Regional Information Report 5J19-03

2018 Northern Southeast Inside Subdistrict Sablefish Fishery Stock Assessment and 2019 Management Plan

by

Jane Sullivan

Andrew Olson

and

Ben Williams

1/2/2020 correction: The length at 50% maturity of 61 cm on page 44 has been corrected to 62.3 cm.

August 2019

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)

Measures (fisheries)

fork length	FL
mideye-to-fork	MEF
mideye-to-tail-fork	METF
standard length	SL
total length	TL

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 5J19-03

2018 NORTHERN SOUTHEAST INSIDE SUBDISTRICT SABLEFISH FISHERY STOCK ASSESSMENT AND 2019 MANAGEMENT PLAN

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The Regional Information Report Series was established in 1987 and was redefined in 2007 to meet the Division of Commercial Fisheries regional need for publishing and archiving information such as project operational plans, area management plans, budgetary information, staff comments and opinions to Board of Fisheries proposals, interim or preliminary data and grant agency reports, special meeting or minor workshop results and other regional information not generally reported elsewhere. Reports in this series may contain raw data and preliminary results. Reports in this series receive varying degrees of regional, biometric and editorial review; information in this series may be subsequently finalized and published in a different department reporting series or in the formal literature. Please contact the author or the Division of Commercial Fisheries if in doubt of the level of review or preliminary nature of the data reported. Regional Information Reports are available through the Alaska State Library and on the Internet at: http://www.sf.adfg.ak.us/statewide/divreports/htlm/intersearch.cfm.

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ABSTRACT

This report provides an overview of the stock assessment, harvest strategy, and regulations effective for the 2019 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 2019 NSEI sablefish commercial fishery annual harvest objective is 920,093 round lb and is based on decrements from an acceptable biological catch of 1,058,037 round lb. The annual harvest objective is allocated to 78 limited entry Commercial Fisheries Entry Commission longline (C61A) permits through an equal quota share (EQS) system, resulting in a 2019 EQS of 11,796 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) using data from fishery-independent surveys (longline and pot gear), commercial fishery CPUE, and biological data (age, weight, length, and maturity) from the surveys and fishery. The NSEI Subdistrict management area consists of all waters as defined in 5 AAC 28.105(a)(2) and shown in Figure 1.

The 2019 NSEI Subdistrict commercial sablefish fishery AHO is 920,093 round lb (Table 1). There are 78 valid Commercial Fisheries Entry Commission permits for 2019, therefore the individual equal quota share (EQS) is 11,796 round lb, a 7.6% increase from the 2018 EQS of 10,967 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). NSEI sablefish abundance has been estimated with a mark–recapture project since 1997 (Carlile et al. 2002; Dressel 2009). A mark–recapture project was conducted in 2018 and provided a point estimate of abundance (Appendix A). This estimate of 2.70 million fish was used, along with biological data from the fishery and longline survey, to forecast abundance and biomass for 2019. The target fishing mortality rate was also updated using these biological data. As in previous years, an $F_{50\%}$ biological reference point was used for calculating the 2019 ABC, resulting in a fishing mortality rate of 6.32% (the fishing mortality rate in 2018 was 6.35%). The 2019 ABC (1,058,037 round lb) increased 9.6% relative to the 2018 ABC (965,354 round lb).

Large year classes of sablefish from 2013 and 2014 have been recruiting to the fishery since 2016. These year classes are expected to mature and contribute to spawning biomass in the next couple of years. ADF&G will continue to monitor survey results, biological data, and recruitment and spawning biomass trends.

A preliminary statistical catch-at-age model is presented as Appendix B to this report. Once reviewed by managers and stakeholders, it will be presented as the management model for this stock.

2018 NSEI SABLEFISH STOCK ASSESSMENT

SUMMARY OF STOCK STATUS

The following summarizes the stock status of sablefish in NSEI from the 2018 commercial fishery and surveys:

- The directed commercial catch in NSEI in 2018 was 855,598 round lb (Figure 2).

