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Northern Southeast Inside Subdistrict Sablefish Management Plan and Stock Assessment for 2020

by

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and

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July 2020

Alaska Department of Fish and Game **Division of Commercial Fisheries**

Symbols and Abbreviations

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Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
id est (that is)	i.e.
latitude or longitude	lat or long
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	log_2, etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

REGIONAL INFORMATION REPORT 5J20-05

NORTHERN SOUTHEAST INSIDE SUBDISTRICT SABLEFISH MANAGEMENT PLAN AND STOCK ASSESSMENT FOR 2020

by

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Division of Commercial Fisheries

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ABSTRACT

This report provides an overview of the stock assessment, harvest strategy, and regulations effective for the 2020 Northern Southeast Inside (NSEI) sablefish *Anoplopoma fimbria* commercial fishery. The NSEI sablefish commercial fishery is scheduled to open August 15 and close November 15, with legal gear restricted to longline only. The 2020 NSEI sablefish commercial fishery annual harvest objective is 1,108,003 round lb and is based on decrements from an acceptable biological catch of 1,216,743 round lb. The annual harvest objective is allocated to 75 limited entry Commercial Fisheries Entry Commission longline (C61A) permits through an equal quota share (EQS) system, resulting in a 2020 EQS of 14,773 round lb for each permit holder.

Key words: sablefish, black cod, *Anoplopoma fimbria*, stock assessment, annual harvest objective, AHO, catch per unit effort, CPUE, Northern Southeast, Chatham Strait, NSEI, mark–recapture, tagging

OVERVIEW

The Alaska Department of Fish and Game (ADF&G) evaluates stock status and establishes the Northern Southeast Inside (NSEI) acceptable biological catch (ABC) and subsequent annual harvest objective (AHO). The NSEI Subdistrict management area (Figure 1) consists of all waters as defined in 5 AAC 28.105(a)(2).

The 2020 NSEI Subdistrict commercial sablefish fishery AHO is 1,108,003 round lb (Table 1). There are 75 valid Commercial Fisheries Entry Commission permits for 2020, which is a reduction of 3 permits from 78 permit holders in 2019. The individual equal quota share (EQS) is 14,773 round lb, a 25% increase from the 2019 EQS of 11,796 round lb (Table 1). The AHO is based on the sablefish ABC (Table 2) with decrements made for sablefish mortality in other fisheries (Table 3; Figure 2).

Two key advancements to the ABC determination process were implemented for the 2020 NSEI sablefish assessment:

1. A new statistical catch-at-age model replaced past methodology that partitioned a mark–recapture abundance estimate to numbers-at-age using fishery age compositions. This reduces ADF&G's reliance on an annual mark–recapture project by integrating multiple indices of abundance and biological data—including catch, mark–recapture abundance estimates, longline survey and fishery CPUE, and longline survey length and age compositions—to estimate recruitment, abundance, and spawning stock biomass of NSEI sablefish since 1975. As in previous years, maximum ABC is defined by F_{50}, the fishing mortality rate that reduces spawning biomass to 50% of equilibrium unfished levels.
2. A new management procedure was implemented that constrains the recommended ABC to a 15% annual maximum change to increase fishing stability and maximize catch.

With these changes, the recommended 2020 ABC is 1,216,743 round lb (F_{ABC} = 0.0659), a 15% increase from the 2019 ABC. The increase in ABC is attributed to the large 2014 year class, which is estimated to be roughly 50% mature in 2020 and includes 27.5% of the forecasted female spawning stock biomass.

The process leading to the determination of the ABC, AHO, and EQS includes compiling fishery and survey data, running the stock assessment, and accounting for additional sources of mortality through the decrements process (Figure 2). Although the ABC is determined prior to the AHO and EQS, this report is organized to make management-related information easily accessible to stakeholders and improve documentation of the stock assessment process by organizing this report into the following sections:

1. 2020 Sablefish Management Plan: Details the decrements process leading to the AHO and EQS and effective regulations for the 2020 NSEI fishery.
2. 2019 Sablefish Stock Assessment and 2020 ABC Determination: Details stock assessment data inputs, methods, results, and subsequent analyses that informed the recommended ABC.

Appendices to this report include methods and results from the former stock assessment method (Appendix A) and an update on sablefish ageing from the ADF&G Age Determination Unit (Appendix B).

2020 SABLEFISH MANAGEMENT PLAN

ANNUAL HARVEST OBJECTIVE DETERMINATION

The 2020 AHO was determined by making the following decrements from the recommended ABC (1,216,743 lb, Table 2):

- estimated sablefish bycatch mortality in the commercial Pacific halibut fishery,
- ADF&G longline survey removals,
- sport fishery guided and unguided harvest,
- mortality from fishery deadloss, and
- subsistence and personal use harvest.

Bycatch mortality in the halibut fishery

Sablefish caught in NSEI during the Pacific halibut individual fishing quota fishery prior to the sablefish fishery season opening (August 15) must be released; however, because not all are expected to survive, bycatch mortality is estimated. Prior to 2003, a 50% bycatch morality rate was applied as bycatch sablefish were permitted to be retained as bait. In 2003, the Alaska Board of Fisheries disallowed retaining bycatch sablefish for bait, and a 25% bycatch mortality rate was assumed for all sablefish caught and released due to the larger hook size in the Pacific halibut fishery. Released sablefish bycatch is calculated as the product of the 3-year average of the sablefish to Pacific halibut ratio from the International Pacific Halibut Commission annual survey and the 3-year average of the Pacific halibut catch in areas greater than 99 fathoms in NSEI.

ADF&G longline survey removals

In 2020, 4 NSEI permit holders will participate in the NSEI longline survey and be allowed to utilize sablefish caught on the survey toward their EQS (Tables 3 and 4). The survey removal decrement was determined by averaging the survey total harvest from the previous 3 years and reducing that by 4 estimated 2020 EQS permits (Tables 3 and 4). The total number of permits allowed to harvest their EQS during the survey was limited to 4 due to the inability of the survey to fulfill all survey permit EQS in previous years (2017–2019) and due to needing to stabilize revenue as the project is experiencing a budgetary deficit.

Sport fish harvest (guided and unguided)

Sablefish sport fish preliminary harvest and release mortality from the guided and unguided sectors are estimated utilizing charter logbooks and the statewide harvest survey (Romberg et al. 2017). Estimates of harvested and released fish are based on the total number of fish and converted to weight using a 3-year average of fish sampled from the guided and unguided sectors. A 10% release mortality rate is applied to the sport fishery; this was based on the 11.7% estimated in

Stachura et al. (2012) and modified to account for difference in gear type (rod and reel versus longline) and handling time.

Mortality from fishery deadloss

Deadloss mortality in the directed sablefish fishery was estimated by applying the percentage of dead sablefish (i.e., recorded as predated by sand fleas, sharks, hooking injury, or other cause of mortality) caught on the NSEI longline survey using the recent 3-year average, 0.9% (2017–2019), to the NSEI sablefish commercial AHO.

Personal use and subsistence harvest

In 2015, personal use harvest was limited to an annual limit of 50 fish per household. Since 2018, participants of the personal use fishery have been allowed to use pot gear with no more than 2 pots per permit and a maximum of 8 pots per vessel when 4 or more permit holders are on board the same vessel. A total of 826 permits were issued in 2019. Annual subsistence and personal use harvest of sablefish was estimated from these permits by applying a 16% handling mortality rate to released sablefish and adding this to the total number of retained sablefish. The 2019 longline survey average weight (5.8 lb) was applied to this harvest to obtain a decrement total.

REGULATIONS

Registration and logbook requirements

Commercial fishermen must register prior to fishing and are required to keep a logbook during the fishery. Completed logbook pages must be attached to the ADF&G copy of the fish ticket at the time of delivery. Confidential ADF&G envelopes for logbook pages may be requested when registering.

Logbooks must include, by set, the date and time gear is set and retrieved, specific location of harvest by latitude and longitude for start and ending positions, hook spacing, amount of gear (number of hooks and skates) used, depth of set, estimated weight of the target species, and the estimated weight of bycatch by species. They must indicate for each set if the target species was sablefish or Pacific halibut and if there was any gear lost. A permit holder must retain all visibly injured or dead sablefish. Sablefish that are not visibly injured or dead may be released unharmed, and the permit holder must record in the logbook, by set, the number of live sablefish released [5 AAC 28.170(f)]. They must record release reason (e.g., fish are small) and whether their personal quota share has been met.

Tagged sablefish

Fishermen are requested to watch for tagged sablefish, record tag number(s), and attach tags directly in the logbook with the corresponding set information. All tags returned will receive a reward. Tag rewards include a t-shirt and entry into an annual drawing for one $1,000, two $500, and four $250 cash rewards. To qualify for entry in the annual drawing, ADF&G requires the following information: the tag, set location (latitude and longitude), date of capture of the fish, and the name and address of the person recovering the tag.

Sablefish possession and landing requirements

In the NSEI Subdistrict, the holder of a Commercial Fisheries Entry Commission permit for sablefish may not retain more sablefish from the directed fishery than the annual amount of sablefish EQS specified in 5 AAC 28.170(f). However, if a permit holder's harvest exceeds the

EQS for that year by not more than 5%, ADF&G shall reduce the permit holder's EQS for the following year by the amount of the overage. If a permit holder's harvest exceeds the permit holder's EQS by more than 5%, the proceeds from the sale of the overage in excess of 5% shall be surrendered to the state and the permit holder may be prosecuted under AS 16.05.723. If a permit holder's harvest is less than the permit holder's EQS established for the year, ADF&G shall increase the permit holder's personal quota share only for the following year by the amount of the underage that does not exceed 5% of the EQS [5 AAC 28.170(k)]. For the 2020 fishing season, 5% of the annual EQS is 739 round lb.

Bycatch allowances for other species

Full retention and reporting of rockfish *Sebastes*, excluding thornyhead rockfish *Sebastolobus*, is required for internal waters (5 AAC 28.171). The allowable bycatch that may be legally landed and sold on an NSEI sablefish permit based on round weight of sablefish and bycatch species or species group on board the vessel is as follows:

- All rockfish, including thornyheads: 15% in aggregate, of which 1% may be demersal shelf rockfish (DSR), which includes yelloweye, quillback, canary, tiger, copper, China, and rosethorn rockfish
- Lingcod: 0%
- Pacific cod: 20%
- Spiny dogfish: 35%
- Other groundfish: 20%

All rockfish in excess of allowable bycatch limits shall be reported as bycatch overage on the fish ticket. All proceeds from the sale of excess rockfish bycatch must be surrendered to the state [5 AAC 28.171(f)].

Sablefish live market

The holder of a Commercial Fisheries Entry Commission or interim use permit for sablefish may possess live sablefish for delivery as live product except that, upon request of a local representative of ADF&G or law enforcement, a permit holder must present sablefish for inspection and allow biological samples to be taken [5 AAC 28.170(l)].

Prohibitions

The operator of a fishing vessel may not take sablefish in the NSEI area with sablefish from another area on board. Also, the operator of a vessel taking sablefish in the NSEI area shall unload those sablefish before taking sablefish in another area [5 AAC 28.170(a–b)].

A vessel, or person onboard a vessel, from which commercial, subsistence, or personal use longline fishing gear was used to take fish in the NSEI or SSEI Subdistricts during the 72-hour period immediately before the start of the commercial sablefish fishery in that subdistrict, or from which that gear will be used during the 24-hour period immediately after the closure of the commercial sablefish fishery in that subdistrict, may not participate in the taking of sablefish in that subdistrict during that open sablefish fishing period. A vessel, or a person onboard a vessel, who has harvested and sold their personal quota share before the final day of the sablefish season in that subdistrict is exempt from the prohibition on fishing longline gear during the 24-hour period immediately following the closure of the sablefish fishery in that subdistrict. In addition, a vessel or a person on board a vessel commercial fishing for sablefish in the NSEI Subdistrict may not operate subsistence or personal use longline gear for groundfish from that vessel until all sablefish harvested in the commercial fishery are offloaded from the vessel.

For additional information, visit the Southeast Regional Groundfish Fisheries web site: http://www.ADF&G.alaska.gov/index.cfm?ADF&G=commercialbyareasoutheast.groundfish.

2019 SABLEFISH STOCK ASSESSMENT AND 2020 ABC DETERMINATION

Sablefish (*Anoplopoma fimbria*) are a highly migratory, long-lived species broadly distributed in the North Pacific Ocean. Although sablefish are a single population, they are managed as separate stocks in Alaska state and federal waters, British Columbia, and in state and federal waters off the U.S. west coast. After 3 decades of declining or suppressed spawning stock biomass in the North Pacific, strong recruitment in 2014 has resulted in a dramatic uptick in numbers (Hanselman et al. 2018).

To improve our understanding of the population dynamics of sablefish in the NSEI (aka Chatham Strait) and provide fishery stability and long-term conservation of this stock, 2 important changes were made to the ABC determination and stock 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 leverage available fishery and survey data (Figure 3), 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. Currently there is no planned marking survey for 2021. Results from a sensitivity analysis suggest the SCAA model performs consistently if the marking survey occurs bi- or triennially (see section titled "Marking Survey Sensitivity Analysis" for more information).

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.[1] The current NSEI harvest policy will continue to define maximum permissible ABC at a fully selected fishing mortality rate of F_{50}, the spawning potential ratio (SPR) based biological reference point that determines the fishing mortality needed to reduce equilibrium female spawning biomass to 50% of unfished levels. However, recommended ABCs will be constrained to a maximum 15% change between years.

The SCAA model results in a maximum permissible ABC of 1,280,406 round lb at a target fully selected fishing mortality of F_{50} (Table 2). This is a 222,369 lb increase (21%) from the 2019 ABC of 1,058,037 round lb. Under the max 15% change management procedure, the recommended

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1 International Pacific Halibut Commission. 2019. IPHC MSE update. Agenda Item 7, IPHC-2019-SRBO14-08, presented at the 14th meeting of the IPHC Scientific Review Board. Available from https://www.iphc.int/uploads/pdf/srb/srb014/ppt/iphc-2019-srb014-08-p.pdf (Accessed June 2020).

2020 ABC is 1,216,743 round lb, a 158,706 lb increase (15%) from the 2019 ABC. 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 57,716 lb and is incorporated directly into the max ABC calculation. See section titled "ABC Recommendations" for more information.

The following are notable results from the SCAA model and reflect potential conservation or assessment 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 4B and 4C). 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 5A). The females in this year class are assumed to be approximately 50% mature in 2020, and they are estimated to account for 27.5% of the female spawning biomass in 2020.
3. The SCAA model is not estimating a large 2016 year class (Figure 5A), 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 ADF&G 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 5B).
5. Similar to the federal sablefish model, the SCAA model is exhibiting strong positive retrospective bias (Figure 6), which means that variables like female spawning stock biomass are overestimated, or tend to reduce when successive years of data are added to the model (see section titled "Retrospective Analysis" for more details).
6. The model has poor fits to the fishery age composition data (Figure 7). The proposed SCAA model fixes fishery and survey selectivity to federal values (Figure 8); 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.
7. 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 9). 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.

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 A1 in Appendix A). Further analysis demonstrated these results were highly sensitive to 3 age-2 individuals sampled in the commercial fishery. When these 3 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 A1 in Appendix A). We do not recommend this model be used to inform management in 2020.

CHANGES TO THE NSEI SABLEFISH ASSESSMENT FOR 2019 RELATIVE TO 2018

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

2. **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 (1975–2019), fishery 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.[2] 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).

3. 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 10).

4. 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

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[2] The R Project for Statistical Computing. 2018. Available for download from https://www.R-project.org/ (Accessed June 2020).

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 fishery releases (see section titled "Biological Reference Points" for more details).

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 5. Uncertainty in parameters are currently estimated using a maximum likelihood approach.

DATA INPUTS

The data used as inputs to the SCAA model biological data, catch, abundance, and composition (Figure 4) are found here: https://github.com/commfish/seak_sablefish/tree/master/data/tmb_inputs).

Weight-at-age

Data from the 2002–2019 longline fishery and 1997–2019 ADF&G 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:

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

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 NSEI fishery, there are large differences in survey and fishery weight-at-age, especially at younger ages (Figure 11A). Consequently, fishery weight-at-age was fit to landed catch biomass, whereas survey weight-at-age was used to estimate exploitable biomass, spawning biomass, and other quantities of interest in the model (Figure 5).

Maturity-at-age

Maturity data from the 1997–2019 ADF&G 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 62.0 cm; the k_{mat} (the slope at the length at 50% maturity) is 0.44; and the age at 50% maturity is 6.2 years

(Figure 11B). Predicted proportions maturity-at-age were used as inputs to the SCAA model and in the calculation of spawning stock biomass (Figure 5).

Annual fits of maturity, though not explicitly used in the SCAA model, can provide insight into changes in the population or cohort-specific dynamics. Of note, the fit to 2019 maturity data suggest that fish matured at younger ages and smaller sizes compared to previous years. It is possible that earlier maturation can be linked to warm environmental conditions in the North Pacific since 2014, or to density-dependent effects driven by the large 2014 year class. Trends in maturity and growth should be monitored in future assessments.

Catch

Catch data from 1975 to 2019 include harvest in the directed sablefish longline fishery, ADF&G longline survey removals, and sablefish retained in other fisheries like the individual fishing quota halibut longline fishery (Figure 3A). Catch estimates from 1975 to 1984 were obtained from Carlile et al. (2002) and 1985–present catch was obtained from fish tickets. 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 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 including mortality from sand fleas, sharks, and whales. Currently these additional sources of mortality are accounted for in the decrements process (see the section titled “Annual Harvest Objective Determination” for more information).

Fishery CPUE

Fishery CPUE, defined as retained lb per hook, was used as an index of abundance from 1980 to 2019 (Figure 3B). 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 from dockside interviews (1980–1996; Carlile et al. 2002) and 0.08 for the contemporary logbook data (1997–present).

