Assessment of the Pacific halibut (*Hippoglossus stenolepis*) stock at the end of 2021

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PURPOSE

To provide the Commission with a detailed report of the 2021 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 2021. A summary of both the data and assessment results, as well as management related information is provided both on the stock assessment webpage and in the meeting materials for the IPHC's 98th Annual Meeting (AM098; IPHC-2022-AM098-10). 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-2022-SA-02); only a few key observations are described here. Fishing mortality in 2021 was estimated to be up 10% from 2020. 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 2021 modelled Fishery-Independent Setline Survey (FISS; see IPHC-2022-AM098-07 and IPHC-2022-AM098-08) detailed a coastwide aggregate Numbers-Per-Unit-Effort (NPUE) which showed a sharp increase, up 17% from 2020. The modelled coastwide FISS Weight-Per-Unit-Effort (WPUE) of legal (O32) Pacific halibut, the most comparable metric to observed commercial fishery catch rates, was 4% higher than the 2020 estimate. Preliminary commercial fishery WPUE (based on all 2021 logbook records available for this assessment) increased 2% coastwide. Biological information (ages and lengths) from both the commercial fishery and FISS shows a shift from the previously dominant 2005 year-class to the 2012 cohort (9 years old in 2021), which now appears stronger than any of the 6 years preceding it and comprised the most abundant age (in number) among all fish encountered by the FISS in 2021. At the coastwide level, individual size-at-age appears to be increasing for younger ages, with positive trends for ages up to about 12, depending on the IPHC Regulatory Area.

This stock assessment continues to be implemented using the generalized stock synthesis software (Methot and Wetzel 2013). The analysis consists of an ensemble of four equally weighted models: two long time-series models, reconstructing historical dynamics back to the beginning of the modern fishery, and two short time-series models incorporating data only from 1992 to the present, a time-period for which estimates of all sources of mortality and survey indices are available for all regions. For each time-series length, there are two models: one fitting to coastwide aggregate data, and one fitting to data disaggregated into the four geographic regions. This combination of models includes uncertainty in the form of alternative hypotheses about several important axes of uncertainty, including: natural mortality rates (estimated in the long time-series models, fixed in the short time-series models), environmental effects on recruitment (estimated in the long time-series models), and other model parameters. Results are based on the approximate probability distributions derived from the ensemble of models, thereby incorporating the uncertainty within each model as well as the uncertainty among models. The 2019 stock assessment represented a full re-analysis of models and data, including an external independent peer review, and a review by the IPHC's Scientific Review Board (SRB; IPHC-

2019-SRB014-R, IPHC-2019-SRB015-R), The 2021 stock assessment represents a second update to the 2019 analysis, adding and updating data sources where available, but retaining the same basic model structure for each of the four component models. Incremental changes from the 2020 assessment (IPHC-2021-SA01) made during 2021 were documented through a two-part review by the IPHC's scientific review process IPHC-2021-SRB018-R, IPHC-2021-SRB019-R).

The results of the 2021 stock assessment indicate that the Pacific halibut stock declined continuously from the late 1990s to around 2012. That trend is estimated to have been largely a result of decreasing size-at-age, as well as somewhat weaker recruitment strengths than those observed during the 1980s. The spawning biomass (SB) is estimated to have increased gradually to 2016, and then decreased to an estimated 191 million pounds (~86,600 t) at the beginning of 2022, with an approximate 95% credible interval ranging from 129 to 277 million pounds (~58,700-125,400 t). The recent spawning biomass estimates from the 2021 stock assessment are very consistent with previous analyses for the period from 2012 to the present. Pacific halibut recruitment estimates show the large cohorts in 1999 and 2005, and for the first time clearly, 2012. Cohorts from 2006 through 2011 are estimated to be much smaller than those from 1999-2005, which has led to recent estimated declines in both the stock and fishery yield as these low recruitments become increasingly important to the age range over which much of the harvest and spawning takes place. Based on age data through 2021, all four assessment models suggest that the 2012 year-class will mature over the next few years and contribute importantly to trends in spawning biomass.

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 2022 was estimated to be 33% (credible interval: 22-54%), the same value estimate for 2021. The probability that the stock is below $SB_{30\%}$ is estimated to be 45% at the beginning of 2022, with less than a 1% chance that the stock is below $SB_{20\%}$. The IPHC's current interim management procedure specifies a target level of fishing intensity of a Spawning Potential Ratio (SPR) corresponding to an $F_{43\%}$; this equates to the level of fishing that would reduce the lifetime spawning output per recruit to 43% of the unfished level given current biology, fishery characteristics and demographics. Based on the 2021 assessment, the 2021 fishing intensity is estimated to correspond to an $F_{46\%}$ (credible interval: 35-63%). 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 2021 directed fisheries and other sources of mortality. The projections for this assessment are more optimistic than those from the 2019 and 2020 assessments due largely to the increasing projected maturity of the 2012 year-class. This translates to a lower probability of stock decline for 2022 than in recent assessments as well as a decrease in this probability through 2023-24. There is greater than a 50% probability of stock decline in 2023 (55-64/100) for the entire range of SPR values from 40-46%, which include the *status quo* TCEY and the $F_{43\%}$ reference level. The 2022 "3-year surplus" alternative, corresponds to a TCEY of 38.0 million pounds (~17,240 t), and a projected SPR of 48% (credible interval 32-63%). At the reference level (a projected SPR of 43%), the probability of spawning biomass decline from 2022 to 2023 is 59%, decreasing to 55% in three years, as the 2012 cohort matures. The one-year risk of the stock dropping below $SB_{30\%}$ ranges from 43% at the $F_{46\%}$ level to 45% at the at the $F_{40\%}$ level of fishing intensity. Sensitivity and retrospective analyses for each of the four models, and a discussion of major sources of uncertainty are 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-2022-SA-02) on the IPHC's stock assessment webpage. Results include current model estimates of stock size and trend reflecting all available data. Specific management information is summarized via a decision table reporting the estimated risks associated with alternative management actions. Mortality tables projecting detailed summaries for fisheries in each IPHC Regulatory Area (and reference levels indicated by the IPHC's interim management procedure) can be explored via the IPHC's mortality projection tool, which is updated in early January each year to reflect end-of-year mortality estimates from all sources.

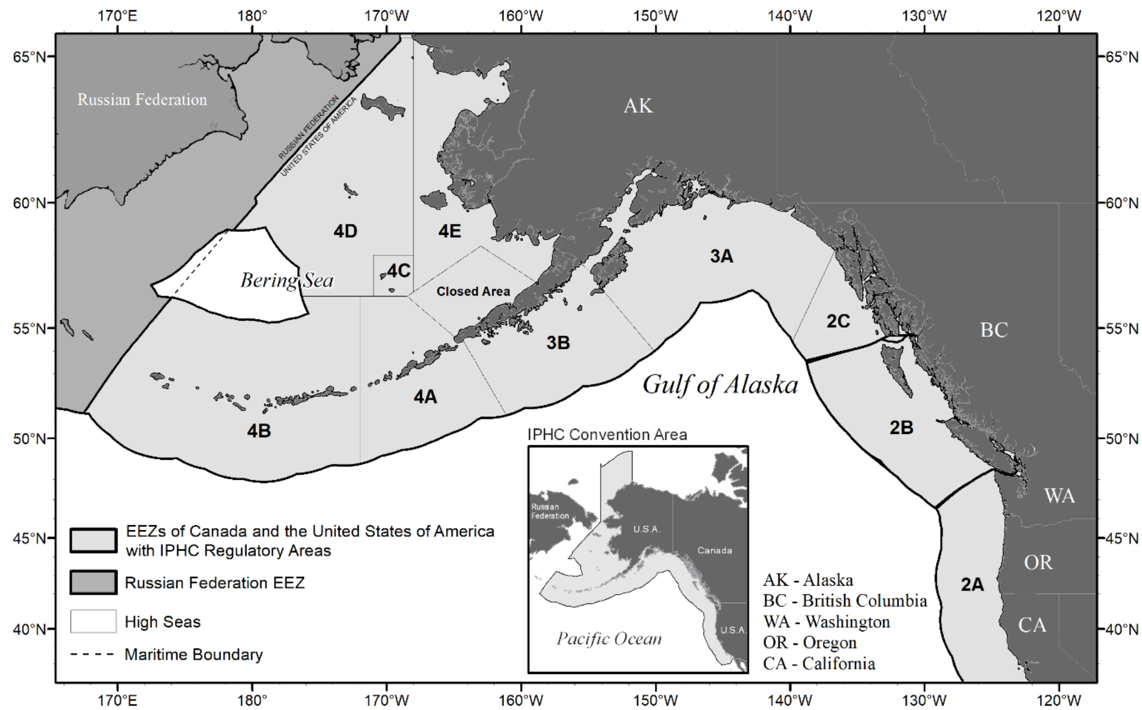

FIGURE 1. IPHC Convention Area (insert) and IPHC Regulatory Areas.

The IPHC's stock assessment and review process has developed from the first *ad hoc* meeting held in 2012 (Stewart et al. 2013) to 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

[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.

assessment. Within this annual review process two types of stock assessments are produced: 1) updated assessments where new data are added but the methods and model structures remain largely unchanged, and 2) full stock assessments occurring every three years in which model structure and methods are revised to reflect new data, approaches and comments from SRB and independent review. The 2015 (Stewart and Martell 2016; Stewart et al. 2016), and the 2019 (Stewart and Hicks 2019; Stewart and Hicks 2020) stock assessments were full analyses. The 2021 stock assessment represents a second update since 2019. Changes, new data, and extensions to existing time-series for 2021 include:

1. Update the version of the stock synthesis software (Methot and Wetzel 2013) used for the analysis (3.30.17).
2. New modelled trend information from the 2021 IPHC's FISS (fishery-independent setline survey), including estimates covering the entire 1890 station design and all IPHC Regulatory Areas.
3. Age, length, individual weight, and average weight-at-age estimates from the 2021 FISS for all IPHC Regulatory Areas.
4. 2021 (and a small amount of 2020) commercial fishery logbook trend information from all IPHC Regulatory Areas.
5. 2021 commercial fishery biological sampling (age, length, individual weight, and average weight-at-age) from all IPHC Regulatory Areas. Sex-ratios-at-age for the 2020 commercial fishery (building on the 2017-2019 sex-ratios used in the 2020 stock assessment).
6. Biological information (lengths and/or ages) from non-directed discards (IPHC Regulatory Areas where available) and the recreational fishery (IPHC Regulatory Area 3A only) from 2020.
7. Updated mortality estimates for 2020 (where preliminary values were used) and estimates for all sources in 2021.

Incremental changes made during 2021 were documented through a two-part review by the IPHC's scientific review process (IPHC-2021-SRB018-R, IPHC-2021-SRB019-R).

DATA SOURCES

Each year, the data sources used to support this assessment are updated to include newly available information and refined to reflect the most current and accurate information available to the IPHC. Major reprocessing and development of supplementary data sources was conducted in 2013, 2015, and again in 2019 (Stewart and Hicks 2019). All available information for the 2021 stock assessment was finalized on 31 October 2021 in order to provide adequate time for analysis and modeling. As has been the case in all years, some data are incomplete, or include projections for the remainder of the year. These include 2021 commercial fishery WPUE, 2021 commercial fishery age composition data, and 2021 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 2022 stock assessment.

Data for stock assessment use are initially compiled by IPHC Regulatory Area, and then aggregated to four Biological Regions: Region 2 (Areas 2A, 2B, and 2C), Region 3 (Areas 3A, 3B), Region 4 (4A, 4CDE) and Region 4B and then coastwide. In addition to the aggregate mortality (including all sizes of Pacific halibut), the assessment includes data from both fishery dependent and fishery independent sources as well as auxiliary biological information, with the most spatially complete data available since the late-1990s. Primary sources of information for this assessment include modelled indices of abundance (IPHC-2022-AM098-08); based on the FISS (in numbers and weight) and other surveys), commercial fishery Catch-Per-Unit-Effort (weight), and biological summaries from both sources (length-, weight-, and age-composition data). In aggregate, the historical time series of data available for this assessment represents a considerable resource for analysis. The range of relative data quality and geographical scope are also considerable, with the most complete information available only in recent decades (Figure 2). A detailed summary of input data used in this stock assessment can be found in IPHC-2022-SA-02 on the IPHC's stock assessment webpage.

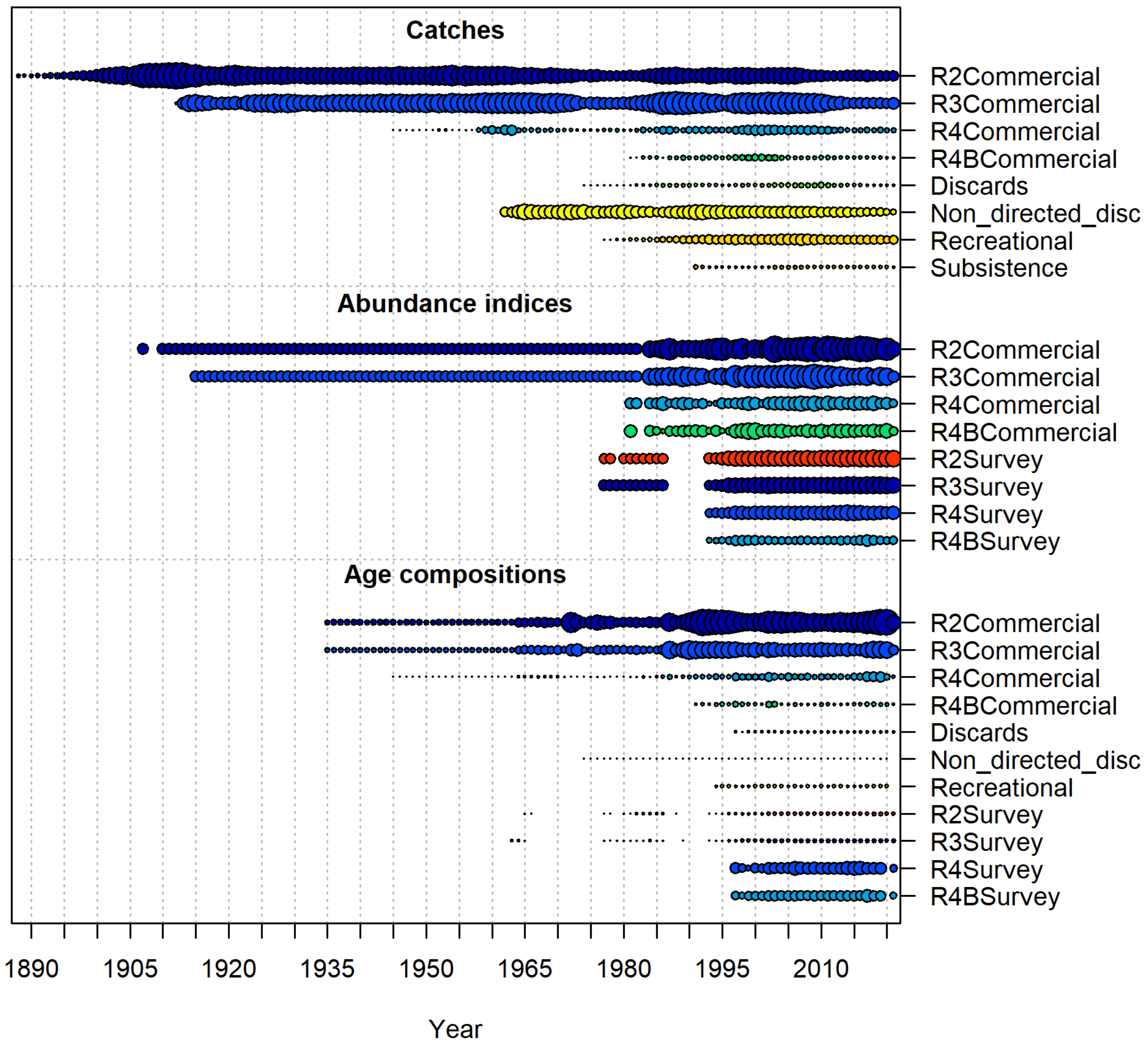

FIGURE 2. Overview of data sources. Circle areas are proportional to magnitude (mortality/catches) or the relative precision of the data (larger circles indicate greater precision for indices of abundance and age composition data).