- The 2019 recommended ABC for NSEI at a fully selected fishing mortality of $F_{50\%}$ = 1,058,037 round lb (Table 2; Figure 3). This is a 92,683 lb increase (9.6%) from the 2018 ABC of 965,354 round lb.
- The population estimate from the 2018 mark–recapture study in NSEI is 2.70 million sablefish (Table 2; Figure 4). This is an increase from the forecasted 2017 mark–recapture estimate of 1.93 million for 2018. The forecast abundance for 2019 is 2.48 million (Table 2; Figure 4). Note that the forecasted abundance will always be lower than the current year's estimate of abundance under the current assessment model. More information on the 2018 mark–recapture experiment can be found in Appendix A.
- Despite a recent large increase in sablefish abundance, fish younger than 7 years are typically immature and therefore not included in setting the ABC. These young fish comprise approximately 20% of the forecasted abundance for 2019 (Figure 5). New for this year was an estimation of mortality from fishery releases. Using a discard mortality of 16%, the estimated mortality from releasing small fish is 19,142 round lb. This mortality from releases is accounted for in the calculation of the AHO.
- Female sablefish are retained at a higher rate than males in the commercial fishery. The predicted proportion of females in the commercial catch is greater than in the longline survey for all ages (Figure 6).
- CPUE in the 2018 NSEI longline survey decreased by 8.7% relative to 2017, from 0.23 to 0.21 numbers per hook (Figure 7). This reflects a 4.5% decrease from the 10-year average CPUE of 0.22 sablefish per hook. There has been no trend in survey CPUE since 1997, and it has not consistently tracked abundance estimates from mark–recapture studies (Figure 4).
- Commercial longline fishery CPUE increased by 18.8% relative to 2017, from 0.81 to 0.97 lb per hook (Figure 8). Fishery CPUE in 2018 was a 14.0% increase from the 10-year average CPUE of 0.85 lb per hook.
- The 2013 and 2014 year classes were well represented in the longline survey age composition (Figure 9). The 2014 year class was first observed in the 2016 commercial fishery age composition data as age-2 fish (Figure 10).
- The NSEI sablefish assessment was developed as a reproducible research product (de Leeuw 2001). It is hosted publicly on the web-based version control service GitHub at https://github.com/commfish/seak_sablefish. This product is considered conditionally reproducible, meaning that users must request any confidential data sourced in the code to produce the full assessment (Schwab et al. 2000). Survey and other nonconfidential data are made available, and all queries and subsequent transformations to the data are included in the analysis.

CHANGES TO THE NSEI SABLEFISH ASSESSMENT FOR 2019 RELATIVE TO 2018

Fishermen in state waters can release small, unmarketable fish if they are healthy (i.e., not dead, sand flea bitten, etc.) per 5 AAC 28.170(f). Due to the high volume of small fish encountered in the 2017 and 2018 fisheries, discard mortality was incorporated directly into the 2018 population dynamics model (2018 Memorandum[1]). These methods were refined in 2019 using equations commonly used in size-structured models for king and Tanner crab stocks in Alaska (e.g., Zheng and Siddeek 2018).

Since data on fishery releases is limited, the probability of a fish being retained was informed by processor grade definitions and prices and modeled as a function of weight (lb), sex, and age (Figure 11). 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 (Figure 11). Retention probabilities were interpolated between these fixed values. By accounting for fishery releases in this manner, fishing mortality is shifted toward older ages, especially for males as they are slower growing than females (Figure 12). Stachura et al. (2012) estimated discard mortality of sablefish to be 11.7% using release–recapture data from a longline survey in Southeast Alaska. However, it is likely that discard mortality in a fishery is higher due to careful fish handling on survey vessels during tagging experiments. We therefore used 16%, the discard mortality rate from the Pacific halibut fishery (Gilroy and Stewart 2013). The halibut fishery is assumed a good 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.

In 2018, the estimate of exploited abundance used to determine the ABC was adjusted to account for uncertainty in recent recruitment events. Estimates of a single recruitment event can decrease significantly as the year class is observed over multiple years of age compositions, and the 2014 year class is now estimated to be 30% less than it was last year (Hanselman et al. 2017; Hanselman et al. 2018). In 2018, an adjustment was made by using the 15th percentile from the posterior distribution of the mark–recapture abundance estimate instead of the mean as the input to the forecast model (2018 Memorandum[2]). This adjustment was a subjective, precautionary measure aimed at stabilizing the fishery by slowing the rate of increase in harvest and reducing the risk of overfishing if the 2013 and 2014 year classes are estimated to be smaller as subsequent years of data are added (i.e., negative retrospective bias). We do not recommend using the 15th percentile method again in 2019. Instead, we recommend that conservation measures are made through the management framework by accounting for the releases of fish in the fishery. Mortality from releasing fish is estimated to be 19,142 round lb in the 2019 fishery, and we recommend this be deducted from the ABC in the calculation of the AHO (Tables 2 and 3). In addition, we recommend continued work on an integrated age-structured model, so that methods for incorporating uncertainty into the estimation of management reference points can be improved in future assessments.

