Assessment of the Pacific halibut (*Hippoglossus stenolepis*) stock at the end of 2024

PREPARED BY: IPHC SECRETARIAT (I. STEWART & A. HICKS; 19 DECEMBER 2024)

PURPOSE

To provide the Commission with a detailed report of the 2024 stock assessment analysis.

EXECUTIVE SUMMARY

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 2024. A summary of the data and assessment results, as well as stock projections and the harvest decision table are provided both on the stock assessment webpage and in the meeting materials for the IPHC's 101st Annual Meeting (AM101; IPHC-2025-AM101-11; IPHC-2025-AM101-13). The input data files for each model included in this stock assessment are available on the IPHC's stock assessment webpage.

A detailed overview of data sources is provided in a separate document (IPHC-2025-SA-02); only a few key observations are described here. Fishing mortality from all sources in 2024 was estimated to be down 5% from 2023. 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 2024 modelled Fishery-Independent Setline Survey (FISS; see IPHC-2025-AM101-09 and) detailed a coastwide aggregate Numbers-Per-Unit-Effort (NPUE) which increased by 3% from 2023 to 2024. The modelled coastwide FISS Weight-Per-Unit-Effort (WPUE) of legal (O32) Pacific halibut, the most comparable metric to observed commercial fishery catch rates, decreased by 9% from 2023 to 2024. Preliminary coastwide commercial fishery WPUE (based on all 2024 logbook records available for this assessment) decreased 2% coastwide. Biological information (ages and lengths) from both the commercial fishery and FISS shows the continuing shift from the previously dominant 2005 year-class to the 2012 cohort (12 years old in 2024) and now the 2016 cohort (8 years old in 2024). At the coastwide level, individual size-at-age showed mixed trends, with flatter trends at younger ages than observed over the last several years and continued declines for the oldest ages.

This stock assessment is 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 all models except the short coastwide time-series model), 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.

This stock assessment represents a second update, following the full assessment conducted in 2022 (IPHC-2023-SA01) and the update conducted in 2023 (IPHC-2024-SA01). There are no structural changes to the assessment methods for 2024. Supporting analyses were reviewed by the IPHC's Scientific Review Board (SRB) in June (SRB024; IPHC-2024-SRB024- 08, IPHC-2024-SRB024-R) and September 2024 (SRB025; IPHC-2024-SRB025-06, IPHC2024-SRB025-R). All data sources that were preliminary in the 2023 stock assessment have been updated, along with the addition of all available data (as of 31 October) from 2024.

The results of the 2024 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 reduced recruitment levels compared to those observed during the 1980s. The spawning biomass (SB) is estimated to have increased gradually to 2016, and then decreased to a low of 145 million pounds (~65,700 t) at the beginning of 2024. At the beginning of 2025, the spawning biomass is estimated to be 149 million pounds (67,500 t) with an approximate 95% credible interval ranging from 97 to 216 million pounds (~44,100-98,200 t). Spawning biomass estimates over the last few years of the time-series are lower than recent stock assessment results. This change in scale for the last few years estimated stock size was caused by the lower-than-expected commercial fishery catch-rates observed in 2023, which dropped by another 5% when updated logs were added for 2024. In addition, the 2024 logbook trends indicated another 2% decrease from 2023. Pacific halibut recruitment estimates show relatively large cohorts in 1999 and 2005, followed by much lower average recruitment beginning in 2006, which has led to recent estimated declines in both the stock and fishery yield as these low recruitments have moved into the spawning biomass. Based on age data through 2024, this assessment estimates that the 2012 and 2016 year-classes are currently the most important in the fishery and survey catches but are only near average when compared to the preceding 15 years.

The most influential source of new information in this assessment was the directed commercial fishery logbook trend, including the 2023 estimate (revised downward by an additional 5% since the 2023 stock assessment) and the 2024 estimate, 2% below that from 2023. The addition of only the fishery information resulted in an 11% decrease in the scale of the 2023 stock assessment estimated spawning biomass for 2023, and an additional decrease of 17% when compared to the 2024 stock assessment results for 2024. Although differences in trend between the FISS and commercial fishery are not uncommon in the historical time-series, the sensitivity of this and last year's assessment results highlights the importance of both time-series in estimating the stock size and trend and the cumulative effects of reduced FISS designs in 2023-24 leading to greater uncertainty in that data source.

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 at the beginning of 2024 was estimated to be 38% (credible interval: 18-55%), slightly higher than the estimate for 2023 (37%). The probability that the stock is below $SB_{30\%}$ is estimated to be 30% at the beginning of 2025, with an 11% chance that the stock is below $SB_{20\%}$. The IPHC's current interim management procedure specifies a reference 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 2024 assessment, the 2024 fishing intensity is estimated to correspond to an $F_{49\%}$ (credible interval: 30-64%). 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 2024 directed fisheries and other sources of mortality. There is at least a 43% probability of stock decline in 2025 for all yields greater than the *status quo*. The 2025 "3-year surplus" alternative, corresponds to a TCEY of 37.4 million pounds (17,000 t), and a projected SPR of 49% (credible interval 25-61%). At the reference level (a projected SPR of 43%), the probability of spawning biomass decline from 2025 to 2026 is 57%, increasing to 58% in three years. The one-year risk of the stock dropping below $SB_{30\%}$ is 26-29% across all alternatives. Sensitivity and retrospective analyses for each of the four models, as well as 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[1] 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-2025-SA-02) on the IPHC's stock assessment webpage. Results in this document include current model estimates of stock size and trend reflecting all available data. Specific management information is summarized via projections and 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) will be reported at the 101st Session of the IPHC Annual Meeting (AM101) in January 2025.

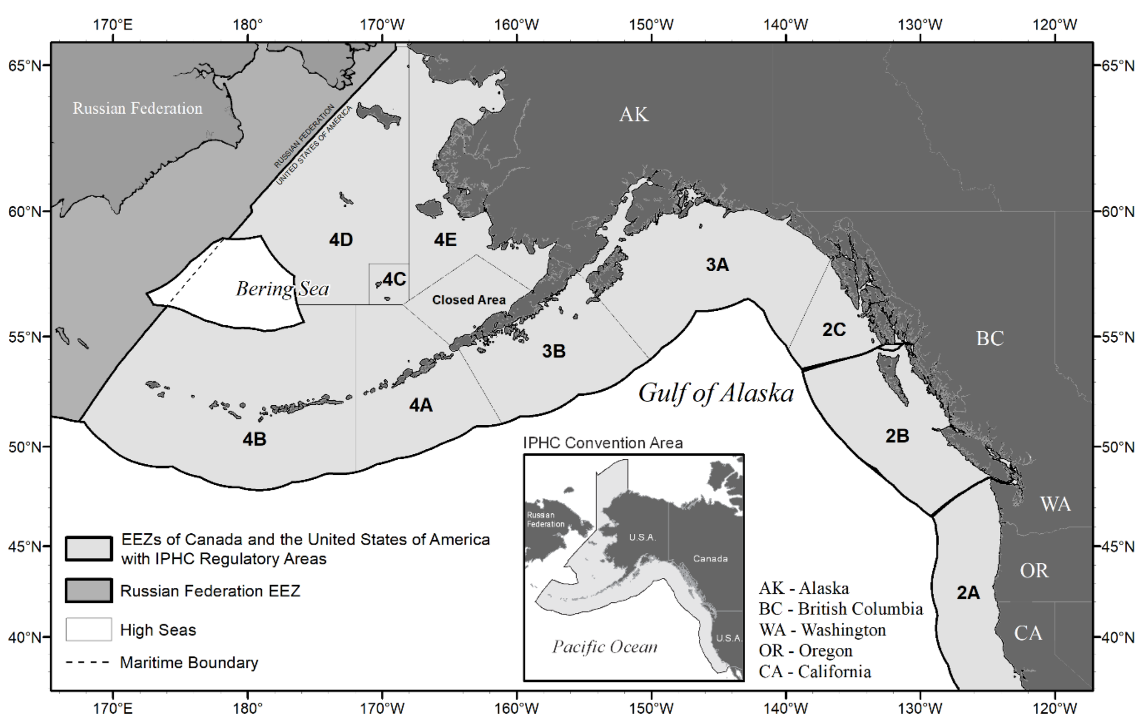

FIGURE 1. IPHC Convention Area (inset) and IPHC Regulatory Areas.

[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.

The IPHC's current stock assessment and review process developed from the first *ad hoc* meeting held in 2012 (Stewart et al. 2013) to the formal SRB process including periodic external independent peer review. 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 approximately every three years in which model structure and methods are revised to reflect new data, approaches and comments from the SRB and independent review. The 2015 (Stewart and Martell 2016; Stewart et al. 2016), 2019 (Stewart and Hicks 2019; Stewart and Hicks 2020), and 2022 (Stewart and Hicks 2023) stock assessments (IPHC-2023-SA01) were full analyses. The 2024 stock assessment is a second update, including routine extensions of existing data series and replacement of preliminary data from the 2022 and 2023 analyses with final information available in 2024. There are no structural changes to the assessment methods for 2024. Supporting analyses were reviewed by the IPHC's Scientific Review Board (SRB) in June (SRB024; IPHC-2024-SRB024- 08, IPHC-2024-SRB024-R) and September 2024 (SRB025; IPHC-2024-SRB025-06, IPHC2024-SRB025-R).

DATA SOURCES

Each year, the data sources used to support this assessment are updated to include the most current and accurate information available to the IPHC. Major reprocessing and development of supplementary data sources was conducted in 2013, 2015, 2019 and again in 2022. The largest change to the underlying data in 2022 was the development of a bootstrapping procedure to estimate the effective sample size of the age-composition data, given the actual sampling design and sample sizes in each year (Stewart and Hicks 2022). No major changes were made to the standard processing of data sources for 2023 or 2024. All available information for the 2023 stock assessment was finalized on 31 October 2024 in order to provide adequate time for analysis and modeling. However, directed commercial fisheries landings and associated estimates of discards were further updated in late November to better reflect the season's projected fishing mortality (the fishery closed on 7 December). As has been the case in all years, some data are incomplete or include projections for the remainder of the year. These include 2024 commercial fishery WPUE, 2024 commercial fishery age composition data, and 2024 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 2025 stock assessment. A detailed description of data sources included in the assessment and used for other analyses supporting harvest policy calculations is provided in a separate document (IPHC-2025-SA-02) on the IPHC's stock assessment webpage.

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-2025-AM101-10); based on the FISS combined with other surveys (in numbers and weight), 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-2025-SA-02 on the IPHC's stock assessment webpage.

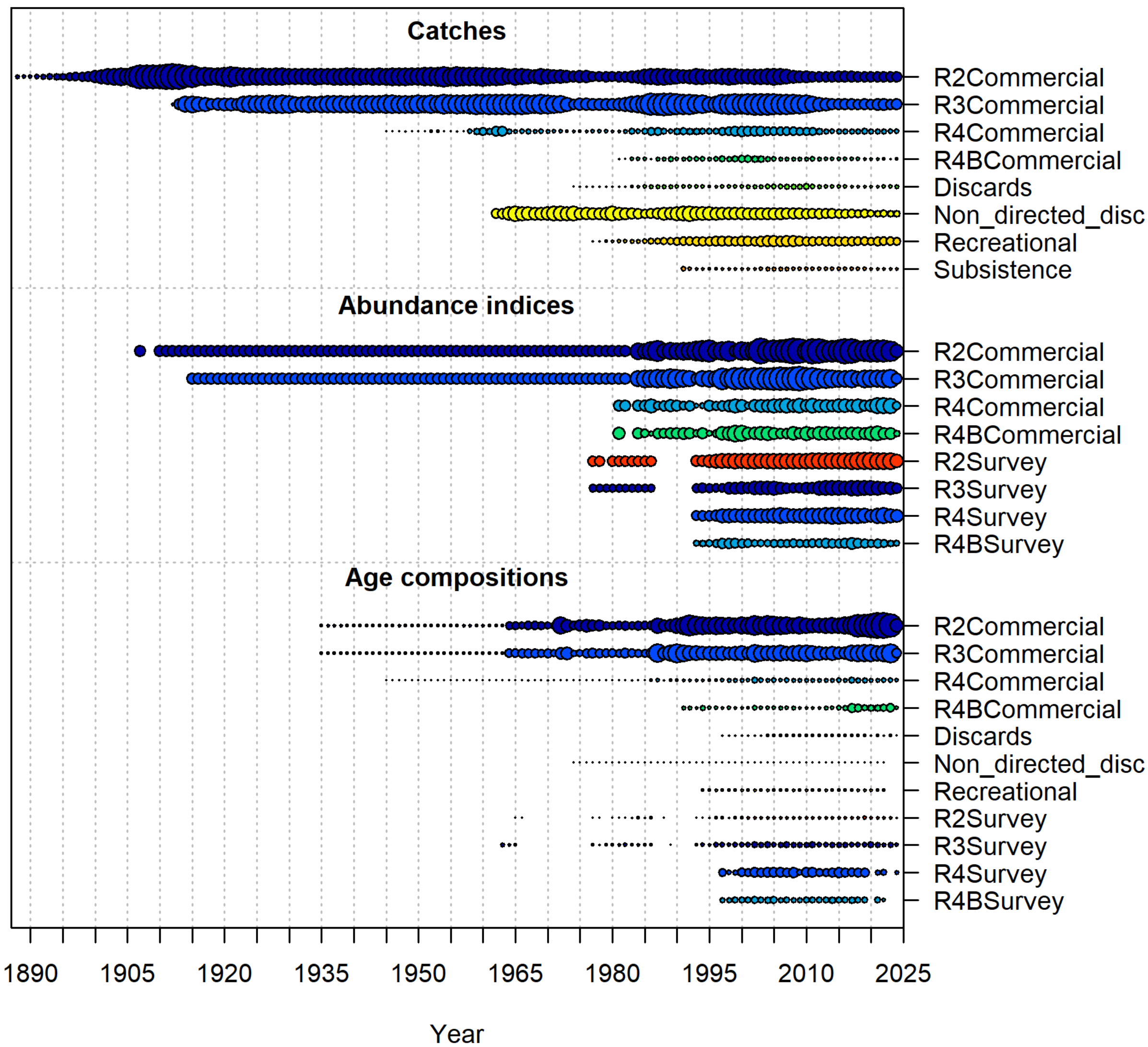

FIGURE 2. Overview of data sources. Circle areas are proportional to magnitude (mortality/catches) or the relative precision of the data (larger circles indicate greater precision for indices of abundance and age composition data).

Briefly, known Pacific halibut mortality consists of directed/targeted 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 1888-2023 mortality has totaled 7.4 billion pounds (~3.4 million metric tons, t). Since 1925, the fishery has ranged annually from 33 to 100 million pounds (15,000-45,000 t) with an annual average of 63 million pounds (~28,000 t). Annual mortality was above this 100-year average from 1985 through 2010 and has averaged 35.7 million pounds (~16,200 t) from 2020-24. Coastwide commercial Pacific halibut fishery landings (including research landings) in 2024 were approximately 20.5 million pounds (~9,300 t), down 6% from

2023. Discard mortality in the directed commercial fishery decreased 9% from 2022 to 2023 to 1.3 million pounds (~590 t) after a 37% increase in 2022. Discard mortality in non-directed fisheries was estimated to be 4.1 million pounds in 2024 (~1,900 t)[2], down 5% from 2023 and remaining below all recent estimates prior to 2021. The total recreational mortality (including estimates of discard mortality) was estimated to be 5.9 million pounds (~2,700 t) down 5% from 2023. Mortality from all sources decreased by 5% to an estimated 32.7 million pounds (~14,800 t) in 2024, the lowest value in 100 years, based on preliminary information available for this assessment.

The 2024 modelled FISS results detailed an estimated coastwide aggregate Numbers-Per-Unit-Effort (NPUE) which increased by 3% from 2023 to 2024, remaining at a level similar to those observed in 2018-2020. Biological Region 3 increased by 1%, while Biological Region 2 increased by 11% and Biological Region 4 decreased by 3%. Biological Region 4B is estimated to have increased by 4%; however, this area has not been sampled since 2022 (and then only partially) and credible intervals reflect a wide plausible range of potential trends, both increasing and decreasing, from 2022 to 2024.

