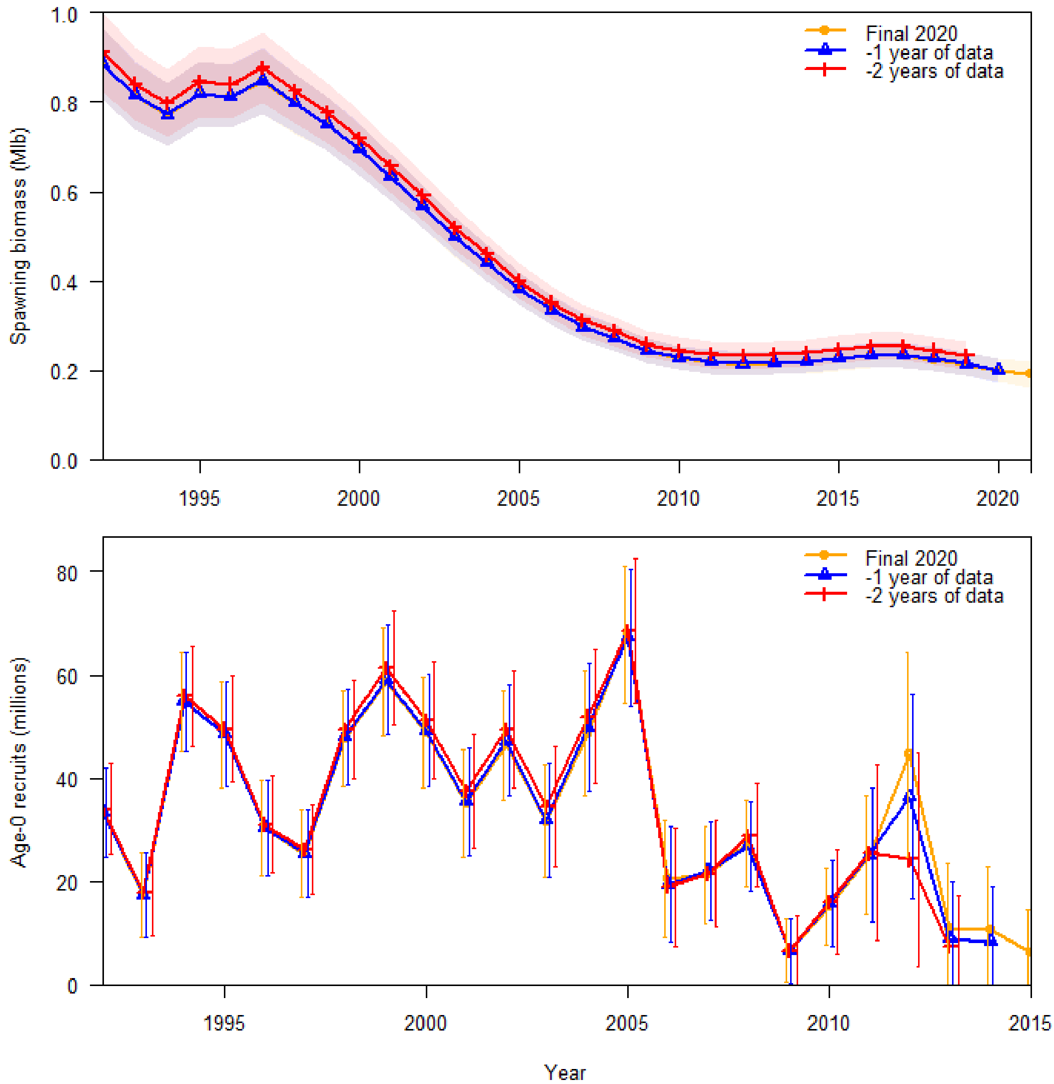

FIGURE 20. Spawning biomass (top panel) and recruitment (bottom panel) estimates from a retrospective analysis sequentially removing terminal years of data from the AAF short model. Shaded regions and vertical whiskers indicate approximate 95% within-model credible intervals.

