Assessment of the Pacific halibut stock at the end of 2015

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Abstract

This stock assessment reports the recent trends and status of the Pacific halibut (*Hippoglossus stenolepis*) resource in the northeastern Pacific Ocean. Commercial fishery landings in 2015 were 24.7 Mlb, up from 23.7 Mlb in 2014. The 2015 setline survey coastwide legal (O32) and total (O32+U32) WPUE were 5% higher than values observed in 2014. Age distributions in 2015 from both the survey and fishery remained similar to those observed in 2011-2014, indicating a relatively stable stock, and no clear evidence of recent strong coastwide recruitments. At the coastwide level, individual size-at-age remains low relative to the rest of the time series, although there has been little change over the last several years.

The 2015 scientific review process produced a number of important recommendations that have been incorporated into this assessment. However, the basic approach used in 2014 remains unchanged: results from four assessment models are combined together into an 'ensemble.' As has been the case since 2012, results from this stock assessment are based on approximate probability distributions derived from the ensemble, thereby incorporating both the uncertainty within each model, as well as the uncertainty among models.

The two long time-series models provide a different perception of current vs. historical stock sizes. The Areas-As-Fleets (AAF) long model suggests the stock is currently increasing gradually and is at 39% of the equilibrium unfished stock size; however the model estimates that current spawning biomass is at only 140% of the minimum values estimated for the 1970s. The coastwide long model also suggests that the stock is currently increasing and at 54% of the equilibrium unfished stock size; however, the current spawning biomass is estimated to be at 236% of the minimum values estimated for the 1970s. The two short models are unable to provide insight into historical dynamics, but also provide differing perspectives of current stock size. These model differences highlight the considerable uncertainty in both the current stock size and trend. The results of the 2015 stock assessment indicate that the Pacific halibut stock declined continuously from the late 1990s to around 2010. That trend is estimated to have been a result of decreasing size-at-age, as well as recent recruitment strengths that are smaller than those observed during the 1980s and 1990s. Since that time period, the estimated female spawning biomass is estimated to have stabilized near 200 Mlb, but with a slightly increasing trend. The median 2016 estimate of exploitable biomass, consistent with the IPHC's current harvest policy, is 185 Mlb.

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 Blue Line of the decision table (representing the application of the current harvest policy) results in a coastwide total mortality of 38.7 Mlb. The stock is projected to increase gradually, given Blue Line levels of future harvest, and decrease with a greater than 50/100 chance for total mortality exceeding around 43 Mlb.

Introduction

This stock assessment reports the status of the Pacific halibut resource in the northeastern Pacific Ocean, including the 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 by the International Pacific Halibut Commission (IPHC) for nearly 100 years. Catch limits for each of eight regulatory areas are set each year by six Commissioners from the United States and Canada. The stock assessment provides a summary of recently collected data, and model estimates of stock size and trend. The 2015 assessment continues to make use of the extensive historical time series of data, as well as integrating both structural and estimation uncertainty via an ensemble of individual models. Specific management information is summarized via a decision table reporting the estimated risks associated with alternative management actions. The harvest policy (Stewart 2016a) provides catch tables illustrating the level of harvest in each regulatory area indicated by the IPHC's current harvest policy (the Blue Line) and other alternatives.

Data sources

Efforts to improve the data sources included in the assessment have been ongoing since 2013. For 2015, this included of a complete reprocessing of all inputs, updating mortality estimates from all sources, and the addition of several new sources of information (Stewart and Martell 2016). Important improvements included: generating weight-at-age estimates by geographic region, improving the weight-at-age calculations for young halibut (< age-7) rarely encountered in the setline survey using data from NMFS trawl surveys, summarizing index variances and age composition sample sizes (particularly by area for the AAF models), adding age information to directly inform the selectivity curves for bycatch, sport, and sublegal discard removals, and extending all age-data arrays to include ages 2-25 (instead of 6-25, used in historical analyses). The treatment of these new and improved sources of information was reviewed by the Scientific Review Board (SRB) in June, 2015 (Cox et al. 2016). In aggregate, the historical time series represents a range of data sources and relative quality, with the most complete information available only in recent years (Fig. 1). A detailed summary of input data used in this stock assessment can be found in Stewart (2016b).

Briefly, over the last 100 years removals have totaled 7.1 billion pounds, ranging annually from 34 to 100 Mlb and an average of 63 Mlb (all weights are reported as 'net' weights, head and guts removed; this is approximately 75% of the round weight). Annual removals were above average from 1985 through 2010 and then decreased annually from a peak in 2004 until 2014 in response to management measures. Commercial fishery landings in 2015 were 24.7 Mlb, up from 23.7 Mlb in 2014. Bycatch mortality was estimated to be 7.7 Mlb, the lowest level in several decades, and total sport removals 7.1 Mlb, up slightly from 2014. Removals from all sources in 2015 were estimated to be 42.0 Mlb, down slightly from 42.1 Mlb in 2014.

The 2015 setline survey coastwide legal (O32) and total (O32+U32) Weight-Per-Unit-Effort (WPUE) were 5% higher than values observed in 2014. For most regulatory areas these estimates are consistent with a relatively flat trend over the last five years. Differences from this general trend included the third consecutive annual decrease in Area 3A, and increases in Areas 2A and

4CDE after a relatively flat recent trend; Area 2C is estimated to have been increasing steadily for the last five years. Setline survey NPUE showed a less pronounced decline from the late 1990s, but a similar trend in the last few years. Commercial WPUE (based on incomplete and unverified logbook records available for this assessment) increased 11% at the coastwide level and showed increases in all areas except 4D from 2014 to 2015, with consistent trends observed for 2B and 2C. Age distributions in 2015, from both the survey and fishery, were similar to those observed in 2011-2014, indicating a relatively stable stock, and no clear evidence of recent strong coastwide recruitments. At the coastwide level, individual size-at-age continues to be low relative to the rest of the time-series, although there has been little change over the last several years.

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 2014a). Although recent modelling efforts have created some new alternatives, no single model satisfactorily approximates all aspects of the available data and scientific understanding. In 2014, an ensemble of four stock assessment models representing a two-way cross of short vs. long time series', and aggregated coastwide vs. Areas-As-Fleets (AAF) models was used to explore the range of plausible current stock estimates. 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 continue to treat the population dynamics as a single aggregate breeding 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.

The ensemble approach recognizes that there is no "perfect" assessment model, and that 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 2015a). As has been the case since 2012, 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. The basic approach to each of the four assessment models used in 2014 (Stewart and Martell 2015b) remains unchanged for 2015. Each of these models (and many alternatives explored during development) has shown a similar historical pattern: a stock declining from the late 1990s, with several years of relative stability at the end of the time-series.

The 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 2014). 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 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. Preliminary evaluation of alternative weighting approaches was presented to the SRB in 2015, and although still needing additional development, they did not suggest weights differing substantially from the *status quo*. 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.