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 1888-2021 mortality has totaled 7.3 billion pounds (~3.3 million metric tons, t), ranging annually from 34 to 100 million pounds (16,000-45,000 t) with an annual average of 63 million pounds (~29,000 t). Annual mortality was above this long-term average from 1985 through 2010 and has averaged 38.5 million pounds (~17,500 t) from 2017-21. Coastwide commercial Pacific halibut fishery landings (including research landings) in 2021 were approximately 24.5 million pounds (~11,100 t), up 9% from 2020. Discard mortality in non-directed fisheries was estimated to be 3.5 million pounds in 2021 (~1,600 t)[2], down 23% from 2020 and representing the smallest estimate in the time-series. The total recreational mortality (including estimates of discard mortality) was estimated to be 7.6 million pounds (~3,470 t) up 43% from reduced fisheries that occurred in 2020. Mortality from all sources increased by 10% to an estimated 37.7 million pounds (~17,100 t) in 2021.

The 2021 modelled FISS results detailed a coastwide aggregate NPUE (numbers per unit effort) which increased by 17% from 2020 to 2021, reversing the declines observed over the last four years. Biological Region 3 increased by 28%, while Biological Region 2 increased by 15%. Biological Regions 4, and 4B (sampled as planned in 2021 after the curtailed survey in 2020) both showed small declines (3 and 2%) and are at or near the lowest values in the estimated time-series. The 2021 modelled coastwide WPUE of legal (O32) Pacific halibut, the most comparable metric to observed commercial fishery catch rates, increased by 4% from 2020 to 2021. This reduced trend relative to that for NPUE indicates that recruitment of younger fish is contributing more to current stock productivity than somatic growth of fish already over the legal minimum size limit. Individual IPHC Regulatory Areas varied from a 57% increase (Regulatory Area 3B) to a 9% decrease (Regulatory Area 4CDE) in O32 WPUE. Preliminary commercial fishery WPUE estimates from 2021 logbooks increased by 2% at the coastwide level. The bias correction to account for additional logbooks compiled after the fishing season resulted in an estimate of no change (+/- 0%) coastwide. Trends varied among IPHC Regulatory Areas and gears; Area-specific trends were mixed, and generally similar to those from the FISS, with the exception of IPHC Regulatory Area 4A which showed a sharp increase in the commercial fishery WPUE.

Biological information (ages and lengths) from the commercial fishery landings continue to show the 2005 year-class as the largest coastwide contributor (in number) to the fish encountered, with the 2012 year-class nearly as abundant. The FISS observed the 2012 cohort (9 years old) at the largest proportion in the total catch of any age class for the first time. Observations of these fish both above and below the commercial fishery minimum size limit indicates their increasing importance to the 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 large implications for overall yield. Direct estimates of the sex-ratio at age for the directed commercial fishery continue to show an average of 80% female (by number) in the landings.

The current trend in population distribution (measured via the modelled FISS catch in weight of all sizes Pacific halibut) appears to be shifting back toward Biological Region 3 after more than a decade of decline. In both 2020 and 2021, the proportion of the population in Biological Regions 2 and 4 have decreased, while Region 4B has stayed relatively constant. 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.

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

STOCK ASSESSMENT

Creating robust, stable, and well-performing stock assessment models for the Pacific halibut stock has historically proven to be problematic due to the highly dynamic nature of the biology, distribution, and fisheries (Stewart and Martell 2014). The stock assessment for Pacific halibut has evolved through many different modeling approaches over the last 30 years (Clark 2003). These changes have reflected improvements in fisheries analysis methods, changes in model assumptions, and responses to recurrent retrospective biases and other lack-of-fit metrics (Stewart and Martell 2014). Although recent modelling efforts have created some new alternatives, no single model satisfactorily approximates all aspects of the available data and scientific understanding. For 2021, an ensemble of four stock assessment models was again used to explore the range of plausible current stock estimates. The ensemble approach recognizes that there is no “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, and therefore a stronger basis for risk assessment.

This stock assessment continues to be implemented using the generalized software stock synthesis (Methot and Wetzel 2013). The analysis consists of an ensemble of four equally weighted models: two long time-series models, reconstructing historical dynamics back to the beginning of the modern fishery, and two short time-series models incorporating data only from 1992 to the present, a time-period for which estimates of all sources of mortality and survey indices are available for all regions. For each time-series length, there are two models: one fitting to coastwide aggregate data, and one fitting to data disaggregated into the four geographic regions (Areas-As-Fleets; AAF). AAF models are commonly applied when biological differences among areas or sampling programs make coastwide summary of data sources problematic (Waterhouse et al. 2014). AAF models to treat the population dynamics as a single aggregate stock, but fit to each of the spatial datasets individually, allowing for differences in selectivity and catchability of the fishery and survey among regions. In addition, the AAF models more easily accommodate temporal and spatial trends in where and how data have been collected, and fishery catches have occurred. This is achieved through explicitly accounting for missing information in some years, rather than making assumptions to expand incomplete observations to the coastwide level.

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

Each of the four models in the ensemble was equally weighted, and within-model uncertainty from each model was propagated through to the ensemble results via the maximum likelihood estimates and an asymptotic approximation to their variance. Point estimates in this stock assessment correspond to median values from the ensemble: with the simple probabilistic interpretation that there is an equal probability above or below the reported value.

COMPARISON WITH PREVIOUS ASSESSMENTS

As in recent analyses, the transition from the 2020 stock assessment to the final 2021 models was performed in a stepwise manner, adding data incrementally to identify which pieces of new information had the largest effect on the results. This 'bridging' analysis included the update to the stock synthesis software version used for 2021 (3.30.17), the updating of 2020 data where needed and the addition of standard data sources for 2021 including FISS and commercial fishery indices, biological sampling and mortality estimates from all sectors. There was little effect on the historical time-series of spawning biomass or recruitment for any of the four models included in the stock assessment (Figures 3-6). For all four models the estimated strength of the 2012 year-class increased with the addition of new data.

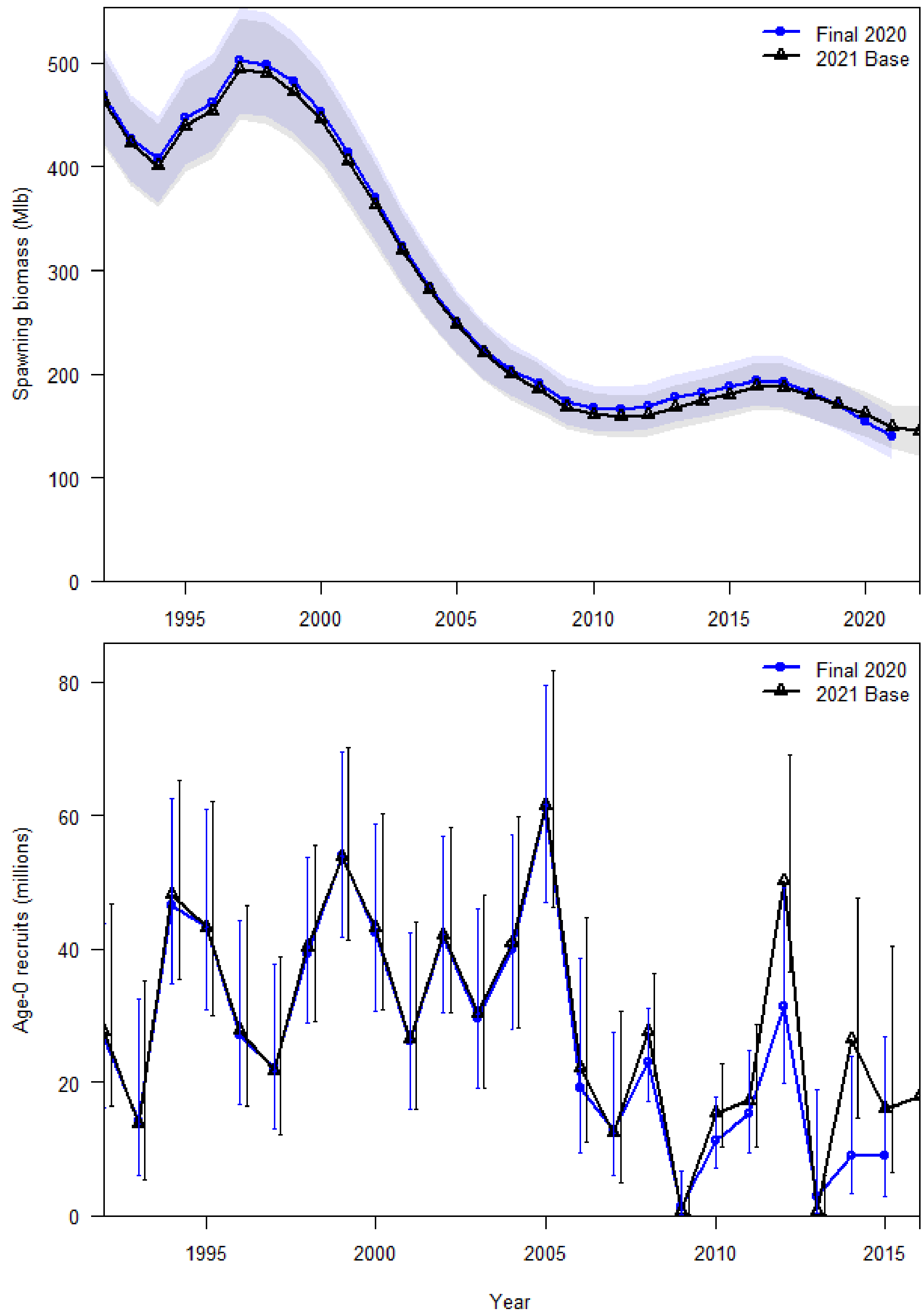

FIGURE 3. Bridging analysis showing the four steps between the 2020 and 2021 stock assessment model estimates of spawning biomass (upper panel) and recruitment (lower panel) for the short coastwide model.

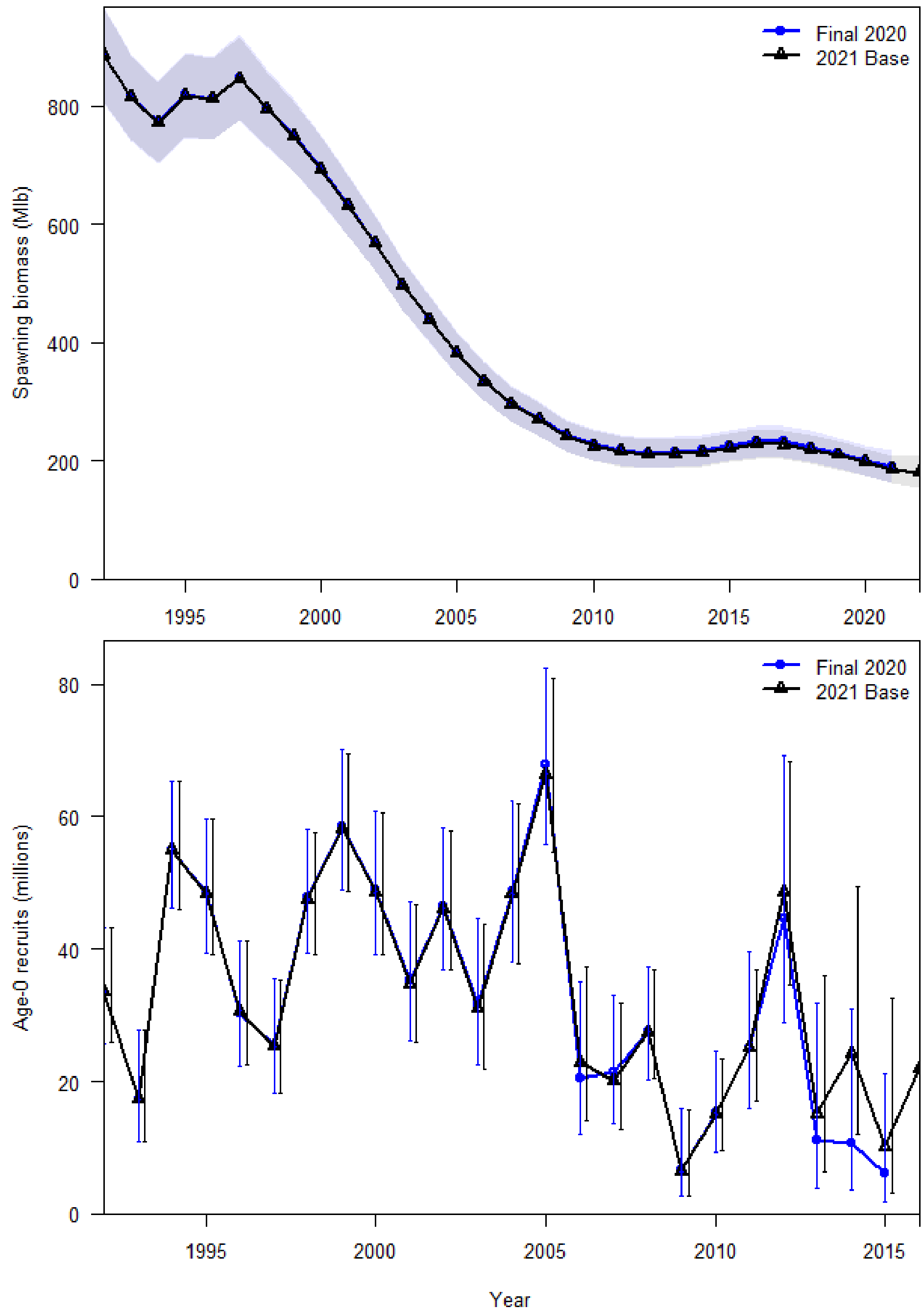

FIGURE 4. Bridging analysis showing the four steps between the 2020 and 2021 stock assessment model estimates of spawning biomass (upper panel) and recruitment (lower panel) for the short AAF model.