Fishery CPUE in 2019 was at a 15-year low (Figure 3B). 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 fishery releases. Future research will be aimed at better understanding 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 to 2019 (Figure 3C). This index was assumed to be lognormally distributed, with a fixed log standard deviation of 0.1. The 1988–1996 longline surveys 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 3C). 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 time 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, ADF&G 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 in May and June, with recaptures occurring in the ADF&G longline survey in late July or early August and the longline fishery from August through November (Beder and Stahl 2016).

The mark–recapture abundance estimates provide an index of exploitable abundance for years when a marking survey occurred (2003–2010, 2012, 2013, 2015, and 2017–2019; Figure 3D). 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 since 2005 (Figure 3D).

The 2019 marking survey released 11,094 tagged fish (Table 6). 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 in Sullivan et al. 2019). A summary of data used in the mark–recapture models is in Table 6.

Mark–recapture abundance estimates were obtained 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:

$$K_i = \begin{cases} (K_0 - D_0) * \exp(-M * t_i) & \text{i} = 1 \\ (K_{i-1} - k_{i-1} - D_{i-1}) * \exp(-M * t_i) & \text{i} > 1 \end{cases} \qquad (2)$$

and

$$N_i = \begin{cases} (N_i * \exp(-M * t_i) & \text{i} = 1 \\ (N_{i-1} - C_{i-1}) * \exp(-M * t_i) & \text{i} > 1 \end{cases} \qquad (3)$$

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 ADF&G 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

$$Pr(k|n,p) = \binom{n}{k} p^k (1-p)^{n-k}. \quad (4)$$

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 7) and survey age compositions from the 1997–2019 longline surveys (Figure 12) 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 reweighting 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 of Alaska (D. Hanselman, Fisheries Research Biologist, NOAA, Juneau, personal communication, April 2019; Hanselman et al. 2018; Heifetz et al. 1999; Figure 13). 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 ADF&G Age Determination Unit.

Length compositions

Sex-structured length data from the 2002–2019 longline fishery (Figures 14 and 15) and 1997–2019 ADF&G longline surveys (Figures 16 and 17) were summarized using the federal conventions for length compositions (Hanselman et al. 2018). The federal assessment uses 2 cm length bins ranging from 41 to 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 14 and 15) have dramatically different patterns than the survey (Figures 16 and 17), 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 fishery releases of small fish. 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 18). 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 pound data were used to inform retention probabilities-at-size (Figure 19). 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, personal communication, July 2018). Remaining retention probabilities were interpolated between these fixed values. Weight-based retention probabilities were translated to sex and age using the longline survey sex- and weight-based von Bertalanffy growth curves (Figure 11A).

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 (s_{50}) and the shape or slope of the logistic curve (δ). Selectivity-at-age (s_a) for this parameterization is defined as

$$s_a = \frac{1}{1+\exp(-\delta(a-s_{50}))}. \qquad (5)$$

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; Figure 8). Estimating selectivity is challenging when accounting for fishery releases because no age or length data are available on the released fish. Further research is needed to better characterize how discarding behavior has changed over time and if discarding was common pre-EQS.

Catchability

Currently 4 parameters for catchability are estimated: 2 for fishery catchability (pre-EQS and EQS) $\ln(q_{fsh})$, 1 for the ADF&G longline survey $\ln(q_{srv})$, and 1 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, 45 (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 parameter that governs the variability in τ and ψ, $\ln(\sigma_R)$, is fixed such that σ_R=1.2 following assumptions in the federal model (Hanselman et al 2019). The parameters τ and ψ are estimated using penalized likelihood.

Future developments are needed to model the recruitment process using random effects, which will allow the estimation of σ_R. Preliminary results suggest that σ_R may be as low as 0.46, which is consistent with other long-lived, low productivity fish species. The assumed federal assessment value of 1.2 is relatively high by national standards and one of the highest among Alaska groundfish stocks (Lynch et al. 2018; Hanselman et al. 2019). These differing assumptions on recruitment may 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. In the federal assessment, 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 may stabilize the estimation of this year class and reduce retrospective patterns (see section titled "Retrospective Analysis" for more information). Future research should prioritize the implementation of this assessment using random effects.

Fishing mortality

There is 1 parameter estimated for mean log-fishing mortality, μ_F, and 45 (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

$$N_{1,a,k} = \begin{cases} 0.5 \cdot \exp(\mu_R - M(a-a_0) + \psi_a) & a_0 < a < a_+ \\ 0.5 \cdot \exp(\mu_R - M(a_+ - 1))/(1-\exp(-M)) & a = a_+ \end{cases}. \quad (6)$$

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

$$N_{t,a,k} = \begin{cases} 0.5 \cdot \exp(\mu_R + \tau_t) & a = a_0 \\ 0.5 \cdot N_{t-1,a-1,k}\exp(-Z_{t-1,a-1,k}) & a_0 < a < a_+ \\ 0.5 \cdot N_{t-1,a-1,k}\exp(-Z_{t-1,a-1,k}) + N_{t-1,a,k}\exp(-Z_{t-1,a,k}) & a = a_+ \end{cases}, \quad (7)$$

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

$$F_t = \exp(\mu_F + \phi_t). \tag{8}$$

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:

$$F_{t,a,k} = s_{t,a,k}^{fsh}(R_{a,k} + D(1 - R_{a,k}))F_t. \tag{9}$$

PREDICTED VALUES

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

$$\hat{I}_t^{fsh} = q_{fsh} \sum_{k=1}^{2} \sum_{a=a_0}^{a+} w_{a,k}^{srv} \cdot s_{t,a,k}^{fsh} \cdot N_{t,a,k} \cdot S_{t,a,k}^{fsh}, \tag{10}$$

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

$$S_{t,a,k}^{fsh} = \exp\left(-\frac{8}{12}\left(M + F_{t,a,k}\right)\right). \tag{11}$$

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

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

$$\hat{I}_t^{srv} = q_{srv} \sum_{k=1}^{2} \sum_{a=a_0}^{a+} s_{t,a,k}^{srv} \cdot N_{t,a,k} \cdot S_{t,a,k}^{srv}. \tag{12}$$

Predicted mark–recapture abundance in year t ($\hat{I}_t^{MR}$) is 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 ($S_{t,a,k}^{fsh}$):

$$\hat{I}_t^{MR} = q_{MR} \sum_{k=1}^{2} \sum_{a=a_0}^{a+} s_{t,a,k}^{fsh} \cdot N_{t,a,k} \cdot S_{t,a,k}^{fsh}. \tag{13}$$

Spawning biomass SB is calculated as

$$SB = \sum_{a=a_0}^{a+} w_{a,f}^{srv} \cdot N_{t,a,f} \cdot S_{t,a,f}^{spawn} \cdot p_a, \tag{14}$$

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) are computed as

$$\hat{P}^{srv}_{t,a} = \Omega_{a',a} \frac{\sum_{k=1}^{2} N_{t,a,k} \cdot s^{srv}_{a,k}}{\sum_{k=1}^{2} \sum_{a=a_0}^{a+} N_{t,a,k} \cdot s^{srv}_{a,k}}, \quad (15)$$

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

$$\hat{P}^{fsh}_{t,a} = \Omega_{a',a} \frac{\sum_{k=1}^{2} C_{t,a,k}}{\sum_{k=1}^{2} \sum_{a=a_0}^{a+} C_{t,a,k}}, \quad (16)$$

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

$$\hat{C}_{t,a,k} = N_{t,a,k} \frac{R_{a,k} F_{t,a,k}}{Z_{t,a,k}} (1 - \exp(-Z_{t,a,k})), \quad (17)$$

where $R_{a,k}$ is the assumed probability of retention by age and sex (Figure 19).

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

$$\hat{Y}_t = \sum_{k=1}^{2} \sum_{a=a_0}^{a+} w^{fsh}_{a,k} \cdot \hat{C}_{t,a,k}. \quad (18)$$

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

$$\widehat{W}_t = \sum_{k=1}^{2} \sum_{a=a_0}^{a+} w^{srv}_{a,k} N_{t,a,k} \frac{D(1 - R_{a,k}) F_{t,a,k}}{Z_{t,a,k}} (1 - \exp(-Z_{t,a,k})). \quad (19)$$

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

$$\hat{P}^{srv}_{t,l,k} = \Lambda_{a,l,k} \frac{N_{t,a,k} \cdot s^{srv}_{a,k}}{\sum_{a=a_0}^{a+} N_{t,a,k} \cdot s^{srv}_{a,k}}. \quad (20)$$

Similarly, fishery length compositions are calculated as

$$\hat{P}^{fsh}_{t,l,k} = \Lambda_{a,l,k} \frac{\hat{C}_{t,a,k}}{\sum_{a=a_0}^{a+} \hat{C}_{t,a,k}}. \quad (21)$$

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}:

$$N_a^{SPR50} = \begin{cases} 1 & a = a_0 \\ N_{a-1}^{SPR50}\exp(-\mathrm{M} - F_{50}s_{a-1,fem}^{fsh}) & a_0 < a < a_+. \\ N_{a-1}^{SPR50}\exp(-\mathrm{M} - F_{50}s_{T,a-1,fem}^{fsh}) + N_a^{SPR50}\exp(-\mathrm{M} - F_{50}s_{T,a,fem}^{fsh}) & a = a_+ \end{cases} \quad (22)$$

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

$$N_a^{SPR100} = \begin{cases} 1 & a = a_0 \\ N_{a-1}^{SPR100}\exp(-\mathrm{M}) & a_0 < a < a_+. \\ N_{a-1}^{SPR100}\exp(-\mathrm{M}) + N_a^{SPR100}\exp(-\mathrm{M}) & a = a_+ \end{cases} \quad (23)$$

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

$$SBPR_{SPR} = \sum_{a=a_0}^{a+} w_{a,f}^{srv} \cdot N_a^{SPR} \cdot S_{T,a,f}^{spawn} \cdot p_a. \quad (24)$$

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

$$\dot{R} = \left(\prod_{t=1}^{T} \exp(\mu_R + \tau_t)\right)^{\frac{1}{T}}. \quad (25)$$

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

$$SB_{SPR} = 0.5 \cdot \dot{R} \cdot SBPR_{SPR}. \quad (26)$$

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

$$\ln L(SPR) = 100 \left(\frac{SBPR_{50}}{SBPR_{100}} - 0.50\right)^2. \quad (27)$$

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, includes the sum of the following likelihood components L, which received individual weights λ:

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

$$\ln L(Y) = \lambda_Y \frac{1}{2\sigma_Y^2} \sum_{t=1}^{T} (\ln(Y_t + c) - \ln(\hat{Y}_t + c))^2, \quad (28)$$

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 are 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:

$$\ln L(I) = \lambda_I \frac{1}{2\sigma_I^2} \sum_{t=1}^{T_I} (\ln(I_t + c) - \ln(\hat{I}_t + c))^2, \quad (29)$$

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 is calculated as the square root of the total sample size in year t:

$$\ln L(P^{age}) = \lambda_{P^{age}} \sum_{t=1}^{T_P^{age}} -\omega_t \sum_{a=a_0}^{a+} (P_{t,a} + c) \cdot \ln(\hat{P}_{t,a} + c), \quad (30)$$

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):

$$\ln L(P^{age}) = \sum_{t=1}^{T_P^{age}} -\Gamma(n_t + 1) - \sum_{a=a_0}^{a+} \Gamma(n_t P_{t,a} + 1) + \Gamma(n_t \theta) - \Gamma(n_t + \theta n_t) + \sum_{a=a_0}^{a+} [\Gamma(n_t P_{t,a} + \theta n_t \hat{P}_{t,a}) - \Gamma(\theta n_t \hat{P}_{t,a})], \quad (31)$$

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

$$\omega_t = \frac{1 + \theta n_t}{1 + \theta}. \quad (32)$$

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 are 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:

$$\ln L(P^{len}) = \lambda_{P^{len}} \sum_{k=1}^{2} \sum_{t=1}^{T_P^{len}} - \omega_t \sum_{l=l_0}^{l+} (P_{t,l} + c) \cdot \ln(\hat{P}_{t,l} + c). \tag{33}$$

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 sum of squares penalized lognormal likelihood, where

$$\ln L(\phi) = \lambda_{\phi} \sum_{t=1}^{T} \phi_t^2, \tag{34}$$

and λ_{ϕ}= 0.1.

6. Recruitment deviations (τ_t) are modeled using a penalized lognormal likelihood

$$\ln L(\tau) = \lambda_{\tau} \sum_{t=1}^{T} (\tau_t - 0.5\sigma_R^2)^2. \tag{35}$$

This is the parameterization used in the federal assessment, where σ_R is fixed at 1.2 (Hanselman et al. 2018). The λ_{τ} is set to 3.5, higher than the weighting of 2.0 in the federal assessment. This increased weighting improves retrospective behavior and improves the stability of recruitment estimates.

Preliminary code is available in the SCAA to model recruitment deviations using random effects, such that

$$\ln L(\tau) = \lambda_{\tau} \sum_{t=1}^{T} \ln(\sigma_R) + \frac{(\tau_t - 0.5\sigma_R^2)^2}{2\sigma_R}, \tag{36}$$

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 (Kristensen et al. 2016).

Priors

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 130 parameters were estimated in the SCAA model, which converged with a maximum gradient component less than 0.001 (Table 7). The objective function value (negative log likelihood) was 5578 (Table 8). The model fits catch, pre-EQS fishery CPUE, and mark–recapture abundance reasonably well in most years (Figure 4). Contemporary fishery CPUE (EQS) does not fit well, with long runs of positive or negative residuals (Figure 4B). The model performs poorly during the period directly following the implementation of EQS in 1994 for all indices, including catch (Figure 4). Further consideration should be given to which abundance indices should be used in the model. For example, because releasing fish 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 estimated 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 5). Recruitment trends are comparable with federal values, and estimates of spawning stock biomass, exploitable biomass, and exploitable abundance, including large recruitment events in 1978 and 2014 (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 20), suggesting that harvest rates during this time period were more than 4 times current levels.

Fits to fishery are shown in Figure 7, and survey age compositions are shown in Figure 12. 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 14 and 15, and fits to female and male survey length compositions are shown in Figures 16 and 17. 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 the model is not predicting the small individuals observed in the survey in recent years (Figures 16 and 17).

Because no data on fishery releases exist, it may not be possible to estimate fishery selectivity that fit 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 (e.g., Zheng and Siddeek 2018). 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 1,280,406 round lb at the target fully selected fishing mortality of F_{50} (Table 2). This is a 222,369 lb increase (21%) 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 57,716 lb, which was included in the max ABC calculation (Table 2). The large increase in estimated mortality from fishery releases between 2019 and 2020 is attributed to differences between the YPR and SCAA models and the abundant 2014 year class.

This large increase in ABC is reliant on the 2014 year class, which includes 27.5% 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. Continued suppressed spawning stock biomass, 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 has expressed concerns through public comment over low economic value of small fish and a need for stability in the sablefish market.[3] Management strategy evaluations conducted by the International Pacific Halibut Commission 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.[4] 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 quickly (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; this will also take into consideration 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.

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 10 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

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[3] Letter from Behnken, L., K. Hansen, J. Erickson, N. Kimball, S. Moreland, D. Besecker, J. Morelli, et al. to the North Pacific Fishery Management Council. Presented at the NPFMC meeting April 2–9, 2018. https://meetings.npfmc.org/CommentReview/DownloadFile?p=ceb44789-7edc-439a-9c2c-de2e5c522d9e.pdf&fileName=E1%20IN%20MEETING%20PUBLIC%20COMMENT.pdf (Accessed June 2020).

[4] International Pacific Halibut Commission. 2019. IPHC MSE update. Agenda Item 7, IPHC-2019-SRBO14-08, presented at the 14th meeting of the IPHC Scientific Review Board. Available from https://www.iphc.int/uploads/pdf/srb/srb014/ppt/iphc-2019-srb014-08-p.pdf (Accessed June 2020).

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:

$$\text{Mohn's } \rho = \sum_{p=1}^{P} \frac{X_{Y-p,p} - X_{Y-p,0}}{Y_{Y-p,0}} / P, \qquad (37)$$

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 0.30, well above the threshold of 0.20 identified for longer-lived species like sablefish (Figure 6; 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. 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.

MARKING SURVEY SENSITIVITY ANALYSIS

The mark–recapture project has formed the foundation of sablefish management in NSEI since 2005 (Figure 4D; Dressel 2009). 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 (Appendix A).

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.

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 4D). 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 from Analysis 1 show the ABC from the SCAA model was approximately 310,000 round lb (37%) higher than the actual recommended ABC in 2015 (Figure 21A). In 2012, 2015, and 2020, however, the ABC from the SCAA model was close to the actual ABC (within 10%). These results reflect maximum ABCs and do not account for the 15% max change management procedure that reduces 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 21B). All models converged with a maximum gradient component <0.001. The ABCs from the different bi- or triennial survey designs were surprisingly similar within years, with the 2018 ABCs resulting in the most variability. These results suggest that the SCAA model performs consistently well in the absence of an annual survey.

Notably, the resulting ABCs from all scenarios in Analysis 2 were higher than the actual ABCs (Figure 21B). The strong positive retrospective pattern of the SCAA model calls into question the validity of the ABC estimates when evaluating the impact of losing the mark–recapture project (Figure 6; see section titled "Retrospective Analysis" for more information). Specifically, these ABCs were calculated using estimates of spawning biomass that were too high given our current understanding of the stock (Figures 5B and 6). These findings provide additional support for initiating a max 15% change procedure, which will dampen the potentially detrimental effects of retrospective bias and provide predictability and stability in the fishery. More analysis is needed to determine whether this level of bias 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 the 15% max change management procedure will provide additional stability in the ABC between years.

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. Update: this was completed by Region I analyst/programmer, Karl Wood, for use during the 2020 marking survey.
- Continue to monitor progress to address ageing discrepancies between ADF&G and NMFS. A description of this issue and progress to date is detailed in Appendix B.
- Improve data input and storage methods for the mark–recovery and countback data. 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.