Comparison with previous assessments

The IPHCs peer review process in 2015 included an SRB meeting to evaluate modelling progress on 16-17 June, and a second meeting to refine the models to be included in the assessment ensemble on 15-16 October, 2015 (Cox et al. 2016). This process produced a number of important recommendations that have been incorporated into the 2015 assessment and will be used to structure the work planned for 2016. Several modeling aspects were explored more deeply than in previous analyses and improved where necessary. These improvements included: updating the constraint on recruitment deviations (σ_r) for consistency with stock-recruitment assumptions, updating relative data weighting to reduce the potential influence of outliers and strong residual patterns, and updating the constraints on time-varying parameters to better reflect degree of estimated variability. Historical assumptions regarding the selectivity curves corresponding to bycatch, recreational, and discard mortality were also updated using newly available data. In addition, a much greater number of sensitivity analyses, alternate model configurations, and diagnostic evaluations were completed than in previous assessments. Despite these changes, comparison with previous stock assessments indicates that the estimates of spawning biomass form the 2015 ensemble are very similar to those from 2012-2014, which lie inside the predicted 50% interval of the ensemble in recent years (Fig. 2). 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 2014 ensemble for 2015 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 2015 stock assessment indicate that the Pacific halibut stock has been declining continuously over much of the last decade (Fig. 3). The differences among the individual models contributing to the ensemble are most pronounced prior to the early 2000s (Fig. 4). However, current stock size estimates also differ substantially among the four models (Fig. 5). 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 and 2005 than in other recent years (Fig. 6). These recent recruitments are much lower than the 1987 year class, and in the coastwide long model below those in the late 1970s and early 1980s (Fig. 7). Recruitments after 2010 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 (Stewart 2016b) 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 Mlb and begun to increase slowly (Table 2, Fig. 3), with plausible values for 2016 ranging from 150 Mlb to almost 300 Mlb (Fig. 8). The median estimate of exploitable biomass consistent with the IPHC's current harvest policy is 185 Mlb at the beginning of 2015. The median from the ensemble suggest that the stock is currently at 43% of equilibrium unfished biomass; however the probability distribution indicates a very wide plausible interval ranging from 3/100 at the 30% level to 90/100 at almost 50% of equilibrium conditions (Fig. 9). All sources of estimated removals for 2015 correspond to a fishing intensity point estimate of $F_{48\%}$ (Table 2, Fig. 10). The range of this distribution is considerable ($F_{41\%}$-$F_{68\%}$), and irregular, reflecting the different distributions estimated within each of the individual models. Harvest levels of this magnitude are generally at or below target rates for many similar stocks.

Long time-series models

The two long time-series models provided different perceptions of current vs. historical stock sizes (Fig. 11). The AAF model suggests that the stock is currently increasing gradually and at 39% of the equilibrium unfished stock size; however the model estimates that current spawning biomass is at only 140% of the minimum values estimated for the 1970s. The coastwide model also suggests that the stock is currently increasing and at 54% of the equilibrium unfished stock size; however, the current spawning biomass is estimated to be at 236% of the minimum values estimated for the 1970s. These differences represent considerable uncertainty in both the current stock size and trend. Recent differences 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. Historical differences appear to be due to the differing assumptions regarding connectivity between Areas 2 and 3 and Area 4 during the early part of the 1900s when there are no data available from Area 4 (Stewart and Martell 2016).

Both of the long time-series models estimate that average halibut recruitment is higher (37 and 71% 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 the use of a single assessment model, there are important sources of uncertainty that are not included. Two primary uncertainties continue hinder our current understanding of the Pacific halibut resource: 1) the sex-ratio of the commercial catch (not sampled due to the dressing of fish at sea), which serves to set the scale of the estimated abundance in tandem with assumptions regarding natural mortality, and 2) the treatment of spatial dynamics and movement rates among regulatory areas, which is represented via the coastwide and AAF approaches, have very strong implications for the current stock trend. Ongoing efforts to test methods for direct marking of fish at sea will continue in 2016 via voluntary marking, collection of genetic samples, and development of a genetic assay. In addition, movement rates for adult and younger halibut (roughly ages 0-6, which were not well-represented in the PIT-tagging study), particularly to and from Area 4, are necessary for parameterizing a spatially explicit stock assessment. Current understanding of these rates has now been summarized (Stewart 2016b), but remains uncertain. The SRB endorsed the staff's plans to continue development of a spatially explicit model during 2016. This effort may provide an additional model for future inclusion into the ensemble approach, structure for an operating model for the Management Strategy Evaluation (MSE), and a general tool for hypothesis testing.

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 relative to levels observed in the 1970s is also major contributor to recent stock trends, but 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 substantially different than those currently observed. Data suggest that the decreasing trend in size-at-age has slowed and observations have been relatively stable over the last decade.

Like most stock assessments, estimated removals from the stock are assumed to be accurate. Therefore uncertainty due to bycatch estimation (observer sampling and representativeness), discard mortality rates, and any other unreported sources of removals in either directed or non-directed fisheries could create significant bias in this assessment. Ongoing research on these topics may help to inform our understanding of these processes in the long-term, but in the near-future it appears likely that a high degree of uncertainty in both stock scale and trend will continue to be an integral part of the annual management process.

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 (0.16) differs substantially from the value estimated in the coastwide model (0.20). 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.

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

A wide range of sensitivity analyses were conducted during the development of the 2015 stock assessment (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 included: the sex-ratio of the commercial catch, the treatment of historical selectivity in the long time-series models, and natural mortality. Although it was not repeated in 2015, uncertainty in the total removals from the stock has been found in previous analyses to directly scale our estimates of stock size. Specifically, if removals are larger than currently estimated (i.e., we are missing some components) the stock size is likely underestimated. This has a much larger potential effect on harvest policy calculations than it does on assessment results. Unobserved mortality can result in 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. IPHC staff in collaboration with NMFS scientists involved with sablefish analyses are also considering how best to estimate and account for potential whale depredation (plundering); future recording of whale interactions in logbooks is anticipated.

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. 12); however terminal biomass estimates remained inside the confidence intervals for the full model result over three of five years of the retrospective analysis. The AAF models showed similar retrospective behavior (Fig. 13), being inside the confidence intervals four of five years.

Forecasts and decision table

Stock projections were conducted using the integrated results from the stock assessment ensemble, summaries of the 2015 fishery, and other sources of mortality, as well as the results of apportionment calculations and the target harvest rates from current IPHC harvest policy (Webster and Stewart 2016, Stewart 2016). The steps included: 1) apportioning the coastwide estimate of exploitable biomass according to the legal-sized (O32) survey catches in each regulatory area (adjusted for hook competition, survey timing, survey expansions and calibrations with supplementary surveys), 2) applying the area-specific target harvest rates to estimate the total CEY for each area, and all other removals associated with a given level of harvest, and 3) calculating the total mortality and projecting the stock trends three years into the future assuming constant values for all sources of removals.

