Summary of the data, stock assessment, and harvest decision table for Pacific halibut (*Hippoglossus stenolepis*) at the end of 2022

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PURPOSE

To provide the Commission with a summary of the data, stock assessment, and harvest decision table at the end of 2022.

INTRODUCTION

In 2022 the International Pacific Halibut Commission (IPHC) undertook its annual coastwide stock assessment of Pacific halibut (*Hippoglossus stenolepis*). This assessment represents a full analysis, following the previous full assessment conducted in 2019, updated in 2020 and again in 2021. Changes from the 2021 assessment were developed and reviewed by the IPHC's Scientific Review Board (SRB), in June (SRB020; IPHC-2022-SRB020-07, IPHC-2022-SRB020-R) and September 2022 (SRB021; IPHC-2022-SRB021-08, IPHC-2022-SRB021-R). Changes to the modelling that were included in the stock assessment and new data for 2022 include:

1. Update the version of the stock synthesis software used for the analysis (3.30.19).
2. Expand the treatment of natural mortality (*M*) to include an informative prior based on longevity and assign increased values at the youngest ages based on meta-analysis of other flatfish species.
3. Improve the basis for data weighting via use of bootstrapped effective sample sizes as model inputs based on the FISS and fishery sampling programs, rather than the raw number of sets/trips used in previous assessments.
4. Estimate *M* in the short time-series Areas-As-Fleets (AAF) model.
5. Include standard updates to mortality estimates from all fisheries, directed commercial fishery and FISS (fishery-independent setline survey) biological and trend information, and other sources including data collected in 2022.

This document provides an overview of the data sources available for the 2022 Pacific halibut stock assessment including the population trends and distribution among IPHC Regulatory Areas based on the modelled IPHC fishery-independent setline survey (FISS), directed commercial fishery data, and results of the stock assessment.

Overall, spawning biomass estimates remain highly consistent with those of recent stock assessments. However, the higher estimated value of natural mortality in the AAF short model when included with the other four models (two of which already estimated natural mortality) strongly affected the ensemble stock assessment estimates of recent and historical fishing intensity. **The 2022 stock assessment estimates a lower level of fishing intensity and higher relative stock status compared to previous assessments, as well as a 26% increase in the yield corresponding to the reference level of fishing intensity ($F_{43\%}$) for 2023 compared to 2022**. Spawning biomass trends appear to have stabilized, as fish from the 2012 year-class, critically important to short-term projections of stock and fishery dynamics, continue to mature.

STOCK AND MANAGEMENT

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).

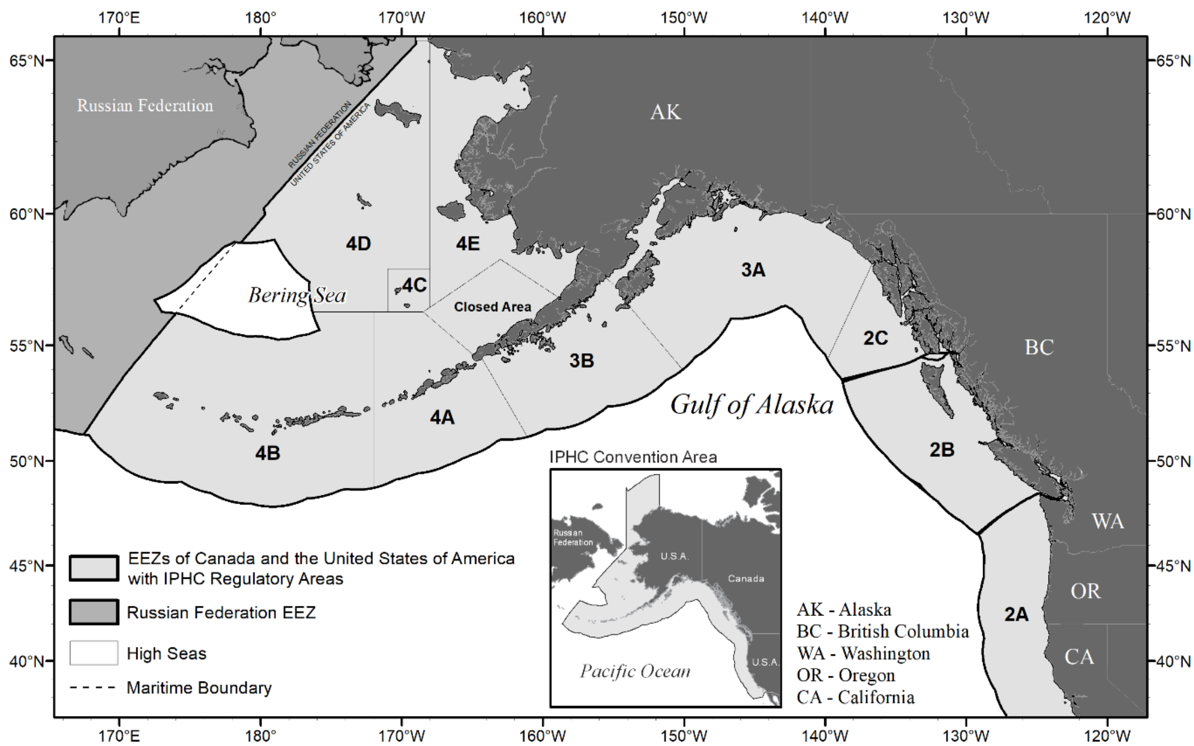

FIGURE 1. IPHC Convention Area (inset) and IPHC Regulatory Areas.

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 summary of recently collected data, and model estimates of stock size and trend. Specific management information is summarized via a decision table reporting the estimated short-term 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 provided in early January 2022 for use during the IPHC's 99th Annual Meeting (AM099).

DATA

Historical mortality

Known Pacific halibut mortality consists of directed commercial fishery landings and discard mortality (including research), recreational fisheries, subsistence, and discard mortality in fisheries targeting other species ('non-directed' fisheries where Pacific halibut retention is prohibited). Over the period 1888-2022, mortality from all sources has totaled 7.3 billion pounds (~3.3 million metric tons, t). Since 1923, the fishery has ranged annually from 34 to 100 million

[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.

pounds (15,000-45,000 t) with an annual average of 63 million pounds (~29,000 t; Figure 2). Annual mortality was above this 100-year average from 1985 through 2010 and has averaged 38.1 million pounds (~17,300 t) from 2018-22.

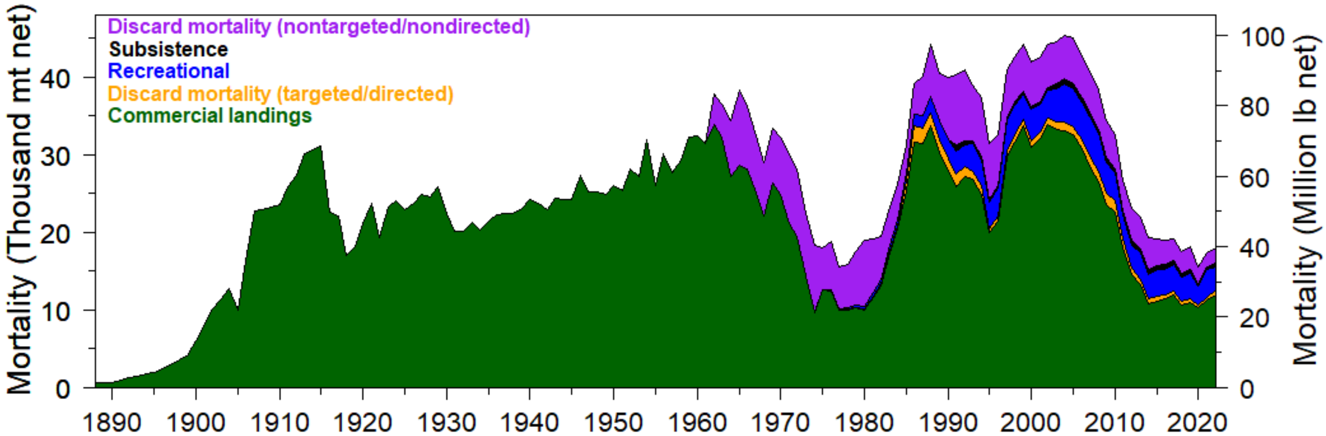

FIGURE 2. Summary of estimated historical mortality by source (colors), 1888-2022.

2022 Fishery and IPHC FISS statistics

Data for stock assessment use are compiled by IPHC Regulatory Area, and then aggregated to four Biological Regions: Region 2 (Areas 2A, 2B, and 2C), Region 3 (Areas 3A, 3B), Region 4 (4A, 4CDE) and Region 4B and then coastwide (Figure 1). The assessment data from both fishery-dependent and fishery-independent sources, as well as auxiliary biological information, are most spatially complete since the late-1990s. Primary sources of information for this assessment include mortality estimates from all sources (IPHC-2022-IM098-07 Rev_1), modelled indices of abundance (IPHC-2022-IM098-08) based on the IPHC's FISS (in numbers and weight) and other surveys, commercial Catch-Per-Unit-Effort (in weight), and biological summaries from both sources (length-, weight-, and age-composition data).

