

# Assessment of the Pacific halibut stock at the end of 2014

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## Abstract

This stock assessment reports the status of the Pacific halibut resource in the northeastern Pacific Ocean. Halibut removals from all sources have ranged annually from 34 to 100 million pounds over the last 100 years, averaging 64 million pounds. After a peak in 2004, annual removals have decreased each year in response to management measures. Total removals in 2014 were estimated to be 43 million pounds, down from 48 million pounds in 2013. The 2014 setline survey total WPUE increased by 6% relative to 2013 (2% for legal-sized halibut only). Observed age distributions continue to indicate a relatively stable stock, but with no clear evidence of particularly 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 20<sup>th</sup> century. The 2014 scientific review process produced a number of important recommendations that have been incorporated into this assessment, including the development and evaluation of several alternative models. Two of these, using the Areas-As-Fleets (AAF) approach were included along with two coastwide models in the 2014 ensemble. The 2014 results therefore represent the integration of four separate stock assessment models, accounting for the uncertainty within each model and among models to generate the final decision table.

The 2014 stock assessment results indicate that the Pacific halibut stock declined rapidly from the late 1990s through 2011, as a result of the decline in the exceptionally strong 1987 year-class, recruitment strengths that are generally 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, with trends varying among the four assessment models. The median 2015 estimate of exploitable biomass, consistent with the IPHC's current harvest policy, is 181 million pounds. The two long time-series models provided a differing perception of current vs. historical stock sizes. The AAF model suggests that the stock is currently increasing gradually and at 35% of the equilibrium unfished stock size; however the model estimates that current spawning biomass is at only 133% of the minimum values estimated for the 1970s. The coastwide model suggests that the stock is currently stable at 37% of the equilibrium unfished stock size; however the model estimates that current spawning biomass is at 211% of the minimum values estimated for the 1970s. These differences represent considerable uncertainty in both the current stock size and trend. Three-year 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. The stock is projected to be stable at or near Blue Line levels of future harvest, increase under reduced removals and decrease as removals exceed around 40 Mlb.

## 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 2014 assessment continues to make use of the extensive historical time-series, as well as integrating both structural and estimation uncertainty via an ensemble of individual models. These models now include implicit treatment of spatial structuring in the data sources and properties of the fishery and setline survey.

## 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). This effort has been extended during 2014 to provide summary datasets by geographic region: Area 2 (2A, 2B, and 2C), Area 3 (3A and 3B), Area 4 (Area 4A and 4CDE), and Area 4B. 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 7 billion pounds, ranging annually from 34 to 100 million pounds over the last 100 years (Table 3 and Fig. 35 in Stewart (2015); 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 2014 were estimated to be 43 million pounds, down from 48 million pounds in 2013. The 2014 setline survey total WPUE increased by 6% relative to 2013, and the legal-size (O32) WPUE by 2%. Commercial catch-rates increased in 2014 by 7% at the coastwide level; however, these records were unverified and incomplete at the time of this assessment. Survey and fishery age distributions continue to indicate a relatively stable stock, with no clear evidence of particularly 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 20<sup>th</sup> 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 and other lack-of-fit (Stewart and Martell 2014). 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 abrupt change between annual cycles,

although necessary, is undesirable from a management perspective. The 2013 stock assessment (Stewart and Martell 2014) introduced the ensemble approach which 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 also used for the 2012 assessment, albeit in a crude manner, by including alternate models using differing values of natural mortality. For 2014, several alternative models were evaluated for inclusion into the stock assessment ensemble.

### **The 2014 Ensemble**

The IPHC’s Scientific Review Board (SRB) met to evaluate modelling progress on 23 June, 2014, and again to review the final set of models for the 2014 ensemble on 22-23 October, 2014 (Cox et al. 2015). These meetings guided the development of a simple stock production model, a Virtual Population Analysis (VPA), and two alternative statistical catch-at-age models, as well as a number of supplementary analyses that provided insight into the dynamics of the halibut population and fishery.

Two models were evaluated but not included directly into the ensemble. The VPA model requires a number of very strong simplifying assumptions in processing the input data and results. These include aggregating all male and female observations, and treating directly the numbers-at-age regardless of sex. Due to the use of surface ageing prior to 2002, the data also had to be aggregated into a plus group at age-15, and fishery and survey catch-at-age must be assumed to be known without error. To produce results comparable to the other models, female spawning biomass had to be estimated via sex-ratio at age from the setline survey. Despite these strong assumptions, VPA models are in use for many fisheries, and therefore provide another check on the scale and trend information from the statistical catch-at-age models. The VPA model estimated a slightly smaller stock size, but very similar trends over the recent and longer time-series (Stewart and Martell, *in review*). Also evaluated in 2014 was a simple surplus production model. This model assumes that change in the setline survey abundance is directly proportional to stock surplus production (the annual yield which can be removed and the stock biomass will remain unchanged). Removals of U26 halibut must be ignored, since these fish are not captured by the survey, thus the surplus yield does not account for all sources of removals. However, this model estimated only four parameters (the initial stock size, the average surplus production or maximum sustainable yield, the stock size producing that yield and the catchability coefficient linking the survey abundance to the population size). This analysis cannot produce estimates of female spawning biomass, or other harvest policy reference points, but did suggest that the surplus production in recent years had been between 40 and 45 Mlb. These values are consistent with both the decision table and harvest policy calculations, and therefore generally corroborate the ensemble results.

Building from the 2013 re-analysis of historical data sources, the summary of data into geographic regions in 2014 (Stewart 2015) provided the basis for creating two AAF models, one using only the most recent and comprehensive data (the short time-series, beginning in 1996), and the second utilizing the full historical record. Briefly, AAF models are commonly applied when biological differences among areas or sampling programs make coastwide summary of data sources problematic. AAF models continue to treat the population dynamics as a single panmictic 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 accommodate

temporal and spatial trends in where and how data have been collected and fishery catches have occurred because each region need not have data for each year modelled.

For 2014, the final ensemble included four individual models: each of both short and long time-series models based on coastwide and AAF data structures. The short time-series model used in 2012 was not retained in the 2014 ensemble, due to its non-orthogonal and highly processed treatment of input data, as well as the redundancy with the alternative short time-series coastwide model developed in 2013. All of these four models were implemented using the Stock Synthesis software, a widely used modeling platform developed at the National Marine Fisheries Service (Methot and Wetzel 2013). 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 Parma 1999, Clark and Hare 2006, Stewart and Martell 2015). 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. In aggregate, these models provide for a risk analysis that is more robust to changes to a single model, or the addition of new models in the future than a single assessment model.

