DRAFT Northern Southeast Inside Subdistrict (NSEI) sablefish 2019 stock assessment and 2020 forecast recommendations

Authors: Jane Sullivan, Rhea Ehresmann, Ben Williams
Contact: jane.sullivan1@alaska.gov

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SUMMARY

Sablefish (*Anoplopoma fimbria*) are a highly migratory, long-lived species broadly distributed in the North Pacific Ocean. Although managed as separate stocks in Alaska state and federal waters, British Columbia, and in state and federal waters off the U.S. west coast, sablefish are broadly considered to comprise a single population. After three decades of declining or suppressed spawning stock biomass in the North Pacific, sablefish have experienced a sudden and dramatic uptick in numbers due to a large year class in 2014 (Hanselman et al. 2018). Fishery scientists and managers have grappled with how to properly assess the sudden changes in the population while providing sound harvest recommendations. As a result, large reductions in the Allowable or Acceptable Biological Catch (ABC) have been recommended over the past three years. For example, the 2020 ABC was reduced by 57% in the federal assessment in order to keep the increase in ABC from 2019 to 2020 to no greater than 25% (Hanselman et al. 2019). The Alaska Department of Fish and Game (ADFG) has made similar reductions and adjustments to the state water stock assessments in recent years (e.g. Sullivan et al. 2019).

To improve our understanding of the population dynamics of sablefish in the Northern Southeast Inside Subdistrict (NSEI, aka Chatham Strait) and provide fishery stability and long-term conservation of this stock, we propose two important changes to the assessment of the NSEI sablefish fishery for 2020:

1. We recommend the adoption of an integrated statistical catch-at-age (SCAA) model to inform NSEI fishery management. The SCAA model will allow for estimation of recruitment strength and variability and provide insight into how sablefish numbers and biomass have changed over time in Chatham Strait. This change means retiring the previous assessment framework, a yield-per-recruit (YPR) model which uses an annual mark-recapture experiment and the current year's fishery age composition (Appendix A). The SCAA will reduce reliance on the mark-recapture project, which is vulnerable to budget cuts.

2. We recommend a management procedure that constrains the recommended ABC to a 15% annual maximum change. This "max 15% change" management procedure has been shown to increase fishery stability, maximize catch, and successfully achieve biological goals in long-term simulations conducted by the International Pacific Halibut Commission (IPHC; https://www.iphc.int/uploads/pdf/srb/srb014/ppt/iphc-2019-srb014-08-p.pdf). The current NSEI harvest policy will continue to define maximum permissible ABC at a fully-selected fishing mortality rate of F_{50}; however, recommended ABCs will be constrained to a maximum 15% change between years.

To account for legal releases of small sablefish in NSEI, fixed retention probabilities and an assumed discard mortality of 16% were incorporated directly into the SCAA model following Sullivan et al. (2019). The mortality from fishery releases under F_{50} is estimated to be 40,889 lb and is incorporated directly into the ABC calculation.

The SCAA model results in a maximum permissible ABC of 1,382,902 round lb at a fully-selected fishing mortality of F_{50}. This is a 324,865 lb increase (30.7%) from the 2019 ABC of 1,058,037 round lb. **Under the max 15% change management procedure, the recommended 2020 ABC is 1,216,743 round lb, a 158,706 lb increase (15%) from the 2019 ABC.**

Quantity/Status	**2019**	**2020**	**Percent change**
Projected total (age 2+) biomass (lb)	*	45,602,155	--
Projected female spawning biomass (lb)	*	15,004,767	--
Unfished female spawning biomass ($SB_{100\%}$, lb)	*	22,409,188	--
Female spawning biomass at F_{50} ($SB_{50\%}$, lb)	*	11,204,594	--
max $F_{ABC} = F_{50}$	0.0632	0.0756	19.6%
F_{ABC}	0.0632	0.0730	15.5%
Mortality from fishery releases (lb)	19,142	40,889	113.6%
max ABC (lb)	1,058,037	1,382,902	30.7%
ABC (lb)	1,058,037	1,216,743	15.0%

* These values were either not reported or not estimated in the 2019 YPR model. They will be available for comparison in 2021.

A summary of results from the YPR model are presented in Appendix A. The YPR model results in a 2020 ABC of 969,547 round lb, an 8.4% decrease from the 2019 ABC (Table 1 of Appendix A). Further analysis demonstrated these results were highly sensitive to three age-2 individuals sampled in the commercial fishery. When these three samples were removed and age compositions were recalculated, the model resulted in a recommended 2020 ABC of 1,338,253 round lb, a 26.5% increase from the 2019 ABC (Table 1 of Appendix A). **We do not recommend this model be used to inform management in 2020.**

The following are notable results from the SCAA model and potential conservation concerns for this stock:

1. The model has poor fits to the fishery CPUE index and overestimates 2019 observations of longline survey and fishery CPUE, both of which declined relative to 2018 (Figure 1 B & C). Fishery CPUE is at a 15-year low.
2. The forecasted increase in spawning biomass relies heavily on the large predicted 2014 year class (Figure 2A). The females in this year class are assumed to be approximately 50% mature in 2020, and they are estimated to account for 25.7% of the female spawning biomass in 2020.
3. The SCAA model is not estimating a large 2016 year class (Figure 2A), which is currently estimated to be 2.5 times the 2014 year class in the current federal assessment (Hanselman et al. 2019). These findings are corroborated by ADFG longline survey age and length compositions and may change with additional years of data.
4. Estimates suggest the sablefish spawning stock biomass remains at a suppressed level compared to the 1980s and 1990s (Figure 2B).
5. The model has poor fits to the fishery age composition data (Figure 3). The proposed SCAA model fixes selectivity to federal values; however, this may be a poor assumption if selectivity differs in the NSEI fishery. Methods to address this problem are in development for future assessments.
6. Mean age and length for males and females has declined dramatically in the longline survey but has remained constant or increased in the fishery (Figure 4). Recent decreases in the survey mean age and length are partially explained by an influx of small fish into the fishery; however, these trends began prior to the 2014 year class and could be indicative of degradation of age and length structure in the population. The different signals in the survey and fishery data are attributed to significant high grading in the NSEI fishery. Last year's assessment took initial steps to account for this unobserved source of mortality, and we recommend future work to refine these methods.

CHANGES TO THE NSEI SABLEFISH ASSESSMENT FOR 2020 RELATIVE TO 2019

1. The primary change to the assessment is the transition from the YPR to the SCAA model. Key differences between these models include:

   Data inputs: The YPR uses the current year's mark-recapture estimate, current year's fishery age compositions, survey weight-at-age estimated from a weight-based von Bertalanffy model (1997-2019), sex ratios from the longline survey, and estimates of female maturity-at-age from longline survey data (1997-2019). The plus group for the YPR model is 42. The SCAA model data inputs include indices of catch (1980-2019), fishery catch-per-unit effort (CPUE) in lb per hook (1980-2019), survey CPUE in numbers per hook (1997-2019), mark-recapture abundance estimates for years with surveys (2005-2019), fishery age and length compositions (2002-2019), and longline survey age and length compositions (1997-2019). The SCAA model uses longline survey (1997-2019) and fishery (2002-2019) weight-at-age estimated from a weight-based von Bertalanffy model and estimates of female maturity-at-age from longline survey data (1997-2019). Consistent with federal assessments for sablefish, the plus group for the SCAA model is 31, which allows us to use the federal ageing error matrix and age-length transition matrices as inputs to the model.

Model structure: The YPR model is a deterministic and equilibrium-based model. Abundance estimates are partitioned into age classes using fishery age compositions, and $F_{50\%}$ is estimated using the optim() function in the statistical software R (R Core Team 2018). The SCAA model is an integrated statistical catch-at-age model that fits abundance indices and composition data using statistical likelihoods.

Estimation of uncertainty: The YPR model does not incorporate uncertainty from the mark-recapture abundance estimates into the estimation of unfished spawning stock biomass or $F_{50\%}$. The SCAA model estimates uncertainty in model parameters using a maximum likelihood approach. It includes measurement error in the data likelihoods, and assumed process error in recruitment. Future versions of the SCAA model will be implemented in a Bayesian framework, and Markov chain Monte Carlo (MCMC) sampling will be implemented using the No-U-Turn (NUTS) sampler in the R library, tmbstan (Monnahan and Kristensen, 2018).

2. Inputs to the mark-recapture estimations have been updated to reflect an invalid assumption that sablefish were sampled for marks during the annual longline surveys. Only tagged individuals have been opportunistically sampled on the survey. Two exceptions include the 2008 and 2010 surveys when countbacks for marks were conducted at the processing plant after the survey. This change results in increased variance estimates for all years but directional changes in point estimates were not consistent across years (Figure 5).
3. Past assessments have recommended refinements to the accounting of mortality from released fish in the assessment. The ABC calculation has been updated this year to include mortality from releases directly. This means that the ABC is calculated as the difference between the estimated landed portion of the catch and the estimated mortality from discards (see section titled Biological Reference Points).

MODEL STRUCTURE

The integrated statistical catch-at-age (SCAA) model presented here was coded in TMB, an R library that leverages C/C++ functionality to calculate first and second order derivatives and was inspired by a similar C/C++ templating software ADMB (Kristensen et al. 2016, Fournier et al. 2012). The TMB code replicates or makes refinements to methods used in a previous ADMB-based, age-structured model for the NSEI sablefish stock (Mueter 2010) that was based on code from an older federal assessment of sablefish that has also been adapted for several Alaska rockfish stocks (Kimura 1990, Sigler 1999). The model can be run as either a single-sex or sex-structured model; however, data inputs are only shown for the sex-structured model. Variable definitions for all equations used in the statistical catch-at-age model can be found in Table 1. Uncertainty in parameters are currently estimated using a maximum likelihood approach.

DATA INPUTS TO THE SCAA MODEL

The data used as inputs to the SCAA model, including biological data, abundance indices, and composition data, can be found at https://github.com/commfish/seak_sablefish/tree/master/data/tmb_inputs. A summary of the available data by year can be found in Figure 6.

Weight-at-age

Data from the 2002–2019 longline fishery and 1997–2019 ADFG longline surveys were used to obtain fishery and survey weight-at-age used in the SCAA model. A weight-based von Bertalanffy growth model was fit to weight-at-age data:

$$\ln(w_a) = \ln W_\infty + \beta \cdot \ln(1 - \exp(-k(a - t_0))) + \varepsilon,$$

where w_a is weight at a given age (lb), W_∞ is the mean asymptotic weight (lb), β is the power in the allometric equation, k relates to the rate at which W_∞ is reached, and t_0 is the theoretical age at weight zero (years). Residuals ε were assumed lognormally distributed to account for increasing variability by age, and the variance of these residuals (σ^2) was estimated. Models were fit separately for each sex and data source using maximum likelihood and the mle() function in R.

The federal assessment uses survey weight-at-age exclusively to fit to catch and effort indices (Hanselman et al. 2018). However, because discarding is permitted in the State fishery, there are large differences in survey and fishery weight-at-age, especially at younger ages (Figure B2A). Consequently, fishery weight-at-age was fit to landed catch biomass, while survey weight-at-age was used to estimate exploitable biomass, spawning biomass, and other quantities of interest in the model (Figure 7A).

Maturity-at-age

Maturity data from the 1997–2019 ADFG longline surveys were used to fit a maturity ogive for female sablefish using logistic regression and the glm() function in R. Maturity-at-length data for this time period were more abundant than maturity-at-age data and appeared to provide the best estimates of maturity; therefore, maturity curves were fit using maturity-at-length data.

Predicted maturity-at-length was transformed to maturity-at-age using fitted values from a length-based von Bertalanffy growth curve fit to survey data. The length-at-50% maturity is 62.1 cm, the k_{mat}, or the slope at the length-at-50% maturity, is 0.45, and the age-at-50% maturity is 6.3 years. Predicted proportions maturity-at-age were used as inputs to the SCAA model and in the calculation of spawning stock biomass (Figure 7B).

Catch

Catch data from 1980-2019 include harvest in the directed sablefish longline fishery, ADFG longline survey removals, and sablefish retained in other fisheries like the IFQ halibut longline fishery (Figure 1A). Catch was estimated in the SCAA model assuming a lognormal distribution with a fixed log standard deviation of 0.05.

Changes in the management structure during this period included a move to Limited Entry in 1985 and the Equal Quota Share (EQS) Program in 1994 (Olson et al. 2017). Additional sources of mortality that are not currently included in this model include sport, subsistence and personal use harvest, estimated bycatch mortality in the halibut fishery, and estimated deadloss, which includes mortality from sand fleas, sharks, and whales. Currently these additional sources of mortality are accounted for in the decrements process used to calculate the Annual Harvest Objective. We recommend that these mortality data be incorporated directly into the model in the future.

Fishery CPUE

Fishery CPUE, defined as retained lb per hook, was used as an index of abundance from 1980-2019 (Figure 1B). Fishery CPUE was estimated in the SCAA model assuming a lognormal distribution with a fixed log standard deviation of 0.1 for the historical data (1980-1996) and 0.08 for the contemporary data (1997 to present).

Fishery CPUE in 2019 was at a 15-year low (Figure 1B). Fishery CPUE decreased from 0.97 to 0.72 lb per hook (-26.0%) between 2018 and 2019. The 2019 fishery CPUE was 15.1% less than the 10-year mean.

Because discarding sablefish is legal in the NSEI fishery, a decline in fishery CPUE may be related to substantial releases of small sablefish. To address this issue, the federal selectivity curve is used in the model, which is estimated assuming 100% mandatory retention. A sex- and age-specific retention probability, coupled with a fixed discard mortality rate, are used to estimate mortality from discards. Future research will be aimed at better understand discarding behavior in the NSEI fishery as it relates to economic and biological factors, and efforts to improve fishery CPUE data quality and standardization are currently underway. Future iterations of this model may exclude fishery CPUE if it remains an uninformative index of abundance.

Survey CPUE

Longline survey CPUE in numbers per hook was used as an index of abundance from 1997–2019 (Figure 1C). This index was assumed to be lognormally distributed, with a fixed log standard deviation of 0.1. The longline surveys in 1988–1996 used a shorter soak time of 1-hr instead of the current 3-11 hr (Carlile et al. 2002, Dressel 2009). These data were omitted because the 1-hr soak time was likely too short to provide an accurate measure of relative abundance (Sigler 1993).

Survey CPUE decreased from 0.21 to 0.19 fish per hook (-10.5%) between 2018 and 2019 (Figure 1C). The 2019 survey CPUE was 12.1% less than the 10-year mean. Several factors may explain this large decrease in survey CPUE, including a change in selectivity (i.e. small fish having a harder being hooked) and exceptional survey conditions in 2019 (e.g., inexperienced vessel captains and crew, poor weather, and fewer stations being sampled due to unsafe conditions). Current research is ongoing to improve survey data quality and standardization.

Mark–recapture abundance

Currently ADFG conducts an annual mark–recapture survey that serves as the basis for stock assessment and management (Green et al. 2016, Stahl and Holum 2010). Fish are tagged during a pot survey from May through June, with recaptures occurring in the ADF&G longline survey in July and the longline fishery from August through November (Beder and Stahl 2016).

The mark-recapture abundance index was included for years when a survey occurred (2003–2010, 2012, 2013, 2015, and 2017–2019; Figure 1D). This index was assumed to be lognormally distributed with a fixed log standard deviation of 0.05. The mark-recapture abundance index increased from 3.01 to 3.14 million fish (+4.3%) between 2018 and 2019 and is the highest estimate it's been since 2005 (Figure 1D).

The 2019 marking survey released 11,094 tagged fish (Table 2). Following methods in past assessments, we accounted for tags recovered outside of the NSEI or period of recapture, natural and fishing mortality, and differences in the size of fish captured in the pot survey and the longline fishery (Appendix A of Sullivan et al. 2019). A summary of data used in the mark-recapture models is in Table 2.

This index of exploitable abundance was developed using a time-stratified Petersen mark–recapture model implemented in the Bayesian software JAGS 4.3.0 (Depaoli et al. 2016). For any given time period i, the number of tagged fish in Chatham Strait (K) and subsequent abundance (N) were modeled as:

$$K_i = \begin{cases} (K_0 - D_0) * \exp(-M * t_i) & \mathrm{i} = 1 \\ (K_{i-1} - k_{i-1} - D_{i-1}) * \exp(-M * t_i) & \mathrm{i} > 1 \end{cases}$$

$$N_i = \begin{cases} (N_i * \exp(-M * t_i) & \mathrm{i} = 1 \\ (N_{i-1} - C_{i-1}) * \exp(-M * t_i) & \mathrm{i} > 1 \end{cases}$$

where K_0 is number of tags released in the ADF&G pot survey, D_0 is the number of tagged fish that are not available to either the ADFG longline survey or to the fishery (tags recovered in halibut fishery or outside of Chatham Strait), M is assumed natural mortality of 0.10 (Johnson and Quinn 1988), k is the number of marked fish recovered, and C is the total catch or number of sablefish removed. N_i was assumed to follow a normal distribution with an uninformed prior (precision = 1×10^{-12}) centered on past assessments' forecast of abundance.

The probability that a sablefish caught in a given time period is marked p_i is informed by the ratio of marks in the population to the total population at that time K_i/N_i. Each p_i is assumed to follow a beta prior distribution $p_i = beta(\alpha, \beta)$, where $\alpha = (K_i/N_i) * x$, $\beta = (1 - K_i/N_i)/x$, and a large x indicates confidence in K_i/N_i. Because N_i was previously assumed to follow vague normal prior, p_i was assigned an informed prior by setting x equal to 10,000.

In each time period, the likelihood of recapturing k marked sablefish given n sampled fish follows a binomial distribution, where

$$Pr(k|n,p) = \binom{n}{k} p^k (1-p)^{n-k}.$$

Additional information on mark-recapture modeling, alternative models considered, and model selection methodology is detailed in Appendix A of Sullivan et al. (2019).

Age compositions

Fishery age compositions from the 2002–2019 longline fishery (Figure 3) and survey (Figure 8) age compositions from the 1997–2019 longline surveys were included in the model. The plus group age was updated from 42 to 31 to maintain consistency with the federal assessment. Sample sizes were deemed insufficient to fit age compositions by sex, so age data have been aggregated for both the survey and fishery. The McAllister and Ianelli (1997) method of tuning composition data by iteratively re-weighting the sample size has been applied to the SCAA model, but results were not ready for this year's assessment. In the interim, effective sample sizes were calculated as the square root of the total sample size by year.

Currently no NSEI-specific ageing error matrix exists. Until this has been fully developed and reviewed, the federal sablefish ageing error matrix has been made available to the State (D. Hanselman, Fisheries Research Biologist, NOAA, Juneau, personal communication April 2019; Hanselman et al. 2018; Heifetz et al. 1999; Figure 9). The ageing error matrix ($\Omega_{a',a}$) is the proportion observed at age a given the true age a'. Ageing error matrices are critical for correcting observed age compositions and estimating recruitment (Fournier and Archibald 1982). Future research should include the development of an ageing error matrix for NSEI in conjunction with the ADFG Age Determination Unit.

Length compositions

Sex-structured length data from the 2002–2019 longline fishery (Figures 10 and 11) and 1997–2019 ADFG longline surveys (Figures 12 and 13) were summarized using the federal conventions for length compositions (Hanselman et al. 2018). The federal assessment uses 2-cm length bins ranging from 41–99 cm. Fish less than 41 cm (l_0) were omitted from the analysis, and fish greater than 99 cm were aggregated into the 99 cm length bin (l_+). Effective sample sizes were calculated as the square root of the total sample size by year.

Length distributions in the fishery (Figures 10 and 11) have dramatically different patterns than the survey (Figures 12 and 13), with few lengths in the fishery less than 60 cm. Full retention is not a requirement in state waters and the length differences between the survey and fishery are attributed to discarding of small fish in the fishery. Because of the bias introduced by allowing fish to be released in the fishery, fishery age and length compositions tend to be poorly fit by the model.