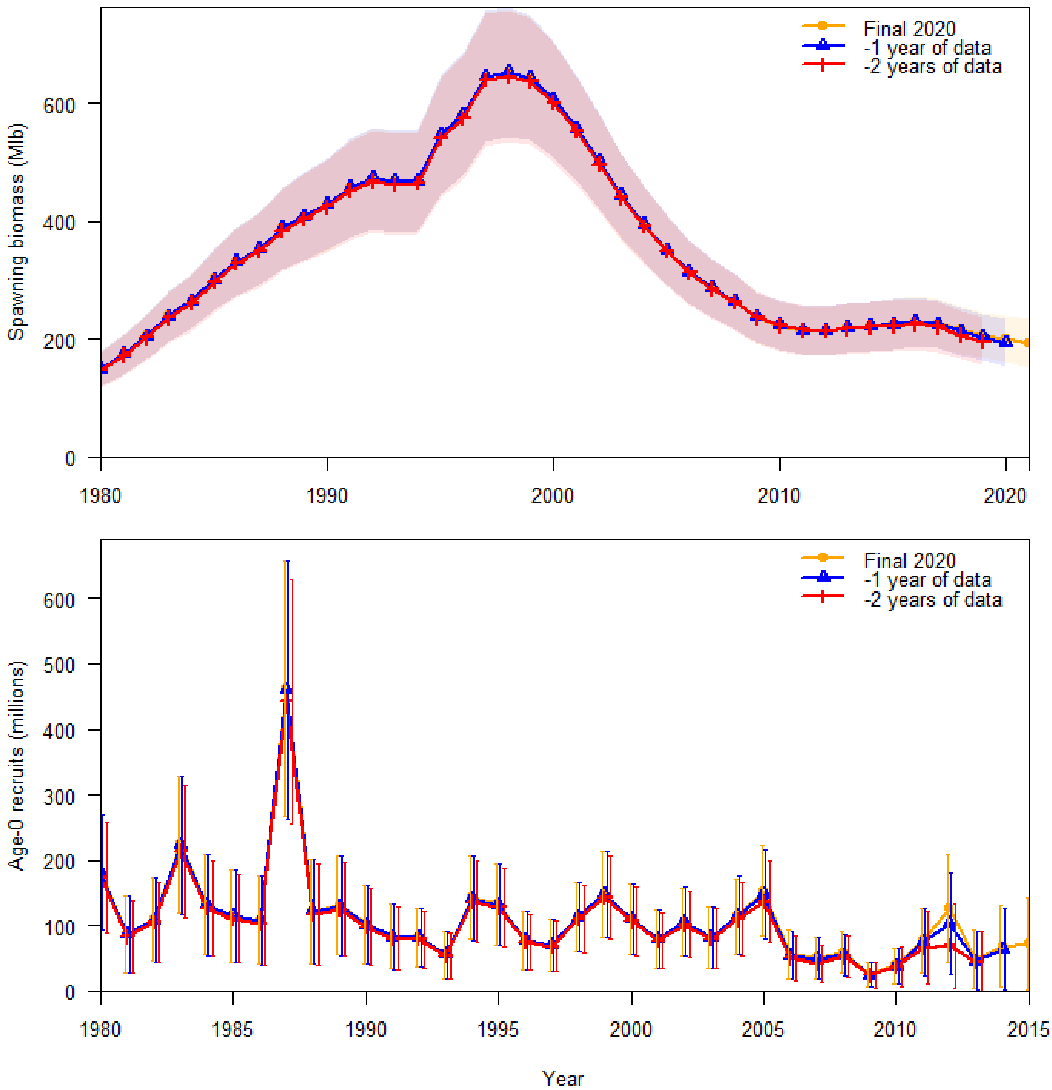

FIGURE 21. Recent spawning biomass (top panel) and recruitment (bottom panel) estimates from a retrospective analysis sequentially removing terminal years of data from the coastwide long model (time series has been truncated to allow for easier inspection of terminal values). Shaded regions and vertical whiskers indicate approximate 95% within-model credible intervals.