The modelled coastwide Weight-Per-Unit-Effort (WPUE) of legal (O32) Pacific halibut, the most comparable metric to observed commercial fishery catch rates, decreased by 9% from 2023 to 2024. Individual IPHC Regulatory Areas varied from an estimated 4% increase (Regulatory Area 4B; noting high uncertainty and high likelihood of bias due to lack of recent sampling) to a 21% decrease (Regulatory Area 3B) in O32 WPUE. Preliminary commercial fishery WPUE estimates from 2024 logbooks showed a 2% decrease from 2023 to 2024 at the coastwide level. However, based on recent updates to in-season preliminary estimates, after accounting for additional logbooks compiled after the fishing season this drop is expected to increase to 7%. Trends varied among IPHC Regulatory Areas, fisheries, and gears; however, all areas showed decreased CPUE in one or more index, with the largest decreases occurring in IPHC Regulatory Area 3B, corresponding to those observed in the FISS. The drop in directed fishery CPUE was very influential in the overall stock assessment estimates (see sensitivity analysis below).

Biological information (ages and lengths) from the commercial fishery landings showed that in 2024 the 2012 year-class (now 12 years old) was again the largest coastwide contributor (in number) to the fish landed. This follows the same patterns observed in 2022-23, after the fishery transitioned from the previously most-abundant 2005 year-class. The FISS also observed the 2012 year-class as a large proportion of the total catch, but the largest proportion comprised the 2016 year-class (age-8 in 2024) also observed in the commercial fishery and recent recreational fisheries. Recent trawl surveys suggest the potential for one or more strong year-classes in 2016-2018; however, the most recent age-length key available is from 2022, so it is difficult to identify specifically which of these year-classes are present in appreciable numbers. Individual size-at-age trends appear mixed through 2024 with previously observed increases for younger ages (<14) reversing in some cases. Direct estimates of the sex-ratio at age for the directed commercial fishery from 2023 (these data lag one year due to laboratory processing time) showed an average of 73% female (by number) in the landings, similar to 2021 and 2022 (74% and 75%).

The population distribution (measured via the modelled FISS catch in weight of all Pacific halibut) showed a continued decrease in Biological Region 3 to the lowest proportion of the coastwide

[2] The IPHC receives preliminary estimates of the current year's non-directed commercial discard mortality 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 from ongoing fisheries through the end of the calendar year. Further updates are anticipated in January 2025.

stock in the time-series. Biological Region 2 increased to the highest proportion observed. Due to the lack of FISS sampling in Biological Region 4B and generally reduced designs in 2023-24. the credible intervals for stock distribution are wide. For Biological Region 4B, the credible stock distribution in 2024 ranges from 4 to 12%. Survey data are insufficient to estimate stock distribution prior to 1993. It is therefore unknown how historical distributions 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 40 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 2024, an ensemble of four stock assessment models was again used to describe the range of plausible current stock estimates. The ensemble approach recognizes that there is no "true" 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 2018). 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; therefore providing a stronger basis for risk assessment.

This stock assessment is implemented using stock synthesis, a generalized stock assessment 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 (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 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 uncertainties, including natural mortality rates (estimated in three of the four models and fixed in one model), 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 truncated 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.

This stock assessment represents a second update, following the full assessment conducted in 2022 (IPHC-2023-SA01) and the update conducted in 2023 (IPHC-2024-SA01). There are no structural changes to the assessment methods for 2024. 2024. Supporting analyses were reviewed by the IPHC's Scientific Review Board (SRB) in June (SRB024; IPHC-2024-SRB024-08, IPHC-2024-SRB024-R) and September 2024 (SRB025; IPHC-2024-SRB025-06, IPHC2024-SRB025-R).

Comparison with previous assessments

As in recent analyses, the transition from the 2023 stock assessment to the final 2024 models was performed in a stepwise manner, adding data incrementally to identify which new information had the largest effect on the results. This 'bridging' analysis included the update to the Stock Synthesis (SS) software from the version used for the 2023 stock assessment (3.30.21) to the most recent release (31 January 2023), 3.30.22.01 (Methot et al. 2024). The changes to the software between these two versions had no effect on the Pacific halibut stock assessment (the results were identical to the final 2023 assessment). However, maintaining a current version (when possible and efficient) reduces the likelihood of compatibility issues with plotting and other auxiliary software and reduces the cumulative transitional burden when future changes are added. No appreciable changes were noted in convergence performance, run times or other technical aspects of the software update.

In the version of the SS software used for 2024, there are a number of new modelling options. Of these, the ability to propagate the process variability in time-varying selectivity parameters into future projections is directly applicable for the Pacific halibut stock assessment. All four assessment models include time-varying selectivity, and bias in the maximum likelihood estimates is accounted for by iteratively solved for the variance parameters (Stewart and Hicks 2022). In recent stock assessments an average of the terminal three years of selectivity was used for all projections. Although the annual selectivity estimated in the four models is not highly variable, estimating projection deviations consistent with the variability estimated for the recent time-series provides the same propagation of variance for time-varying selectivity that is used for recruitment variability. This change was implemented for 2024 but made little difference to the estimated variance of the management quantities; this is likely due to the relatively low current exploitation rates and modest variability in selectivity leading to only minor translation of change in fishery selectivity to population estimates over a short-term projection. This change comes at no additional computational cost and will ensure that future combinations of models and data will appropriately reflect the uncertainty in fishery selectivity.

Because there was little change in the assessment results due to updating all but one of the data sources included in this assessment, only the fishery data is highlighted with a separate step in the bridging analysis. The update to the fishery data included sex-specific age data for 2023, unsexed ages for 2024, a revised estimate using the full set of logbooks now available for the 2023 CPUE (5% lower coastwide than the preliminary data last year) and a preliminary 2024 CPUE estimate using logbooks through the end of October 2024. All four of the models showed only minor differences in the early portions of the time-series' (Figures 3-6). As was observed last year, the 2024 data caused all of the models to estimate a lower spawning biomass for the most recent few years (2021+), and to again slightly reduce the estimate of the 2012 year-class strength compared to the 2022 and 2023 stock assessments (see sensitivity analysis below for ensemble results of this bridging step).

Comparison of this year's ensemble results with previous stock assessments indicates that the estimates of spawning biomass from the 2023 ensemble remain very consistent with those from the 2012-2019 assessments, but slightly below the terminal estimates from the 2020-2022 stock assessments. However, each of the previous terminal assessment values lie inside the predicted 50% interval of the current ensemble (Figure 7). The uncertainty is much greater up to around 2010 reflecting the differences among the four individual models, particularly the beginning of the time-series' in the two short models. The estimated fishing intensity from the 2022 and 2023 stock assessments is generally lower than other recent assessments due to the change in estimating female natural mortality in 2022. However, the 2024 stock assessment estimates a slightly higher level of fishing intensity than in those two assessments, with the fishing intensity in 2023 estimated to be $F_{47\%}$, compared to $F_{52\%}$ in the 2023 stock assessment (Figure 8).

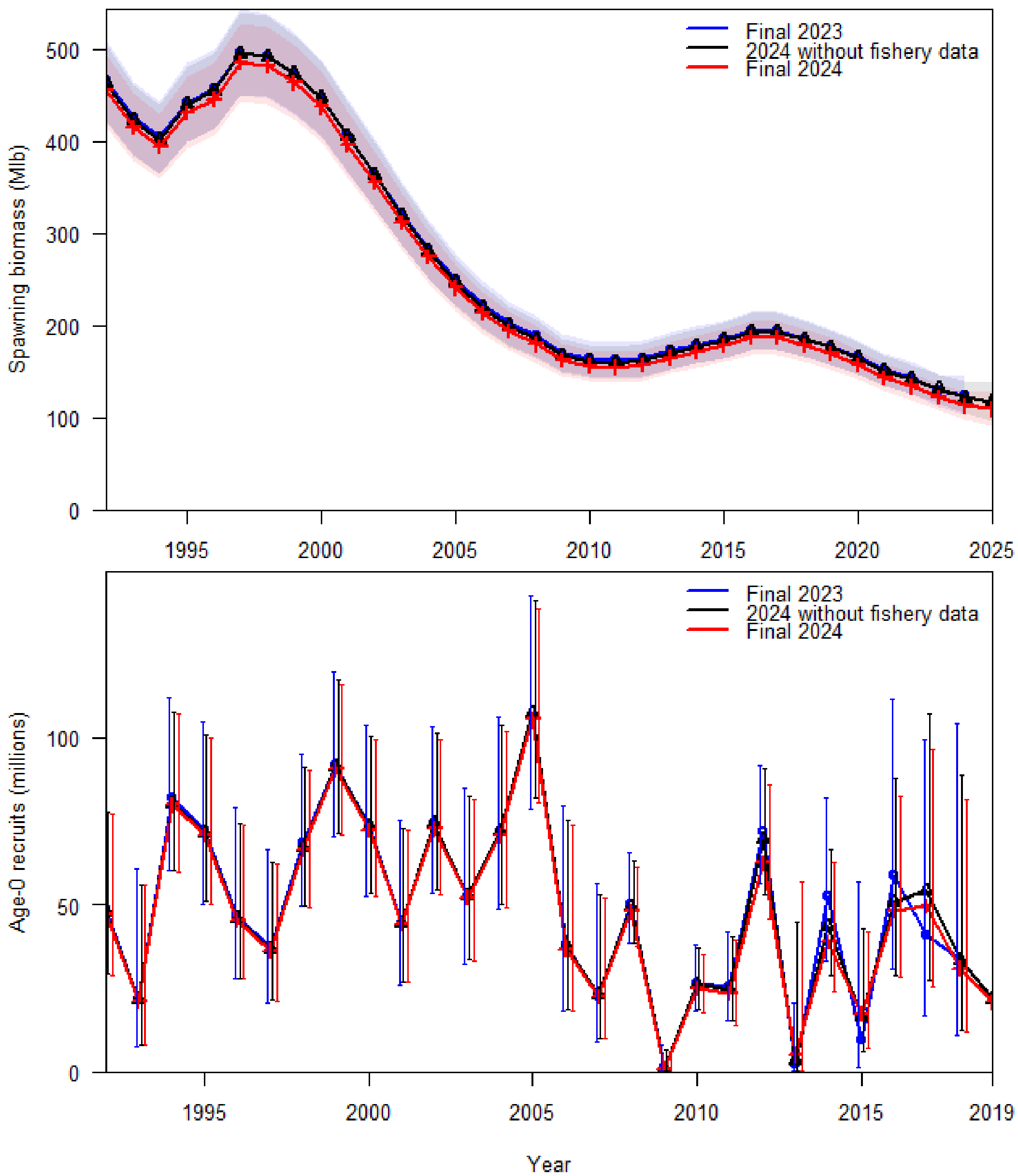

FIGURE 3. Bridging analysis showing the change from the 2023 to final 2024 stock assessment model estimates of spawning biomass (upper panel) and recruitment (lower panel) for the short coastwide model.

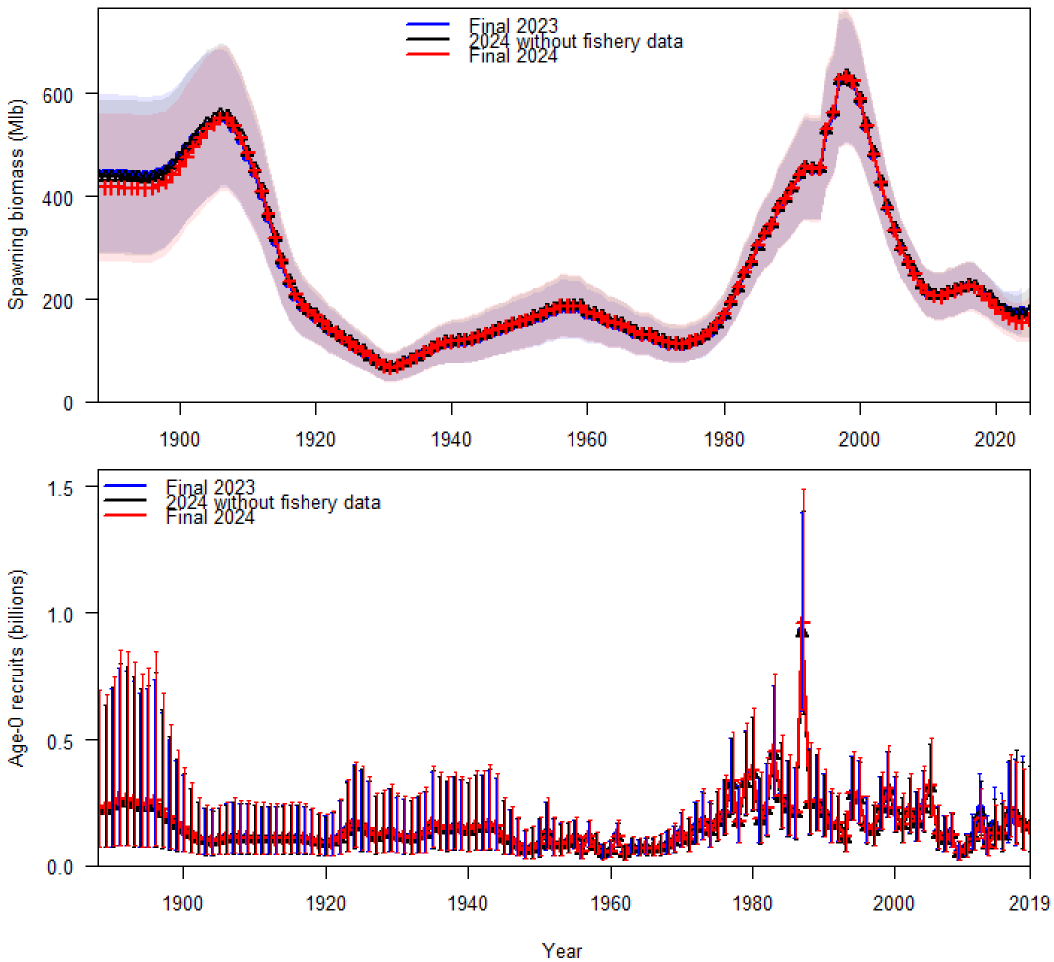

FIGURE 4. Bridging analysis showing the change from the 2023 to final 2024 stock assessment model estimates of spawning biomass (upper panel) and recruitment (lower panel) for the long coastwide model.

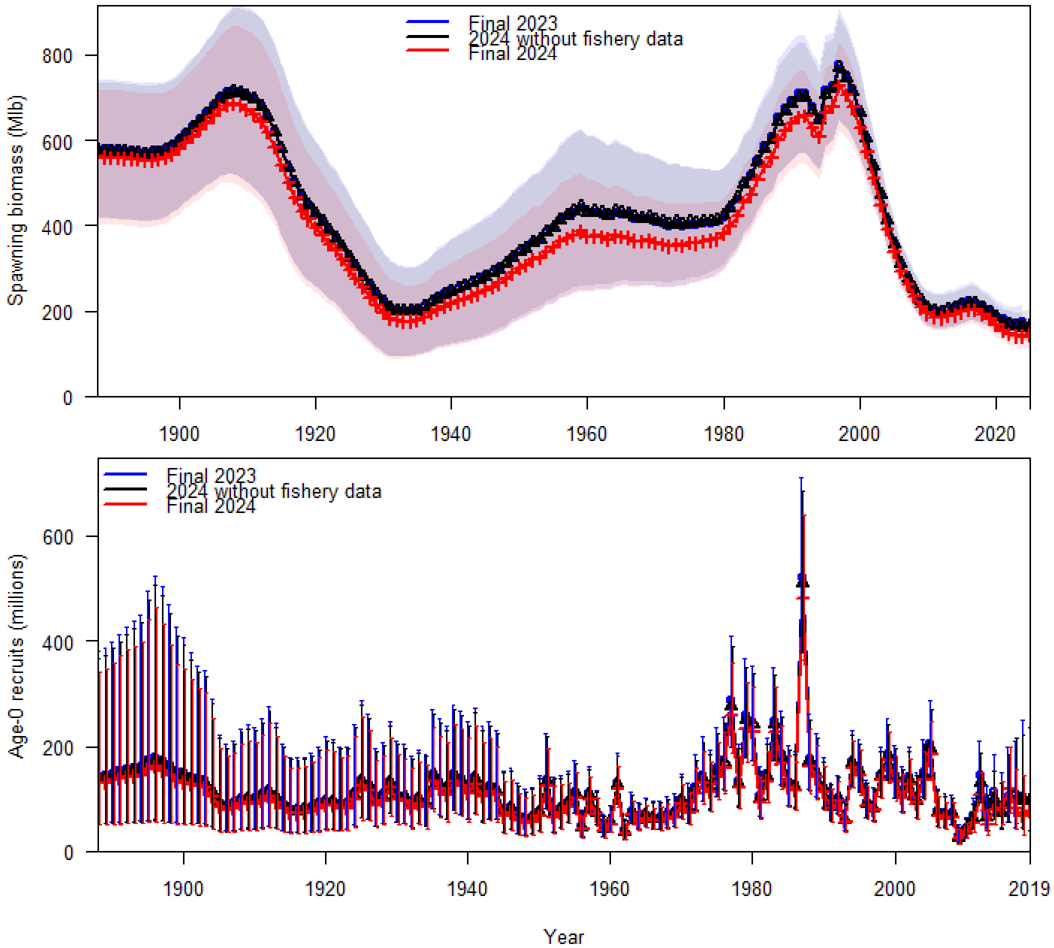

FIGURE 5. Bridging analysis showing the change from the 2023 to final 2024 stock assessment model estimates of spawning biomass (upper panel) and recruitment (lower panel) for the long AAF model.