Finally, the selective harvest of larger-bodied fish results in large differences between survey and fishery size-at-age. Until an age-length key is developed for NSEI, the federal age-length keys ($\Lambda_{a,l,k}$) will be used to fit both survey and fishery length compositions (D. Hanselman, Fisheries Research Biologist, NOAA, Juneau, personal communication April 2019; Hanselman et al. 2018; Echave et al. 2012; Figure 14). Ultimately, separate age-length keys should be developed for each data source to account for the differences in survey and fishery size-at-age.

Retention probability

The release of healthy (i.e. not dead, sand flea bitten, etc.) sablefish is allowed in state waters. To model the discarding behavior in the NSEI fishery, processor grade and price per lb data were used to inform retention probabilities at size (Figure 15). Based on conversations with groundfish port sampling staff and fishermen, the lower bound of the Grade 2/3 (3.1 round lb) was assigned a 10% retention probability, the lower bound of the Grade 3/4 (4.9 round lb) was assigned a 50% retention probability, and everything greater than 8 round lb was assigned a 100% retention probability (A. Olson, Groundfish Project Leader, ADF&G July 2018). Remaining retention probabilities were interpolated between these fixed values. Weight-based retention probabilities were translated to sex and age using sex- and weight-based von Bertalanffy growth curves (Figure 7A).

MODEL PARAMETERS

Natural mortality

Natural mortality M was assumed constant over time and age and fixed at 0.10 (Johnson and Quinn 1988). Code infrastructure has been developed to estimate M using a prior as is done in the federal assessment, but this methodology will not be implemented until prior distributions can be thoroughly analyzed.

Discard mortality

Stachura et al. (2012) estimated discard mortality D of sablefish to be 11.7% using release-recapture data from a longline survey in Southeast Alaska. It is likely that discard mortality in a fishery is higher due to careful fish handling on survey vessels during tagging experiments. Therefore, the discard mortality rate from the Pacific halibut fishery, D=16%, was used (Gilroy and Stewart 2013). The Pacific halibut fishery is assumed a reasonable proxy for sablefish, because the fisheries utilize similar gear and frequently the same vessels and crew participate in both fisheries. Moreover, both species are considered hardy and do not experience barotrauma.

Selectivity

The longline fishery and survey are assumed to follow a logistic selectivity pattern. The current parameterization of the logistic curves uses s_{50} and δ, which represent the ages at which 50% of fish are selected by the gear and the shape or slope of the logistic curve, respectively. Selectivity-at-age (s_a) for this parameterization is defined as

$$s_a = \frac{1}{1 + \exp(-\delta(a - s_{50}))}.$$

Selectivity is fit separately for the longline fishery (fsh) and survey (srv). There is flexibility to define discrete time blocks for both fishery and survey selectivity.

Currently fishery and survey selectivity are fixed in the model using federal selectivity values for the derby (pre-EQS), contemporary fishery (EQS), and longline survey (Hanselman et al. 2018).

Estimating selectivity is challenging when accounting for fishery releases because no age or length data are available on the discarded population. Further information is needed to better characterize how discarding behavior has changed over time and if discarding was common pre-EQS.

Catchability

Currently four parameters for catchability are estimated: two for fishery catchability (pre-EQS and EQS) $\ln(q_{fsh})$, one for the ADFG longline survey $\ln(q_{srv})$, and one for the mark–recapture abundance index $\ln(q_{MR})$.

Recruitment and initial numbers-at-age

The numbers-at-age matrix N is parameterized with mean log-recruitment μ_R, 40 (T) log-recruitment deviations τ, mean log initial numbers-at-age μ_N, and 28 ($A-2$) deviations from mean log initial numbers-at-age ψ.

The recruitment process was modeled using random effects, which allows the estimation of $\ln(\sigma_R)$, the parameter that governs the variability in τ and ψ.

Fishing mortality

There is one parameter estimated for mean log-fishing mortality, μ_F, and 40 (T) log-fishing mortality deviations ϕ.

POPULATION DYNAMICS

The population dynamics of this model are governed by the following state dynamics equations, where the number of sablefish N in year $t = 1$, age a, and sex k are defined as

$$N_{1,a,k} = \begin{cases} 0.5 \cdot \exp(\mu_R - M(a - a_0) + \psi_a) & a_0 < a < a_+ \\ 0.5 \cdot \exp(\mu_R - M(a_+ - 1))/(1 - \exp(-M)) & a = a_+ \end{cases}$$

Recruitment to age-2 in all years and the remaining projected N_a matrix is defined as

$$N_{t,a,k} = \begin{cases} 0.5 \cdot \exp(\mu_R + \tau_t) & a = a_0 \\ 0.5 \cdot N_{t-1,a-1,k}\exp(-Z_{t-1,a-1,k}) & a_0 < a < a_+ \\ 0.5 \cdot N_{t-1,a-1,k}\exp(-Z_{t-1,a-1,k}) + N_{t-1,a,k}\exp(-Z_{t-1,a,k}) & a = a_+ \end{cases}$$

where the total instantaneous mortality, $Z_{t,a,k}$, is the sum of natural mortality M and fishing mortality $F_{t,a,k}$. Sex ratios are assumed 50/50 at time of recruitment, thus any changes in sex ratios in the population over time are the result of sex-specific, fully-selected fishing mortality.

Total annual fishing mortality F_t is defined as

$$F_t = \exp(\mu_F + \phi_t).$$

Fishing mortality is modeled as a function of fishery selectivity $s_{t,a,k}$, retention probability $R_{a,k}$ (the age-specific probability of being landed given being caught, Figure 15), and discard mortality D:

$$F_{t,a,k} = s_{t,a,k}^{fsh}(R_{a,k} + D(1 - R_{a,k}))F_t.$$

PREDICTED VALUES

Predicted fishery CPUE (lb per hook) in year t $\hat{I}_t^{fsh}$ was defined as a function of fishery catchability q_{fsh} and biomass available to the fishery:

$$\hat{I}_t^{fsh} = q_{fsh} \sum_{k=1}^{2} \sum_{a=a_0}^{a+} w_{a,k}^{srv} \cdot s_{t,a,k}^{fsh} \cdot N_{t,a,k} \cdot S_{t,a,k}^{fsh},$$

where $w_{a,k}^{srv}$ is estimated mean weight-at-age by sex in the longline survey. Survival ($S_{t,a,k}^{fsh}$) to the beginning of the fishery in August is defined as

$$S_{t,a,k}^{fsh} = \exp\left(-\frac{8}{12}\left(M + F_{t,a,k}\right)\right).$$

Survival equations include natural and fishing mortality because the model assumes continuous fishing mortality.

Predicted longline survey CPUE (numbers per hook) in year t ($\hat{I}_t^{srv}$) was defined as a function survey catchability q^{srv}, abundance available to the survey, and survival to the beginning of the survey in July ($S_{t,a,k}^{srv}$):

$$\hat{I}_t^{srv} = q_{srv} \sum_{k=1}^{2} \sum_{a=a_0}^{a+} s_{t,a,k}^{srv} \cdot N_{t,a,k} \cdot S_{t,a,k}^{srv}.$$

Predicted mark–recapture abundance in year t ($\hat{I}_t^{MR}$) was defined as a function of mark–recapture catchability q^{MR}, abundance available to the fishery, and survival to the beginning of the NSEI fishery in August ($S_{t,a,k}^{fsh}$):

$$\hat{I}_t^{MR} = q_{MR} \sum_{k=1}^{2} \sum_{a=a_0}^{a+} s_{t,a,k}^{fsh} \cdot N_{t,a,k} \cdot S_{t,a,k}^{fsh}.$$

Spawning biomass SB was calculated as

$$SB = \sum_{a=a_0}^{a+} w_{a,f}^{srv} \cdot N_{t,a,f} \cdot S_{t,a,f}^{spawn} \cdot p_a,$$

where $w_{a,f}^{srv}$ is mean weight-at-age of females in the longline survey, $S_{t,a,f}^{spawn}$ is the fraction of females surviving to spawn in February, and p_a is the proportion of mature females at age. In the single sex model, proportion of females at age in the survey r_a is used to obtain the female portion of the N matrix.

Predicted survey age compositions (sexes combined) were computed as

$$\hat{P}_{t,a}^{srv} = \Omega_{a\prime,a} \frac{\sum_{k=1}^{2} N_{t,a,k} \cdot s_{a,k}^{srv}}{\sum_{k=1}^{2} \sum_{a=a_0}^{a+} N_{t,a,k} \cdot s_{a,k}^{srv}},$$

where $\Omega_{a\prime,a}$ is the ageing error matrix. Predicted fishery age compositions (sexes combined) were computed as

$$\hat{P}_{t,a}^{fsh} = \Omega_{a\prime,a} \frac{\sum_{k=1}^{2} C_{t,a,k}}{\sum_{k=1}^{2} \sum_{a=a_0}^{a+} C_{t,a,k}},$$

where $\hat{C}_{t,a,k}$ is the predicted landed catch in numbers-at-age by sex derived from a modified Baranov catch equation:

$$\hat{C}_{t,a,k} = N_{t,a,k} \frac{R_{a,k} F_{t,a,k}}{Z_{t,a,k}} (1 - \exp(-Z_{t,a,k})),$$

where $R_{a,k}$ is the assumed probability of retention by age and sex (Figure 15).

Predicted landed catch in biomass $\hat{Y}$ was calculated as the product of fishery weight-at-age $w_{a,k}^{fsh}$ and landed catch in numbers-at-age:

$$\hat{Y}_t = \sum_{k=1}^{2} \sum_{a=a_0}^{a+} w_{a,k}^{fsh} \cdot \hat{C}_{t,a,k}.$$

The predicted biomass of discarded sablefish estimated to die ($\widehat{W}_t$) with an assumed discard mortality (D) of 0.16 is

$$\widehat{W}_t = \sum_{k=1}^{2} \sum_{a=a_0}^{a+} w_{a,k}^{srv} N_{t,a,k} \frac{D(1 - R_{a,k}) F_{t,a,k}}{Z_{t,a,k}} (1 - \exp(-Z_{t,a,k})).$$

Predicted survey length compositions were calculated using the sex-specific age-length keys ($\Lambda_{a,l,k}$), such that

$$\hat{P}_{t,l,k}^{srv} = \Lambda_{a,l,k} \frac{N_{t,a,k} \cdot s_{a,k}^{srv}}{\sum_{a=a_0}^{a+} N_{t,a,k} \cdot s_{a,k}^{srv}}.$$

Fishery length compositions were calculated as

$$\hat{P}_{t,l,k}^{fsh} = \Lambda_{a,l,k} \frac{\hat{C}_{t,a,k}}{\sum_{a=a_0}^{a+} \hat{C}_{t,a,k}}.$$

BIOLOGICAL REFERENCE POINTS

Biological reference points for NSEI sablefish were developed for the SCAA model following the federal assessment ADMB code (D. Hanselman, Fisheries Research Biologist, NOAA, Juneau, personal communication April 2019). They are based on spawning potential ratio (SPR), or the average fecundity of a recruit over its lifetime divided by the average fecundity of a recruit over its lifetime when the stock is unfished. Spawning stock biomass is used as a proxy for fecundity, which assumes that weight-at-age and fecundity-at-age are proportionally related.

The theoretical numbers-at-age per recruit (N_a^{SPR}) under the current harvest policy F_{50} (the fishing mortality that results in a SPR of 50%) is initialized with 1, then populated assuming the most recent year's values (T) for female fishery selectivity-at-age and estimated F_{50}:

$$N_a^{SPR50} = \begin{cases} 1 & a = a_0 \\ N_{a-1}^{SPR50} \exp(-\mathrm{M} - F_{50} s_{a-1,fem}^{fsh}) & a_0 < a < a_+ \\ N_{a-1}^{SPR50} \exp(-\mathrm{M} - F_{50} s_{T,a-1,fem}^{fsh}) + N_a^{SPR50} \exp(-\mathrm{M} - F_{50} s_{T,a,fem}^{fsh}) & a = a_+ \end{cases}.$$

The N_a^{SPR} under unfished conditions (relating to an SPR of 100%) collapses to

$$N_a^{SPR100} = \begin{cases} 1 & a = a_0 \\ N_{a-1}^{SPR100} \exp(-\mathrm{M}) & a_0 < a < a_+ \\ N_{a-1}^{SPR100} \exp(-\mathrm{M}) + N_a^{SPR100} \exp(-\mathrm{M}) & a = a_+ \end{cases}.$$

The spawning biomass per recruit ($SBPR_{SPR}$) under fished (e.g., SPR = 50%) and unfished (SPR = 100%) conditions is

$$SBPR_{SPR} = \sum_{a=a_0}^{a+} w_{a,f}^{srv} \cdot N_a^{SPR} \cdot S_{T,a,f}^{spawn} \cdot p_a.$$

Equilibrium recruitment is assumed to be equal to the geometric mean of the full estimated recruitment time series such that

$$\dot{R} = \left(\prod_{t=1}^{T} \exp(\mu_R + \tau_t) \right)^{\frac{1}{T}}$$

This assumption differs from the federal model, which assumes the arithmetic mean instead of the geometric mean. The geometric mean is a more appropriate measure of central tendency because sablefish recruitment is best described by a multiplicative function. Using the arithmetic mean in this case results in an equilibrium value for recruitment that is biased high.

Assuming a 50/50 sex ratio for recruitment, equilibrium female spawning biomass (SB_{SPR}) under fished and unfished conditions is calculated as

$$SB_{SPR} = 0.5 \cdot \dot{R} \cdot SBPR_{SPR} \, .$$

The SPR-based fishing mortality rate of F_{50} is estimated using penalized likelihood, The SPR-based biological reference points are estimated using penalized likelihood, where

$$\ln L(SPR) = 100 \left(\frac{SBPR_{50}}{SBPR_{100}} - 0.50\right)^2 .$$

In addition to F_{50}, F_{35}, F_{40}, F_{60}, and F_{70} are estimated for comparison.

The maximum permissible ABC is calculated as the difference between the predicted landed proportion of the catch ($\hat{Y}_{T+1}$) and the estimated mortality from releases ($\widehat{W}_{T+1}$) under F_{50} using forecasted estimates of abundance (N_{T+1}). Equation details for $\hat{Y}_{T+1}$ and $\widehat{W}_{T+1}$ are detailed in the section of this report titled Predicted Values.

LIKELIHOOD COMPONENTS

The objective function, or the total negative log-likelihood to be minimized, included the sum of the following likelihood components L, which received individual weights λ:

1. Landed catch biomass (Y) was modeled using a lognormal likelihood where σ_Y was assumed to be 0.05:

$$\ln L(Y) = \lambda_Y \frac{1}{2\sigma_Y^2} \sum_{t=1}^{T} (\ln(Y_t + c) - \ln(\hat{Y}_t + c))^2,$$

where λ_Y = 1.0 and c is a small constant set at 0.0001 to allow approximately zero catches in log-space.

2. Fishery CPUE, survey CPUE, and the mark–recapture abundance index were modeled using lognormal likelihoods, where σ_I was assumed to be 0.08 for the fishery and survey CPUEs and 0.05 for the mark–recapture abundance index:

$$\ln L(I) = \lambda_I \frac{1}{2\sigma_I^2} \sum_{t=1}^{T_I} (\ln(I_t + c) - \ln(\hat{I}_t + c))^2,$$

where T_I is the number of years of data for each index and λ_I is set to 1.0.

3. Fishery and survey age compositions were modeled using the multinomial likelihood (P^{age}), where effective sample size ω_t was calculated as the square root of the total sample size in year t:

$$\ln L(P^{age}) = \lambda_{P^{age}} \sum_{t=1}^{T_P^{age}} -\omega_t \sum_{a=a_0}^{a+} (P_{t,a} + c) \cdot \ln(\hat{P}_{t,a} + c),$$

where T_P^{age} is the number of years of data for each age composition, $\lambda_{P^{age}}$ is set to 1.0, and c prevents the composition from being 0 in the likelihood calculation.

The Dirichlet-multinomial likelihood is also available in the SCAA code, which derives effective sample size? through the estimation of an additional parameter θ (Thorson et al. 2017):

$\ln L(P^{age}) = \sum_{t=1}^{T_P^{age}} -\Gamma(n_t + 1) - \sum_{a=a_0}^{a+} \Gamma\,(n_t P_{t,a} + 1) + \Gamma(n_t\theta) - \Gamma(n_t + \theta n_t) +$
$\sum_{a=a_0}^{a+} [\Gamma(n_t P_{t,a} + \theta n_t\, \hat{P}_{t,a}) - \Gamma(\theta n_t\, \hat{P}_{t,a})],$

where n is the input sample size. The relationship between n, θ, and ω is

$$\omega_t = \frac{1 + \theta n_t}{1 + \theta}.$$

Further exploration is needed to implement the Dirichlet-multinomial; therefore, only results for the multinomial likelihood are presented in the current assessment.

4. Fishery and survey length compositions by sex were modeled using the multinomial likelihood (P^{len}), where effective sample size ω_t was calculated as the square root of the total sample size in year t:

$$\ln L(P^{len}) = \lambda_{P^{len}} \sum_{k=1}^{2} \sum_{t=1}^{T_P^{len}} -\omega_t \sum_{l=l_0}^{l+} (P_{t,l} + c) \cdot \ln(\hat{P}_{t,l} + c).$$

T_P^{len} is the number of years of data for each length composition and λ_{Plen} is set to 1.0.

5. Annual log-fishing mortality deviations (ϕ_t) were modeled using a penalized lognormal likelihood, where

$$\ln L(\phi) = \lambda_\phi \sum_{t=1}^{T} \phi_t^2,$$

and λ_ϕ=0.1.

6. Recruitment deviations (τ_t) are modeled as random effects, such that

$$\ln L(\tau) = \lambda_\tau \sum_{t=1}^{T} \ln(\sigma_R) + \frac{(\tau_t - 0.5\sigma_R^2)^2}{2\sigma_R}$$

where $-0.5\sigma^2$ is a bias correction needed to obtain the expected value (mean) instead of the median, and λ_τ is fixed to 2.0. The initial numbers-at-age deviations ψ_a are implemented in the same way as recruitment deviations and are governed by the same σ_R. Unlike ADMB, TMB allows fast implementation of nonlinear random effects models by estimating the marginal likelihood of the fixed effects via the Laplace approximation and estimating the random effects using empirical Bayes methods.

An alternative method is available in the SCAA code to model recruitment deviations using a penalized lognormal likelihood

$$\ln L(\tau) = \lambda_\tau \sum_{t=1}^{T} (\tau_t - 0.5\sigma_R^2)^2.$$

This is the parameterization used in the federal assessment, where σ_R is fixed at 1.2 (Hanselman et al. 2018). Only results for the random effects approach are presented in the current assessment.

7. Because the mark–recapture abundance index scales the exploitable population, a normal prior is imposed on q_{MR} of 1.0 with a standard deviation of 0.1. Vague priors are assigned to fishery and survey q. Future work on this model should include the development of priors for fishery and survey q.

MODEL RESULTS

A total of 122 parameters were estimated in the SCAA model (Table 3). The objective function value (negative log likelihood) was 5,404.4 (Table 4). The model fits catch, pre-EQS fishery CPUE, and mark–recapture abundance reasonably well in most years (Figure 1). Contemporary fishery CPUE (EQS) does not fit well, with long runs of positive or negative residuals (Figure 1). The model performs poorly during the period directly following the implementation of EQS in 1994 for all indices, including catch (Figure 1). Further consideration should be given to which abundance indices should be used in the model. For example, because discarding is legal in NSEI and past logbook data have not required released fish to be recorded, fishery CPUE may not be a suitable index of abundance. Starting in 2019, fishermen were required to provide an estimate of number of released sablefish by set; however, there is no record of length or weight of these releases. Finally, variability in catch, survey and fishery CPUE indices, and the mark-recapture abundance estimate was assumed. Future enhancements could include estimating this variability using available data.