All data sources are reprocessed each year to include new information from the terminal year, as well as any additional information for or changes made to the entire time-series. For 2022, the most important information came from the modelled index of abundance reflecting the 2022 FISS and associated biological sampling. Routine updates of logbook records from the 2022 (and earlier) directed commercial fishery, as well as age-frequency observations and individual weights from the commercial fishery were also included. Directed commercial fishery sex-ratios at age were available for 2021 (building on the time-series from 2017-2020 previously available). All mortality estimates (including changes to the existing time-series where new estimates have become available) were extended to include 2022. All available information was finalized on 1 November 2022 in order to provide adequate time for analysis and modeling. As has been the case in all years, some data are incomplete (commercial fishery logbook and age information), or include projections for the remainder of the year (mortality estimates for ongoing fisheries or for fisheries where final estimation is still pending).

Coastwide commercial Pacific halibut fishery landings (including research landings) in 2022 were approximately 26.1 million pounds (~11,900 t), up 6% from 2021[2]. Discard mortality in non-

[2] The mortality estimates reported in this document are those available on 1 November 2021 and used in the assessment analysis; they include projections through the end of the fishing season.

directed fisheries was estimated to be 4.5 million pounds in 2022 (~2,000 t)[3], up 17% from 2021 which was the lowest estimate in the time-series. The total recreational mortality (including estimates of discard mortality) was estimated to be 6.6 million pounds (~3,000 t) down 14% from 2021. Mortality from all sources increased by 4% to an estimated 39.7 million pounds (~18,000 t) in 2022 based on preliminary information available for this assessment.

The 2022 modelled FISS results detailed a coastwide aggregate NPUE (numbers per unit effort) which decreased by 8% from 2021 to 2022, back to levels similar to those observed in 2018-2020 (Figure 3). Biological Region 3 decreased by 12%, while Biological Region 2 increased by 1%. Biological Regions 4, and 4B both showed small declines (2 and 6%) and are at the lowest values in the estimated time-series. The 2022 modelled coastwide WPUE of legal (O32) Pacific halibut, the most comparable metric to observed commercial fishery catch rates, decreased by 18% from 2021 to 2022. This reduced trend relative to that for NPUE indicates younger fish are contributing increasingly more to current stock productivity than somatic growth of fish already over the legal minimum size limit (particularly the 2012 year-class). Individual IPHC Regulatory Areas varied from a 10% increase (Regulatory Area 2A) to a 37% decrease (Regulatory Area 3A) in O32 WPUE (Figure 4).

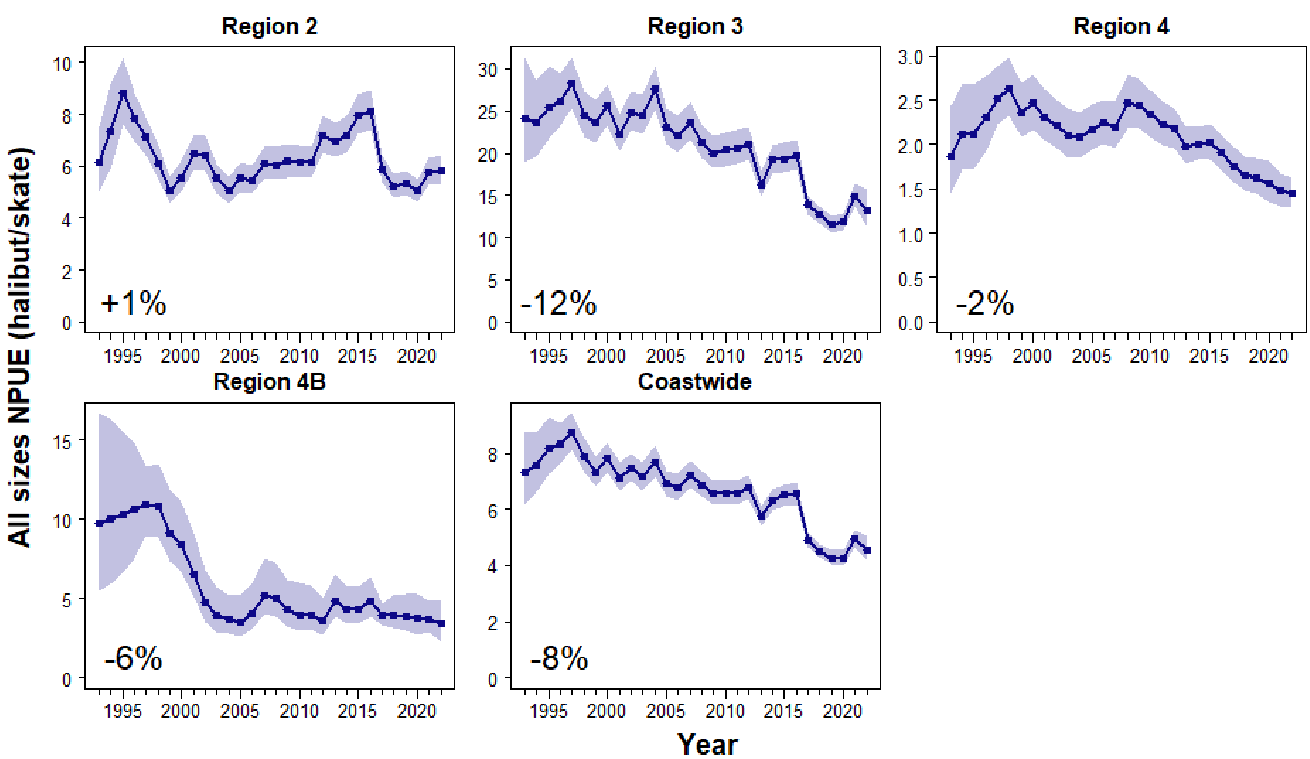

FIGURE 3. Trends in modelled FISS NPUE by Biological Region, 1993-2022. Percentages indicate the change from 2021 to 2022. Shaded zones indicate 95% credible intervals.

Preliminary commercial fishery WPUE estimates from 2022 logbooks showed a similar trend to the FISS index, decreasing by 15% at the coastwide level (Figure 5). The bias correction to

[3] The IPHC receives preliminary estimates of the current year's non-directed commercial discard mortality in from the NOAA-Fisheries National Marine Fisheries Service Alaska Regional Office, Northwest Fisheries Science Center, and Fisheries and Oceans Canada in late October. Where necessary, projections are added to approximate the total mortality through the end of the calendar year. Further updates are anticipated in January 2023 and will be incorporated into final projections for 2023.

account for additional logbooks compiled after the fishing season resulted in an estimate of −18% coastwide. Trends varied among IPHC Regulatory Areas and gears; however, all areas except 2A showed decreased CPUE in one or both gear types.

Biological information (ages and lengths) from the commercial fishery landings showed that in 2022 the fishery transitioned from the 2005 year-class to the 2012 year-class (now 10 years old) as the largest coastwide contributor (in number) to the fish encountered. The FISS also observed the 2012 year-class at the largest proportion in the total catch of any age class. Continued observation of these fish both above and below the commercial fishery minimum size limit indicates their importance to the current stock and to future fisheries. Individual size-at-age appears to be increasing for younger ages (<=14) in most IPHC Regulatory Areas and coastwide. Although size-at-age changes slowly, if the current pattern persists into older ages, it could have positive implications for overall future yield.