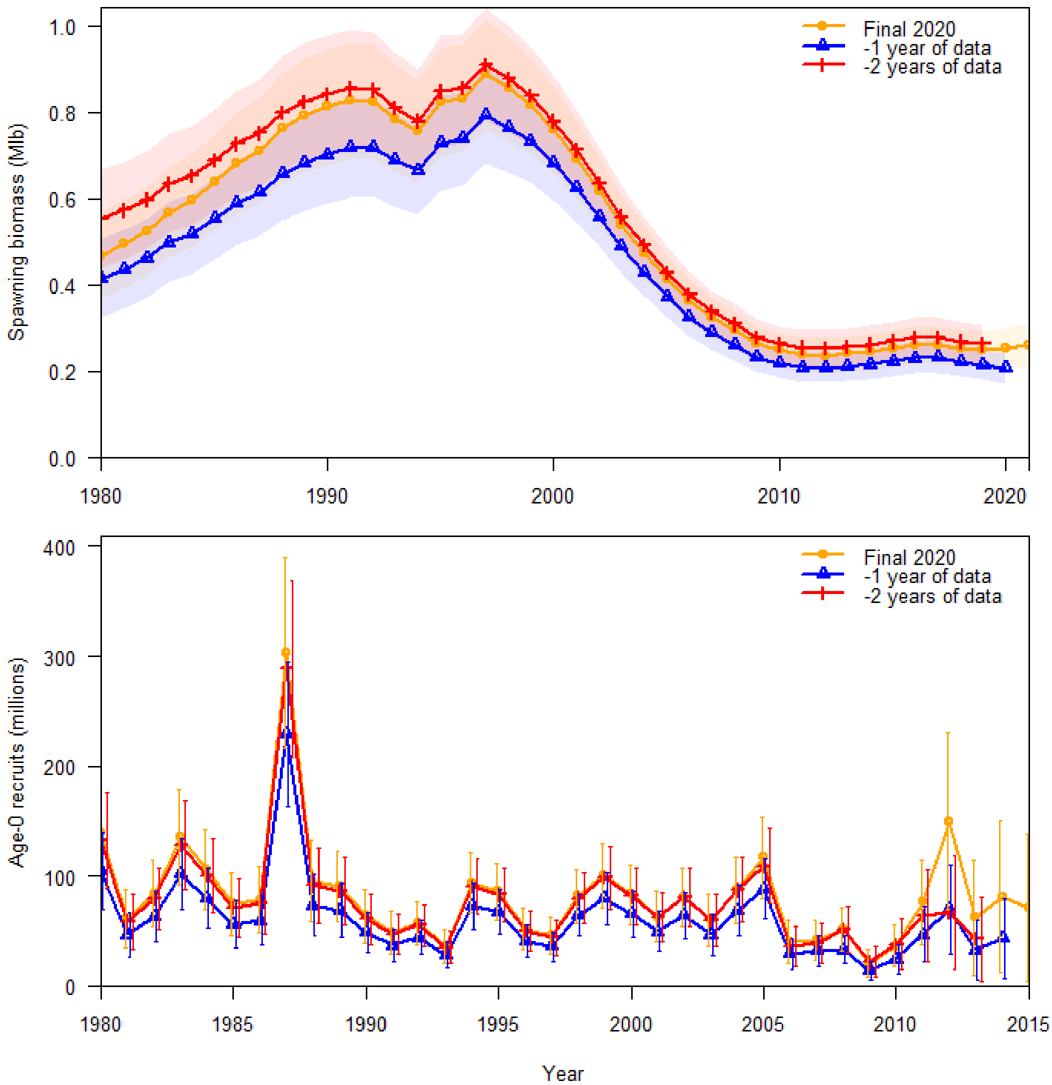

FIGURE 22. Recent spawning biomass (top panel) and recruitment (bottom panel) estimates from a retrospective analysis sequentially removing terminal years of data from the AAF long model (time series has been truncated to allow for easier inspection of terminal values). Shaded regions and vertical whiskers indicate approximate 95% within-model credible intervals.

FORECASTS AND DECISION TABLE

Stock projections were conducted using the integrated results from the stock assessment ensemble in tandem with summaries of the 2020 directed and non-directed fisheries. The harvest decision table (Table 2) 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 2021 (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 levels of mortality intended for evaluation of stock and management procedure dynamics including:

- No mortality (useful to evaluate the stock trend due solely to population processes)
- The mortality at which there is a 50% chance that the spawning biomass will be smaller in three years than in 2021 ("*3-year surplus*")
- The mortality consistent with repeating the TCEY set for 2019 (36.6 million pounds, 16,600 t; *"status quo"*).
- The mortality consistent with the current "Reference" SPR ($F_{43\%}$) level.
- A 60 million pound (~27,200 t) 2021 TCEY

A grid of alternative TCEY values corresponding to SPR values from 40% to 46% is also provided to allow for finer detail across the range of estimated SPR values identified by the MSE process as performing well with regard to stock and fishery objectives. 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 2021 (median value with the 95% credible interval below) are reported.