Derived indices of age-2 recruitment, female spawning stock biomass, and exploitable abundance and biomass (i.e. available to the fishery) suggest that this stock has been in a period of low productivity since the mid-1990s (Figure 2). Recruitment trends are comparable with federal values, and estimates of spawning stock biomass, exploitable biomass, and exploitable abundance are on par with past and current ADFG estimates (Hanselman et al. 2019, Sullivan et al. 2019). A time series of fishing mortality and harvest rate (the ratio of predicted total catch to exploitable biomass) shows that peak exploitation occurred in the decade following the transition to EQS, 1995-2005 (Figure 16), suggesting that harvest rates during this time period were more than four times current levels.

Results are sensitive to assumptions on recruitment, and methods used to model recruitment differ between the SCAA model and the federal assessment. The SCAA model estimates recruitment deviations using a random effects approach, and the federal assessment uses penalized likelihood. The fundamental difference between these methods is the treatment of σ_R, the parameter governing variability in recruitment, which is estimated using random effects but must be fixed using penalized likelihood. The federal assessment fixes σ_R at 1.2, a relatively high value by national standards and one of the highest among Alaska groundfish stocks (Lynch et al. 2018, Hanselman et al. 2019). The SCAA model estimates σ_R to be 0.46, which is consistent with other long-lived, low productivity fish species. These differing assumptions on recruitment have large implications for the estimation of the large 2014 year class, subsequent increases in population abundance and spawning biomass, and estimation of biological reference points. The 2014 year class was originally estimated to be 10 times larger than mean recruitment and has since reduced by more than half (Hanselman et al. 2018, Hanselman et al. 2019). Estimating recruitment as a random effect stabilizes this year class; however, further analysis is needed to understand the retrospective performance of the SCAA model.

Fits to fishery and survey age compositions are shown in Figures 3 and 8, respectively. Although the model fits the general shape of the age compositions in most years, there are poor residual patterns. Additionally, the model appears to underestimate fits to the plus group ages, which should be explored in future assessments. Fits to female and male fishery length compositions are shown in Figures 10 and 11, respectively. Fits to female and male survey length compositions are shown in Figures 12 and 13, respectively. Like the age compositions, the model predicts the general shape of the length compositions for both the survey and fishery in most years. Despite this, there are also poor residual patterns in the length compositions, and in particular the model is not predicting the small individuals observed in the survey in recent years (Figures 12 and 13).

Because no data on fishery releases exist, it may not be possible to estimate fishery selectivity while fitting to the composition data. Stock assessments that account for discarded catch frequently have observer data and will overcome this challenge through the estimation of a separate selectivity curve for discarded catch. Methods to improve fits to fishery composition data should be developed in future assessments, including modeling changes in retention probability over time using price-per-pound and catch composition data.

ABC RECOMMENDATIONS

The SCAA model results in a maximum permissible ABC (max ABC) of 1,382,902 round lb at a fully-selected fishing mortality of F_{50}. This is a 324,865 lb increase (30.7%) from the 2019 ABC of 1,058,037 round lb. Mortality from fishery releases under F_{50} assuming fixed retention probabilities and a discard mortality of 0.16 is estimated to be 40,889 lb. This value is included directly into the max ABC calculation.

This large increase in ABC is reliant on the 2014 year class, which comprises 25.7% of the forecasted 2020 spawning stock biomass. This is the third consecutive year of large increases in max ABC under the F_{50} harvest policy, and ABC is expected to continue to increase as the 2014 year class grows. Concerns over suppressed spawning stock biomass, a degraded population age structure, and uncertainty in the magnitude of the 2014 year class have prompted conservative management actions in response to the increasing sablefish population.

The Alaska Longline Fishermen Association (ALFA) has expressed concerns through public comment over low economic value of small fish and a need for stability in the sablefish market (e.g. Behnken et al. 2018 in E1 IN MEETING PUBLIC COMMENT). Management strategy evaluations conducted by the International Pacific Halibut Commission (IPHC) have demonstrated that a conservative harvest policy, coupled with management procedures to reduce interannual variability in quotas, can increase fishery stability, maximize catch, and successfully achieve biological goals (https://www.iphc.int/uploads/pdf/srb/srb014/ppt/iphc-2019-srb014-08-p.pdf). Specific management procedures include a maximum 15% change in the ABC between years (max 15% change) and "Slow up, Fast down," which would increase the ABC slowly (1/3 of the change in max ABC) and decrease slowly (1/2 of the change in max ABC). We recommend adopting a max 15% change management procedure to promote fishery stability and predictability between years, while accounting for biological uncertainty and conservation concerns. **Under the max 15% change management procedure, the recommended 2020 ABC is 1,216,743 round lb, a 158,706 lb increase (15%) from the 2019 ABC.**

An examination of past management performance relative to the current model-estimated stock status suggests that estimated total catch (the sum of landed and discarded catch assumed to die) has been within the F_{50} estimated for 2019-2020 since 2016 (Figure 17). However, catch exceeded the recommended harvest under the current F_{50} every year prior to 2016 and exceeded a more liberal harvest policy of F_{40} every year prior to 2009. This is consistent with estimated annual fishing mortality rates, which are estimated to be very high between 1995–2005 likely due to lack of reliable surveys and assessment methodology during this time period (Figure 17). Given past high exploitation rates on this stock, a conservative harvest policy of F_{50} coupled with a max 15% change management procedure is warranted.

EVALUATING THE IMPACT OF MARK-RECAPTURE ABUNDANCE ESTIMATES ON ABC RECOMMENDATIONS

The mark-recapture project has formed the foundation of sablefish management in NSEI since 2005 (Figure 1D). The abundance estimate from the mark-recapture project provides a snapshot of the exploitable abundance in NSEI, and annual surveys allow analysts and managers to track trends in the population over time. The current YPR model uses the abundance estimate as an input. Without it, modeling options are limited to decrementing fishing and natural mortality from the previous year's estimated numbers-at-age, or using the current year's age compositions and the previous year's abundance estimate in the YPR model.

The marking survey did not occur in 2011, 2014, and 2016 due to budget cuts, and this survey is vulnerable to future budget restrictions. One benefit of implementing an SCAA model is reduced reliance on the mark-recapture project and resultant abundance estimate. By integrating multiple sources of abundance and compositional data, the SCAA model can estimate current stock status, F_{50}, and ABC without an updated mark-recapture abundance estimate.

Methods

To evaluate the impact of the mark-recapture abundance estimates on ABC recommendations, the following simulations were conducted:

1. Analysis 1: The SCAA model was run for assessment years without a mark-recapture abundance estimate (2011, 2014, and 2016) to obtain ABC recommendations for 2012, 2015, and 2017, respectively. These were compared to the actual ABC in those years. In addition, the SCAA model was run without the 2019 mark-recapture abundance estimate to evaluate the impact on the 2020 ABC.
2. Analysis 2: The SCAA model was run for 2015-2019 assuming a biennial and triennial marking survey since 2005 to obtain ABC recommendations for 2016 – 2020. Predicted values from the SCAA model were used to fill in missing mark-recapture abundance estimates in 2011, 2014, and 2016 (Figure 1D). Four survey configurations were considered:
    a. Biennial survey (2005, 2007, 2009, 2011, 2013, 2015, 2017, 2019)
    b. Biennial survey (2006, 2008, 2010, 2012, 2014, 2016, 2018)
    c. Triennial survey (2005, 2008, 2011, 2014, 2017)
    d. Triennial survey (2006, 2009, 2012, 2015, 2018)

Results and discussion

Results from Analysis 1 show the ABC from the SCAA model was approximately 270,000 and 570,000 round lb higher than the actual recommended ABC in 2012 and 2017, respectively (Figure 18A). In 2015 and 2020, however, the ABC from the SCAA model was close to the actual ABC. These results, however, reflect maximum ABCs and do not account for the 15% max change management procedure that would reduce interannual variability.

Analysis 2 results show ABC estimates from the SCAA model for 2016 – 2020 assuming the mark-recapture project occurred bi- or triennially (Figure 18B). For the 2016 ABC, the models with the biennial (2006 – 2018) and triennial (2005 – 2017) designs did not converge, so these results were omitted. The ABCs from the different bi- or triennial survey designs were surprisingly similar within years. The 2017 and 2018 ABCs were the most variable, with the triennial surveys book-ending the spread in both years (Figure 18B). More analysis is needed to determine whether this level of variability is acceptable in meeting biological goals for NSEI sablefish.

This analysis demonstrates that harvest recommendations can be made for NSEI sablefish in the absence of an annual marking survey. A biennial survey design provided the most consistency in ABC estimates between 2016 and 2020; however, a triennial survey may suffice given the conservative F_{50} harvest policy and, if implemented, the 15% max change management procedure will provide additional stability in the ABC between years.

RETROSPECTIVE ANALYSIS

Retrospective patterns are defined as “systematic changes in estimates of population size, or other assessment model-derived quantities, that occur as additional years of data are added to, or removed from, a stock assessment” (Hurtado-Ferro et al. 2015). They cause over- or underestimation of stock size, which can lead to flawed harvest recommendations or management advice. For example, a positive retrospective pattern or bias can result in overestimation of stock biomass, which if persistent over many years, will result in the realized fishing mortality rate exceeding the target harvest policy (i.e. overfishing). Alternatively, a persistent negative retrospective pattern or bias will translate into foregone yields and fishing opportunity.

A preliminary retrospective analysis was conducted for the 2019 NSEI sablefish assessment. Following guidance from the North Pacific Fishery Management Council's Groundfish Plan Team (Hanselman et al. 2013), we examined spawning biomass by dropping the last ten years of data (i.e. "peels"), plotted spawning biomass time series for each model run, and plotted the relative changes in reference to the terminal model (2019 in this case). We calculated Mohn's ρ for spawning biomass, which is the mean of the relative differences between the terminal year estimates in each year of the time series and the corresponding estimates in those years from each peel. The Mohn's ρ reported here is revised from its original equation (Mohn 1999, Hanselman et al. 2013), such that:

$$\text{Mohn's } \rho = \sum_{p=1}^{P} \frac{X_{Y-p,p} - X_{Y-p,0}}{Y_{Y-p,0}} / P,$$

where Y is the last year in the full time series, p is the number of years at the end of the peeled data series, and X denotes the estimate of the quantity of interest (e.g., spawning biomass).

Results from the preliminary retrospective analysis showed a strong positive retrospective bias in spawning biomass and a Mohn's ρ of 0.26, which is above the threshold of 0.20 identified for longer-lived species like sablefish (Figure 19; Hurtado-Ferro et al. 2015). This retrospective pattern is consistent with past federal sablefish assessments that showed similarly large positive retrospective patterns (Hanselman et al. 2013). At the time, this result was attributed to the high contrast in the sablefish catch time series, which is also a feature of the NSEI sablefish fishery.

The strong positive retrospective pattern calls into question the validity of SCAA model estimates of ABC made in the previous analysis evaluating the impact of losing the mark-recapture project (Figure 18). Specifically, these ABCs were calculated using estimates of spawning biomass that were too high given our current understanding of the stock (Figures 18 and 19). These findings provide additional support for initiating a max 15% change procedure, which will dampen the potentially detrimental effects of retrospective bias while providing predictability and stability in the fishery. Future developments should further explore the poor retrospective patterns identified in this analysis and consider alternative parameterizations (e.g. time-varying selectivity or natural mortality) that could alleviate this problem.

FUTURE WORK AND RECOMMENDATIONS

Data collection, data storage, and survey design

These tasks have been identified as priorities for Groundfish Project staff:

- Development of a new data entry application for the marking survey should be prioritized within the next year. The current application is no longer connected to a maintained database, and we risk losing valuable data while at sea.
- Data input and storage methods for the mark recovery and countback data should be improved. The countback data are currently stored in spreadsheets on the network drive. The spreadsheets are heavily formatted, do not use consistent data types, and contain no metadata. Consequently, they are difficult to use, and easily lost or changed by anyone with network access.
- We recommend publishing Regional Operation Plans for the longline survey and the port sampling program. Survey designs for these projects have not had biometric review in over a decade.

High priorities for SCAA model developments

These tasks should be developed within 1-2 years of implementing the SCAA model. They are critical components of a well-developed statistical catch-at-age model.

- Implement the SCAA model in a Bayesian framework.
- Explore poor retrospective patterns and consider alternative parameterizations to improve retrospective performance.
- Develop framework to conduct sensitivity analyses on fixed selectivity, maturity, natural mortality, etc.
- Develop framework to conduct projections to evaluate stock status and assess risk.

Long-term or on-going priorities for SCAA model developments

These tasks should be developed within 2-5 years of SCAA implementation. While they are not critical to the implementation of the model, they will improve model-based inference, understanding of stock dynamics, and data quality.

- Develop methods to improve fits to fishery composition data. This may include conducting research to better understand discarding behavior and how it has changed over time using a bioeconomic model that incorporates price per pound data. It may also include exploring alternative ways to estimate selectivity.

- Explore poor fits to plus group age composition data.

- Review indices of abundance used in the SCAA model. We recommend a CPUE standardization for the longline survey and fishery CPUE indices. These indices lack contrast and are therefore uninformative, and they do not track perceived or model-estimated trends in abundance. Preliminary CPUE standardizations for both indices have proved promising, and a more complete analysis is warranted. This effort should also include developing algorithms to identify trip and set targets and allocating total trip landings to set effort.

- Continue progress on data weighting methods. Code was developed for McAllister and Ianelli (1997) in 2020; however, further exploration is warranted before including these estimated effective sample sizes into the model.
- Develop ageing error matrices and age-length keys for NSEI.
- Develop priors for catchability and other relevant parameters.
- Assess alternative sources of data, especially historical biological and catch data (Carlile et al. 2002). There are also mark-recapture data from 1997-2004 that are not currently accessible.
- Develop methods to account for additional sources of mortality, including sport, subsistence and personal use harvest, estimated bycatch mortality in the halibut fishery, and estimated deadloss, which includes mortality from sand fleas, sharks, and whales.
- Explore methods for estimating M with a prior or assuming age-specific M rates.

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REFERENCES

Beder, A., J. Stahl. 2016. Northern Southeast Inside Commercial Sablefish Fishery and Survey Activities in Southeast Alaska, 2015. Alaska Department of Fish and Game, Fishery Management Report No. 15-27, Anchorage, Alaska.

Carlile, D. W., Richardson, B., Cartwright, M., and O'Connell, V.M. 2002. Southeast Alaska sablefish stock assessment activities 1988–2001, Alaska Department of Fish and Game, Division of Commercial Fisheries Juneau, Alaska.

Depaoli, S., James P. Clifton, and Patrice R. Cobb. 2016. Just Another Gibbs Sampler (JAGS) Flexible Software for MCMC Implementation. Journal of Educational and Behavioral Statistics 41.6: 628-649.

Dressel, S.C. 2009. 2006 Northern Southeast Inside sablefish stock assessment and 2007 forecast and quota. Alaska Department of Fish and Game, Fishery Data Series No. 09-50, Anchorage, Alaska.

Echave, K. B., D. H. Hanselman, M. D. Adkison, M. F. Sigler. 2012. Inter-decadal changes in sablefish, *Anoplopoma fimbria,* growth in the northeast Pacific Ocean. Fish. Bull. 210:361-374.

Fournier, D. and C. P. Archibald. 1982. A general theory for analyzing catch at age data. Can. J. Fish. Aq. Sci. 39: 1195-1207.

Fournier, D. A., H. J. Skaug, J. Ancheta, J. Ianelli, A. Magnusson, M.N. Maunder, A. Nielsen, and J. Sibert. 2012. AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. Optim. Methods Softw. 27, 233-249.

Gilroy, H.L. and I.J. Stewart. 2013. Incidental mortality of halibut in the commercial halibut fishery (Wastage). IPHC Report of Assessment and Research Activities 2012. p. 53-60.

Green, K., Baldwin, A. and Stahl, J. 2016. Northern Southeast Inside (Chatham Strait) sablefish marking survey. Alaska Department of Fish and Game Regional Operation Plan, CF.1J.2015.06, 1–24.

Hanselman, D. H., C. J. Rodgveller, K. H. Fenske, S. K. Shotwell, K. B. Echave, P. W. Malecha, and C. R. Lunsford. 2019. Chapter 3: Assessment of the sablefish stock in Alaska. In: Stock assessment and fishery evaluation report for the groundfish resources of the GOA and BS/AI as projected for 2020. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306 Anchorage, AK 99501.

Hanselman, D. H., C. J. Rodgveller, K. H. Fenske, S. K. Shotwell, K. B. Echave, P. W. Malecha, and C. R. Lunsford. 2018. Chapter 3: Assessment of the sablefish stock in Alaska. In: Stock assessment and fishery evaluation report for the groundfish resources of the GOA and BS/AI as projected for 2019. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306 Anchorage, AK 99501.

Hanselman, D. H., C. J. Rodgveller, C. R. Lunsford, and K. H Fenske. 2017. Chapter 3: Assessment of the sablefish stock in Alaska. In: Stock assessment and fishery evaluation report for the groundfish resources of the GOA and BS/AI as projected for 2018. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306 Anchorage, AK 99501.

Hanselman, D.H., W. Clark, and M. Sigler. 2013. Retrospective investigations group report. http://www.afsc.noaa.gov/REFM/stocks/Plan_Team/2013/Sept/Retrospectives_2013_final3.pdf

Heifetz, J., D. Anderl, N.E. Maloney, and T.L. Rutecki. 1999. Age validation and analysis of ageing error from marked and recaptured sablefish, Anoplopoma fimbria. Fish. Bull. 97: 256-263.

Hurtado-Ferro, F., Szuwalski, C. S., Valero, J. L., Anderson, S. C., Cunningham, C. J., Johnson, K. F., Licandeo, R., McGilliard, C. R.,Monnahan, C. C., Muradian, M. L., Ono, K., Vert-Pre, K. A., Whitten, A. R., and Punt, A. E. Looking in the rear-view mirror: bias and retrospective patterns in integrated, age-structured stock assessment models. ICES Journal of Marine Science, 72: 99–110.

Johnson, S. L., and T. J. Quinn II. 1988. Catch-Age Analysis with Auxiliary Information of sablefish in the Gulf of Alaska. Contract report to National Marine Fisheries Service, Auke Bay, Alaska. 79 pp. Center for Fisheries and Ocean Sciences, University of Alaska, Juneau, Alaska.

Kimura, D. K. 1990. Approaches to age-structured separable sequential population analysis. Can. J. Fish. Aquat. Sci. 47: 2364-2374.

Kristensen, K., A. Nielsen, C. W. Berg, H. Skaug, B. M. Bell. 2016. TMB: Automatic Differentiation and Laplace Approximation. Journal of Statistical Software, 70(5), 1-21.doi:10.18637/jss.v070.i05.

Lynch, P. D., R. D. Methot, and J. S. Link (eds.). 2018. Implementing a Next Generation Stock Assessment Enterprise. An Update to the NOAA Fisheries Stock Assessment Improvement Plan. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/SPO-183, 127 p. doi: 10.7755/TMSPO.183

McAllister, M. K., Ianelli, J. N. 1997. Bayesian stock assessment using catch-age data and the sampling: importance resampling algorithm. Can. J. Fish. Aquat. Sci. 54,284–300.

Mohn, R. 1999. The retrospective problem in sequential population analysis: An investigation using cod fishery and simulated data. ICES J. Mar. Sci. 56: 473-488

Monnahan, C. C. and Kristensen, K. 2018. No-U-turn sampling for fast Bayesian inference in ADMB and TMB: Introducing the adnuts and tmbstan R packages. PloS one, 13, e0197954.

Mueter, F. 2010. Evaluation of stock assessment and modeling options to assess sablefish population levels and status in the Northern Southeast Inside (NSEI) management area. Alaska Department of Fish and Game, Special Publication No. 10-01, Anchorage, Alaska.

Olson, A., Stahl, J., Vaughn, M., Carroll, K. and Baldwin, A. 2017. Annual management report for the Southeast and Yakutat commercial groundfish Fisheries, 2017. Alaska Department of Fish and Game Fishery Management Report, No. 17-54, 1–47.

