Assessment of the Pacific halibut stock at the end of 2013

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Abstract

This stock assessment reports the status of the Pacific halibut resource in the northeastern Pacific Ocean. A thorough exploration of all data sources was completed and reviewed by the Scientific Review Board (SRB) during 2013. This included the historical record to the early 1900's, as well as updated 2013 information from the survey and commercial fishery. Halibut removals from all sources have totaled 6.9 billion pounds, ranging annually from 34 to 100 million pounds over the last 100 years. After a peak in 2004, annual removals have decreased each year due to management actions in response to declining survey and commercial catch rates and stock assessment estimates. Total removals in 2013 were estimated to be 46 million pounds, down from 52 million pounds in 2012. The 2013 setline survey WPUE decreased by 12% relative to 2012. Observed age distributions continue to indicate a relatively stable stock, but with no evidence of strong recruitments in recent years. Individual size-at-age remains low relative to levels observed in the past several decades, although comparable to those estimated for the early portion of the 20th century. The 2013 SRB meeting produced a number of important recommendations that have been incorporated into the 2013 assessment. The extensive evaluation of data sources, allowed for the development of two additional stock assessment models in 2013, one comparable with the 2012 model, and the other including the full historical time-series. These models produced results that were very close in scale to those from the 2012 stock assessment for the most recent years, corroborating the final results from 2012. This effort provided estimates of historical trends which generated much needed context for both the recent declines in the stock, and current abundance levels. All three of these models were included in an "ensemble" analysis, an approach endorsed by the SRB, which integrated the uncertainty within each model and among models into the final decision table.

The 2013 stock assessment results indicate that the Pacific halibut stock has been declining continuously over much of the last decade, primarily as a result of recruitment strengths that are much smaller than those observed through the 1980s and 1990s, as well as decreasing size-at-age. In the last few years, female spawning biomass is estimated to have stabilized near 200 million pounds. The 2014 estimate of exploitable biomass consistent with the IPHC's current harvest policy is 170.29 million pounds. The long time-series model provided several alternative reference points for comparison: the stock is currently estimated to be at 38% of the long-term average equilibrium spawning biomass, and 34% of the current stock size projected in the absence of fishing. It is also estimated to be considerably larger (187%) than the spawning biomass estimate from the late 1970s. As in 2012, forecast projections were conducted for a range of alternative management actions; and probabilities of various risk metrics are reported in a decision-making table framework. The application of the current harvest policy results in the Blue Line of the decision table with a coastwide TCEY of 33.49 million pounds.

Introduction

This stock assessment reports the status of the Pacific halibut resource in the northeastern Pacific Ocean, including the territorial waters of the United States and Canada. As in recent assessments, the resource is modeled as a single stock extending from northern California to the Aleutian Islands and Bering Sea, including all inside waters of the Strait of Georgia and Puget Sound. Potential connectivity with the western Pacific Ocean resource is considered slight and is unaccounted for.

The halibut fishery has been closely managed for nearly 100 years, and much is known about the history of fishery removals, population trends, and biological characteristics. The 2013 assessment is the first in recent years to make use of the historical time-series. It also introduces a new approach to the annual stock assessment that does not rely on a single model, but instead focuses on understanding how estimates of stock dynamics and status compare among multiple approaches.

Data sources

A thorough exploration of data sources for the entire historical record, as well as updated 2013 information was completed and reviewed by the Scientific Review Board (SRB) during 2013 (Stewart 2014; Cox et al. 2014). Briefly, halibut removals (including all sources of mortality: target fishery landings and discards, bycatch in non-target fisheries, research, sport, and personal use) have totaled 6.9 billion pounds, ranging annually from 34 to 100 million pounds over the last 100 years (Table 3 and Fig. 33 in Stewart 2014); all weights in this document are reported as 'net' weights, head and guts removed; this is approximately 75% of the round weight). The average removal over this period has been 64 million pounds. Annual removals were above the 100-year average from 1985 through 2010. After a peak in 2004, annual removals have decreased each year due to management actions in response to declining survey and commercial catch rates and stock assessment estimates. Total removals in 2013 were estimated to be 46 million pounds, down from 52 million pounds in 2012. The 2013 setline survey WPUE decreased by 12% relative to 2012, back to the level observed in 2011. Commercial catch-rates also declined (by 8%) at the coastwide level. Survey and fishery age distributions continue to indicate a relatively stable stock, with no evidence of strong recruitments in recent years. Individual size-at-age remains low relative to levels observed in the past several decades, although comparable to those estimated for the early portion of the 20th century.

Assessment

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 (Stewart and Martell, *In press*). The 2012 stock assessment resolved the most recent retrospective bias (Stewart et al. 2013), and produced estimates of stock size that were considerably lower than previous analyses. This type of annual change, although necessary, is undesirable from a management perspective, and the 2013 stock assessment presents an approach that could make the process much more robust to model changes in the future.

Ensemble approach

The IPHC's Scientific Review Board (SRB) met to evaluate the stock assessment data and modeling conducted since the 2012 assessment on 1-3 October, 2013. This meeting produced a number of important recommendations that have been incorporated into the 2013 assessment and will be used to structure the work planned for 2014.

The re-analysis of all data sources, particularly the historical series, provided the basis for several new avenues of stock assessment modeling. The first was to recreate the existing stock assessment model 'from scratch', using independently coded software (Stock Synthesis; a widely used modeling platform developed at the National Marine Fisheries Service; Methot and Wetzel, 2013). This model was based on fully reprocessed and orthogonal data sources. Although similar in structure to the 2012 assessment model, alternative approaches to many of the technical aspects of the model (e.g., selectivity) that are more consistent with stock assessments for other North Pacific groundfish species were applied. This effort corroborated the results of the 2012 stock assessment in terms of recent stock size estimates; however it suggested somewhat larger biomass in the late 1990s and early 2000s.

A second extension included developing an assessment model that could accommodate all of the historical information from the commercial fishery and setline survey, accounting for changes in the fishery, introduction of size limits, spatial expansions, transition from "J" to circle hooks, and many other technical details of these series. A broader understanding of stock dynamics has been significantly hindered by the narrow view possible from the extremely short time-series in recent assessments. This analysis allowed for a re-evaluation of the link between environmental conditions in the North Pacific and halibut recruitment success (Clark and Hare 2006), and exploration of the fixed value for natural mortality used since 1998 (Clark and Parma 1999). With a comprehensive time-series of stock size estimates, this model also allowed for a comparison of alternate reference point calculations. Importantly, this model provided a second independent comparison with the results from 2012, using almost 100 years of additional data. The long time-series model, like the alternate short-time-series model, produced results that were very close in scale to those from the 2012 stock assessment for the most recent years. The long time-series model also provided much needed insight into the historical series as well as context for the recent declines in the stock and current abundance levels.

The focus in recent assessment cycles has been primarily centered on the technical aspects of a single stock assessment model, rather than on the more general goals of understanding the dynamics of the halibut resource, gaining perspective on where the stock is relative to past status, and evaluating how management actions influence the stock trends. Changes in annual assessment models, due to technical improvements (e.g., the retrospective bias), different interpretations or assumptions about biological data (e.g., natural mortality), and other modifications have led to variable yield estimates, unproductive debate about technical details during management deliberations, and a reduction in confidence about the annual assessment results. A solution to this dilemma, called "ensemble modeling", was endorsed by the SRB, and draws from the field of weather and hurricane forecasting (e.g., Hamill et al. 2012). This approach recognizes that there is no "perfect" assessment model, and that robust risk assessment can only be achieved via the inclusion of multiple models in the estimation of management quantities and the uncertainty about these quantities. This approach was actually used for the 2012 assessment, albeit in a crude manner, by including alternate models using differing values of natural mortality. However, this was identified at the time as only a preliminary means to address the uncertainty in management quantities pending further analysis.

For the 2013 stock assessment, an ensemble of all three alternative models now available for the halibut stock was used to produce the stock estimates and decision table results. As in 2012, arbitrary but reasonable weights were assigned to each alternative model: for 2013 each of the three models were assigned equal probabilities. The result are combined estimates of stock size and reference points that are substantially more robust to current or future technical changes to any one of the underlying models and a decision table provided in exactly the same manner as in 2012. This approach can be transparently improved in the future as additional models become available.

Comparison with the 2012 stock assessment

Comparison with previous stock assessments indicates that the 2013 results are very close to those from 2012, which lie inside the 50% interval of the ensemble (Fig. 1). When the 2012 stock assessment model was enhanced with the re-processed and newly available data, the point estimates for 2014 were also quite similar to the current results (Table 1). This 'bridge' comparison suggests that the 2013 assessment provides additional (improved estimates of uncertainty and historical perspective), but not conflicting information with the recent trends presented last year. The differences among the models contributing to the ensemble are most pronounced prior to the early 2000s (Fig. 2), and these differences are represented in the increased uncertainty in the 2013 results.

Biomass, recruitment and reference point results

Ensemble

The results of the 2013 stock assessment indicate that the Pacific halibut stock has been declining continuously over much of the last decade as a result of recruitment strengths that are much smaller than those observed through the 1980s and 1990s. Recruitments after 2007 do not yet have information available in the fishery or survey data, and therefore remain highly uncertain. Observed decreases in size-at-age have also been an important contributor to recent stock declines. In the last few years, the estimated female spawning biomass appears to have stabilized near 200 million pounds (Table 2 and Fig. 3). The 2014 estimate of exploitable biomass consistent with the IPHC's current harvest policy is 170.29 million pounds.