The decision table provides a comparison of the relative risk (in times out of 100), 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") and fishery performance identified in the current harvest policy. 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 2015),
- 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 of the decision table, the total mortality of all sizes and from all sources, the total coastwide fishery CEY, and the associated level of fishing intensity (median value with the 95% credible range below; 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 *Fx%*, 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 2015. 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 2016 can be directly evaluated in terms of projected total mortality and risk.

Slightly more optimistic than the results from last year's assessment, the stock is projected to increase gradually over 2017-2019 in the absence of any removals, and for removals of up to around 40 Mlb (Table 3, Fig. 14). For removals around 40 Mlb, projections are relatively flat. The risk of stock declines begins to increase for levels of harvest above 40 Mlb of total mortality, becoming more pronounced by 2019 (Table 3; Fig. 15). The Blue Line (38.7 Mlb total removals) corresponds to a 19/100 chance of stock decline in 2017 and a 45/100 chance in 2019.

For metrics directly based on current harvest policy (stock status, fishery trend, and fishery status), there is a relatively small chance (<23/100) that the stock will decline below the 30% reference point 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 2017-2019 if the current harvest policy were applied in those years.

Future research

Based on data and model exploration completed during 2015, and recommendations from the SRB, future research will continue to focus on the following topics identified in previous assessments:

1) Continued expansion of the ensemble of models used in the stock assessment. Specifically, an explicit spatial model 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. Longer term efforts will include explicit modelling of growth within potential assessment models.
2) Continued development of weighting approaches for models included in the ensemble, potentially including fit to the survey index of abundance, retrospective and predictive performance.

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. There are several avenues of research that can be explored using a spatial model, but not with the currently available structures.
5) Explore methods for including uncertainty in wastage and bycatch estimates in the assessment (they are now only evaluated in the catch tables) 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, and a more natural approach for combining the individual models in the ensemble.
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 2015 biomass point estimates (median ensemble value; Mlb) from the 2014 and current assessments.

Quantity	2014 Assessment	2015 Assessment
2015 Exploitable biomass	181	175
2015 Spawning biomass	209	209

Table 2. Median population (Mlb) and fishing intensity estimates (based on median Spawning Potential Ratio) from the 2015 assessment.

Year	Spawning biomass	Fishing intensity ($F_{XX\%}$)	Exploitable biomass
1996	483.7	48%	662.2
1997	520.8	42%	718.2
1998	513.5	41%	677.4
1999	498.4	39%	673.5
2000	469.8	38%	626.0
2001	433.9	36%	551.0
2002	392.4	32%	485.9
2003	347.3	29%	422.0
2004	309.8	26%	371.4
2005	275.7	25%	327.1
2006	247.6	25%	287.4
2007	226.6	25%	251.8
2008	212.0	25%	224.4
2009	193.7	26%	195.1
2010	186.2	26%	178.1
2011	183.5	31%	167.5
2012	185.2	37%	161.1
2013	191.9	39%	159.7
2014	200.1	46%	163.2
2015	209.3	48%	175.4
2016	219.0	NA	185.1

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 2017		in 2019		in 2017		in 2019		in 2017		in 2019		in 2016
2016 Alternative	Total removals (M lb)	Fishery CEY (M lb)	Fishing intensity	is less than 2016	is 5% less than 2016	is less than 2016	is 5% less than 2016	is less than 30%	is less than 20%	is less than 30%	is less than 20%	is less than 2016	is 10% less than 2016	is less than 2016	is 10% less than 2016	is above target
No removals	0.0	0.0	$F_{100\%}$	<1	<1	<1	<1	1	<1	<1	<1	<1	<1	<1	<1	0
FCEY = 0	11.6	0.0	$F_{79\%}$ 60%-84%	<1	<1	<1	<1	1	<1	<1	<1	<1	<1	<1	<1	<1
	20.0	8.2	$F_{68\%}$ 49%-75%	<1	<1	3	<1	2	<1	1	<1	<1	<1	<1	<1	<1
	30.0	18.0	$F_{58\%}$ 39%-67%	3	<1	28	9	2	<1	2	<1	4	2	5	2	7
Blue Line	38.7	26.6	$F_{51\%}$ 33%-61%	19	<1	45	32	2	<1	6	<1	44	33	44	35	50
status quo FCEY	41.4	29.2	$F_{49\%}$ 31%-59%	28	<1	48	38	3	<1	7	<1	53	44	50	44	62
Maintain 2015 SPR	42.9	30.7	$F_{48\%}$ 30%-58%	32	<1	50	40	3	<1	8	<1	58	49	53	48	68
	50.0	37.6	$F_{43\%}$ 27%-54%	45	3	64	48	3	<1	14	<1	90	74	82	68	96
	60.0	47.4	$F_{41\%}$ 23%-50%	50	22	73	55	4	<1	23	1	>99	99	>99	97	>99
				a	b	c	d	e	f	g	h	i	j	k	l	m