- Development and publication of 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 using random effects to estimate variability in recruitment. Initial code to troubleshoot this issue can be found at https://github.com/commfish/seak_sablefish/issues/51.
- Implement the SCAA model in a Bayesian framework. Preliminary work has been done using the R library tmbstan (Monnahan and Kristensen 2018). The process is currently very slow; the next steps include optimizing the NUTS algorithm using methods detailed in the supplementary material of Monnahan and Kristensen (2018).
- 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 Ongoing Priorities for SCAA Model Developments

These tasks should be developed within 2–5 years of SCAA implementation. Although 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 1997–2004 mark–recapture data that are not currently accessible.
- Explore methods for estimating *M* with a prior or assuming age-specific *M* rates.

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TABLES

Table 1.–Annual harvest objective (round lb), equal quota share (round lb), reported harvest (round lb), exvessel value, number of permits, and effort (days) for the directed commercial NSEI sablefish fishery, 1985–2019.

Year	Annual harvest objective	Equal quota share[a]	Harvest	Exvessel value (mil)	No. of permits	No. of days
1985	2,380,952	–	2,951,056	$2.0	105	3
1986	2,380,952	–	3,874,269	$2.9	138	2
1987	2,380,952	–	3,861,546	$3.5	158	1
1988	2,380,952	–	4,206,509	$4.5	149	1
1989	2,380,952	–	3,767,518	$2.9	151	1
1990	2,380,952	–	3,281,393	$3.5	121	1
1991	2,380,952	–	3,955,189	$6.9	127	1
1992	2,380,952	–	4,267,781	$4.9	115	1
1993	2,380,952	–	5,795,974	$5.6	120	1
1994	4,761,905	38,889	4,713,552	$9.1	121	30
1995	4,761,905	38,889	4,542,348	$7.7	121	30
1996	4,761,905	38,889	4,673,701	$9.9	121	61
1997	4,800,000	39,300	4,753,394	$11.6	122	76
1998	4,800,000	41,700	4,688,008	$7.4	116	76
1999	3,120,000	28,000	3,043,273	$6.6	112	76
2000	3,120,000	28,600	3,082,159	$7.4	111	76
2001	2,184,000	19,600	2,142,617	$4.6	111	76
2002	2,005,000	18,400	2,009,380	$4.8	109	76
2003	2,005,000	18,565	2,001,643	$4.8	108	93
2004	2,245,000	20,787	2,229,956	$4.5	108	93
2005	2,053,000	19,400	2,026,131	$5.0	106	93
2006	2,053,000	19,550	2,033,786	$5.1	105	93
2007	1,488,000	14,500	1,501,478	$3.8	103	93
2008	1,508,000	15,710	1,513,040	$4.9	96	93
2009	1,071,000	12,170	1,071,554	$3.6	88	93
2010	1,063,000	12,218	1,054,276	$4.4	87	93
2011	880,000	10,602	882,779	$4.9	83	93
2012	975,000	12,342	969,535	$3.6	79	93
2013	1,002,162	12,848	971,499	$2.9	78	93
2014	745,774	9,561	772,260	$3.2	78	93
2015	786,748	10,087	780,534	$3.4	78	93
2016	650,754	8,343	646,238	$3.2	78	93
2017	720,250	9,234	714,401	$3.9	78	93
2018	855,416	10,967	855,598	$3.5	78	93
2019	920,093	11,796	922,755	$3.1	78	93
2020	1,108,003	14,773	N/A	N/A	75	93

[a] The equal quota share program was implemented in 1994.

Table 2.–Summary of biological reference points for the 2020 acceptable biological catch (ABC) determination.

Quantity/Status	2019	2020	Percent change
Projected total (age 2+) biomass (lb)	[a]	48,513,401	NA
Projected female spawning biomass (lb)	[a]	15,679,118	NA
Unfished female spawning biomass ($SB_{100\%}$, lb)	[a]	24,853,774	NA
Female spawning biomass at F_{50} ($SB_{50\%}$, lb)	[a]	12,426,887	NA
max $F_{ABC} = F_{50}$	0.0632	0.0765	21.0%
Recommended F_{ABC}	0.0632	0.0659	4.3%
Mortality from fishery releases (lb)	19,142	57,716	201.5%
Max ABC (lb)	1,058,037	1,280,406	30.7%
Recommended ABC (lb)	1,058,037	1,216,743	15.0%

[a] These values were either not reported or not estimated in the 2019 yield-per-recruit model. They will be available for comparison in 2021.

Table 3.–Decrement types and amounts, 2015–2020. Estimated catch is in round lb of sablefish.

	Year					
	2015	2016	2017	2018	2019	2020
Acceptable biological catch	986,481	807,559	850,113	965,354	1,058,037	1,216,743
Decrement Type (lb)	Estimated Mortality					
Bycatch mortality in halibut fishery	38,963	27,915	26,136	19,583	18,434	16,207
ADF&G longline survey removal decrement (excluding catch retained by permit holders for their equal quota share)	74,689	53,914	29,290	15,875	26,260	24,698
Guided sport fish harvest	51,910	44,509	43,656	41,179	33,135	35,004
Unguided sport fish harvest	5,212	7,015	3,911	5,872	11,340	5,280
Mortality from fishery deadloss	9,218	6,719	4,250	5,699	8,046	9,729
Mortality from fishery releases	–	–	–	–	19,142	–
Subsistence and personal use harvest	19,741	16,734	22,621	21,730	21,587	17,821
Total decrements	199,733	156,805	129,863	109,938	137,944	108,740
Annual harvest objective	786,748	650,754	720,250	855,416	920,093	1,108,003
Permit holders	78	78	78	78	78	75
Equal quota share	10,087	8,343	9,234	10,967	11,796	14,773

Table 4.–Sablefish harvest (round lb) from the NSEI longline survey, 1988–2019, survey removal decrement (survey harvest minus the combined harvest allocated to the equal quota shares of permit holders aboard the survey vessels), and the number of permit holders participating in the survey.

Year	ADF&G survey harvest	Survey decrement	No. of permit holders participating in longline survey
1988	25,135	–	–
1989	20,602	–	–
1990	32,513	–	–
1991	24,692	–	–
1992	18,902	–	–
1993	30,992	–	–
1994	24,016	–	–
1995	53,041	–	–
1996	48,066	–	–
1997	51,005	–	–
1998	79,471	–	–
1999	58,924	–	–
2000	88,940	–	–
2001	116,998	–	–
2002	101,873	–	–
2003	111,545	–	–
2004	98,254	–	–
2005	128,042	–	–
2006	105,830	–	–
2007	111,067	–	–
2008	116,816	–	–
2009	111,610	–	–
2010	108,907	76,654	3
2011	117,894	50,866	6
2012	120,505	77,499	3
2013	95,393	77,261	3
2014	97,318	80,814	3
2015	92,888	74,689	3
2016	82,100	53,914	5
2017	92,922	29,290	7
2018	84,055	15,875	7
2019	65,347	26,260	5
2020	N/A	24,698	4

Table 5.–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

-continued-

Table 5.–Page 2 of 2.

Variable	Definitions
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 6.–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, 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 7.–Parameter estimates and standard errors from the statistical catch-at-age (SCAA) model.

Parameter	Estimate	Standard error
fsh_logq	-17.709	0.043
fsh_logq	-17.036	0.024
srv_logq	-16.370	0.023
mr_logq	-0.049	0.010
log_rbar	12.932	0.072
log_rec_devs_1975	0.851	0.404
log_rec_devs_1976	0.937	0.424
log_rec_devs_1977	0.994	0.440
log_rec_devs_1978	1.035	0.455
log_rec_devs_1979	0.989	0.443
log_rec_devs_1980	3.771	0.138
log_rec_devs_1981	0.840	0.403
log_rec_devs_1982	0.817	0.395
log_rec_devs_1983	0.788	0.385
log_rec_devs_1984	0.788	0.380
log_rec_devs_1985	0.761	0.370
log_rec_devs_1986	0.703	0.356
log_rec_devs_1987	0.582	0.337
log_rec_devs_1988	0.388	0.315
log_rec_devs_1989	0.196	0.297
log_rec_devs_1990	0.037	0.284
log_rec_devs_1991	-0.058	0.275
log_rec_devs_1992	-0.093	0.269
log_rec_devs_1993	-0.031	0.269
log_rec_devs_1994	0.216	0.275
log_rec_devs_1995	0.491	0.278
log_rec_devs_1996	0.652	0.296
log_rec_devs_1997	1.006	0.301
log_rec_devs_1998	1.295	0.269
log_rec_devs_1999	0.918	0.296
log_rec_devs_2000	0.500	0.290
log_rec_devs_2001	0.627	0.286
log_rec_devs_2002	1.017	0.235
log_rec_devs_2003	0.470	0.283
log_rec_devs_2004	0.361	0.269
log_rec_devs_2005	0.470	0.261
log_rec_devs_2006	0.384	0.266
log_rec_devs_2007	0.313	0.263
log_rec_devs_2008	0.384	0.257
log_rec_devs_2009	0.426	0.249
log_rec_devs_2010	0.110	0.260
log_rec_devs_2011	0.142	0.263
log_rec_devs_2012	0.378	0.269
log_rec_devs_2013	0.806	0.280

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Table 7.–Page 2 of 3.

Parameter	Estimate	Standard error
log_rec_devs_2014	1.147	0.270
log_rec_devs_2015	0.761	0.373
log_rec_devs_2016	2.587	0.347
log_rec_devs_2017	1.028	0.453
log_rec_devs_2018	0.861	0.406
log_rec_devs_2019	0.755	0.384
log_rinit	13.329	0.118
log_rinit_devs_3	0.805	0.391
log_rinit_devs_4	0.781	0.387
log_rinit_devs_5	0.765	0.385
log_rinit_devs_6	0.754	0.384
log_rinit_devs_7	0.744	0.382
log_rinit_devs_8	0.735	0.380
log_rinit_devs_9	0.728	0.379
log_rinit_devs_10	0.720	0.378
log_rinit_devs_11	0.714	0.377
log_rinit_devs_12	0.710	0.376
log_rinit_devs_13	0.708	0.376
log_rinit_devs_14	0.706	0.376
log_rinit_devs_15	0.705	0.375
log_rinit_devs_16	0.704	0.375
log_rinit_devs_17	0.704	0.375
log_rinit_devs_18	0.704	0.375
log_rinit_devs_19	0.705	0.375
log_rinit_devs_20	0.705	0.375
log_rinit_devs_21	0.706	0.375
log_rinit_devs_22	0.707	0.376
log_rinit_devs_23	0.708	0.376
log_rinit_devs_24	0.708	0.376
log_rinit_devs_25	0.709	0.376
log_rinit_devs_26	0.710	0.376
log_rinit_devs_27	0.711	0.376
log_rinit_devs_28	0.711	0.376
log_rinit_devs_29	0.712	0.377
log_rinit_devs_30	0.713	0.377
log_Fbar	-2.645	0.335
log_F_devs_1975	-0.829	0.347
log_F_devs_1976	-0.825	0.347
log_F_devs_1977	-1.366	0.346
log_F_devs_1978	-1.012	0.345
log_F_devs_1979	-0.579	0.344
log_F_devs_1980	-0.874	0.344
log_F_devs_1981	-1.115	0.343
log_F_devs_1982	-0.952	0.342
log_F_devs_1983	-0.627	0.340

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Table 7.–Page 3 of 3.

Parameter	Estimate	Standard error
log_F_devs_1984	-0.802	0.338
log_F_devs_1985	-0.424	0.338
log_F_devs_1986	-0.191	0.338
log_F_devs_1987	-0.249	0.338
log_F_devs_1988	-0.153	0.338
log_F_devs_1989	-0.232	0.338
log_F_devs_1990	-0.295	0.338
log_F_devs_1991	-0.051	0.338
log_F_devs_1992	0.116	0.337
log_F_devs_1993	0.534	0.337
log_F_devs_1994	0.484	0.338
log_F_devs_1995	0.594	0.338
log_F_devs_1996	0.775	0.338
log_F_devs_1997	0.943	0.338
log_F_devs_1998	1.099	0.337
log_F_devs_1999	0.849	0.338
log_F_devs_2000	0.979	0.338
log_F_devs_2001	0.737	0.338
log_F_devs_2002	0.683	0.338
log_F_devs_2003	0.665	0.338
log_F_devs_2004	0.765	0.338
log_F_devs_2005	0.715	0.338
log_F_devs_2006	0.701	0.338
log_F_devs_2007	0.438	0.338
log_F_devs_2008	0.464	0.338
log_F_devs_2009	0.168	0.338
log_F_devs_2010	0.121	0.338
log_F_devs_2011	-0.056	0.338
log_F_devs_2012	0.071	0.338
log_F_devs_2013	0.053	0.338
log_F_devs_2014	-0.144	0.338
log_F_devs_2015	-0.139	0.338
log_F_devs_2016	-0.334	0.338
log_F_devs_2017	-0.291	0.338
log_F_devs_2018	-0.185	0.338
log_F_devs_2019	-0.226	0.339
log_spr_F_35	-1.989	0.293
log_spr_F_40	-2.190	0.277
log_spr_F_50	-2.570	0.266
log_spr_F_60	-2.952	0.278
log_spr_F_70	-3.370	0.319

Table 8.–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 composed of the data likelihood, penalized likelihoods, and priors on the catchability parameters.

Likelihood component	Likelihood	% of Data likelihood
Catch	18.9	0.3
Fishery CPUE	189.7	3.5
Survey CPUE	43.9	0.8
Mark–recapture abundance	77.7	1.4
Fishery ages	149.6	2.7
Survey ages	136.6	2.5
Fishery lengths	2805.8	51.0
Survey lengths	2074.0	37.7
Data likelihood	5496.3	100.0
Fishing mortality penalty	1.8	
Recruitment penalty	65.2	
SPR penalty	0.0	
Sum of catchability priors	14.4	
Total likelihood	5577.7	

FIGURES

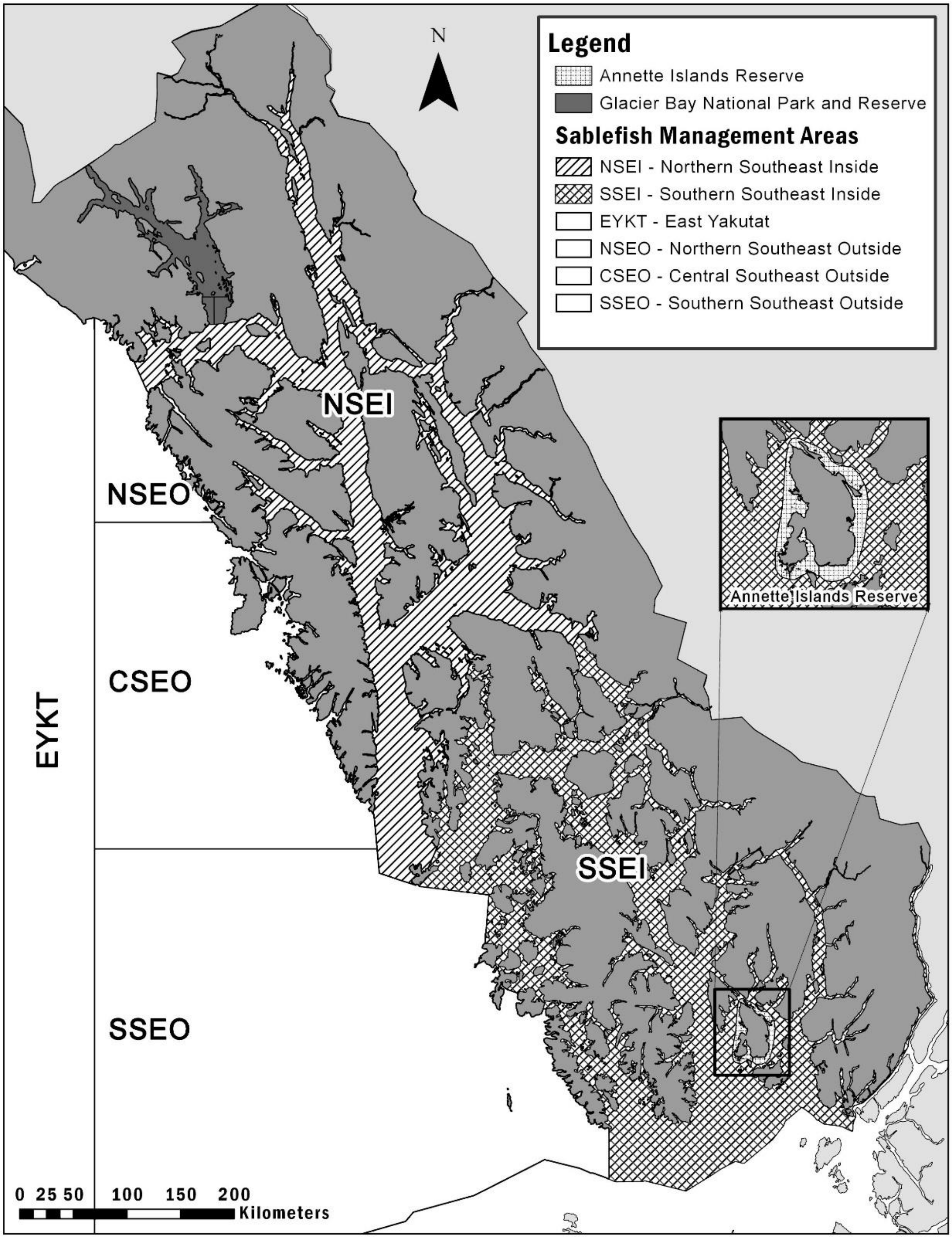

Figure 1.–NSEI and SSEI Subdistricts including restricted waters of Glacier Bay National Park and Preserve and Annette Islands Reserve.