As was the case in 2013, each of the models in the ensemble was equally weighted, and differences in uncertainty within models propagated in the integration of results. In the future it should be possible to refine this weighting based on the lack-of-fit to key data sources, retrospective patterns within models, as well as consistency of the results with biological understanding. It is also anticipated that spatially explicit models will be evaluated for potential inclusion into the ensemble in future years. In this manner, the ensemble approach can be transparently improved in the future as additional models and refinements to existing models become available.

The risk analysis and decision table include the full probability distribution from the assessment. Therefore, key quantities such as reference points and stock size are reported as cumulative distributions, such that the entire plausible range can be evaluated. Where necessary, point estimates reported in this assessment correspond to median values from the ensemble.

### **Comparison with previous assessments**

Comparison with previous stock assessments indicates that the 2014 spawning biomass results are very similar to those from 2012 and 2013, which lie inside the 50% interval of the ensemble in recent years (Fig. 1). Models prior to 2012, which had shown a problematic retrospective pattern, suggested terminal stock sizes in the mid-2000s that are no longer considered plausible. The estimates from these models for the late 1990s now occur at the lower edge of the plausible range: all four of the current models suggest a larger spawning biomass during that period. Point estimates from the 2013 ensemble for 2014 were extremely similar to the current results given the degree of uncertainty (Table 1).

## 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 (Fig. 2). The differences among the individual models contributing to the ensemble are most pronounced prior to the early 2000s (Fig. 3). However, current stock size estimates also differ substantially among the four models (Fig. 4). 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 Areas 2 and 3 in the AAF models. Differences are also apparent in the recent recruitment estimates, which suggest larger recruitments in 1999, 2002 and 2004-2005 than in other recent years (Fig. 5). These recent recruitments are much lower than the 1987 year class, and (in the coastwide model) substantially below those in the late 1970s and early 1980s (Fig. 6). Recruitments after 2008 do not yet have information available in the fishery or survey data, and therefore remain highly uncertain. In addition to recruitment trends, 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, Fig. 2, and Fig. 7), with plausible values ranging from 150 Mlb to 250 Mlb. The estimate of exploitable biomass consistent with the IPHC's current harvest policy is 181 Mlb at the beginning of 2015. The current level of spawning biomass is estimated to be 42% of the equilibrium condition in the absence of fishing, with a 10 out of 100 chance that the stock is below the 30% relative spawning biomass harvest policy threshold. All sources of estimated removals for 2014 correspond to a fishing intensity point estimate of  $F_{43\%}$  (Fig. 9). Harvest levels of this magnitude are generally consistent with target rates for many similar stocks.

### Long time-series models

The two long time-series models provide historical biomass estimates that are integrated with the current stock assessment results. The two long time-series models provided a differing perception of current vs. historical stock sizes (Fig. 10). The AAF model suggests that the stock is currently increasing gradually and at 35% of the equilibrium unfished stock size; however the model estimates that current spawning biomass is at only 133% of the minimum values estimated for the 1970s. The coastwide model suggests that the stock is currently stable at 37% of the equilibrium unfished stock size; however the model estimates that current spawning biomass is at 211% of the minimum values estimated for the 1970s. These differences represent considerable uncertainty in both the current stock size and trend. They are likely attributable to the separation of signals from each region (particularly Area 2, with the longest time-series of data), and allowance for different properties in each region's fishery and survey.

Both of the long time-series models indicate that average halibut recruitment is estimate to be higher (32 and 72% for the coastwide and AAF models respectively) during favorable Pacific Decadal Oscillation (PDO) regimes, a standard indicator of productivity in the north Pacific. This result is consistent with that of Clark and Hare (2002, 2006). Historically, these regimes included positive conditions prior to 1947, poor conditions from 1947-1977, positive conditions from 1978-2006, and poor conditions from 2007 to 2013.

## Major sources of uncertainty

This stock assessment includes significant 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 a substantial improvement over previous assessments, there are important sources of uncertainty that are not included.

A key source of uncertainty is the spatial structure of the assessment model, and the spatial processes in the underlying stock, particularly the distribution of recruitment (juvenile halibut), and their subsequent movement rates among regulatory areas as sub-legal and legal-sized fish. The SRB endorsed the staff's plans to continue development of additional alternative models using explicit spatial structure for future stock assessments, as well as refinement of available models to better accommodate spatial processes influencing population age- and sex-ratios. These efforts may provide alternate models for future inclusion into the ensemble approach.

As was identified in 2013, another source of uncertainty is 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 assessment relies on sex-ratios observed in the setline survey to inform the relative selectivity for male and female halibut in the commercial fishery catch. All the models are sensitive to this assumption, particularly the coastwide models. Efforts begun in 2014 to test methods for direct marking of fish at sea will continue to be developed in 2015.

The link between halibut recruitment strengths and environmental conditions remains poorly understood, and there is no guarantee that observed correlations 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 (6-10 years). Reduced size-at-age in the current stock relative to levels observed in the 1970s is a major contributor to stock trends which is poorly understood. The historical record suggests that size-at-age changes relatively slowly; therefore, although projection of future values is highly uncertain, near-term values are unlikely to be dramatically different than those currently observed.

Since 2012, natural mortality has been an important source of uncertainty included in the stock assessment. In 2012, three fixed levels were used to bracket the plausible range of values. In 2013, the three models contributing to the ensemble included both fixed and estimated values of natural mortality. In the current ensemble, the models again span both fixed (0.15/year for female halibut) and estimated values. The female value estimated in the AAF model (0.14) differs substantially from the value estimated in the coastwide model (0.21). This discrepancy contributes to the difference in scale and productivity for the two models, but is not easily reconciled at present. Although this uncertainty is directly incorporated into the ensemble results, it remains an avenue for future investigation.

Like most stock assessments, estimated removals from the stock are assumed to be accurate. Therefore uncertainty due to bycatch estimation (direct sampling variance where there is low coverage and representativeness for unobserved fishing activity), discard mortality rates, and any other unreported sources of removals in either directed or non-directed fisheries could create significant bias in this assessment.

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 and retrospective analyses

The wide range of sensitivity analyses conducted during the 2013 process remain relevant to the 2014 results, as these were all conducted with the coastwide long time-series model. 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 2014 assessment continues to rely on indirect estimates from the sex-ratios observed in the setline survey. Specifically, separate selectivity is estimated for the fishery and setline survey, but the relative difference in selectivity for male and female halibut estimated for the setline survey (using sex-specific data) is assumed to apply to the fishery data. Results in 2013 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 in Stewart and Martell 2014).