In 2018 and in past assessments, fishery weight-at-age was used to calculate exploited biomass and the ABC. In 2019, longline survey weight-at-age predicted from a weight-based von Bertalanffy growth model was used for all calculations. Longline survey weight-at-age provides a more accurate portrayal of size-at-age of the exploitable population, because it includes smaller fish that would be released in the fishery (Figure 13). Because the fishery opens directly following

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[1] J. Sullivan, B. Williams, and A. Olson. 2018 NSEI sablefish assessment. State of Alaska, Department of Fish and Game, Division of Commercial Fisheries Memorandum. June 20, 2018. https://github.com/commfish/seak_sablefish/blob/master/text/2018_NSEI_sablefish_forecast_FINAL.pdf (Accessed August 2019).

[2] Ibid.

the end of the longline survey, it is unlikely a seasonal effect could account for the differences in fishery and survey weight-at-age.

In past assessments the plus group (age 42+) weight-at-age was calculated as the empirical mean weight from all samples aged 42 and older. Because this estimate was influenced by outliers, we now use the predicted value for age-42 fish from a weight-based von Bertalanffy growth model to estimate weight-at-age for fish older than age 42. Weight-at-age and maturity estimates used in the yield-per-recruit model, estimate of biomass, and ABC calculations are presented in Figure 13.

ABUNDANCE ESTIMATION AND DETERMINING THE ACCEPTABLE BIOLOGICAL CATCH

The 2018 marking survey released 9,678 tagged fish. A suite of modified Petersen mark–recapture models was developed to account 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. Candidate models that accounted for movement in and out of NSEI and incorporated fishery CPUE were explored. Detailed information on mark–recapture modeling, including model development methods and model selection results, are outlined in Appendix A. The model selected for this assessment allowed capture probability to vary over time and resulted in a 2018 abundance estimate of 2.70 million fish (Table 2). Retrospective analysis shows the current model's abundance estimates follow a similar trend and general magnitude as past model estimates (Figure 4).

The 2018 mark–recapture abundance estimate (N_{2018} in the equation below) was partitioned into sex-specific age classes using the 2018 commercial fishery age compositions and projected into 2019 (Figure 5):

$$N_{2019,s,a} = \begin{cases} \frac{N_{2018,s,a-1} p_{s,a-1} \phi_s}{S_{a-1,s}} \exp(-Z_{2018,s,a-1}) & a_0 < a < a_+ \\ \frac{N_{2018,s,a-1} p_{s,a-1} \phi_s}{S_{a-1,s}} \exp(-Z_{2018,s,a-1}) + \frac{N_{2018,s,a} p_{s,a} \phi_k}{S_{s,a}} \exp(-Z_{2018,s,a}) & a = a_+ \end{cases} \qquad (1)$$

where $p_{s,a}$ is the fishery proportion at age a by sex s in 2018 (Figure 10), ϕ_s is the sex ratio in the fishery in 2018 (Figure 6), and $S_{s,a}$ is the sex-specific fishery selectivity-at-age (Hanselman et al. 2018). Total instantaneous mortality-at-age $Z_{s,a}$ is the sum of fishing mortality $F_{s,a}$ and natural mortality M, which is assumed to be 0.10 (Johnson and Quinn 1988).

This produced an estimated forecast of exploited abundance of 2.48 million fish for 2019 (Table 2). Multiplying by longline survey weight-at-age produced an exploited biomass forecast of 20,131,204 round lb (Table 2). Mean weight-at-age was predicted from a weight-based von Bertalanffy growth model fit to survey weight and age data from 1997 to 2018 (Figure 13).

The fishing mortality used to calculate the ABC (F_{ABC}) was obtained from a yield-per-recruit analysis and fixed to $F_{ABC} = F_{50\%}$, where $F_{50\%}$ corresponds to the F that would reduce the spawning biomass to 50% of the unfished levels. Biological inputs to the yield-per-recruit model included longline survey weight-at-age and maturity-at-age from the longline survey (Figure 13).