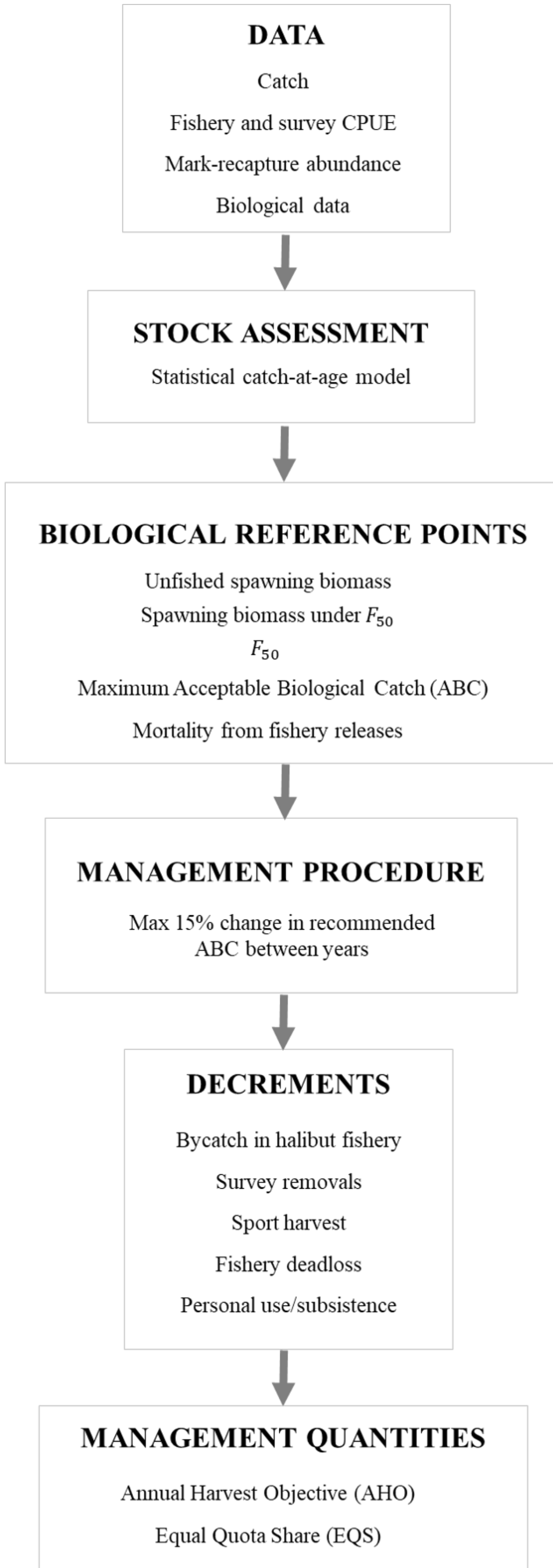

Figure 2.–NSEI stock assessment process and steps to determining the acceptable biological catch (ABC), annual harvest objective (AHO), and equal quota share (EQS).

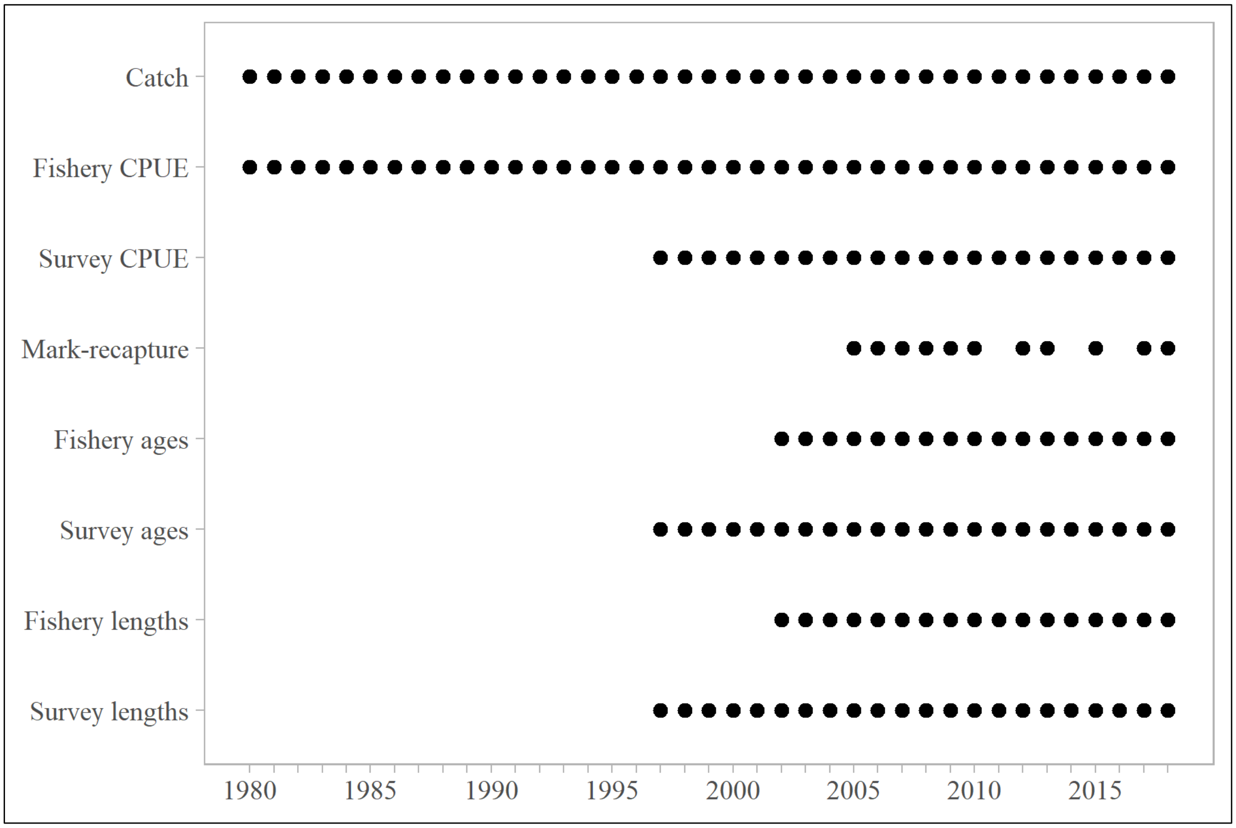

Figure 3.–A summary of the available data sources in NSEI by year.

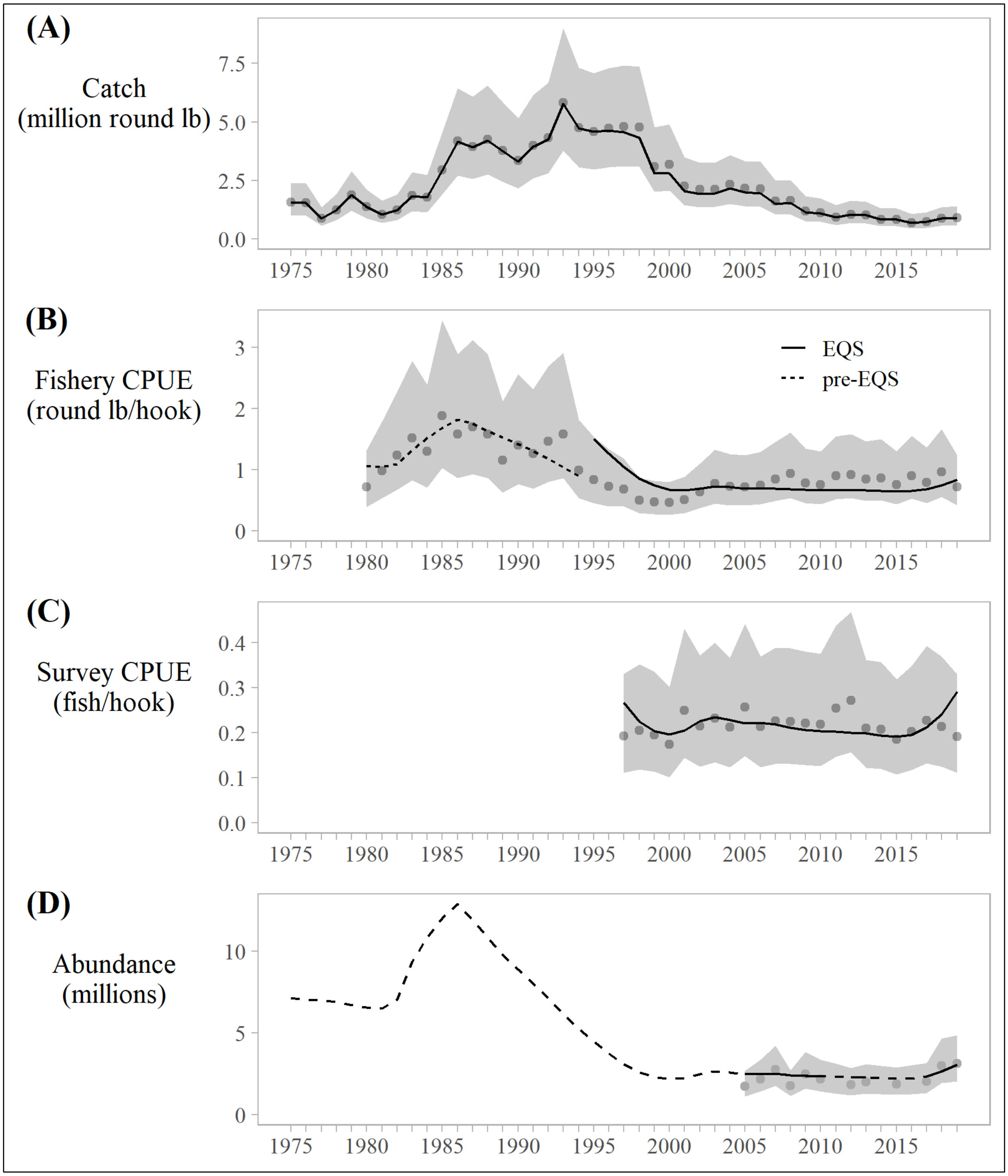

Figure 4.–Fits to indices of catch and abundance with the assumed error distribution shown as shaded grey polygons. Input data are shown as grey points and model fits are shown in black. Indices include (A) harvest (million round lb); (B) fishery CPUE in round lb per hook with separate selectivity and catchability time periods before and after the implementation of the equal quota share (EQS) program in 1994; (C) survey CPUE 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 available (solid) and were not available (dashed).

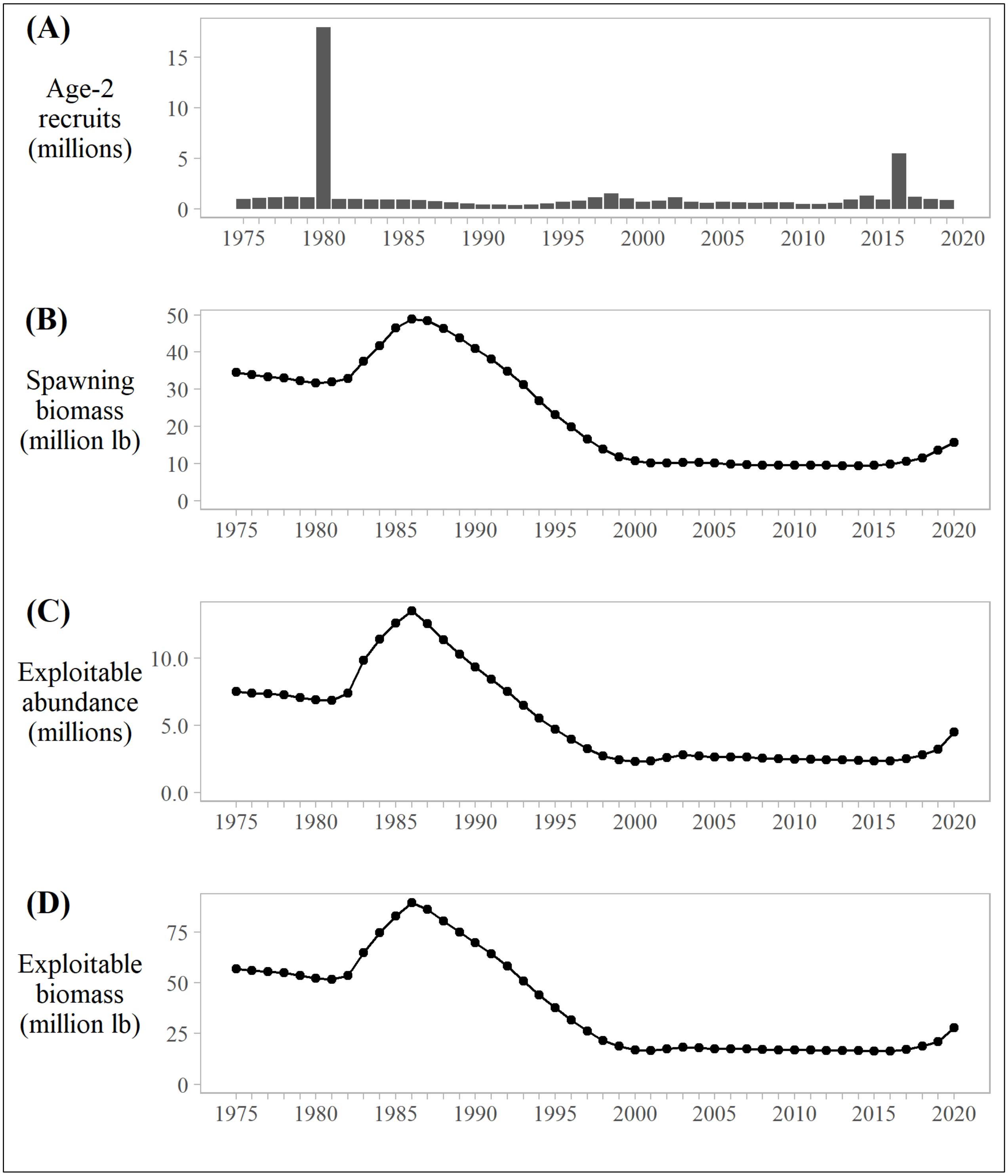

Figure 5.–Model predictions of (A) age-2 recruitment (millions); (B) female spawning stack biomass (million lb); (C) exploitable abundance (millions); and (D) exploitable biomass (million lb).

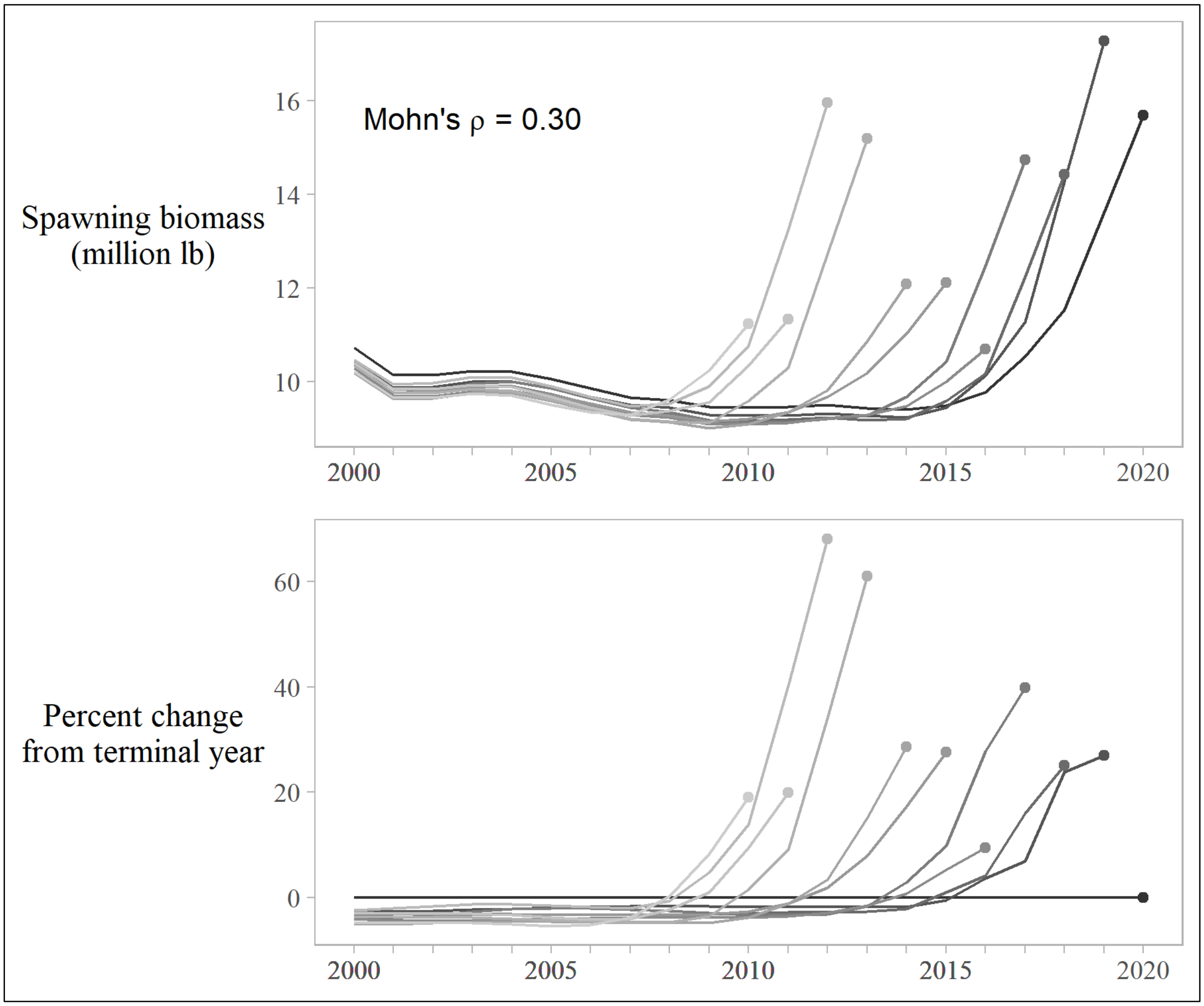

Figure 6.–Mohn's ρ and retrospective peels of sablefish spawning biomass for the last 9 years.