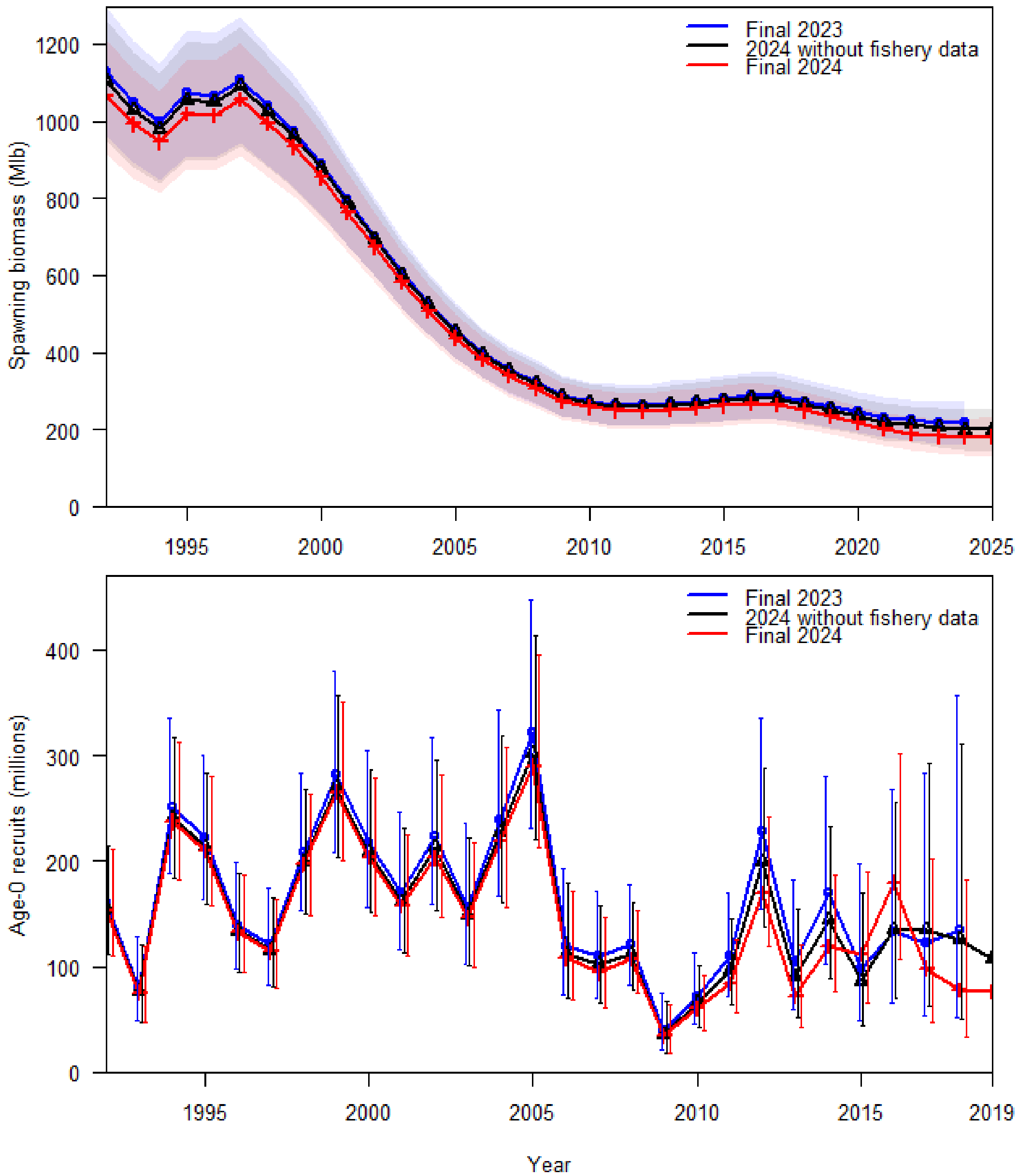

FIGURE 6. Bridging analysis showing the change from the 2023 to final 2024 stock assessment model estimates of spawning biomass (upper panel) and recruitment (lower panel) for the short AAF model.

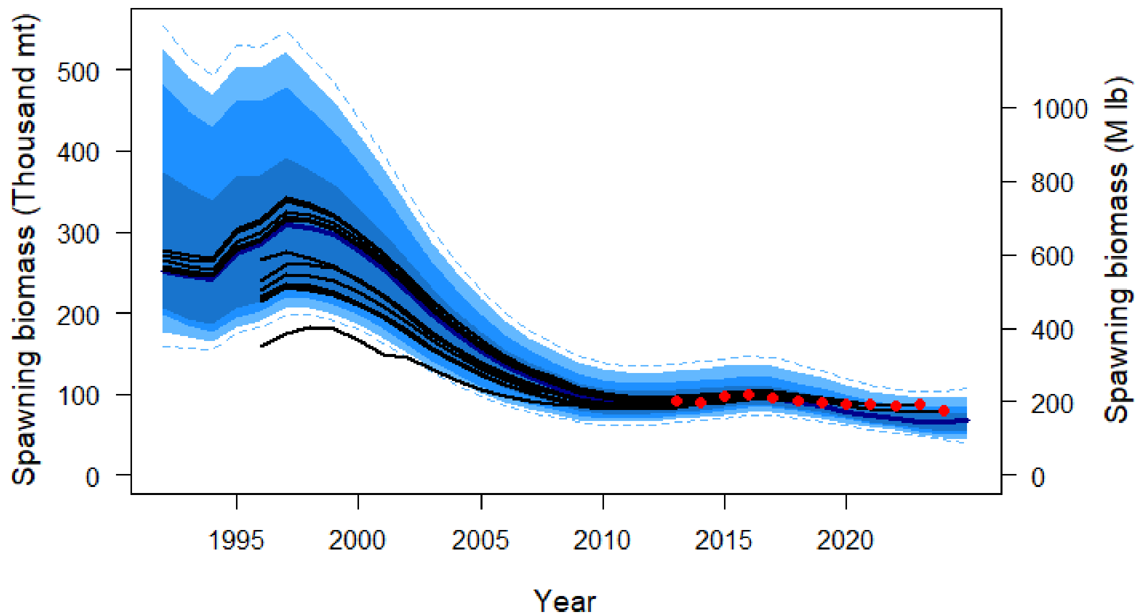

FIGURE 7. Retrospective comparison of female spawning biomass among recent IPHC stock assessments. Black lines indicate estimates from assessments conducted in 2012-2023 with the terminal estimate shown as a red point. The shaded distribution denotes the 2024 ensemble: the dark blue line indicates the median (or "50:50 line") with an equal probability of the estimate falling above or below that level; and 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 2022 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 lower recruitment than observed during the 1980s. The spawning biomass increased gradually to 2016, and then decreased to an estimated 145 million pounds (~65,700 t) at the beginning of 2024. At the beginning of 2025 the spawning biomass is estimated to have increased slightly due to the continued maturation of the 2012 year-class and the onset of maturity of the 2016 year-class. The current spawning biomass estimate (at the beginning of 2025) is 149 million pounds (67,500 t), with an approximate 95% credible interval ranging from 97 to 216 million pounds (~44,100-98,200 t; Figure 9). The differences among the individual models contributing to the ensemble are most pronounced prior to the early 2000s (Figure 10); however, current stock size estimates also differ substantially among the four models (Figure 11). The differences in both scale and recent trend reflect the structural assumptions, e.g., higher natural mortality estimated in three models and dome-shaped selectivity for Biological Regions 2 and 3 in the AAF models.

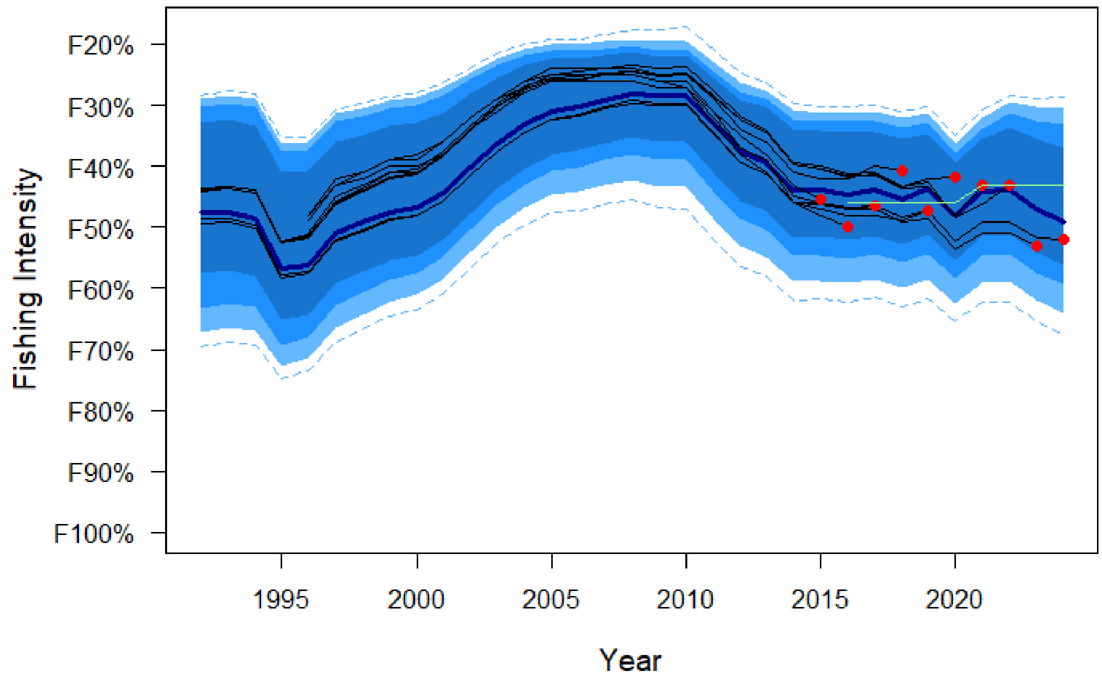

FIGURE 8. Retrospective comparison of fishing intensity (measured as $F_{xx\%}$, where xx% indicates the Spawning Potential Ratio (SPR) or the reduction in the lifetime reproductive output due to fishing) among recent IPHC stock assessments. Thin black lines indicate estimates of fishing intensity from assessments conducted in 2014-2023 with the projection for the mortality limit adopted based on that assessment shown as a red point. The shaded distribution denotes the 2024 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; and 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. The green line indicates the reference level of fishing intensity used by the Commission in each year it has been specified ($F_{46\%}$ during 2016-2020 and $F_{43\%}$ during 2021-2024).

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.

			Fishing	Fishing	Recruitment				Age-8+ biomass			
Year	SB	SB interval	intensity ($F_{XX\%}$)	intensity interval	CW Long	CW Short	AAF Long	AAF Short	CW Long	CW Short	AAF Long	AAF Short
1992	556	390-1,161	48%	29-67%	168.8	47.4	95.8	153	1,706	1,125	2,060	3,119
1993	542	378-1,083	47%	28-66%	114.3	21.3	56.9	75	1,600	1,072	1,909	2,873
1994	534	365-1,033	49%	29-67%	288.6	79.9	159	238.2	1,526	1,006	1,805	2,673
1995	604	404-1,114	57%	36-73%	272.2	70.8	145.1	210	2,132	1,337	2,248	3,324
1996	628	419-1,108	56%	36-71%	160.3	45.4	88	132.4	2,095	1,329	2,234	3,239
1997	683	457-1,151	51%	31-66%	145.3	36.3	79.2	114.1	2,155	1,391	2,299	3,280
1998	675	454-1,083	49%	31-64%	233.9	66.6	135.4	197.6	2,052	1,346	2,180	3,071
1999	654	437-1,017	47%	29-62%	305.5	90.5	172.8	265.7	1,890	1,252	2,010	2,797
2000	612	412-929	47%	29-61%	226.7	72.4	133.4	203.3	1,714	1,155	1,839	2,536
2001	559	373-832	44%	27-58%	164.1	44.2	103.1	157.9	1,511	1,021	1,636	2,220
2002	499	333-733	40%	25-54%	220.6	72.6	126.3	203.2	1,445	971	1,544	2,081
2003	438	292-635	36%	22-50%	175.8	52.2	92.7	146.4	1,378	913	1,448	1,934
2004	385	256-554	33%	21-47%	236.7	70.6	136.3	219.2	1,256	835	1,321	1,756
2005	337	225-479	31%	20-45%	316.7	105.6	183.6	290.1	1,131	746	1,192	1,574
2006	296	199-419	30%	20-44%	127.3	36.8	68.6	108.1	1,072	701	1,123	1,483
2007	266	180-374	29%	20-43%	105.7	22.6	63.1	94.4	1,070	693	1,103	1,467
2008	241	167-341	28%	19-42%	124.4	48	66.2	106.9	1,019	668	1,054	1,408
2009	215	151-305	28%	20-43%	49.5	1.1	25.4	34.4	922	603	968	1,298
2010	201	145-288	28%	19-43%	66	25.1	36.1	60.5	884	587	924	1,252
2011	194	143-280	33%	23-49%	106.9	23.5	53	84.1	837	562	870	1,184
2012	192	145-278	38%	26-53%	185.6	62.7	108.8	170	836	566	861	1,181
2013	197	153-285	39%	28-55%	77.2	5.1	50.4	72.3	889	617	901	1,244
2014	200	158-290	44%	31-59%	131.4	39	78.9	119.6	842	598	858	1,180
2015	206	164-296	44%	31-59%	130.8	17.6	82.5	111.8	790	567	817	1,114
2016	212	172-303	45%	31-59%	227.3	48.4	120	179.8	764	572	789	1,074
2017	210	171-298	44%	31-59%	191	49.6	81.2	98.5	695	520	731	982
2018	199	163-282	45%	32-60%	159	31	68	77.7	635	491	674	906
2019	188	154-266	44%	31-59%	151.7	21	76.5	76.5	614	465	639	860
2020	174	143-246	48%	36-62%	NA	NA	NA	NA	651	492	661	897
2021	161	131-228	44%	32-59%	NA	NA	NA	NA	607	436	628	843
2022	152	122-218	44%	30-59%	NA	NA	NA	NA	606	432	622	836
2023	146	112-211	47%	30-62%	NA	NA	NA	NA	599	392	620	817
2024	145	103-211	49%	30-64%	NA	NA	NA	NA	670	403	662	871
2025	149	97-216	NA	NA	NA	NA	NA	NA	715	423	666	847

Differences are also apparent in the absolute scale of recent recruitment estimates; however, relative recruitments from all four models show larger year-classes in 1999 and 2005 than in all subsequent years (Figure 12, 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 13). Cohorts from 2006 through 2016 are estimated to be smaller than those from 1999-2005 which has resulted in declines in both the stock and fishery yield as these low recruitments became increasingly important to the age range over which much of the harvest and spawning takes place. The 2024 stock assessment estimates a stronger 2016 year-class than those from 2006 through 2015, except the 2012 cohort. Based on the most recent trend and age data, both the 2012 and 2016 cohorts will be very important to the projected spawning biomass over the next 2-4 years. The 2016 year-class is only just beginning to mature in 2024 (at age 8), assuming the historical average maturity schedule currently used in the assessment. All models are estimating a slightly increasing or stable 8+ biomass from a low in 2023 and the ensemble shows a similar pattern in the spawning biomass through the beginning of 2025 (Table 1). Recruitment estimates after 2016 remain highly uncertain, and those after 2019 are poorly informed by any direct information from the fishery and survey data.