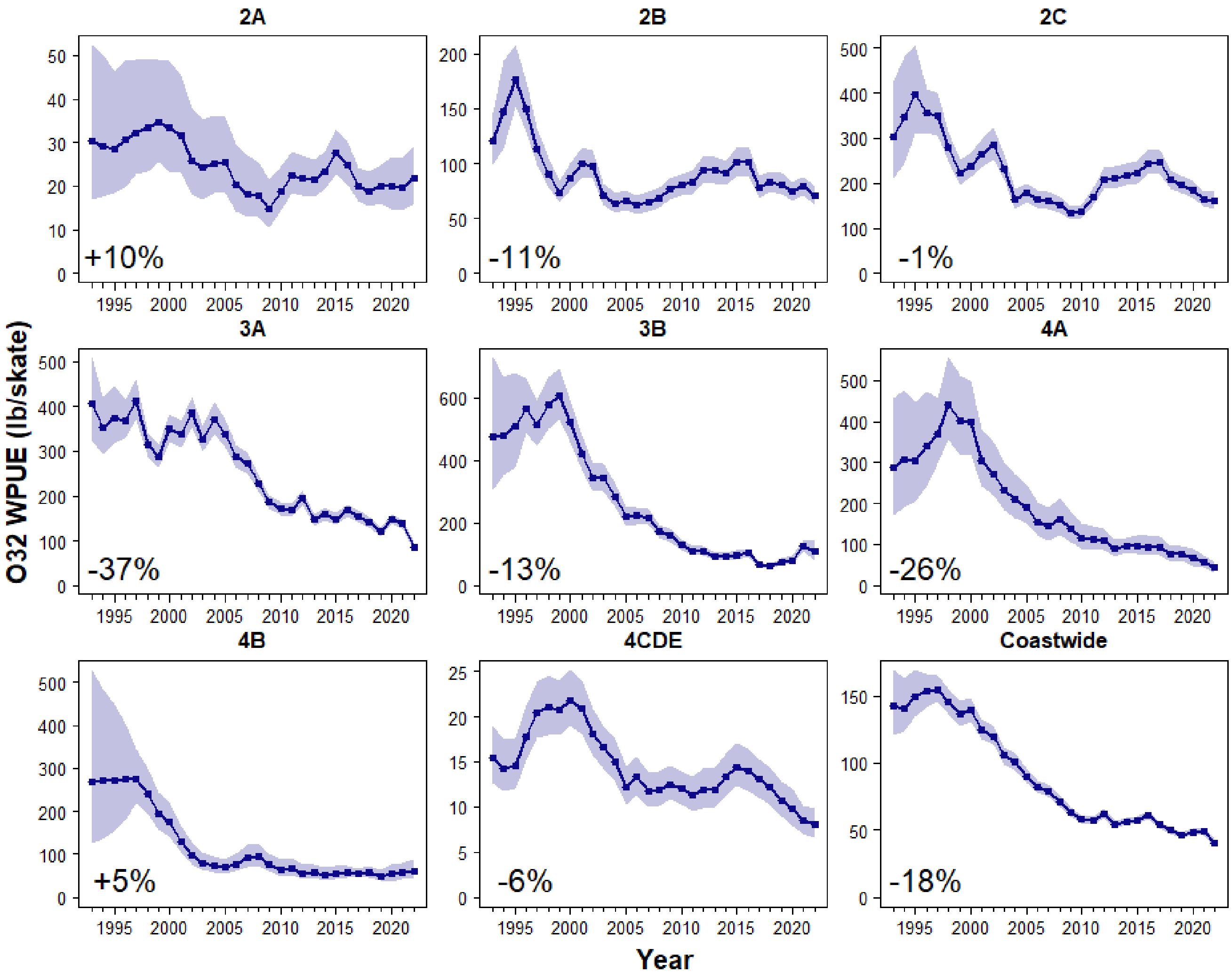

FIGURE 4. Trends in modelled FISS legal (O32) WPUE by IPHC Regulatory Area, 1993-2022. Percentages indicate the change from 2021 to 2022. Shaded zones indicate 95% credible intervals.

Biological stock distribution

The current trend in population distribution (measured via the modelled FISS catch in weight of all Pacific halibut) showed a sharp drop in Biological Region 3 after increases in 2020 and 2021. This corresponds to an increase in all other Biological Regions (Figure 6; recent years in Table 1). Survey data are insufficient to estimate stock distribution prior to 1993. It is therefore unknown how historical distributions or the average distribution in the absence of fishing mortality may compare with recent observations.

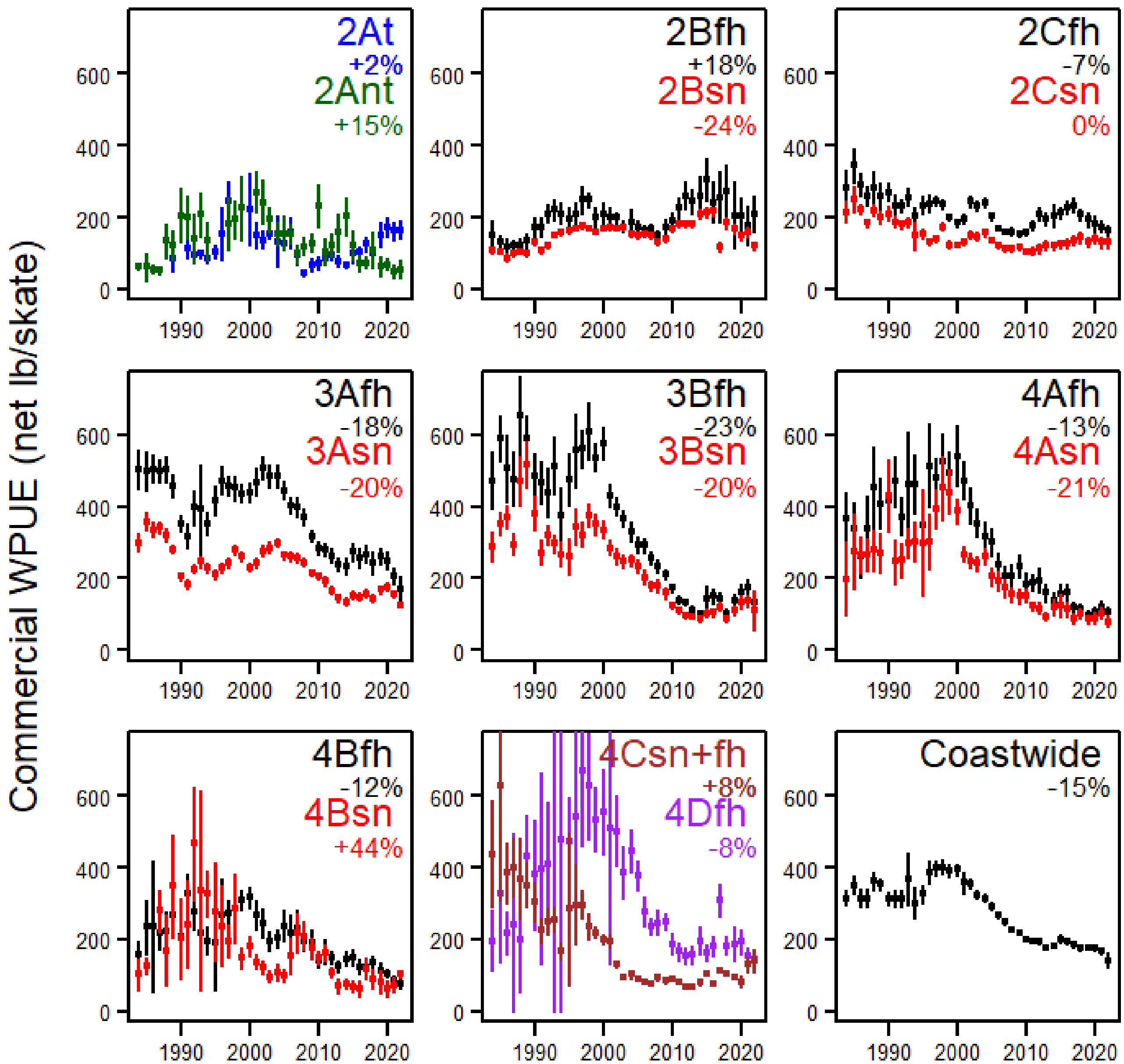

FIGURE 5. Trends in commercial fishery WPUE by IPHC Regulatory Area and fishery or gear, 1984-2022. The tribal fishery in 2A is denoted by “2At”, non-tribal by “2Ant”, fixed hook catch rates by “fh” and snap gear catch rates by “sn” for IPHC Regulatory Areas 2B-4D. Percentages indicate the change from 2020 to 2021 uncorrected for bias due to incomplete logbooks (see text above). Vertical lines indicate approximate 95% confidence intervals.