Long time-series model

The long time-series model provides, for the first time in recent years, historical estimates that are integrated with the current stock assessment results. This model was able to recreate the population age structure, and match the patterns in survey and commercial catch rates observed during the historical period (Fig. 4). Using the estimates produced from the long time-series model, halibut recruitment is estimated to be 37% higher, on average, during favorable Pacific Decadal Oscillation (PDO) regimes, a standard indicator of productivity in the North Pacific (Table 3). This is very consistent with the results of Clark and Hare (2002, 2006). Historically, these regimes have lasted approximately 30 years with positive conditions prior to 1947, poor conditions from 1947-1977, positive conditions from 1978-2006 and now poor conditions from 2007 to the present. Recruitment during the period from 1977 to 2006 was estimated to have been far higher than observed during any portion of the historical record (Fig. 5), leading to much larger stock sizes (Fig. 6), and therefore fishery yields available during this period.

There are number of useful reference levels against which to compare the current stock estimates. For the two shorter time-series models, the same calculation of the threshold 30% relative spawning biomass as has been used in recent assessments (spawning biomass per recruit, assuming average recruitment levels from a poor productivity regime) was used to populate the decision table. The longer time-series model also provides a comparable estimate to these values, suggesting the stock is at approximately 38% of the average condition expected in a poor recruitment period with relatively poor size-at-age (Fig. 7). This model also suggests the stock remains substantially higher than spawning biomass values estimated during the historical period (i.e., in the late 1920s and early 1930s just after the commission was formed, and again in the late 1970s at the end of a long period of poor recruitment; Table 3). Another comparison possible with the long time-series model is achieved by projecting the historical stock dynamics in the absence of fishery removals (assuming the same recruitment variability and the observed size-at-age), and comparing the relative trends. This analysis suggests that stock increases in the 1980s and 1990s as well as the recent stock declines would likely have occurred even in the absence of anthropogenic removals: changes in average recruitment and size at-age have been largely dictating stock trends (Fig. 8). The spawning biomass is currently estimated to be at 34% of the level projected from that analysis.

An additional analysis possible with the long time-series model is the evaluation of trends in surplus production, or the amount of biomass produced each year in excess of that needed to maintain the standing stock. Surplus production represents the change in stock size from one year to the next, plus the removals during that year. Specifically, if the stock stays at exactly the same level for two years, the removals were exactly equal to the surplus production. During the early 1900s, removals exceeded the annual surplus production and the halibut stock was 'fished-down' from previous very lightly exploited levels (Fig. 9). During much of the 20th century removals were very close to the annual surplus production, which increased as size-at-age increased. Estimated surplus production declined in the 1970s in response to poor recruitment over previous decades, then increased dramatically during the 1980s following substantially increased recruitment (and despite declining size-at-age). Although annual removals exceeded annual surplus production in the early 2000s, previous year's production was still available for harvest. In the last few years, surplus production is estimated to have declined back to levels near or slightly below the long-term average observed for the stock (Fig. 9).

Major sources of uncertainty

This stock assessment includes uncertainty associated with estimation of model parameters, treatment of the data (e.g., short and long time-series, overlap among sources) structuring of selectivity (length vs. age-based), natural mortality (fixed in the short time-series models vs. estimated in the long time-series model), and other differences among the three models included in the ensemble. The relative uncertainty in management quantities can be seen in the distribution for exploitable biomass, a quantity created for the current harvest policy that is used to generate the harvest rates and for apportionment. The distribution for the 2014 value is very broad, such that the small differences between the estimate from the 2013 assessment and the 2012 model (Table 1) are statistically insignificant (Fig. 10). Although this is a substantial improvement over the 2012 assessment, there are other important sources of uncertainty that are not included.

During 2012, natural mortality was identified as the most influential fixed parameter in the Pacific halibut stock assessment. Alternate values of natural mortality were therefore used to create three models from which the decision table was constructed. The fixed values used were 0.1, 0.15 (the value used in the primary assessment model) and 0.2. This approach was necessary, because the 2012 assessment model was unable to resolve a reasonable estimated value. This was not necessary for the 2013 stock assessment, as alternate values of natural mortality are included in the models contributing to the ensemble. Specifically, using the larger data sets, the long time-series model produces an estimate of female natural mortality of 0.2 (+/- 0.03; it contains sufficient data for estimation), and the value of 0.15 is retained in the 2012 and short time-series models.

An important unaddressed source of uncertainty is the spatial structure of the assessment model. The SRB endorsed the staff's plans to develop additional alternative models using both implicit and explicit spatial structure for future stock assessments, and these efforts may provide alternate models for inclusion into the ensemble approach.

The recent trends of reduced recruitment appear consistent with the transition from a positive to a negative PDO regime, however the correlation between halibut recruitment and environmental conditions remains poorly understood, and there is no guarantee that it will continue in the future. Therefore, recruitment variability remains a significant source of uncertainty in current stock estimates (due to the substantial lag between birth year and direct observation in the fishery and survey data) as well as short-term stock projections. Long-term projections would be entirely dominated by currently unobserved recruitment dynamics, as well as potential changes in size-at-age. The current low size-at-age is also a major driver of stock trends; unfortunately, the mechanisms involved are poorly understood. However, the historical record suggests that size-at-age changes relatively slowly; therefore, although highly uncertain, near-term future values are unlikely to be dramatically different than those currently observed.

Future expansion of the ensemble approach will continue to improve uncertainty estimates, and create assessment results that are robust to changes in individual models, data sets and other sources of historical changes in stock assessment results from year to year.

Sensitivity analyses

A wide range of sensitivity analyses were conducted during the 2013 process, but only a few of particular interest reported here. Because all three models tended to behave in a similar manner to changes in various assumptions, and because only the long-time-series model could be used to investigate certain processes, it is used for all analyses reported below.

The most influential source of uncertainty uncovered among sensitivity analyses conducted for 2013 was the sex-ratio of the commercial catch. There is no direct information available (due to dressing of fish at sea prior to observation by IPHC port samplers), and so the 2013 assessment relies on indirect estimates from the sex-ratios observed in the setline survey. These indirect estimates are either directly applied to estimate the size and age composition of the catch following the methods of Clark and Hare (2006) as has been done in recent assessments, or informing the model parameters defining the relative selectivity for the commercial fishery. Results were found to be very sensitive to this choice: a +/- 10% change in the relative selectivity for males vs. females (and therefore the sex-ratio of the catch) resulted in a 50 million pound range in the estimate of spawning biomass (Fig. 11). Efforts are underway to evaluate methods for direct sampling via collaboration with industry such that this assumption can be explored further in future assessments. Future assessments may be able to include alternative models to represent this uncertainty within the ensemble.

Three sensitivity analyses were conducted to investigate the relative importance of uncertainty in several sources of halibut removals. These analyses were based on questions posed during the 2012 assessment and management process, or due to new information regarding methods for generating removals estimates. The first of these sensitivity analyses tested the influence of alternate levels of bycatch in non-target fisheries. Bycatch estimates are, for most regulatory areas, based on less than complete monitoring of all fishing activities, and therefore there is uncertainty associated with estimation, as well as the applicability of these estimates to fishing activity that went unmonitored (Williams, 2014). This sensitivity analysis explored the influence on the coastwide stock assessment of significantly higher (doubled) and lower (halved) levels of bycatch. There was little difference in the relative trends estimated for both alternatives; however doubling the bycatch did increase the estimated spawning stock estimate for 2014 by just over eight million pounds (Fig. 12). Additional sensitivity analyses to changes in bycatch that are non-constant over time might have different effects. The historical record of industrial fishing in the northeast Pacific Ocean suggests several temporally-restricted scenarios of bycatch mortality that may be plausible; these and others will be explored in the future. Area-specific changes and potential effects on the application of the harvest policy within specific areas could also be the subject of future analyses.

Estimates of recreational removals have historically not included any estimates of mortality associated with captured and subsequently discarded halibut (Williams 2014). During 2013, estimates of recreational discards were produced for the fishery in Areas 2C and 3A (S. Meyer, ADFG; letter to the IPHC, 13 November, 2013). That analysis indicated that additional mortality on the order of 2-3% of the retained catch might be reasonable given the regulations currently in place. With no direct estimates for other regulatory areas, and little comparability among regulations currently and historically in place, it is difficult to hypothesize what magnitude of total coastwide recreational wastage might be plausible. Therefore, a simple sensitivity of adding 5% to all recreational removals in all years was conducted. This revealed that for the coastwide stock assessment there was no appreciable change in the estimated spawning biomass time-series (Fig. 13). Further evaluation into proxy estimates for each regulatory area, as well as sensitivity of harvest policy application to recreational wastage will be explored in future analyses.

The final sensitivity analysis reported here investigates the magnitude of directed commercial fishery wastage. As outlined in Gilroy and Stewart (2014), methods for estimating commercial wastage were improved for 2013; however, estimates remain indirect except for Area 2B which applies logbook-reported U32 discards beginning in 2006. Because of the indirect nature of the wastage estimates, the true level of uncertainty remains unknown. For this reason, a model run using doubled values of the estimated wastage was conducted. The results of this analysis indicated little difference in either the relative trend or scale of the coastwide assessment estimates (Fig. 14). As for the other sensitivity analyses, area-specific effects could be more pronounced given the harvest policy calculations and non-uniform estimates of wastage.