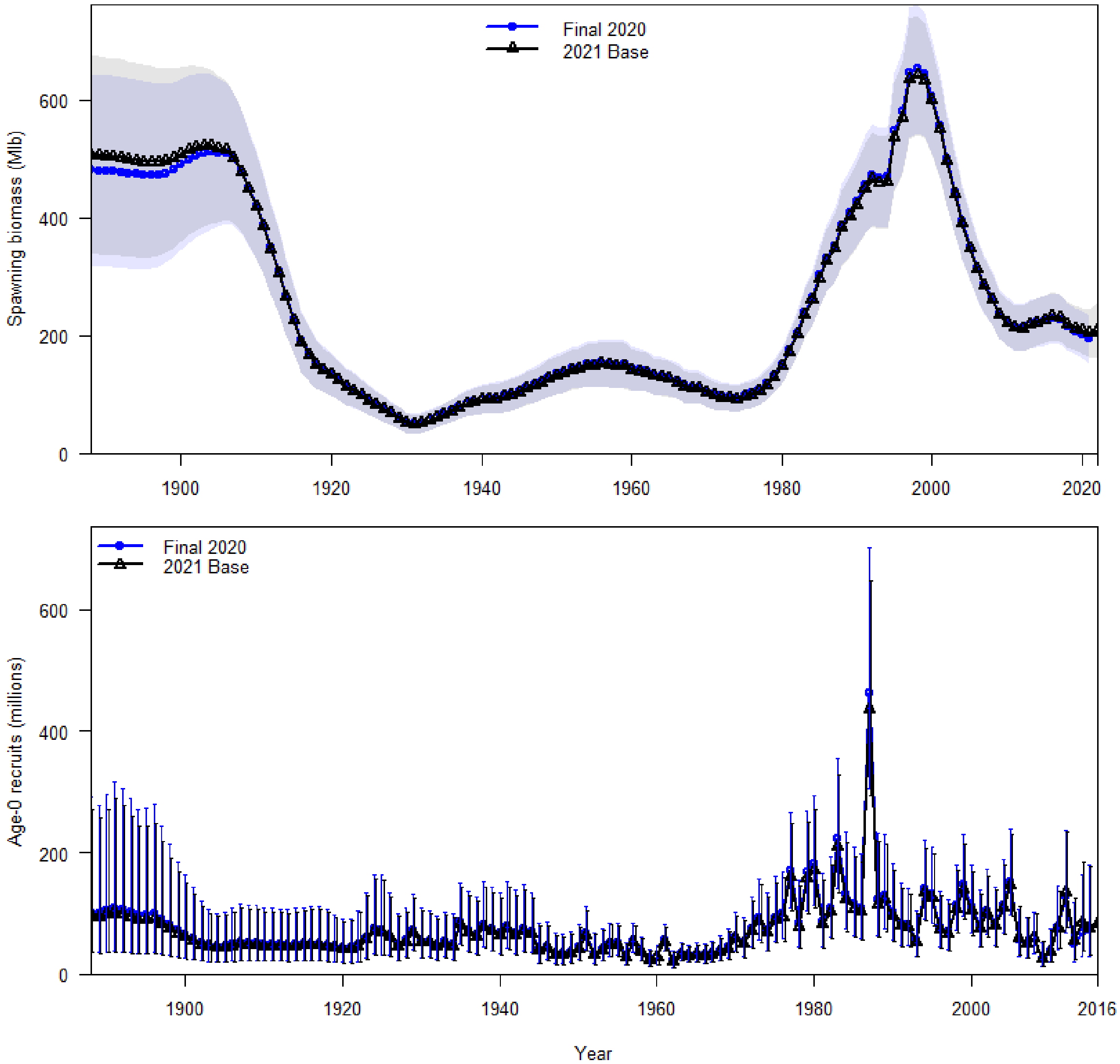

FIGURE 5. Bridging analysis showing the four steps between the 2020 and 2021 stock assessment model estimates of spawning biomass (upper panel) and recruitment (lower panel) for the long coastwide model.

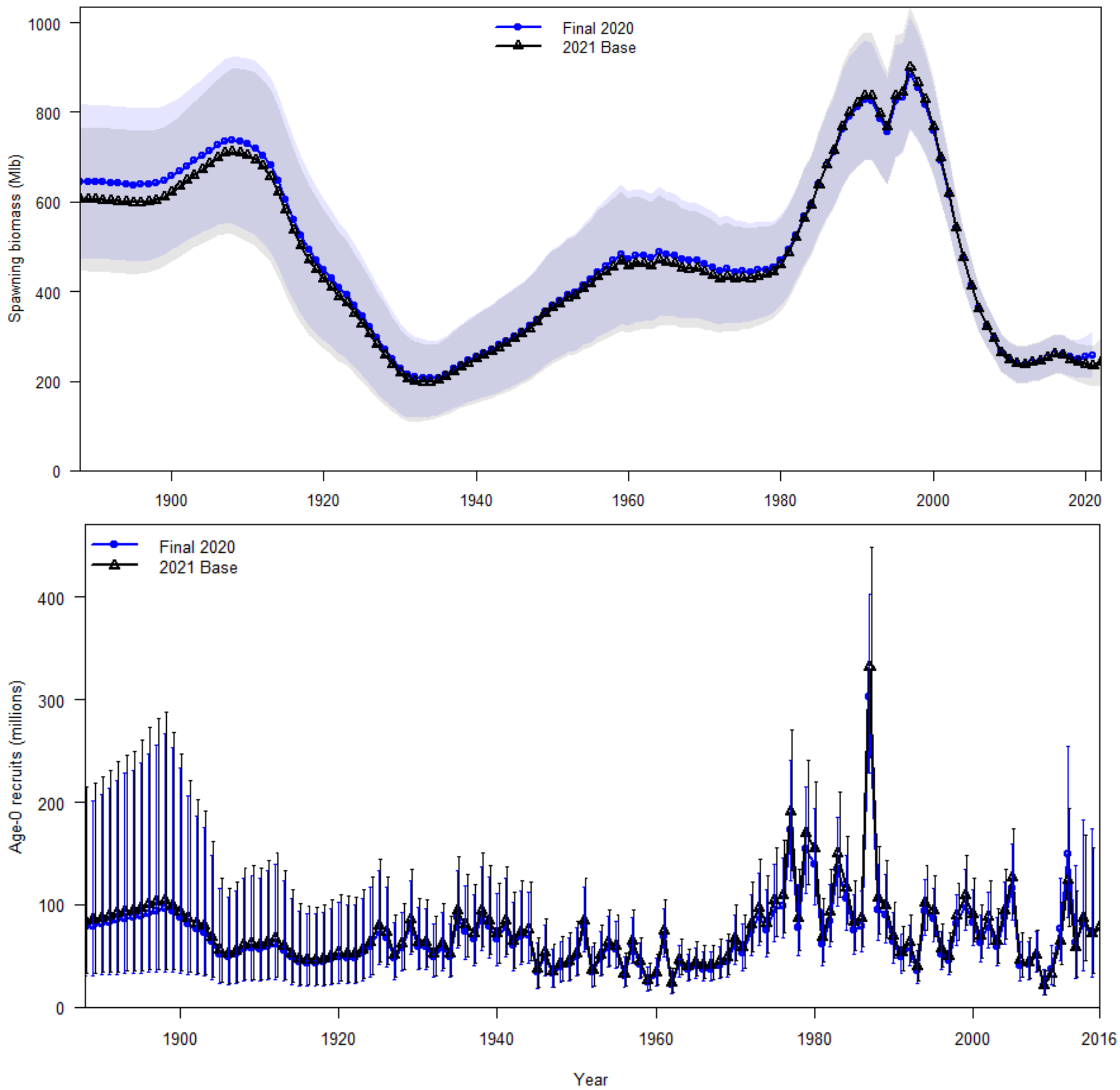

FIGURE 6. Bridging analysis showing the four steps between the 2020 and 2021 stock assessment model estimates of spawning biomass (upper panel) and recruitment (lower panel) for the long AAF model.

Comparison of this year's ensemble results with previous stock assessments indicates that the estimates of spawning biomass from the 2021 ensemble remain very consistent with those from the 2012-20 assessments. Each of the previous terminal assessment values lie inside the predicted 50% interval of the current ensemble (Figure 7). The uncertainty is much greater prior to approximately 2005 reflecting the differences among the four individual models, particularly the beginning of the time-series' in the two short models.

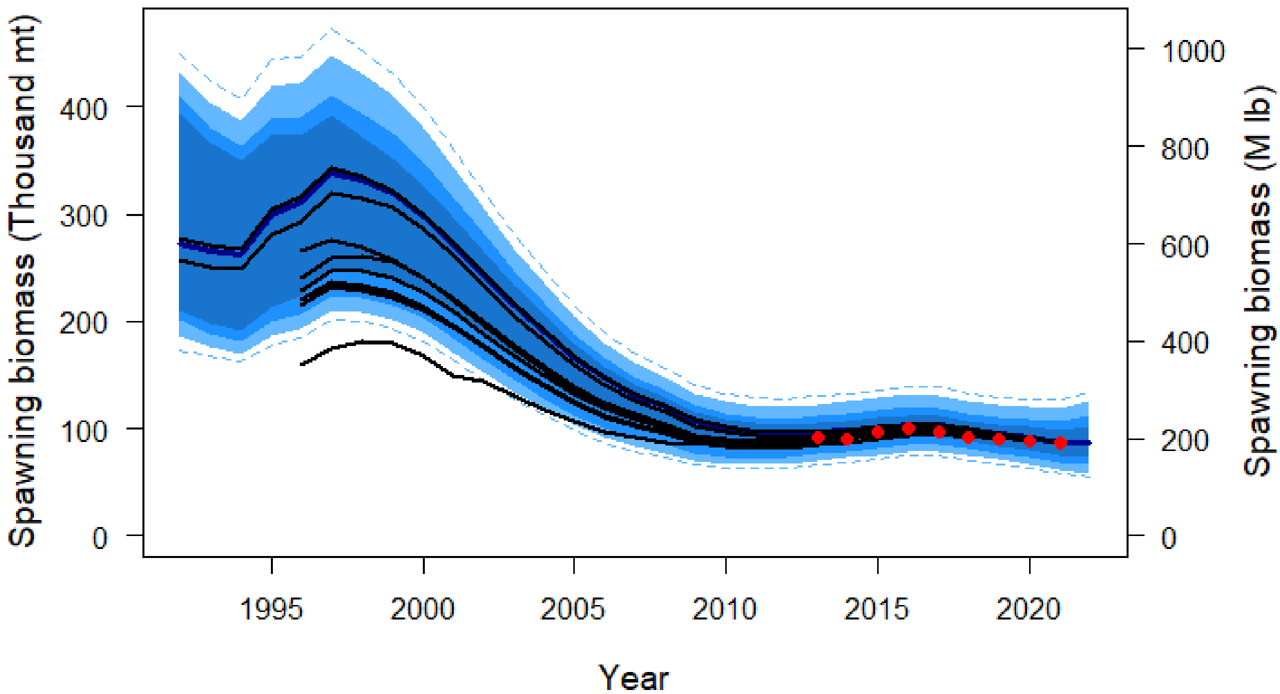

FIGURE 7. Retrospective comparison among recent IPHC stock assessments. Black lines indicate estimates of spawning biomass from assessments conducted from 2012-2020 with the terminal estimate shown as a point, the shaded distribution denotes the 2021 ensemble: the dark blue line indicates the median (or "50:50 line") with an equal probability of the estimate falling above or below that level; colored bands moving away from the median indicate the intervals containing 50/100, 75/100, and 95/100 estimates; dashed lines indicating the 99/100 interval.

BIOMASS, RECRUITMENT, AND REFERENCE POINT RESULTS

Ensemble

The results of the 2021 stock assessment indicate that the Pacific halibut stock declined continuously from the late 1990s to around 2012 (Figure 7, Table 1). That trend is estimated to have been largely a result of decreasing size-at-age, as well as somewhat weaker recruitment strengths than those observed during the 1980s. The spawning biomass (SB) is estimated to have increased gradually to 2016, and then decreased to an estimated 191 million pounds (~86,600 t) at the beginning of 2022, with an approximate 95% credible interval ranging from 129 to 277 million pounds (~58,700-125,400 t; Figure 8). The differences among the individual models contributing to the ensemble are most pronounced prior to the early 2000s (Figure 9); however, current stock size estimates (at the beginning of 2022) also differ substantially among the four models (Figure 10). The differences in both scale and recent trend reflect the structural assumptions, e.g., higher natural mortality estimated in the long coastwide model and dome-shaped selectivity for Biological Regions 2 and 3 in the AAF models.

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	599	411-952	44%	29-62%	78.1	27.7	63.4	33.5	1,603	1,132	2,440	1,856
1993	585	390-890	43%	28-61%	53.4	13.8	39.7	17.4	1,505	1,075	2,246	1,704
1994	580	373-852	44%	29-61%	135.0	48.0	102.0	54.8	1,442	1,011	2,123	1,606
1995	659	410-925	52%	36-68%	125.8	43.3	93.6	48.3	2,008	1,350	2,652	1,939
1996	685	424-931	51%	36-66%	74.2	27.7	56.9	30.5	1,975	1,337	2,608	1,922
1997	747	462-988	46%	31-61%	67.2	21.8	49.8	25.3	2,040	1,402	2,673	1,986
1998	731	459-948	44%	30-59%	108.3	40.3	88.8	47.5	1,941	1,357	2,505	1,869
1999	703	442-904	42%	29-57%	139.5	53.8	109.2	58.2	1,788	1,265	2,288	1,719
2000	656	416-838	41%	29-57%	104.2	43.1	90.4	48.6	1,621	1,166	2,078	1,578
2001	599	377-761	38%	27-54%	76.8	26.4	69.1	34.7	1,429	1,032	1,838	1,404
2002	538	338-675	34%	25-50%	100.2	42.1	87.5	46.1	1,369	982	1,723	1,328
2003	473	296-591	30%	22-46%	80.2	30.4	64.6	30.9	1,306	925	1,608	1,241
2004	418	260-519	27%	21-44%	109.0	41.0	94.5	48.3	1,189	848	1,459	1,133
2005	366	228-451	25%	20-42%	147.4	61.5	126.1	66.4	1,069	758	1,307	1,017
2006	324	203-397	25%	20-41%	59.3	22.3	46.2	22.9	1,012	713	1,231	957
2007	290	184-355	24%	19-40%	50.3	12.4	43.5	20.1	1,006	704	1,204	929
2008	265	170-325	23%	18-40%	59.9	27.6	51.5	27.5	956	677	1,157	894
2009	237	154-292	24%	19-41%	26.4	0.8	20.8	6.5	865	611	1,064	819
2010	222	148-275	24%	18-41%	37.8	15.3	33.0	15.0	826	592	1,023	786
2011	213	145-267	28%	22-45%	76.6	17.3	65.1	25.0	780	564	969	741
2012	210	147-265	32%	26-50%	135.1	50.1	124.0	48.6	780	565	967	735
2013	213	154-270	34%	28-51%	54.8	0.8	58.1	15.2	834	613	1,021	774
2014	216	160-275	39%	31-55%	85.2	26.5	87.4	24.3	790	593	971	741
2015	222	166-282	40%	31-56%	75.7	16.1	71.5	10.1	745	560	925	709
2016	229	173-290	41%	31-56%	83.3	17.9	78.2	22.0	724	563	904	700
2017	228	172-288	41%	31-56%	NA	NA	NA	NA	664	510	839	649
2018	218	164-277	43%	32-59%	NA	NA	NA	NA	618	482	789	608
2019	210	156-269	42%	32-59%	NA	NA	NA	NA	642	464	807	596
2020	202	147-265	48%	37-64%	NA	NA	NA	NA	763	529	945	644
2021	192	135-263	46%	35-63%	NA	NA	NA	NA	757	470	961	612
2022	191	129-277	NA	NA	NA	NA	NA	NA	790	482	1,026	605

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 subsequent years until 2012 (Figure 11, Table 1). All of these recent recruitments are much lower than the 1987 cohort, and in the two long time-series models they are at or below those in the late 1970s and early 1980s (Figure 12). Cohorts from 2006 through 2011 are estimated to be much smaller than those from 1999-2005 which has resulted in declines in both the stock and fishery yield as these low recruitments become increasingly important to the age range over which much of the harvest and spawning takes place. Based on the most recent trend and age data, this assessment estimated the 2012 cohort to be critically important to the projected spawning biomass over the next 2-4 years. Nineteen percent (19%) of this cohort is estimated to be mature in 2021 and increasing to 56% by 2024, assuming the historical average maturity schedule currently used in the assessment (see sensitivity analyses below). Short-term trends in fishery yield are relatively flat as the fisheries transition from older fish to the younger 2012 year-class, as was observed in the 2021 fisheries. All models are estimating a slight increase in 8+ biomass from a low in 2018 or 2019 but the ensemble shows continued decline in spawning biomass through the beginning of 2022 (Table 1). Recruitment estimates after 2013 remain highly uncertain, and those after 2016 poorly informed by any direct information from the fishery and survey data.