The projections for this assessment are slightly more optimistic than in the 2019 assessment, based on an increase in the estimates of the 2011 and, to a greater degree, the 2012 year classes. However, a high probability of stock decline (approximately 2/3) is again estimated for the entire range of SPR values from 40-46%. 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 24.4 million pounds (~11,068 t), corresponding to a projected SPR of 58% (credible interval 39-76%; Table 2, Figure 23). At the status quo TCEY (36.6 million lb, (~16,600 t), the probability of spawning biomass declines is 62 and 61% for one and three years respectively. At the reference level (a projected SPR of 43%) the probability of spawning biomass decline to 2022 is 65%, decreasing to 63% in three years, as the 2011 and 2012 cohorts mature. The one-year risk of the stock dropping below $SB_{30\%}$ ranges from 35% (at the 3-year surplus level) to 41% at the reference TCEY. Over three years these probabilities range from 29% to 44% depending on the level of mortality.

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 (IPHC-2021-AM097-10).

ACKNOWLEDGEMENTS

We thank all of the IPHC Secretariat staff for their contributions to data collection, analysis and preparation for the stock assessment. We also thank the staff at the NMFS, DFO, ADFG, WDFW, ODFW, and CDFW for providing the annual information required for this assessment in a timely manner. The SRB and Science Advisors provided valuable input during the 2020 process.

TABLE 2. Harvest decision table for 2021. 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.

		2021 Alternative		3-Year Surplus		Status quo		Reference $F_{43\%}$					
		Total mortality (M lb)	0.0	25.7	36.8	37.9	39.1	40.3	41.5	42.9	44.1	61.3	
		TCEY (M lb)	0.0	24.4	35.5	36.6	37.8	39.0	40.3	41.6	42.8	60.0	
		2021 fishing intensity	$F_{100\%}$	$F_{58\%}$	$F_{46\%}$	$F_{45\%}$	$F_{44\%}$	$F_{43\%}$	$F_{42\%}$	$F_{41\%}$	$F_{40\%}$	$F_{30\%}$	
		Fishing intensity interval	--	39-76%	29-65%	29-64%	28-63%	27-62%	26-61%	26-60%	25-59%	18-49%	
Stock Trend (spawning biomass)	in 2022	is less than 2021	<1	42	61	62	64	65	66	67	69	82	a
		is 5% less than 2021	<1	7	32	34	36	39	41	44	46	66	b
	in 2023	is less than 2021	<1	51	62	63	64	65	66	67	69	81	c
		is 5% less than 2021	<1	32	53	54	55	56	57	59	59	74	d
	in 2024	is less than 2021	<1	50	60	61	62	63	64	66	67	80	e
		is 5% less than 2021	<1	40	55	56	57	57	58	59	60	74	f
Stock Status (Spawning biomass)	in 2022	is less than 30%	29	35	39	40	40	41	41	42	42	47	g
		is less than 20%	<1	<1	<1	<1	1	1	1	1	1	4	h
	in 2023	is less than 30%	23	32	39	40	40	41	42	43	43	49	i
		is less than 20%	<1	<1	2	2	3	3	4	5	5	19	j
	in 2024	is less than 30%	12	29	38	39	40	41	42	43	44	50	k
		is less than 20%	<1	<1	4	5	6	8	9	10	12	25	l
Fishery Trend (TCEY)	in 2022	is less than 2021	0	17	48	49	50	50	50	51	51	77	m
		is 10% less than 2021	0	6	41	44	46	48	49	50	50	63	n
	in 2023	is less than 2021	0	21	49	50	50	50	50	51	51	75	o
		is 10% less than 2021	0	11	45	47	48	49	50	50	50	64	p
	in 2024	is less than 2021	0	23	49	50	50	50	50	51	51	74	q
		is 10% less than 2021	0	13	47	48	49	49	50	50	50	64	r
Fishery Status (Fishing intensity)	in 2021	is above $F_{43\%}$	0	15	48	49	50	50	50	51	51	78	s