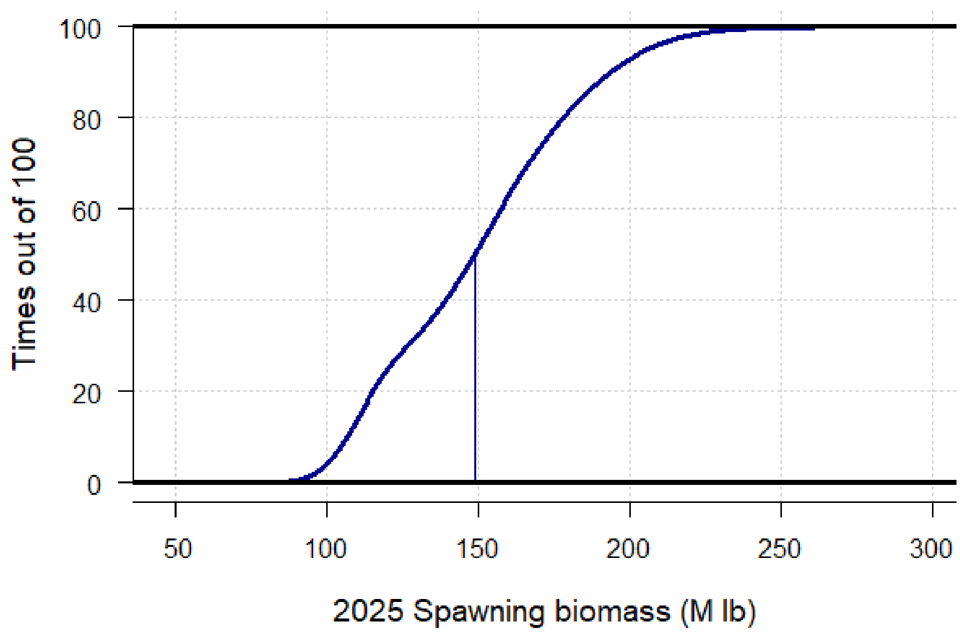

FIGURE 9. Cumulative distribution of the estimated spawning biomass at the beginning of 2025. Curve represents the estimated probability that the biomass is less than or equal to the value on the x-axis; vertical line represents the median (149 million pounds; ~67,500 t).

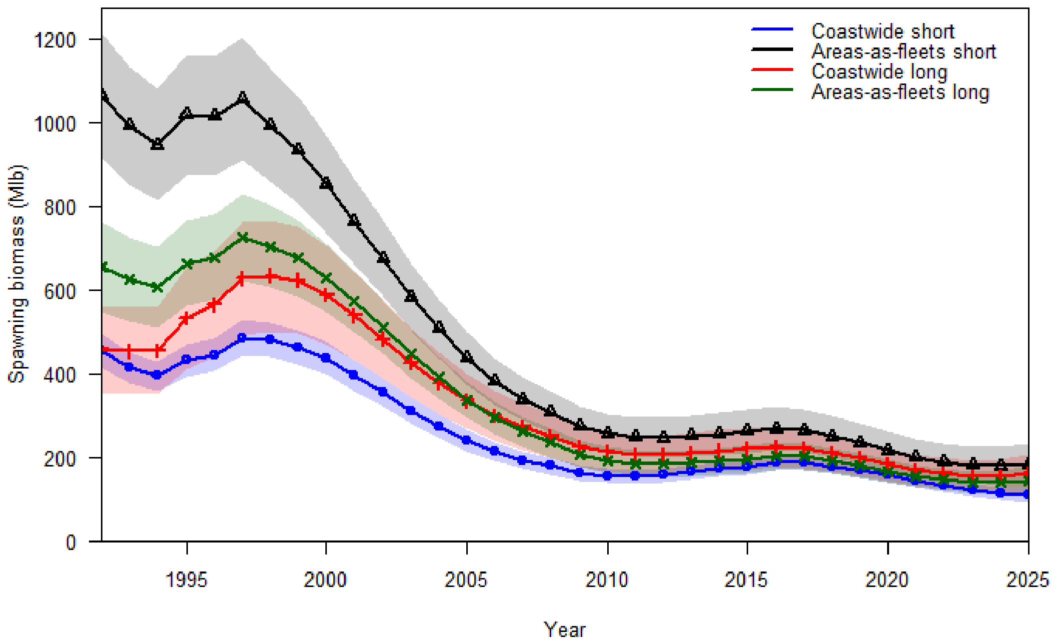

FIGURE 10. Estimated spawning biomass trends (1992-2025) based on the four individual models included in the 2024 stock assessment ensemble. Series indicate the maximum likelihood estimates; shaded intervals indicate approximate 95% credible intervals.

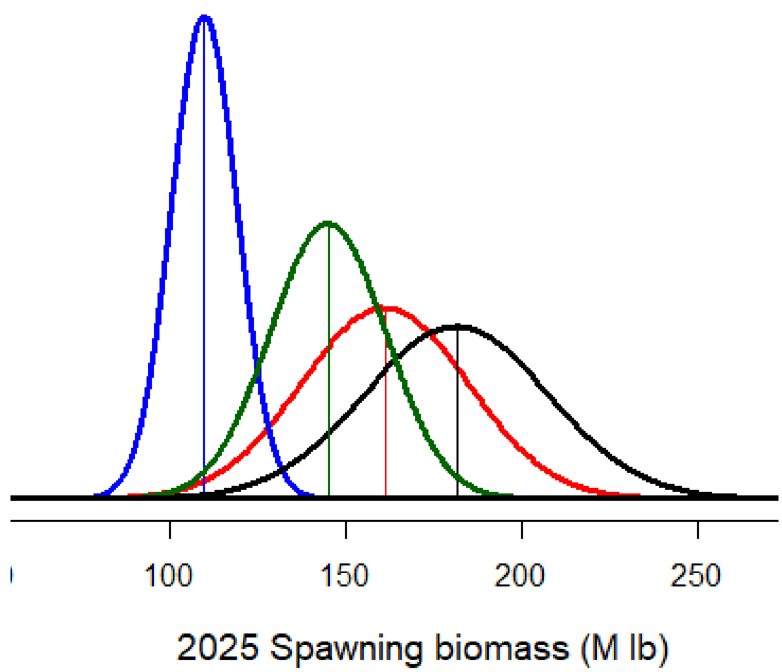

FIGURE 11. Distribution of individual model estimates for the 2025 spawning biomass. Vertical lines indicate the median values.

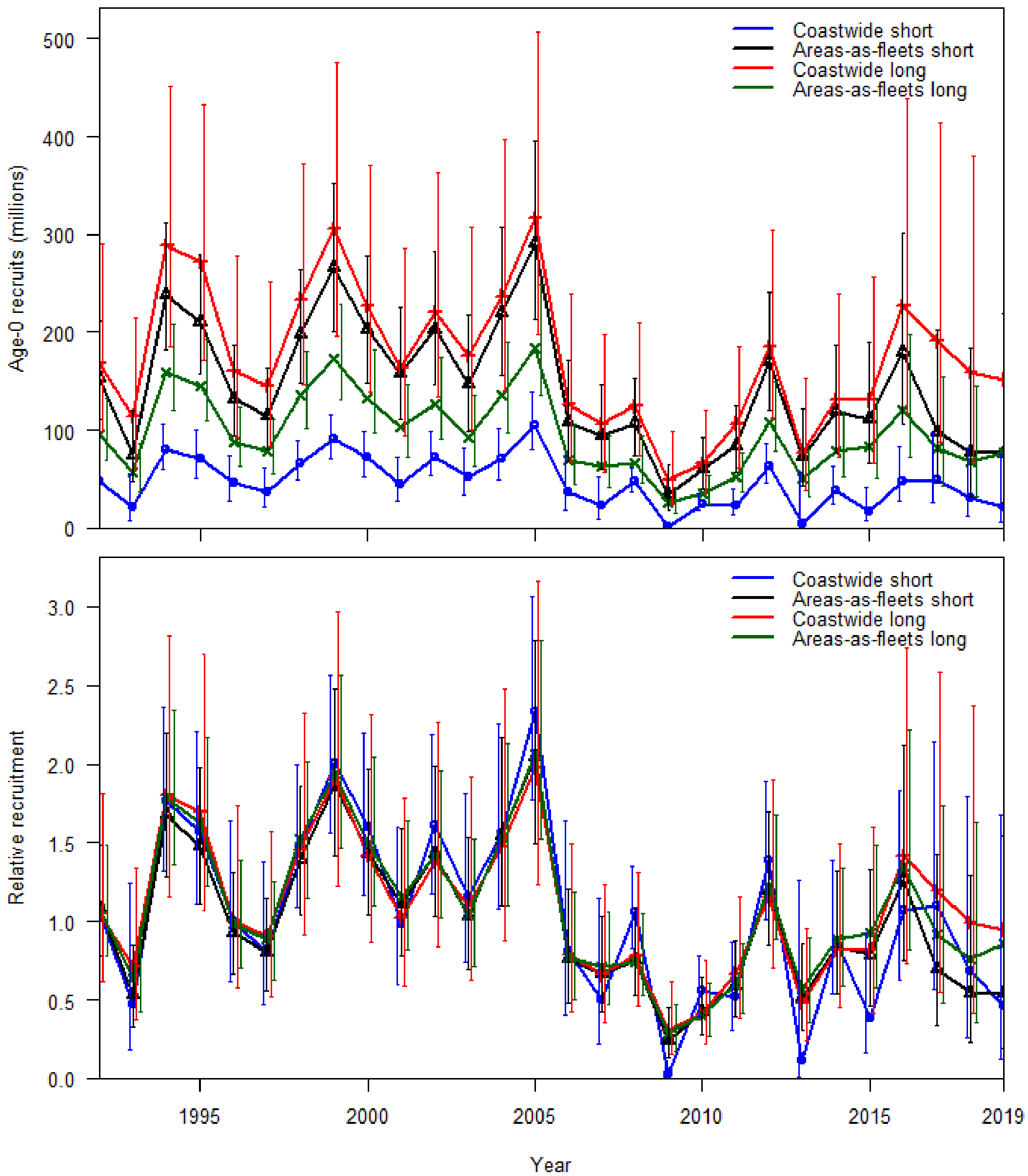

FIGURE 12. Estimated trends in age-0 recruitment (upper panel) and relative recruitment (standardized to the mean for each model over this time-period; lower panel) 1992-2019, based on the four individual models included in the 2024 stock assessment ensemble. Series indicate the maximum likelihood estimates; vertical lines indicate approximate 95% credible intervals.

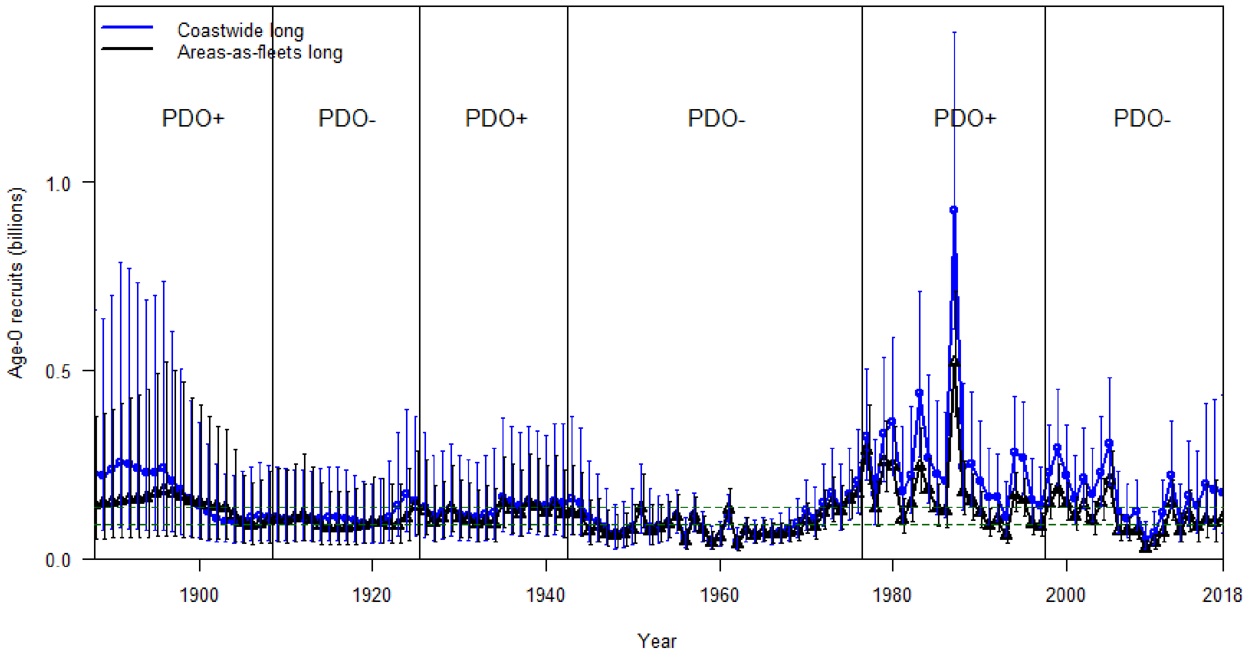

FIGURE 13. Trend in historical recruitment strengths (by birth year) estimated by the two long time-series models, including the effects of the Pacific Decadal Oscillation (PDO) regimes.

Ecosystem conditions

Average Pacific halibut recruitment is estimated to be higher (59 and 53% for the coastwide and AAF models respectively) during favorable Pacific Decadal Oscillation (PDO) regimes (Mantua et al. 1997). 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 through 2024 showing negative average conditions (data were only available through October for 2024). Although strongly correlated with historical recruitments, it is unclear whether the effects of climate change and other recent anomalous conditions in both the Bering Sea and Gulf of Alaska are comparable to those observed in previous decades (Litzow et al. 2020).

Reference points

The IPHC's interim management procedure uses a relative spawning biomass of 30% as a trigger, below which the reference fishing intensity is reduced. At a relative spawning biomass limit of 20%, directed fishing is halted due to the critically low biomass condition. This calculation is based on recent biological conditions currently influencing the stock and therefore measures only the effect of fishing on the spawning biomass, and not natural fluctuations due to recruitment variability and weight-at-age. The relative spawning biomass decreased continuously over the period 1992-2011 to just below 30% (Figure 14). Since 2016, the relative spawning biomass has increased slightly to 38% at the beginning of 2025 (credible interval: 18-55%). This result indicates that recruitment and size-at-age have generally been more important to the trend in spawning biomass than fishing, particularly over the last few years. That the spawning biomass has been decreasing in recent years and the relative spawning biomass has been increasing is not inconsistent: the biomass projected to occur in the absence of fishing (the denominator of the relative biomass calculation) has also been decreasing, and at a higher rate than the actual estimated spawning biomass (Figure 15). This indicates that recent management actions have eased the effect of fishing on the spawning biomass. The probability that the stock is below the

$SB_{30\%}$ level is estimated to be 30% at the beginning of 2025 (Figure 16), with a 11% chance that the stock is below $SB_{20\%}$ (Table 2).

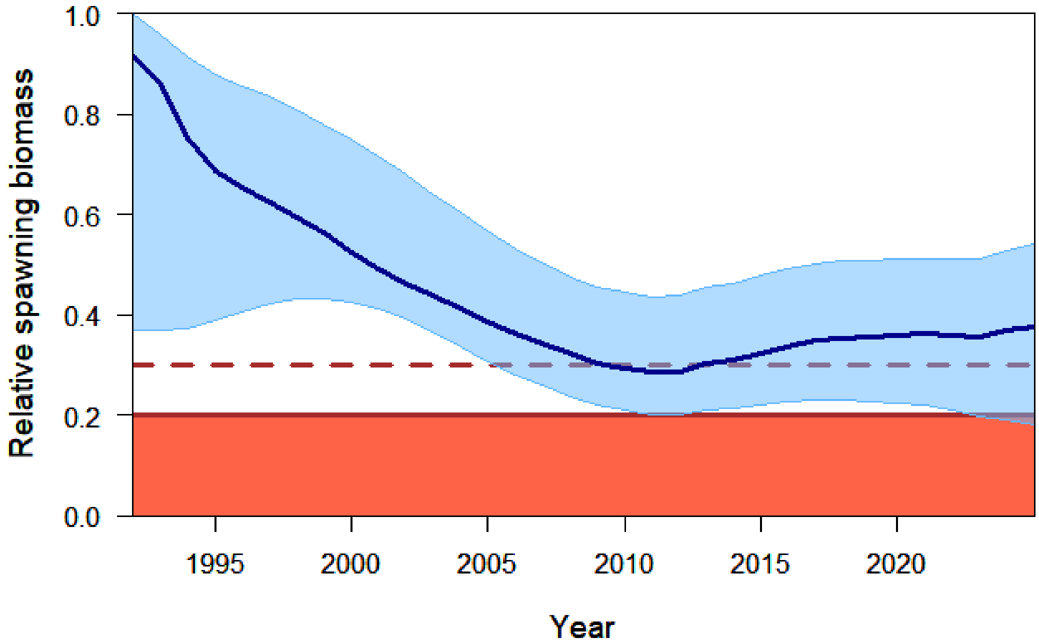

FIGURE 14. Estimated time-series of relative spawning biomass (compared to the unfished condition in each year) based on the median (dark blue line) and approximate 95% credibility interval (blue shaded area). IPHC management procedure reference points ($SB_{30\%}$ and $SB_{20\%}$) are shown as dashed and solid lines respectively, with the region of biological concern (<$SB_{20\%}$) shaded in red.