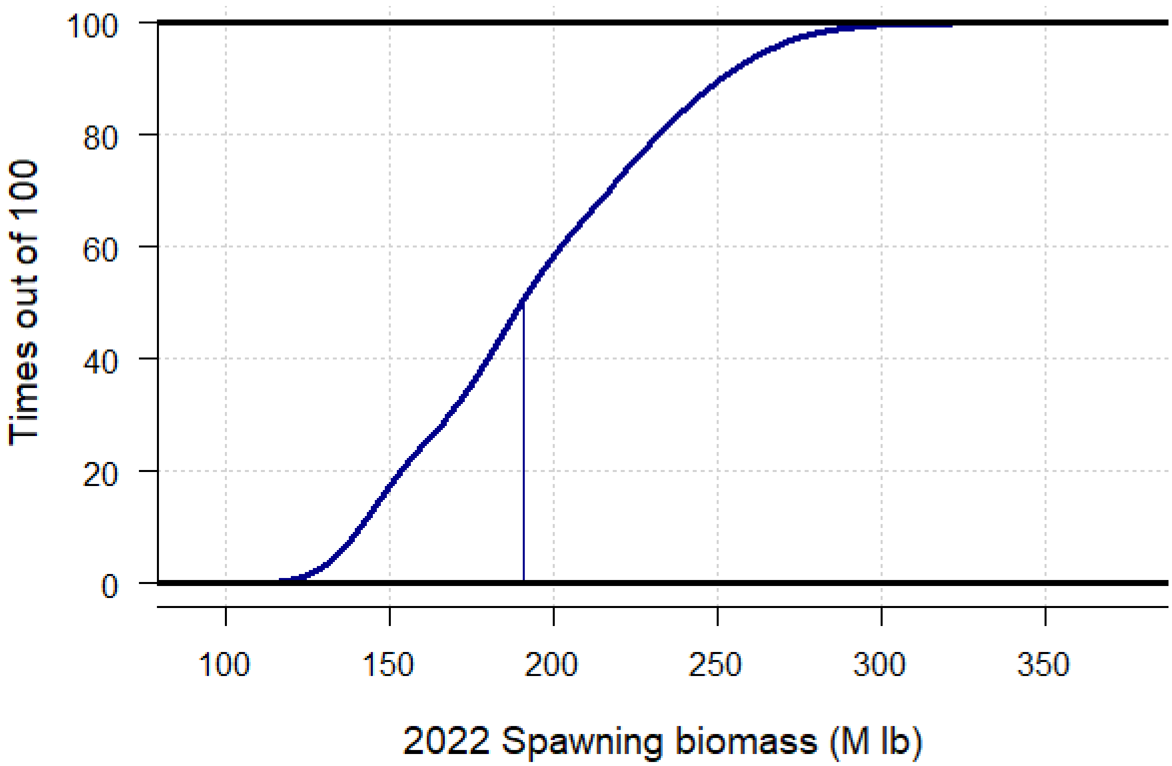

FIGURE 8. Cumulative distribution of the estimated spawning biomass at the beginning of 2022. Curve represents the estimated probability that the biomass is less than or equal to the value on the x-axis; vertical line represents the median (191 million pounds; ~86,600 t).

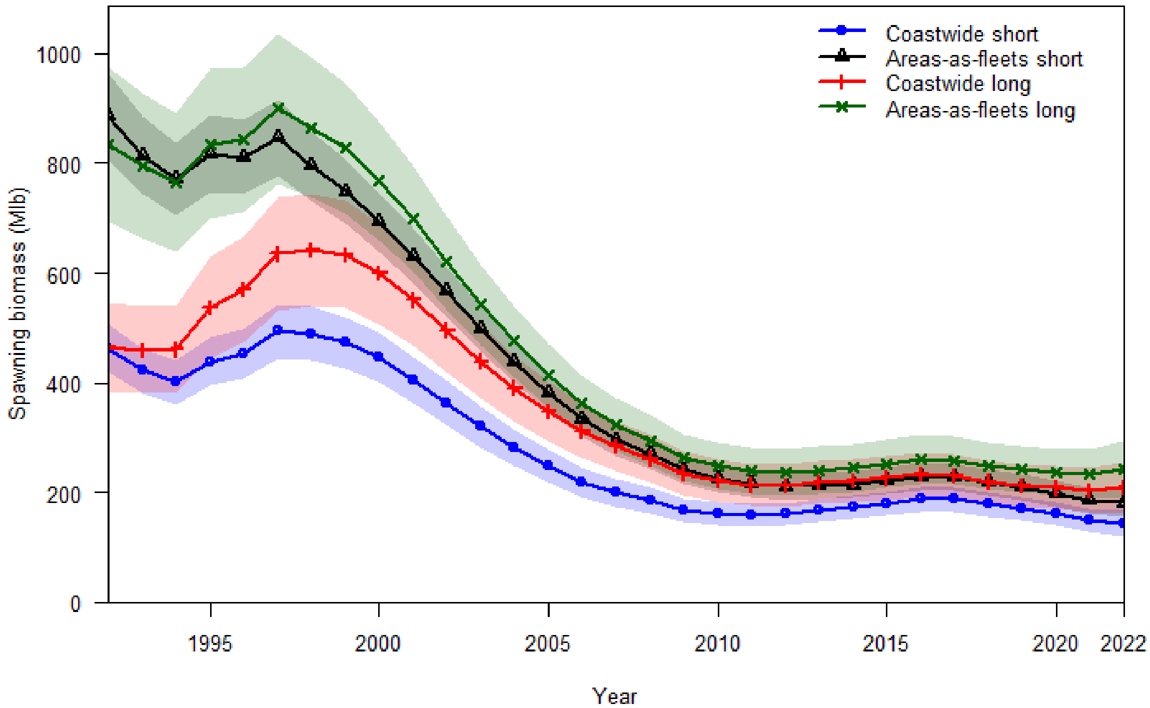

FIGURE 9. Estimated spawning biomass trends (1996-2022) based on the four individual models included in the 2020 stock assessment ensemble. Solid lines indicate the maximum likelihood estimates; shaded intervals indicate approximate 95% credible intervals.

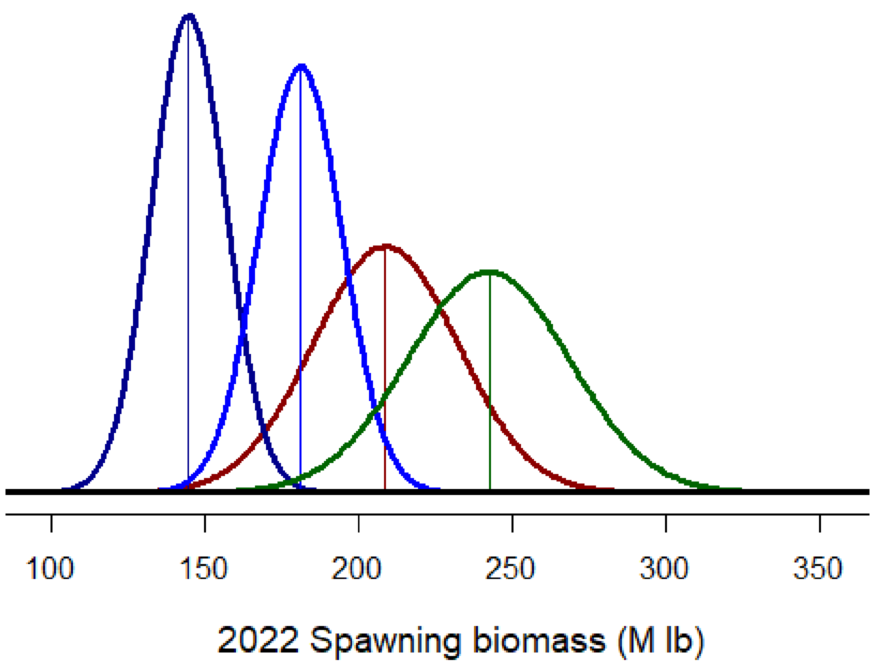

FIGURE 10. Distribution of individual model estimates for the 2022 spawning biomass. Vertical lines indicate the median values.

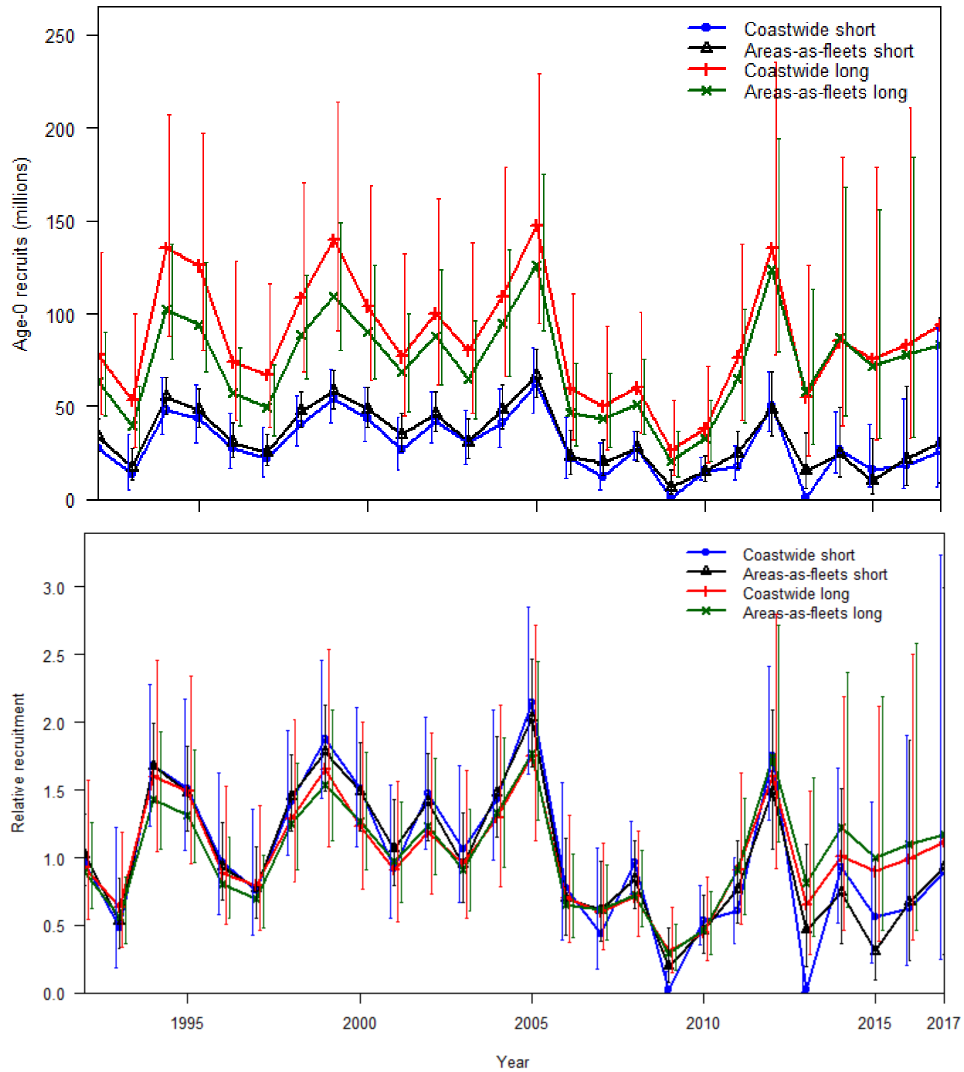

FIGURE 11. Estimated age-0 recruitment trends (1992-2017; upper panel) and relative trends (mean=1 for all models; lower panel) from the four individual models included in the 2021 stock assessment ensemble. Series indicate the maximum likelihood estimates; vertical lines indicate approximate 95% credible intervals.