Retrospective analyses

A retrospective analysis using the long time-series model revealed little pattern in recent spawning biomass estimates as data are sequentially removed from the model (Fig. 15). Importantly, even the estimates deviating by the greatest degree from the current time-series were still contained in the estimated confidence intervals. This was not the case for assessment results conducted from 2006 through 2011 which included a very strong retrospective bias (Hare, 2012; Fig. 1).

Forecasts and decision table

As in 2012, stock projections were conducted using the coastwide stock assessment (all three models in the ensemble), summaries of the 2013 fishery, and other sources of mortality, as well as the results of apportionment calculations and harvest policy application. The steps included: 1) apportioning the coastwide estimate of exploitable biomass according to the survey catch rates in each regulatory area, adjusted for hook competition and survey timing (Webster and Stewart 2014), 2) applying the area-specific harvest rates to estimate the total CEY, and all other removals associated with a given level of harvest, and 3) calculating the total mortality and projecting the stock trends one and three years into the future.

The current harvest policy for Pacific halibut utilizes a ramp from target harvest rates down to no fishing between 30% and 20% relative spawning biomass (Fig. 16). Target harvest rates are 21.5% in Areas 2A, 2B, 2C and 3A, and 16.125% to Areas 3B, 4A, 4B, and 4CDE. Because the harvest policy is defined at the area-specific level, the results of apportionment calculations (Webster and Stewart 2014) are needed evaluate the harvest intensity, even though the assessment is conducted at a coastwide scale. Specifically, in order to compare the coastwide harvest rate estimated in the stock assessment to a target level, exploitable biomass must be apportioned to area, and then area-specific catch limits aggregated back to the coastwide level (Fig. 17). Using this method, harvest rates are estimated to have been above target levels for the last decade, although mortality reductions in the most recent three years (2010-2013) have brought the realized rate much closer to the target (Fig. 18). This calculation is based on the 2013 stock assessment results, and therefore does not correspond to the estimates and targets available as historical management decisions were being made.

The decision table (Table 4) provides a comparison of the relative risk, using a number of different stock and fishery metrics (columns) for a range of harvest levels in 2014 (rows). The decision table for 2013 is very similar in format to that reported in 2012, with a few changes to improve the clarity of the results. These changes include reporting probabilities as “times out of 100”, integrating one- and three-year projection for all quantities into a single table, organizing all row descriptions clearly outside the table contents, and more clearly delineating the metrics associated with the current harvest policy from those relating only to stock trend.

The block of columns entitled Stock Trend (a-d) provides an evaluation of the risks of various harvest levels to the short term trend in spawning biomass, without reference to a particular harvest policy. The remaining columns portray these risks relative to the spawning biomass reference points (e-h) and fishery performance (i-m) consistent with the current harvest policy. The 2014 alternative harvest levels (rows) provided include: no mortality (useful to evaluate the stock trend due solely to population processes), no directed mortality (but accounting for bycatch and non-scaling sport and personal use removals), the Blue Line (consistent with the current harvest policy and, historically, IPHC staff advice), the *status quo* removals (O26 mortality at the same level estimated in 2013), as well as a number of arbitrary values intended to foster the evaluation of the relative change in risk probability across a range of total mortality levels. As in 2012, additional alternatives will be produced during management deliberations such that all potential alternatives for 2014 can be evaluated in terms total mortality and associated risk.

The stock is projected to increase slightly in the absence of any mortality during 2014, and all levels of harvest above 30 million pounds of total mortality resulted in declines in the current stock size by 2015 (Table 4; Fig. 19), although there is considerable uncertainty associated with these projections. There is estimated to be only a 1/100 chance of greater than a 5% decline in spawning biomass from 2014 to 2015 for the Blue Line removals. The *status quo* removals correspond to an 8/100 chance of at least a 5% decline in spawning biomass, and 60 million pounds of total mortality a 38/100 chance. There is a higher probability of stock decline over the three year projections due to the delayed effects of recent recruitment, trends in size-at-age and compounding removals. As the stock stabilizes to biomass levels consistent with more recent recruitment levels (following the decline from much higher levels), it is reasonable to expect a greater response in stock trend to annual management decisions.

The metrics directly based on the current harvest policy (stock status, fishery trend, and fishery status), show a relatively small chance (<26/100) that the stock will decline below the 30% or 20% reference points in both the one- and three-year projections and under all alternatives presented. For removals in excess of the Blue Line, there is a greater than 50/100 probability that the fishery CEY would be smaller in 2015 and 2017 than if the current harvest policy were applied. The Blue Line removals correspond exactly to the application of the current harvest policy, and therefore the coastwide harvest rate target (Fig. 18). Because of the small decrease in the estimate of exploitable biomass relative to the value estimated in 2012, repeating the *status quo* removals would result in a slightly higher harvest rate than realized in 2013. A total mortality of 40 million pounds corresponds to an intermediate harvest rate, still above the Blue Line, but representing a reduction from 2013 (Fig. 18).

Future research

Based on data and model exploration completed during 2013, and recommendations from the SRB, future research will focus on the following topics:

1) Development of methods for sampling the sex-ratio of the commercial catch. The current assessment assumes that the setline survey sex-ratio is indicative of the commercial catch, but there are currently no direct observations to test this assumption. The results of the stock assessment are sensitive to the sex-ratio, and therefore this source of uncertainty is a high priority for future data collection.

2) Continued expansion of the ensemble of models used in the stock assessment. Specifically, implicit and explicit spatial models will be developed that will allow for incorporation of the uncertainty due to spatial processes such as migration and recruitment distribution among regulatory areas.

3) Bayesian methods for fully integrating parameter uncertainty may provide improved uncertainty estimates within models contributing to the ensemble.

4) Further investigation of the factors contributing to recruitment strength and observed size-at-age in order to better project trends in these quantities.

5) Exploration of methods for estimating wastage and bycatch in the assessment model as a function of effort, in order to better capture these sources uncertainty.

6) Analysis of projection methods for weight-at-age to determine if alternatives to recent trend might provide better estimates of likely future values and the uncertainty associated with these values.

7) Integration of the assessment results in the decision table with ongoing developments in the harvest policy arising through the MSE process.

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Table 1. Comparison of 2014 biomass point estimates (millions of net pounds) using the 2012 assessment model and from the 2013 ensemble analysis.

Quantity	2012 Assessment model	2013 Ensemble
2014 Exploitable biomass	176	170
2014 Spawning biomass	198	197

Table 2. Median population estimates (million lb) from the 2013 ensemble.

Year	Spawning biomass	Exploitable biomass
1997	570.3	796.8
1998	573.2	749.5
1999	563.2	739.7
2000	531.2	683.1
2001	489.0	597.8
2002	441.6	527.6
2003	390.5	458.6
2004	347.5	403.1
2005	307.7	353.7
2006	274.3	308.6
2007	248.9	268.4
2008	229.1	235.2
2009	206.3	202.7
2010	197.6	185.3
2011	193.5	174.6
2012	193.6	168.9
2013	194.9	168.4
2014	196.8	170.3

Table 3. Time-series of population estimates (million lb, recruits in millions) from the long time-series model.

Year	Age-8+ biomass	Spawning biomass	Age-0 recruits	Year	Age-8+ biomass	Spawning biomass	Age-0 recruits
1888	1,160.8	477.7	70.5	1933	324.9	52.8	34.2
1889	1,159.9	477.1	67.9	1934	339.6	56.6	31.1
1890	1,158.6	476.7	70.3	1935	338.7	60.9	54.9
1891	1,156.7	476.1	72.8	1936	351.6	66.4	48.8
1892	1,154.3	475.1	71.1	1937	382.6	72.9	40.1
1893	1,150.3	473.7	69.0	1938	395.7	78.2	54.4
1894	1,145.7	471.8	66.0	1939	405.0	83.3	48.6
1895	1,143.5	469.8	65.8	1940	400.4	86.2	43.8
1896	1,164.6	469.0	67.6	1941	400.1	88.1	55.5
1897	1,181.6	468.5	61.9	1942	398.3	89.7	44.4
1898	1,201.2	469.0	57.5	1943	431.2	92.3	49.2
1899	1,224.7	471.6	51.8	1944	453.5	94.9	49.2
1900	1,245.1	476.0	46.4	1945	465.0	98.2	25.8
1901	1,258.0	480.1	39.5	1946	494.1	103.1	31.3
1902	1,261.6	482.5	33.6	1947	510.6	106.7	22.3
1903	1,260.8	483.4	31.0	1948	518.5	111.2	24.8
1904	1,259.5	482.8	29.6	1949	547.9	117.6	26.4
1905	1,246.7	479.3	29.4	1950	558.2	122.2	29.8
1906	1,232.8	477.8	29.8	1951	568.0	125.4	48.2
1907	1,198.7	467.5	31.0	1952	588.0	131.2	24.6
1908	1,145.4	448.7	31.5	1953	562.1	133.1	27.9
1909	1,081.1	424.8	32.9	1954	563.4	139.3	31.2
1910	1,010.4	398.6	31.5	1955	546.3	140.8	33.1
1911	938.5	370.5	31.3	1956	551.5	146.1	22.0
1912	862.1	337.2	31.4	1957	553.3	145.7	35.7
1913	786.8	301.3	31.8	1958	564.9	145.3	27.0
1914	711.9	262.7	32.2	1959	622.8	147.5	18.1
1915	644.4	225.8	31.8	1960	604.0	141.5	21.0
1916	583.1	191.4	32.4	1961	606.0	140.6	34.8
1917	546.2	169.4	31.5	1962	606.0	137.9	17.6
1918	513.2	151.1	29.1	1963	597.5	132.0	22.8
1919	493.2	140.5	27.1	1964	588.3	131.0	21.6
1920	473.6	130.9	26.4	1965	587.5	127.1	20.7
1921	451.4	120.5	27.5	1966	562.8	122.4	21.6
1922	427.1	109.4	31.4	1967	518.5	116.6	25.7
1923	413.3	103.4	38.1	1968	493.9	114.0	29.8
1924	394.7	95.2	45.7	1969	503.8	113.6	35.0
1925	375.2	87.1	47.1	1970	470.7	108.2	43.9
1926	356.0	80.4	42.3	1971	449.8	102.8	39.4
1927	333.8	73.3	30.5	1972	434.3	98.9	56.1
1928	310.0	65.5	37.6	1973	425.1	97.3	66.9
1929	290.3	58.5	48.7	1974	413.4	95.4	45.7
1930	276.3	51.5	38.0	1975	429.7	99.6	61.0
1931	280.3	48.7	37.5	1976	451.9	102.4	64.5
1932	301.3	49.7	30.1	1977	487.7	108.0	104.8