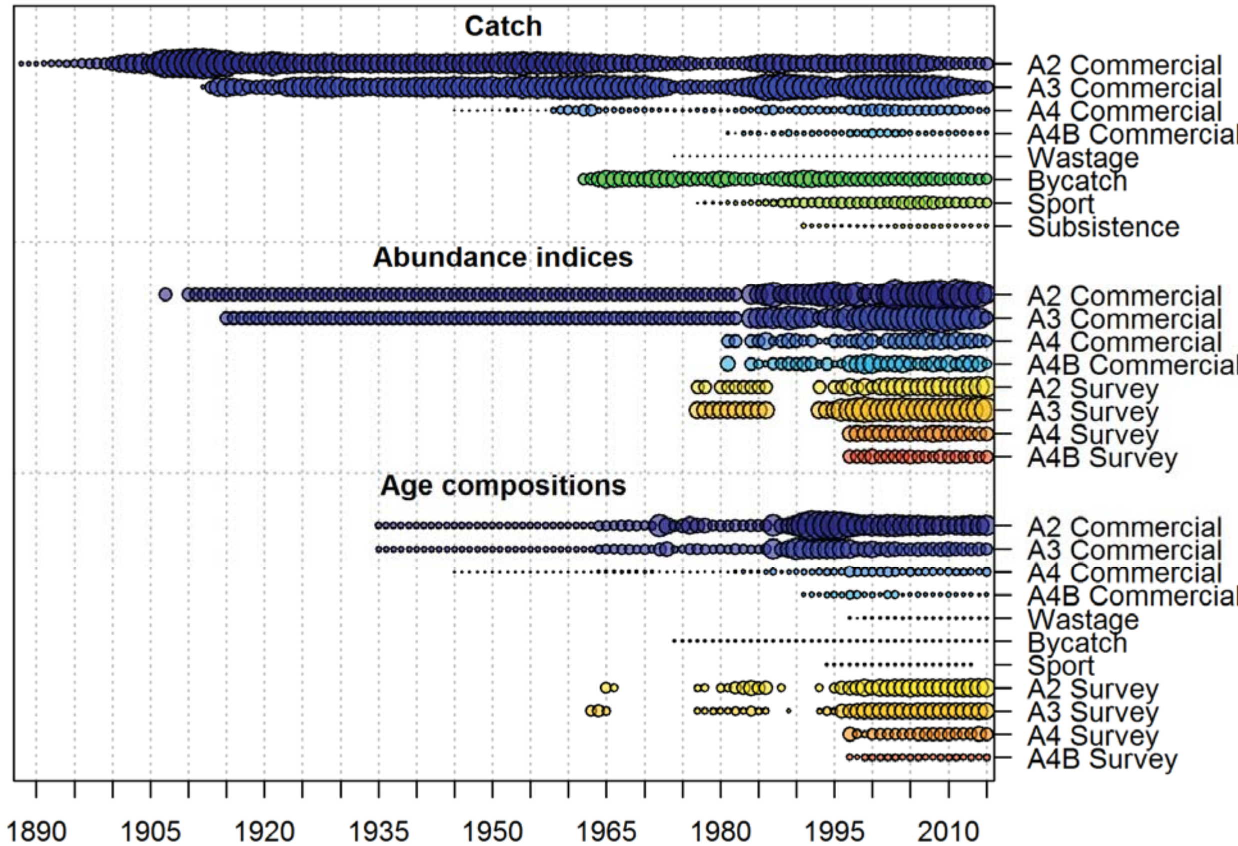

Figure 1. Overview of data sources. Circle areas are proportional to magnitude (catches) or the relative precision of the data (indices of abundance and age composition data).

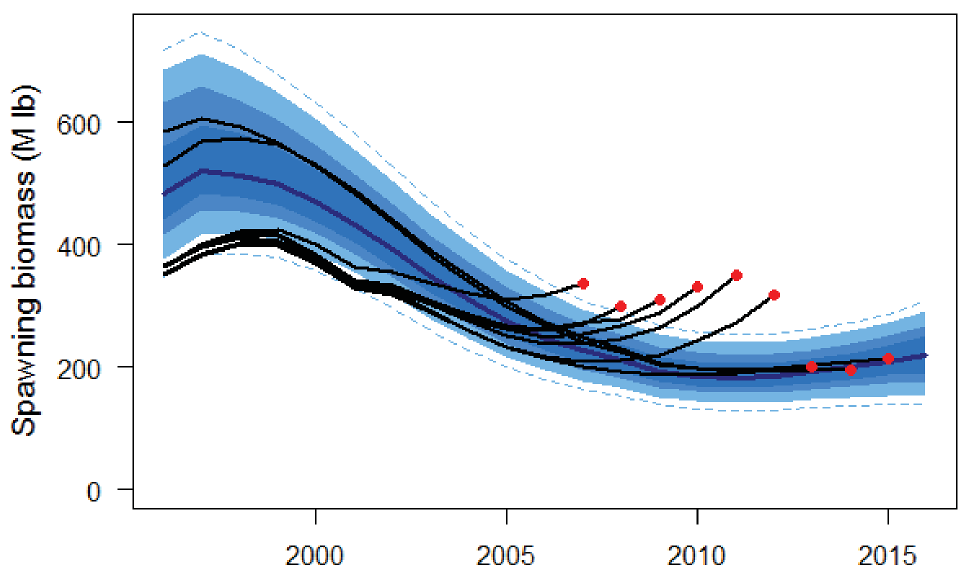

Figure 2. Retrospective comparison among recent stock assessments. The black lines denote point estimates from previous assessments conducted in 2006-2014. The shaded area represents the approximate probability distribution from the 2015 ensemble.

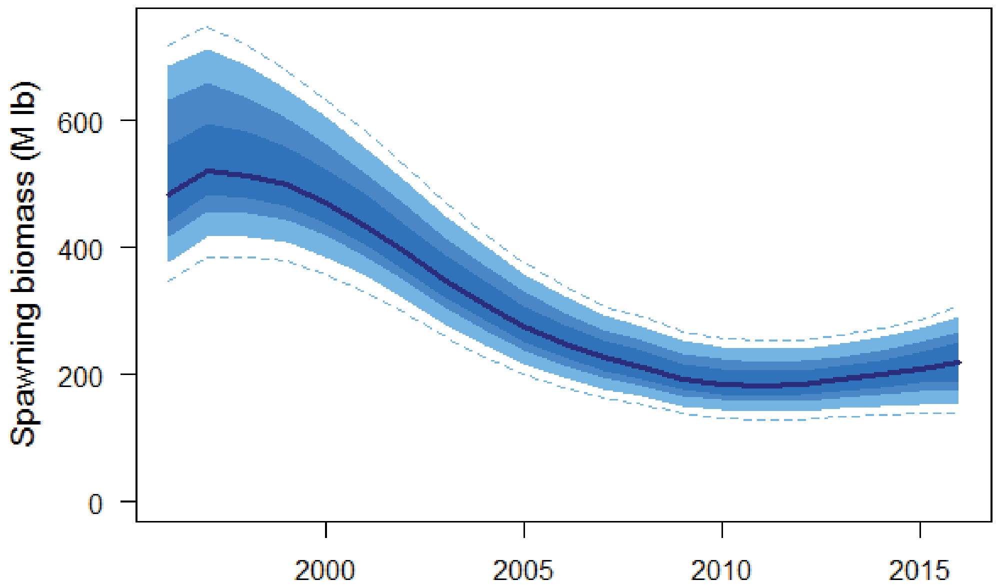

Figure 3. Trend in spawning biomass estimated in the 2015 stock assessment. The dark line indicates the median (or "50:50 line") with an equal probability of the estimate falling above or below that level; colored bands moving away from the median indicate the intervals containing 50/100, 75/100, and 95/100 estimates; outer dashed lines indicating the 99/100 interval.

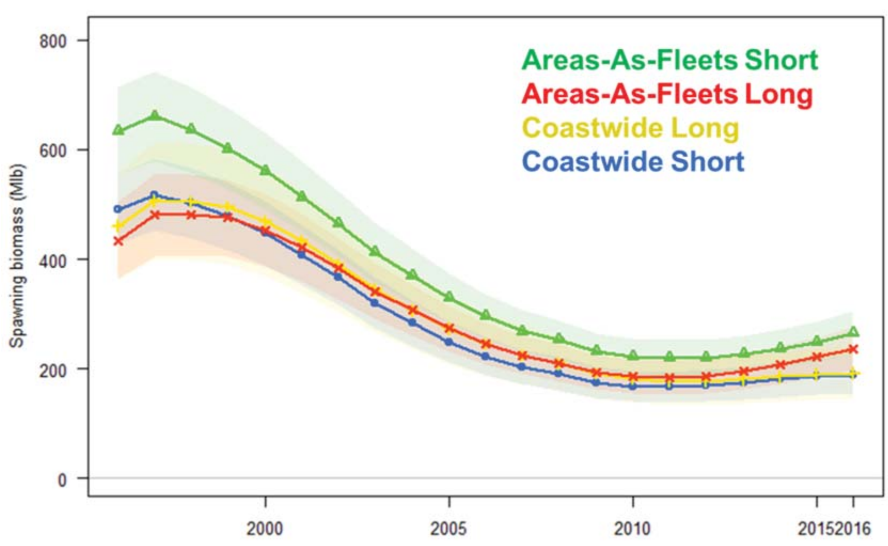

Figure 4. Comparison of models included in the 2014 stock assessment. Solid lines with points indicate point estimates, dashed lines and shading approximate 95% confidence intervals reflecting within-model uncertainty.