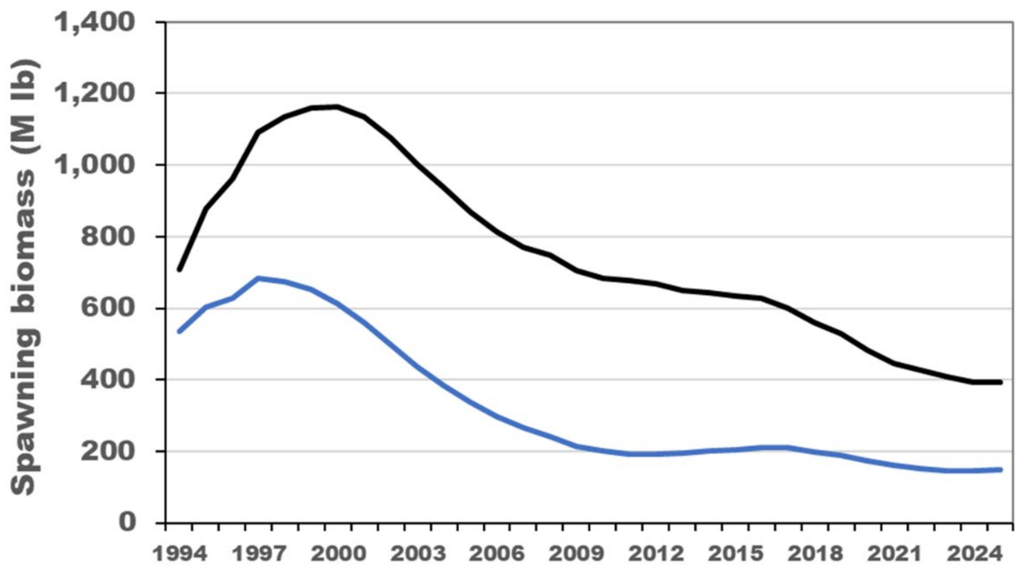

FIGURE 15. Estimated time-series' of spawning biomass (blue line) and spawning biomass in the absence of fishing (black line).

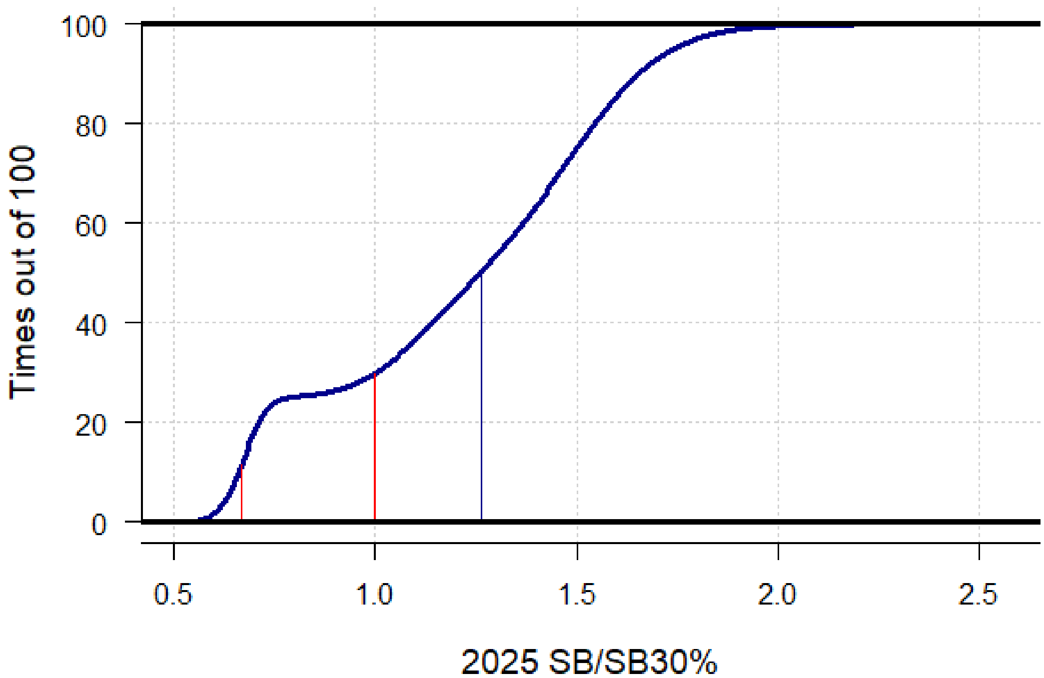

FIGURE 16. Cumulative distribution of ensemble 2025 spawning biomass estimates relative to the $SB_{30\%}$ reference point. Curve represents the estimated probability that the biomass is less than or equal to the value on the x-axis. Vertical lines denote the values corresponding to the fishing intensity trigger and limit in the IPHC's harvest policy (red; $SB_{30\%}$ *and* $SB_{20\%}$), and the median (blue; $SB_{42\%}$).

The IPHC's current interim management procedure specifies a reference level of fishing intensity of $F_{43\%}$, based on the Spawning Potential Ratio (SPR; prior to 2021 the reference level was $F_{46\%}$). This reference 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. Fishing intensity is estimated to have been below reference levels from 2020 through 2023 (Figure 8) and to have decreased to an estimate of $F_{49\%}$ (credible interval: 30-64%) in 2024 (Figure 17). 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 has increased slowly since then (Figure 18).

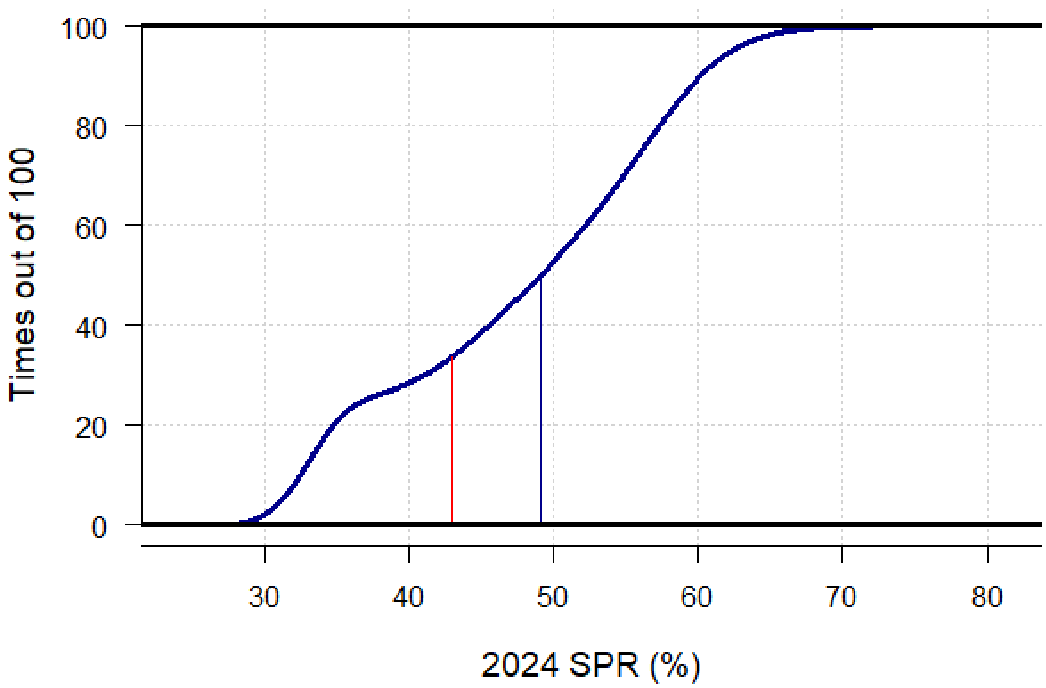

FIGURE 17. Cumulative distribution of the estimated fishing intensity (based on the Spawning Potential Ratio) estimated to have occurred in 2024. Curve represents the estimated probability that the fishing intensity is less than or equal to the value on the x-axis. Vertical lines indicate the reference ($F_{43\%}$; red) and the median value ($F_{49\%}$; blue). The x-axis represents high to low fishing intensity when moving from left to right.

Long time-series models

The two long time-series models provided different perceptions of current vs. historical stock sizes, particularly for the lowest points in the series occurring in the 1930s and 1970s (Figure 19). The AAF model estimates that recent stock sizes are below those estimated for the 1970s, 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 four of the models represent only simple approximations. Recent differences are small, and 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 in the AAF models. Historical differences appear to be due to the differing implicit assumptions regarding connectivity between Biological 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).

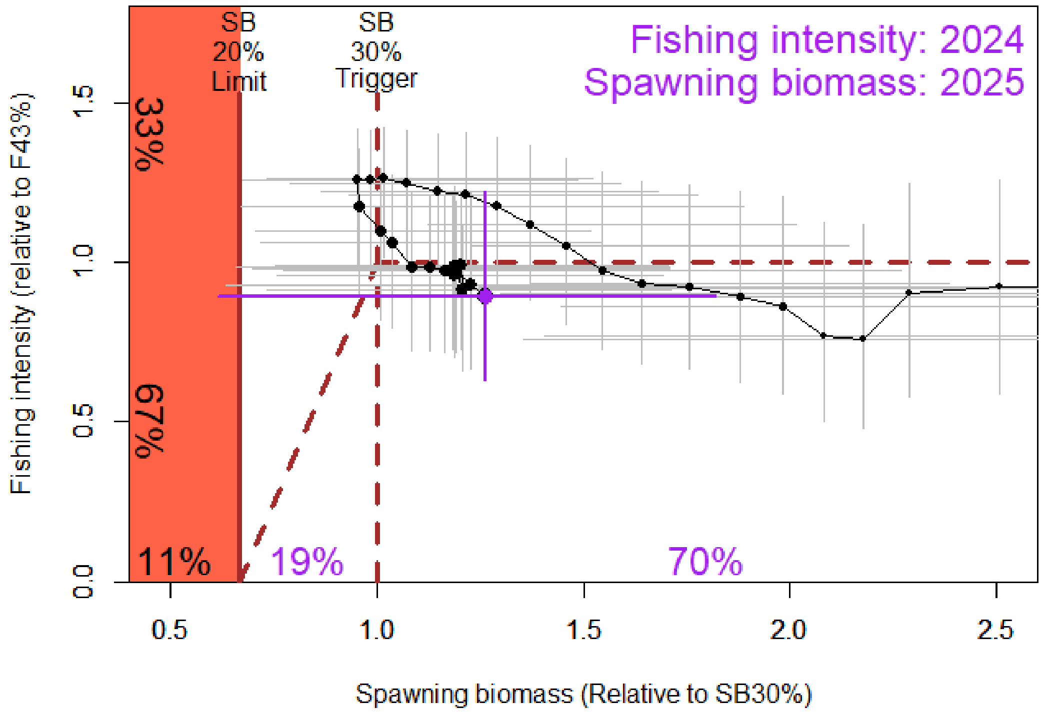

FIGURE 18. Phase plot showing the time-series of estimated spawning biomass (1993-2025) and fishing intensity (1992-2024) relative to current reference points. Dashed lines indicate the $F_{43\%}$ (horizontal) reference fishing intensity (measured in SPR) and linear reduction below the $SB_{30\%}$ (vertical) trigger, the red area indicates levels below the $SB_{20\%}$ limit. Each year is denoted by a solid point (credible intervals by horizontal and vertical whiskers), with the relative fishing intensity in 2024 and spawning biomass at the beginning of 2025 shown as the largest point (purple). Percentages along the y-axis indicate the probability of being above and below $F_{43\%}$ in 2024; 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 2025.

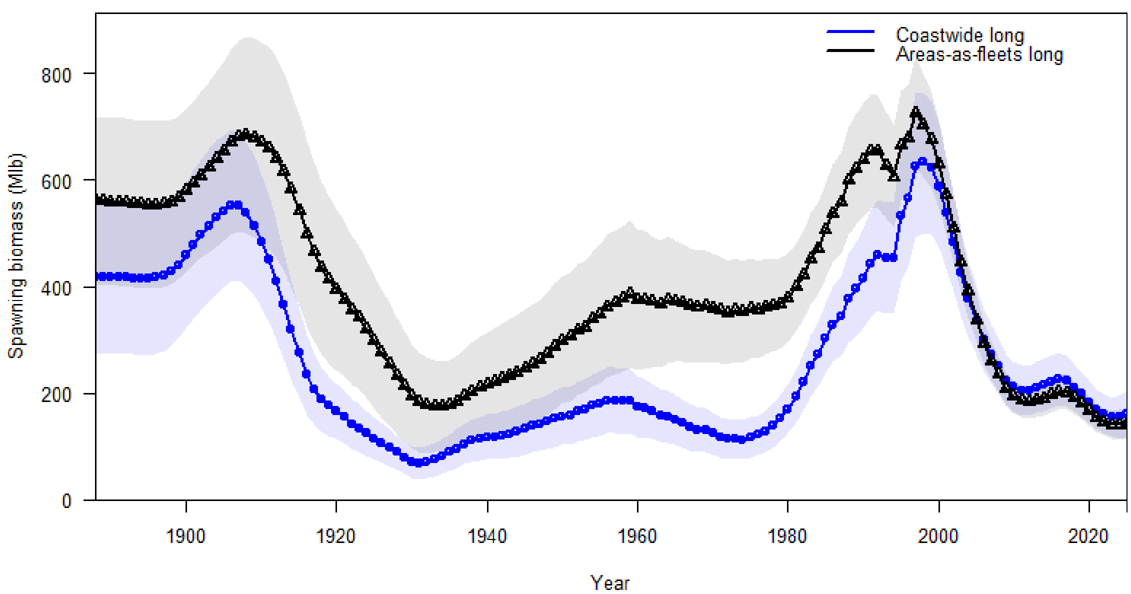

FIGURE 19. Spawning biomass estimates from the two long time-series models. Shaded region indicates the approximate 95% within-model credible interval. The black (upper) series is the Areas-As-Fleets model and the blue (lower) series is the coastwide model.

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 2023 assessment includes seven years (2017-23) of sex-ratio information from the directed commercial fishery landings. However, uncertainty in historical ratios, and the degree of variability likely present in those historical ratios remains unknown. Additional years of data are likely to further inform selectivity parameters and cumulatively reduce uncertainty in recent stock size moving into the future. The treatment of spatial dynamics (and implicitly 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 fishery mortality. 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+ years) and survey data (6+ 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 mortality in either directed or non-directed fisheries (e.g. whale/marine mammal depredation) could create bias in this assessment.

Maturation schedules are currently under renewed investigation by the IPHC (see sensitivity analyses below). 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 the spatial and temporal variability inherent in these biological processes.

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, unchanged since 2022, the four models use both fixed (0.15/year for female Pacific halibut) and estimated values. Estimates are highly correlated with the relative commercial fishery selectivity of males and females, which is currently estimated based on only seven years of available data. Although this uncertainty is directly incorporated into the ensemble results, uncertainty in female natural mortality in the coastwide short model is not and remains an avenue for future investigation.