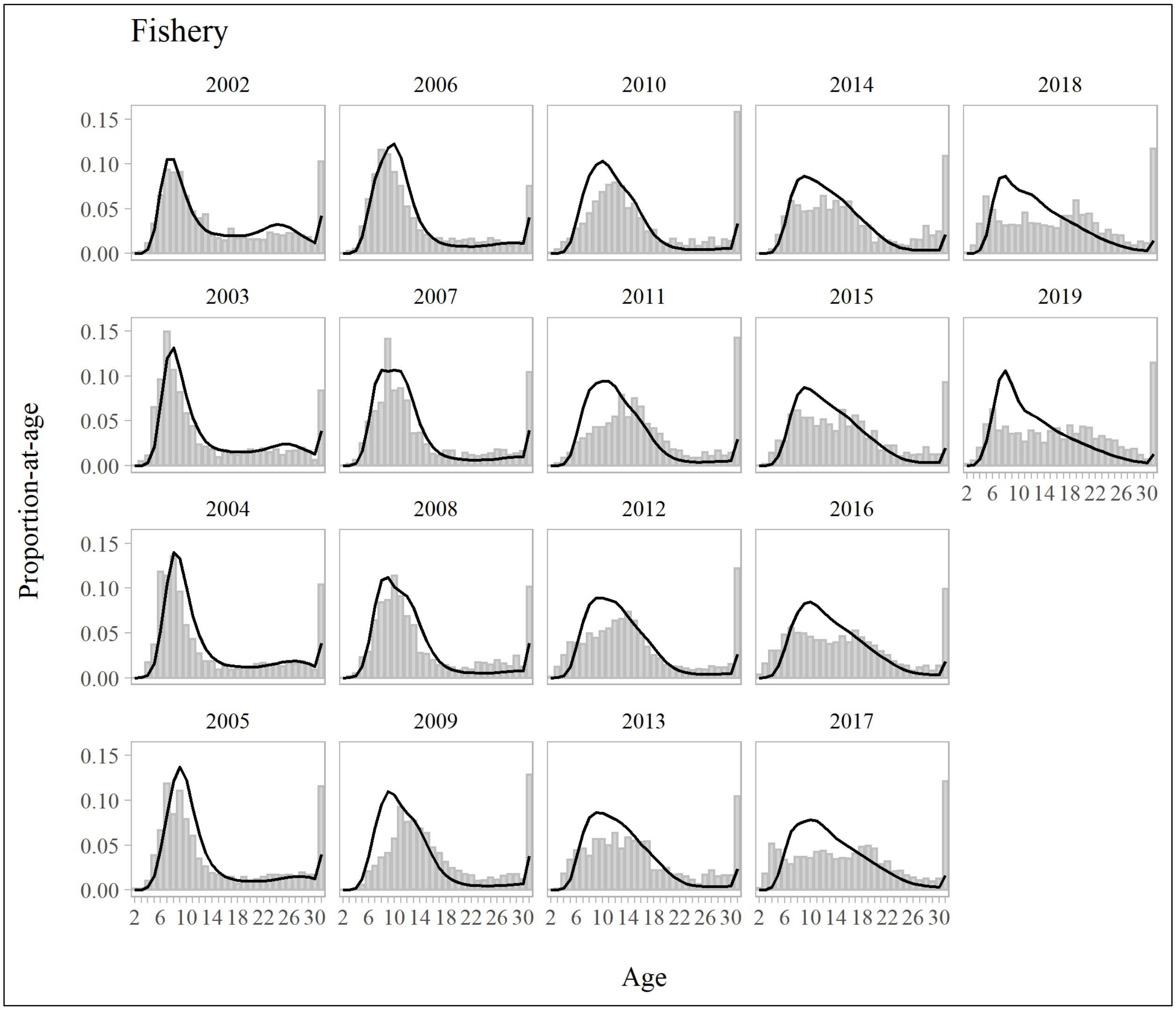

Figure 7.–Fits to fishery age compositions, 2002–2019. Observed (gray bars) and predicted proportions-at-age (black lines) shown.

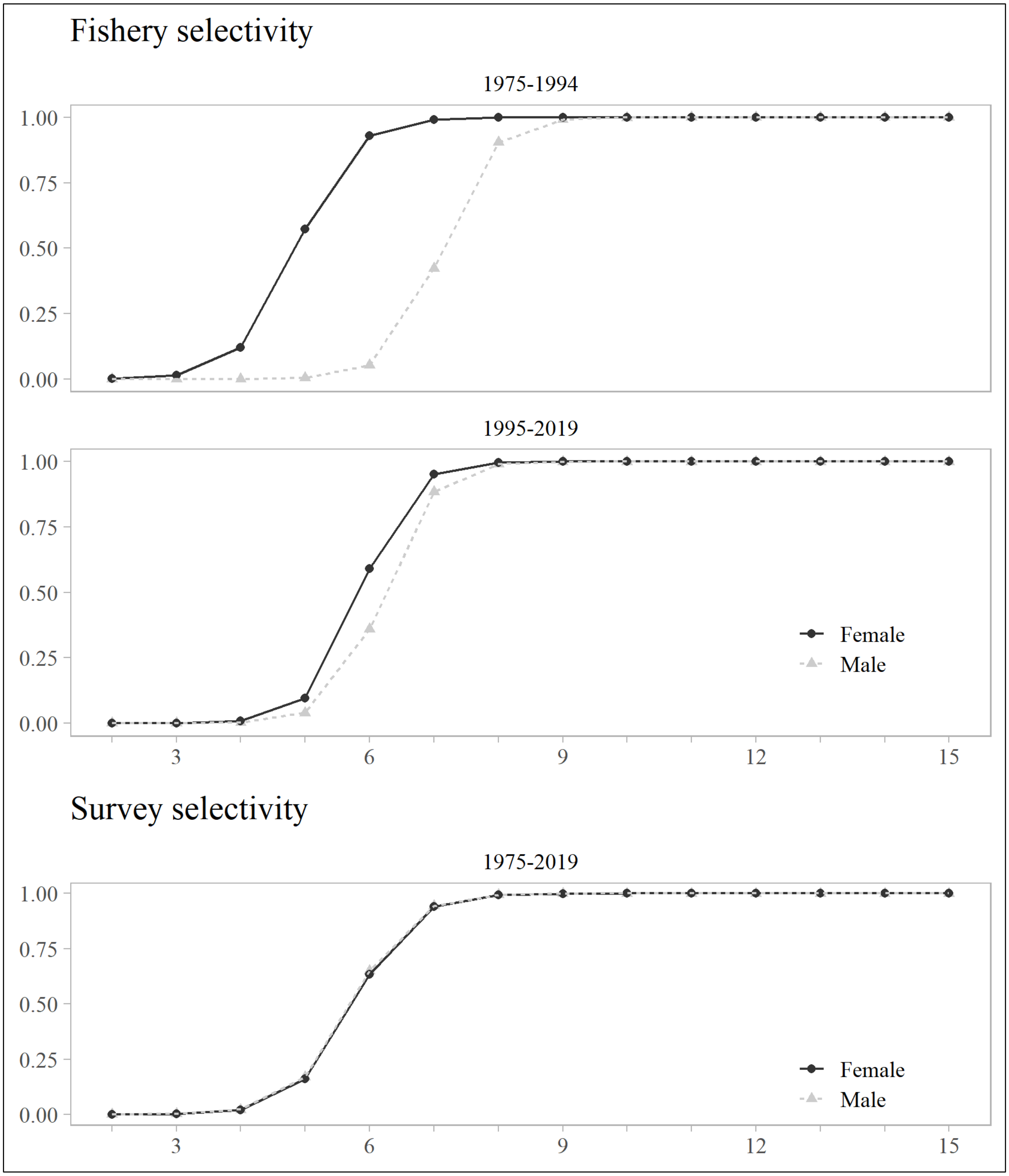

Figure 8.–Sex-specific selectivity curves from the federal stock assessment that are fixed in the statistical catch-at-age model. The break in fishery selectivity in 1995 corresponds to the transition to the individual fishing quota and equal quota share programs.

Source: Federal stock assessment from Hanselman et al. (2018).

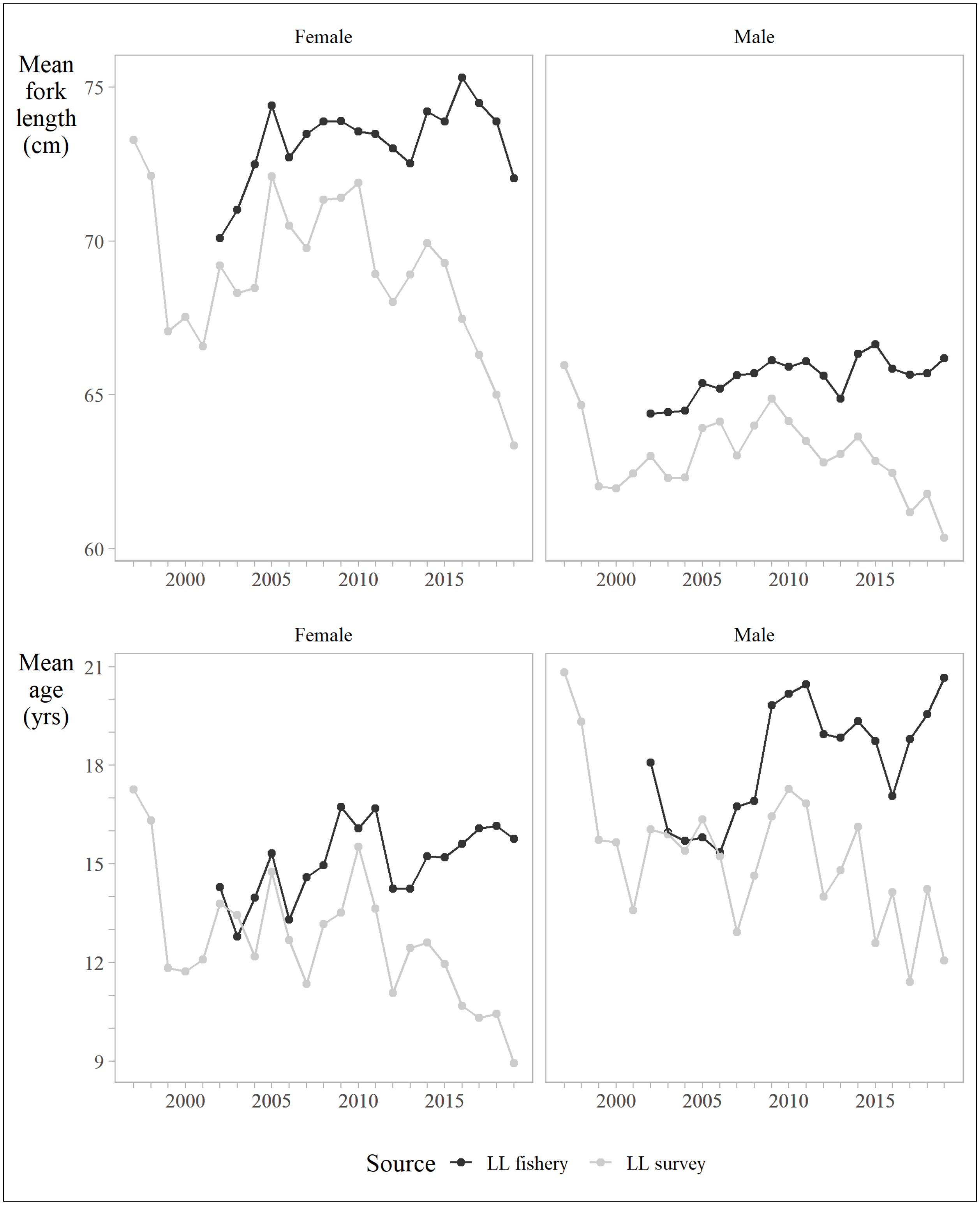

Figure 9.–A comparison of mean fork length (cm) and age (yrs) by sex in the NSEI longline fishery (black) and NSEI longline survey (grey).

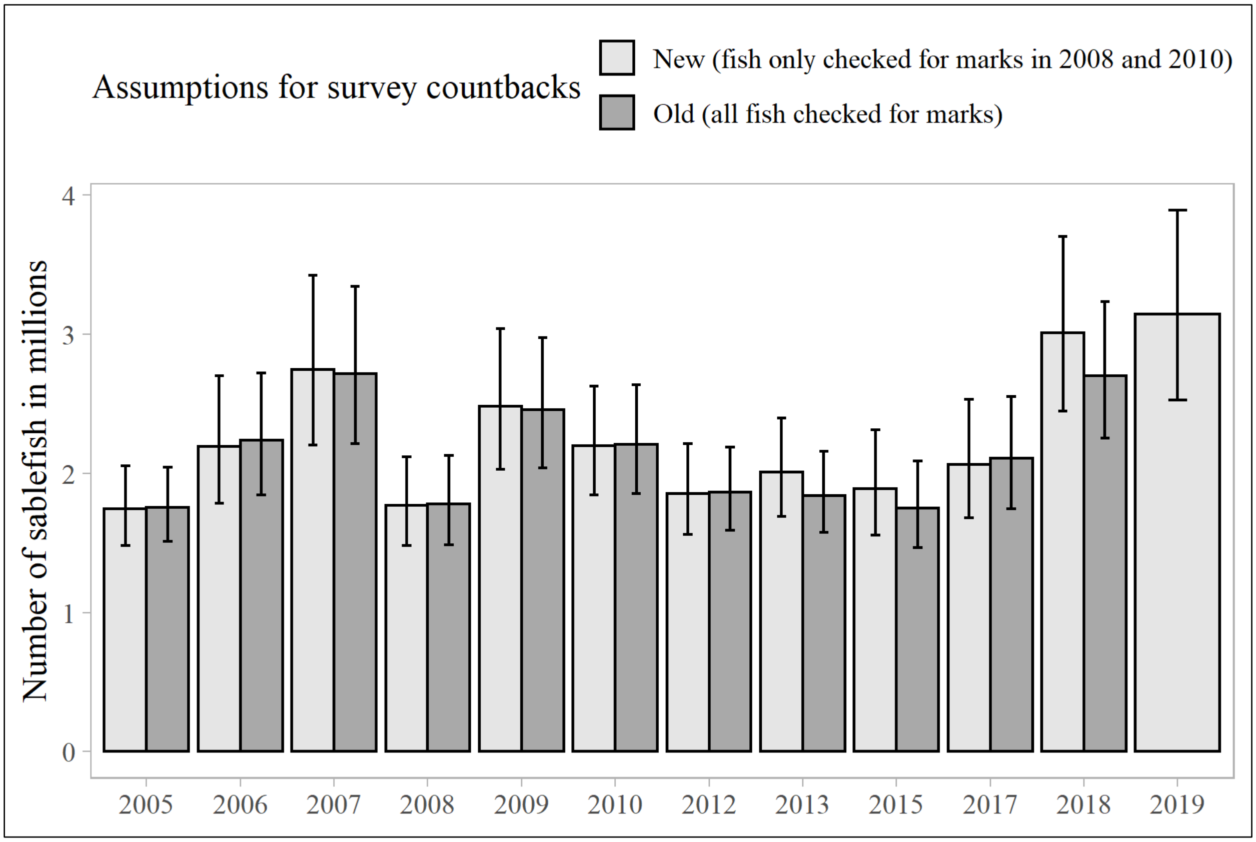

Figure 10.–A comparison of mark–recapture abundance estimates (number of sablefish in millions) using different assumptions about countbacks in the NSEI longline survey.

Note: 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.

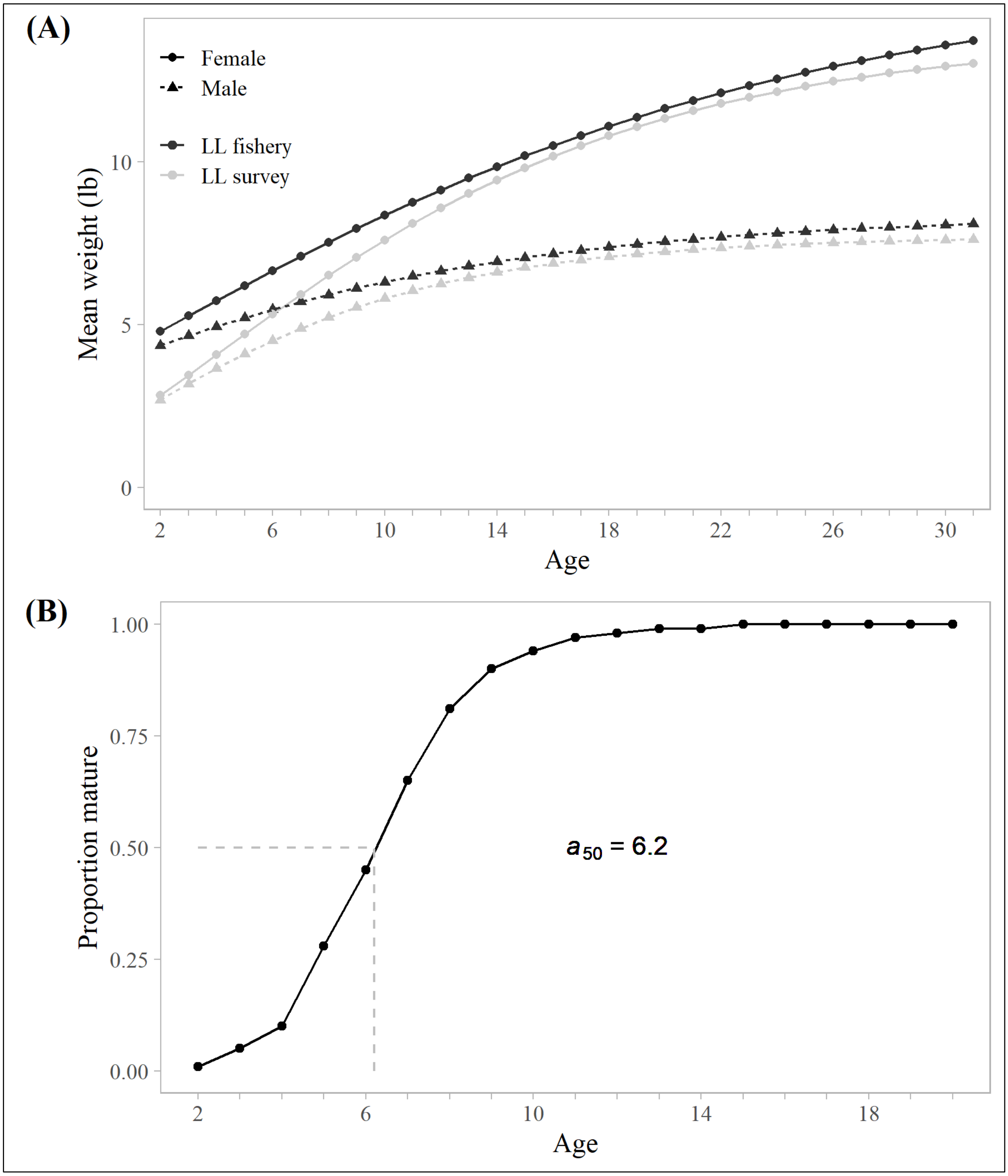

Figure 11.–Biological inputs to the statistical catch-at-age model, including (A) von Bertalanffy growth model predictions of weight-at-age (lb) by sex from the longline fishery (black) and ADF&G longline survey (grey); and (B) proportion mature-at-age for females estimated from the longline survey with the age at 50% maturity (a_{50}=6.2 yr).