Table 3. Continued.

Year	Age-8+ biomass	Spawning biomass	Age-0 recruits
1978	547.5	118.1	58.8
1979	595.1	131.0	108.3
1980	676.8	148.4	136.9
1981	785.7	172.8	67.5
1982	853.6	200.7	68.2
1983	941.8	231.1	143.8
1984	995.9	252.7	106.7
1985	1,142.8	280.3	68.7
1986	1,180.4	302.6	59.6
1987	1,279.7	316.5	342.8
1988	1,465.0	344.8	52.1
1989	1,455.6	362.3	93.2
1990	1,431.2	379.4	66.5
1991	1,543.4	400.3	52.5
1992	1,561.4	416.7	54.0
1993	1,482.5	420.1	32.1
1994	1,403.1	420.8	88.9
1995	1,966.8	491.9	88.7
1996	1,947.3	529.9	48.9
1997	1,973.5	570.4	44.6
1998	1,886.4	573.4	73.6
1999	1,749.2	565.2	101.9
2000	1,591.9	534.1	72.1
2001	1,410.8	492.4	54.5
2002	1,334.8	444.4	70.8
2003	1,267.6	392.7	42.0
2004	1,154.1	349.5	69.4
2005	1,038.9	309.5	63.6
2006	979.0	276.2	33.9
2007	973.5	250.6	30.6
2008	927.7	231.1	36.7
2009	845.6	207.6	47.6
2010	809.6	197.3	48.1
2011	744.2	189.8	47.9
2012	725.1	185.2	47.7
2013	702.2	181.8	47.5
2014	667.5	183.1	47.6

Table 4. Decision table of yield alternatives (rows) and risk metrics (columns). Values in the table represent the probability, in “times out of 100” of a particular risk.

				Stock Trend				Stock Status				Fishery Trend				Fishery Status
				Spawning biomass				Spawning biomass				Fishery CEY from the harvest policy				Harvest rate
				in 2015		in 2017		in 2015		in 2017		in 2015		in 2017		in 2014
2014 Alternative	Total removals (M lb)	Fishery CEY (M lb)	Harvest rate	is less than 2014	is 5% less than 2014	is less than 2014	is 5% less than 2014	is less than 30%	is less than 20%	is less than 30%	is less than 20%	is less than 2014	is 10% less than 2014	is less than 2014	is 10% less than 2014	is above target
No removals	0.0	0.0	0.0%	5/100	<1/100	23/100	4/100	3/100	<1/100	1/100	<1/100	0/100	0/100	0/100	0/100	0/100
FCEY = 0	11.4	0.0	5.0%	31/100	<1/100	32/100	18/100	3/100	<1/100	2/100	<1/100	0/100	0/100	0/100	0/100	<1/100
	20.0	8.5	10.1%	33/100	<1/100	37/100	24/100	4/100	<1/100	3/100	<1/100	<1/100	<1/100	<1/100	<1/100	<1/100
	30.0	18.2	15.9%	39/100	<1/100	66/100	41/100	4/100	<1/100	5/100	<1/100	5/100	2/100	8/100	4/100	7/100
Blue Line	36.4	24.5	19.7%	56/100	1/100	82/100	63/100	5/100	<1/100	6/100	1/100	43/100	20/100	74/100	47/100	50/100
	40.0	28.0	21.8%	68/100	1/100	87/100	73/100	5/100	<1/100	8/100	1/100	85/100	52/100	96/100	84/100	92/100
	45.0	32.8	24.7%	82/100	4/100	93/100	83/100	6/100	1/100	10/100	1/100	>99/100	95/100	>99/100	99/100	>99/100
status quo	48.5	36.1	26.7%	88/100	8/100	95/100	87/100	6/100	1/100	13/100	1/100	>99/100	>99/100	>99/100	>99/100	>99/100
	55.0	42.6	30.5%	95/100	23/100	98/100	94/100	6/100	1/100	19/100	2/100	>99/100	>99/100	>99/100	>99/100	>99/100
	60.0	47.5	33.5%	98/100	38/100	99/100	97/100	7/100	1/100	26/100	2/100	>99/100	>99/100	>99/100	>99/100	>99/100
				a	b	c	d	e	f	g	h	i	j	k	l	m

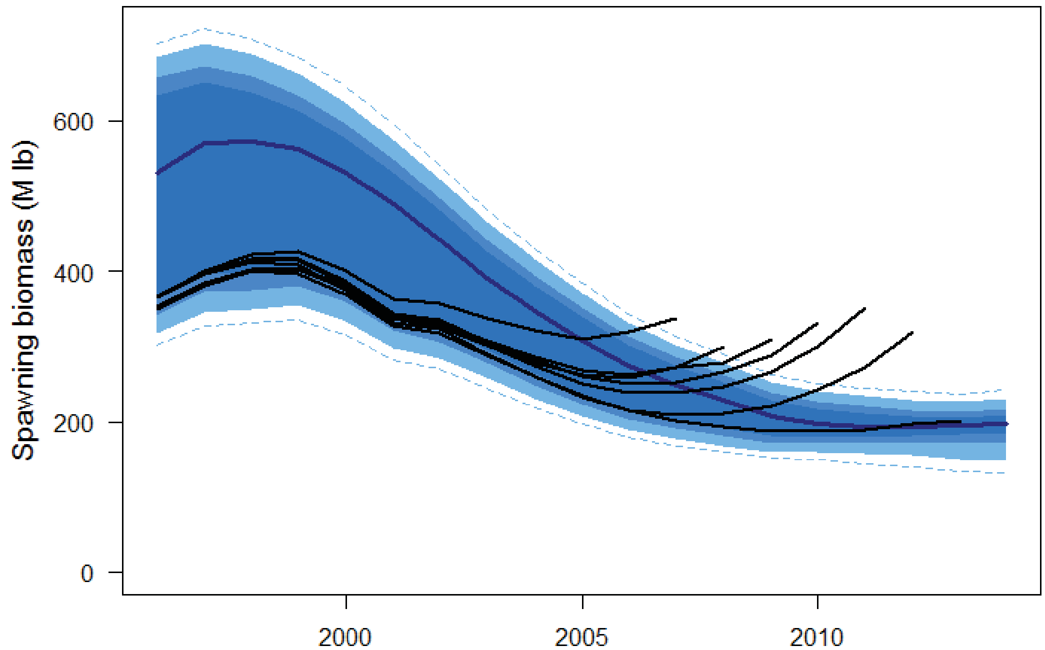

Figure 1. Retrospective analysis among recent stock assessments. The black lines denote previous assessments ending in 2006, 2007, 2008, 2009, 2010, 2011 and 2012. The dark blue line indicates the median (or "50:50 line"; with equal probability of the estimate falling above or below that level) from the 2013 assessment; 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.

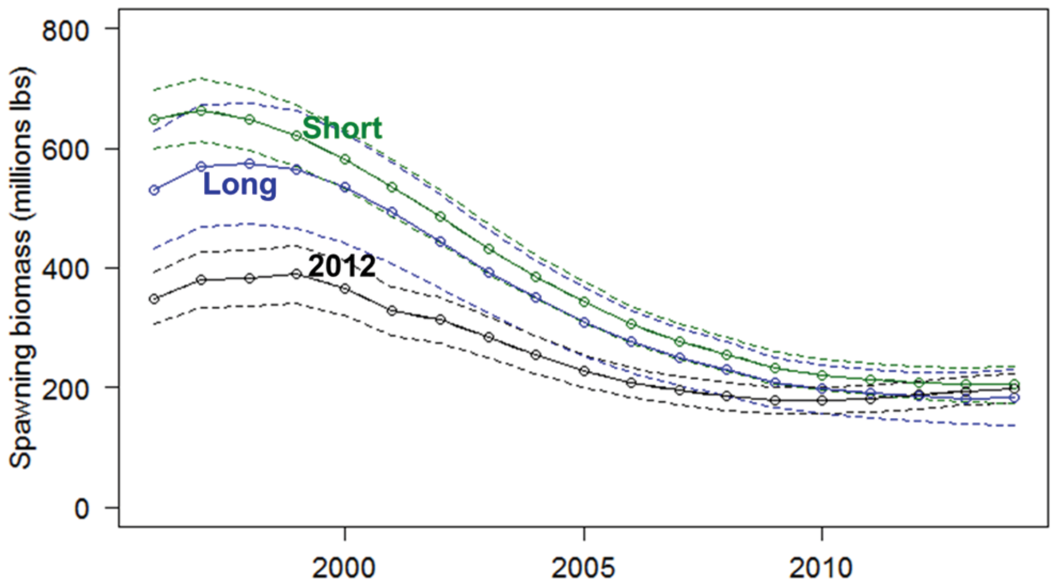

Figure 2. Comparison of models included in the 2013 stock assessment.