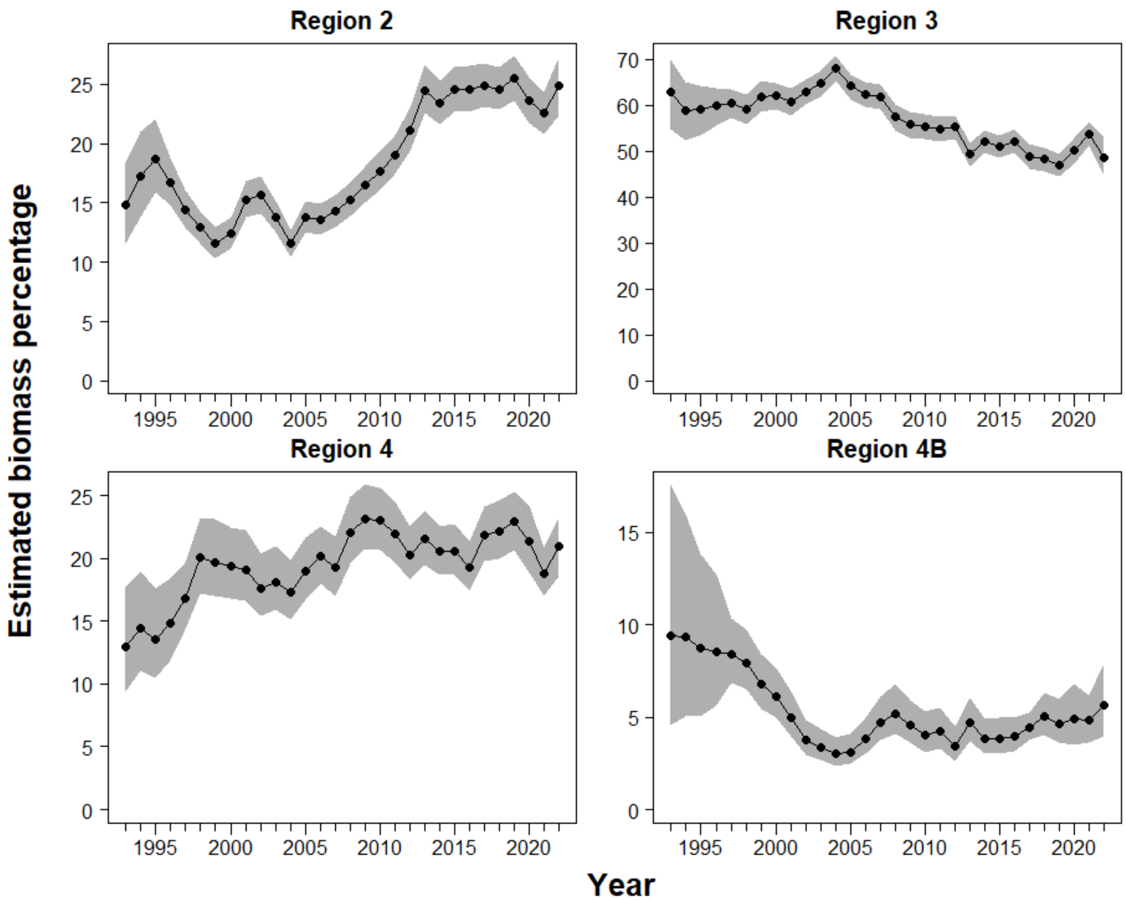

FIGURE 6. Estimated stock distribution (1993-2022) based on modelled survey catch weight per unit effort of all sizes of Pacific halibut. Shaded zones indicate 95% credible intervals.

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

Year	Region 2 (2A, 2B, 2C)	Region 3 (3A, 3B)	Region 4 (4A, 4CDE)	Region 4B
2018	24.6%	48.3%	22.1%	5.1%
2019	25.5%	46.9%	22.9%	4.7%
2020	23.6%	50.1%	21.4%	4.9%
2021	22.6%	53.8%	18.8%	4.8%
2022	24.8%	48.6%	20.9%	5.6%

STOCK ASSESSMENT

This stock assessment continues to be implemented using the generalized software stock synthesis (Methot and Wetzel 2013). The analysis consists of an ensemble of four equally weighted models: two long time-series models, reconstructing historical dynamics back to the beginning of the modern fishery, and two short time-series models incorporating data only from 1992 to the present, a time-period for which estimates of all sources of mortality and survey indices for all regions are available. For each time-series length, there are two models: one fitting to coastwide aggregate data, and one fitting to data disaggregated into the four Biological

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 three of the four models), environmental effects on recruitment (estimated in the long time-series models), and other model parameters.

The results of this stock assessment are based on the approximate probability distributions derived from the ensemble of models, thereby incorporating the uncertainty within each model (parameter or estimation uncertainty) as well as the uncertainty among models (structural uncertainty). This uncertainty provides a basis for risk assessment and reduces the potential for abrupt changes in management quantities as improvements and additional data are added to individual models. The four models continue to be equally weighted. Within-model uncertainty was propagated through to the ensemble results via the maximum likelihood estimates and an asymptotic approximation to individual model variance estimates. 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.

The 2019 stock assessment was a full analysis, including a complete re-evaluation of all data sources and modelling choices, particularly those needed to accommodate the newly available sex-ratio at age data from the commercial fishery. The 2020 and 2021 stock assessments represented updates, adding data sources where available, but retaining the same basic model structure for each of the four component models. The 2022 assessment was another full assessment; all changes from the 2021 assessment were developed and reviewed by the IPHC's Scientific Review Board (SRB), in June (SRB020; IPHC-2022-SRB020-07, IPHC-2022-SRB020-R) and September 2022 (SRB021; IPHC-2022-SRB021-08, IPHC-2022-SRB021-R).

The most important change in the 2022 assessment was the estimation of natural mortality (*M*) in the short AAF model. Natural mortality has been a primary source of uncertainty in the Pacific halibut stock assessment (and in most fisheries analyses) for decades. Prior to 1998, the Pacific halibut stock assessment used a value of 0.20. This was changed to a value of 0.15 in 1998, based on concerns that the consequences of an inaccurate estimate were less serious if the value was underestimated (Clark 1999; Clark and Parma 1999). The value of 0.15 was used for female Pacific halibut for all analyses until 2012. In the 2012 assessment, alternate values of natural mortality were used to include a broader range of uncertainty in the harvest decision table (Stewart et al. 2013). In the 2013 assessment, a model (similar to the current coastwide long time-series model) was included that estimated a higher level of natural mortality directly from the data (Stewart and Martell 2014). For the 2014 stock assessment, four models were used, two of which estimated natural mortality (both at higher values) and two relied on the fixed value of 0.15 (Stewart and Martell 2015). This approach of four models, two estimating natural mortality and two using the fixed value of 0.15 continued through the 2021 assessment. With the additional years of data available and the directed commercial fishery sex-ratio time series reaching 4 years in length, for the 2022 stock assessment there was sufficient information to estimate natural mortality directly in the AAF short model, leading estimation in 3 of the 4 models contributing to the ensemble. Estimates for female Pacific halibut from these three models span values of 0.184 (AAF long), 0.213 (AAF short) and 0.215 (coastwide long); the coastwide short model retains the fixed value of 0.15. With equal weighting of the four models the median productivity estimates (e.g., yield at a given level of fishing intensity) are considerably higher than the 2021 and earlier assessment models, as reflected in the projections reported below.

BIOMASS AND RECRUITMENT TRENDS

The results of the 2022 stock assessment indicate that the Pacific halibut stock declined continuously from the late 1990s to around 2012 (Figure 7). That trend is estimated to have been largely a result of decreasing size-at-age, as well as somewhat weaker recruitment strengths than those observed during the 1980s. The spawning biomass (SB) is estimated to have increased gradually to 2016, and then decreased to an estimated 192 million pounds (~87,100 t) at the beginning of 2023, with an approximate 95% credible interval ranging from 122 to 272 million pounds (~55,400-123,200 t; Figure 8). The recent spawning biomass estimates from the 2022 stock assessment are very consistent with previous analyses, back to 2012 (Figure 9) and suggest that the trend is effectively flat after a slow decline since 2016.