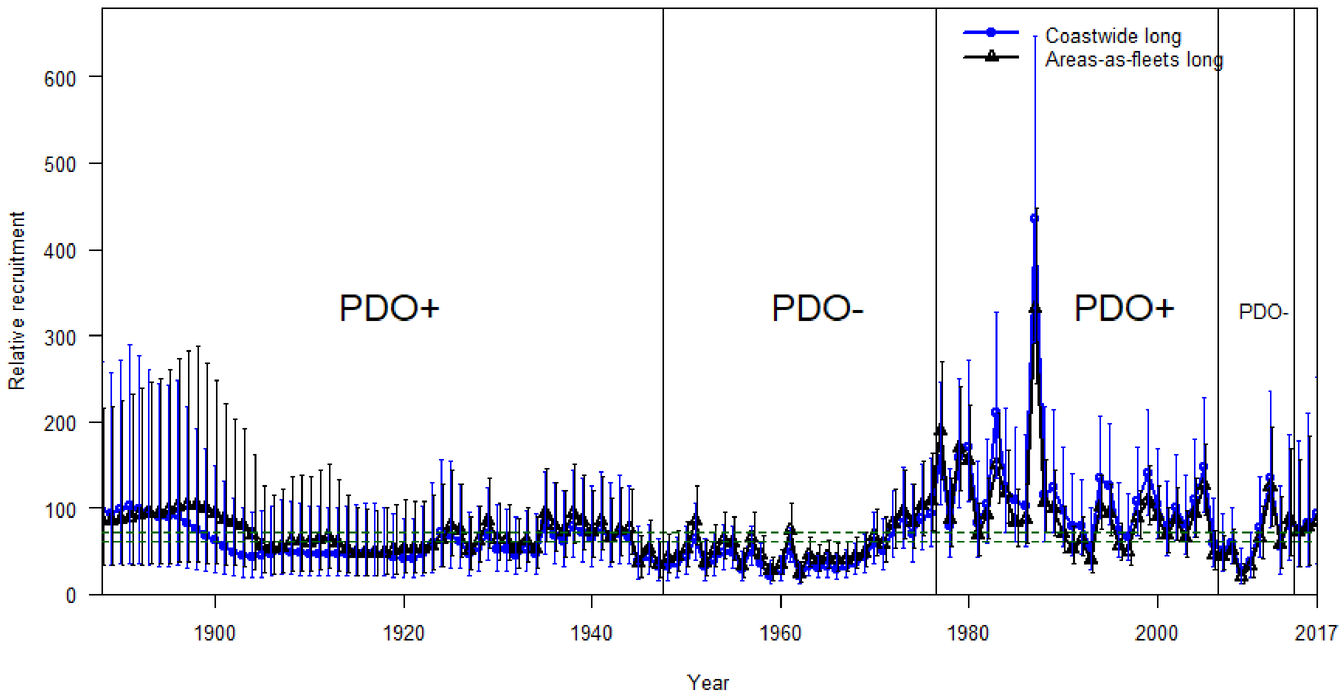

FIGURE 12. Trend in historical recruitment strengths (by birth year) estimated by the two long time-series models, including the effects of the Pacific Decadal Oscillation (PDO) regimes.

Ecosystem conditions

Average Pacific halibut recruitment is estimated to be higher (71 and 72% for the coastwide and AAF models respectively) during favorable Pacific Decadal Oscillation (PDO) regimes, a widely used indicator of productivity in the north Pacific. Historically, these regimes included positive conditions prior to 1947, poor conditions from 1947-77, positive conditions from 1978-2006, and poor conditions from 2007-13. Annual averages from 2014 through 2019 were positive, with 2020 and 2021 showing negative average conditions (data were only available through September for 2021). 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.

Reference points

The IPHC's interim management procedure uses a relative spawning biomass of 30% as a trigger, below which the target fishing intensity is reduced. At a spawning biomass limit of 20%, directed fishing is halted due to the critically low biomass condition. Beginning with the 2019 stock assessment, this calculation has been based on recent biological conditions rather than a long-term static average. By using current weight-at-age and estimated recruitments that are influencing the current stock only, the 'dynamic' calculation measures the effect of fishing on the spawning biomass. The relative spawning biomass decreased continuously over the period 1992-2012, then increased gradually to just above the $SB_{30\%}$ fishery trigger after 2015 (Figure 13). Since 2016, the relative spawning biomass has increased slightly to 33% at the beginning of 2022 (credible interval: 22-54%). This result reflects the greater effects of reduced recruitment, rather than fishing in the last few years. The probability that the stock is below the $SB_{30\%}$ level is estimated to be 45% at the beginning of 2022, with less than a 1% chance that the stock is below $SB_{20\%}$ (Figure 14).

The IPHC's current interim management procedure specifies a target level of fishing intensity of $F_{43\%}$, based on the Spawning Potential Ratio (SPR). This target 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. For the second year in a row fishing intensity is estimated to have been below reference levels and projections based on adopted mortality limits. Based on the 2021 assessment, the 2021 fishing intensity is estimated to correspond to an $F_{46\%}$ (credible interval: 35-63%), slightly higher than 2020 (when many fisheries did not achieve projected performance) and lower than other years since the late 1990s (Table 1; Figures 15 and 16). Comparing the relative spawning biomass and fishing intensity over the recent historical period provides for an evaluation of trends conditioned on the currently defined reference points via a 'phase' plot. The phase plot for Pacific halibut shows that the relative spawning biomass decreased as fishing intensity increased through 2010, then increased as the fishing intensity decreased through 2016, and has been relatively stable since then (Figure 17).

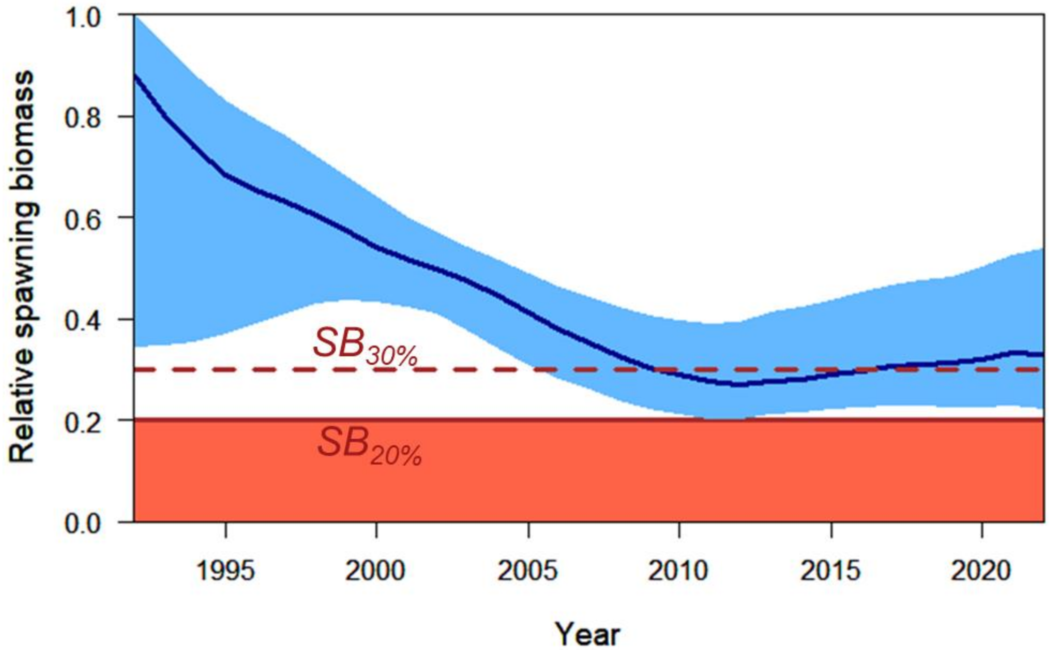

FIGURE 13. Estimated time-series of relative spawning biomass (compared to the unfished condition in each year) based on the median (dark blue line) and approximate 95% credibility interval (blue shaded area). IPHC management procedure reference points ($SB_{30\%}$ and $SB_{20\%}$) are shown as dashed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

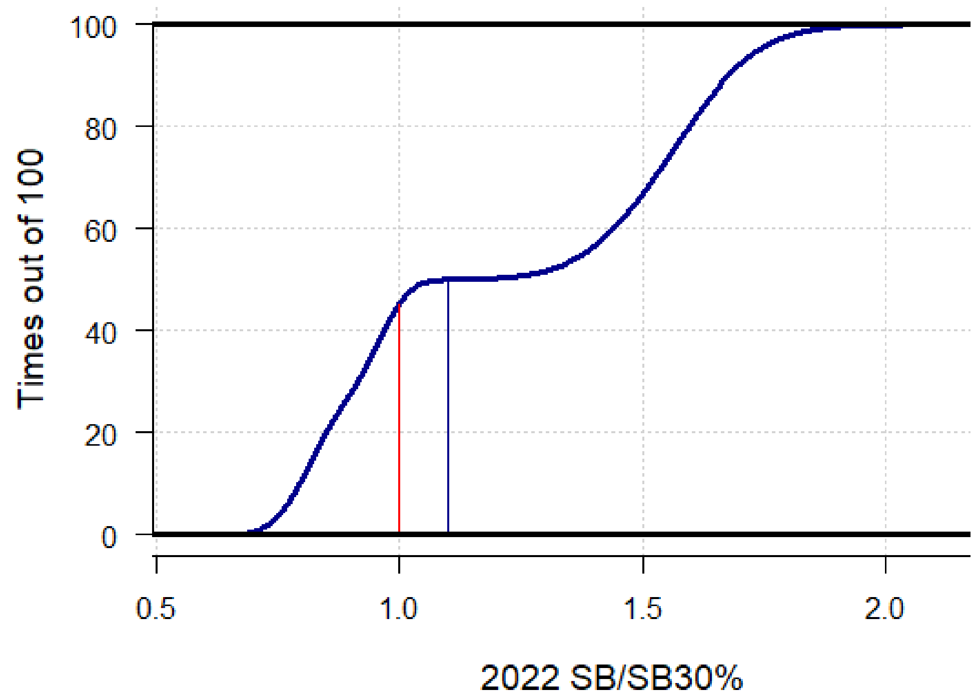

FIGURE 14. Cumulative distribution of ensemble 2022 spawning biomass estimates relative to the $SB_{30\%}$ reference point. Curve represents the estimated probability that the biomass is less than or equal to the value on the x-axis. Vertical lines denote the values corresponding to the fishery threshold in the IPHC's harvest policy (red; $SB_{30\%}$), and the median (blue; 33%).

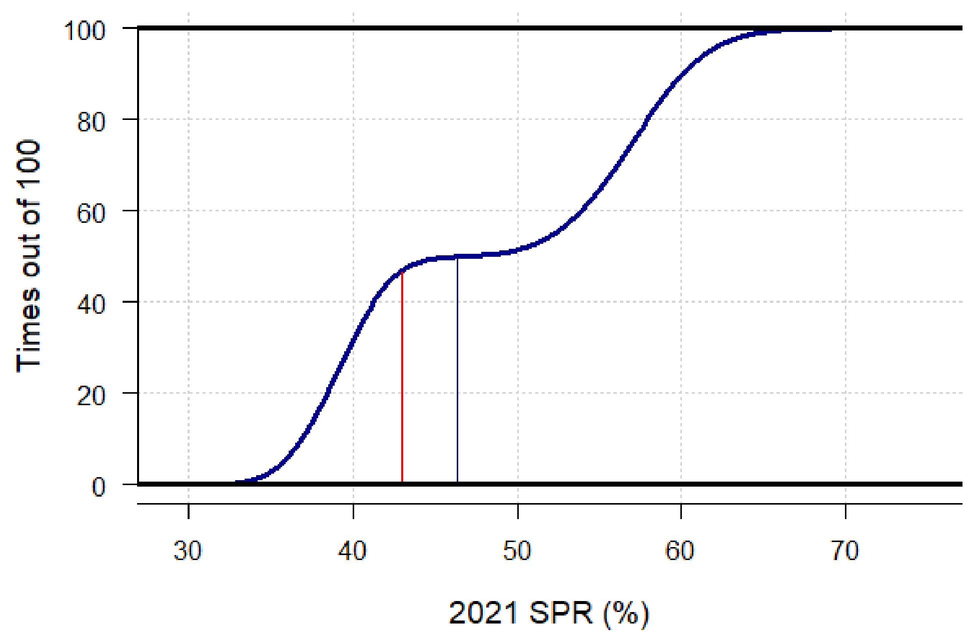

FIGURE 15. Cumulative distribution of the estimated fishing intensity (based on the Spawning Potential Ratio) estimated to have occurred in 2021. Curve represents the estimated probability that the fishing intensity is less than or equal to the value on the x-axis. Vertical lines indicates the reference ($F_{43\%}$; red) and the median value ($F_{46\%}$; blue).

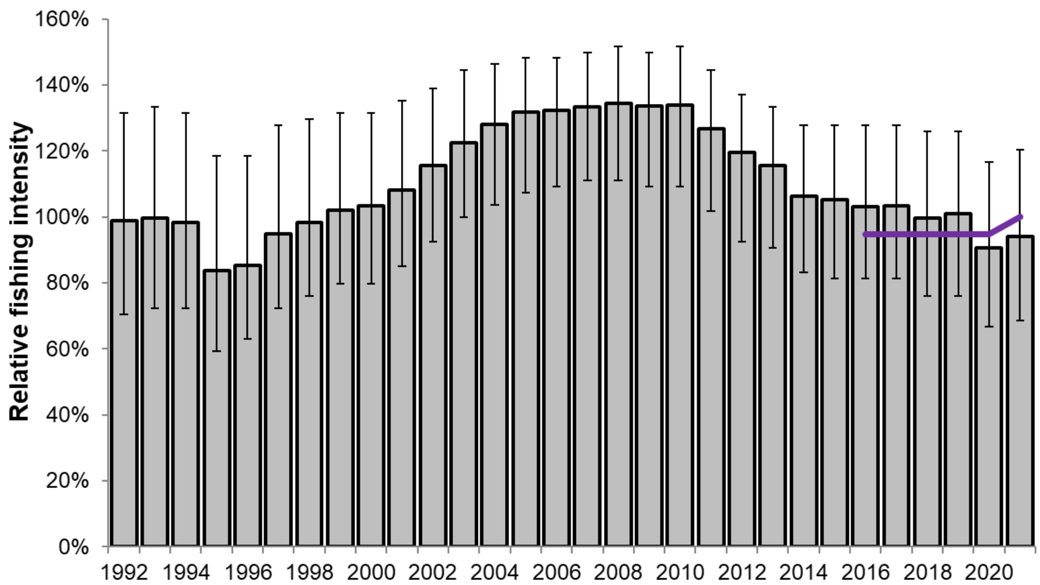

FIGURE 16. Recent estimated fishing intensity (1992-2021; based on SPR) relative to the SPR=43% reference (2021) and SPR=46% reference (2016-2020; purple line). Vertical lines indicate approximate credible intervals.

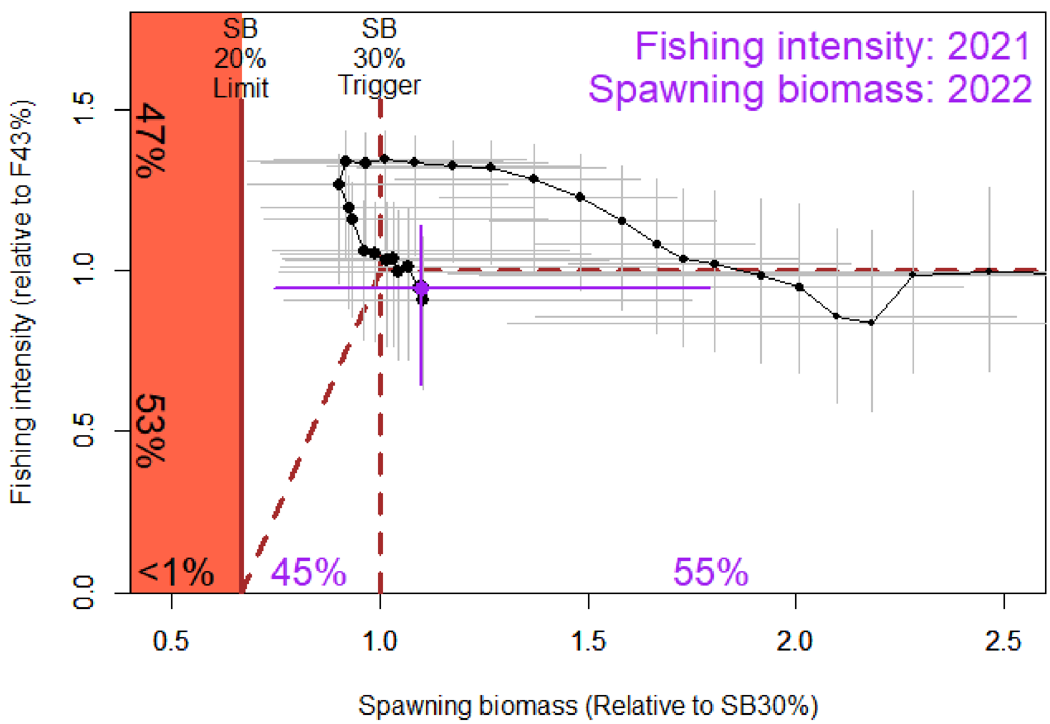

FIGURE 17. Phase plot showing the time-series of estimated spawning biomass (1993-2022) and fishing intensity (1992-2021) relative to current reference points. Dashed lines indicate the $F_{43\%}$ (horizontal) reference fishing intensity and linear reduction below the $SB_{30\%}$ (vertical) trigger, 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 2021 and spawning biomass at the beginning of 2022 shown as the largest point (purple). Percentages along the y-axis indicate the probability of being above and below $F_{43\%}$ in 2021; 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 2022.