Three sensitivity analyses were conducted in 2013 to investigate the relative importance of uncertainty in several sources of halibut removals. The results indicated that significantly higher (doubled) and lower (halved) levels of bycatch did not change the relative stock trends, but that adding additional removals suggested a larger stock. This result is expected, as the stock must have been productive enough to support these additional removals and still generate the observed trends. This general result suggests that sources of removals missing from current accounting may positively increase our estimates how much harvest the stock can support. Within the stock assessment models, this can be realized via changes in estimated natural mortality and/or the magnitude of recruitment strengths without appreciably altering the stock trend. Future analyses will be aimed at including uncertainty in discard mortality rates and the magnitude of both wastage and bycatch directly within the stock assessment models.

A retrospective analysis was performed for each of the individual models contributing to this assessment. Both coastwide models showed little pattern in the most recent years, but slightly higher estimates as additional data were removed from each (Fig. 11). The AAF models showed even less retrospective pattern (Fig. 12). All models estimates for the terminal three years of the retrospective analysis were included in the currently estimated confidence intervals.

## Forecasts and decision table

Stock projections were conducted using the ensemble assessment (all four models), summaries of the 2014 estimated removals, as well as the results of apportionment calculations and harvest policy application (Webster and Stewart 2015, Stewart 2015). The steps included: 1) apportioning the coastwide estimate of exploitable biomass according to the survey catch rates in each regulatory area (Webster and Stewart 2015), 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 assuming constant values for all sources of removals.

The decision table provides a comparison of the relative risk, using stock and fishery metrics (columns), for a range of alternative harvest levels for 2015 (rows). The block of columns entitled “Stock Trend” (columns a-d) provides for evaluation of the risks to 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 (“Stock Status”; columns e-h) and fishery

performance identified in the current harvest policy (columns i-m). The alternatives 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 (repeating the FCEYs adopted for 2014), as well as arbitrary values (at 10 Mlb increments) intended to foster the evaluation of the relative change in risk probability across a range of total mortality levels. For each row, the total mortality of all sizes and from all sources, the total coastwide fishery CEY and the associated median level of fishing intensity (measured via the Spawning Potential Ratio) are reported. Fishing intensity reflects the relative reduction in equilibrium spawning biomass per recruit from all sources and sizes of removals, reported as  $F_{xx\%}$ , for comparison to other processes in both nations where harvest rate targets and limits are commonly reported in these units. An alternative *status quo* reports the harvest levels that maintain the same fishing intensity estimated in 2014. As in previous years, it is expected that additional alternatives will be produced during the IPHCs annual process such that all management alternatives considered for 2015 can be directly evaluated in terms projected total mortality and risk.

The stock is projected to increase gradually over 2016-2018 in the absence of any removals, and for removals of up to 20 Mlb. For removals around 40 Mlb, projections are relatively flat. The risk of stock declines begins to increase relatively rapidly for levels of harvest above 40 million pounds of total mortality resulted in projected declines in 2016, and becoming more pronounced by 2018 (Table 3; Fig. 13). The Blue Line (38.7 Mlb total removals) corresponds to a 19/100 chance of stock decline in 2016 and a 23/100 chance in 2018, somewhat more optimistic than recent assessment results.

For metrics directly based on current harvest policy (stock status, fishery trend, and fishery status), there is a relatively small chance (<24/100) that the stock will decline below the 30% or 20% reference points in projections for all the levels of removals evaluated. For removals in excess of the Blue Line, there is a greater than 50/100 probability that the fishery CEY would be smaller in 2016-2018 if the current harvest policy were applied in those years. As the stock stabilizes to biomass levels consistent with recent recruitment and size-at-age, it is reasonable to expect a greater response in stock trend to annual management decisions.

## Future research

Based on data and model exploration completed during 2014, and recommendations from the SRB, future research will focus on the following topics:

- 1) Continued expansion of the ensemble of models used in the stock assessment. Specifically, explicit spatial models will be developed that may allow for improved incorporation of the uncertainty due to spatial processes such as migration and recruitment distribution among regulatory areas.
- 2) As development of additional models for the ensemble is reduced, there will be more emphasis on evaluation and diagnosis of each individual model. A document describing in detail the technical specifications, fits to the data sources and results will be developed for review during 2015.

- 3) Continued development of methods for sampling the sex-ratio of the commercial catch. 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.
- 4) Further investigation of the factors contributing to recruitment strength, recruitment distribution, and the information available from trawl surveys, particularly in the Bering Sea.
- 5) Explore methods for including uncertainty in wastage and bycatch estimates in the assessment in order to better capture these sources uncertainty.
- 6) Bayesian methods for fully integrating parameter uncertainty may provide improved uncertainty estimates within the models contributing to the assessment.
- 7) Integration of the assessment analyses with ongoing development of the harvest policy and Management Strategy Evaluation process.

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**Table 1. Comparison of 2014 biomass point estimates (median ensemble value; Mlb) from the 2013 and current assessments.**

| Quantity                 | 2013 Assessment | 2014 Assessment |
|--------------------------|-----------------|-----------------|
| 2014 Exploitable biomass | 170             | 170             |
| 2014 Spawning biomass    | 197             | 209             |

**Table 2. Median population (Mlb) and fishing intensity estimates (based on median Spawning Potential Ratio) from the 2014 assessment.**

| Year | Spawning biomass | Fishing intensity ( $F_{xx\%}$ ) | Exploitable biomass |
|------|------------------|----------------------------------|---------------------|
| 1996 | 584.6            | 49%                              | 779.2               |
| 1997 | 605.7            | 43%                              | 809.6               |
| 1998 | 591.8            | 42%                              | 762.7               |
| 1999 | 567.1            | 40%                              | 746.8               |
| 2000 | 529.5            | 40%                              | 688.3               |
| 2001 | 483.9            | 38%                              | 603.0               |
| 2002 | 434.5            | 34%                              | 532.2               |
| 2003 | 382.6            | 30%                              | 460.5               |
| 2004 | 339.5            | 28%                              | 403.6               |
| 2005 | 299.5            | 26%                              | 352.6               |
| 2006 | 266.7            | 26%                              | 307.9               |
| 2007 | 241.5            | 25%                              | 266.9               |
| 2008 | 224.4            | 25%                              | 236.3               |
| 2009 | 204.6            | 26%                              | 203.9               |
| 2010 | 197.8            | 27%                              | 186.4               |
| 2011 | 195.3            | 31%                              | 175.6               |
| 2012 | 197.2            | 35%                              | 169.2               |
| 2013 | 203.9            | 38%                              | 168.8               |
| 2014 | 208.5            | 43%                              | 169.7               |
| 2015 | 215.1            | NA                               | 180.6               |