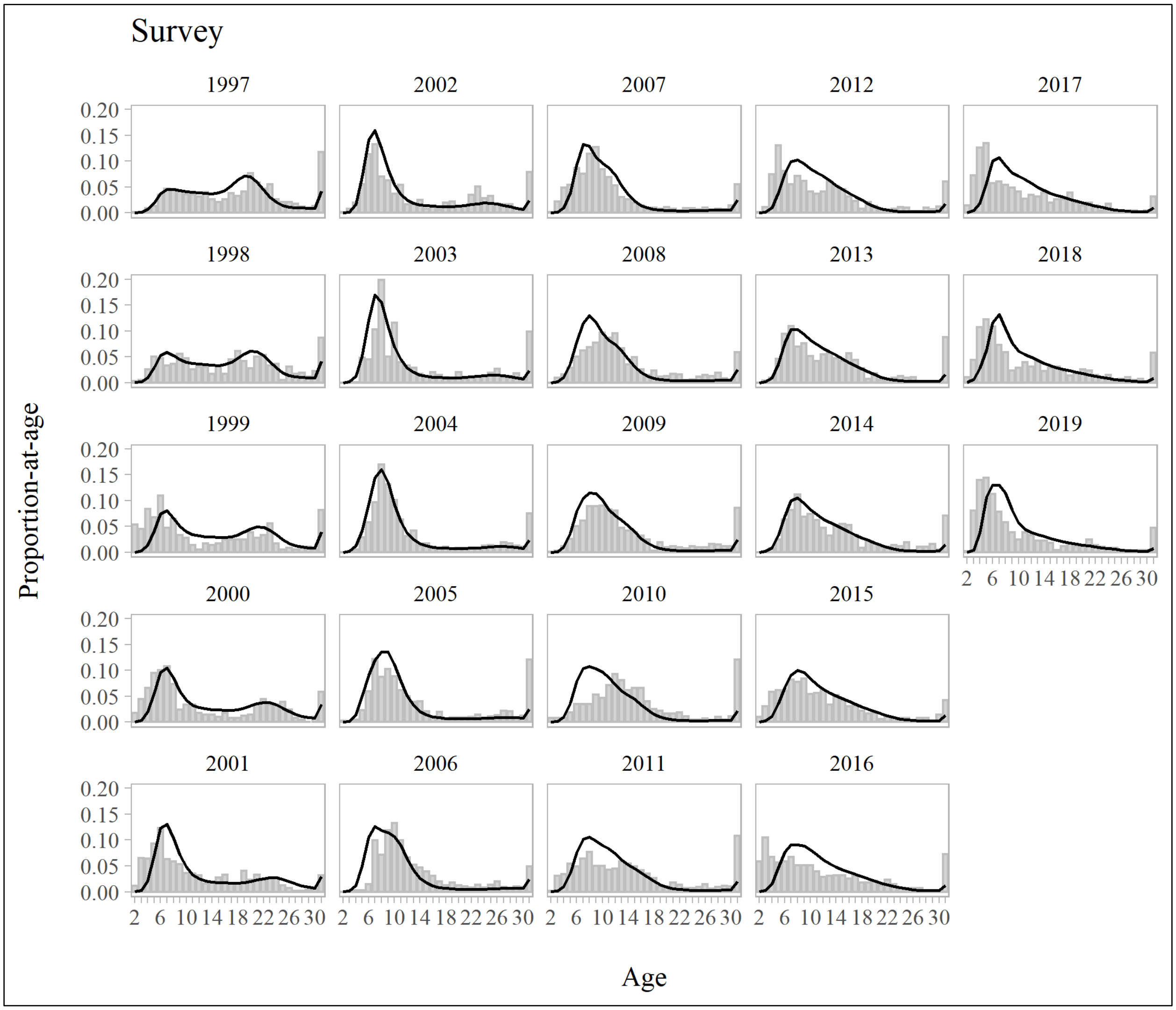

Figure 12.–Fits to survey age compositions, 1997–2019. Observed (gray bars) and predicted proportions-at-age (black lines) shown.

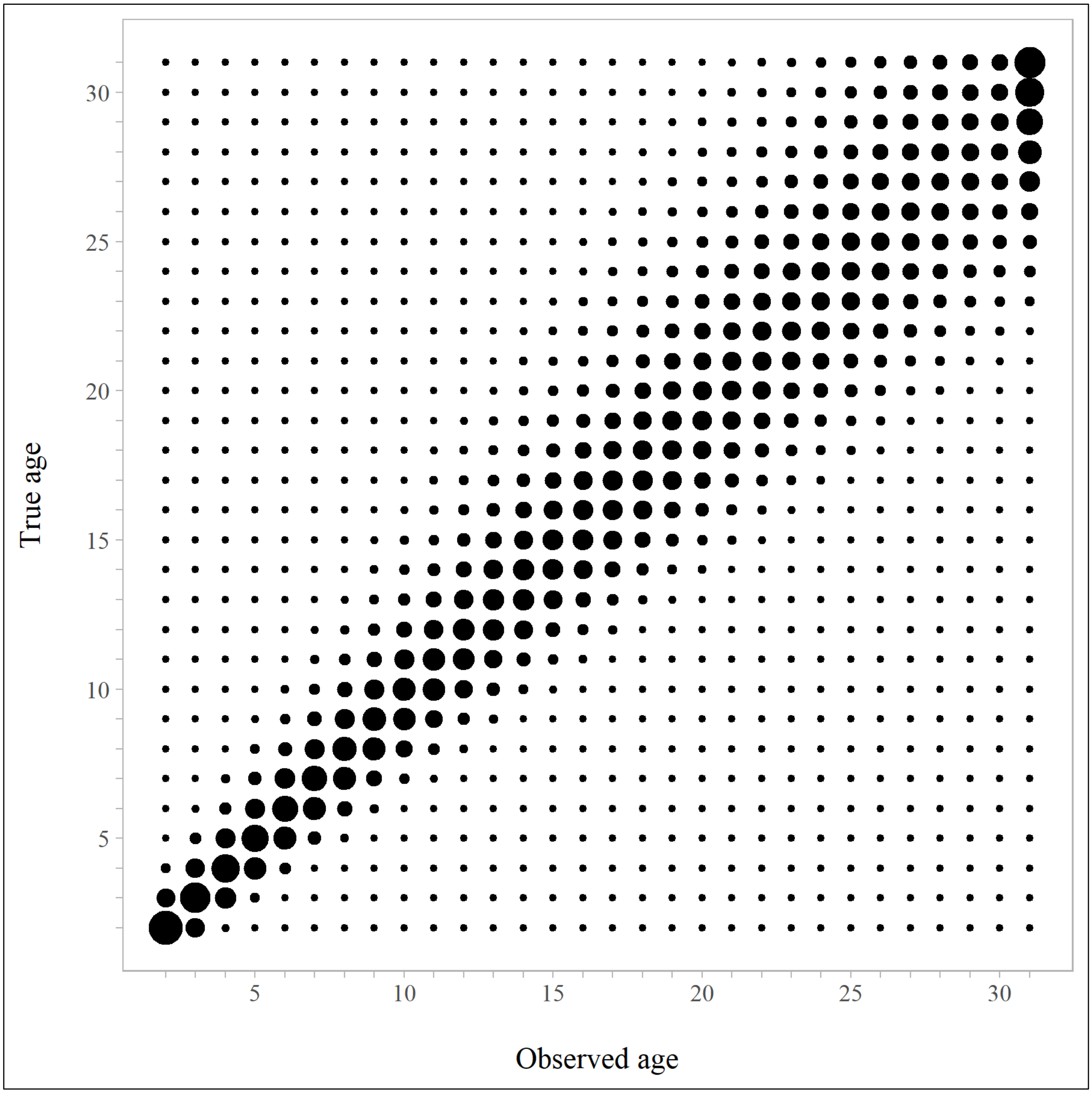

Figure 13.–Ageing error matrix used in the model, showing the probability of observing an age given the true age.

Source: Heifetz et al. 1999.

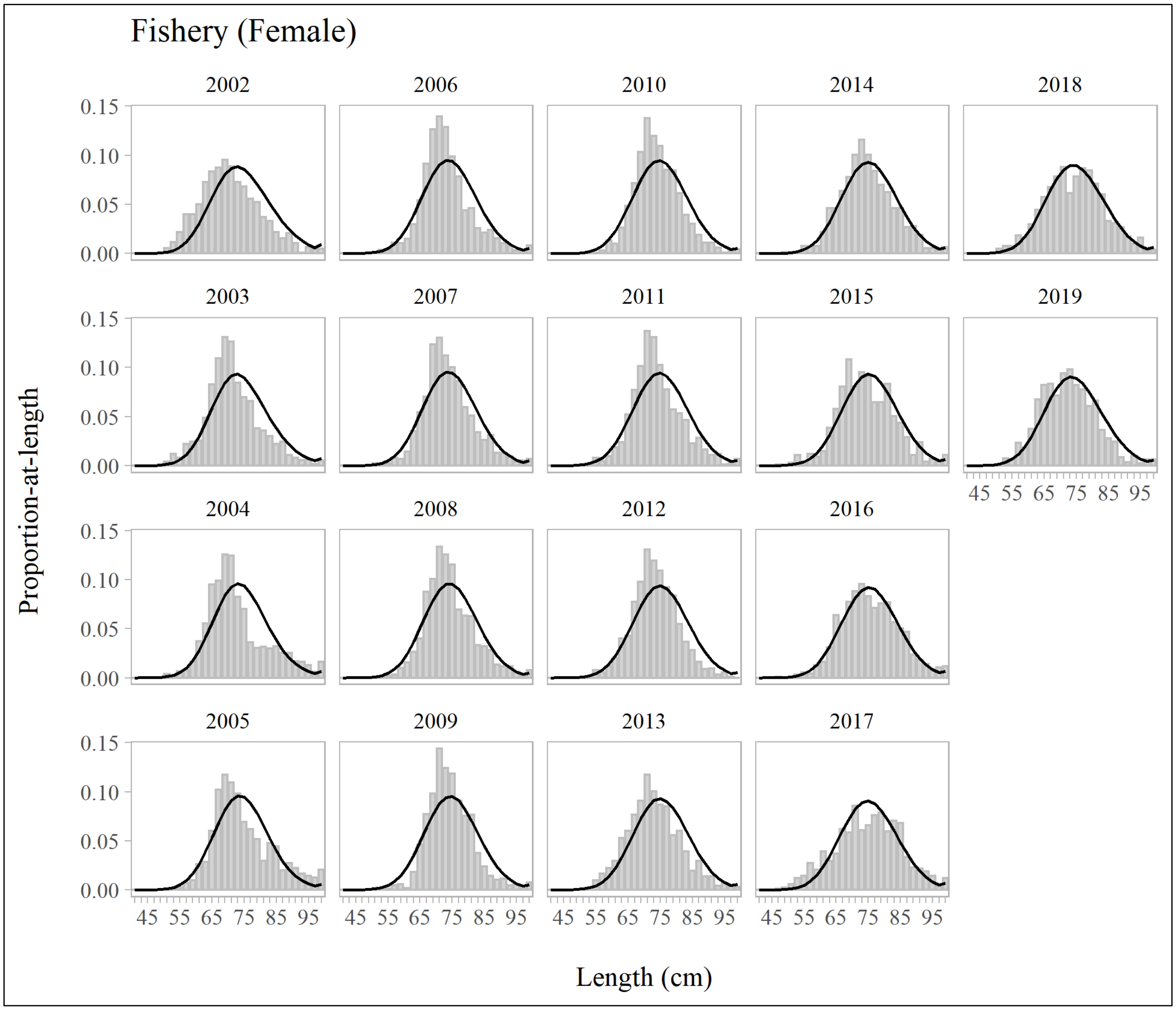

Figure 14.–Fits to female fishery length compositions, 2002–2019. Observed (gray bars) and predicted proportions-at-age (black lines) shown.

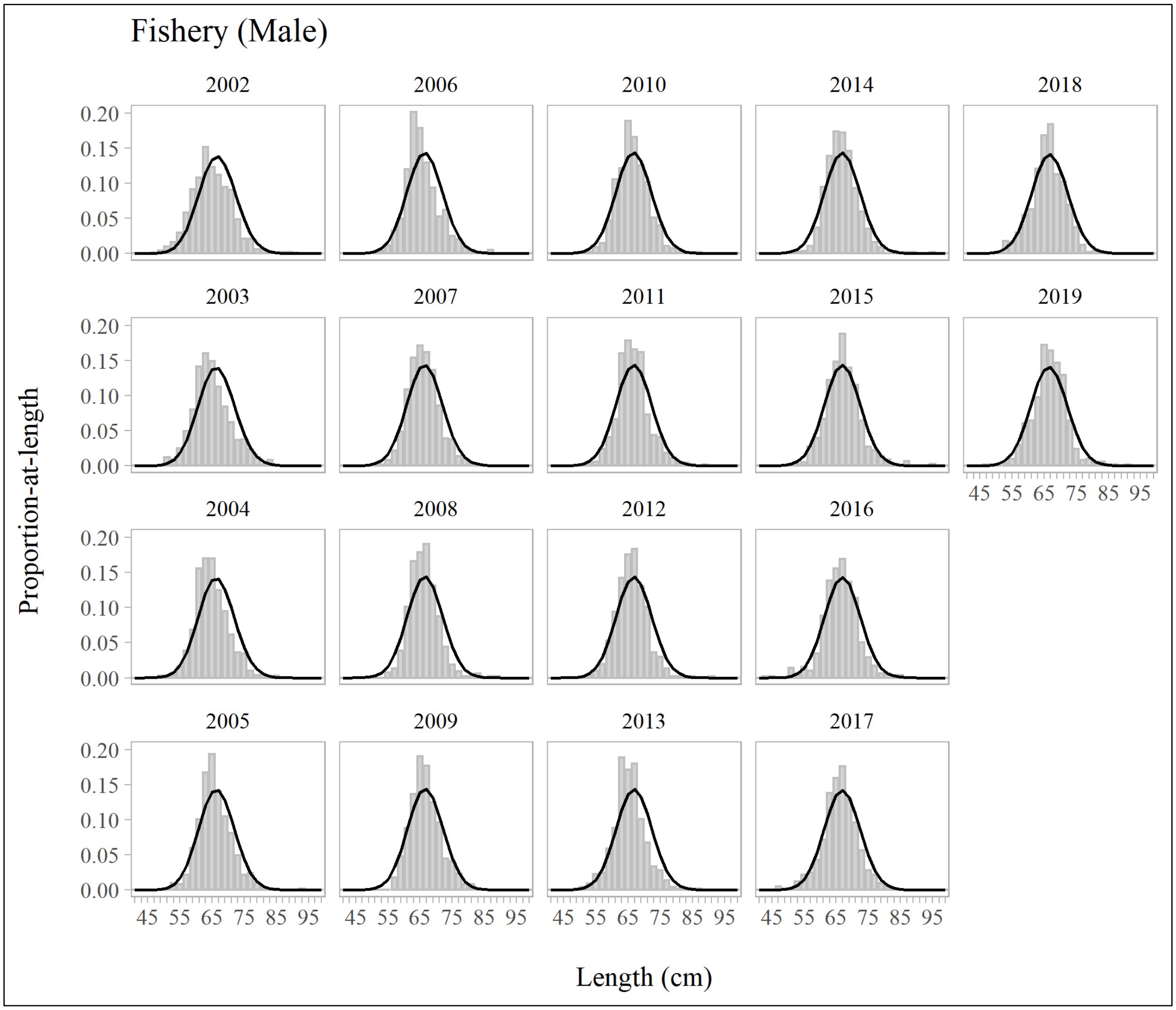

Figure 15.–Fits to male fishery length compositions, 2002–2019. Observed (gray bars) and predicted proportions-at-age (black lines) shown.