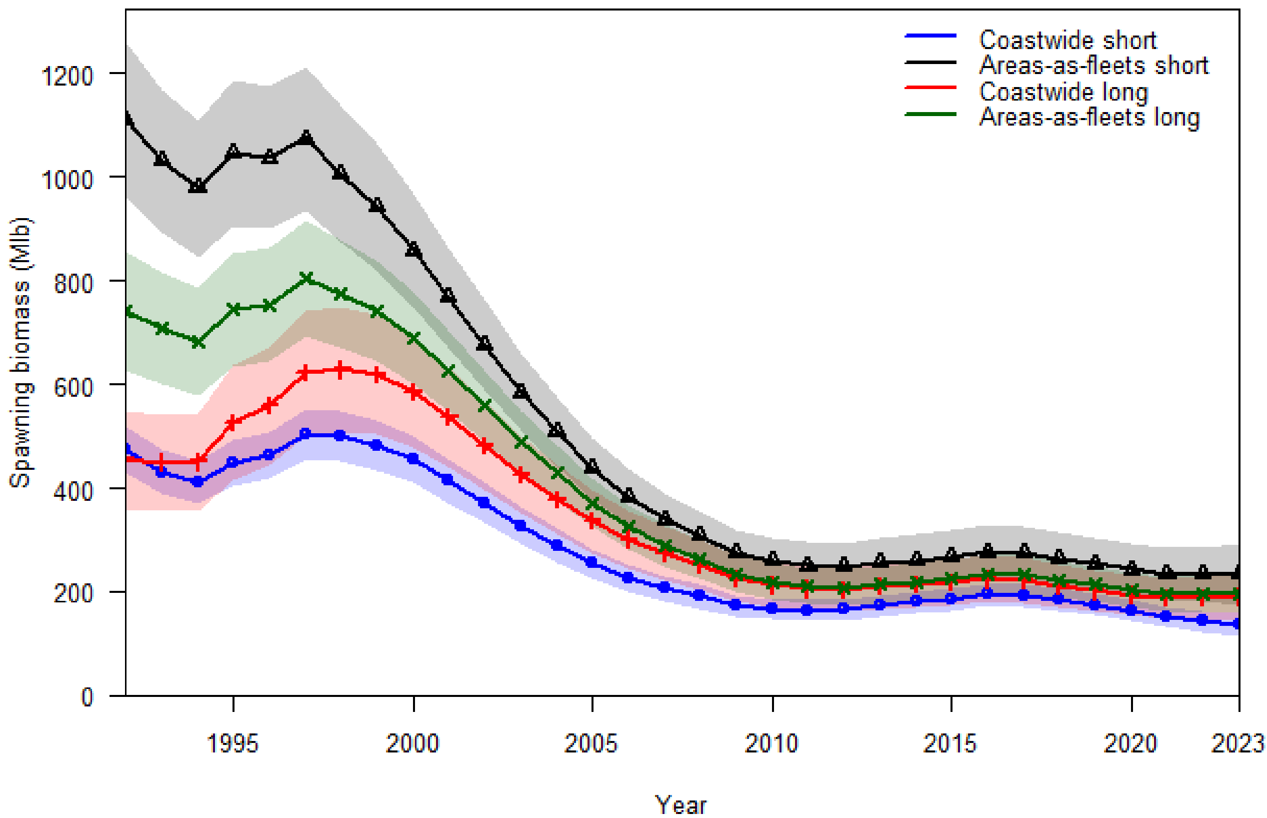

FIGURE 7. Estimated spawning biomass trends (1992-2023) based on the four individual models included in the 2022 stock assessment ensemble. Series indicate the maximum likelihood estimates; shaded intervals indicate approximate 95% credible intervals.

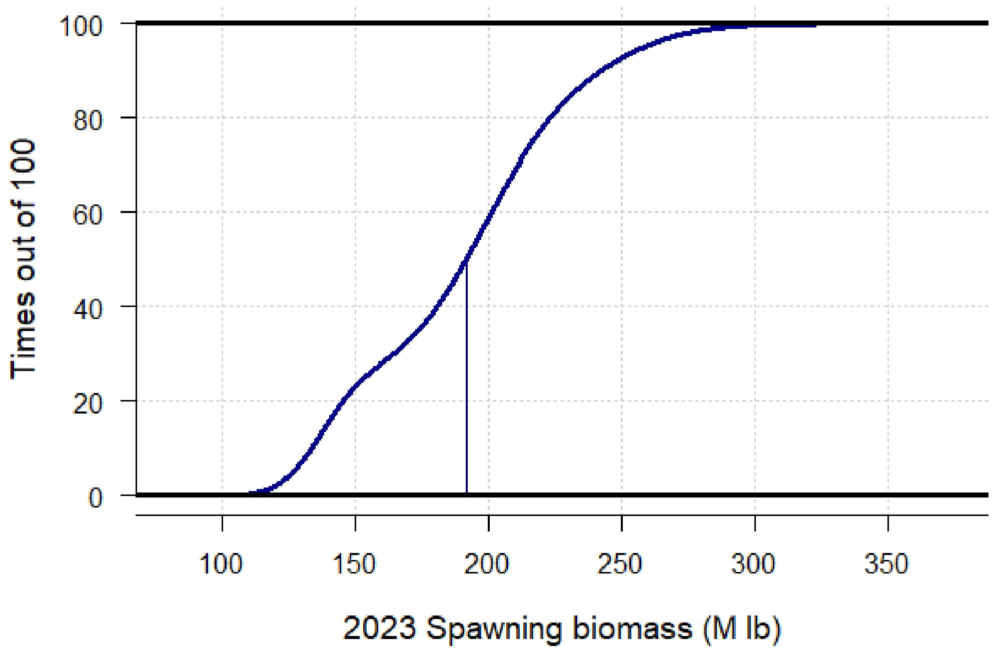

FIGURE 8. Cumulative distribution of the estimated spawning biomass at the beginning of 2023. Curve represents the estimated probability that the biomass is less than or equal to the value on the x-axis; vertical line represents the median (192 million pounds, ~87,100 t).

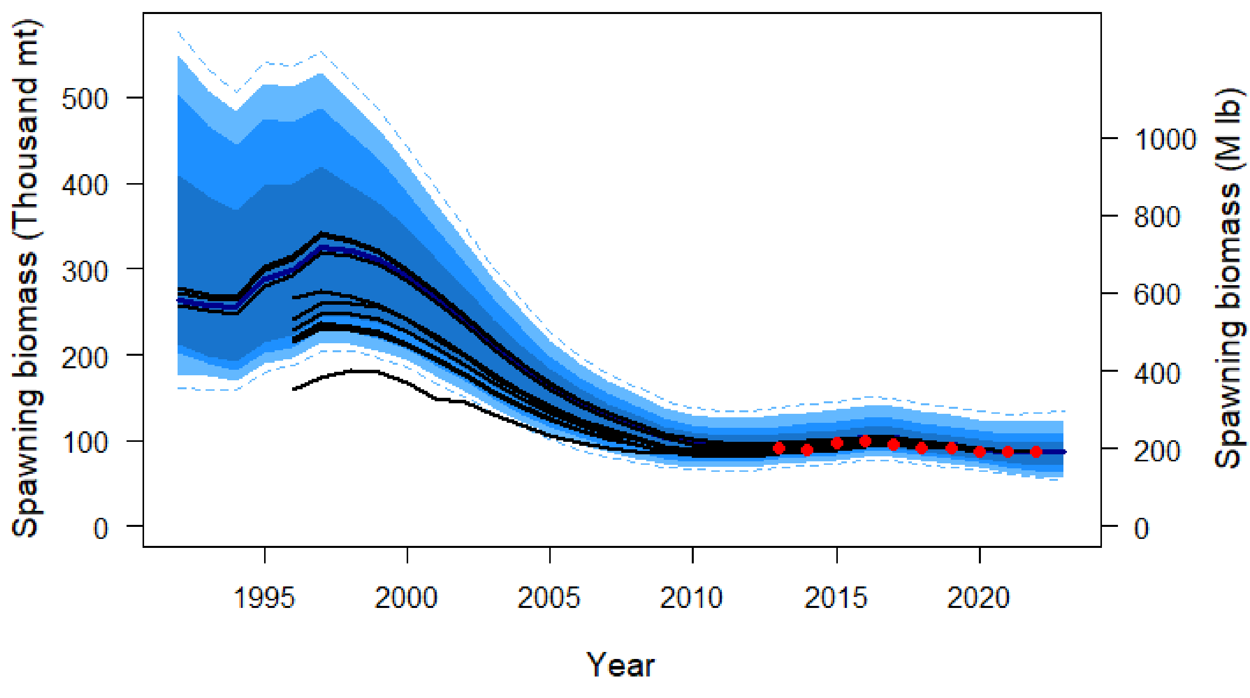

FIGURE 9. Retrospective comparison of female spawning biomass among recent IPHC stock assessments. Black lines indicate estimates from assessments conducted in 2012-2021 with the terminal estimate shown as a red point. The shaded distribution denotes the 2022 ensemble: the dark blue line indicates the 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.

In contrast to the close correspondence of the spawning biomass estimates between this assessment and previous analyses, the time-series of fishing intensity is estimated to be considerably lower than in past assessments (Figure 10). All but one of the recent assessments (2015) projected a fishing intensity for the pending adopted mortality limits higher than estimated in the 2022 assessment, with this change attributable to the transition from 2 to 3 models estimating higher natural mortality. The relative trend over the historical period does remain similar: much higher fishing intensity estimated for the early 2000s through about 2012.