R Core Team. 2018. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Sigler, M. F. 1993. Stock assessment and management of sablefish Anoplopoma fimbria in the Gulf of Alaska. PhD Dissertation. University of Washington. 188 pp.

Sigler, M. F., 1999. Estimation of sablefish, Anoplopoma fimbria, abundance off Alaska with an age-structured population model. Fishery Bulletin, 97: 591-603.

Stachura, M. M., C. R. Lunsford, C. J. Rodgveller, and J. Heifetz. 2012. Estimation of discard mortality of sablefish (Anoplopoma fimbria) in Alaska longline fisheries. Fishery Bulletin 110(2):271–279.

Stahl, J. P. and D. D. Holum. 2010. 2009 NSEI (Chatham Strait) sablefish tagging survey. Alaska Department of Fish and Game, Fishery Data Series No. 10-30, Anchorage.

Sullivan, J., Olson, A. and Williams, B. 2019. 2018 Northern Southeast Inside subdistrict sablefsh fishery stock assessment and 2019 management plan. Alaska Department of Fish and Game Regional Information Report, No. 5J19-03, 1–81.

Thorson, J. T., Johnson, K. F., Methot, R. D., & Taylor, I. G. 2017. Model-based estimates of effective sample size in stock assessment models using the Dirichlet-multinomial distribution. Fisheries Research, 192, 84-93.

TABLES

Table 1. Variable definitions for the statistical catch-at-age (SCAA) model.

Variable	Definitions
Indexing and model dimensions	
T	Number of years in the model
t	Index for year in model equations
A	Number of ages in the model
a	Index for age in model equations
a_0	Recruitment age (age-2)
a_+	Plus group age (age-31)
l	Index for length bin in model equations
l_0	Recruitment length bin (41 cm)
l_+	Plus group length bin (99 cm)
fsh	NSEI longline fishery
srv	ADF&G longline survey
MR	Mark–recapture abundance
Parameters	
M	Instantaneous natural mortality
F	Instantaneous fishing mortality
Z	Total instantaneous mortality
S	Total annual survival
D	Discard mortality
s_{50}	Age at which 50% of fish are selected to the gear
s_{95}	Age at which 95% of fish are selected to the gear
δ	Slope parameter in the logistic selectivity curve
q	Catchability
μ_R	Mean log recruitment
τ_t	Log recruitment deviations
μ_N	Mean log initial numbers-at-age
ψ_a	Log deviations of initial numbers-at-age
σ_R	Variability in recruitment and initial numbers-at-age
μ_F	Mean log fishing mortality
ϕ_t	Log fishing mortality deviations
θ	Dirichlet-multinomial parameter related to effective sample size

Data and predicted variables	
w_a	Weight-at-age
p_a	Proportion mature-at-age
R	Retention probability
s_a	Selectivity-at-age
$\Omega_{a',a}$	Ageing error matrix (proportion observed at age given the true age a')
$\Lambda_{a,l,k}$	Age-length key (proportion in length bin given age and sex)
N	Numbers-at-age
C	Landed catch in numbers-at-age
I, $\hat{I}$	Indices of abundance, $\hat{I}$ are predicted values
P_a, $\hat{P}_a$	Age compositions, $\hat{P}_a$ are predicted values
P_l, $\hat{P}_l$	Length compositions, $\hat{P}_l$ are predicted values
Y, $\hat{Y}$	Landed catch biomass, $\hat{Y}$ are predicted values
$\hat{W}$	Estimated mortality from fishery releases (biomass)
λ	Weight for likelihood component
L	Likelihood
ω	Effective sample size for age and length compositions
n	Input sample size for Dirichlet-multinomial likelihood
c	Small constant (0.00001)

Table 2. A summary of data inputs to the mark-recapture models, including total individuals tagged (K), the total number of tags remaining once size-selectivity is accounted for (K_0), tags not available to the longline survey or fishery (captured in other fisheries or outside Chatham, D_0), recaptured individuals in the longline survey and fishery (k_{srv} and k_{fsh}), number of sampled individuals in the longline survey and fishery (n_{srv} and n_{fsh}), tags not available to the fishery (captured outside Chatham or in other fisheries during the survey, D_{srv}), and tags recaptured in other fisheries or outside Chatham during the fishery (D_{fsh}) for years with a tagging survey from 2005-2019.

Year	K	K_0	D_0	k_{srv}	n_{srv}	D_{srv}	k_{fsh}	n_{fsh}	D_{fsh}
2005	7,118	7,118	9	0	0	104	690	180,999	84
2006	5,325	5,325	3	0	0	46	503	203,878	38
2007	6,158	6,055	2	0	0	43	335	150,729	61
2008	5,450	5,412	4	40	15,319	54	431	156,313	71
2009	7,071	7,054	7	0	0	51	285	105,709	62
2010	7,443	7,307	4	54	14,765	60	331	106,201	28
2012	7,582	7,548	23	0	0	70	380	97,134	53
2013	7,961	7,921	24	0	0	89	374	99,286	113
2015	6,862	6,765	1	0	0	73	242	70,273	32
2017	7,096	6,933	3	0	0	42	197	60,409	11
2018	9,678	9,160	13	0	0	77	183	65,940	135
2019	11,094	10,208	6	0	0	51	155	47,995	123

Table 3. Parameter estimates from the statistical catch-at-age model.

Parameter	Estimate	Standard error
fsh_logq	-17.842	0.043
fsh_logq	-17.047	0.024
srv_logq	-16.365	0.023
mr_logq	-0.049	0.010
log_rbar	13.447	0.070
log_rec_devs_1980	0.267	0.356
log_rec_devs_1981	0.303	0.362
log_rec_devs_1982	0.326	0.364
log_rec_devs_1983	0.317	0.358
log_rec_devs_1984	0.297	0.349
log_rec_devs_1985	0.245	0.336
log_rec_devs_1986	0.175	0.322
log_rec_devs_1987	0.068	0.305
log_rec_devs_1988	-0.092	0.286
log_rec_devs_1989	-0.259	0.270
log_rec_devs_1990	-0.396	0.259
log_rec_devs_1991	-0.482	0.251
log_rec_devs_1992	-0.497	0.245
log_rec_devs_1993	-0.434	0.245
log_rec_devs_1994	-0.210	0.252
log_rec_devs_1995	0.036	0.260
log_rec_devs_1996	0.229	0.275
log_rec_devs_1997	0.495	0.279
log_rec_devs_1998	0.590	0.275
log_rec_devs_1999	0.447	0.268
log_rec_devs_2000	0.042	0.265
log_rec_devs_2001	0.155	0.261
log_rec_devs_2002	0.478	0.236
log_rec_devs_2003	-0.023	0.256
log_rec_devs_2004	-0.138	0.243
log_rec_devs_2005	-0.065	0.240
log_rec_devs_2006	-0.133	0.241
log_rec_devs_2007	-0.182	0.237
log_rec_devs_2008	-0.137	0.235
log_rec_devs_2009	-0.096	0.232
log_rec_devs_2010	-0.368	0.233
log_rec_devs_2011	-0.367	0.236
log_rec_devs_2012	-0.156	0.243
log_rec_devs_2013	0.243	0.266
log_rec_devs_2014	0.565	0.260
log_rec_devs_2015	0.233	0.389

Parameter	Estimate	Standard error
log_rec_devs_2016	1.990	0.607
log_rec_devs_2017	0.372	0.379
log_rec_devs_2018	0.226	0.346
log_rec_devs_2019	0.138	0.330
log_rinit	14.000	0.121
log_rinit_devs_age_3	2.707	0.206
log_rinit_devs_age_4	0.247	0.351
log_rinit_devs_age_5	0.133	0.329
log_rinit_devs_age_6	0.055	0.316
log_rinit_devs_age_7	-0.003	0.309
log_rinit_devs_age_8	-0.045	0.303
log_rinit_devs_age_9	-0.045	0.304
log_rinit_devs_age_10	-0.039	0.304
log_rinit_devs_age_11	-0.032	0.305
log_rinit_devs_age_12	-0.025	0.306
log_rinit_devs_age_13	-0.019	0.307
log_rinit_devs_age_14	-0.015	0.308
log_rinit_devs_age_15	-0.012	0.308
log_rinit_devs_age_16	-0.008	0.308
log_rinit_devs_age_17	-0.003	0.309
log_rinit_devs_age_18	0.002	0.310
log_rinit_devs_age_19	0.007	0.310
log_rinit_devs_age_20	0.012	0.311
log_rinit_devs_age_21	0.018	0.312
log_rinit_devs_age_22	0.024	0.313
log_rinit_devs_age_23	0.029	0.313
log_rinit_devs_age_24	0.035	0.314
log_rinit_devs_age_25	0.040	0.315
log_rinit_devs_age_26	0.045	0.316
log_rinit_devs_age_27	0.049	0.316
log_rinit_devs_age_28	0.054	0.317
log_rinit_devs_age_29	0.058	0.318
log_rinit_devs_age_30	0.062	0.318
log_sigma_r	-0.780	0.123
log_Fbar	-2.738	0.354
log_F_devs_1980	-2.042	0.367
log_F_devs_1981	-3.155	0.365
log_F_devs_1982	-2.868	0.359
log_F_devs_1983	-3.108	0.358
log_F_devs_1984	-2.452	0.358
log_F_devs_1985	-0.612	0.358
log_F_devs_1986	-0.274	0.358

Parameter	Estimate	Standard error
log_F_devs_1987	-0.270	0.358
log_F_devs_1988	-0.131	0.358
log_F_devs_1989	-0.170	0.358
log_F_devs_1990	0.115	0.358
log_F_devs_1991	0.345	0.358
log_F_devs_1992	0.498	0.358
log_F_devs_1993	0.892	0.357
log_F_devs_1994	0.786	0.357
log_F_devs_1995	0.874	0.357
log_F_devs_1996	0.999	0.357
log_F_devs_1997	1.145	0.357
log_F_devs_1998	1.266	0.357
log_F_devs_1999	0.971	0.357
log_F_devs_2000	1.055	0.357
log_F_devs_2001	0.766	0.357
log_F_devs_2002	0.681	0.357
log_F_devs_2003	0.663	0.357
log_F_devs_2004	0.775	0.357
log_F_devs_2005	0.732	0.357
log_F_devs_2006	0.723	0.357
log_F_devs_2007	0.483	0.357
log_F_devs_2008	0.549	0.358
log_F_devs_2009	0.293	0.358
log_F_devs_2010	0.275	0.358
log_F_devs_2011	0.106	0.358
log_F_devs_2012	0.237	0.358
log_F_devs_2013	0.243	0.358
log_F_devs_2014	0.048	0.358
log_F_devs_2015	0.052	0.358
log_F_devs_2016	-0.152	0.358
log_F_devs_2017	-0.135	0.358
log_F_devs_2018	-0.064	0.358
log_F_devs_2019	-0.145	0.358
log_spr_F_35	-2.004	0.290
log_spr_F_40	-2.203	0.275
log_spr_F_50	-2.582	0.265
log_spr_F_60	-2.963	0.278
log_spr_F_70	-3.380	0.319

Table 4. Negative likelihood values and percent of each component to the total likelihood. The data likelihood is the sum of all likelihood contributions from data. The total likelihood is comprised of the data likelihood, penalized likelihoods, random effects, and priors.

Likelihood component	Likelihood	% of Data likelihood
Catch	16.9	0.3
Fishery CPUE	197.2	3.6
Survey CPUE	39.4	0.7
Mark-recapture abundance	81.3	1.5
Fishery ages	143.6	2.6
Survey ages	131.3	2.4
Fishery lengths	2744.4	50.6
Survey lengths	2069.5	38.2
Data likelihood	5423.6	100.0
Fishing mortality penalty	5.1	--
Recruitment likelihood	-38.5	--
SPR penalty	0.0	--
Sum of catchability priors	14.3	--
Total likelihood	5404.4	--

FIGURES

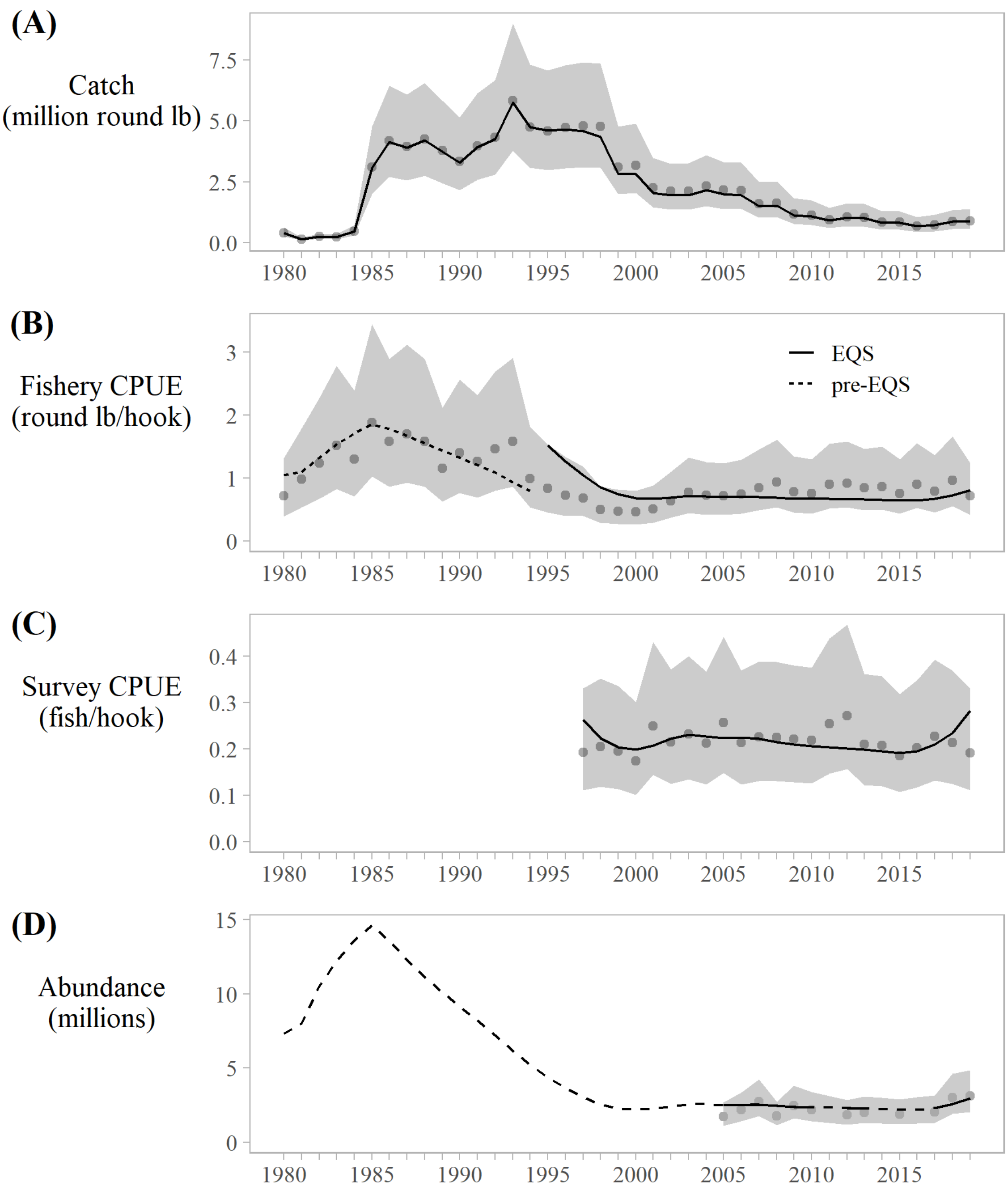

Figure 1. Fits to indices of catch and abundance with the assumed error distribution shown as shaded grey polygons. Input data are shown as grey points and model fits are shown in black. Indices include (A) harvest (round mt); (B) fishery catch per unit effort in round kg per hook with separate selectivity and catchability time periods before and after the implementation of the Equal Quota Share program in 1994; (C) survey catch per unit effort in number of fish per hook; and (D) mark–recapture abundance estimates in millions. Solid and dashed lines in panel D reflect years for which data were and were not available, respectively.

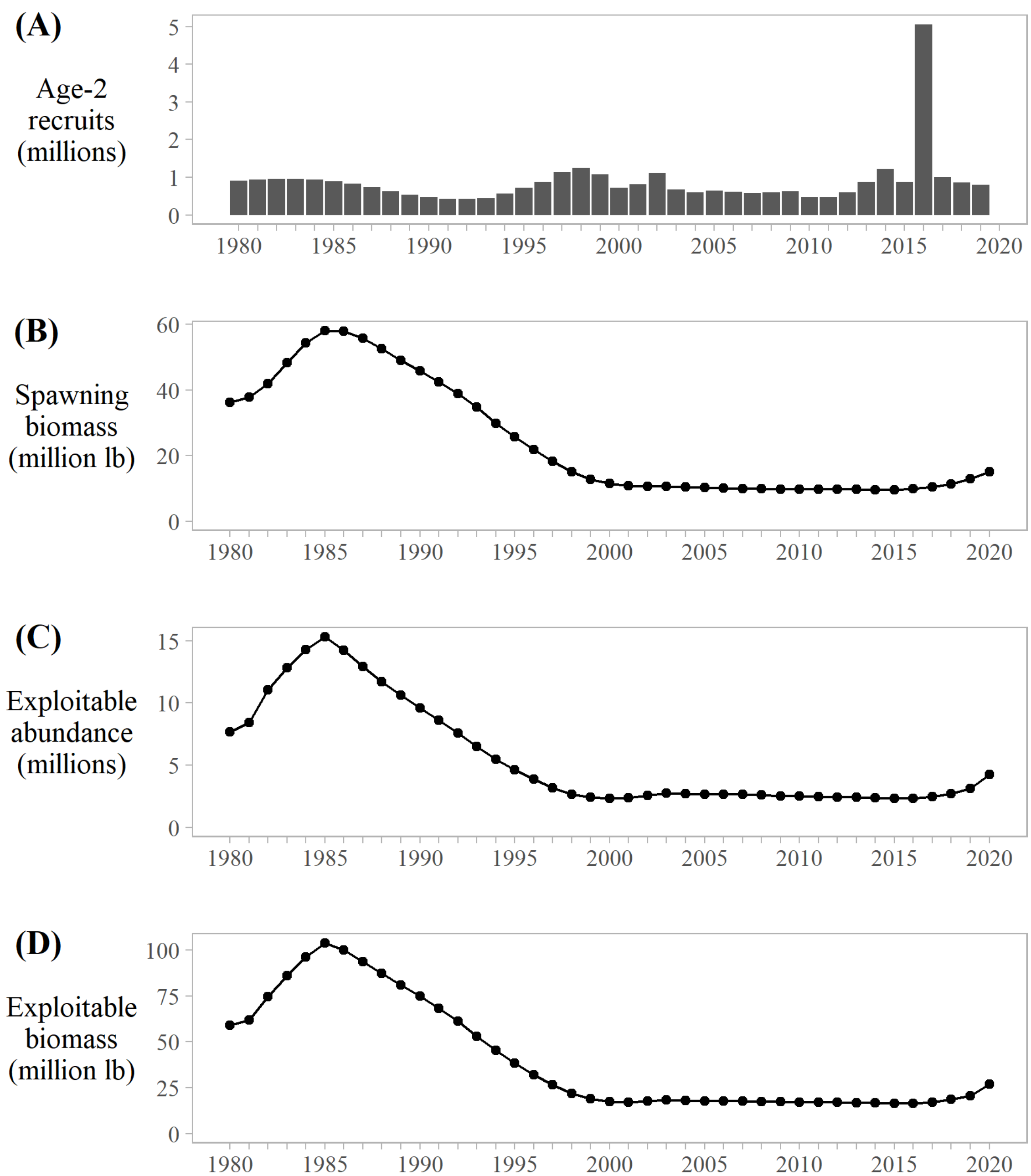

Figure 2. Model predictions of (A) age-2 recruitment (millions), (B) female spawning stack biomass (million lb), (C) exploitable abundance (millions), and (D) exploitable biomass (million lb).