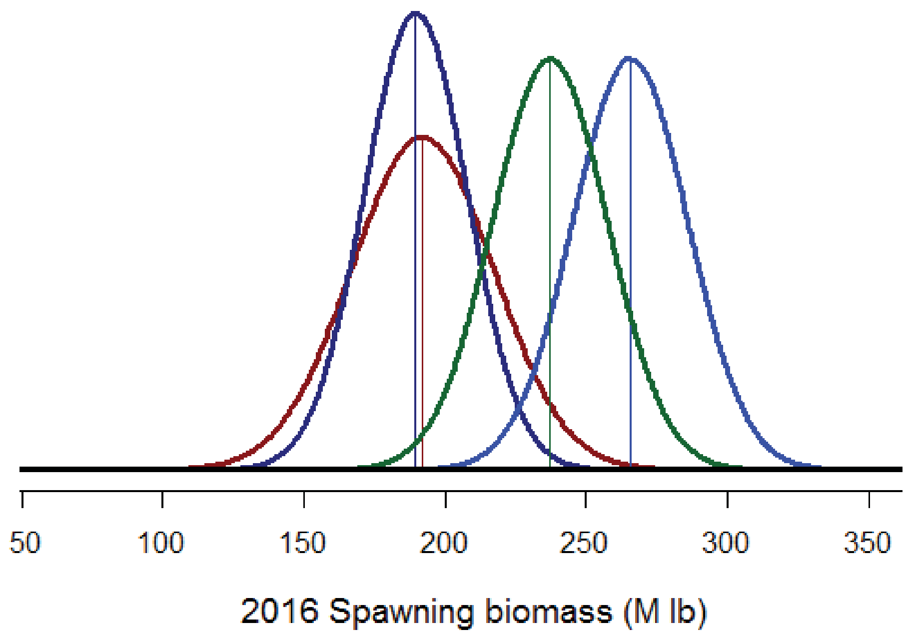

Figure 5. Distribution of individual model estimates for the 2016 spawning biomass. Vertical lines indicate the median values.

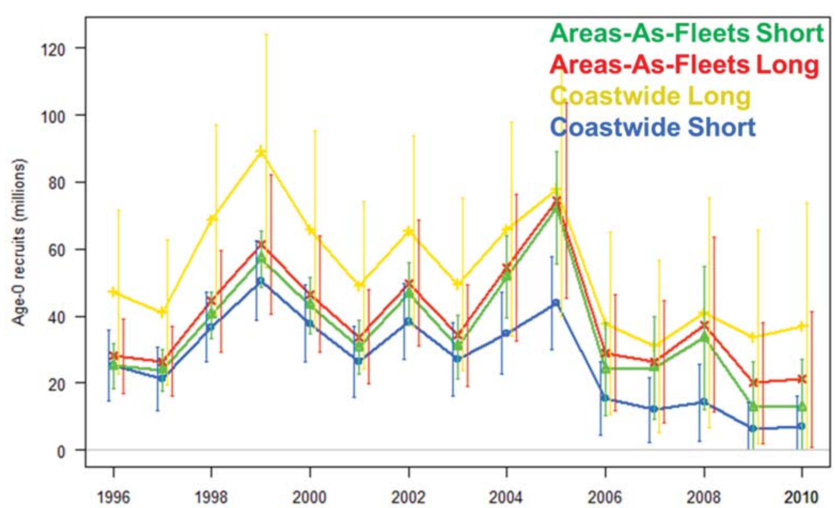

Figure 6. Recent recruitment strengths (by birth year) estimated by all four ensemble models.

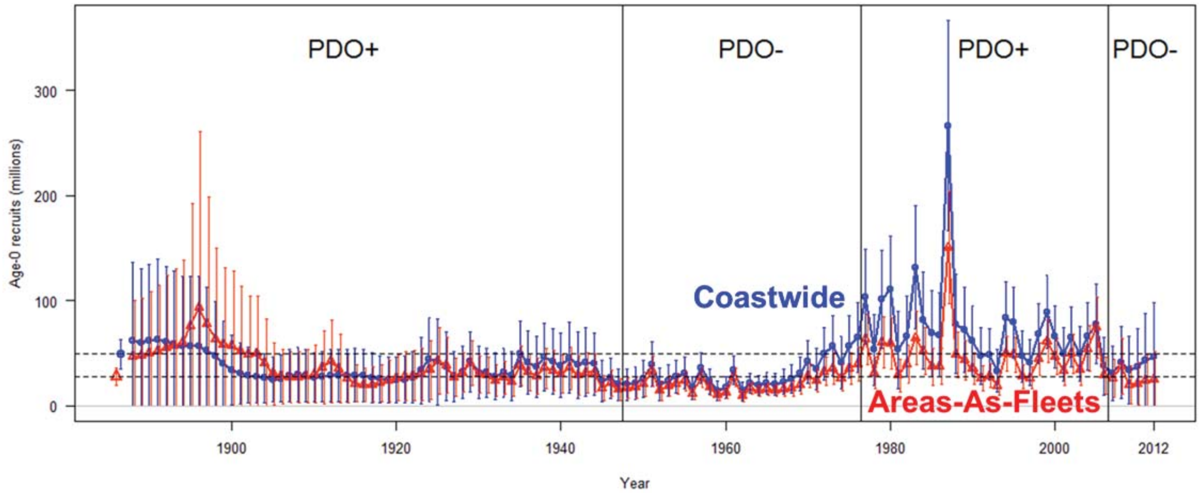

Figure 7. Trend in historical recruitment strengths (by birth year) estimated by the two long time-series models, including the effects of the Pacific Decadal Oscillation (PDO) regimes. Note that estimates after 2009 are highly uncertain, as they are not yet informed by any direct observations.