**Table 3. 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 2016           |                      | in 2018           |                      | in 2016          |                       | in 2018          |                       | in 2016                             |                                 | in 2018                         |                       | in 2015         |
|                   | is less than 2015 | is 5% less than 2015 | is less than 2015 | is 5% less than 2015 | is less than 30% | is 20% less than 2015 | is less than 30% | is 20% less than 2015 | is less than 10% less than 2015     | is less than 10% less than 2015 | is less than 10% less than 2015 | is 10% less than 2015 | is above target |
| 2015 Alternative  |                   |                      |                   |                      |                  |                       |                  |                       |                                     |                                 |                                 |                       |                 |
| No removals       | 0.0               | 0.0                  | 0.0               | 0.0                  | 0.0              | 0.0                   | 0.0              | 0.0                   | 0.0                                 | 0.0                             | 0.0                             | 0.0                   | 0/100           |
| FCEY = 0          | 13.1              | 0.0                  | 0.0               | 0.0                  | 0.0              | 0.0                   | 0.0              | 0.0                   | 0.0                                 | 0.0                             | 0.0                             | 0.0                   | <1/100          |
|                   | 20.0              | 7.7                  | 7.7               | 7.7                  | 7.7              | 7.7                   | 7.7              | 7.7                   | 7.7                                 | 7.7                             | 7.7                             | 7.7                   | <1/100          |
|                   | 30.0              | 16.5                 | 16.5              | 16.5                 | 16.5             | 16.5                  | 16.5             | 16.5                  | 16.5                                | 16.5                            | 16.5                            | 16.5                  | 4/100           |
| Blue Line         | 38.7              | 25.0                 | 25.0              | 25.0                 | 25.0             | 25.0                  | 25.0             | 25.0                  | 25.0                                | 25.0                            | 25.0                            | 25.0                  | 50/100          |
| status quo        | 41.4              | 27.5                 | 27.5              | 27.5                 | 27.5             | 27.5                  | 27.5             | 27.5                  | 27.5                                | 27.5                            | 27.5                            | 27.5                  | 50/100          |
| Maintain 2014 SPR | 43.3              | 29.5                 | 29.5              | 29.5                 | 29.5             | 29.5                  | 29.5             | 29.5                  | 29.5                                | 29.5                            | 29.5                            | 29.5                  | 88/100          |
|                   | 50.0              | 36.0                 | 36.0              | 36.0                 | 36.0             | 36.0                  | 36.0             | 36.0                  | 36.0                                | 36.0                            | 36.0                            | 36.0                  | >99/100         |
|                   | 60.0              | 45.8                 | 45.8              | 45.8                 | 45.8             | 45.8                  | 45.8             | 45.8                  | 45.8                                | 45.8                            | 45.8                            | 45.8                  | >99/100         |

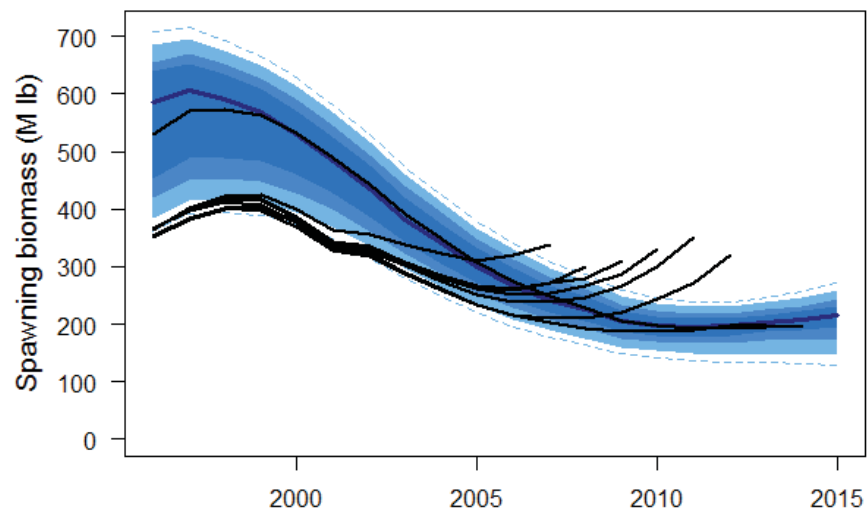


**Figure 1. Retrospective comparison among recent stock assessments. The black lines denote point estimates from previous assessments conducted in 2006-2013. The dark blue line indicates the median (or “50:50 line”; with equal probability of the estimate falling above or below that level) from the 2014 assessment; colored bands moving away from the median indicate the intervals containing 50/100, 75/100, and 95/100 estimates; outer dashed lines indicating the 99/100 interval.**

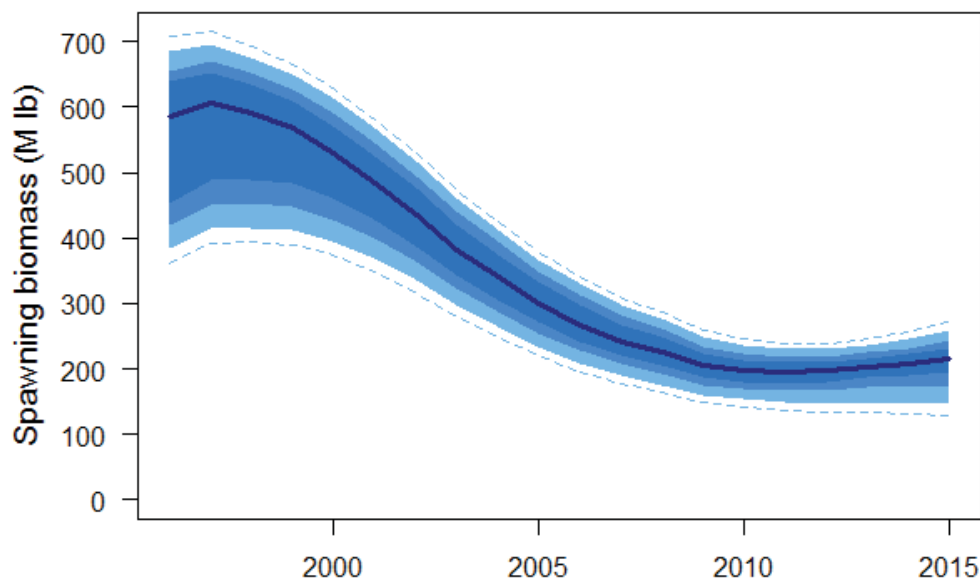


**Figure 2. Trend in spawning biomass estimated in the 2014 stock assessment. The dark line indicates the median (or “50:50 line”) with an equal probability of the estimate falling above or below that level; colored bands moving away from the median indicate the intervals containing 50/100, 75/100, and 95/100 estimates; outer dashed lines indicating the 99/100 interval.**