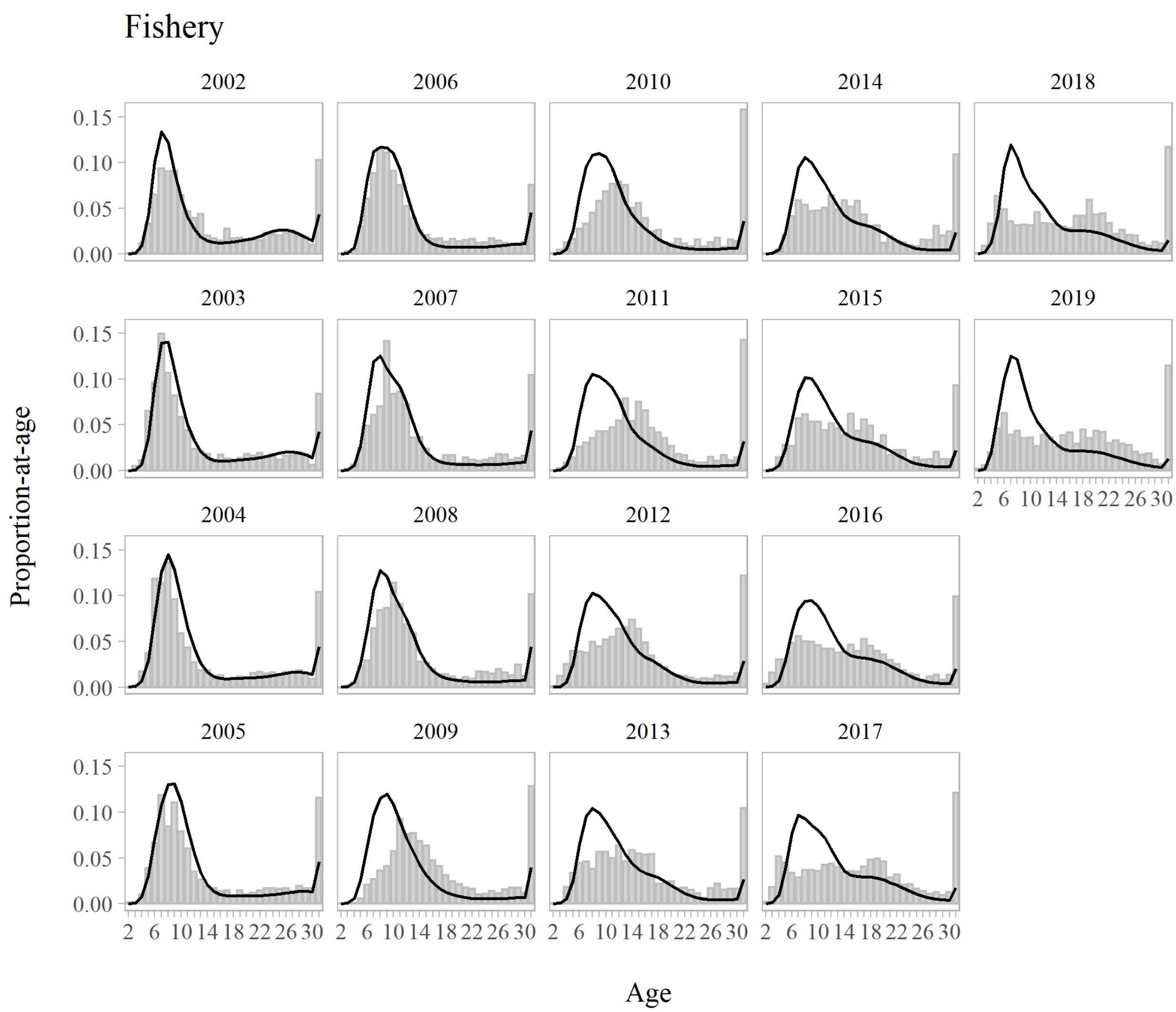

Figure 3. Fits to fishery age compositions, 2002–2019. Observed (gray bars) and predicted proportions-at-age (black lines) shown.

Figure 4. A comparison of mean fork length (cm) and age (yr) by sex in the NSEI longline fishery (black) and NSEI longline survey (grey).

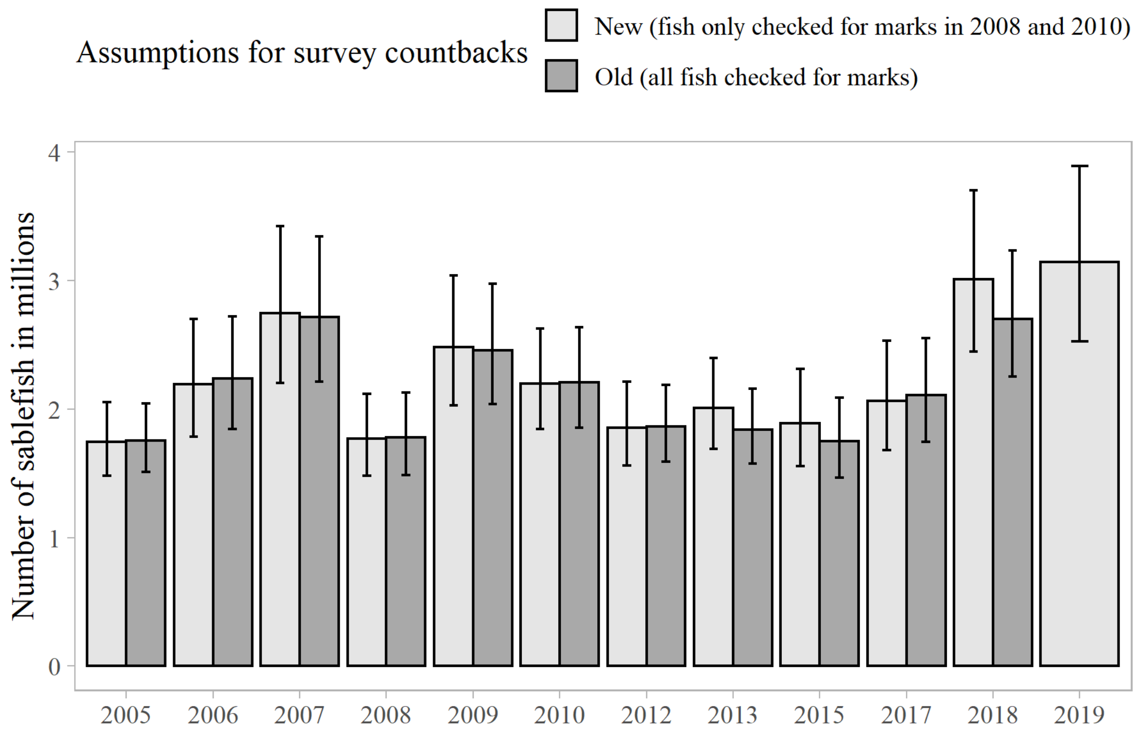

Figure 5. A comparison of mark-recapture abundance estimates (number of sablefish in millions) using different assumptions about countbacks in the NSEI longline survey. Past assessments assumed all fish on the survey were checked for marks; however, this assumption was only valid for 2008 and 2010. Correcting this assumption increased 95% credible intervals (error bars) but did not have a consistent directional effect on the expected values. The mark-recapture model for 2019 was not run using the old assumption.

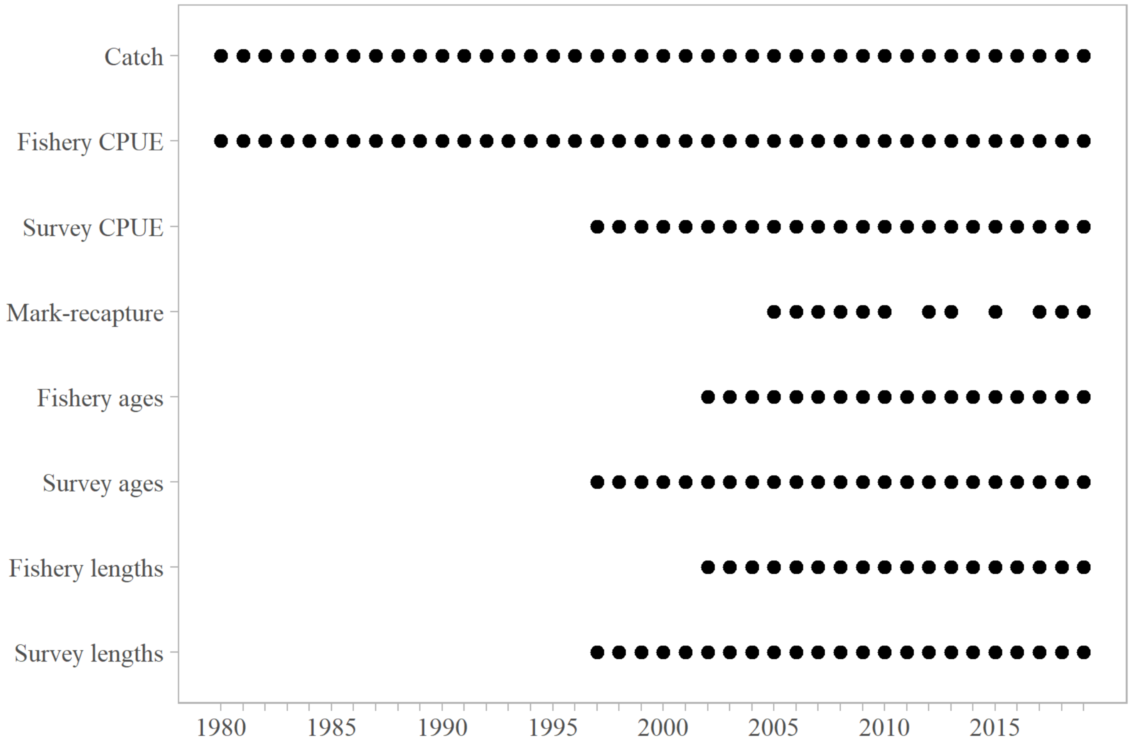

Figure 6. A summary of the available data sources in NSEI by year.

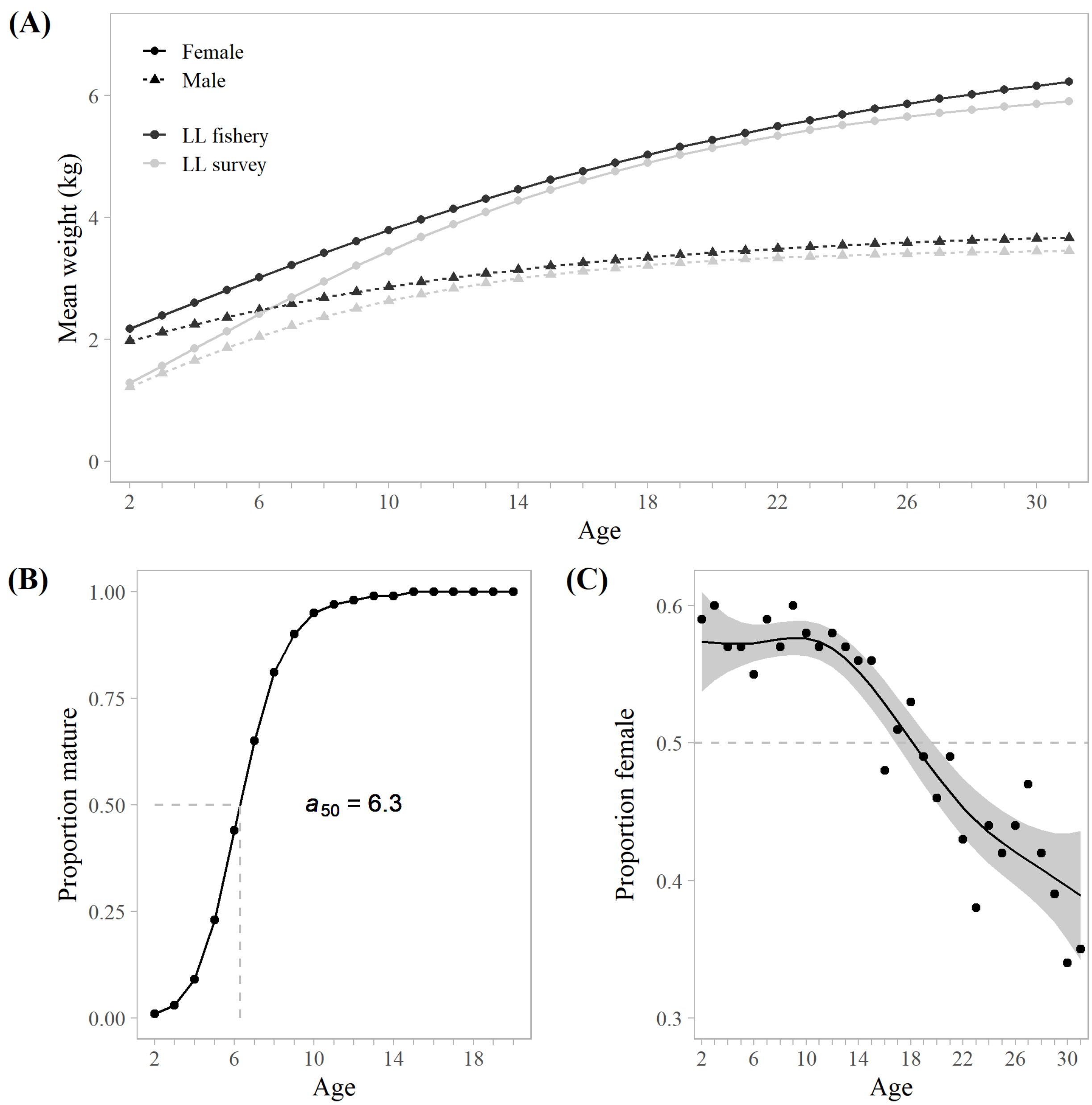

Figure 7. Biological inputs to the statistical catch-at-age model, including: (A) von Bertalanffy growth model predictions of weight-at-age (kg) by sex from the longline fishery (black) and ADF&G longline survey (grey); (B) proportion mature at age for females estimated from the longline survey with the age at 50% maturity (a_{50}=6.3 yr); and (C) proportion female in the longline survey, where the curve is the fitted line from a generalized additive model +/- 2 standard error.

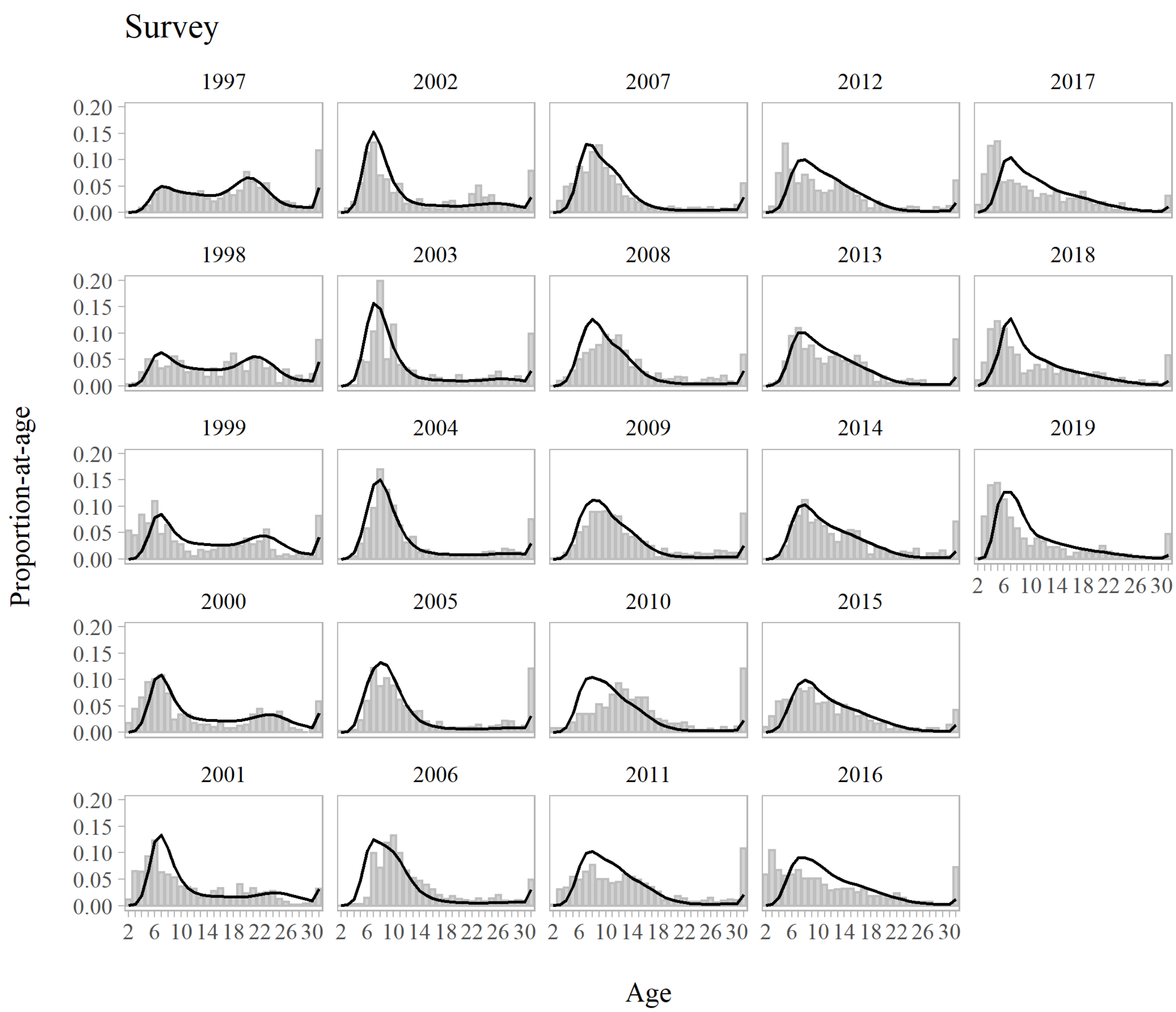

Figure 8. Fits to survey age compositions, 1997–2019. Observed (gray bars) and predicted proportions-at-age (black lines) shown.