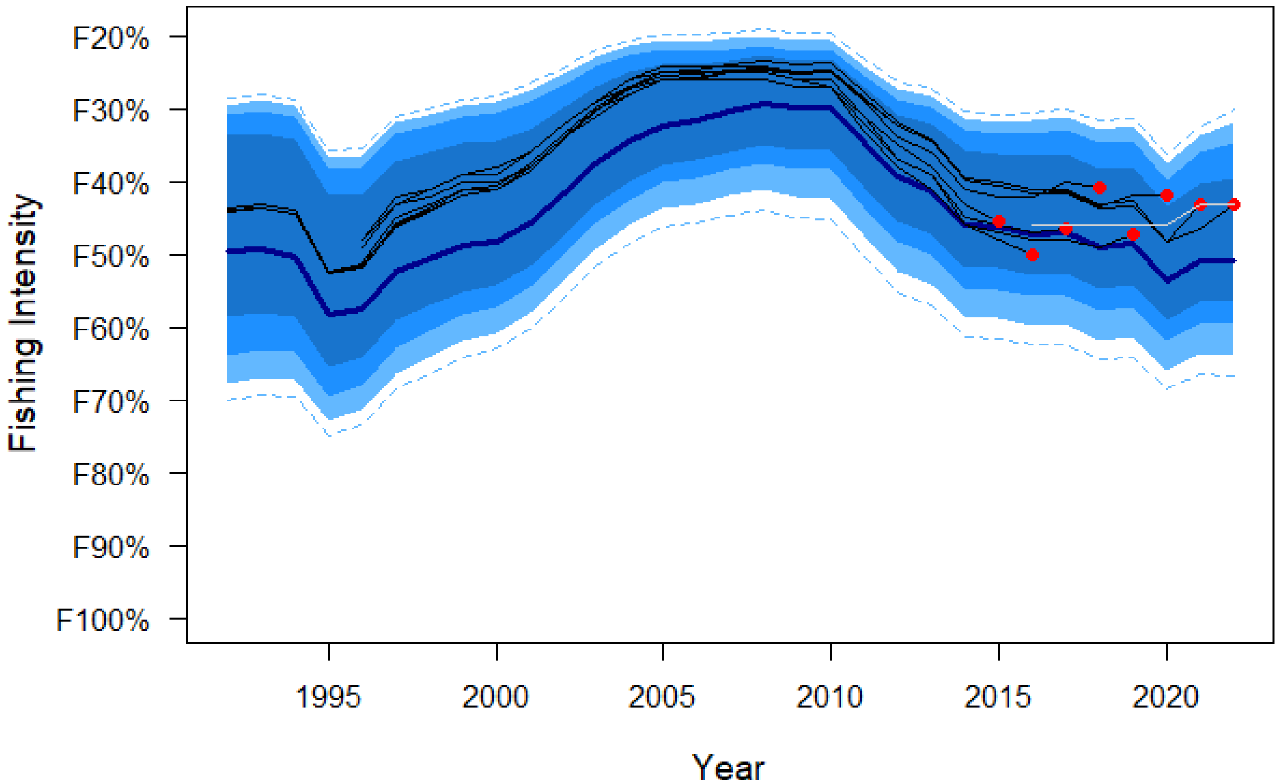

FIGURE 10. Retrospective comparison of fishing intensity (measured as $F_{xx\%}$, where xx% indicates the Spawning Potential Ratio (SPR) or the reduction in the lifetime reproductive output due to fishing) among recent IPHC stock assessments. Black lines indicate estimates of fishing intensity from assessments conducted in 2014-2021 with the projection for the mortality limit adopted based on that assessment shown as a red point. The shaded distribution denotes the 2022 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 grey 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 2021-2022).

Average Pacific halibut recruitment is estimated to be higher (71 and 72% for the coastwide and AAF models respectively) during favorable Pacific Decadal Oscillation (PDO) regimes, a widely recognized indicator of ecosystem productivity in the north Pacific (primarily the Gulf of Alaska). 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 and 2021 (through September) showing negative average conditions. Although strongly correlated with historical recruitments, it is unclear whether recent conditions are comparable to those observed in previous decades.

Pacific halibut recruitment estimates show the recent large cohorts in 1999 and 2005 (Figure 11). Cohorts from 2006 through 2011 are estimated to be much smaller than those from 1999-2005, which has resulted in a decline in both the stock and fishery yield as these low recruitments have moved into the spawning biomass. Based on age data through 2022, individual models in this assessment produced estimates of the 2012 year-classes that were slightly lower than the magnitude of the 2005 year-class. The 2012 year-class is estimated to be 29% mature in 2022 and the maturation of this cohort has a strong effect on the short-term projections.

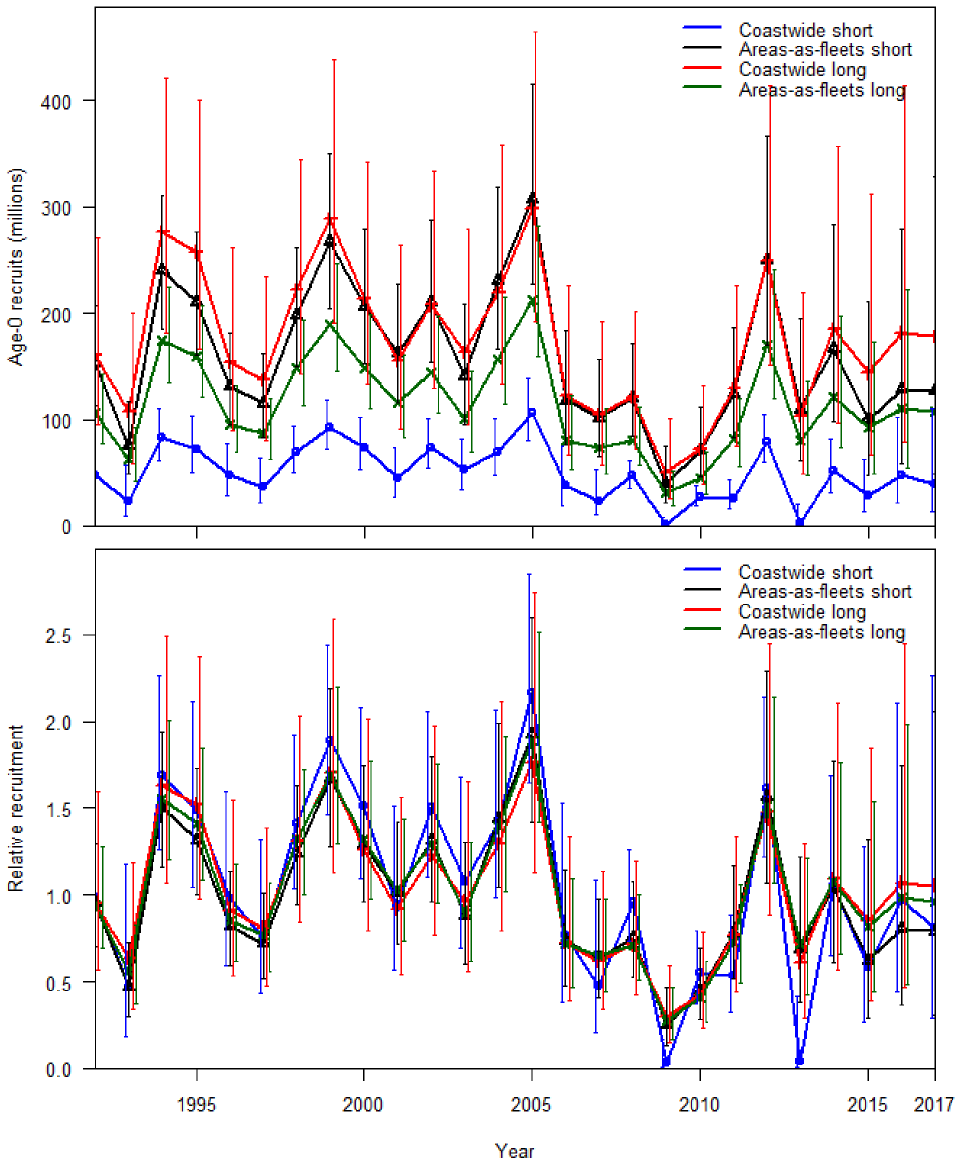

FIGURE 11. Estimated trends in age-0 recruitment (upper panel) and relative recruitment (standardized to the mean for each model over this time-period; lower panel) 1992-2017, based on the four individual models included in the 2022 stock assessment ensemble. Series indicate the maximum likelihood estimates; vertical lines indicate approximate 95% credible intervals.

The IPHC's interim management procedure uses a relative spawning biomass of 30% as a trigger, below which the reference fishing intensity is reduced. At a spawning biomass limit of 20%, directed fishing is halted due to the critically low biomass condition. This calculation is based on recent biological conditions: current weight-at-age and estimated recruitments still influencing the stock. Thus, the 'dynamic' calculation measures only the effect of fishing on the spawning biomass. The relative spawning biomass in 2023 was estimated to be 42% (credible interval: 21-55%) slightly higher than the estimate for 2022 (41%). Both of these estimates are much higher than those from the 2021 stock assessment (i.e., 2022 was estimated at 33%), with the change caused by the higher estimate of natural mortality in the current analysis. The probability that the stock is below the $SB_{30\%}$ level is estimated to be 25% at the beginning of 2023, with less than a 1% chance that the stock is below $SB_{20\%}$. 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 (44%), and the coastwide model above (172%). 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 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. The 2022 fishing intensity is estimated to correspond to $F_{51\%}$ (credible interval: 32-64%; Table 2). All three years from 2020-2022 are estimated to be less than values for the last 20+ years, and less than those estimated in recent stock assessments. Comparing the relative spawning biomass and fishing intensity over the recent historical period shows that the relative spawning biomass decreased as fishing intensity increased through 2010, then subsequently increased (Figure 12).

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 assessment utilized five years (2017-21) of sex-ratio information from the directed commercial fishery landings. However, uncertainty in historical ratios 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. This assessment also does not include mortality, trends, or explicit demographic linkages in 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.

TABLE 2. Status summary of the Pacific halibut stock and fishery in the IPHC Convention Area at beginning of 2023.