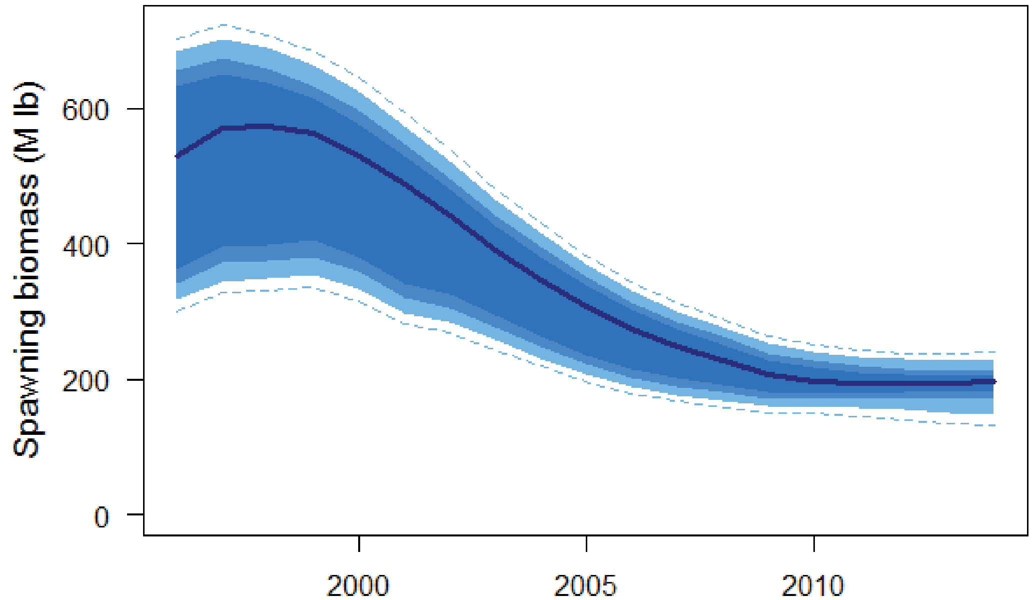

Figure 3. Trend in spawning biomass estimated in the 2013 stock assessment. The dark line indicates the median (or "50:50 line") with an equal probability of the estimate falling above or below that level; colored bands moving away from the median indicate the intervals containing 50/100, 75/100, and 95/100 estimates; dashed lines indicating the 99/100 interval.

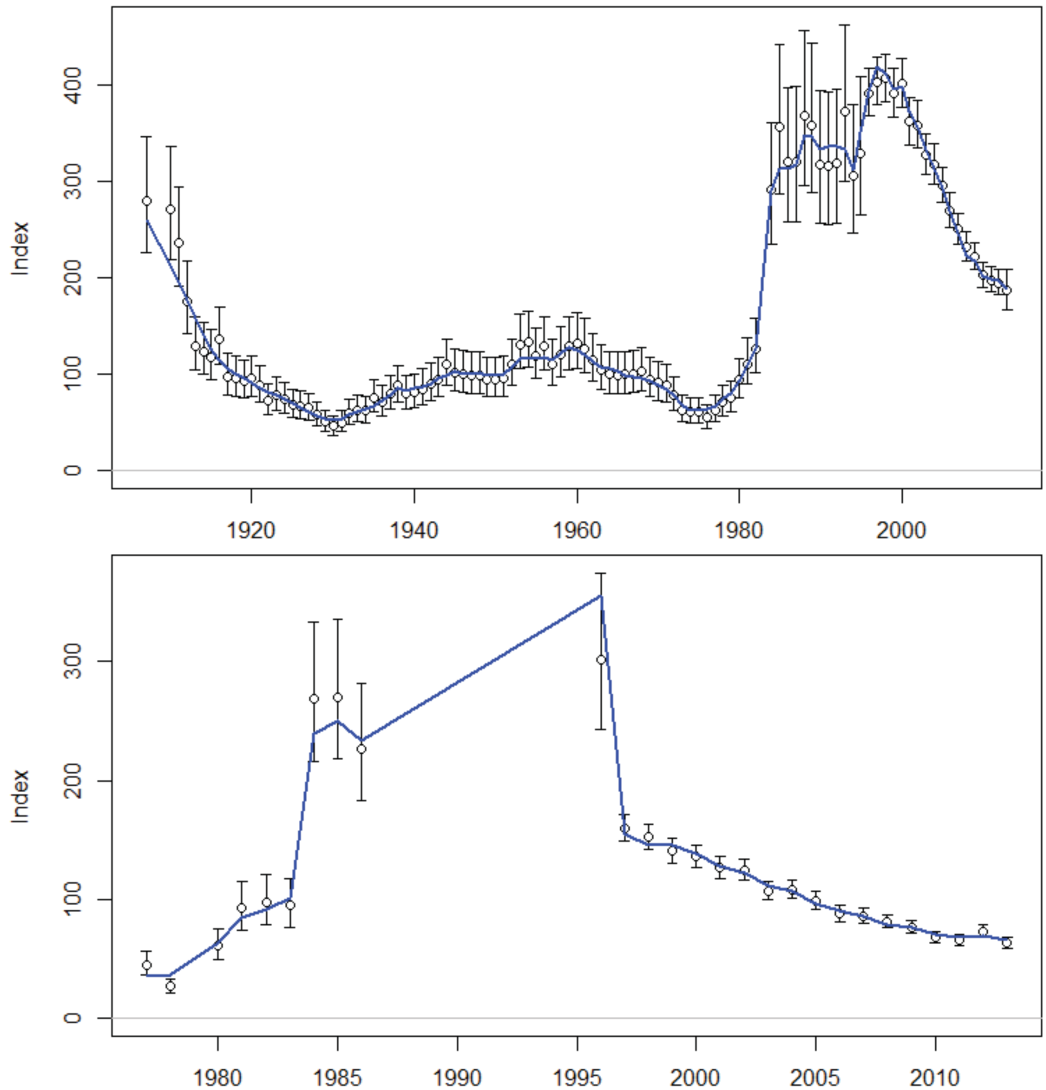

Figure 4. Observed (points with 95% confidence intervals) and predicted (lines) fishery (upper panel) and survey (lower panel) catch-rates. Note that the abrupt change in scale from 1983-1984 is due to the introduction of circle hooks to the fishery and survey.

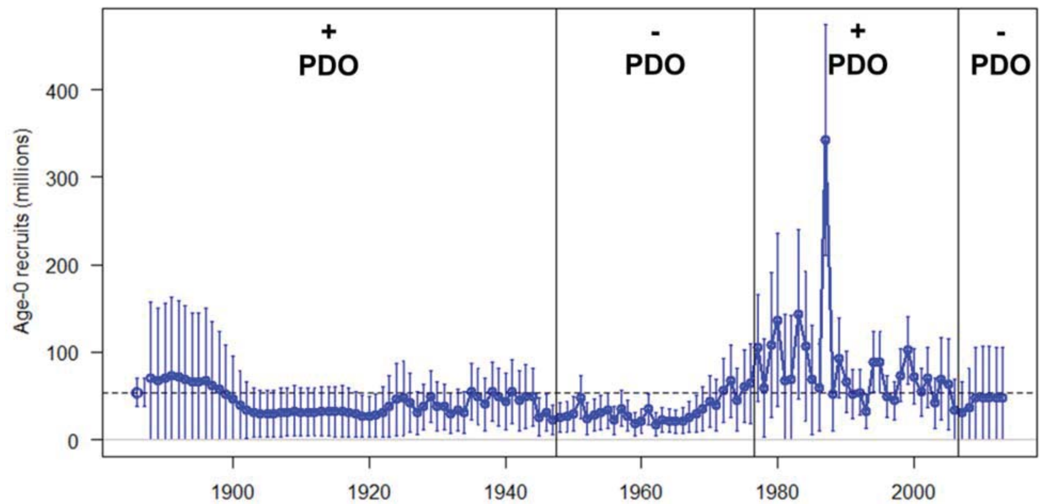

Figure 5. Trend recruitment strengths (by birth year) estimated by the long time-series model. Dashed horizontal line indicates the average level in the absence of fishing and under poor recruitment conditions. Vertical lines indicate the Pacific Decadal Oscillation (PDO) regimes estimated from environmental data. Note that estimates after 2008 are highly uncertain, as they are not yet informed by any direct observations.