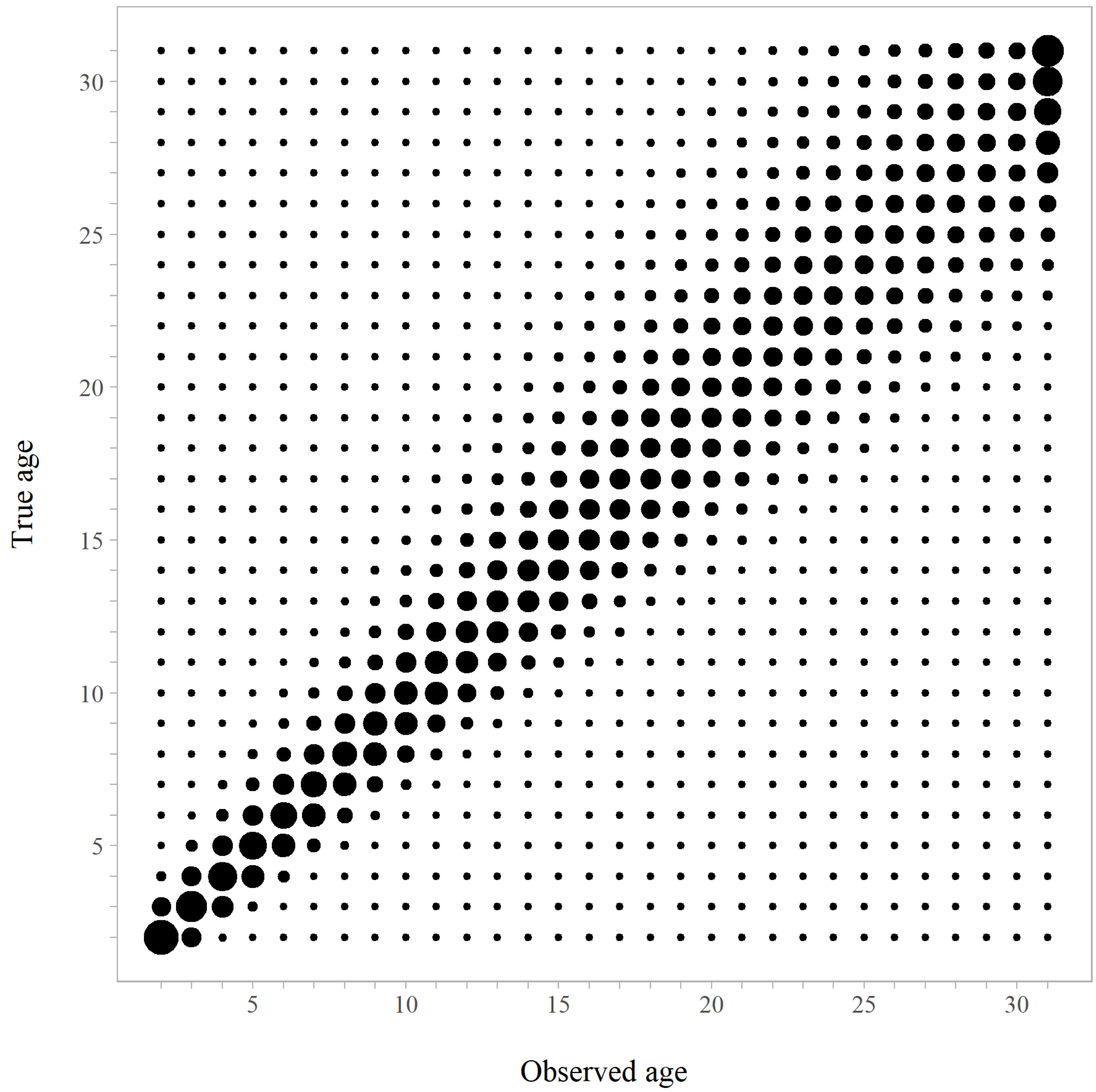

Figure 9. Ageing error matrix used in the model, showing the probability of observing an age given the true age (Heifetz et al. 1999).

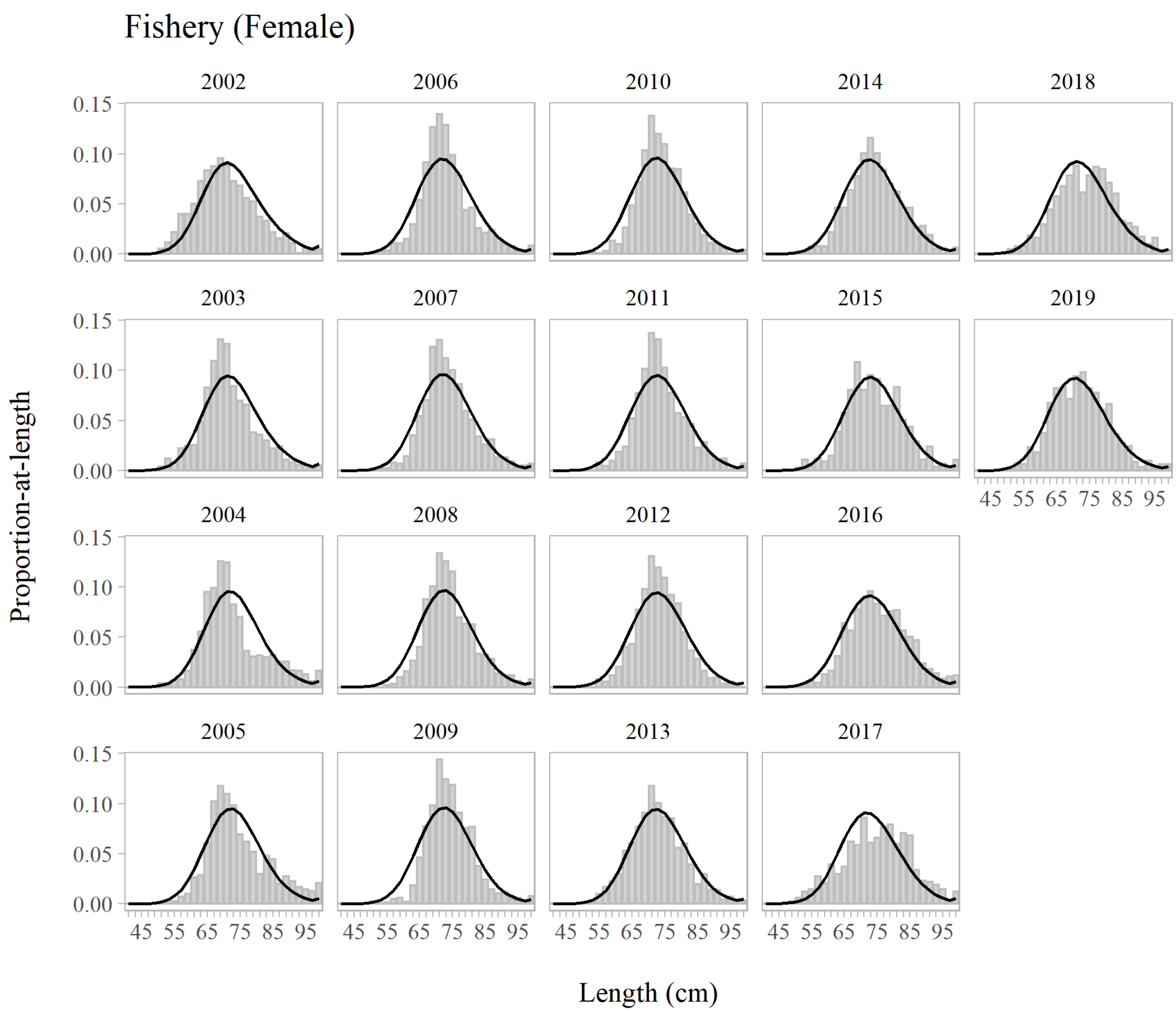

Figure 10. Fits to female fishery length compositions, 2002–2019. Observed (gray bars) and predicted proportions-at-age (black lines) shown.

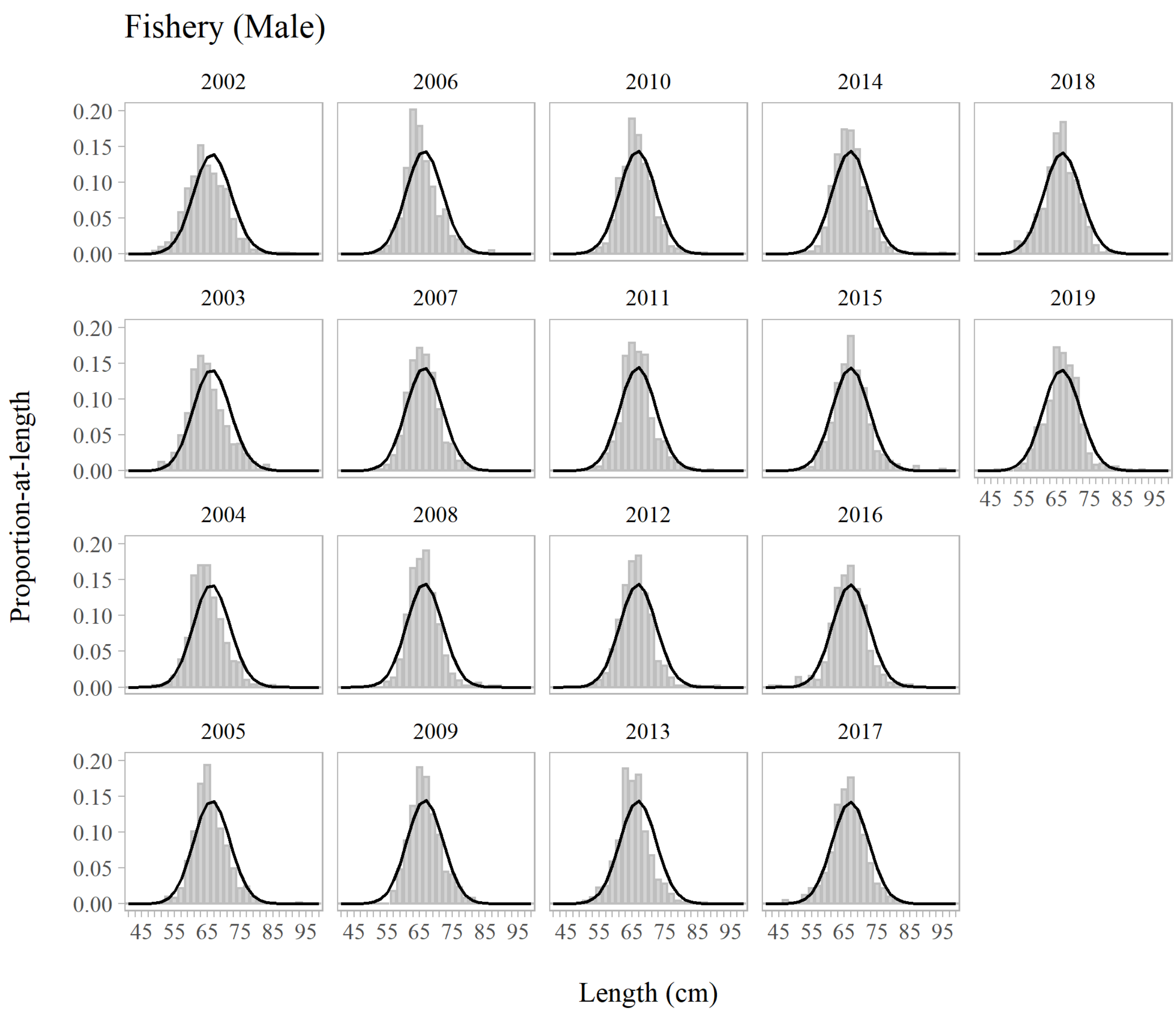

Figure 11. Fits to male fishery length compositions, 2002–2019. Observed (gray bars) and predicted proportions-at-age (black lines) shown.

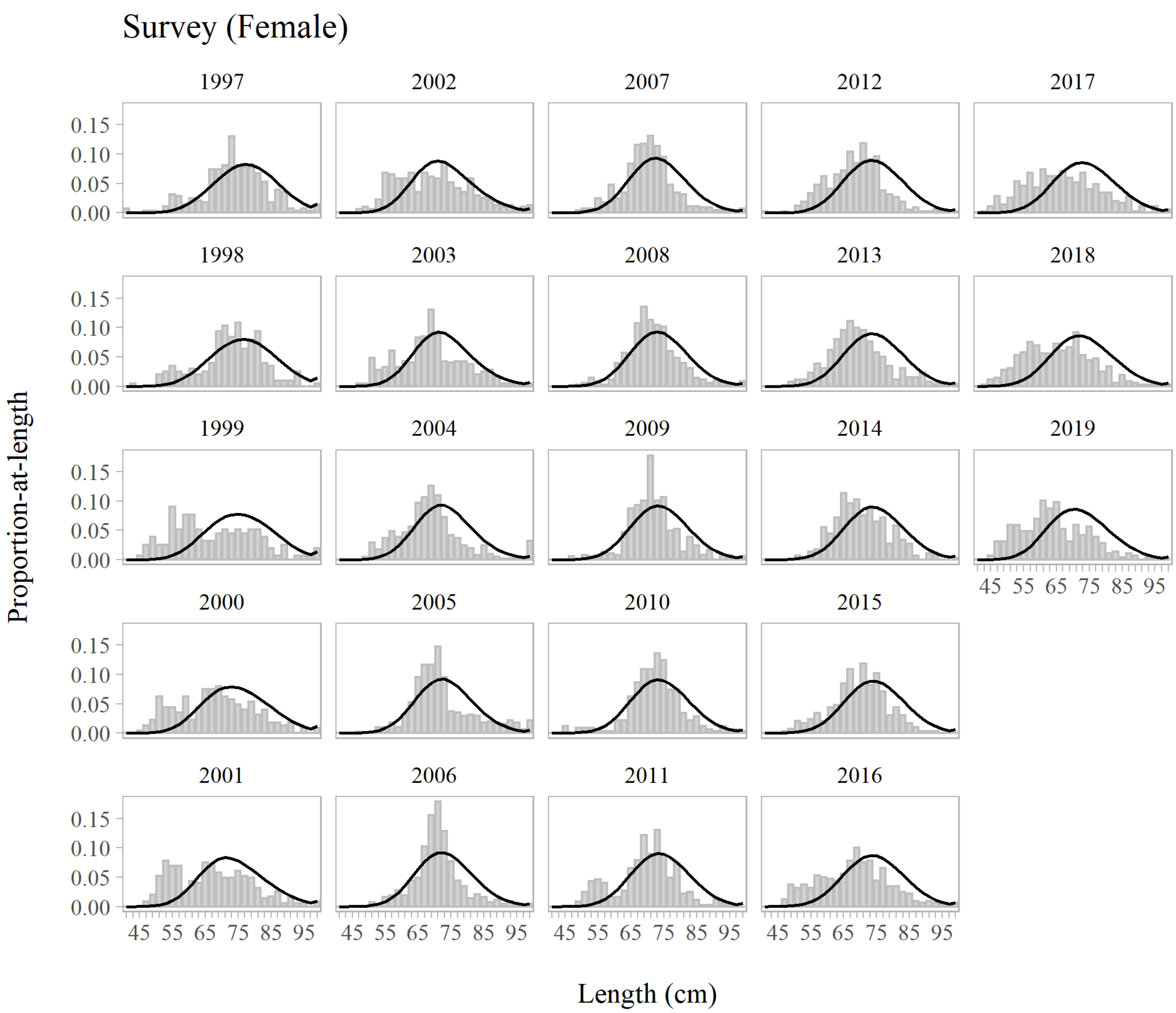

Figure 12. Fits to female survey length compositions, 1997–2019. Observed (gray bars) and predicted proportions-at-age (black lines) shown.

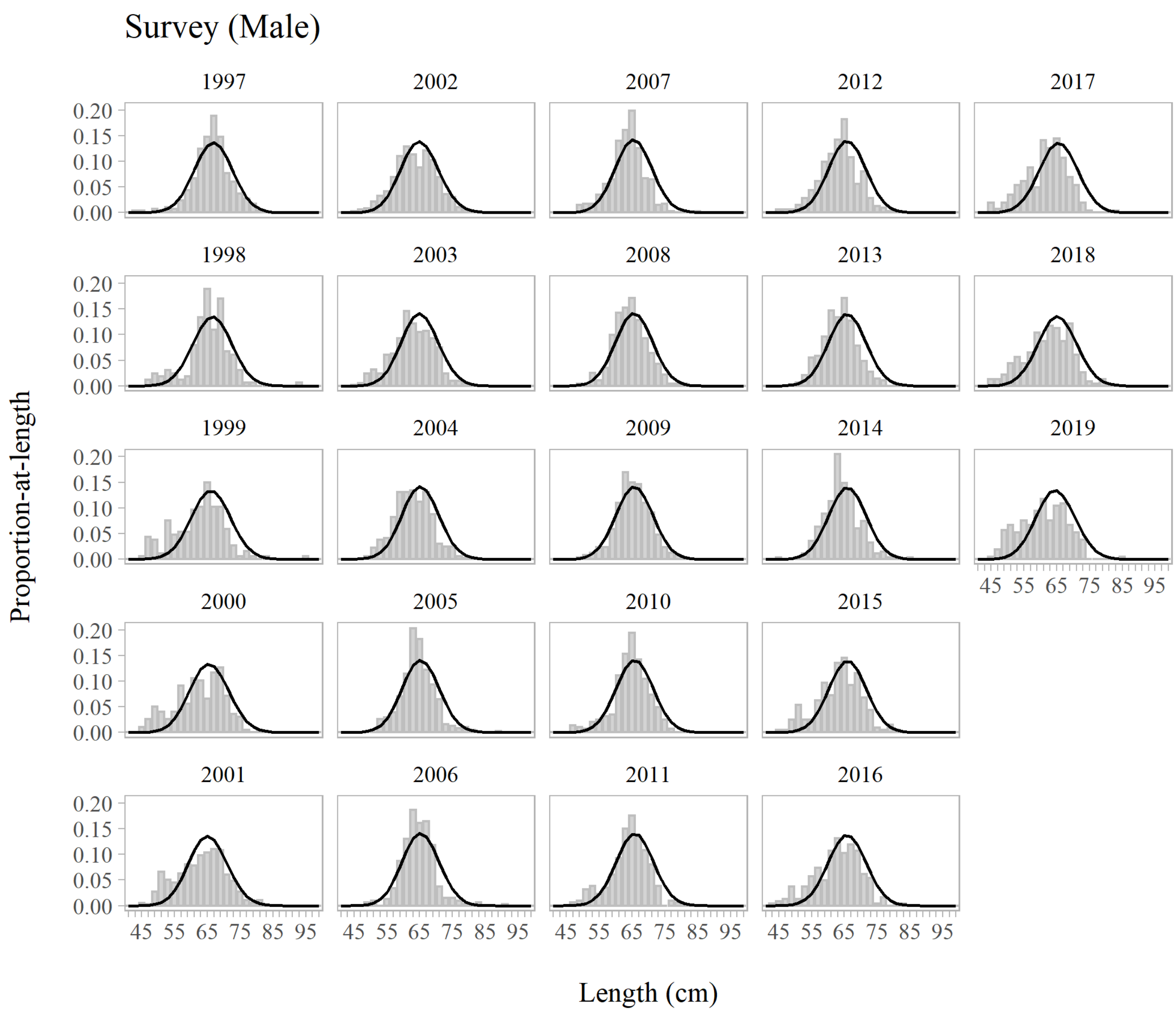

Figure 13. Fits to male survey length compositions, 1997–2019. Observed (gray bars) and predicted proportions-at-age (black lines) shown.

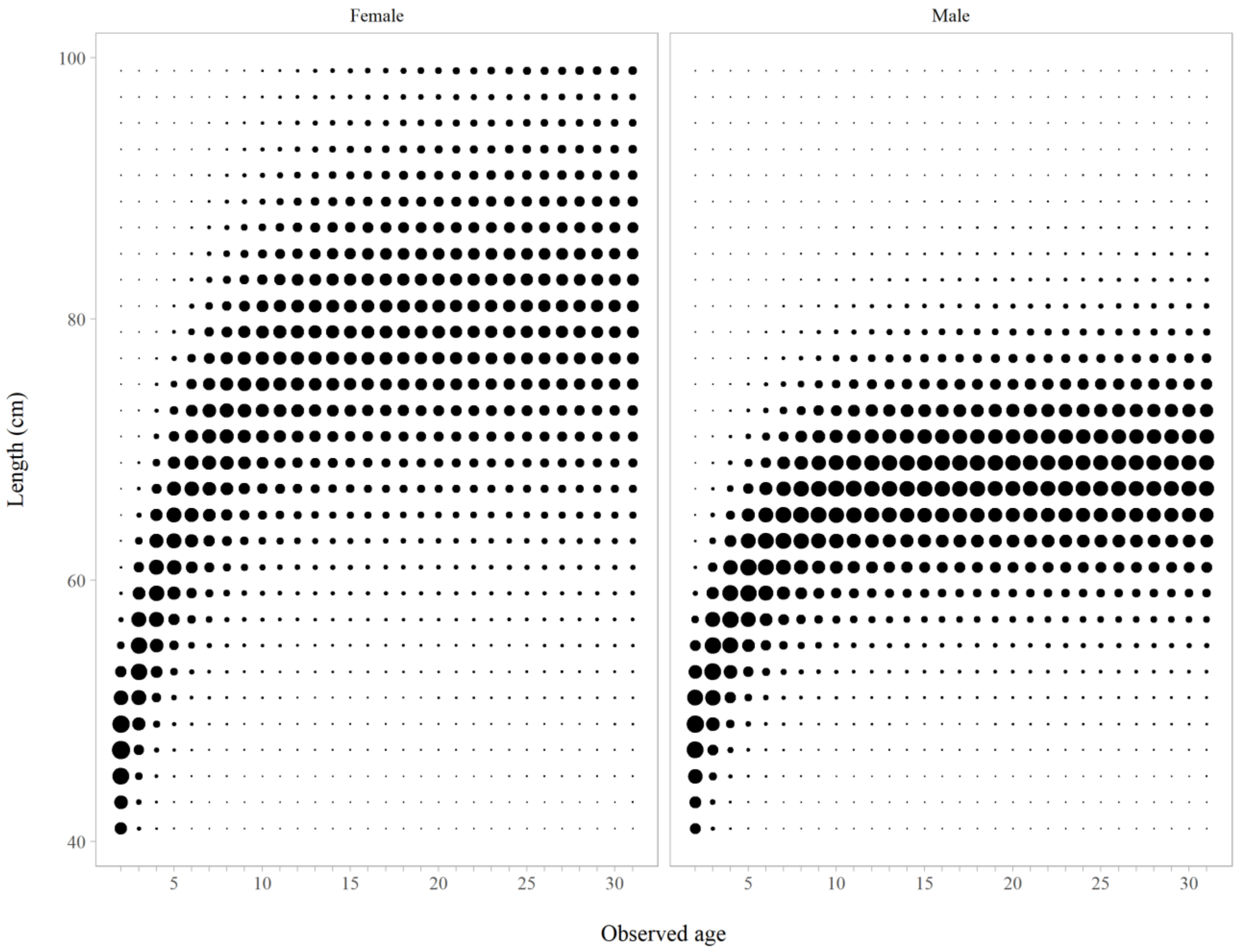

Figure 14. Age-length key used in the SCAA model, with the relative size of the bubbles reflecting the probability that a fish of a given age falls within a certain length bin (Echave et al. 2012). The probabilities sum to 1 across each age.