Indicators	Values	Trends	Status
Biological			
SPR_{2022}: P(SPR<43%): P(SPR<limit):	51% (32-64%)[2] 27% Limit not specified	Fishing intensity unchanged from 2021 to 2022	**Fishing intensity below reference level[3]**
SB_{2023} (Mlbs): SB_{2023}/SB_0: $P(SB_{2023}<SB_{30})$: $P(SB_{2023}<SB_{20})$:	192 (122–272) Mlbs 42% (21-55%) 25% <1%	SB decreased 16% from 2016 to 2023	**Not overfished[4]**
Biological stock distribution:	See Tables and Figures	Region 3 decreased from 2021 to 2022	**Within historical ranges**
Fishery Context			
Total mortality 2022: Percent retained 2022: Average mortality 2018–22:	39.69 Mlbs, 18,003 t[1] 85% 38.10 Mlbs, 17,284 t	Mortality increased from 2021 to 2022	**2022 mortality near 100-year low**

[1] Weights in this document are reported as 'net' weights, head and guts removed; this is approximately 75% of the round (wet) weight.
[2] Ranges denote approximate 95% credible intervals from the stock assessment ensemble.
[3] Status determined relative to the IPHC's interim reference Spawning Potential Ratio level of 43%.
[4] Status determined relative to the IPHC's interim management procedure biomass limit of $SB_{20\%}$.

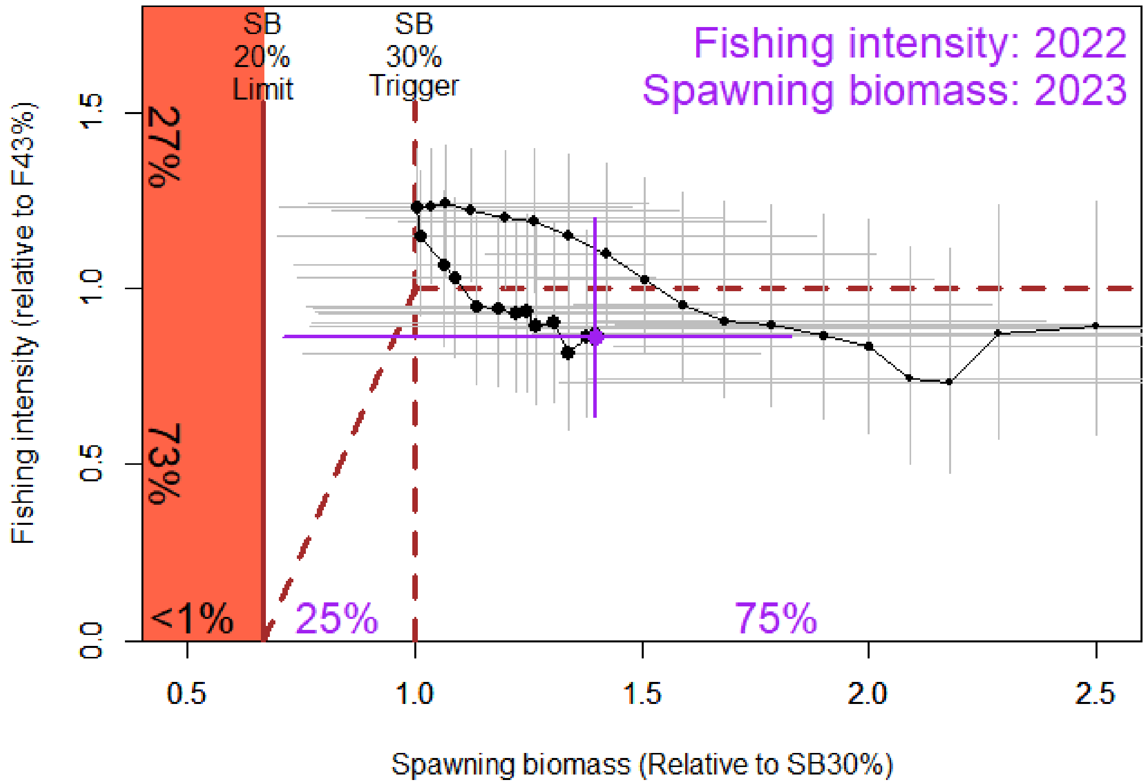

FIGURE 12. Phase plot showing the time-series (1992-2023) of estimated spawning biomass and fishing intensity relative to the reference points specified in the IPHC's interim management procedure. Dashed lines indicate the current $F_{43\%}$ (horizontal) reference fishing intensity, with linear reduction 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 2022 and spawning biomass at the beginning of 2023 shown as the largest point (purple). Percentages along the y-axis indicate the probability of being above and below $F_{43\%}$ in 2022; 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 2023.

Additional important contributors to assessment uncertainty (and potential bias) include the lag in estimation of incoming recruitment between birth year and direct observation in the fishery and survey data (6-10 years). Like most stock assessments, there is no direct information on natural mortality, and increased uncertainty for some estimated components of the fishery mortality. Fishery mortality estimates are assumed to be accurate; therefore, uncertainty due to discard mortality estimation (observer sampling and representativeness), discard mortality rates, and any other documented mortality in either directed or non-directed fisheries (e.g., whale depredation) could create bias in this assessment. Maturation schedules and fecundity 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 trends in these biological processes at the scale of the entire population.

Projections beyond three years are avoided due to the lack of mechanistic understanding of the factors influencing size-at-age and relative recruitment strength, the two most important factors in historical population trends.

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. Results of the IPHC's ongoing Management Strategy Evaluation (MSE) process can inform the development of management procedures that are robust to estimation uncertainty via the stock assessment, and to a wide range of hypotheses describing population dynamics.

OUTLOOK

Stock projections were conducted using the integrated results from the stock assessment ensemble in tandem with summaries of the 2022 directed and non-directed fisheries. The harvest decision table (Table 3) 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 2023 (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)
- A 30 million pound (~13,600 t) 2022 TCEY
- The mortality consistent with repeating the TCEY set for 2021 (41.22 million pounds, 18,697 t; *"status quo"*)
- The mortality at which there is a 50% chance that the spawning biomass will be smaller in three years than in 2023 ("*3-year surplus*")
- The mortality consistent with the current "Reference" SPR ($F_{43\%}$) level
- A 60 million pound (~27,200 t) 2022 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 column of the decision table, the total fishing mortality (including all sizes and sources), the coastwide TCEY and the associated level of fishing intensity projected for 2023 (median value with the 95% credible interval below) are reported.

The projections for this assessment are much more optimistic than those from recent assessments due to the increase in the estimated productivity of the stock resulting from 3/4 rather than 2/4 models estimating natural mortality at much higher values than the historical fixed assumption of 0.15. Further, the trend in spawning biomass is estimated to have stabilized as the 2012 year-class continues to mature. This translates to a lower probability of stock decline at higher yields for 2023 than in recent assessments as well as a decrease in this probability through 2024-26. There is greater than a 50% probability of stock decline in 2024 (53-86/100) for all yields greater than the *status quo*, including the entire range of SPR values from 40-46%. The 2023 “3-year surplus” alternative, corresponds to a TCEY of 43.0 million pounds 19,504 t), and a projected SPR of 48% (credible interval 28-62%; Table 3, Figure 13). At the reference level (a projected SPR of 43%), the probability of spawning biomass decline from 2023 to 2024 is 75%, decreasing to 71% in three years. The one-year risk of the stock dropping below $SB_{30\%}$ is 25% across all alternatives.

TABLE 3. Harvest decision table for 2023 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.

		2023 Alternative			***Status quo***	**3-Year Surplus**				***Reference $F_{43\%}$***					
		Total mortality (M lb)	**0.0**	**31.3**	**42.5**	**44.3**	**48.1**	**49.8**	**51.5**	**52.3**	**55.1**	**57.1**	**59.1**	**61.3**	
		TCEY (M lb)	**0.0**	**30.0**	**41.2**	**43.0**	**46.8**	**48.4**	**50.2**	**52.0**	**53.8**	**55.8**	**57.8**	**60.0**	
		2023 fishing intensity	$F_{100\%}$	$F_{59\%}$	$F_{50\%}$	$F_{48\%}$	$F_{46\%}$	$F_{45\%}$	$F_{44\%}$	$F_{43\%}$	$F_{42\%}$	$F_{41\%}$	$F_{40\%}$	$F_{39\%}$	
		Fishing intensity interval	--	37-71%	29-63%	28-62%	26-59%	25-59%	24-58%	24-57%	23-56%	22-55%	21-54%	21-53%	
Stock Trend (spawning biomass)	in 2024	is less than 2023	<1	20	49	53	63	67	71	75	79	83	86	89	a
		is 5% less than 2023	<1	2	13	15	22	25	28	31	35	39	43	47	b
	in 2025	is less than 2023	<1	18	46	50	60	64	68	72	76	80	83	87	c
		is 5% less than 2023	<1	6	24	28	36	40	44	48	52	57	62	67	d
	in 2026	is less than 2023	<1	20	46	50	60	63	67	71	75	79	82	85	e
		is 5% less than 2023	<1	10	31	35	43	47	51	55	59	64	68	72	f
Stock Status (Spawning biomass)	in 2024	is less than 30%	25	25	25	25	25	25	25	25	25	25	25	25	g
		is less than 20%	<1	<1	1	1	1	1	2	2	2	2	3	3	h
	in 2025	is less than 30%	18	25	25	25	25	25	25	25	25	25	25	25	i
		is less than 20%	<1	<1	1	2	3	3	4	4	5	6	6	7	j
	in 2026	is less than 30%	6	23	25	25	25	25	25	25	25	25	25	25	k
		is less than 20%	<1	<1	2	3	4	5	6	6	7	9	10	11	l
Fishery Trend (TCEY)	in 2024	is less than 2023	0	17	28	31	38	41	45	50	55	59	64	69	m
		is 10% less than 2023	0	11	26	27	32	35	38	42	46	51	55	60	n
	in 2025	is less than 2023	0	15	28	30	37	41	45	50	55	60	66	71	o
		is 10% less than 2023	0	11	26	27	32	35	38	42	47	52	57	62	p
	in 2026	is less than 2023	0	14	28	30	37	41	46	51	56	62	67	72	q
		is 10% less than 2023	0	10	25	27	32	35	39	43	48	53	58	64	r
Fishery Status (Fishing intensity)	in 2023	is above $F_{43\%}$	0	19	29	31	38	42	46	50	54	59	63	68	s