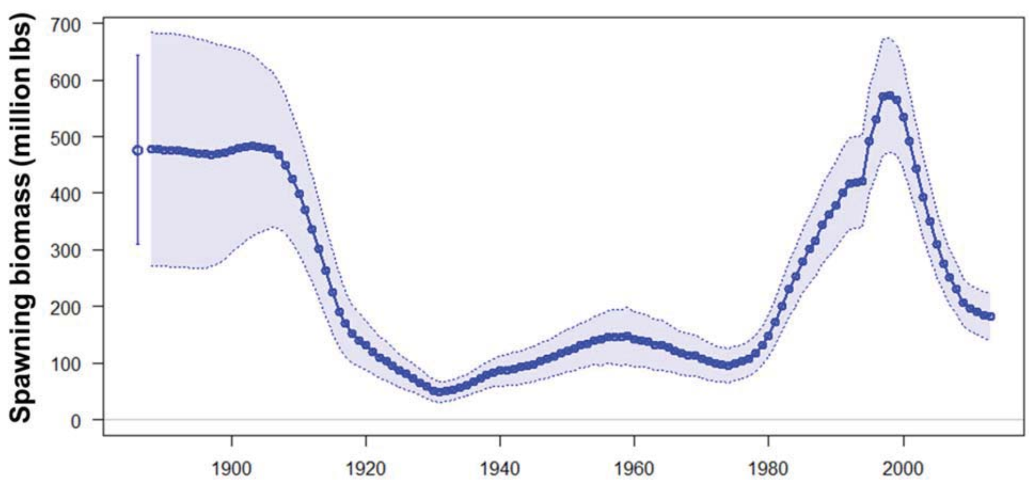

Figure 6. Spawning biomass estimates from the long time-series model.

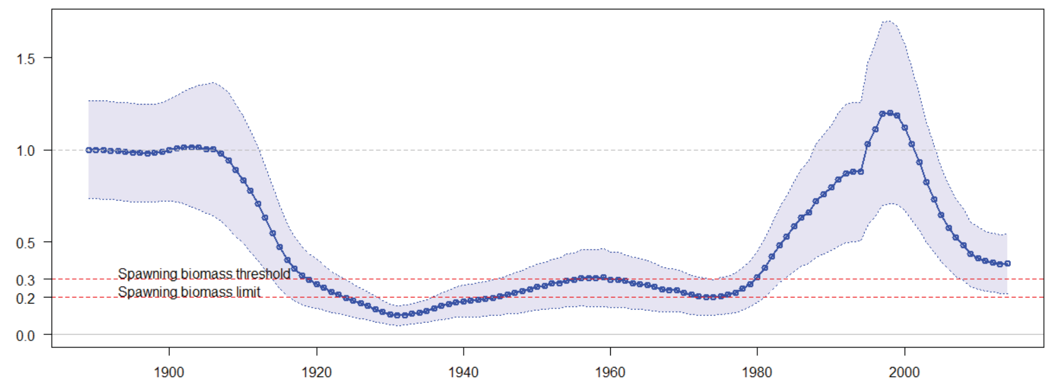

Figure 7. Time-series of relative spawning biomass estimates from the long time-series model.

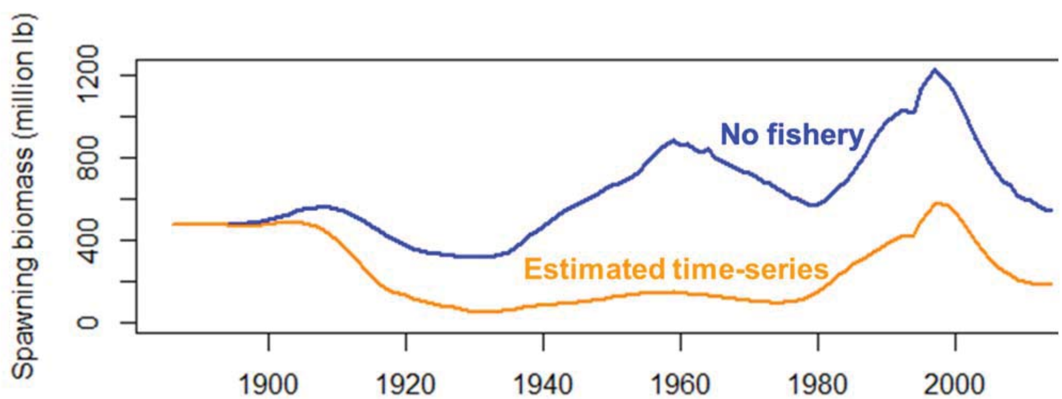

Figure 8. Estimated spawning biomass time-series from the long time-series model (lower, orange line) and recreated time-series in the absence of fishery removals (upper, blue line).

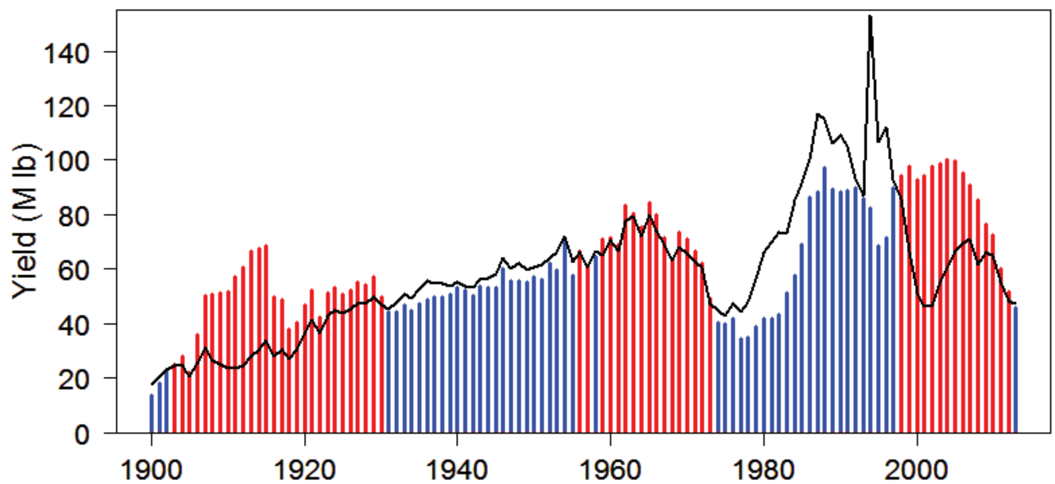

Figure 9. Time-series of removals (vertical bars) corresponding to levels above (red) and below (blue) the annual surplus production calculated based on the change in spawning biomass.

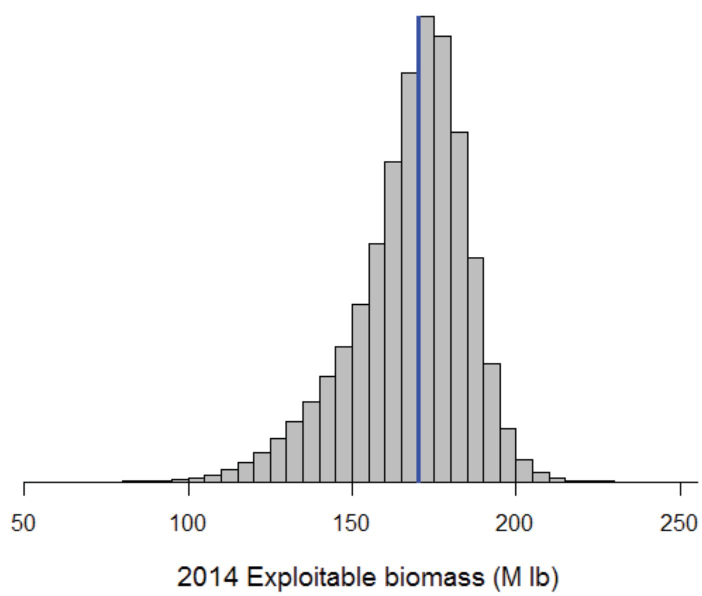

Figure 10. Distribution of 2014 exploitable biomass estimates including only model and estimation uncertainty, not uncertainty in the selectivity ogive generating the calculation.

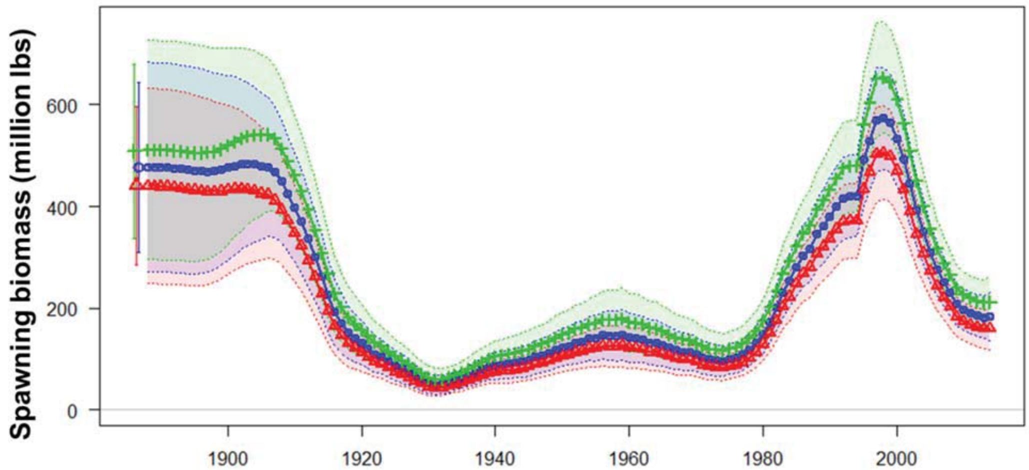

Figure 11. Sensitivity analysis to the assumption regarding relative selectivity of male and female halibut.