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 18). 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 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 assumptions regarding connectivity between Regions 2-3 and Regions 4-4B during the early part of the 1900s when there are no data available from Regions 4-4B (Stewart and Martell 2016).

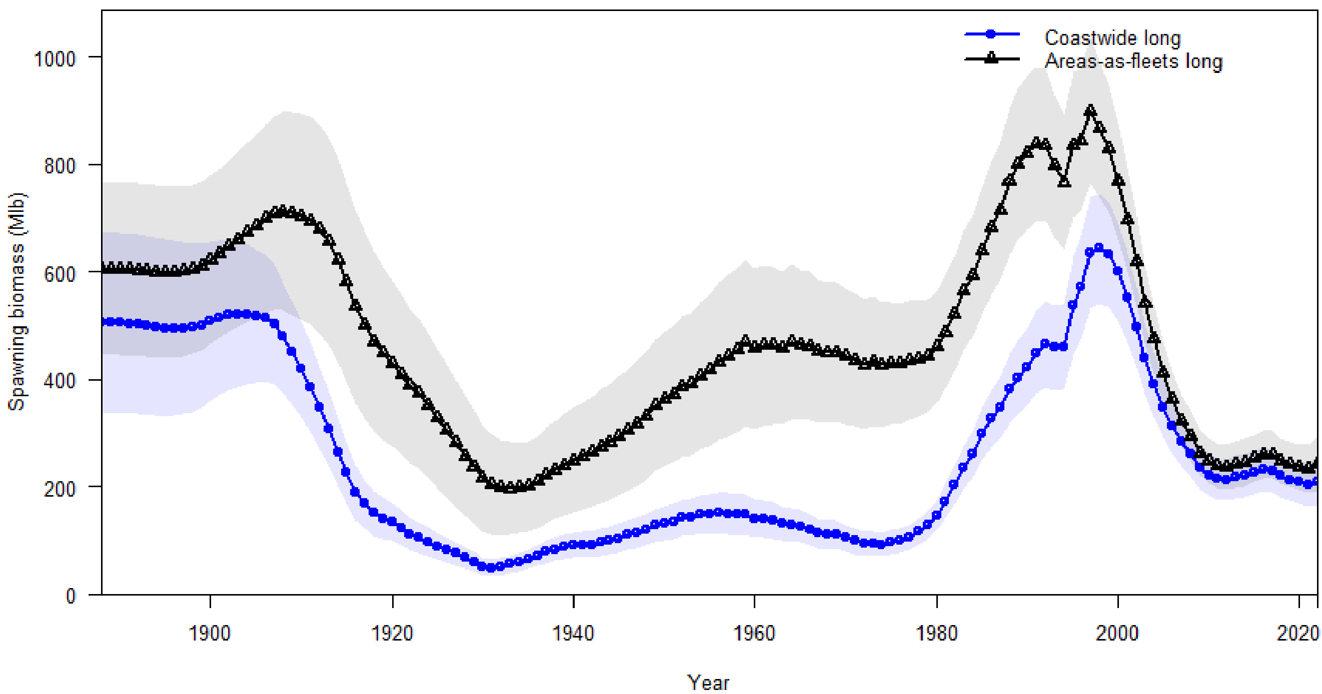

FIGURE 18. Spawning biomass estimates from the two long time-series models. Shaded region indicates the approximate 95% within-model credible interval. The black (upper) series is the Areas-As-Fleets model and the blue (lower) series is the coastwide model.

MAJOR SOURCES OF UNCERTAINTY

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

The 2021 assessment includes four years (2017-20) of sex-ratio information from the directed commercial fishery landings. However, uncertainty in historical ratios, and the degree of variability likely present in those and future fisheries remains unknown. Additional years of data are likely to further inform selectivity parameters and cumulatively reduce uncertainty in stock size 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. Ongoing research to better understand the stock structure within the Convention Area as well as connectivity to Western North Pacific waters is ongoing. These investigations are particularly important for understanding the dynamics in IPHC Regulatory Area 4B, which is potentially the most demographically isolated of the eight IPHC Regulatory Areas.

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 depredation) could create bias in this assessment.

Maturation schedules are currently under renewed investigation by the IPHC. 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, the models use both fixed (0.15/year for female Pacific halibut) and estimated values. The female value estimated in the long AAF model (0.19) differs from the value estimated in the coastwide model (0.21). Both of these estimates are highly correlated to the relative commercial fishery selectivity of males and females, which is currently estimated based on only the four years of available data. Estimates of these processes contribute to the difference in scale and productivity for the two models which are not easily reconciled at present. Although this uncertainty is directly incorporated into the ensemble results, uncertainty in female natural mortality in the two short models is not and remains an avenue for future investigation.

This stock assessment contains a broad representation of uncertainty in stock levels when compared to analyses for many other species. This is due to the inclusion of both within-model (parameter or estimation uncertainty) and among-model (structural) uncertainty. Due to the many remaining uncertainties in Pacific halibut biology and population dynamics, a high degree of uncertainty in both stock scale and trend will continue to be an integral part of an annual management process, which can result in variable mortality limits from year to year. Potential solutions to reduce the variability in mortality limits include management procedures that utilize multi-year management approaches, which are being tested with the MSE framework.

SENSITIVITY AND RETROSPECTIVE ANALYSES

A wide range of sensitivity analyses have been conducted during the development of the 2015 and 2019 full stock assessments (Stewart and Hicks 2019; Stewart and Martell 2016). These efforts form the primary basis for the identification of important sources of uncertainty outlined above. The most important contributors to estimates of both population trend and scale 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. In order to ensure that research priorities are closely linked with stock assessment uncertainties and in preparation for the upcoming full stock assessment in 2022, sensitivity analyses were conducted in 2021 to investigate: the effects of unobserved whale depredation, the treatment of the PDO and trends in spawning output (due to skip spawning or changes in maturity schedules).

For the first of these analyses, unobserved whale depredation was added to the coastwide short assessment model, ramping from zero to a 10% increase in directed commercial fishery mortality in 2021. The results indicated that underestimating the fishery-related mortality would lead to underestimating the spawning biomass across the entire recent time-series (Figure 19). The second analysis removed the PDO covariate from the two long time-series models. Results indicated that conditions in the late 1800s were affected to the greatest degree (both models) but in the long AAF model there were changes to the scale of the estimated spawning biomass throughout the time-series (Figure 20). Differences in the most recent years, which would have the greatest effect on the calculation of reference points were relatively small; however, this sensitivity illustrates the greater uncertainty in the overall scale of the population in the AAF long model as well as the correlation in scaling among recruitments over the entire time-series. Finally, a large change in maturity (shifting the maturity schedule either up or down 3 years in age with this effect increasing linearly over the most recent 15 years) was explored using the coastwide short assessment model. Such a trend is likely more extreme than would be plausible; however, this sensitivity clearly showed the strong effect on the estimated spawning biomass: increasing when maturity was shifting to younger ages and decreasing when maturity was shifting to older ages (Figure 21). This result supports the prioritization of maturity, fecundity and skip spawning as current and near-term research foci.

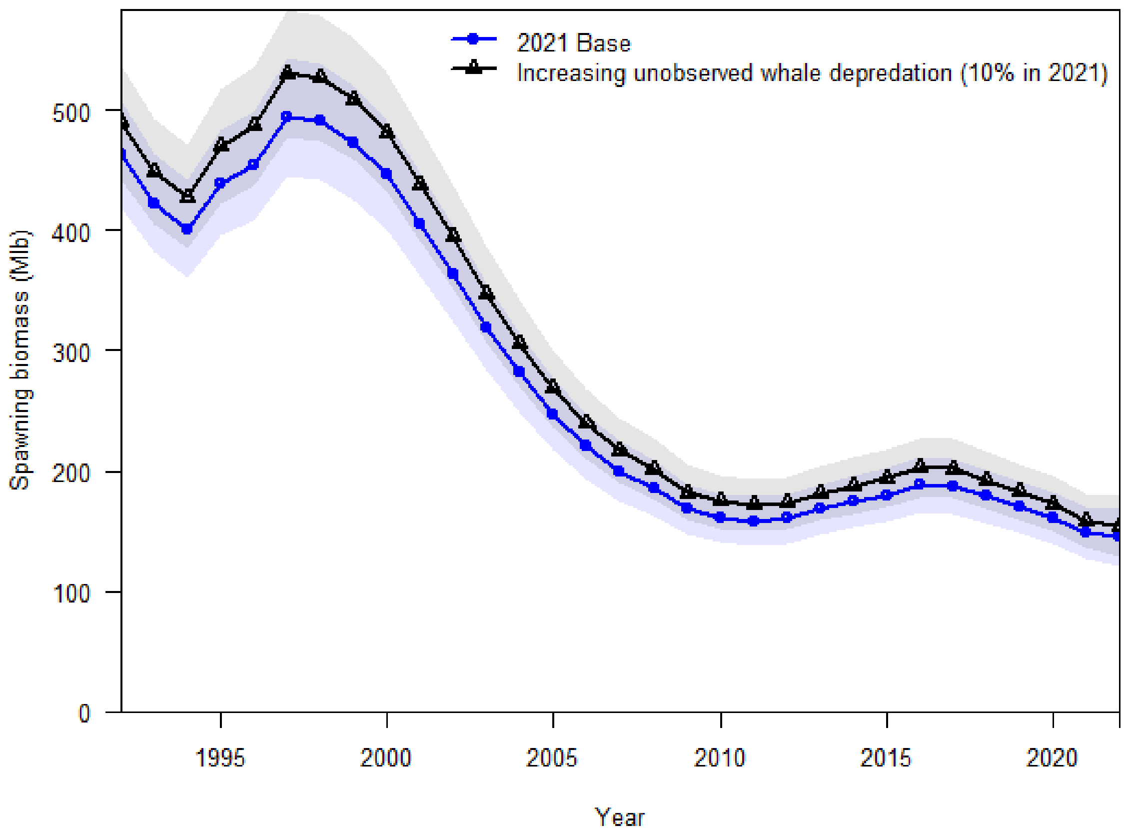

FIGURE 19. Spawning biomass estimates from a sensitivity analysis to increasing whale depredation mortality (0-10% over the period 1995-2021) using the coastwide short model. Shaded regions and vertical whiskers indicate approximate 95% within-model credible intervals.

To illustrate the effects of recent data separate from all other model changes and data updates, retrospective analyses were performed for each of the individual models contributing to the assessment. This exercise consists of sequentially removing the terminal year's data and rerunning the assessment model. This is commonly done for five or more years; however, the current models, restructured for the 2019 stock assessment around estimation of commercial fishery selectivity separately for males and females, rely on sex-ratios-at-age which are only available from 2017-2020. Therefore, the retrospective for this year's assessment includes three 'peels', each cumulatively removing one year of data (2021, 2020-2021, and 2019-2021). Estimates for relative male and female selectivity parameters become less certain with reduced data and required at least two years of data for reliable estimation. As data accumulate since this change in model structure it will be possible to extend the range of retrospective analyses further (as this assessment has compared to the 2020 assessment).

The retrospective analysis revealed that spawning biomass time series for each of the four stock assessment models changed very little as the terminal year's data were removed; with the highest variance in the results observed for the AAF long model but no clear trends (Figures 22-25; upper panels). As noted above, the AAF long model was very sensitive to the estimated values for natural mortality, which were correlated with relative male and female selectivity in the directed commercial fishery. This result highlights the 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 2019 to 2021 data on the magnitude of the estimated 2012 year-class.

This cohort is informed by each year of additional data and the estimated magnitude increased strongly across the three model runs (Figures 22-25; lower panels).

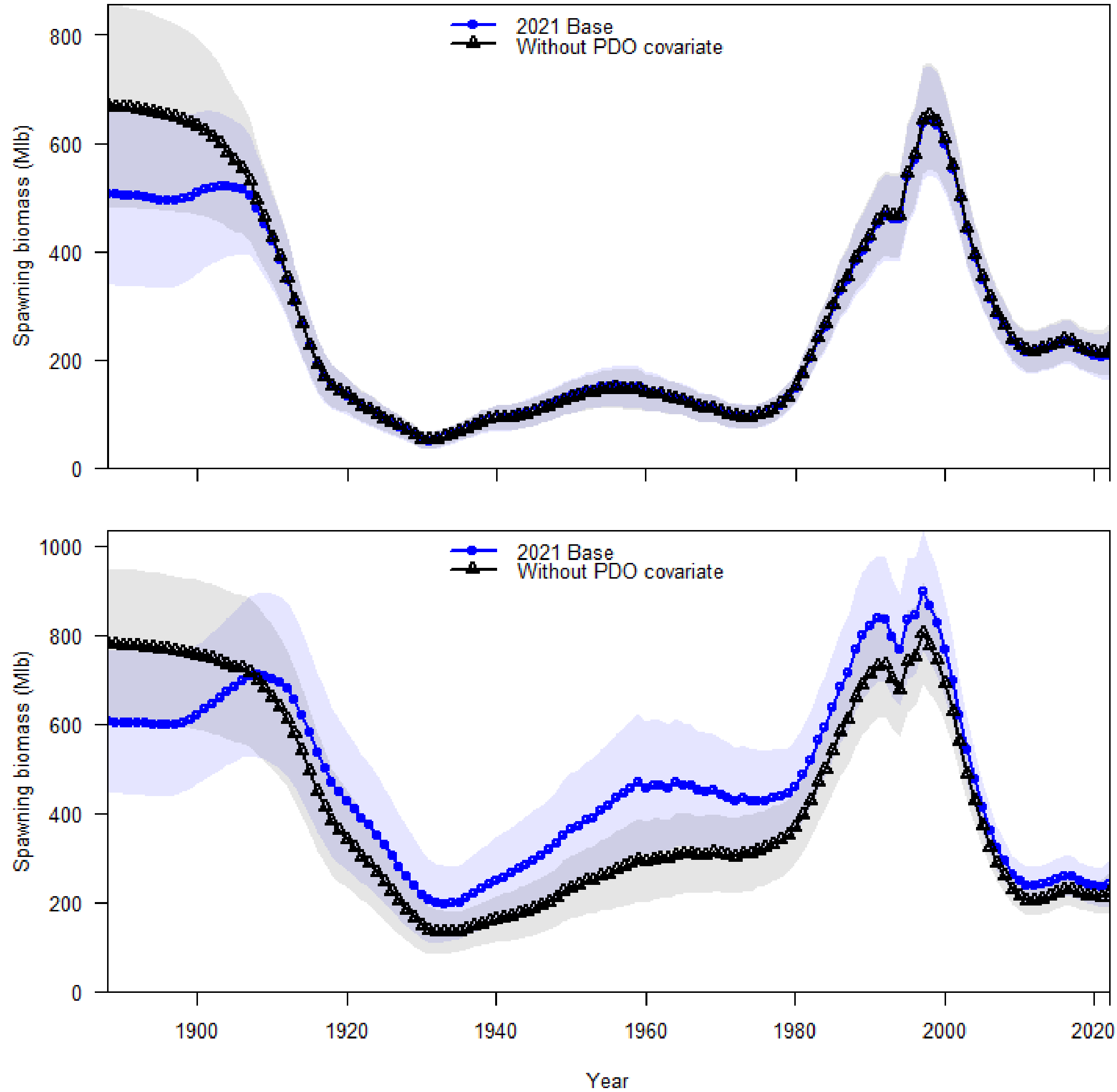

FIGURE 20. Spawning biomass estimates based on the long coastwide model (upper panel) and long AAF model (lower panel) from a sensitivity analysis to removing the PDO as a covariate to average equilibrium recruitment in the stock-recruit function. Shaded regions and vertical whiskers indicate approximate 95% within-model credible intervals.