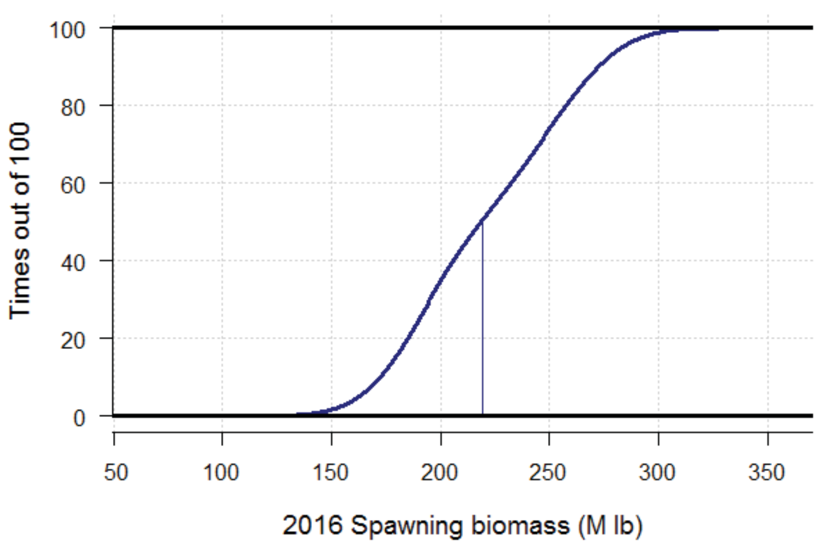

Figure 8. Cumulative distribution of 2016 ensemble spawning biomass estimate. Curve represents the estimated probability that the biomass is less than or equal to the value on the x-axis. Vertical line indicates the median value (219 Mlb).

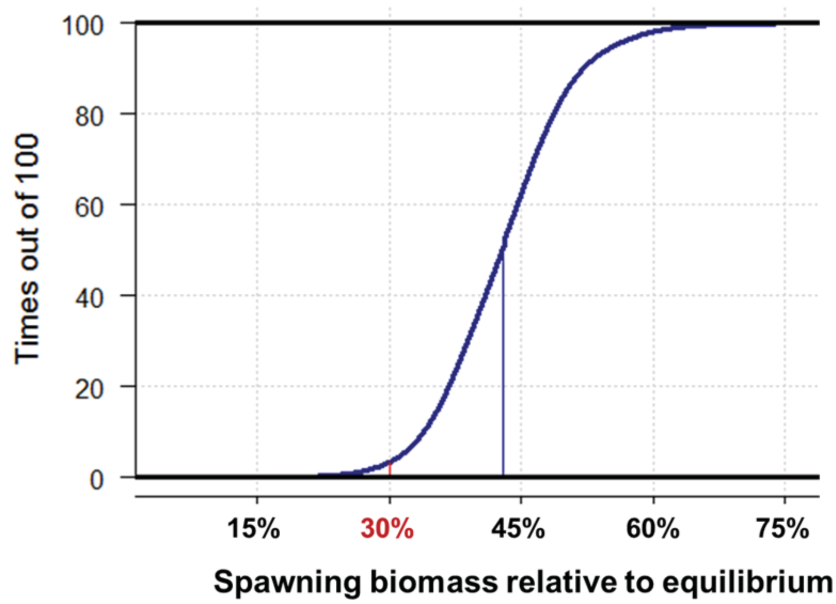

Figure 9. Cumulative distribution of 2016 ensemble spawning biomass estimates relative to the equilibrium spawning biomass in the absence of fishing. Curve represents the estimated probability that the biomass is less than or equal to the value on the x-axis. Vertical lines indicate the median value (43%), and the value corresponding to the IPHC's harvest policy threshold (30%).

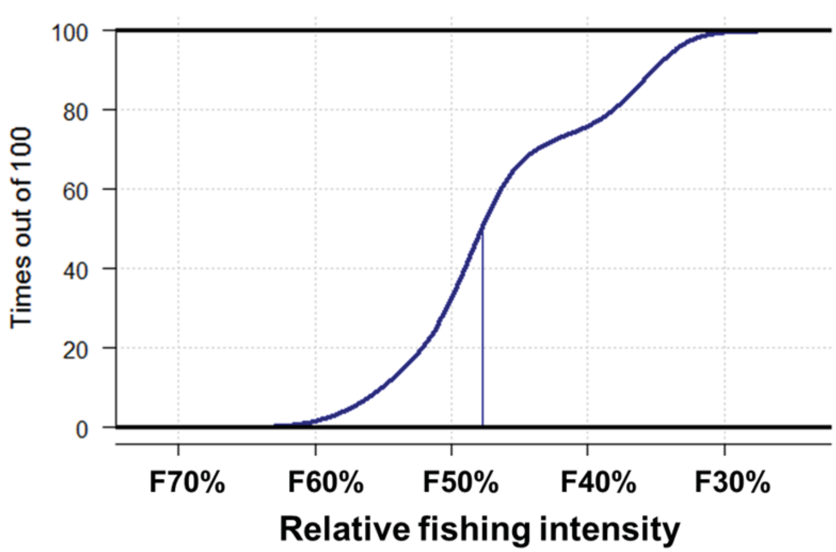

Figure 10. Cumulative distribution of the estimated relative fishing intensity (based on the Spawning Potential Ratio) in 2015. Curve represents the estimated probability that the biomass is less than or equal to the value on the x-axis. Vertical line indicates the median value (*$F_{48\%}$*).

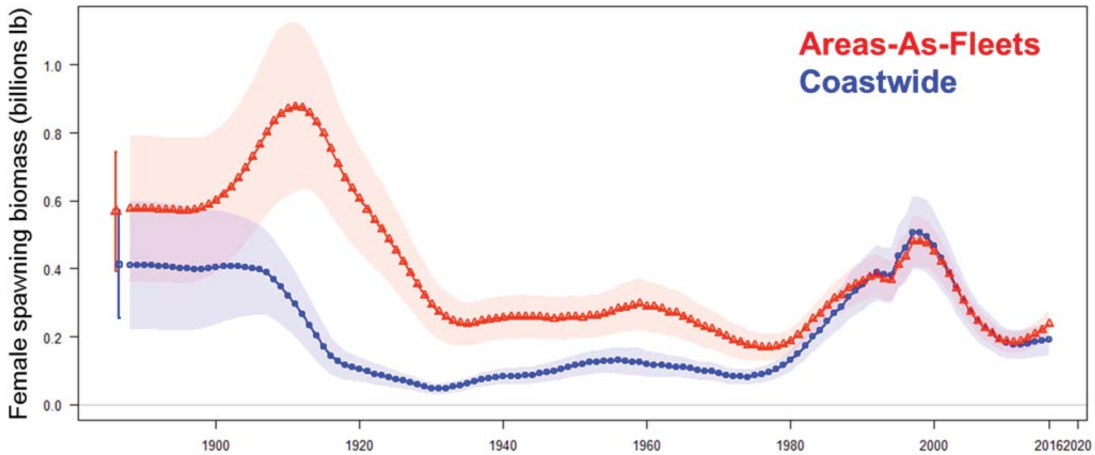

Figure 11. Spawning biomass estimates from the two long time-series models. Shaded region indicates the approximate 95% within-model confidence interval.