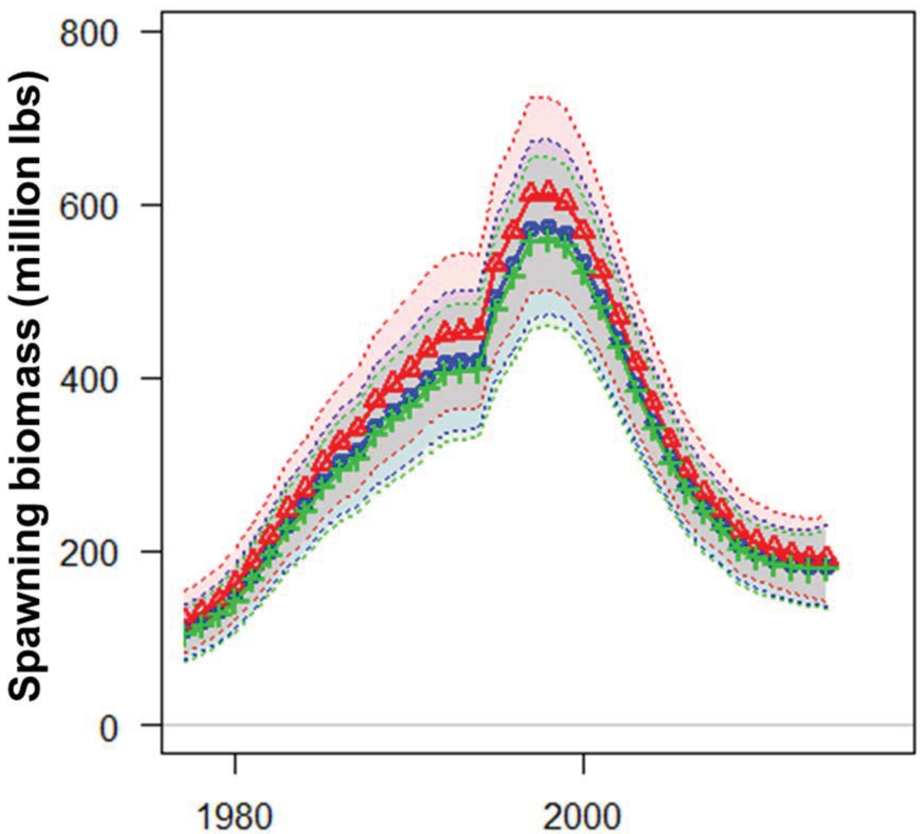

Figure 12. Sensitivity analysis to higher (doubled) and lower (halved) levels of bycatch from non-target fisheries.

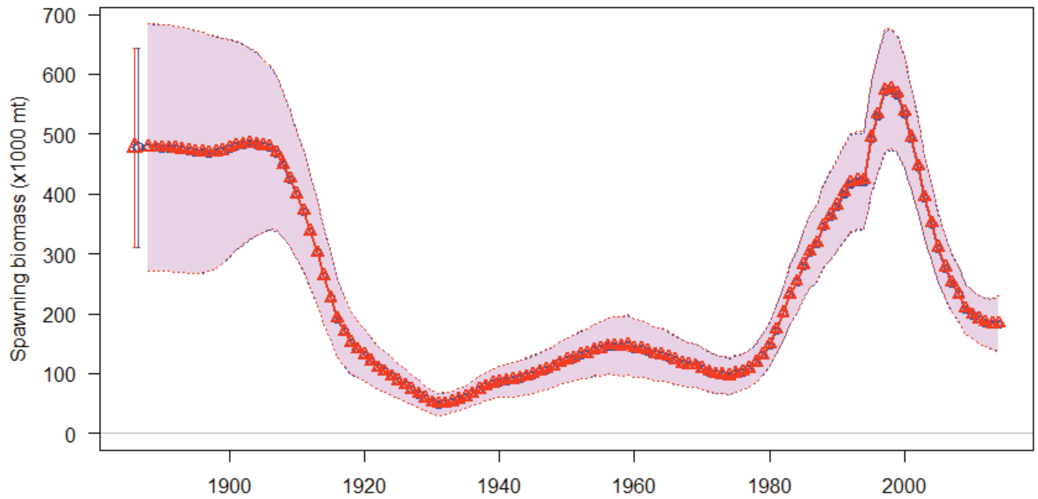

Figure 13. Sensitivity analysis to an increase in recreational mortality of 5%.

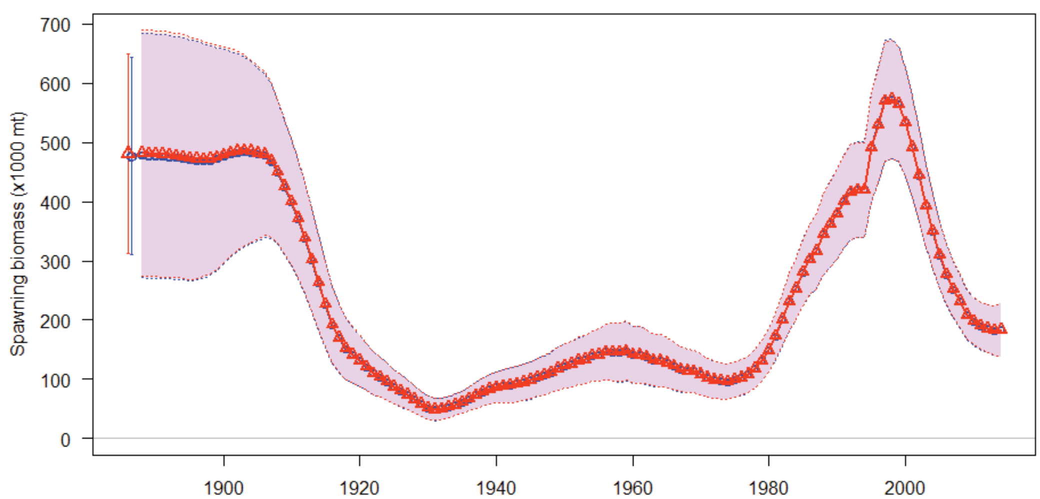

Figure 14. Sensitivity analysis to a doubling of the wastage estimated for the directed commercial fishery.

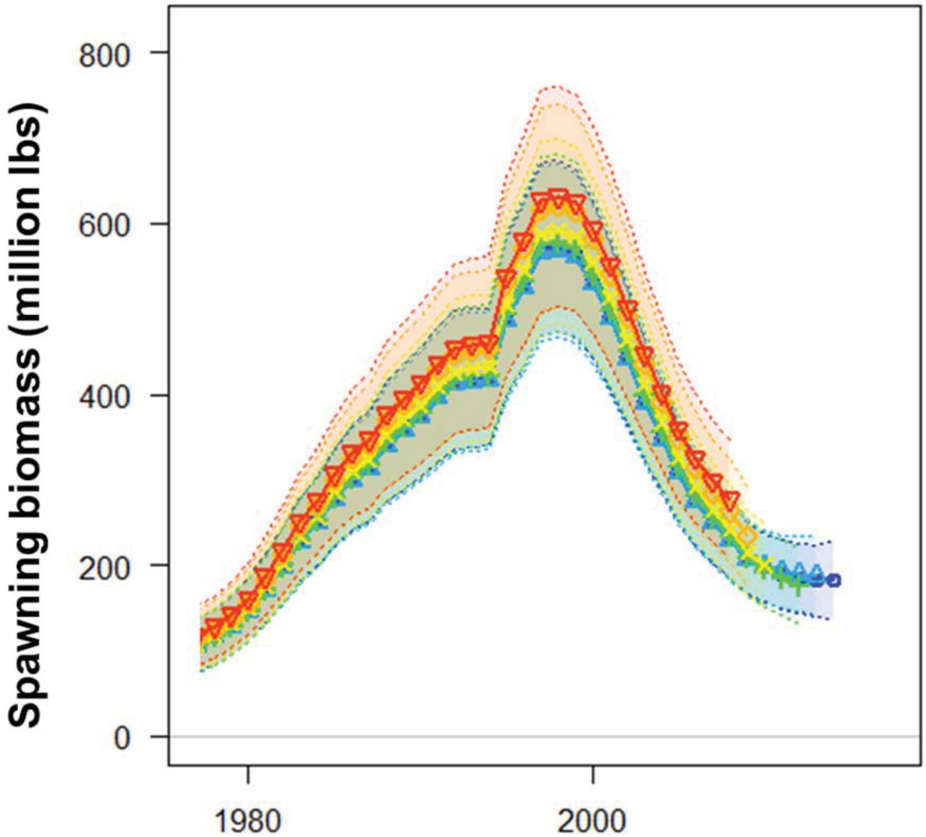

Figure 15. Results of the retrospective analysis on spawning biomass estimates using the long time-series model. Dashed lines and shaded regions indicate within-model 95% uncertainty intervals.