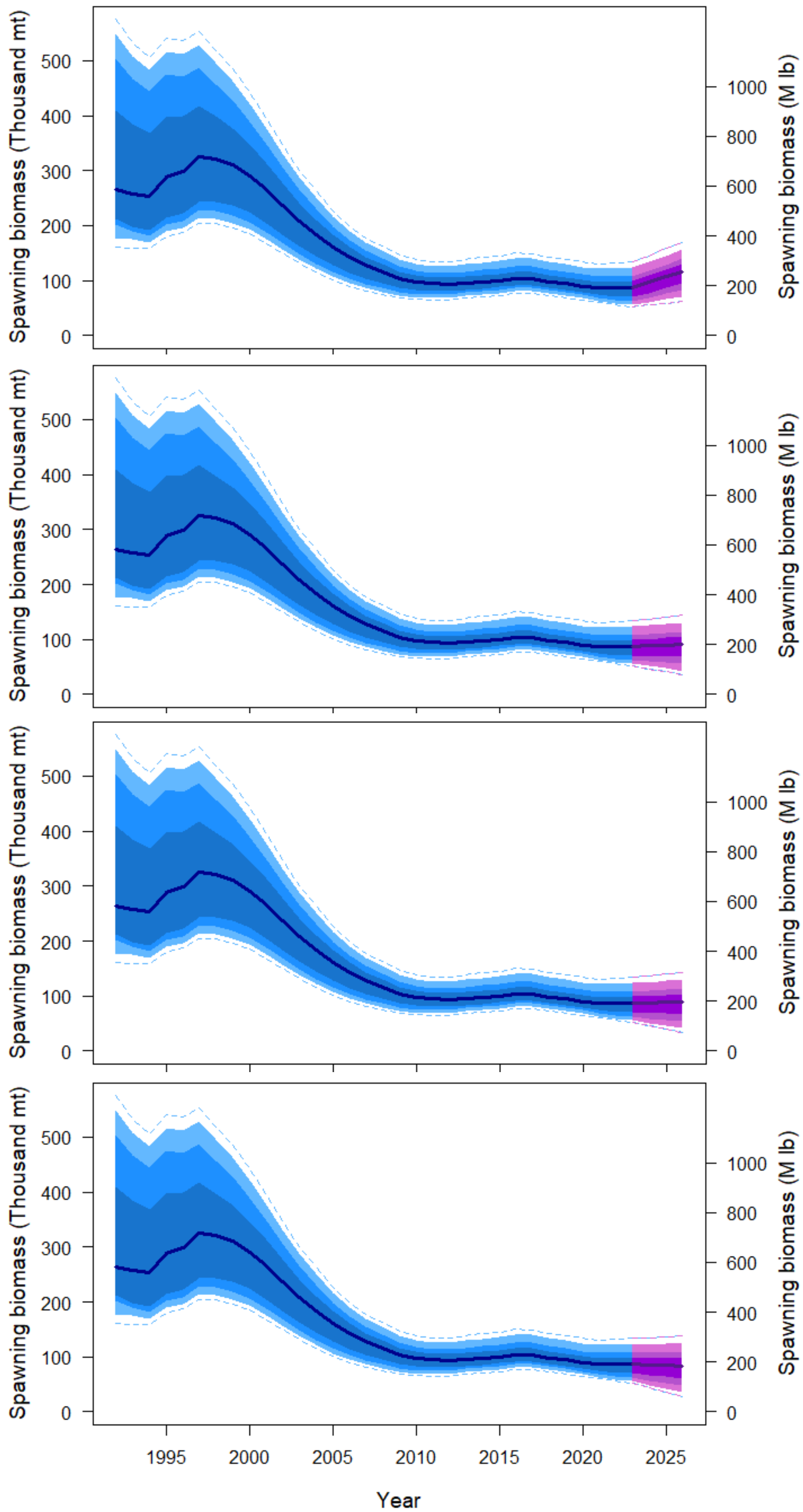

FIGURE 13. Three-year projections of stock trend under alternative levels of mortality: no fishing mortality (upper panel), the *status quo* TCEY set in 2022 of 41.2 million pounds, 18,697 t; second panel), the 3-year surplus (a TCEY of 43.0 million pounds, 19,504 t; third panel), and the TCEY projected for the IPHC's interim management procedure (52.0 million pounds, 23,564 t; lower panel).

SCIENTIFIC ADVICE

Sources of mortality: In 2022, total Pacific mortality due to fishing increased to 39.69 million pounds (18,003 t), above the 5-year average of 38.10 million pounds (17,284 t). Of that total, 85% comprised the retained catch (Table 2), down from 87% in 2021.

Fishing intensity: The 2022 fishing mortality corresponded to a point estimate of SPR = 51%; there is a 27% chance that fishing intensity exceeded the IPHC's current reference level of $F_{43\%}$ (Table 2). The Commission does not currently have a coastwide fishing intensity limit reference point.

Stock status (spawning biomass): Current (beginning of 2023) female spawning biomass is estimated to be 192 million pounds (87,058 t), which corresponds to an 25% chance of being below the IPHC trigger reference point of $SB_{30\%}$, and less than a 1% chance of being below the IPHC limit reference point of $SB_{20\%}$. The stock is estimated to have declined by 16% since 2016 but is currently at 42% of the unfished state. Therefore, the stock is considered to be '**not overfished**'. Projections indicate that mortality consistent with the interim management procedure reference fishing intensity ($F_{43\%}$) is very likely to result in further declining biomass levels in the near future.

Stock distribution: After increases in 2020-2021, the proportion of the coastwide stock represented by Biological Region 3 has decreased sharply in 2022, (Figure 6, Table 1). This trend occurs in tandem with increases in Biological Regions 2, 4 and 4B; however, all regions remain within the historical range observed from 1993-2021.

Additional risks not included in this analysis: Directed commercial fishery catch rates coastwide, and in nearly all IPHC Regulatory Areas were at or near the lowest observed in the last 40 years. The spawning biomass is also estimated to be near the lowest observed since the 1970s. Harvest levels based on a TCEY greater than 43 million pounds are likely to result in further declines in both the stock and fishery, despite being consistent with long-term sustainable harvest rates. The fishery in 2022 largely transitioned from the 2005 year-class to the 2012 year-class, contributing to observed reduced catch rates. This year-class is estimated to be only 29% mature in 2022; the spawning stock and fishery will be relying on this cohort heavily in the near future.

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 and are included in the IPHC's 5-year research plan (IPHC-2022-IM098-06).

DETAILED MANAGEMENT INFORMATION

The IPHC's recent interim management procedure determined the TCEY distribution method through 2022. Detailed description of the distribution of the TCEY among IPHC Regulatory Areas and fishery sectors will be provided for the 2023 Annual Meeting (AM098), based on guidance from the Commission and updated end-of-year mortality estimates for non-directed commercial fishery discard mortality.

ADDITIONAL INFORMATION

A more detailed description of the stock assessment (IPHC-2023-SA-01) and the data sources (IPHC-2023-SA-02), will be published directly to the stock assessment page on the IPHC's website. That page also includes recent peer review documents and previous stock assessment documents. Further, the IPHC's website contains many interactive tools for both FISS and commercial fishery information, as well as historical data series providing detailed tables of data and other information.

RECOMMENDATION/S

That the Commission:

a) **NOTE** paper IPHC-2022-IM098-11 which provides a summary of data, the 2022 stock assessment and the harvest decision table for 2023.

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