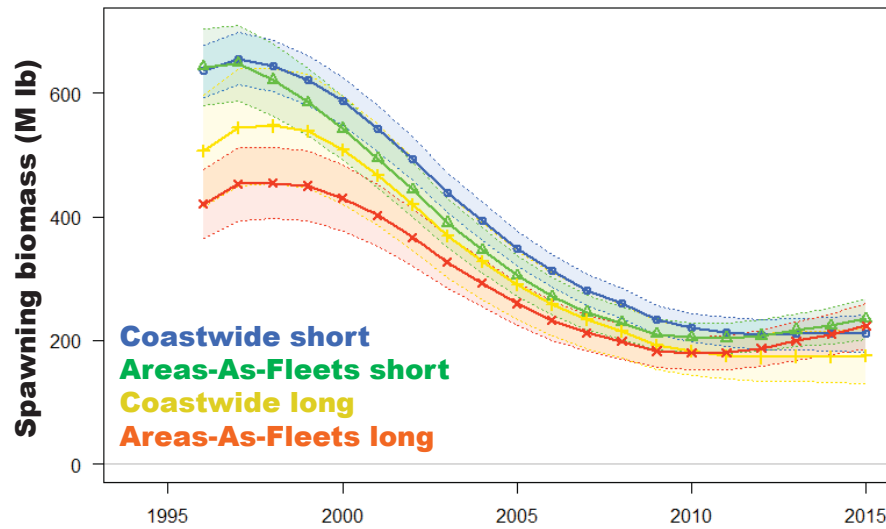


Figure 3. Comparison of models included in the 2014 stock assessment. Solid lines with points indicate point estimates, dashed lines and shading approximate 95% confidence intervals reflecting within-model uncertainty.

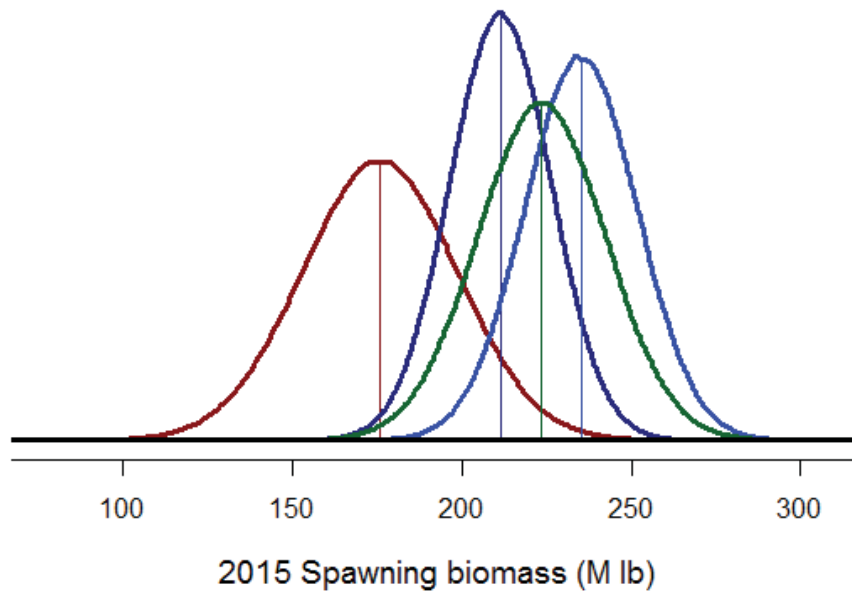


Figure 4. Distribution of individual model estimates for the 2015 spawning biomass. Vertical lines indicate the median values.

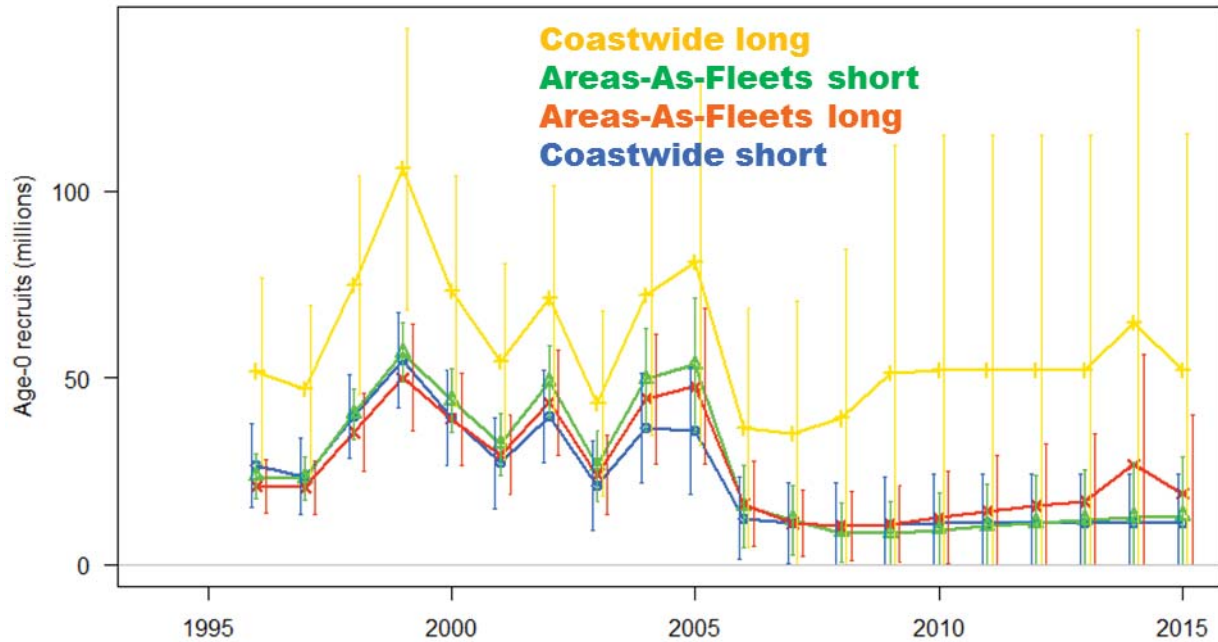


**Figure 5. Trend recent recruitment strengths (by birth year) estimated by all four ensemble models. Note that estimates after 2008 are highly uncertain, as they are not yet informed by any direct observations.**