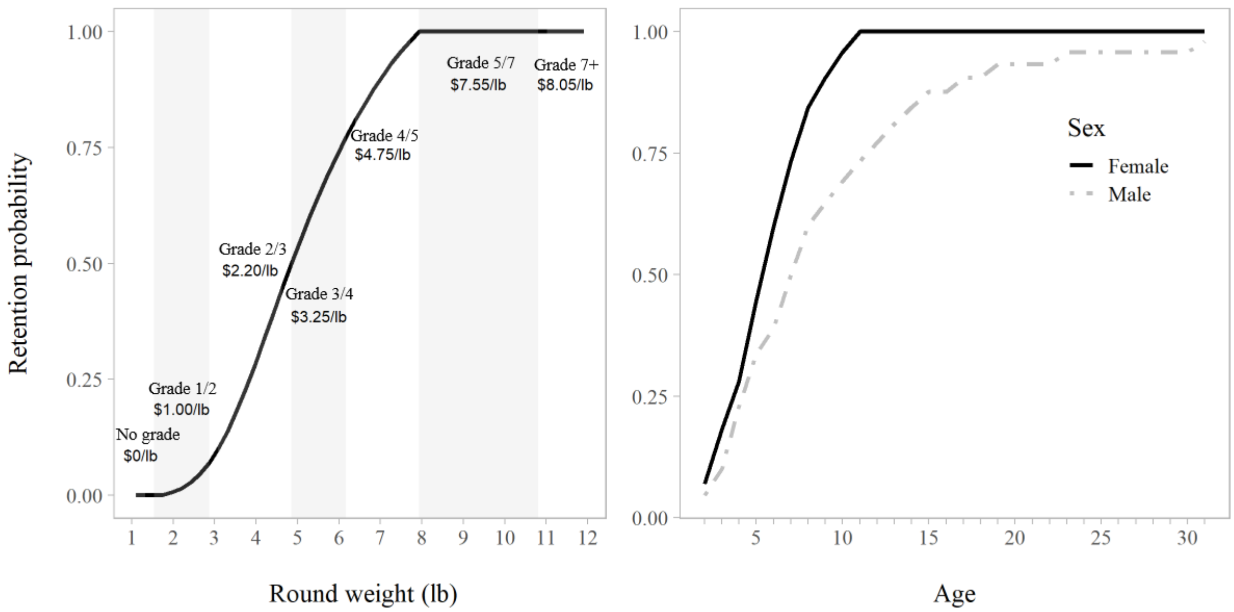

Figure 15. The probability of retaining a fish as a function of weight in round lb (left panel), sex, and age (right panel). Shaded regions correspond to processor grade and price in dressed lb.

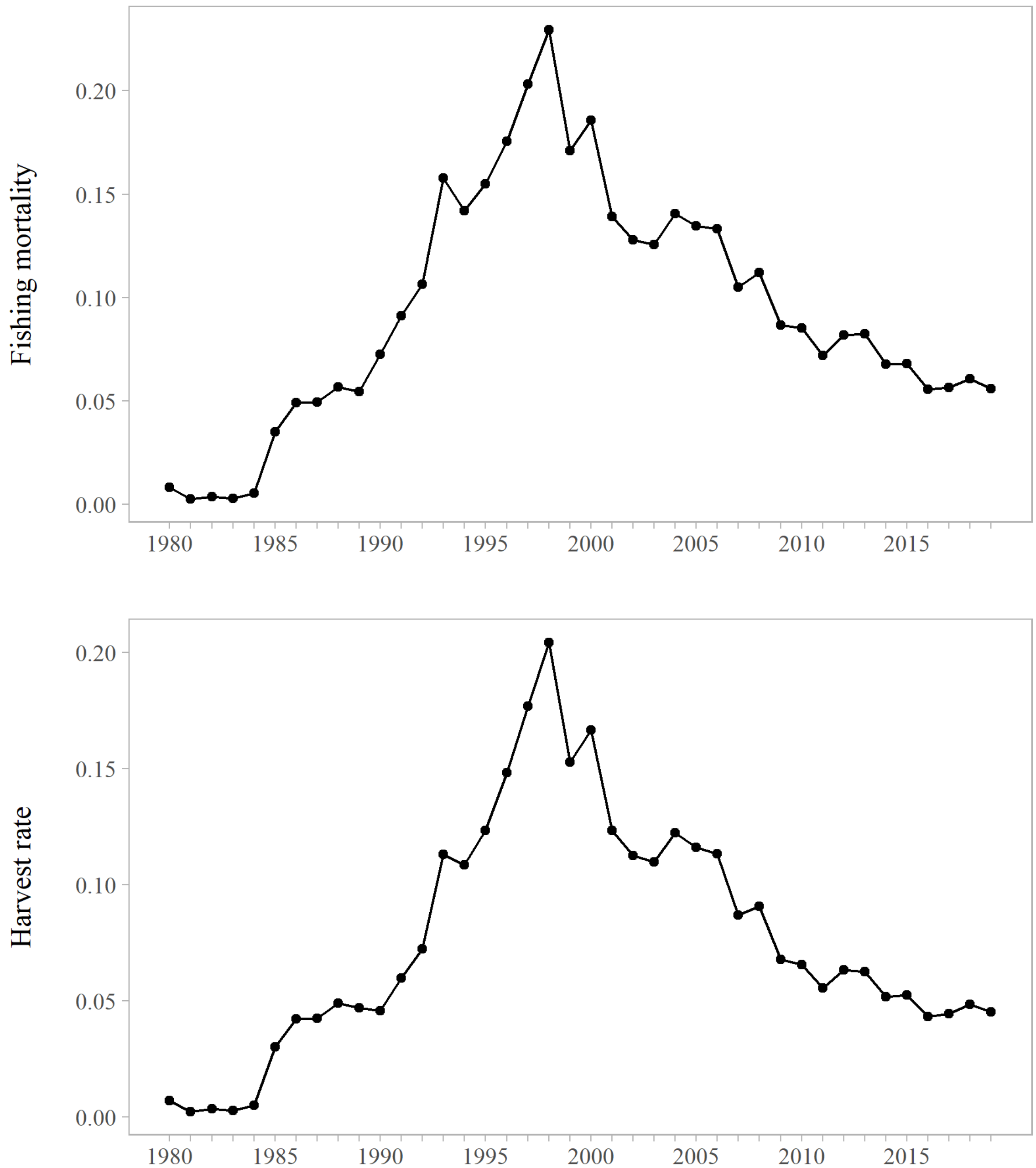

Figure 16. Model-estimated fishing mortality rate (top) and realized harvest rate (bottom), defined as the ratio of total estimated catch to exploitable biomass. Total estimated catch is the sum of landed catch and discarded biomass assumed to die post-release.

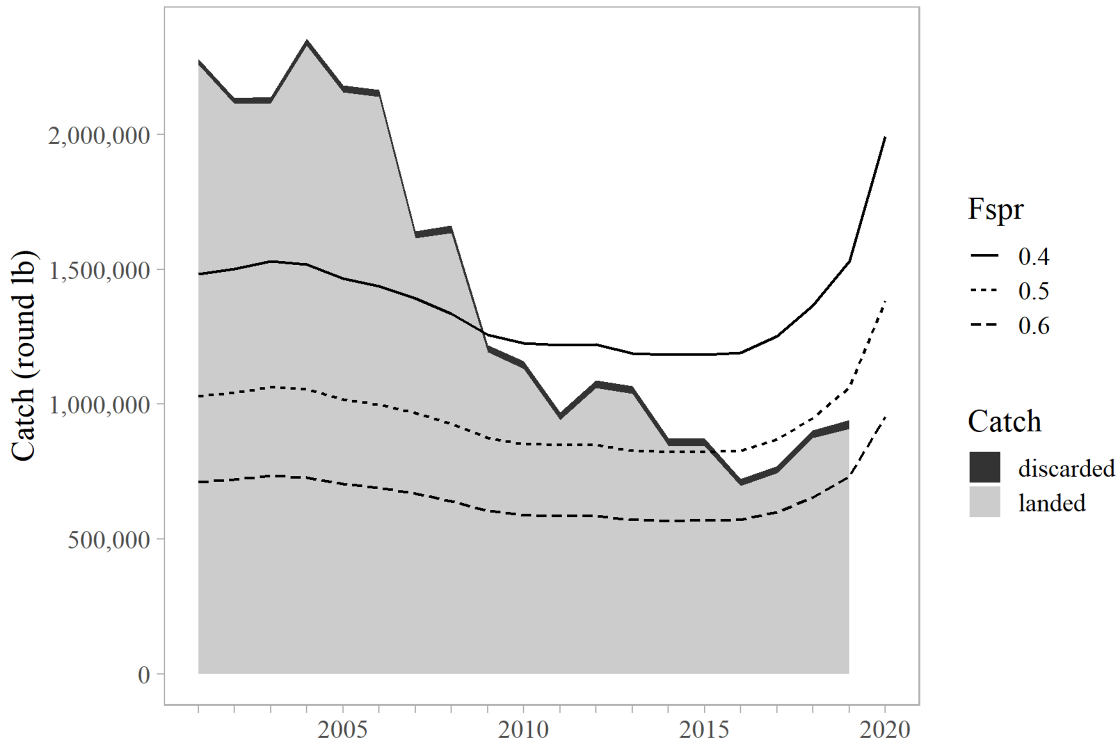

Figure 17. Retrospective harvest policies using current estimates of F_{40}, F_{50} (the current harvest policy), and F_{60} compared with total estimated catch. Total estimated catch is the sum of observed landed catch calculated from fish ticket data and the estimated mortality from discards.

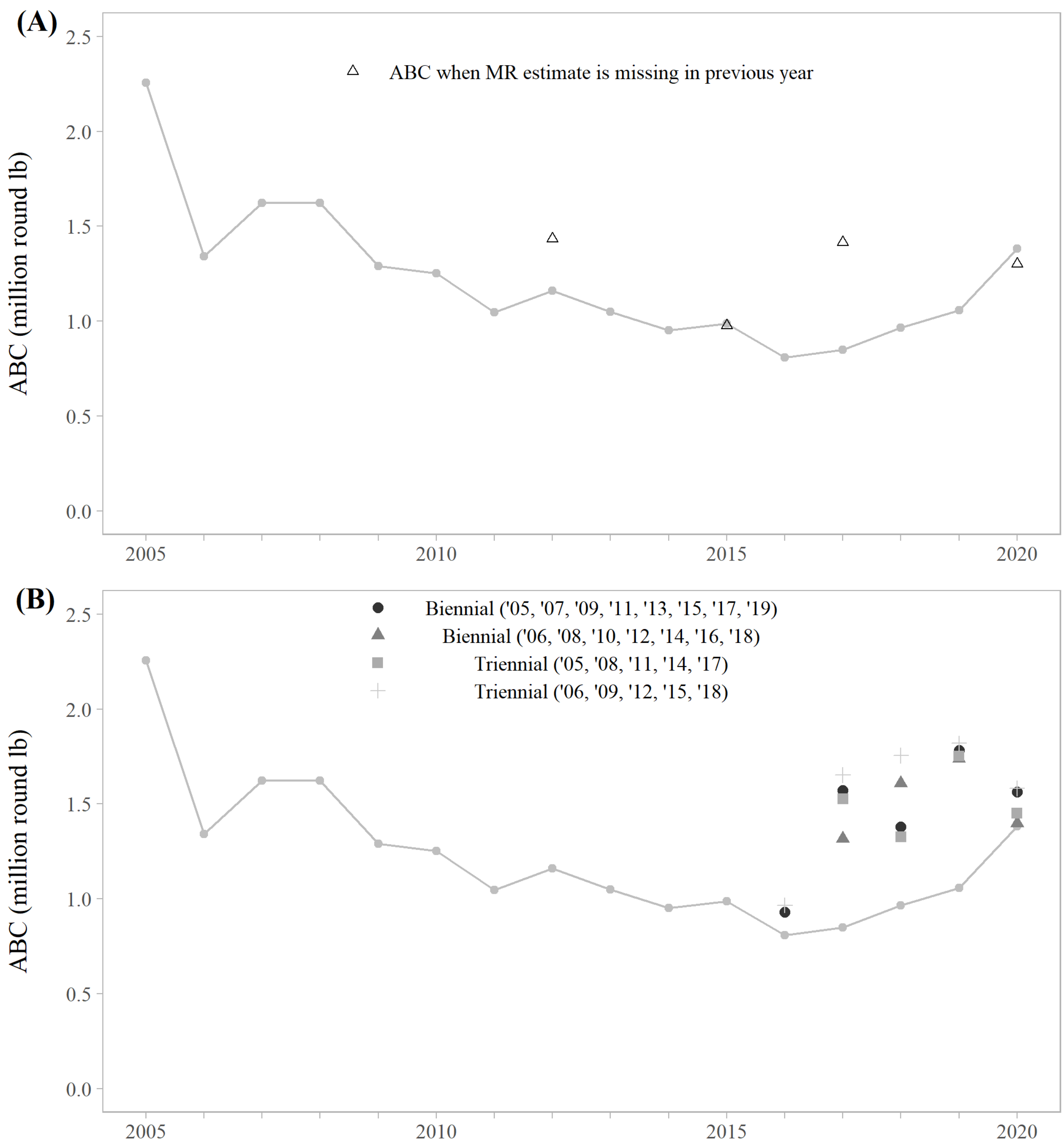

Figure 18. A comparison of actual Acceptable Biological Catch (ABC, million round lb) recommendations from 2005 – 2020 (grey points and lines) to ABC output from the statistical catch-at-age (SCAA) model, where (A) shows the ABC from the SCAA model following a year without a mark-recapture (MR) abundance estimate, and (B) shows the ABC from the SCAA model in 2016 – 2020 assuming the MR survey only occurs biennially or triennially. Results are not shown for the biennial (2006 – 2018) or triennial (2005 – 2017) in 2016, because the models did not converge in those years.

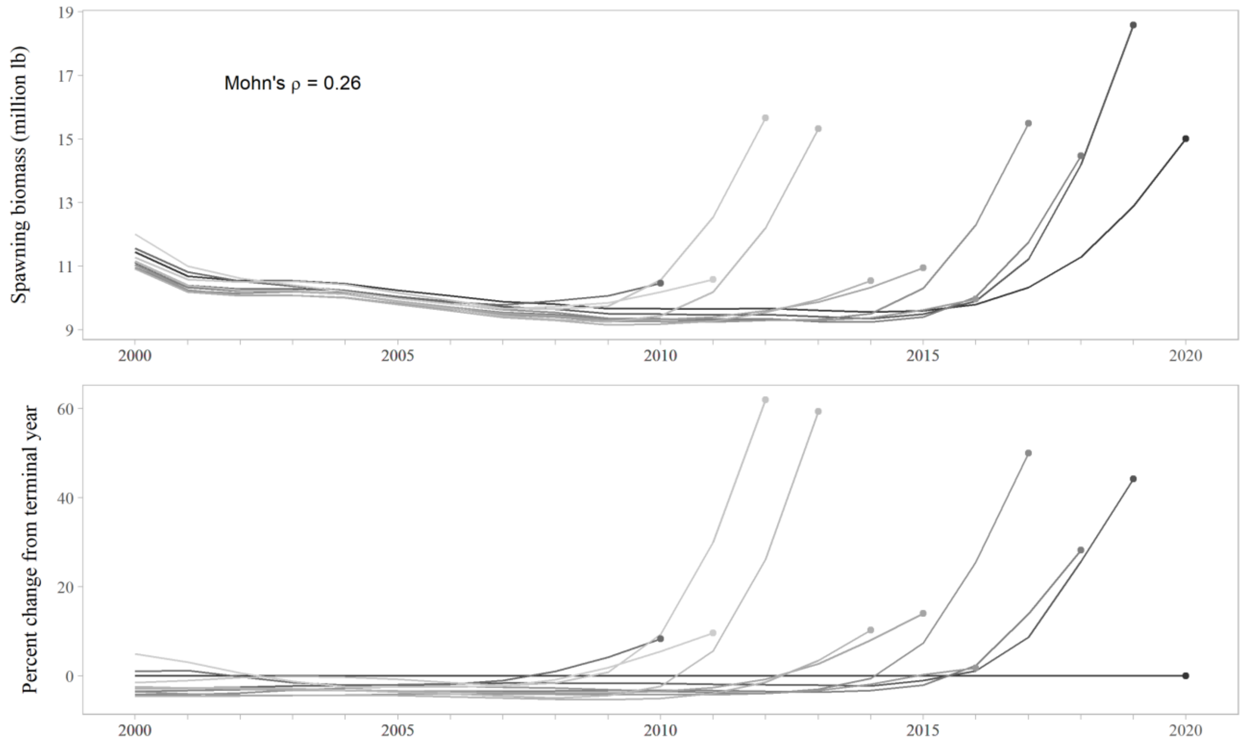

Figure 19. Mohn’s ρ and retrospective peels of sablefish spawning biomass for the last nine years.

APPENDIX A: A SUMMARY OF RESULTS FROM THE STATUS QUO YIELD-PER-RECRUIT (YPR) MODEL

The 2019 mark-recapture abundance estimate ($\hat{N}_{2019}$) of 3,142,733 fish was treated as an index of the exploitable abundance in the YPR model. It was partitioned into sex-specific age classes using the 2019 commercial fishery age compositions ($p_{s,a}$), the 2019 sex ratio (ϕ_s) in the commercial fishery, and sex-specific fishery selectivity-at-age from the current federal assessment (Hanselman et al. 2019):

$$\dot{N}_{2019,s,a} = \frac{\hat{N}_{2019} p_{s,a-1} \phi_s}{S_{a-1,s}}.$$

When summed over sex and age, $\dot{N}_{2019}$ was 4,213,864, which was assumed to be the available abundance in the population during the midpoint of the fishery. Remaining sources of mortality for 2019 were decremented to obtain the forecast of available abundance by sex and age for 2020, such that:

$$\dot{N}_{2020,s,a} = \begin{cases} \dot{N}_{2019,s,a-1} \exp(-Z_{2019,s,a-1}) & a_0 < a < a_+ \\ \dot{N}_{2019,s,a-1} \exp(-Z_{2019,s,a-1}) + \dot{N}_{2019,s,a} \exp(-Z_{2019,k,a}) & a = a_+ \end{cases}.$$

The total instantaneous mortality-at-age $Z_{s,a}$ is the sum of half the fishing mortality F in 2019 and natural mortality M, which was fixed at 0.10 (Johnson and Quinn 1998):

$$Z_{2019,s,a} = M + \frac{F_{2019}}{2} S_{s,a}(R_{s,a} + \Omega(1 - R_{s,a})),$$

where F is modeled as a function of $S_{s,a}$, retention probability $R_{s,a}$ (i.e. the sex- and age-specific probability of being landed given being caught), and discard mortality Ω. This method of accounting for discards shifts fishing mortality toward older ages, especially for males that are slower growing than females (Sullivan et al. 2019). The Ω was assumed to be 0.16, the discard mortality used in the Pacific halibut fishery (Gilroy and Stewart 2013). Pacific halibut are a reasonable proxy for sablefish because they are large-bodied, long-lived benthic fish that do not experience barotrauma. $R_{a,s}$ was informed by processor grade and price and defined as a function of weight, which is converted to age and sex using survey weight-at-age. $R_{a,s}$ were fixed to the same values as the SCAA model (Figure 15).