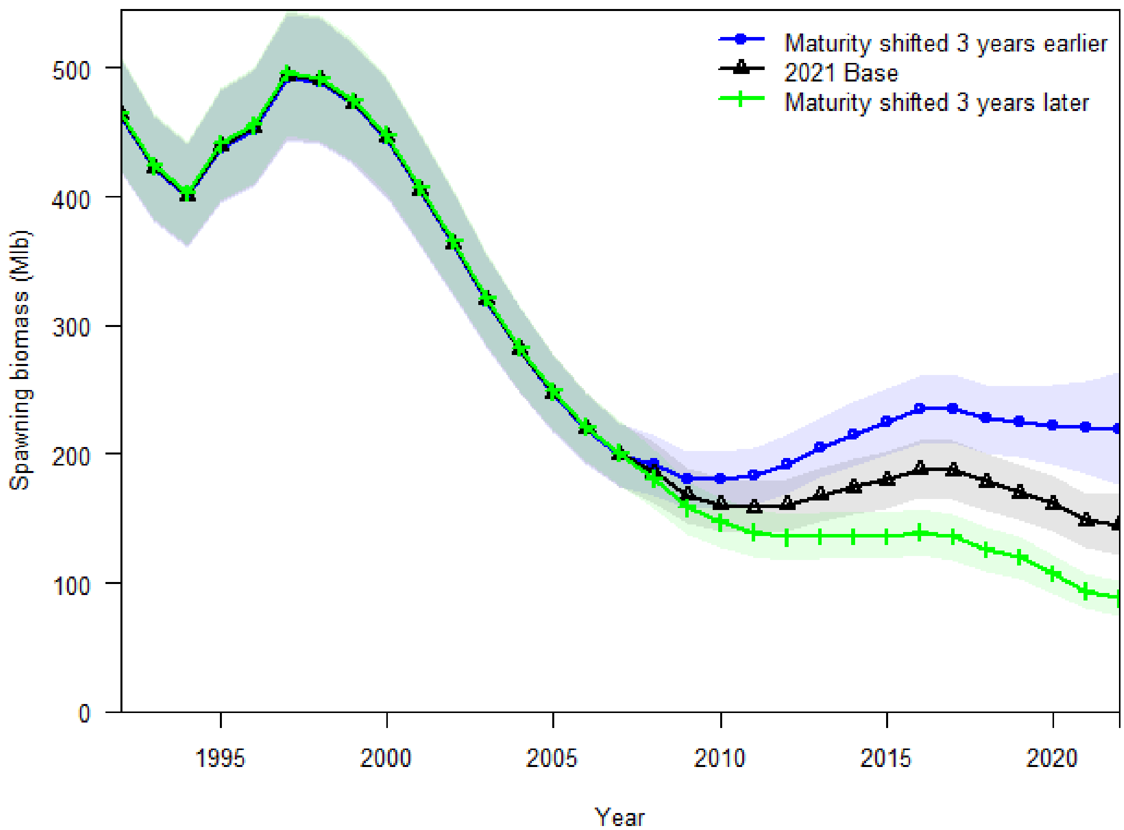

FIGURE 21. Spawning biomass estimates from a sensitivity analysis to shifting the maturity schedule (+/- 0-3 years increasing over 2007-2021) using the coastwide short model. Shaded regions and vertical whiskers indicate approximate 95% within-model credible intervals.

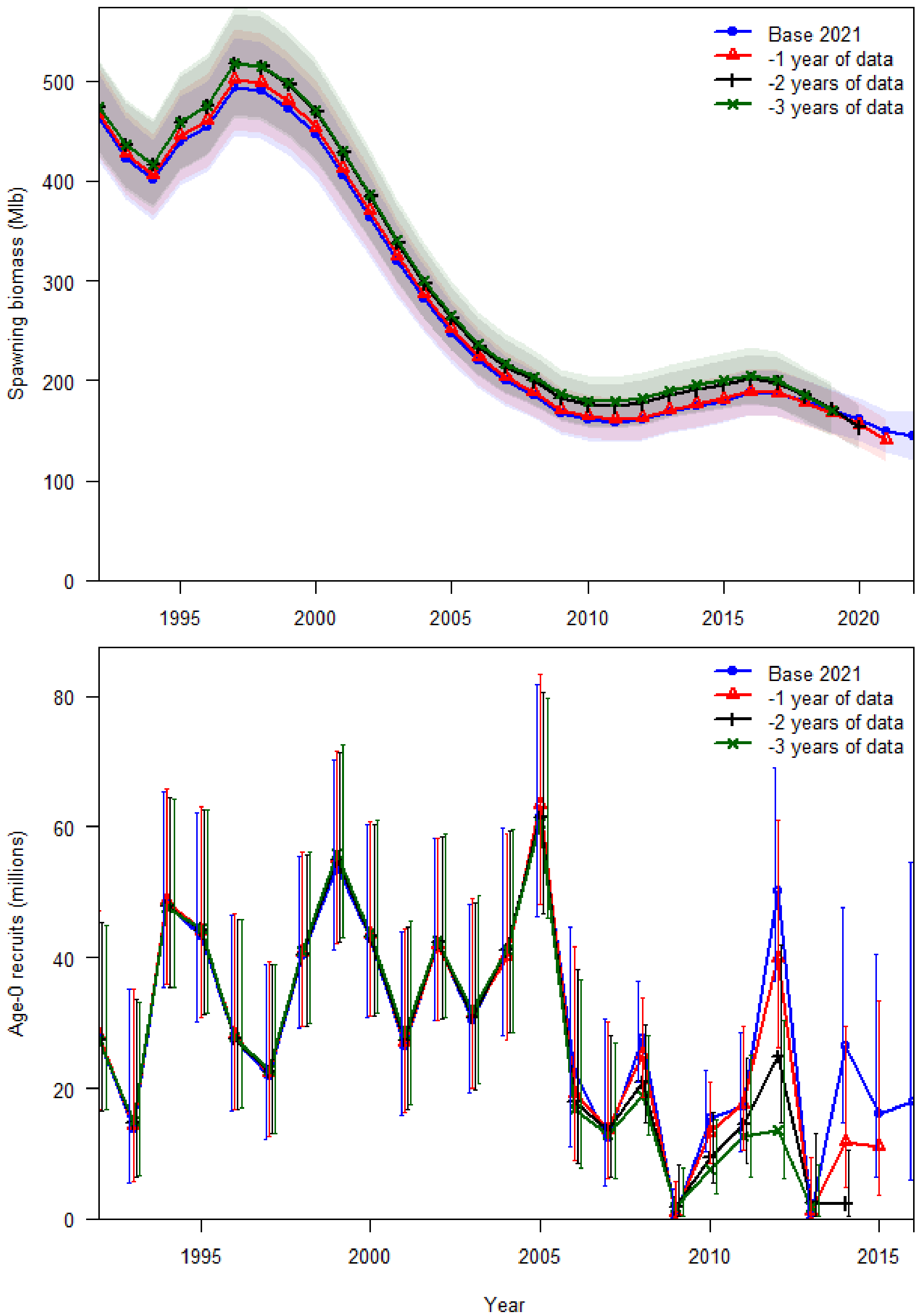

FIGURE 22. Spawning biomass (top panel) and recruitment (bottom panel) estimates from a retrospective analysis sequentially removing terminal years of data from the coastwide short model. Shaded regions and vertical whiskers indicate approximate 95% within-model credible intervals.

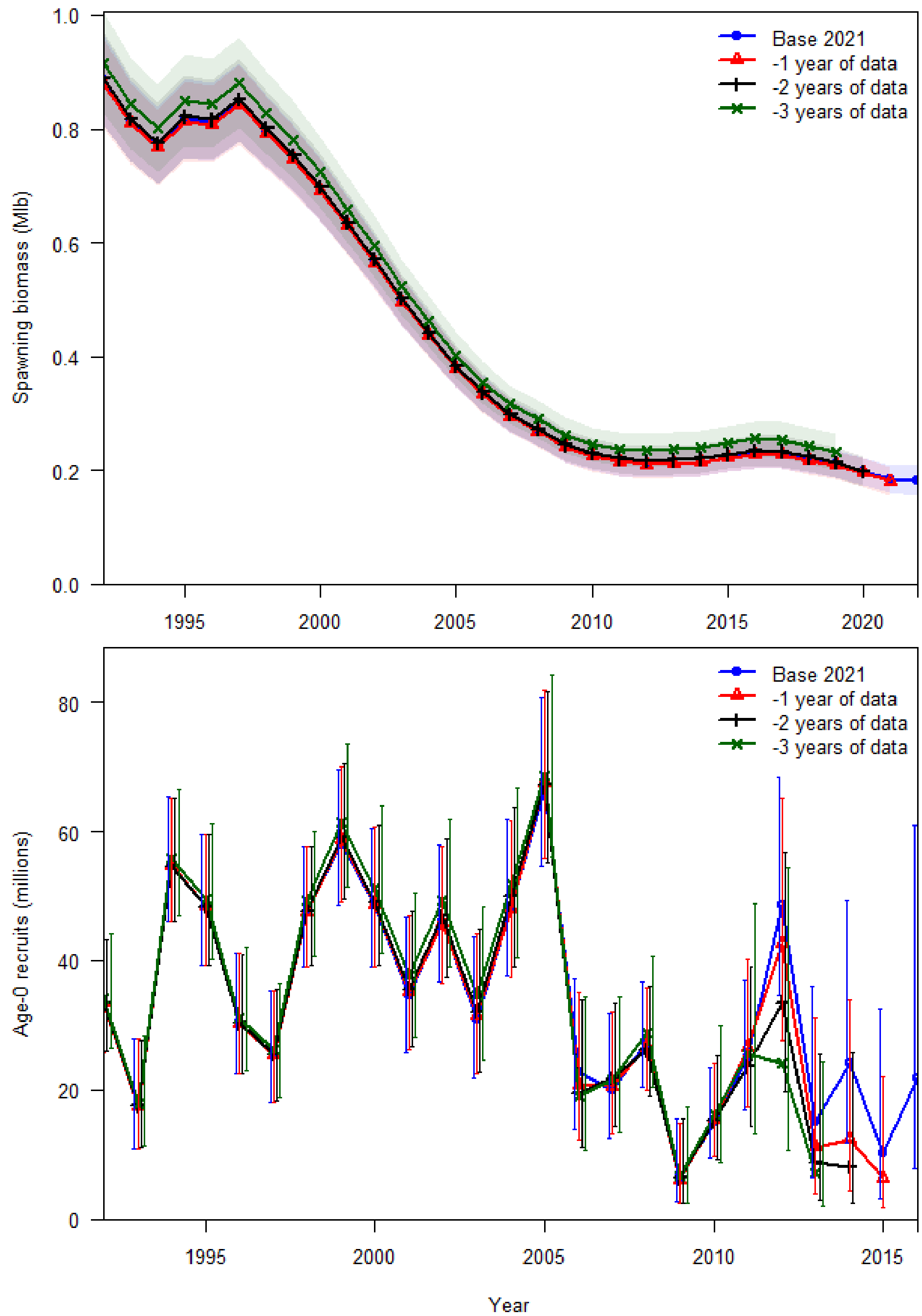

FIGURE 23. Spawning biomass (top panel) and recruitment (bottom panel) estimates from a retrospective analysis sequentially removing terminal years of data from the AAF short model. Shaded regions and vertical whiskers indicate approximate 95% within-model credible intervals.