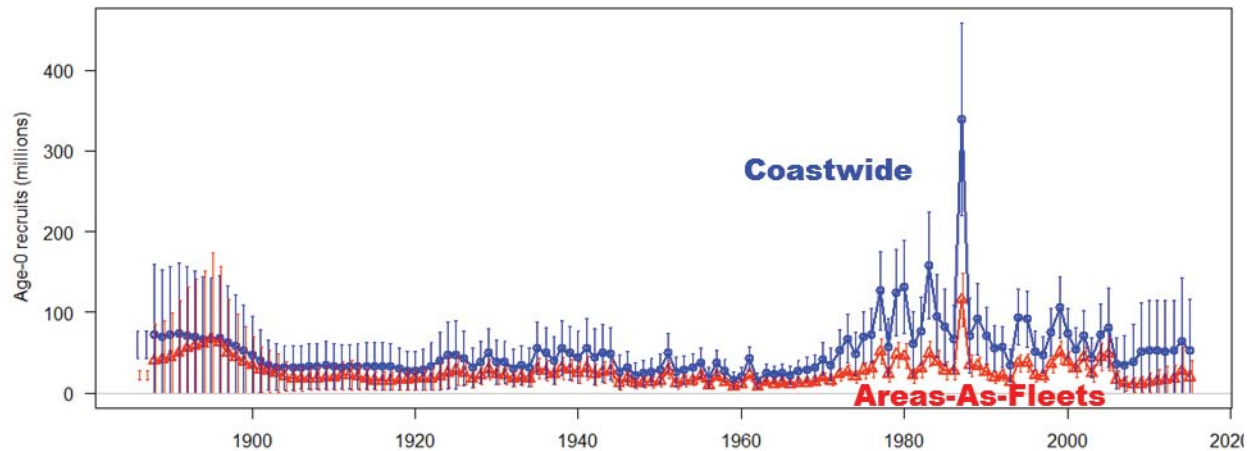


**Figure 6. Trend in historical recruitment strengths (by birth year) estimated by the two long time-series models, including the effects of the Pacific Decadal Oscillation (PDO) regimes. Note that estimates after 2008 are highly uncertain, as they are not yet informed by any direct observations.**

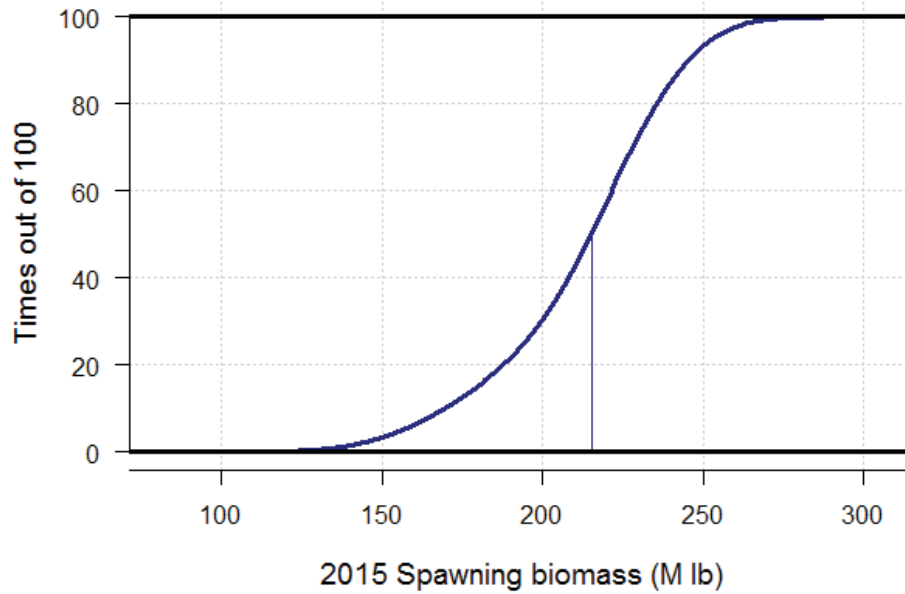


**Figure 7. Cumulative distribution of 2015 spawning biomass estimates. Vertical line indicates the median value (215 Mlb).**

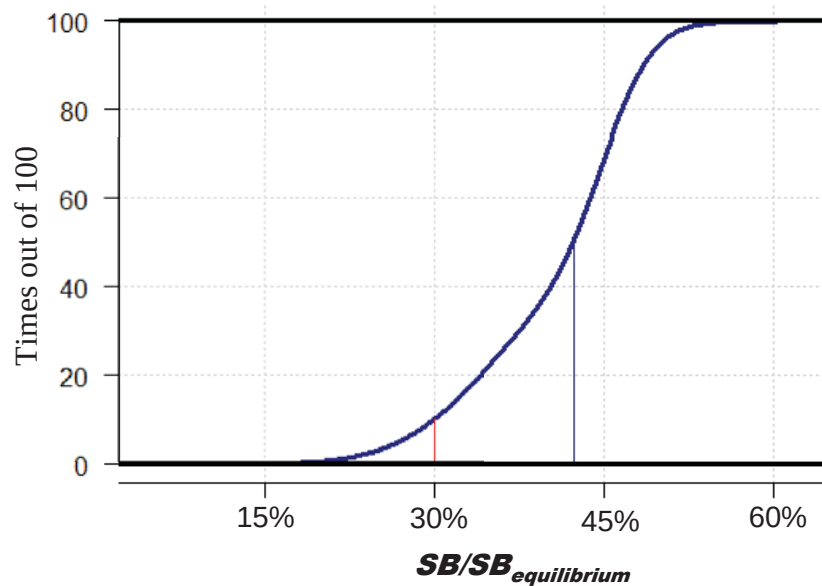


**Figure 8. Cumulative distribution of 2015 spawning biomass estimates relative to the equilibrium spawning biomass in the absence of fishing. Vertical lines indicate the median value (42%), and the value corresponding to the IPHC's harvest policy threshold (30%).**