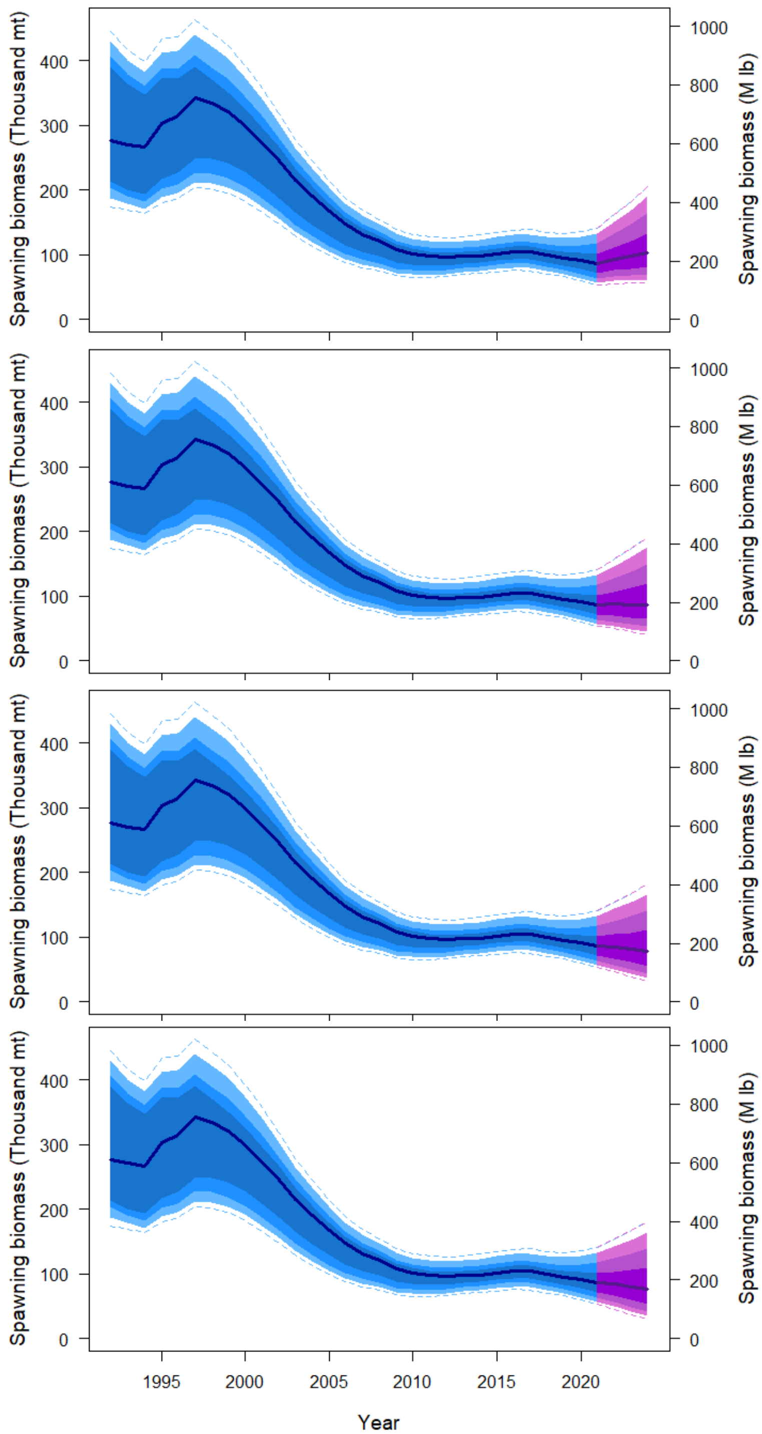

FIGURE 23. Three-year projections of stock trend under alternative levels of mortality: no fishing mortality (upper panel), the 3-year surplus (a TCEY of 24.4 million pounds, ~11,068 t; second panel), the *status quo* TCEY from 2020 of 36.6 million pounds, 16,600 t; third panel), and the TCEY projected for the IPHC's interim management procedure (39.0 million pounds, 17,690 t; lower panel).

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