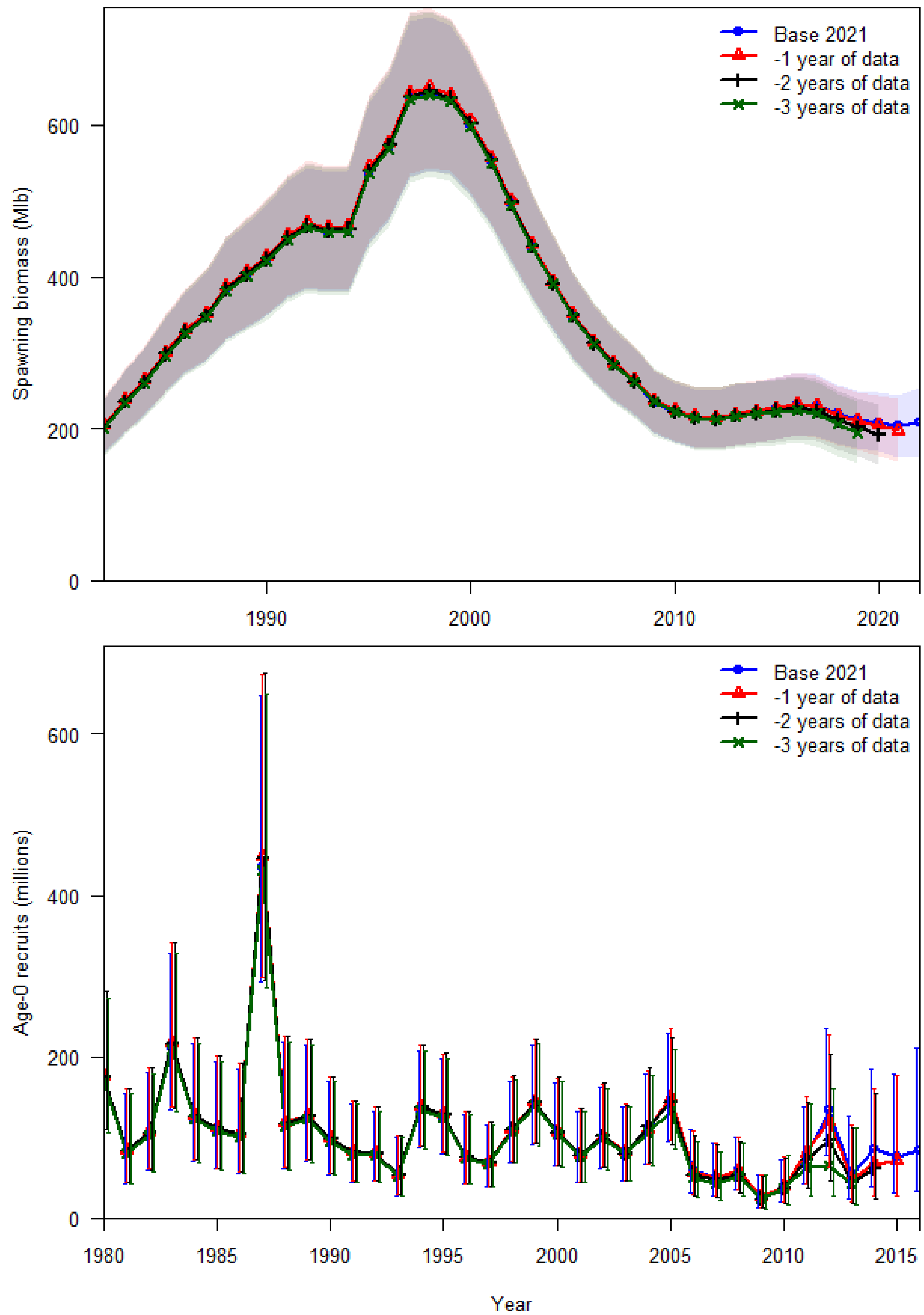

FIGURE 24. Recent spawning biomass (top panel) and recruitment (bottom panel) estimates from a retrospective analysis sequentially removing terminal years of data from the coastwide long model (time series has been truncated to allow for easier inspection of terminal values). Shaded regions and vertical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

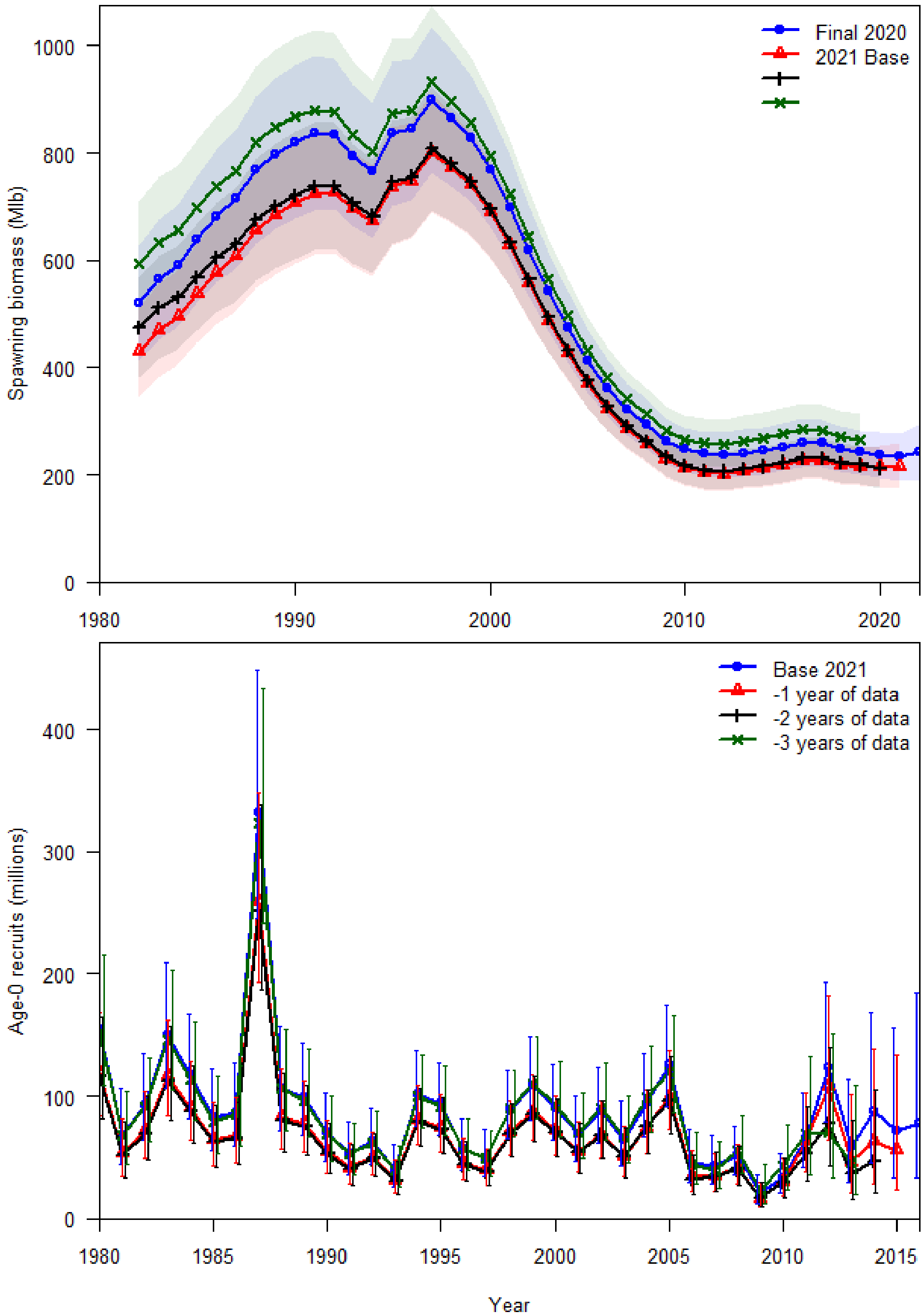

FIGURE 25. Recent spawning biomass (top panel) and recruitment (bottom panel) estimates from a retrospective analysis sequentially removing terminal years of data from the AAF long model (time series has been truncated to allow for easier inspection of terminal values). Shaded regions and vertical whiskers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

FORECASTS AND DECISION TABLE

Stock projections were conducted using the integrated results from the stock assessment ensemble in tandem with summaries of the 2021 directed and non-directed fisheries. The harvest decision table (Table 2) provides a comparison of the relative risk (in times out of 100), using stock and fishery metrics (rows), against a range of alternative harvest levels for 2022 (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 at which there is a 50% chance that the spawning biomass will be smaller in three years than in 2022 ("*3-year surplus*")
- The mortality consistent with repeating the TCEY set for 2021 (39.0 million pounds, 17,690 t; *"status quo"*).
- 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 2022 (median value with the 95% credible interval below) are reported.

The projections for this assessment are more optimistic than those from the 2019 and 2020 assessments due to the increasing projected maturity of the 2012 year-class. This translates to a lower probability of stock decline for 2022 than in recent assessments as well as a decrease in this probability through 2023-24. There is greater than a 50% probability of stock decline in 2023 (55-64/100) for the entire range of SPR values from 40-46%, which include the *status quo* TCEY and the $F_{43\%}$ reference level. The 2022 "3-year surplus" alternative, corresponds to a TCEY of 38.0 million pounds (~17,240 t), and a projected SPR of 48% (credible interval 32-63%; Table 2, Figure 26). At the reference level (a projected SPR of 43%), the probability of spawning biomass decline from 2022 to 2023 is 59%, decreasing to 55% in three years, as the 2012 cohort matures. The one-year risk of the stock dropping below $SB_{30\%}$ ranges from 43% at the $F_{46\%}$ level to 45% at the at the $F_{40\%}$ level of fishing intensity.

RESEARCH PRIORITIES

Research priorities for the stock assessment and related analyses have been consolidated with those for the IPHC's MSE and the Biological Research program (IPHC-2022-AM098-11).

ACKNOWLEDGEMENTS

We thank all of the IPHC Secretariat staff for their contributions to data collection, analysis and preparation for the stock assessment. We also thank the staff at the NMFS, DFO, ADFG, WDFW, ODFW, and CDFW for providing the annual information required for this assessment in a timely manner. The SRB and Science Advisors provided valuable input during the 2021 process.

TABLE 2. Harvest decision table for 2022. 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.

		2022 Alternative				**3-Year Surplus**		***Status quo***		***Reference $F_{43\%}$***				
		Total mortality (M lb)	**0.0**	**31.2**	**38.7**	**39.2**	**39.9**	**40.2**	**41.1**	**42.4**	**43.8**	**45.2**	**46.6**	**61.2**
		TCEY (M lb)	**0.0**	**30.0**	**37.5**	**38.0**	**38.7**	**39.0**	**39.9**	**41.2**	**42.6**	**44.0**	**45.4**	**60.0**
		2022 fishing intensity	$F_{100\%}$	$F_{53\%}$	$F_{46\%}$	$F_{46\%}$	$F_{45\%}$	$F_{45\%}$	$F_{44\%}$	$F_{43\%}$	$F_{42\%}$	$F_{41\%}$	$F_{40\%}$	$F_{32\%}$
		Fishing intensity interval	--	38-69%	32-64%	32-63%	32-63%	31-63%	31-62%	30-61%	29-60%	28-59%	28-59%	21-51%
Stock Trend (spawning biomass)	in 2023	is less than 2022	<1	39	55	55	56	57	58	59	61	63	64	84
		is 5% less than 2022	<1	3	14	16	18	19	21	25	30	34	37	58
	in 2024	is less than 2022	<1	39	53	54	55	55	56	58	59	61	62	80
		is 5% less than 2022	<1	16	37	39	40	41	43	46	48	50	52	66
	in 2025	is less than 2022	<1	33	49	50	51	52	53	55	56	58	60	77
		is 5% less than 2022	<1	18	38	39	41	42	43	46	48	50	52	67
Stock Status (Spawning biomass)	in 2023	is less than 30%	31	40	43	43	43	43	44	44	44	45	45	48
		is less than 20%	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	1
	in 2024	is less than 30%	16	34	39	39	40	40	41	41	42	43	44	49
		is less than 20%	<1	<1	<1	<1	<1	1	1	1	1	1	1	6
	in 2025	is less than 30%	4	29	36	37	37	37	38	40	41	42	43	49
		is less than 20%	<1	<1	1	1	1	1	1	1	2	2	3	12
Fishery Trend (TCEY)	in 2023	is less than 2022	0	21	48	49	49	49	50	50	50	50	51	70
		is 10% less than 2022	0	7	41	42	44	45	47	48	49	50	50	58
	in 2024	is less than 2022	0	22	48	48	49	49	50	50	50	50	50	69
		is 10% less than 2022	0	9	41	42	44	45	46	48	49	50	50	58
	in 2025	is less than 2022	0	22	47	48	48	49	49	50	50	50	50	68
		is 10% less than 2022	0	10	40	42	43	44	46	48	49	49	50	58
Fishery Status (Fishing intensity)	in 2022	is above $F_{43\%}$	0	20	48	49	49	50	50	50	50	50	51	70

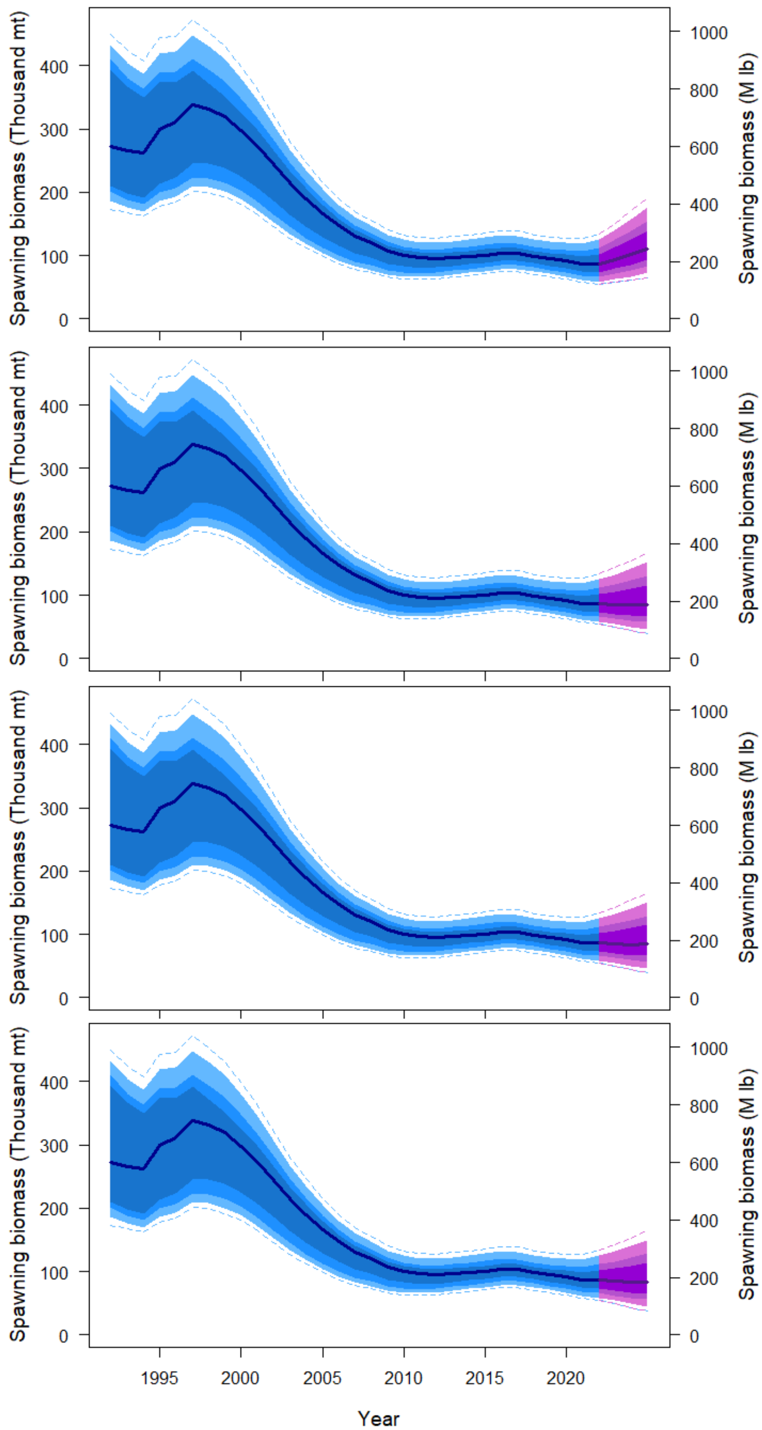

FIGURE 26. Three-year projections of stock trend under alternative levels of mortality: no fishing mortality (upper panel), the 3-year surplus (a TCEY of 38.0 million pounds, ~17,240 t; second panel), the *status quo* TCEY from 2020 of 39.0 million pounds, 17,690 t; third panel), and the TCEY projected for the IPHC's interim management procedure (41.2 million pounds, 18,690 t; lower panel).

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