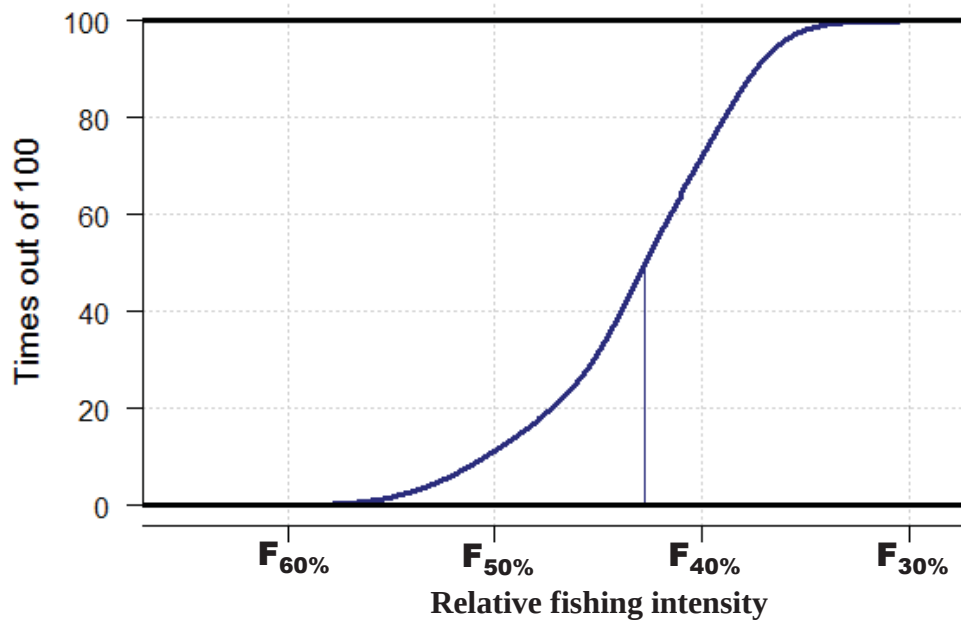


Figure 9. Cumulative distribution of the estimated relative fishing intensity (based on the Spawning Potential Ratio) in 2014. Vertical line indicates the median value (43%).

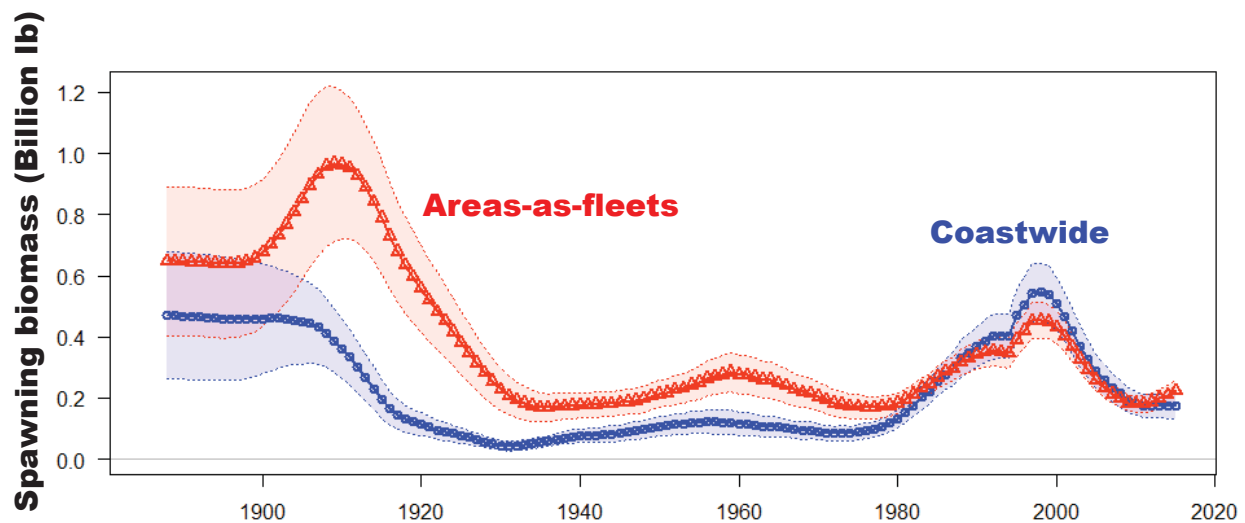


Figure 10. Spawning biomass estimates from the two long time-series models. Shaded region indicates the approximate 95% within-model confidence interval.

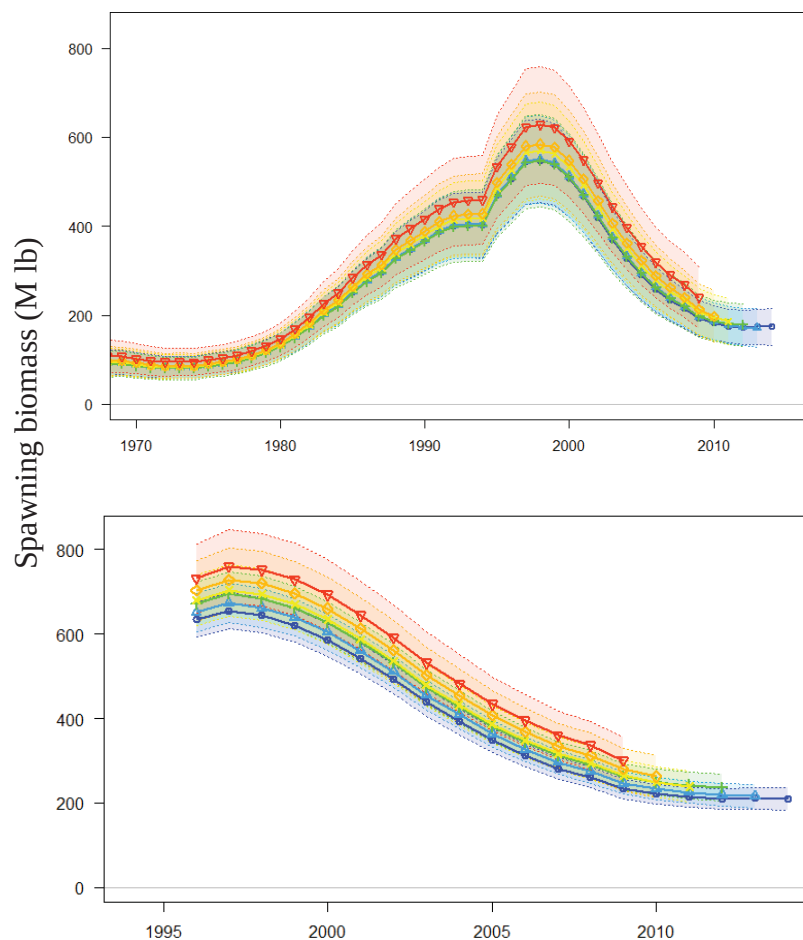


**Figure 11. Results of the retrospective analysis on spawning biomass estimates using the coastwide long (upper panel) and coastwide short (lower panel) time-series models and sequentially removing one year of data for five years. Dashed lines and shaded regions indicate within-model 95% uncertainty intervals.**