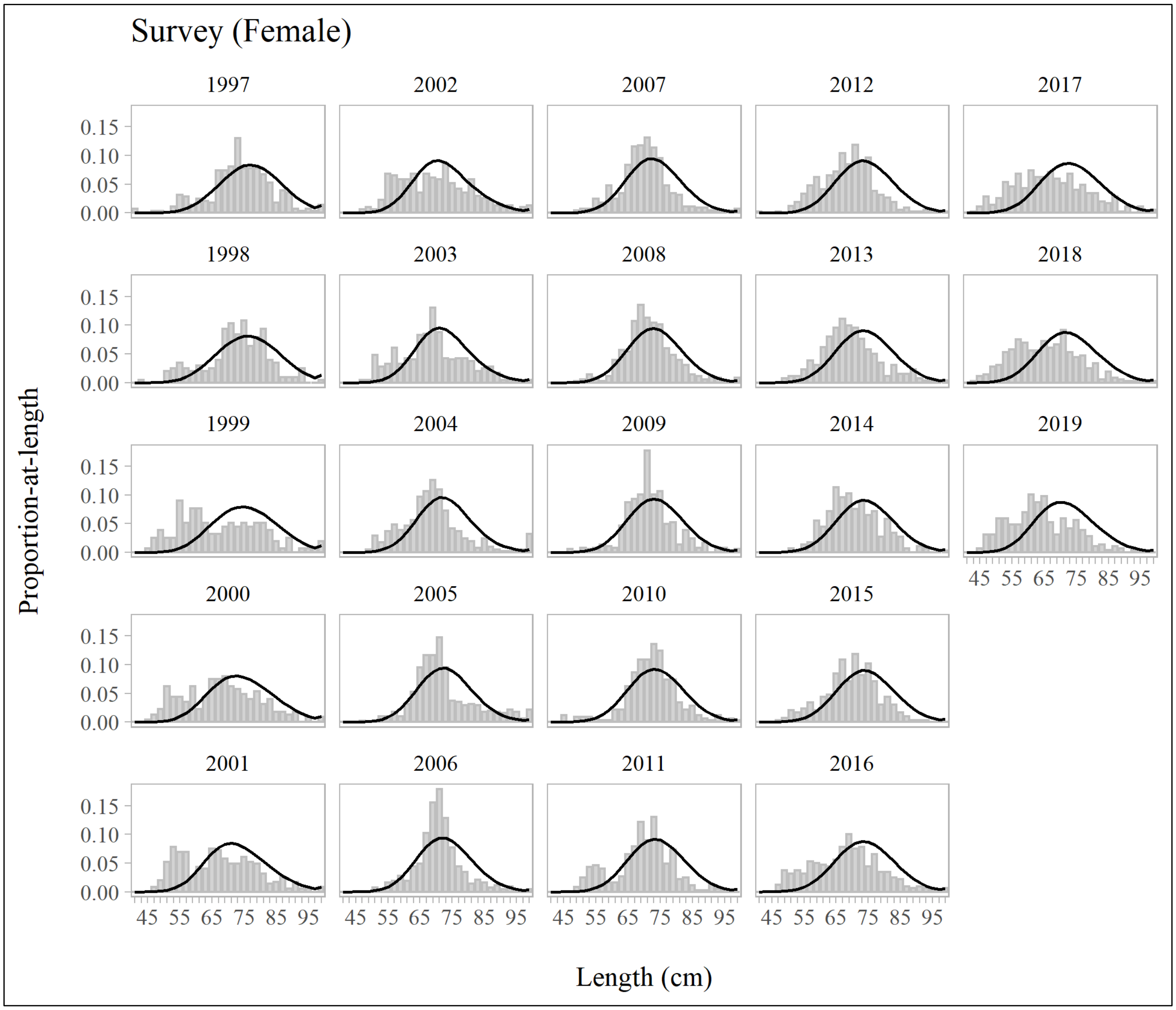

Figure 16.–Fits to female survey length compositions, 1997–2019. Observed (gray bars) and predicted proportions-at-age (black lines) shown.

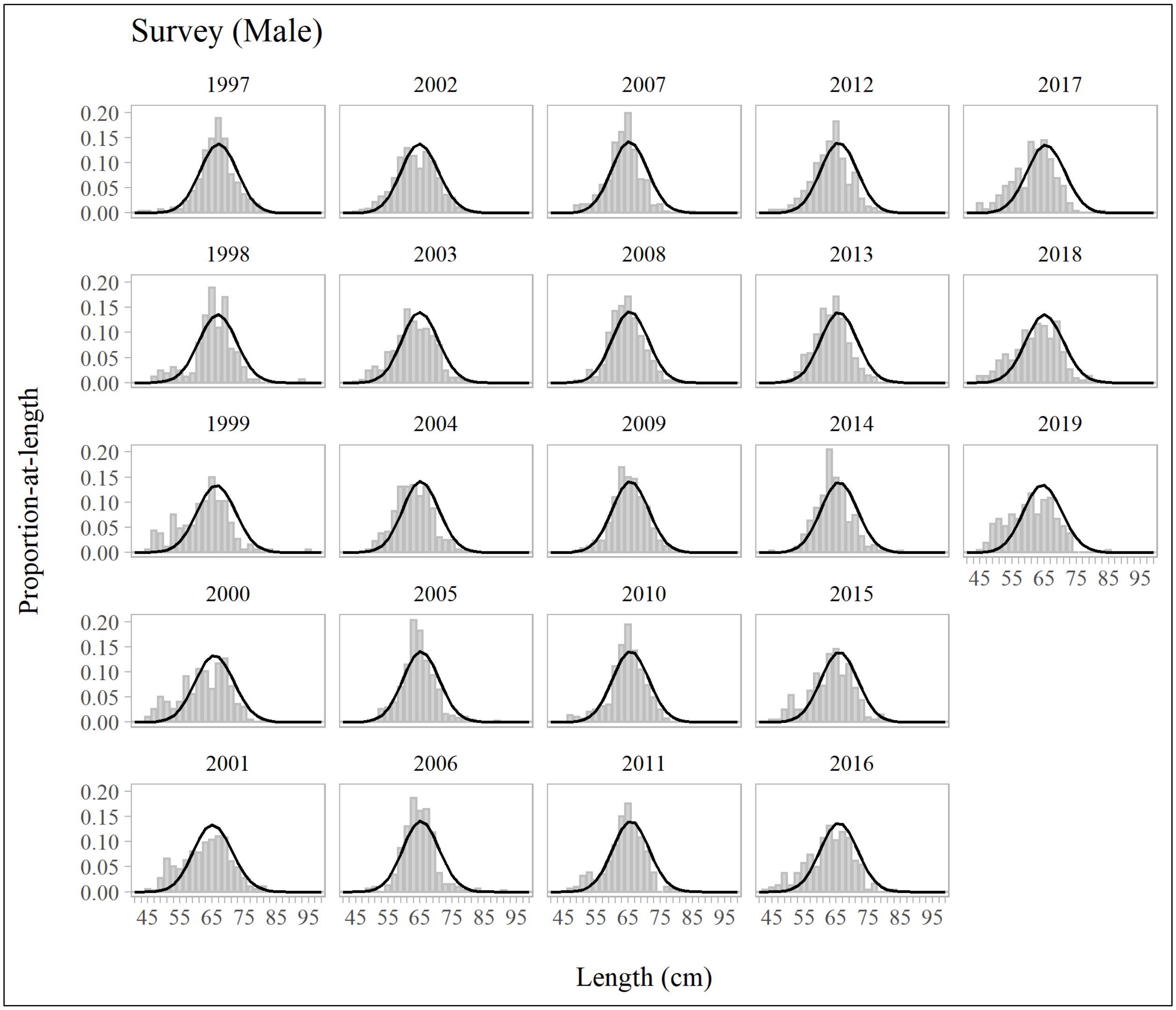

Figure 17.–Fits to male survey length compositions, 1997–2019. Observed (gray bars) and predicted proportions-at-age (black lines) shown.

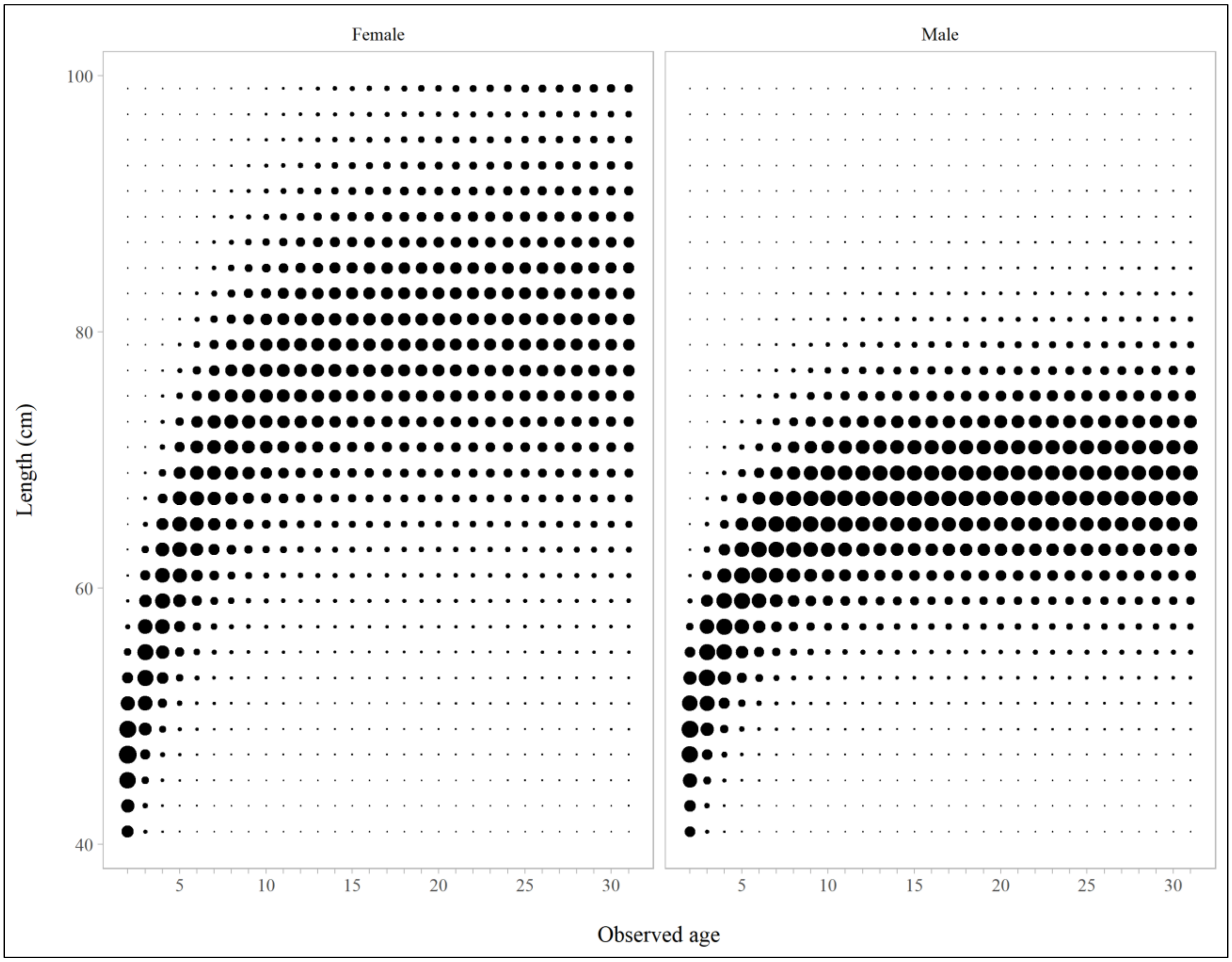

Figure 18.–Age–length key used in the statistical catch-at-age model, with the relative size of the bubbles reflecting the probability that a fish of a given age falls within a certain length bin. The probabilities sum to 1 across each age.

Source: Echave et al. 2012.

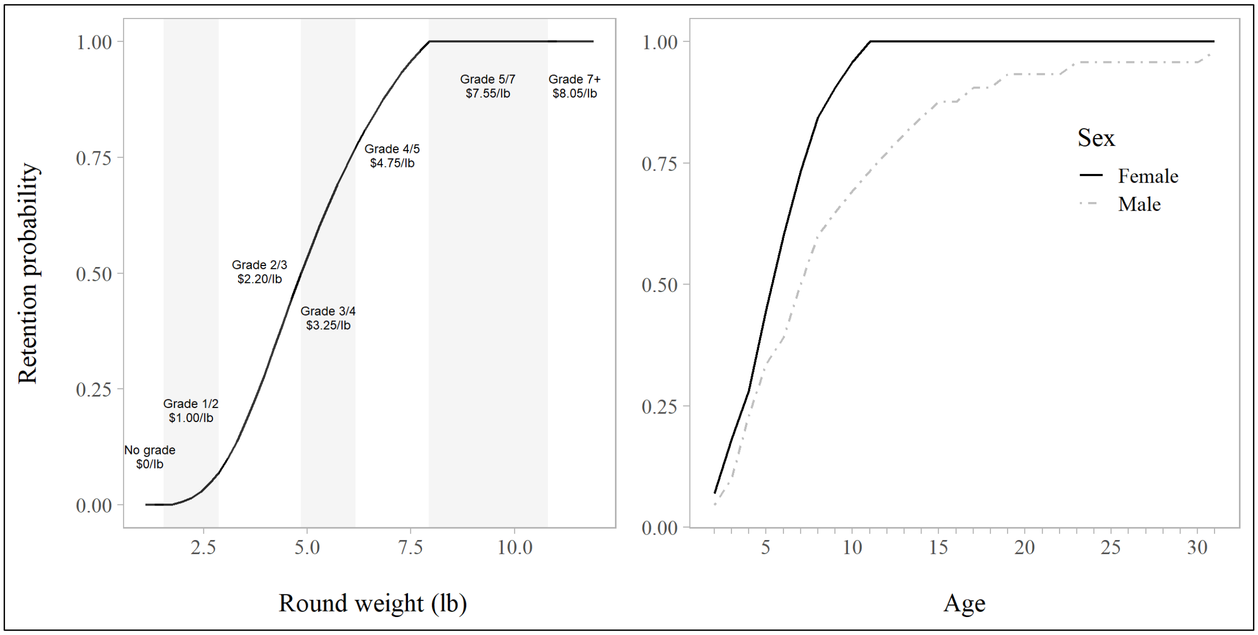

Figure 19.–The probability of retaining a fish as a function of weight in round lb (left panel), sex, and age (right panel). Shaded regions correspond to processor grade and price in dressed lb.

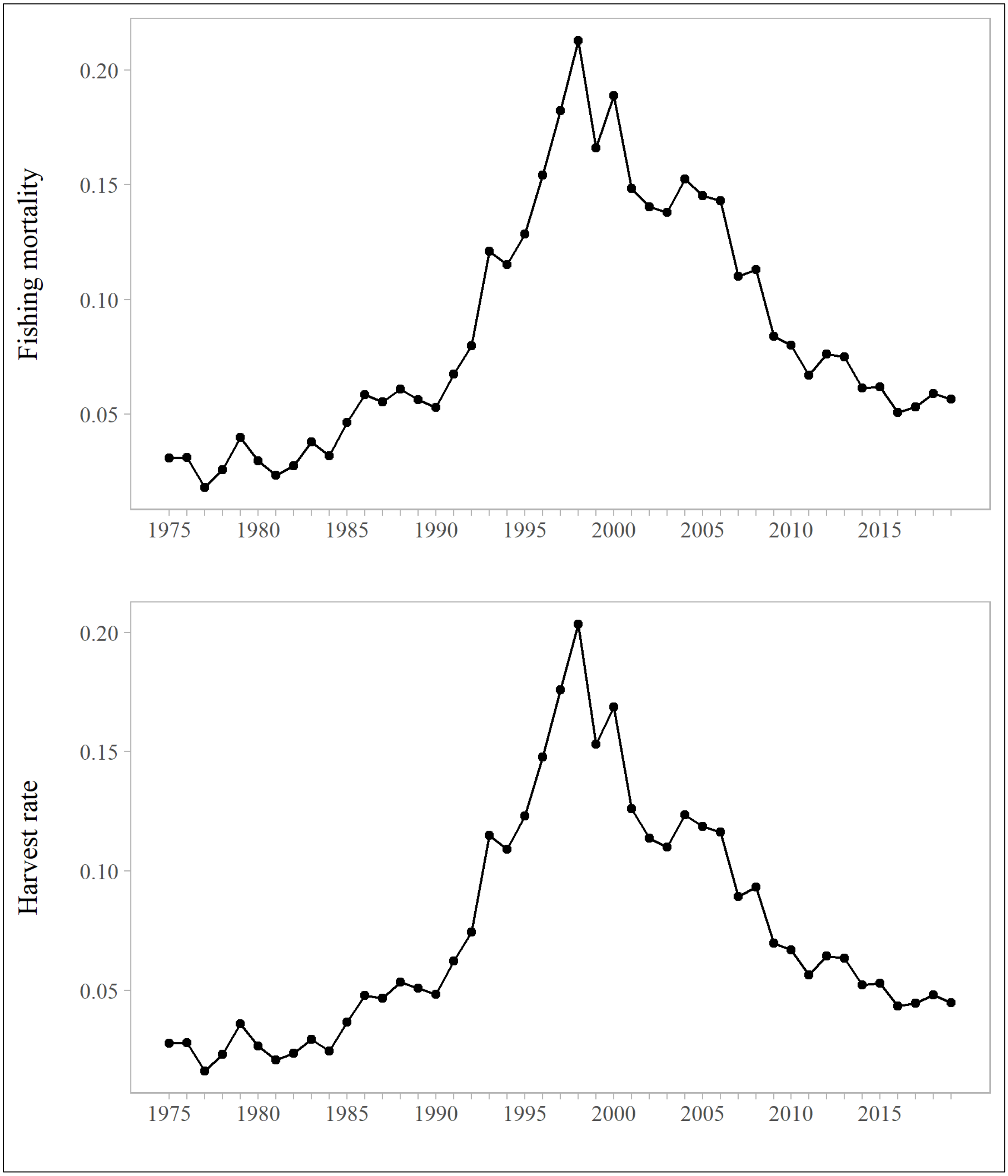

Figure 20.–Model-estimated fishing mortality rate (top) and realized harvest rate (bottom), defined as the ratio of total estimated catch to exploitable biomass. Total estimated catch is the sum of landed catch and discarded biomass assumed to die postrelease.