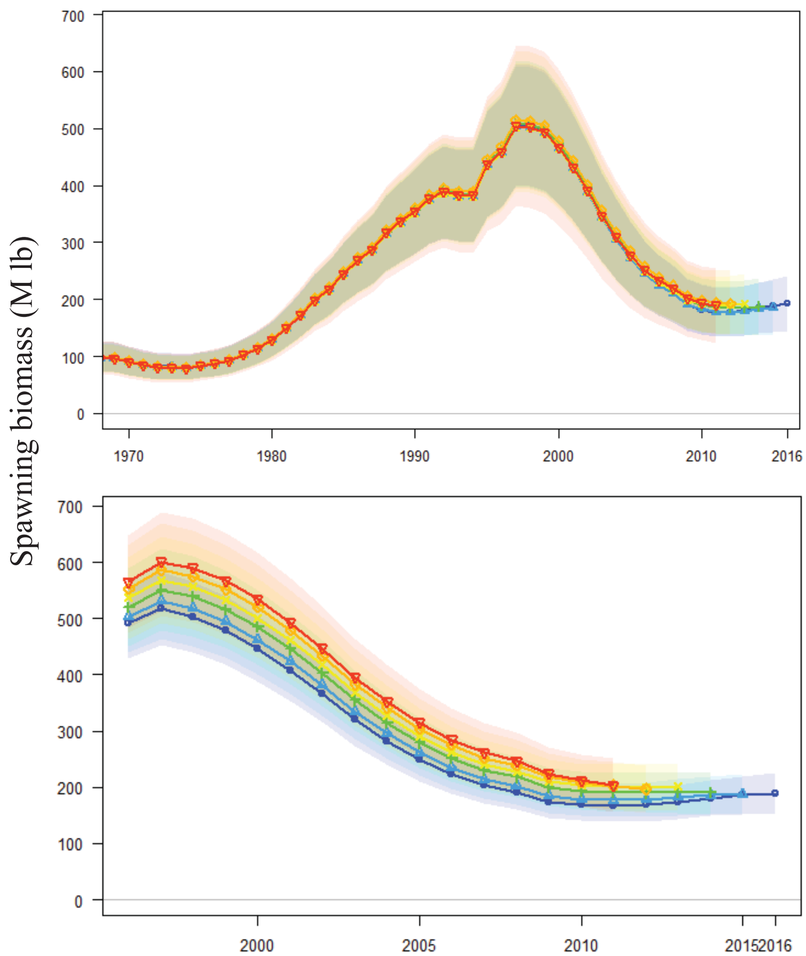

Figure 12. Results of the retrospective analysis on spawning biomass estimates using the coastwide long (upper panel) and coastwide short (lower panel) time-series models and sequentially removing one year of data for five years. Dashed lines and shaded regions indicate within-model 95% uncertainty intervals.

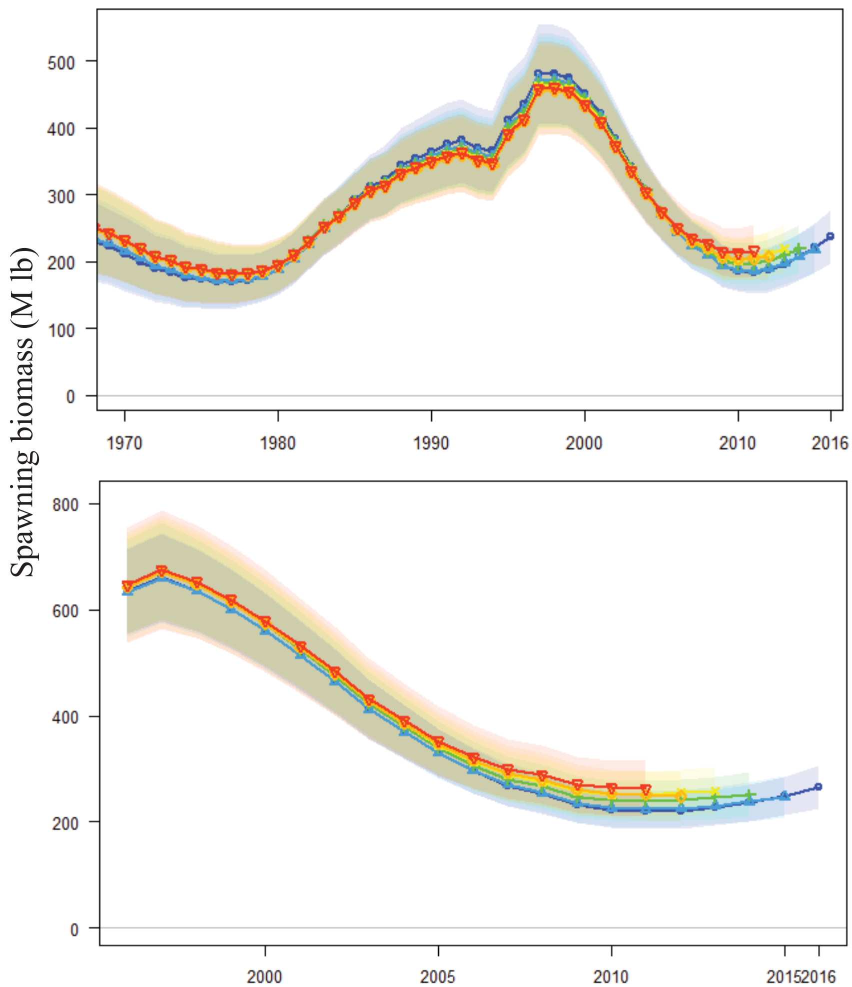

Figure 13. Results of the retrospective analysis on spawning biomass estimates using the Areas-As-Fleets long (upper panel) and Areas-As-Fleets short (lower panel) time-series models and sequentially removing one year of data for five years. Dashed lines and shaded regions indicate within-model 95% uncertainty intervals.