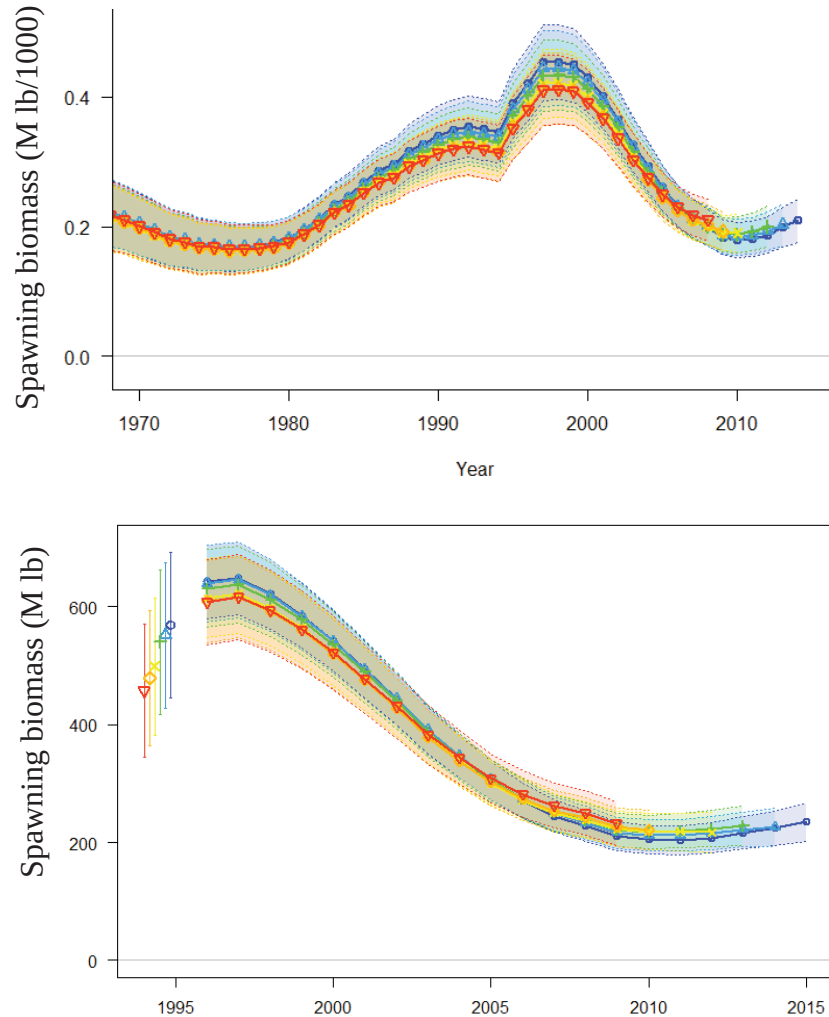


**Figure 12. Results of the retrospective analysis on spawning biomass estimates using the Areas-As-Fleets long (upper panel) and Areas-As-Fleets short (lower panel) time-series models and sequentially removing one year of data for five years. Dashed lines and shaded regions indicate within-model 95% uncertainty intervals.**

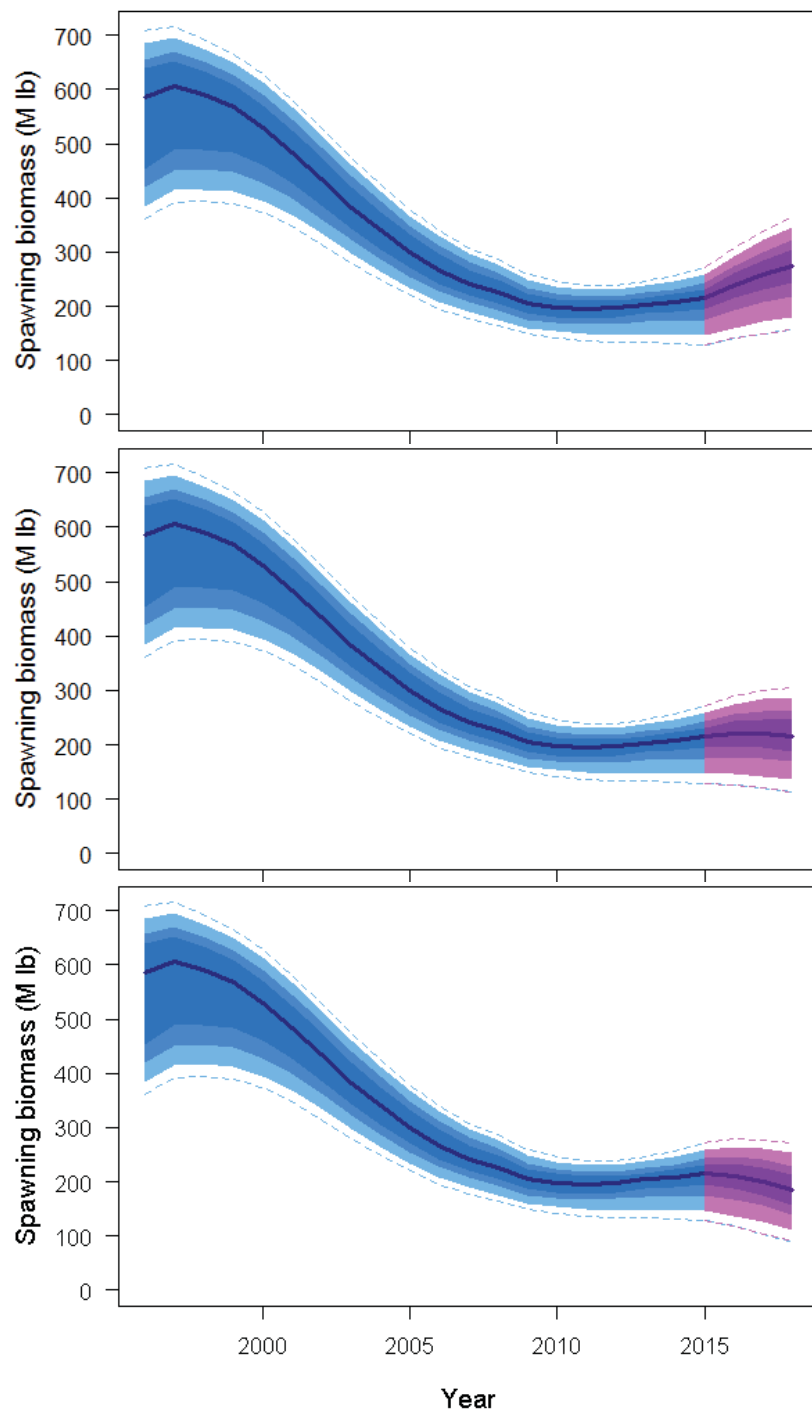


**Figure 13. Three-year projections of stock trend under alternative levels of mortality: no removals (upper panel), Blue Line removals (middle panel) and 60 Mlb of total removals (lower panel).**