The 2024 stock assessment, similar to the 2023 assessment, was very sensitive to the addition of new directed commercial fishery data (ages and CPUE), as well as the update to the previous year's preliminary information (sex-specific ages and CPUE reflecting a larger dataset of logbooks). In 2023 these data alone resulted in an 11% decrease in the scale of the current spawning biomass estimate; in 2024 this effect was 17%. The reduction in estimated commercial fishery catch rates from the time the data sets for the stock assessment are closed until the data are relatively complete (sometime the following year) has been previously identified. Concern over the potential for incomplete fishery CPUE to bias the assessment results led to the recommendation to 'down-weight' the terminal year via doubling the estimated variance in the index (IPHC-2017-SRB11-R). However, when the CPUE and other data provide differing information on the recent stock scale and/or trend this approach of inflating the variance may make subsequent analyses more sensitive to the change in CPUE rather than less. Historically this has not been an issue, however in both the 2023 and 2024 stock assessments it has. An alternative analysis was conducted this year using the estimated variance without any inflation and applying an additional 5% decrease from the observed (now updated) 2023 value to the preliminary 2024 estimate (see risks not included in the decision table below). The sensitivity of the stock assessment to updated fishery information likely also reflects the increased uncertainty in recent FISS results. Conflicting signals from these data sources may indicate a lag in information or the potential for bias in one or both series. Commercial fishery data is known to respond to factors other than population trends (e.g., bycatch avoidance, interactions with other fisheries, whale depredation). With large portions of the full FISS design unsampled in recent years it is possible that indices of abundance and/or age composition data are biased relative to true population trends. Simulation analyses conducted during 2024 indicate that biased FISS trends would translate into biased assessment results (IPHC-2024-SRB025-06). Until there are one or more relatively comprehensive FISS designs completed, the potential for biased information will be unknown.

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 inter-annual variability in mortality limits include management procedures that utilize multi-year management approaches and/or constraints on the inter-annual change in the TCEY. These are being tested with the MSE framework (IPHC-2025-AM101-12).

CONVERGENCE, SENSITIVITY AND RETROSPECTIVE ANALYSES

Basic convergence checks applied to all models included successful calculation of the Hessian matrix, checks for reasonable uncertainty in and correlations among estimated model parameters and tracking of results through sequential model or data changes to ensure plausible results. Final model runs were further evaluated via running models from a wide range of starting values ('jittering', using at least 100 different starting points), and ensuring that no model discovered a better likelihood than was used to produce the final assessment results. Convergence to the maximum likelihood estimate varied from 46-65% indicating that the starting points were sufficiently over-dispersed to provide a solid test for alternative minima.

Following the bridging analysis of stepwise introduction of new data toward the final 2024 stock assessment, a sensitivity analysis was conducted to illustrate the effect of updating the 2023 and 2024 commercial fishery data on the ensemble results. When the ensemble estimates were produced leaving out this single source of updated information, the results showed much closer agreement with stock assessments through 2023 (Figure 20).

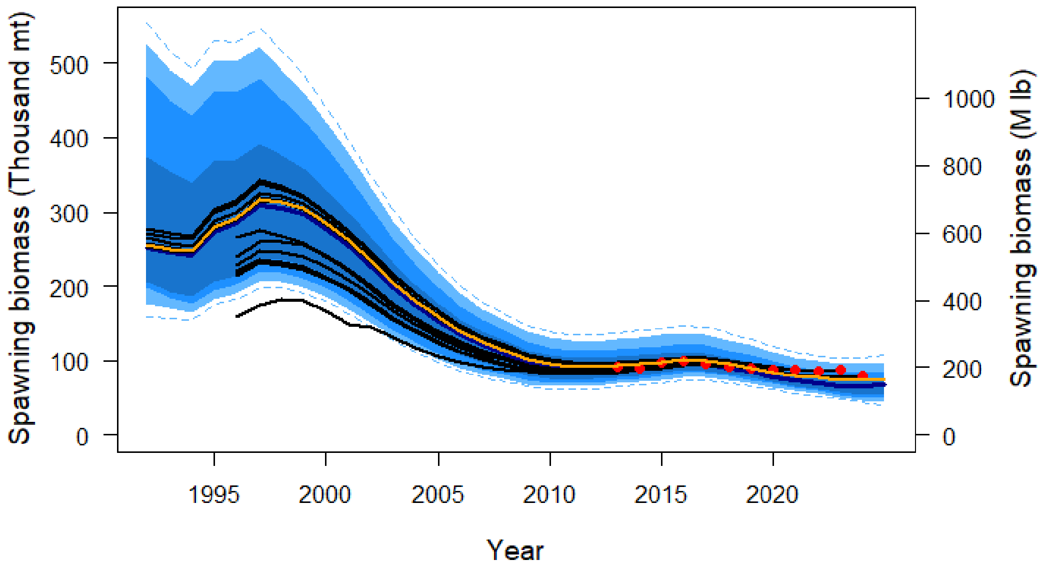

FIGURE 20. Sensitivity analysis to the removal of commercial fishery information from 2024 (yellow line) compared to the retrospective comparison of female spawning biomass among recent IPHC stock assessments. Black lines indicate estimates from assessments conducted in 2012-2023 with the terminal estimate shown as a red point. The shaded distribution denotes the 2024 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; and 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.

During the development of the 2022 full stock assessment a wide range of bridging and sensitivity analyses were conducted (IPHC-2022-SRB020-07). 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 have included: the sex ratio of the directed commercial fishery landings, the treatment of historical selectivity in the long time-series models, and natural mortality. Likelihood profiles were used to investigate the sources of information on natural mortality and the general level of agreement among data sets. In addition, the 2022 assessment included extensive evaluation of the treatment of the PDO as a covariate with average recruitment. The results have supported the prioritization of maturity, fecundity and skip spawning as current and near-term research foci. An updated maturity ogive is anticipated to be available for inclusion in the full stock assessment planned for 2025. Preliminary analyses suggest that histology-based maturity indicates a greater fraction of young Pacific halibut and a smaller fraction of older Pacific halibut are mature than currently included in the stock assessment (IPHC-2025-AM101-15). This type of shift in the maturity curve has the effect of decreasing the importance of older individual fish and increasing the reproductive contribution of younger fish. A simple sensitivity analysis was performed by replacing the current curve with the preliminary histological curve for the entire time series (i.e., assuming that maturity does not change over time and is better approximated with the new information). This sensitivity resulted in a larger estimated spawning biomass over the last 30 years (Figure 21). This result is highly preliminary and may change prior to the 2025 stock assessment.

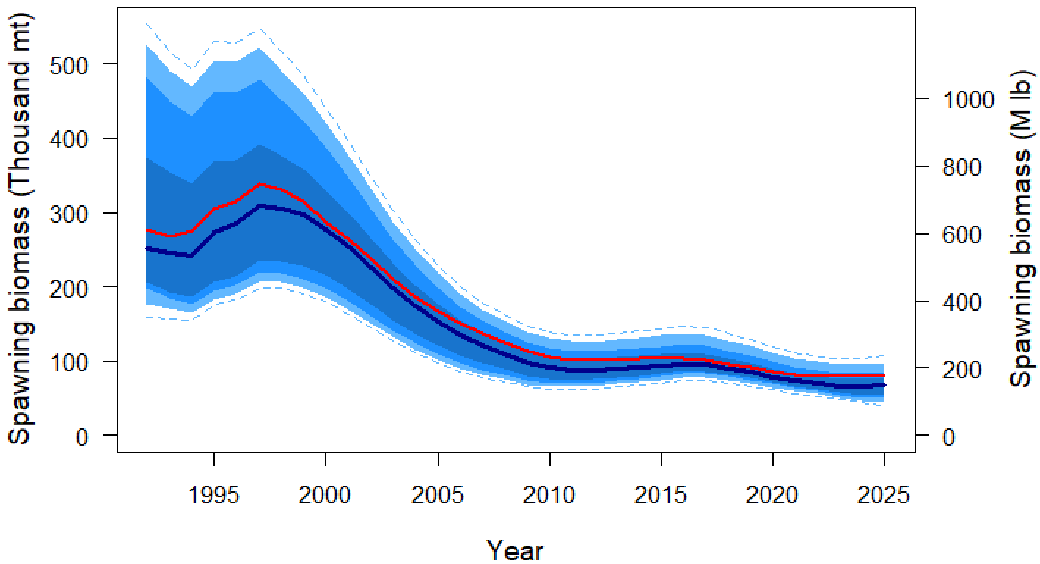

FIGURE 21. Sensitivity to preliminary results from the ongoing histological maturity study (red line) compared to the female spawning biomass estimated from the final 2024 stock assessment. The shaded distribution denotes the 2024 ensemble: the dark blue line indicates the median (or "50:50 line") with an equal probability of the estimate falling above or below that level; and 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.

To illustrate the effects of sequentially adding 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. The current models rely on commercial sex-ratios-at-age which are only available from 2017-2023. Therefore, the retrospective for this year's assessment includes seven 'peels', each cumulatively removing one year of data (2024, 2023-2024, 2022-2024, 2021-2024, 2020-2024, 2019-2024, and 2018-2024). Estimates for relative male and female selectivity parameters become less certain with reduced data and required at least one year of data for reliable estimation and preferably more. As data accumulate since this change in model structure the retrospective analyses will be more informative of recent data effects rather than being affected by lack of information to inform selectivity differences.

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 short and long models where the estimates of spawning biomass generally decreased with the removal of 2-7 years of data (Figures 22-25; upper panels). As noted above, these models were very sensitive to the estimated values for natural mortality, which were correlated with relative male and female selectivity in the directed commercial fishery; removing four and five recent years of data left a paucity of sex ratio information to estimate differences in male and female selectivity. This result highlights the ongoing need for additional observations of the sex-ratio of commercial fishery landings. The second clear result from the retrospective analysis was the effect of recent data on the magnitude of the estimated 2012 year-class. This cohort is better informed by each year of additional data and the estimated magnitude increased across the model runs in the early years and then decreased with the addition of the 2023 and 2024 data (Figures 22-25; lower panels).

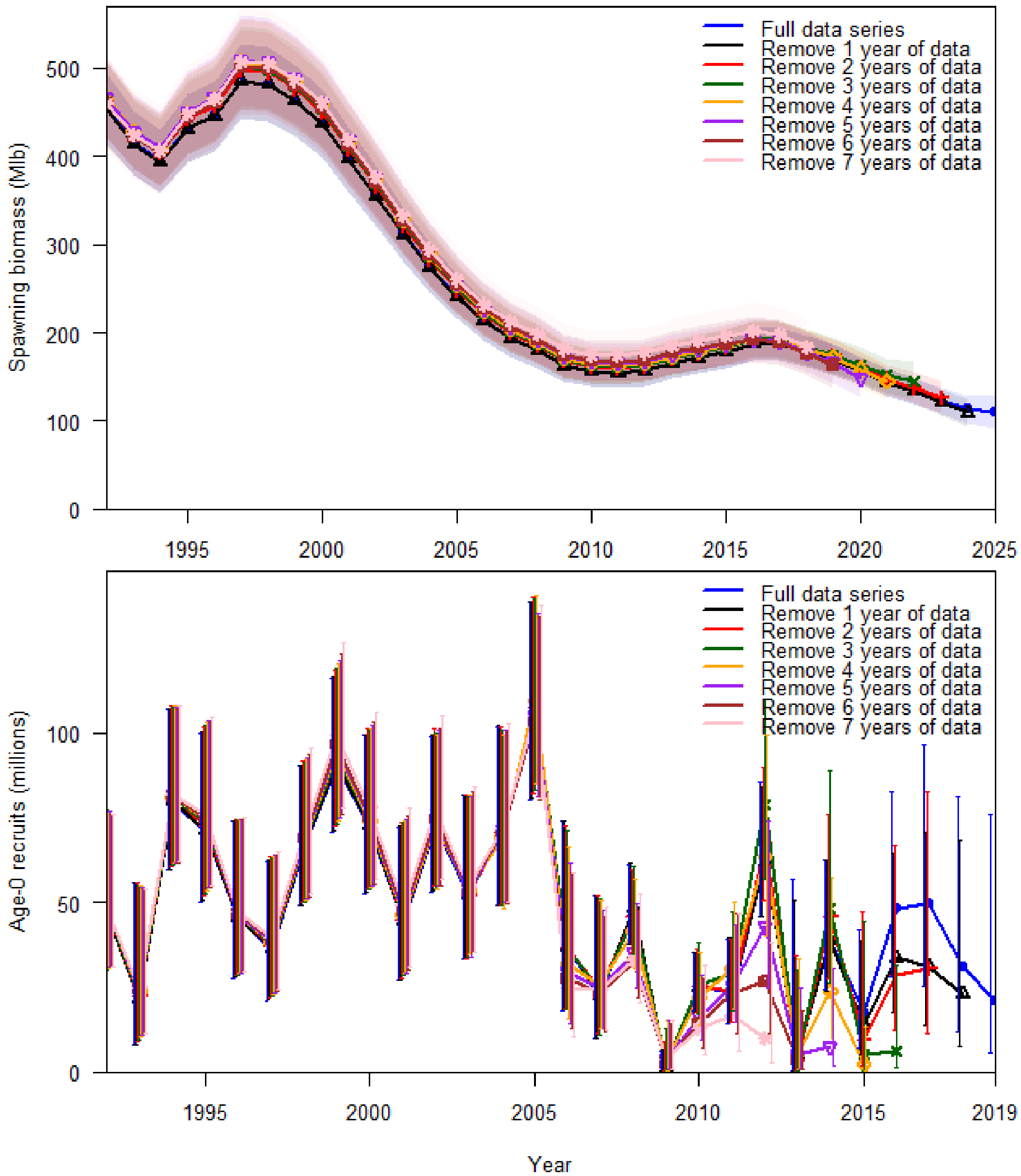

FIGURE 22. Spawning biomass (top panel) and recruitment (bottom panel) estimates from a retrospective analysis sequentially removing terminal years of data from the coastwide short model. Shaded regions and vertical whiskers indicate approximate 95% within-model credible intervals.

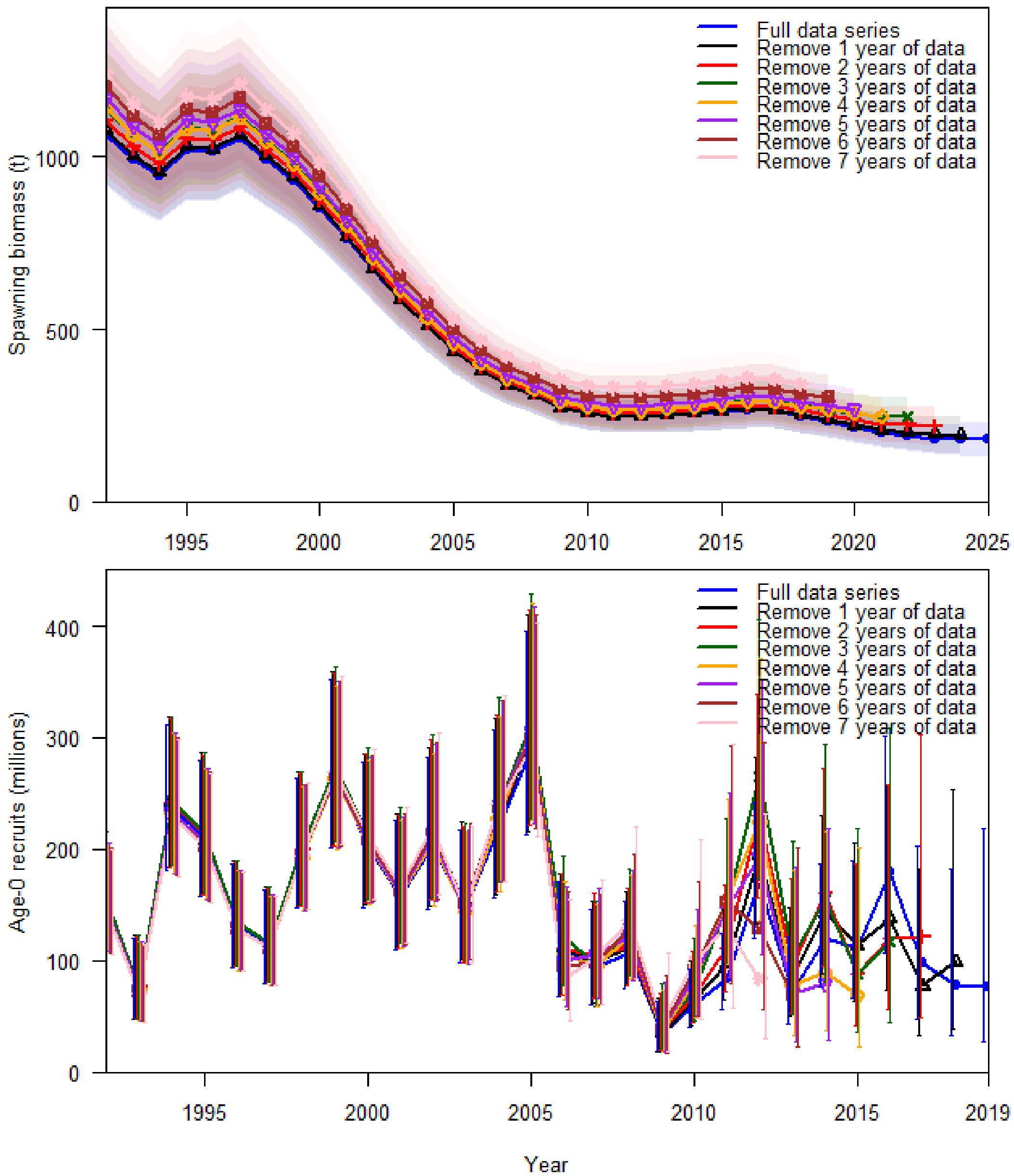

FIGURE 23. Spawning biomass (top panel) and recruitment (bottom panel) estimates from a retrospective analysis sequentially removing terminal years of data from the AAF short model. Shaded regions and vertical whiskers indicate approximate 95% within-model credible intervals.