The available abundance for 2020 when summed over sex and age ($\dot{N}_{2020}$) was 3,827,732. Multiplying by the female portion of $\dot{N}_{2020,s,a}$ by longline survey weight-at-age produced a spawning biomass (SB_{2020}) of 11,249,096 lb. The fully-selected fishing mortality used to calculate the ABC (F_{ABC}) was obtained from a yield-per-recruit analysis and fixed to $F_{ABC} = F_{50}$, where F_{50} corresponds to the F that would reduce the spawning biomass (SB) to 50% of the unfished levels. F_{50} was estimated using the optim() function in the statistical software R (R Core Team 2018). Biological inputs to the yield-per-recruit model include longline survey weight-at-age ($w_{s,a}$) and estimated maturity from the longline survey. These were the same values used in the SCAA model.

$\dot{N}_{2020,s,a}$ was converted to exploitable abundance $\ddot{N}_{2020,s,a}$ by multiplying by sex and age specific fishery selectivities. Multiplying $\ddot{N}_{2020,s,a}$ by $w_{s,a}$ yields exploitable biomass ($\ddot{B}_{2020,s,a}$). Total $\ddot{N}_{2020}$ and $\ddot{B}_{2020}$ were 2,240,916 fish and 18,073,484 round lb, respectively.

A modified Baranov catch equation was used to calculate the ABC:

$$\mathrm{ABC}_{2020} = \sum_{s=1}^{2} \sum_{a=2}^{a+} w_{s,a} \, (\dot{N}_{2020,s,a}) \frac{R_{s,a} S_{s,a} F_{50}}{Z_{s,a}} (1 - \exp(-Z_{s,a})).$$

The biomass of discarded sablefish estimated to die with an assumed discard mortality of 0.16 D_{2020} is

$$\mathrm{D}_{2020} = \sum_{s=1}^{2} \sum_{a=2}^{a+} w_{s,a} \, (\dot{N}_{2020,s,a}) \frac{\Omega S_{s,a} (1 - R_{s,a}) F_{50}}{Z_{s,a}} (1 - \exp(-Z_{s,a})).$$

An ABC of 969,547 round lb was calculated as the landed portion of the total catch under F_{50} for 2020. This is a 9.4% decrease from the 2019 ABC of 1,058,037. The discarded catch assumed to die in 2020 given a 16% discard mortality rate (D_{2020}) was 16,827 round lb, a 12% decrease from last year's estimated D_{2019} of 19,142 round lb.

The 9.4% decrease in the ABC was surprising given the increase in the mark-recapture abundance estimate. Further analysis determined these results were highly sensitive to the fishery age composition data, specifically the number of age-2 individuals sampled. When the mark-recapture estimate $\widehat{N}_{2019}$ is partioned into available numbers-at-age by sex $\dot{N}_{2019,s,a}$, three age-2 individuals in the fishery age composition data caused a large spike in the estimated number of available age-2 individuals in the population. These fish are not selected to the fishery, however, thus the final exploitable biomass decreased. To demonstrate the large impact of these few samples, a sensitivity analysis by removing these samples, recalculating the fishery age compositions, and re-running the YPR model. Results from this analysis show that because there are fewer two and three year old fish assumed to be in the population, the estimates $\dot{N}_{2019}$ and $\dot{N}_{2020}$ decrease significantly. However, because a greater portion of the available fish are mature and selected to the fishery, estimates of SB_{2020}, $\ddot{N}_{2020}$, $\ddot{B}_{2020}$, ABC_{2020} increase dramatically Table 1). Estimates of mortality from discards does not increase proportionally to the ABC because there are relatively fewer young fish in the population that would be subject to discard mortality. The removal of three data points effectively changed the ABC recommendation a 9.6% decrease from the 2019 ABC to a 26.5% increase from the 2019 ABC. The sensitivity of the YPR model results to slight changes in the fishery age compositions highlight how important it is to incorporate measurement error into model predictions.

REFERENCES

Gilroy, H.L. and I.J. Stewart. 2013. Incidental mortality of halibut in the commercial halibut fishery (Wastage). IPHC Report of Assessment and Research Activities 2012. p. 53-60.

Hanselman, D. H., C. J. Rodgveller, K. H. Fenske, S. K. Shotwell, K. B. Echave, P. W. Malecha, and C. R. Lunsford. 2019. Chapter 3: Assessment of the sablefish stock in Alaska. In: Stock assessment and fishery evaluation report for the groundfish resources of the GOA and BS/AI as projected for 2020. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306 Anchorage, AK 99501.

Johnson, S. L., and T. J. Quinn II. 1988. Catch-Age Analysis with Auxiliary Information of sablefish in the Gulf of Alaska. Contract report to National Marine Fisheries Service, Auke Bay, Alaska. 79 pp. Center for Fisheries and Ocean Sciences, University of Alaska, Juneau, Alaska.

Sullivan, J., Olson, A. and Williams, B. 2019. 2018 Northern Southeast Inside subdistrict sablefsh fishery stock assessment and 2019 management plan. Alaska Department of Fish and Game Regional Information Report, No. 5J19-03, 1–81.

TABLES

Table 1. A comparison of results from YPR model in the base model and in the sensitivity analysis when three age-2 samples are removed.

Quantity	YPR base model results	YPR sensitivity results	Percent difference
Assessment year available abundance $\dot{N}_{2019}$	4,213,864	3,424,165	-23.1
Forecasted available abundance $\dot{N}_{2020}$	3,827,732	3,058,464	-25.2
Forecasted spawning biomass SB_{2020}	11,249,096	15,645,106	28.1
Forecasted exploitable abundance $\ddot{N}_{2020}$	2,240,916	2,938,120	23.7
Forecasted exploitable biomass $\ddot{B}_{2020}$	18,073,484	24,485,613	26.2
ABC_{2020}	969,547	1,338,253	27.6

APPENDIX B: CONVERSION TABLES

Questions frequently arise regarding conversion of length to age, weight, or dressed weight. Conversions were developed for stakeholder reference using data from the NSEI longline survey (1997 – 2019) and NSEI longline fishery (2002 – 2019). Given these relationships were estimated using NSEI-specific data, they are not intended to be a definitive source of length-at-age, weight-at-age, or weight-length conversions for sabelfish coastwide.

The length-weight or allometric relationship is estimated from NSEI longline survey data for both sexes combined, where round weight in kg (W) is a function of fork length in cm (L):

$$W = \alpha L^{\beta}.$$

The estimated parameters for sexes combined are α = 0.00000877 (SE = and β = 3.05. The conversion between kg to lb is 2.20462, and the assumed conversion between round weight and Eastern cut dressed weight is 0.63. Resultant conversion tables from the generalized allometric equation are reported in Table 1.

Length and weight-based von Bertalanffy growth equations were used to develop sex-specific relationships of length-at-age and weight-at-age, respectively. Resultant conversion tables from the sex-specific length- and weight-based von Bertalanffy growth equation for the NSEI longline survey and fishery are reported in Tables 2 and 3, respectively.

The length-based von Bertalanffy function,

$$\mathrm{a} = L_{\infty}\big(1 - \exp(-k * (a - t_0)\big),$$

estimates age (a) as a function of lengh and three parameters, L_{∞} (asympotic length), k (the rate at which L_{∞} is reached), and t_0 (the theoretical where length is zero).

The estimated length-based von Bertalanffy growth parameters for males in the NSEI longline survey are L_{∞}= 69.1 (SE = 0.15), k = 0.13 (SE = 0.004), and t_0 = -8.46 (SE = 0.41). The estimated parameters for females in the NSEI longline survey are L_{∞}= 87.4 (SE = 0.38), k = 0.09 (SE = 0.003), and t_0 = -8.44 (SE = 0.34). The estimated parameters for males in the NSEI fishery are L_{∞}= 70.77 (SE = 0.17), k = 0.08 (SE = 0.003), and t_0 = -19.9 (SE = 0.87). The estimated paramters for females in the NSEI fishery are L_{∞}= 87.51 (SE = 0.29), k = 0.06 (SE = 0.002), and t_0 = -15.32 (SE = 0.42). The growth parameters from the fishery should not be assumed to reflect realistic growth parameters for sablefish; however, they are used as estimated mean fishery length-at-age.

The weight-based von Bertalanffy growth equation was fit assuming a multiplicative error structure, such that

$$\ln(w_a) = \ln W_{\infty} + \beta \cdot \ln(1 - \exp(-k(a - t_0))),$$

where weight-age-age in whole kg (w_a) is a function of age and thee parameters, W_{∞} (asymptotic weight), a new k (the rate at which W_{∞} is reached), and a new t_0 (theoretical age where weight is zero). The β parameters are estimated from sex-specific allomentry equations and were estimated to be 3.00 and 3.07 for males and females, respectively.

The estimated weight-based von Bertalanffy growth parameters for males in the NSEI longline survey are W_{∞}= 3.5 (SE = 0.02), k = 0.15 (SE = 0.005), and t_0 = -6.19 (SE = 0.30). The estimated parameters for females in the NSEI longline survey are W_{∞}= 6.3 (SE = 0.09), k = 0.10 (SE = 0.003), and t_0 = -6.86 (SE = 0.28). The estimated parameters for males in the NSEI longline fishery are W_{∞}= 3.8 (SE = 0.02), k = 0.10 (SE = 0.004), and t_0 = -14.87 (SE = 0.76). The estimated parameters for females in the NSEI longline fishery are W_{∞}= 7.2 (SE = 0.08), k = 0.07 (SE = 0.002), and t_0 = -14.75 (SE = 0.42). Similar to the length-based growth function, the parameters from the fishery should not be assumed to reflect realistic growth parameters for sablefish. They are only used as estimated mean fishery weight-at-age.

Table 1. Conversion table from fork length to round weight (kg), round weight (lb), and dressed weight (lb) using the Eastern cut conversion of 0.63. These relationships are based on an allometric equation estimated using data with both sexes combined.

Fork length (cm)	Round weight (kg)	Round weight (lb)	Dressed weight, Eastern cut (lb)
40	0.67	1.48	0.93
41	0.73	1.61	1.01
42	0.78	1.72	1.08
43	0.84	1.85	1.17
44	0.90	1.98	1.25
45	0.97	2.14	1.35
46	1.03	2.27	1.43
47	1.10	2.43	1.53
48	1.18	2.60	1.64
49	1.25	2.76	1.74
50	1.33	2.93	1.85
51	1.42	3.13	1.97
52	1.50	3.31	2.08
53	1.59	3.51	2.21
54	1.69	3.73	2.35
55	1.78	3.92	2.47
56	1.88	4.14	2.61
57	1.99	4.39	2.76
58	2.10	4.63	2.92
59	2.21	4.87	3.07
60	2.32	5.11	3.22
61	2.44	5.38	3.39
62	2.57	5.67	3.57
63	2.70	5.95	3.75
64	2.83	6.24	3.93
65	2.97	6.55	4.13
66	3.11	6.86	4.32
67	3.25	7.17	4.51
68	3.40	7.50	4.72
69	3.56	7.85	4.94
70	3.72	8.20	5.17
71	3.88	8.55	5.39
72	4.05	8.93	5.63
73	4.23	9.33	5.88
74	4.41	9.72	6.13
75	4.59	10.12	6.38
76	4.78	10.54	6.64
77	4.97	10.96	6.90

Fork length (cm)	Round weight (kg)	Round weight (lb)	Dressed weight, Eastern cut (lb)
78	5.17	11.40	7.18
79	5.38	11.86	7.47
80	5.59	12.32	7.76
81	5.80	12.79	8.06
82	6.03	13.29	8.38
83	6.25	13.78	8.68
84	6.48	14.29	9.00
85	6.72	14.82	9.33
86	6.97	15.37	9.68
87	7.22	15.92	10.03
88	7.47	16.47	10.38
89	7.74	17.06	10.75
90	8.00	17.64	11.11

Table 2. Sex-specific NSEI longline survey conversion table for fork length to age, round weight (kg), round weight (lb), and dressed weight (lb) using the Eastern cut conversion of 0.63.

Sex	Age	Fork length (cm)	Round weight (kg)	Round weight (lb)	Dressed weight, Eastern cut (lb)
Female	2	51.5	1.29	1.3	2.8
Female	3	54.4	1.56	1.6	3.4
Female	4	57.0	1.85	1.9	4.1
Female	5	59.4	2.13	2.1	4.7
Female	6	61.6	2.41	2.4	5.3
Female	7	63.5	2.69	2.7	5.9
Female	8	65.4	2.95	3.0	6.5
Female	9	67.0	3.21	3.2	7.1
Female	10	68.5	3.45	3.5	7.6
Female	11	69.9	3.68	3.7	8.1
Female	12	71.2	3.89	3.9	8.6
Female	13	72.4	4.09	4.1	9.0
Female	14	73.4	4.28	4.3	9.4
Female	15	74.4	4.45	4.5	9.8
Female	16	75.3	4.61	4.6	10.2
Female	17	76.1	4.76	4.8	10.5
Female	18	76.8	4.9	4.9	10.8
Female	19	77.5	5.03	5.0	11.1
Female	20	78.1	5.14	5.1	11.3
Female	21	78.7	5.25	5.3	11.6
Female	22	79.2	5.35	5.4	11.8
Female	23	79.7	5.43	5.4	12.0
Female	24	80.1	5.51	5.5	12.2
Female	25	80.5	5.59	5.6	12.3
Female	26	80.9	5.66	5.7	12.5
Female	27	81.2	5.72	5.7	12.6
Female	28	81.5	5.77	5.8	12.7
Female	29	81.8	5.82	5.8	12.8
Female	30	82.0	5.87	5.9	12.9
Female	31	82.3	5.91	5.9	13.0
Male	2	50.6	1.22	1.2	2.7
Male	3	52.8	1.44	1.4	3.2
Male	4	54.8	1.66	1.7	3.7
Male	5	56.4	1.86	1.9	4.1
Male	6	57.9	2.05	2.1	4.5
Male	7	59.3	2.22	2.2	4.9
Male	8	60.4	2.37	2.4	5.2
Male	9	61.4	2.51	2.5	5.5
Male	10	62.4	2.63	2.6	5.8

Sex	Age	Fork length (cm)	Round weight (kg)	Round weight (lb)	Dressed weight, Eastern cut (lb)
Male	11	63.1	2.74	2.7	6.0
Male	12	63.8	2.84	2.8	6.3
Male	13	64.5	2.92	2.9	6.4
Male	14	65.0	3.00	3.0	6.6
Male	15	65.5	3.06	3.1	6.8
Male	16	65.9	3.12	3.1	6.9
Male	17	66.3	3.17	3.2	7.0
Male	18	66.6	3.21	3.2	7.1
Male	19	66.9	3.25	3.3	7.2
Male	20	67.2	3.28	3.3	7.2
Male	21	67.4	3.31	3.3	7.3
Male	22	67.6	3.34	3.3	7.4
Male	23	67.8	3.36	3.4	7.4
Male	24	67.9	3.38	3.4	7.5
Male	25	68.0	3.39	3.4	7.5
Male	26	68.2	3.41	3.4	7.5
Male	27	68.3	3.42	3.4	7.5
Male	28	68.4	3.43	3.4	7.6
Male	29	68.4	3.44	3.4	7.6
Male	30	68.5	3.45	3.5	7.6
Male	31	68.6	3.45	3.5	7.6

Table 3. Sex-specific NSEI longline fishery conversion table for fork length to age, round weight (kg), round weight (lb), and dressed weight (lb) using the Eastern cut conversion of 0.63.

Sex	Age	Fork length (cm)	Round weight (kg)	Round weight (lb)	Dressed weight, Eastern cut (lb)
Female	2	2.2	58.7	4.8	3.0
Female	3	2.4	60.5	5.3	3.3
Female	4	2.6	62.1	5.7	3.6
Female	5	2.8	63.7	6.2	3.9
Female	6	3.0	65.2	6.7	4.2
Female	7	3.2	66.6	7.1	4.5
Female	8	3.4	67.9	7.5	4.8
Female	9	3.6	69.1	8.0	5.0
Female	10	3.8	70.2	8.4	5.3
Female	11	4.0	71.3	8.8	5.5
Female	12	4.1	72.3	9.1	5.8
Female	13	4.3	73.3	9.5	6.0
Female	14	4.5	74.1	9.9	6.2
Female	15	4.6	75.0	10.2	6.4
Female	16	4.8	75.7	10.5	6.6
Female	17	4.9	76.5	10.8	6.8
Female	18	5.0	77.2	11.1	7.0
Female	19	5.2	77.8	11.4	7.2
Female	20	5.3	78.4	11.6	7.3
Female	21	5.4	79.0	11.9	7.5
Female	22	5.5	79.5	12.1	7.6
Female	23	5.6	80.0	12.4	7.8
Female	24	5.7	80.5	12.5	7.9
Female	25	5.8	80.9	12.7	8.0
Female	26	5.9	81.3	12.9	8.2
Female	27	6.0	81.7	13.1	8.3
Female	28	6.0	82.1	13.3	8.4
Female	29	6.1	82.4	13.5	8.5
Female	30	6.2	82.7	13.6	8.6
Female	31	6.2	83.0	13.7	8.7
Male	2	2.0	57.1	4.4	2.8
Male	3	2.1	58.1	4.7	2.9
Male	4	2.2	59.0	4.9	3.1
Male	5	2.4	59.9	5.2	3.3
Male	6	2.5	60.7	5.5	3.5
Male	7	2.6	61.4	5.7	3.6
Male	8	2.7	62.1	5.9	3.7
Male	9	2.8	62.7	6.1	3.9
Male	10	2.9	63.3	6.3	4.0

Sex	Age	Fork length (cm)	Round weight (kg)	Round weight (lb)	Dressed weight, Eastern cut (lb)
Male	11	2.9	63.8	6.5	4.1
Male	12	3.0	64.3	6.6	4.2
Male	13	3.1	64.8	6.8	4.3
Male	14	3.1	65.2	6.9	4.4
Male	15	3.2	65.6	7.1	4.4
Male	16	3.3	66.0	7.2	4.5
Male	17	3.3	66.4	7.3	4.6
Male	18	3.4	66.7	7.4	4.7
Male	19	3.4	67.0	7.5	4.7
Male	20	3.4	67.2	7.5	4.8
Male	21	3.5	67.5	7.6	4.8
Male	22	3.5	67.7	7.7	4.8
Male	23	3.5	68.0	7.8	4.9
Male	24	3.5	68.2	7.8	4.9
Male	25	3.6	68.4	7.9	5.0
Male	26	3.6	68.5	7.9	5.0
Male	27	3.6	68.7	8.0	5.0
Male	28	3.6	68.8	8.0	5.0
Male	29	3.6	69.0	8.0	5.1
Male	30	3.7	69.1	8.1	5.1
Male	31	3.7	69.2	8.1	5.1