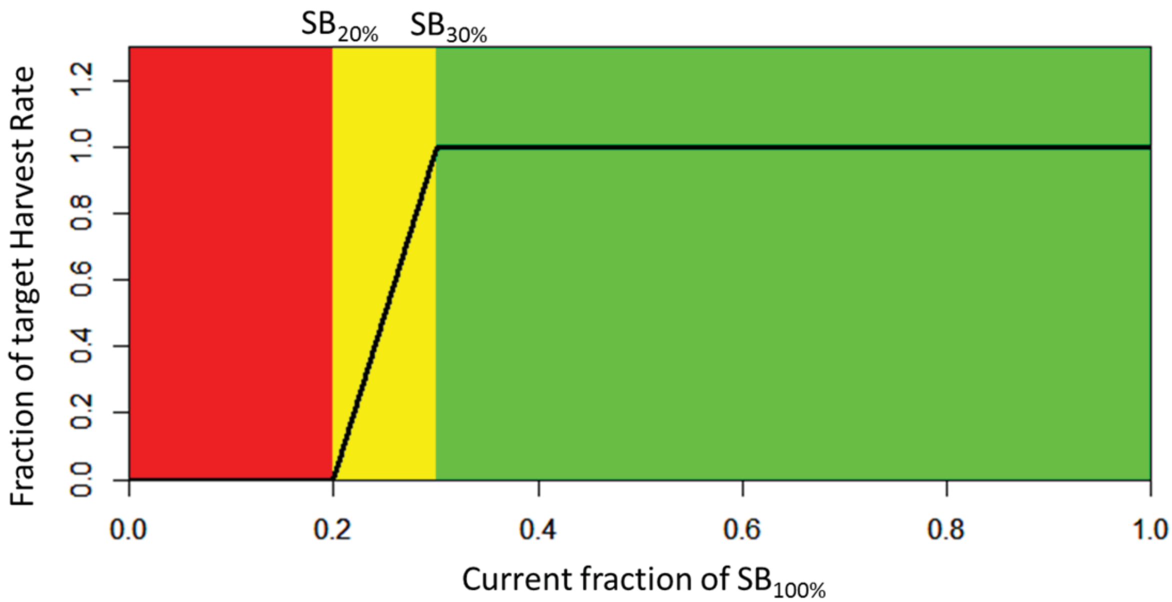

Figure 16. Illustration of the current IPHC harvest control rule for determining the relative target harvest rate as a function of relative spawning biomass, consistent with the IPHC's overall harvest policy.

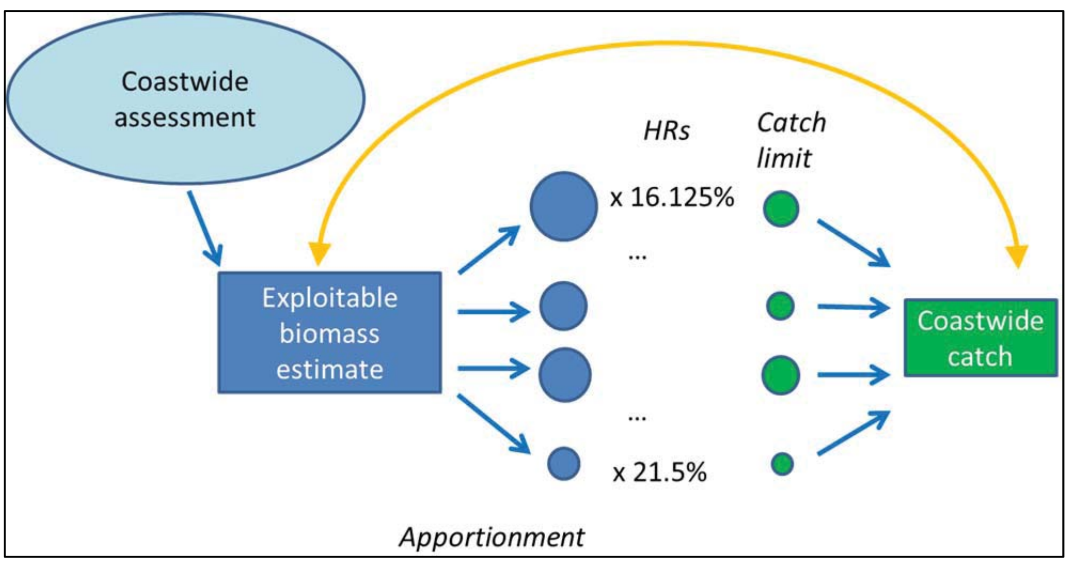

Figure 17. Illustration of the method for calculating the coastwide harvest rate consistent with the IPHC's harvest policy.

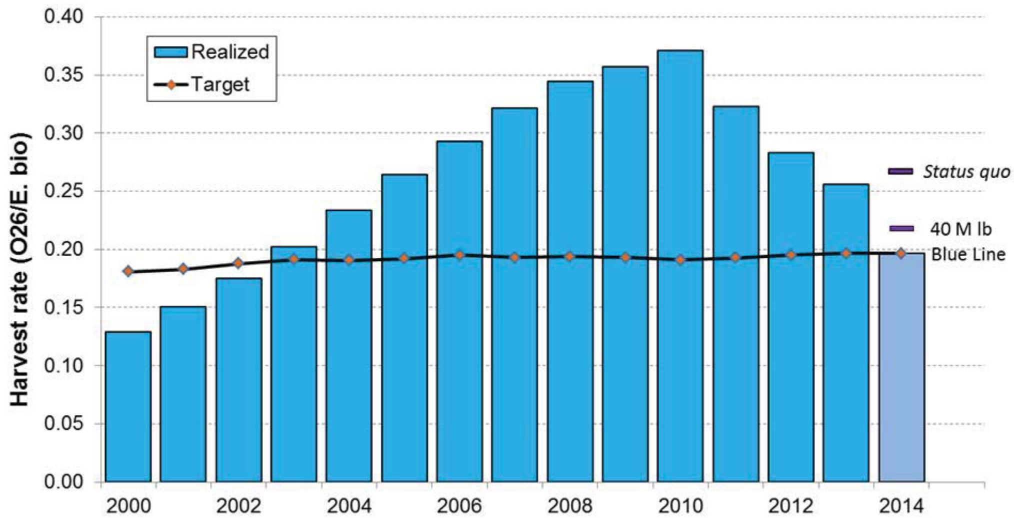

Figure 18. Time series of estimated coastwide harvest rates (bars) and hindcast harvest rate targets (line). Hindcast annual harvest rate targets correspond to the current estimate of exploitable biomass, not the estimate in that year. Values for 2014 represent alternatives from the decision table.

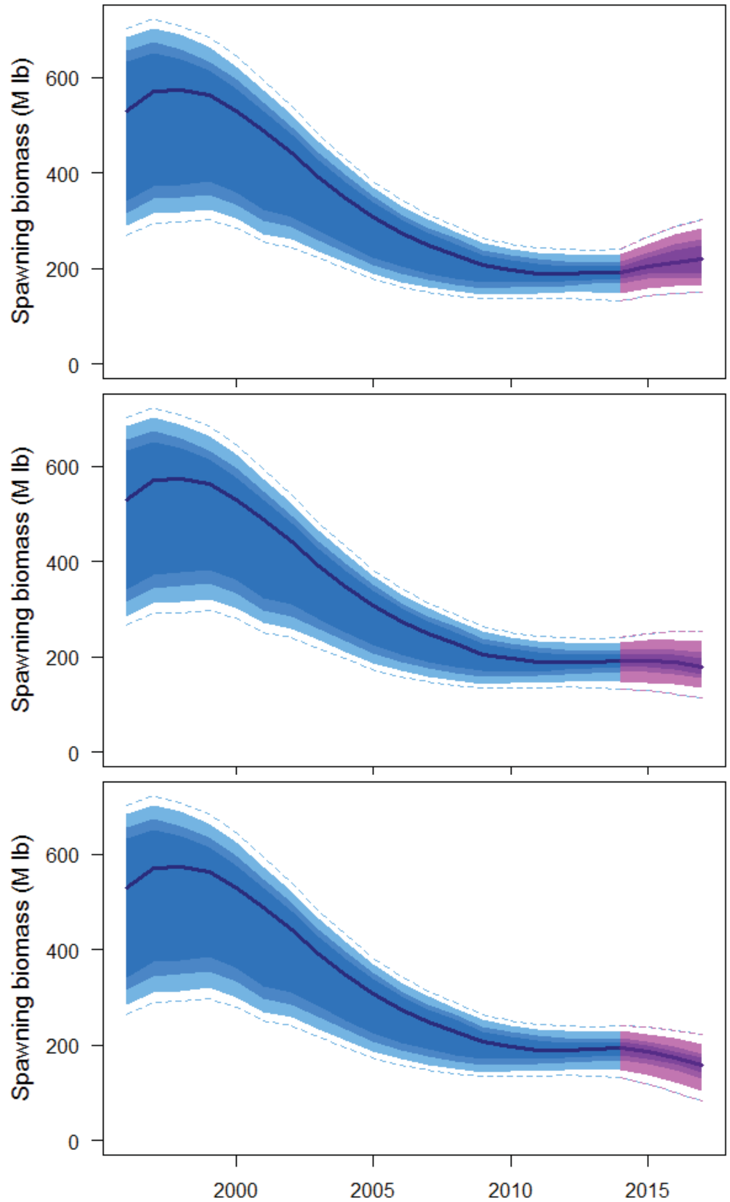

Figure 19. Three-year projections under alternative levels of mortality: no removals (upper panel), Blue Line removals (middle panel) and 60 million lbs removals (lower panel).