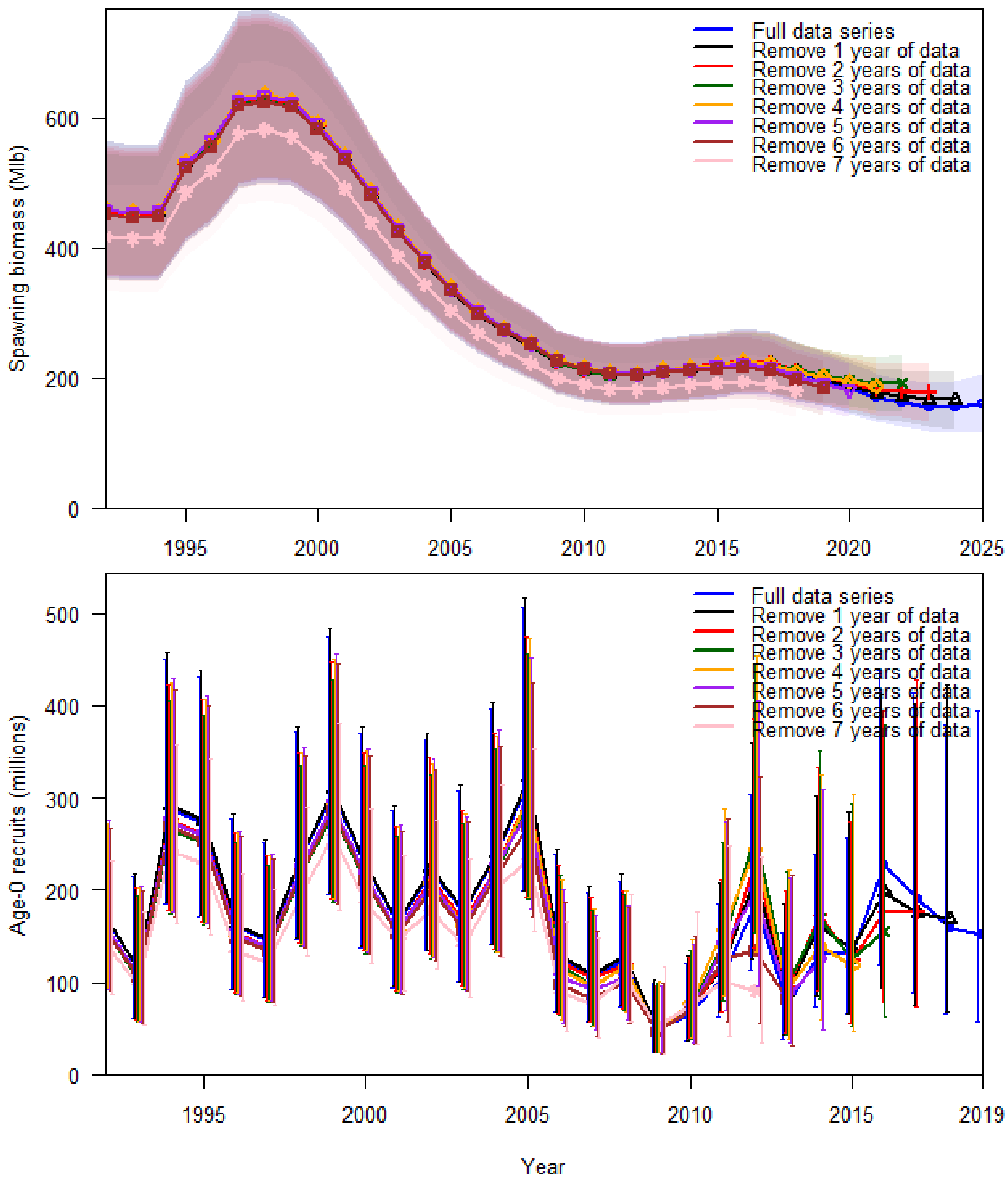

FIGURE 24. Recent spawning biomass (top panel) and recruitment (bottom panel) estimates from a retrospective analysis sequentially removing terminal years of data from the coastwide long model (time series has been truncated to allow for easier inspection of terminal values). Shaded regions and vertical whiskers indicate approximate 95% within-model credible intervals.

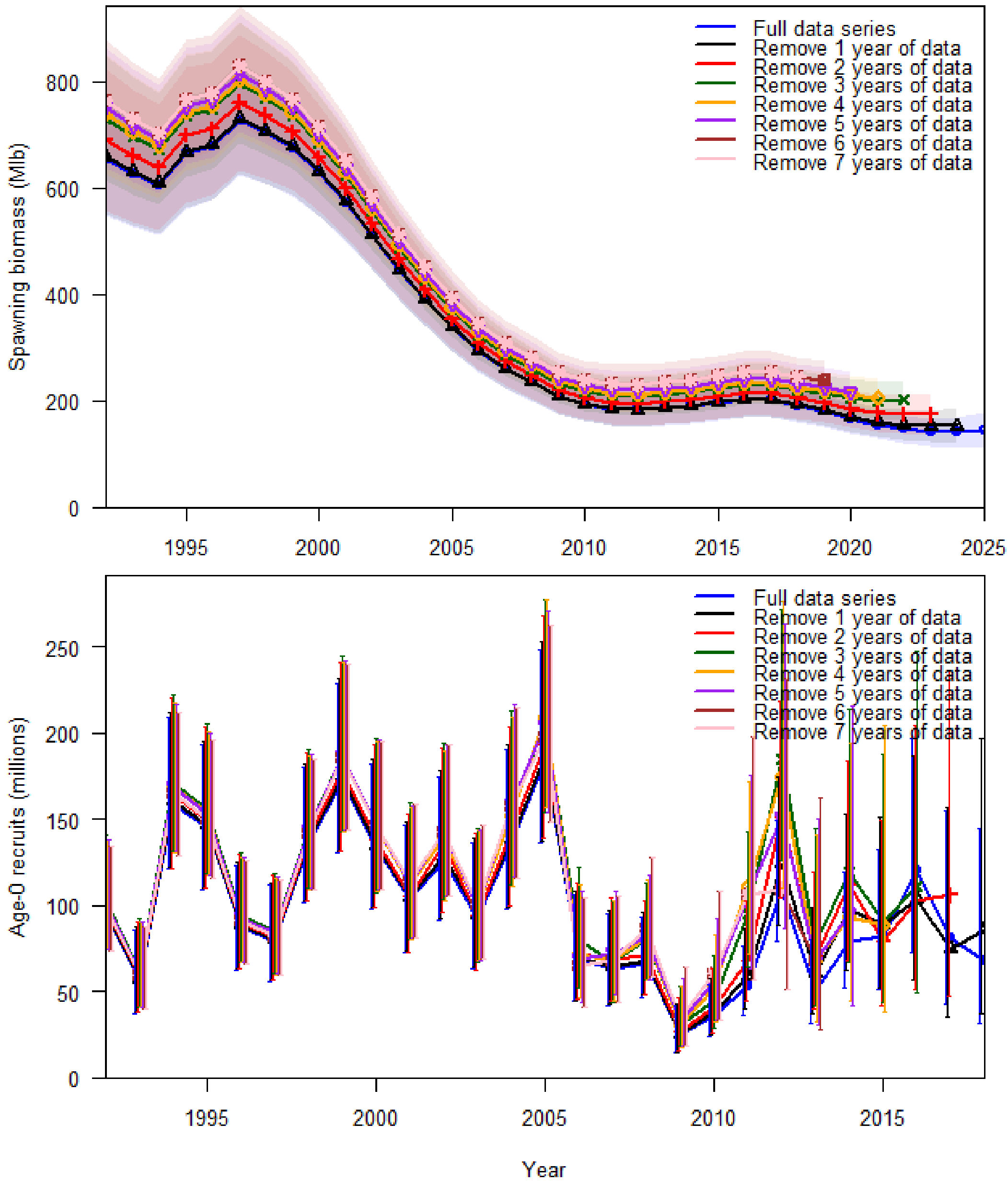

FIGURE 25. Recent spawning biomass (top panel) and recruitment (bottom panel) estimates from a retrospective analysis sequentially removing terminal years of data from the AAF long model (time series has been truncated to allow for easier inspection of terminal values). Shaded regions and vertical whiskers indicate approximate 95% within-model credible intervals.

FORECASTS AND DECISION TABLE

Short-term tactical stock projections under varying levels of mortality are conducted using the results from the 2024 stock assessment. Standard projections are based on existing Catch Sharing Agreements/Plans (CSPs) for directed commercial and recreational fisheries where they exist, as well as summaries of the 2024 and earlier directed and non-directed fisheries. Specifically, the projected mortality levels are based on the three-year running average non-directed discard mortality[3] through the most recent year (2024, per the decision during AM096

[3]. The North Pacific Fishery Management Council adopted a new method for setting the Prohibited Species Catch (PSC) limit for Pacific halibut mortality in the Amendment 80 (A80) trawl sector in 2024. This approach adjusts PSC limits based on the

para. 97). Subsistence harvest is assumed to be constant at the most recent year's estimates. The discard mortality for the directed commercial fisheries is assumed to occur at the same rate observed in the most recent year, and to scale up or down with the projected landings.

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 coastwide alternative harvest levels for 2024 (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) include several levels of mortality intended for evaluation of stock and management procedure dynamics including:

- No fishing mortality (useful to evaluate the stock trend due solely to population processes)
- The mortality consistent with repeating the coastwide TCEY set for 2024 (the *status quo*)
- Bracketing alternatives 5 and 10% above and below the *status quo*
- Alternatives of 15% and 25% below the *status quo* requested by the Commission at IM100 (IPHC-2024-IM100-R)
- The mortality at which there is less than or equal to a 50% chance that the spawning biomass will be smaller in 2028 than in 2025 ("*3-year surplus*")
- The mortality consistent with the current "Reference" SPR ($F_{43\%}$) level of fishing intensity
- The mortality consistent with the Maximum Economic Yield (*MEY*) proxy SPR ($F_{40\%}$) level of fishing intensity
- The mortality consistent with the Maximum Sustainable Yield (*MSY*) proxy SPR ($F_{35\%}$) level of fishing intensity
- Other levels of mortality spaced between the above alternatives to provide for continuous evaluation of the change in risk across alternative yields

For each column of the decision table, the projected total fishing mortality (including all sizes and sources), the coastwide TCEY and the associated level of estimated fishing intensity projected for 2025 (median value with the 95% credible interval below) are reported.

Spawning biomass estimates in 2024 from the 2024 stock assessment are lower (17%) than those in last year's stock assessment, but the recent estimated trend is nearly flat (+3% from 2024 to 2025). Updated estimates of the 2012 and 2016 year-classes (both larger than all those occurring from 2006-2011) show that these two year-classes will be highly important in the short-term stock projections as both will be maturing over the next several years. However, these two

NOAA Fisheries Eastern Bering Sea trawl survey and the modelled FISS index of abundance for IPHC Regulatory Areas 4A, 4B, and 4CDE. This new approach resulted in a 20% reduction to the A80 sector's PSC limit in 2024 and an additional 5% reduction for 2025. However, the actual halibut mortality has been far below the aggregate PSC limit for all sectors in the Bering Sea and Aleutian Islands (52% in 2024). Therefore, it is unclear whether any future adjustments to the 3-year running average approach might be warranted, as actual mortality could still go up or down from the three year-average under current conditions. Recent actual non-directed discard mortality estimates in both IPHC Regulatory Areas 2A and 2B and in the Gulf of Alaska are similarly far below full regulatory limits (29% in 2024).

year-classes are insufficient to support short-term fishing mortality appreciably higher than the *status quo* without a decrease in spawning biomass. Risks are similar over the three-year projection period as both year-classes continue to mature.

Projections indicate that the spawning biomass would increase in the absence of any fishing mortality, with risks of stock decline over one and three years both less than 1/100 (Table 2, Figure 26). At the *status quo* coastwide TCEY (35.28 million pounds), risks of stock decrease over one and three years are 43/100 and 45/100 (Figure 27). For all harvest levels that exceed the three-year surplus (37.4 million pounds) risks of stock decline are larger than 50/100, and reaching 88/100 for the coastwide TCEY that is projected to correspond to the $F_{35\%}$ *MSY* proxy harvest level in 2025. Alternative harvest levels around the *status quo* (+/- 5 and 10%) are projected to result in levels of fishing intensity ranging from $F_{50\%}$ to $F_{44\%}$, similar to those estimated in recent years. For larger reductions to the status quo (-15% and -25%) risk of one year stock decrease drops to 26/100 and 16/100 respectively. The alternatives around the status quo span a range of stock trajectories from increasing (all alternatives up to the *status quo*) to decreasing (*status quo* +10%). At the reference level of fishing mortality ($F_{43\%}$) the 2025 coastwide TCEY is projected to be 39.8 million pounds (41.7 million pounds of total mortality including U26 non-directed discard mortality). Stock decline over the next three years is projected to be likely (57/100 to 58/100) at this level of fishing intensity. The probability of a reduction in the coastwide TCEY in order to maintain a fishing intensity no greater than $F_{43\%}$ over the next three years is projected to be 49/100. All projections result in a probability of the relative spawning biomass dropping below the $SB_{30\%}$ threshold over the next three years of 17-28/100. The probability of dropping below the $SB_{20\%}$ limit is estimated to be <1-21%.

RISKS NOT INCLUDED IN THE HARVEST DECISION TABLE

The IPHC's current management procedure uses threshold and limit reference points in relative spawning biomass (current estimate compared to the spawning biomass estimated to have occurred in that year in the absence of any fishing mortality). This calculation measures the effects of fishing on the stock. Other factors affecting the spawning biomass (i.e., trends in recruitment and weight-at-age) have resulted in the absolute spawning biomass in 2022-2024 estimated to be lower than at any time in the last 34 years. Although this does not represent a conservation concern at this time, low stock size results in additional risks to the IPHC's Fishery Independent Setline Survey (FISS) design objective of revenue neutrality and to fishery efficiency and economic viability. Further, the modelled FISS index in 2024 extends the 20-year trend in the stock distribution shifting from Biological Region 3 toward Biological Region 2. Finally, increased environmental/climate-related variability in the marine ecosystems comprising the Pacific halibut species range in Convention waters lead to little expectation that historical productivity patterns may be relevant for future planning. Specifically, it is unclear whether long-term productivity levels are likely to occur under continued climate change, or whether increases or decreases may be likely for critical life-history stages of Pacific halibut. Recent poor recruitment (2006+) seems to suggest that the stock is in a state of low productivity with no indication of when this prevailing condition may change. Finally, the extremely important role of the directed commercial fishery data in informing reductions in the estimated scale of recent biomass in the stock assessment is a new phenomenon observed only in the last two stock assessments. To the degree that the FISS designs have been limited in those years there is an ongoing uncertainty about why these two time-series are providing different or lagged signals.