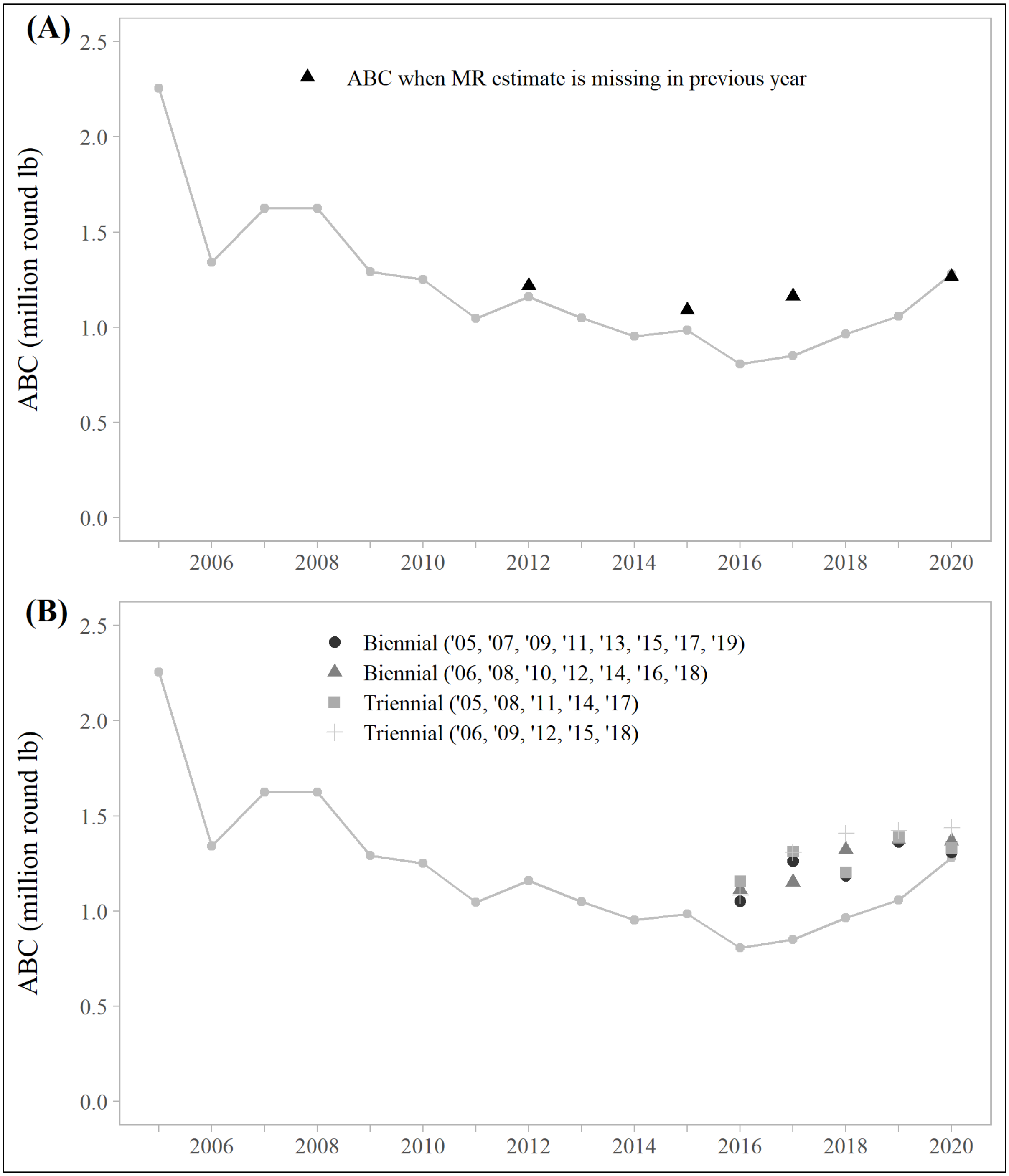

Figure 21.–A comparison of actual acceptable biological catch (ABC; million round lb) recommendations from 2005 to 2020 (grey points and lines) to ABC output from the statistical catch-at-age (SCAA) model, where (A) shows the ABC from the SCAA model following a year without a mark–recapture (MR) abundance estimate, and (B) shows the ABC from the SCAA 2016–2020 model assuming the MR survey only occurs biennially or triennially.

APPENDICES

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 yield-per-recruit (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):

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

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

$$\dot{N}_{2020,s,a} = \begin{cases} \dot{N}_{2019,s,a-1} \exp\left(-Z_{2019,s,a-1}\right) & a_0 < a < a_+ \\ \dot{N}_{2019,s,a-1} \exp\left(-Z_{2019,s,a-1}\right) + \dot{N}_{2019,s,a} \exp\left(-Z_{2019,k,a}\right) & a = a_+ \end{cases}. \quad (2)$$

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):

$$Z_{2019,s,a} = M + \frac{F_{2019}}{2} S_{s,a} \left(R_{s,a} + \Omega\left(1 - R_{s,a}\right)\right), \quad (3)$$

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 (see Figure 15 in this report, page 54).

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 YPR 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.[1] Biological inputs to the YPR 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.

[1] The R Project for Statistical Computing. 2018. Available for download from https://www.R-project.org/ (Accessed June 2020).

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$\dot{N}_{2020,s,a}$ 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 $\ddot{N}_{2020}$ was 2,240,916 fish, and $\ddot{B}_{2020}$ was 18,073,484 round lb.

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

$$\mathrm{ABC}_{2020} = \sum_{s=1}^{2}\sum_{a=2}^{a+} w_{s,a}\,(\dot{N}_{2020,s,a})\frac{R_{s,a}S_{s,a}F_{50}}{Z_{s,a}}(1-\exp(-Z_{s,a})). \quad (4)$$

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

$$\mathrm{D}_{2020} = \sum_{s=1}^{2}\sum_{a=2}^{a+} w_{s,a}\,(\dot{N}_{2020,s,a})\frac{\Omega S_{s,a}(1-R_{s,a})F_{50}}{Z_{s,a}}(1-\exp(-Z_{s,a})). \quad (5)$$

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 partitioned 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, the final exploitable biomass decreased. To demonstrate the large impact of these few samples, a sensitivity analysis was conducted 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 2- and 3-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 A1). 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 3 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.

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Table A1.–A comparison of results from YPR model in the base model and in the sensitivity analysis when 3 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 A REFERENCES

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Appendix B: Memorandum from Age Determination Unit on sablefish ageing discrepancies and misclassification of the 2014 year class.

THE STATE of ALASKA
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MEMORANDUM

TO: Jane Sullivan
Biometrician II

DATE: June 9, 2020

PHONE: 907-465-3054

SUBJECT: Age comparison with tag-recaptured sablefish

FROM: Kevin McNeel
Fishery Biologist III

In March 2019, the Alaska Department of Fish & Game (ADF&G) Commercial Fishery Biometrician, Jane Sullivan, identified a difference between Federal and State peak sablefish year class using longline survey data (Fig. 1). Sablefish are a difficult species to estimate the age using the otolith break and burn technique. Three common difficulties are identifying the first year of growth, growth that occurs in the same calendar year of capture (plus growth), and strong sub annual bands (checks). Different laboratories that estimate ages of sablefish compare and distribute information through the Committee of Age Reading Experts (CARE) to document and improve sablefish otolith age estimation methods. However, there is still a need to quantify and assure the accuracy (i.e. validate) of each laboratory's estimates. Validation is done by comparing age estimates with collections of otoliths with known age though objective data (e.g. mark-recapture studies). To validate ADF&G sablefish ages, a collection of otoliths with paired tag-recapture data were aged using the otolith break and burn technique.

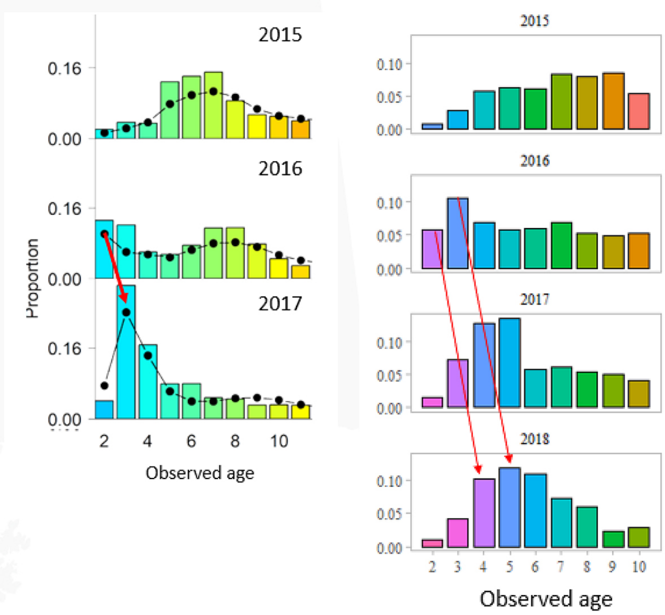

Figure 1: Federal (left) and State (right) sablefish longline survey age composition by year and proportion. Red arrows indicate strong year classes that are different between the two surveys.

The ADF&G Mark Tag and Age Lab Age Determination Unit (ADU) received 41 sablefish otoliths from the National Oceanic and Atmospheric Administration Alaska Fisheries Science Center. The sablefish were tagged as juveniles in St. John the Baptist Bay and caught between May 1998 and August 2015. Ages were estimated based on tagging data by calculating the time at sea (between tagging and recapture) and subtracting the age at tagging. The age at tagging was estimated using a comparison of juvenile fish across capture month (Fig. 2). This suggested that most fish were one-year-old at the time of tagging, but one individual was likely less than one-year-old. The ADU used the ages estimated with the tag data to validate ages estimated using an otolith break and burn technique (CARE 2006).

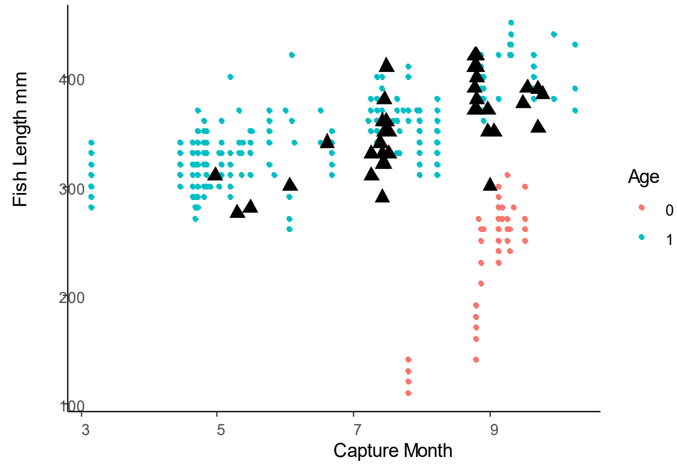

Figure 2. Juvenile sablefish length across capture month. Black triangles represent tagged fish and blue and red points represent historical size at capture data throughout the Gulf of Alaska.

Sablefish otolith ages were estimated by four trained age readers of varying experience using break and burn pattern interpretation published CARE Manual on generalized age determination procedures for groundfish (CARE 2006). Each age reader independently estimated the age and if there were disagreements between estimated ages, a final estimate was developed by all four age readers. Images of each otolith were annotated to document otolith pattern interpretation and to investigate possible improvements to criteria.

Ages estimated from tagging data were 1-19 years, and ages estimated using otoliths were 1-26 years (Fig 3., Table 1). Over 30% of reader estimates agreed with the tag age, and 90% of reader estimates were within ±3 years of the tag age. There were also no significant differences between the resolved and tag age estimates. This was based on one-sided t-tests of each tag age where the count was greater than two (Ogle 2016). Analyses of bias suggested that resolved ages tended to be marginally older and reader estimates were significantly biased older than the tagging data (McBride 2015). Even though there was error and evidence of bias, these data agree as much if not more than prior comparisons of tag data to expert sablefish age readers (published online at http://care.psmfc.org/index.php?option=com_content&task=view&id=29&Itemid=35).

To improve criteria, age readers compared annotated images with the tag data. Based on these comparisons, we found no consistent changes in criteria that would improve age estimates based on the identification of the first annulus and

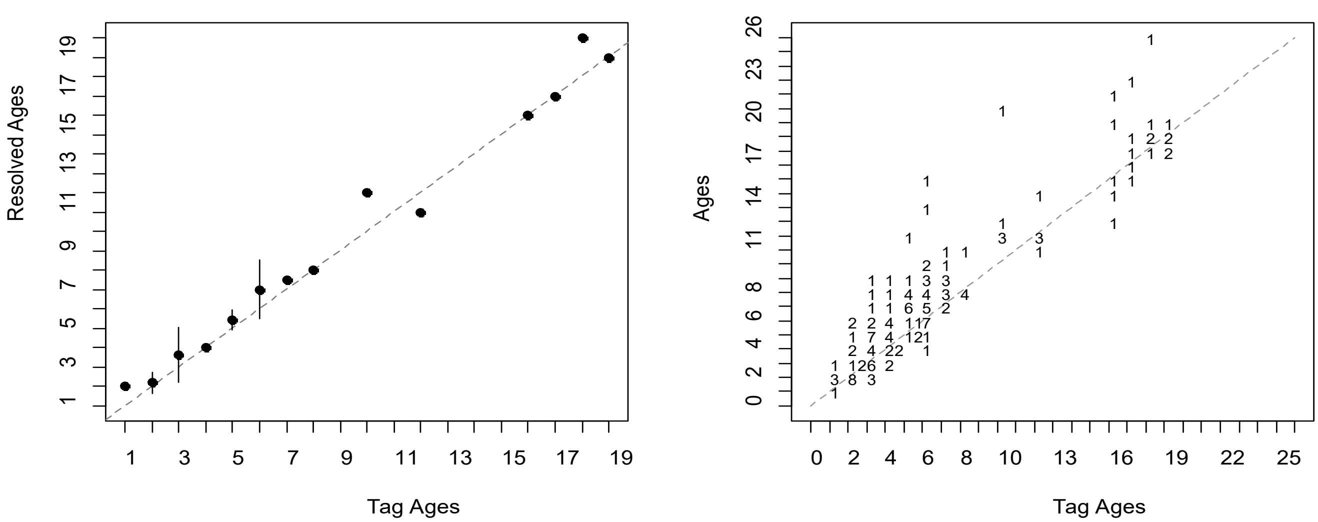

Figure 3. Sablefish age bias plots of resolved (left) and individual age estimates (right) compared with tag-recapture estimated ages. Dashed lines represent agreement between ages. For resolved ages (left), the mean age is represented by a dot and the 95% confidence intervals based on a one-way t-test is represented by vertical lines; intervals were only calculated when there were more than two comparisons. For individual age comparisons (right), the number of age comparisons are tabulated across ages.

plus growth. Sablefish are known to have checks that can be misidentified as annual marks and we believe these checks are the cause of disagreement between the tag data and otolith age estimates. The ADU will continue to work with individual age readers and member agencies of CARE to improve criteria to identify checks, but there were again, no improvements to the ADU sablefish otolith age estimation criteria that could improve the observed age bias. To address the original observation, the trend in overestimation could be causing a false 2013 year class in the State sablefish longline survey age composition (Fig. 1); however, a direct comparison of the ADU ages to ages estimated by Federal longline survey age readers needs to be made to fully address this issue. This sample of otoliths will be sent to other age estimation programs throughout the Pacific Northwest to perform similar comparisons. The result of those comparisons among agency ages will be published to the CARE website and discussed at the next biennial CARE meeting. Further work to compare Federal and State age estimates and to validate both laboratory's ages needs to be done to address whether the identified differences between the age compositions is a result of age estimation error.

References

CARE. 2006. Manual on generalized age determination procedures for groundfish. Pacific States Marine Fisheries Commission.

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Ogle, D. H. 2016. FSA: Fisheries Stock Analysis. R package version 0.8.10.

Table 1: Sablefish age data estimated from individual age readers using broken and burned otoliths (A-D), resolved ages after disagreement was identified (Resolved), and ages estimated using tag and recapture information (Tag).

Specimen	A	B	C	D	Resolved	Tag
2847	8	7	6	7	6	5
2885	5	4	5	5	5	3
2899	6	7	9	6	6	5
2900	8	9	9	9	8	7
2902	8	6	4	6	4	4
2923	8	7	4	5	4	3
2934	14	16	8	10	9	6
2993	4	6	3	4	4	4
3036	15	20	22	13	16	16
3040	26	19	18	19	20	18
3045	12	7	7	6	6	5
3081	6	3	3	3	3	2
3082	4	3	3	3	2	2
3090	18	20	18	19	19	19
3092	7	5	4	5	4	4
3101	5	3	3	4	2	2
3105	6	5	5	6	5	5
3108	3	3	2	3	2	2
3109	7	6	5	6	5	5
3113	6	5	6	5	4	3
3115	5	5	5	5	5	5
3116	8	5	8	8	5	5
3125	6	5	4	4	4	4
3130	8	7	9	10	7	6
3133	12	15	12	12	11	12
3134	6	2	2	2	2	2
3138	3	2	2	1	2	1
3165	9	4	4	5	4	4
3172	12	21	12	13	12	10
3209	6	8	8	7	6	6
3214	6	7	6	5	6	6
3221	8	11	10	7	7	7
3237	9	3	3	3	3	3
3243	3	3	2	2	2	3
3250	6	9	4	6	7	6
3283	4	4	3	4	4	4
3288	4	4	4	4	4	4
3292	11	8	8	8	8	8
3306	23	19	16	18	17	17