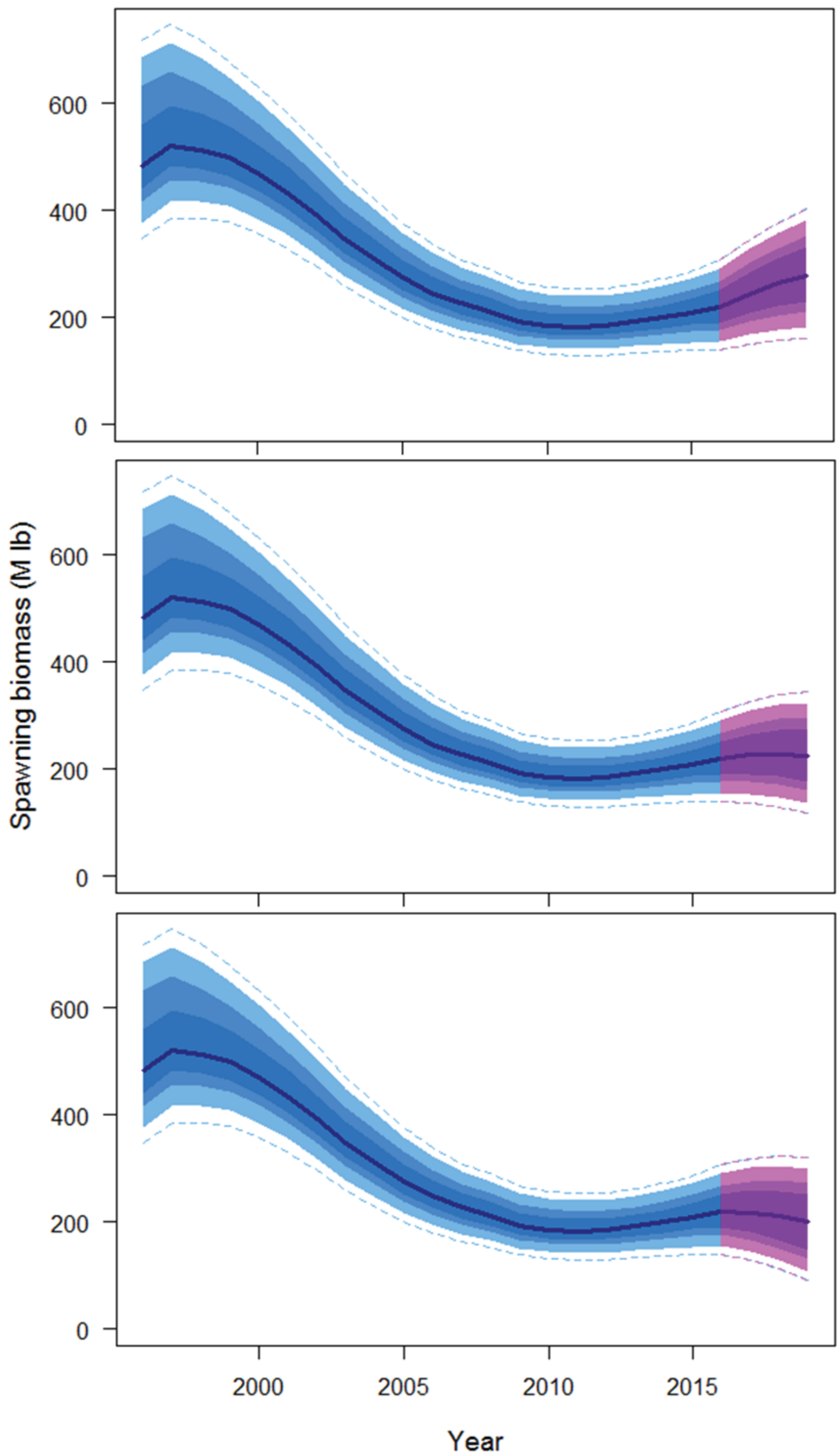

Figure 14. Three-year projections of stock trend under alternative levels of mortality: no removals (upper panel), Blue Line removals (middle panel) and 60 Mlb of total removals (lower panel).

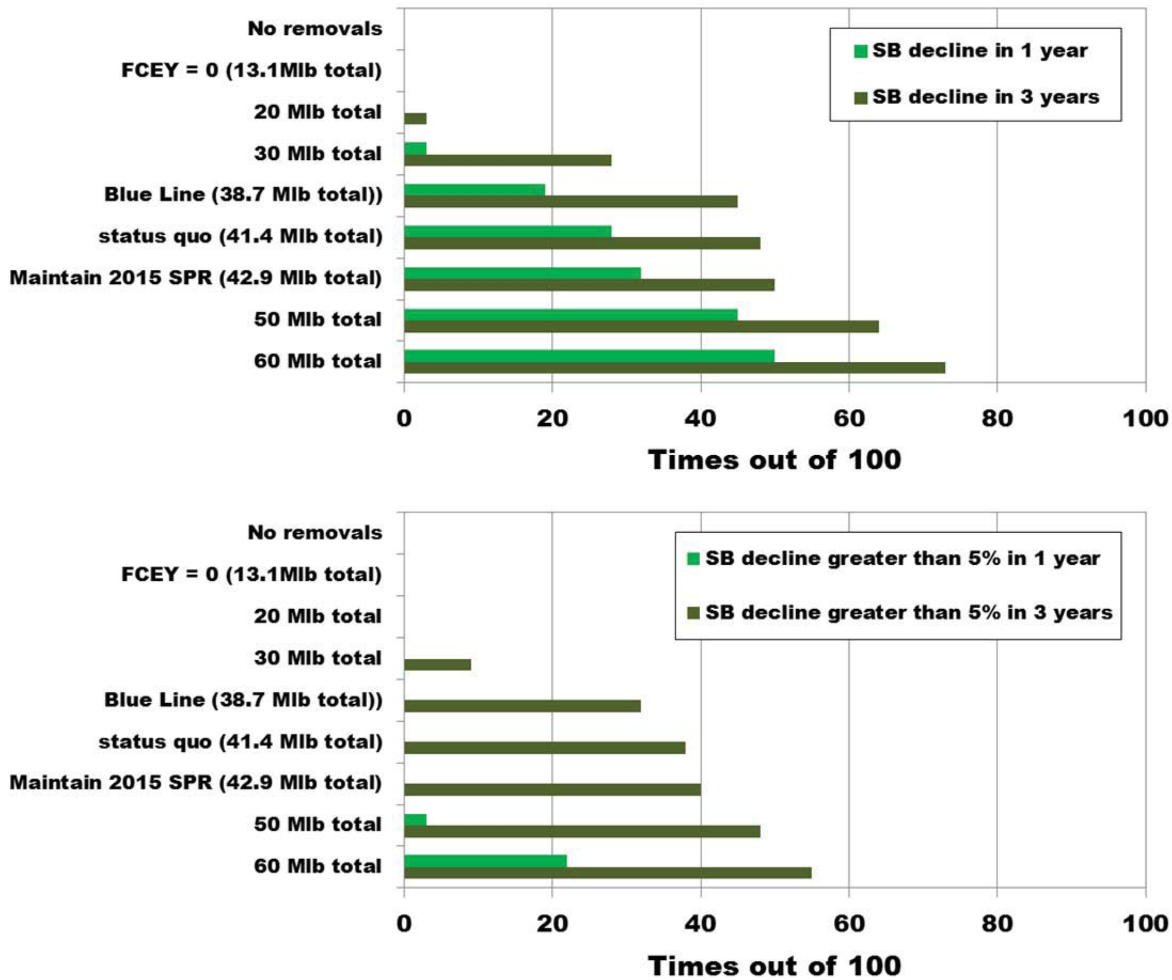

Figure 15. Risk of stock decline (upper panel) and stock decline of at least 5% (lower panel) for each alternative management action presented in the decision table (results represent columns a-d).