An alternative projection was conducted, using 2024 commercial fishery catch rates corrected for the magnitude of changes observed in the 2023 data after additional logs had been collected through 2024. This projection used the status quo mortality for 2025 and resulted in an estimated SPR of 46%, compared to the value of 47% using preliminary commercial fishery data available through October 2024. Based on this result, if commercial data updates in 2025 are similar to those in recent years, it seems likely that the 2025 stock assessment may estimate a higher fishing intensity for a given management alternative than is reflected in the current decision table.

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 programs (IPHC-2025-AM101-06).

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 NOAA Fisheries, DFO, ADF&G, WDFW, ODFW, and CDFW for providing the annual information required for this assessment in a timely manner. The SRB and Science Advisors continue to provide valuable guidance and input during the development and review process.

TABLE 2. Harvest decision table for 2025-2027 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.

2025 Alternative					*Status quo -25%*	*Status quo -15%*	*Status quo -10%*	*Status quo -5%*	*Status quo*	$F_{46\%}$	3-Year Surplus	*Status quo +10%*	*Reference* $F_{43\%}$	*MEY proxy*	*MSY proxy*	
		Total mortality (M lb)	0.0	21.8	28.3	31.8	33.6	35.4	37.1	37.8	39.0	40.7	41.7	46.1	55.1	
		TCEY (M lb)	0.0	20.0	26.5	30.0	31.8	33.5	35.3	35.9	37.2	38.8	39.8	44.3	53.2	
		2025 fishing intensity	$F_{100\%}$	$F_{63\%}$	$F_{55\%}$	$F_{51\%}$	$F_{50\%}$	$F_{48\%}$	$F_{47\%}$	$F_{46\%}$	$F_{45\%}$	$F_{44\%}$	$F_{43\%}$	$F_{40\%}$	$F_{35\%}$	
		Fishing intensity interval	--	41-75%	33-69%	30-66%	28-65%	27-63%	26-62%	25-62%	25-61%	24-60%	23-59%	21-56%	17-51%	
Stock Trend (spawning biomass)	in 2026	is less than 2025	<1	5	16	26	31	37	43	45	49	54	57	70	88	a
		is 5% less than 2025	<1	<1	2	4	6	8	11	12	14	17	19	29	50	b
	in 2027	is less than 2025	<1	7	21	30	35	40	45	47	50	55	58	69	86	c
		is 5% less than 2025	<1	2	8	14	18	22	26	27	30	34	37	48	70	d
	in 2028	is less than 2025	<1	8	20	30	35	40	45	47	50	55	58	70	87	e
		is 5% less than 2025	<1	3	11	18	22	26	30	32	36	40	43	55	77	f
Stock Status (Spawning biomass)	in 2026	is less than 30%	26	26	27	27	27	27	27	27	28	28	28	28	29	g
		is less than 20%	1	5	7	8	9	10	10	11	11	12	12	14	18	h
	in 2027	is less than 30%	25	25	26	26	26	26	26	26	26	26	26	27	28	i
		is less than 20%	<1	2	4	6	7	8	9	9	10	11	12	15	20	j
	in 2028	is less than 30%	17	25	25	25	25	26	26	26	26	26	26	27	28	k
		is less than 20%	<1	1	3	5	6	7	8	9	10	11	12	16	21	l
Fishery Trend (TCEY)	in 2026	is less than 2025	0	7	24	28	31	34	38	39	42	46	49	60	80	m
		is 10% less than 2025	0	4	22	26	27	29	32	33	35	38	39	48	67	n
	in 2027	is less than 2025	0	6	23	27	30	33	37	38	41	46	48	60	81	o
		is 10% less than 2025	0	4	20	25	27	29	31	32	34	37	39	49	69	p
	in 2028	is less than 2025	0	5	21	26	29	33	37	38	41	46	49	61	82	q
		is 10% less than 2025	0	3	18	23	26	28	31	32	34	37	40	50	71	r
Fishery Status (Fishing intensity)	in 2025	is above $F_{43\%}$	0	7	25	29	32	35	39	41	44	47	50	59	78	s

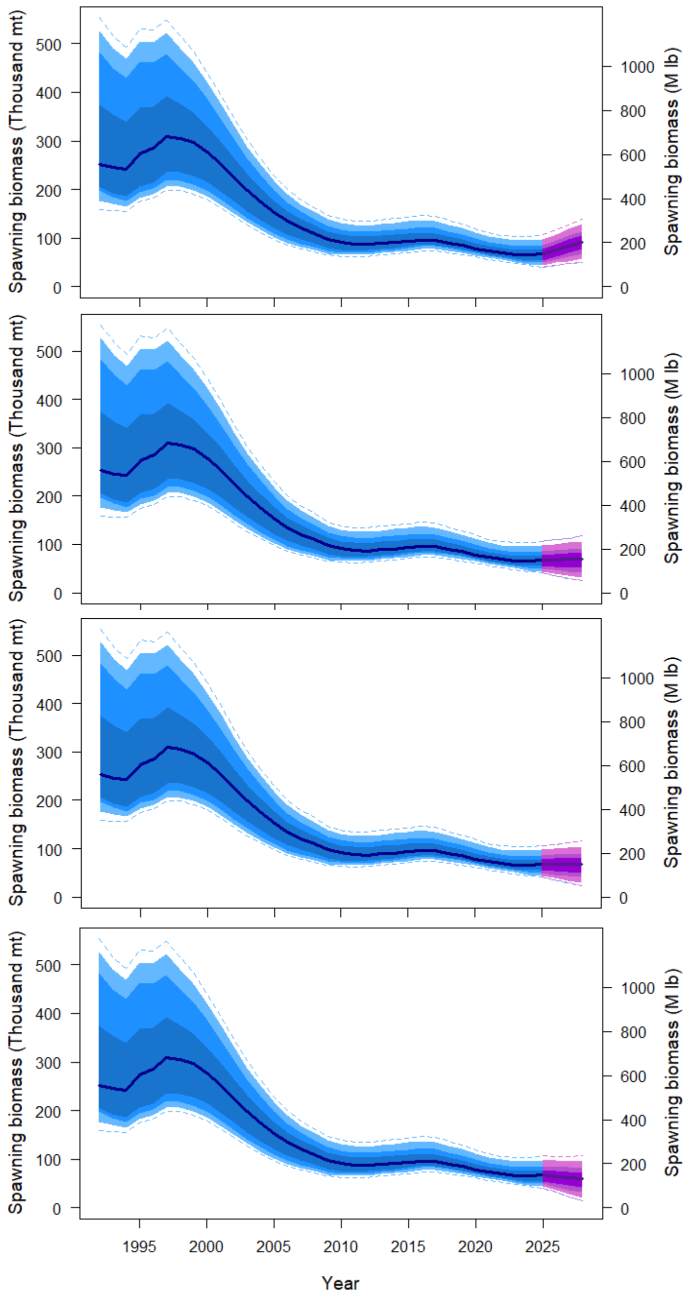

FIGURE 26. Three-year projections of stock trend under alternative levels of mortality corresponding to various reference points: no fishing mortality (upper panel), the 3-year surplus (37.2 million pounds; second panel), and the TCEY projected for the $F_{43\%}$ reference level of fishing intensity (39.8 million pounds, third panel) and the TCEY projected for the $F_{35\%}$ MSY proxy level of fishing intensity (53.2 million pounds, bottom panel).

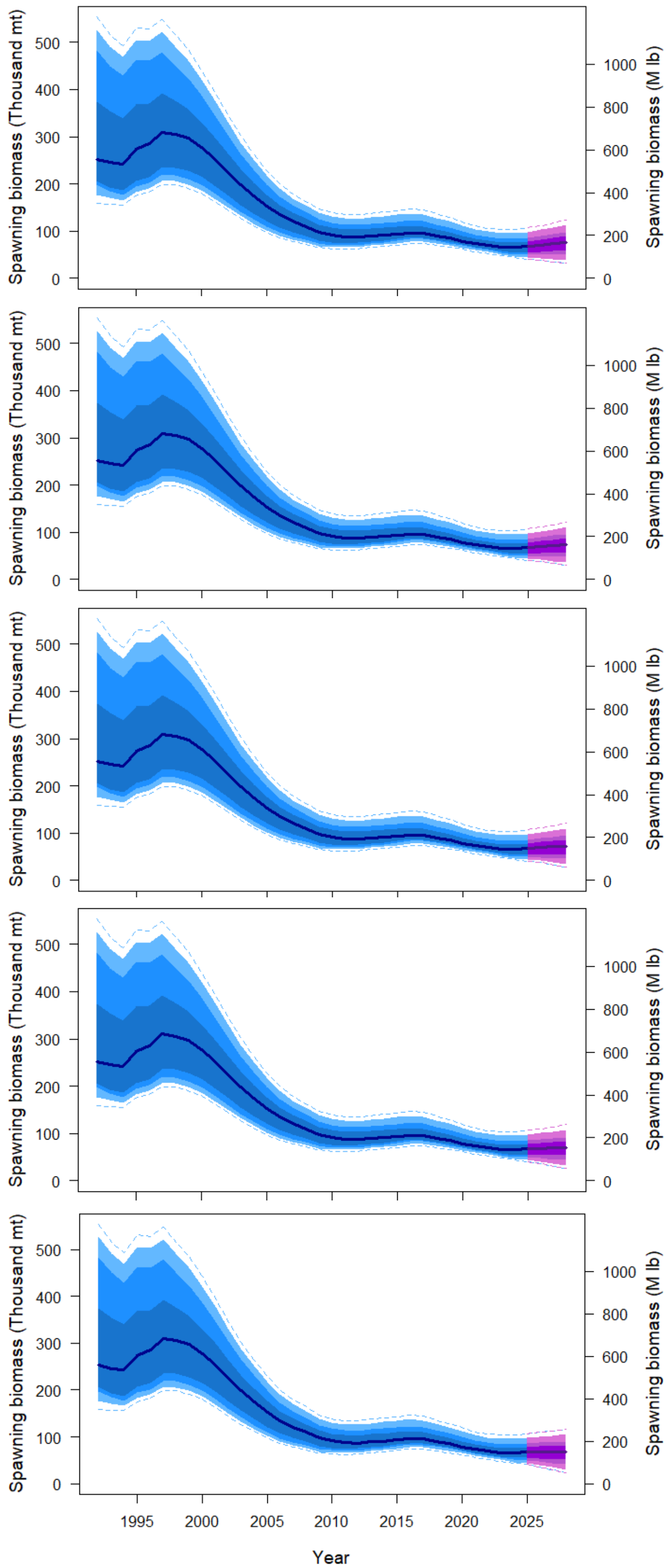

FIGURE 27. Three-year projections of stock trend under alternative levels of mortality corresponding around the *status quo* coastwide TCEY from 2024: the *status quo* coastwide TCEY -25% (26.5 million pounds; upper panel), the *status quo* coastwide TCEY -15% (30.0 million pounds; second panel), the *status quo* coastwide TCEY -10% (31.8 million pounds; third panel), the *status quo* coastwide TCEY set in 2024 (35.28 million pounds; fourth panel) and the *status quo* coastwide TCEY +10% (38.8 million pounds; bottom panel).

References

Clark, W.G. 2003. A model for the world: 80 years of model development and application at the international Pacific halibut commission. Natural Resource Modeling **16**(4): 491-503.

Clark, W.G., and Hare, S.R. 2006. Assessment and management of Pacific halibut: data, methods, and policy. International Pacific Halibut Commission Scientific Report No. 83, Seattle, Washington. 104 p.

Clark, W.G., Hare, S.R., Parma, A.M., Sullivan, P.J., and Trumble, R.J. 1999. Decadal changes in growth and recruitment of Pacific halibut (*Hippoglossus stenolepis*). Canadian Journal of Fisheries and Aquatic Sciences **56**: 242-252.

IPHC. 2017. Report of the 11th sesion of the IPHC scientific review board (SRB11). Seattle, WA. IPHC-2017-SRB11-R. 18 p.

IPHC. 2020. Report of the 96th Session of the IPHC Annual Meeting (AM096). Anchorage, Alaska, USA, 3-7 February 2020. IPHC-2020-AM096-R. 51 p.

IPHC. 2024. Report of the 100th session of the IPHC Interim Meeting (IM100). Electronic meeting, 25-26 November 2024. IPHC-2024-IM100-R. 28 p.

Litzow, M.A., Hunsicker, M.E., Bond, N.A., Burke, B.J., Cunningham, C.J., Gosselin, J.L., Norton, E.L., Ward, E.J., and Zador, S.G. 2020. The changing physical and ecological meanings of North Pacific Ocean climate indices. Proceedings of the National Academy of Sciences of the United States of America **117**(14): 7665-7671. doi:10.1073/pnas.1921266117.

Mantua, N.J., Hare, S.R., Zhang, Y., Wallace, J.R., and Francis, R.C. 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. Bulletin of the American Meteorological Society **78**(6): 1069-1079.

Methot, R.D., and Wetzel, C.R. 2013. Stock synthesis: A biological and statistical framework for fish stock assessment and fishery management. Fisheries Research **142**: 86-99. doi:http://dx.doi.org/10.1016/j.fishres.2012.10.012.

Methot, R.D., Wetzel, C.R., Taylor, I.G., Doering, K.L., Perl, E.F., and Johnson, K.F. 2024. Stock Synthesis user manual version 3.30.22.1. NOAA Fisheries, Seattle, Washington. January 31, 2024. 256 p.

Planas, J. 2022. IPHC 5-year biological and ecosystem science research plan: update. IPHC-2022-AM098-11. 13 p.

Stewart, I., and Hicks, A. 2019. 2019 Pacific halibut (*Hippoglossus stenolepis*) stock assessment: development. IPHC-2019-SRB014-07. 100 p.

Stewart, I., and Hicks, A. 2020. Assessment of the Pacific halibut (*Hippoglossus stenolepis*) stock at the end of 2019. IPHC-2020-SA-01. 32 p.

Stewart, I., and Hicks, A. 2022. Development of the 2022 Pacific halibut (*Hippoglossus stenolepis*) stock assessment. IPHC-2022-SRB020-07. 128 p.

Stewart, I., and Webster, R. 2023. Overview of data sources for the Pacific halibut stock assessment, harvest policy, and related analyses. IPHC-2023-SA-02. 59 p.

Stewart, I., and Hicks, A. 2023. Assessment of the Pacific halibut (*Hippoglossus stenolepis*) stock at the end of 2022. IPHC-2023-SA-01. 37 p.

Stewart, I., Hicks, A., Webster, R., and Wilson, D. 2023. Summary of the data, stock assessment, and harvest decision table for Pacific halibut (*Hippoglossus stenolepis*) at the end of 2022. IPHC-2023-AM099-11. 21 p.

Stewart, I.J., and Martell, S.J.D. 2014. A historical review of selectivity approaches and retrospective patterns in the Pacific halibut stock assessment. Fisheries Research **158**: 40-49. doi:10.1016/j.fishres.2013.09.012.

Stewart, I.J., and Martell, S.J.D. 2015. Reconciling stock assessment paradigms to better inform fisheries management. ICES Journal of Marine Science **72**(8): 2187-2196. doi:10.1093/icesjms/fsv061.

Stewart, I.J., and Martell, S.J.D. 2016. Appendix: Development of the 2015 stock assessment. IPHC Report of Assessment and Research Activities 2015. p. A1-A146.

Stewart, I.J., and Hicks, A.C. 2018. Interannual stability from ensemble modelling. Canadian Journal of Fisheries and Aquatic Sciences **75**: 2109-2113. doi:10.1139/cjfas-2018-0238.

Stewart, I.J., Monnahan, C.C., and Martell, S. 2016. Assessment of the Pacific halibut stock at the end of 2015. IPHC Report of Assessment and Research Activities 2015. p. 188-209.

Stewart, I.J., Martell, S., Webster, R.A., Forrest, R., Ianelli, J., and Leaman, B.M. 2013. Assessment review team meeting, October 24-26, 2012. IPHC Report of Assessment and Research Activities 2012. p. 239-266.

Ualesi, K. 2023. IPHC Fishery-independent-setline-survey (FISS) design and implementation in 2022. IPHC-2023-AM099-08.

Waterhouse, L., Sampson, D.B., Maunder, M., and Semmens, B.X. 2014. Using areas-as-fleets selectivity to model spatial fishing: Asymptotic curves are unlikely under equilibrium conditions. Fisheries Research **158**: 15-25. doi:10.1016/j.fishres.2014.01.009.

Webster, R. 2023. Space-time modelling of survey data. IPHC-2023-AM099-09. 6 p.