Fishing mortality is modeled as a function of fishery selectivity $S_{s,a}$, retention probability $R_{s,a}$ (the age-specific probability of being landed given being caught), and discard mortality Ω:

$$F_{s,a} = S_{s,a}(R_{s,a} + \Omega(1 - R_{s,a}))F. \qquad (2)$$

Discard mortality Ω is assumed to be 0.16, the discard mortality rate 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. Retention probability by sex and age $R_{s,a}$ is informed by processor grade and price and defined as a function of weight (Figure 11), which is converted to age and sex using survey weight-at-age (Figure 13). This method of accounting for fishery releases shifts fishing mortality toward older ages, especially for males that are slower growing than females (Figure 12).

Using longline survey weight-at-age by sex $w_{s,a}$ from a weight-based von Bertalanffy growth model, a modified Baranov catch equation is used to calculate the ABC in 2019:

$$ABC_{2019} = \sum_{s=1}^{2}\sum_{a=2}^{a+} w_{s,a}\left(N_{2019,s,a}\right)\frac{R_{s,a}S_{s,a}F}{Z_{s,a}}\left(1 - \exp\left(-Z_{s,a}\right)\right). \qquad (3)$$

The biomass of released sablefish estimated to die with an assumed discard mortality of 0.16 D_{2019} is

$$D_{2019} = \sum_{s=1}^{2}\sum_{a=2}^{a+} w_{s,a}\left(N_{2019,s,a}\right)\frac{\Omega S_{s,a}\left(1 - R_{s,a}\right)F}{Z_{s,a}}\left(1 - \exp\left(-Z_{s,a}\right)\right). \qquad (4)$$

The 2019 ABC is estimated to be 1,058,037 round lb, and the released portion of the catch assumed to die is 19,142 round lb (Tables 2 and 3). Figure 2 shows the 2019 ABC in the context of ABCs recommended since 2005.

Unlike last year, the resultant changes in ABC from 2018 to 2019 are different between NOAA and ADF&G. Although the federal stock assessment for sablefish reported an increase in the survey index and had projected an increase in biomass in 2018, they saw a decrease in estimated spawning biomass and recommended that the ABC stay constant from 2018 to 2019. The recommended federal ABC for the 2019 commercial longline sablefish fishery is 33.22 million lb, a 0.7% increase from the 2018 ABC of 32.97 million lb after whale depredation was accounted for (Hanselman et al. 2018). This reflects a 45% reduction from the maximum permissible ABC (Hanselman et al. 2018). A 9.6% increase in the ABC is recommended for the ADF&G NSEI sablefish stock assessment. It is important to remember that the F_{ABC} in Table 2 is not directly comparable to the federal harvest policy of $F_{40\%}$, because the methods used to assess abundance and determine F values are different.

RECOMMENDATIONS FOR FUTURE STOCK ASSESSMENTS

It is a priority for continuing development and implementation of an integrated statistical catch-at-age stock assessment model for NSEI sablefish. Preliminary results for this model are outlined in Appendix B. The NSEI sablefish mark–recapture study is integral to understanding the population dynamics of sablefish in Chatham Strait and providing sound management advice. Consequently, we recommend the continuation of the annual tagging survey.

2019 SABLEFISH MANAGEMENT PLAN

ANNUAL HARVEST OBJECTIVE DETERMINATION

The 2019 AHO was determined by making the following decrements from the recommended ABC (1,058,037 lb):

- 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,
- mortality from fishery releases, and
- subsistence and personal use harvest.

Bycatch Mortality in the Halibut Fishery

Sablefish caught in NSEI during the Pacific halibut individual fishing quota (IFQ) 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 2019, 5 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 5 estimated 2019 EQS permits (Tables 3 and 4). The total number of permits allowed to harvest their EQS during the survey was limited to 5 due to the inability of the survey to provide adequate EQS in excess of 5 permits in previous years (2017 and 2018).

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% (2016–2018), to the NSEI sablefish commercial AHO.

Mortality from Fishery Releases

In 2019, a 16% fishery discard mortality used in the Pacific halibut fishery (Gilroy and Stewart 2013) was applied to the sablefish-directed fishery to account for mortality of released fish. Permit holders are allowed to release uninjured sablefish per 5 AAC 28.170 (f).

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 604 permits were issued in 2018. 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 2018 longline survey average weight (6.3 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 record release reason (e.g., fish are small) and whether their personal quota share (PQS) has been met.

Tagged Sablefish

Fishermen are requested to watch for tagged sablefish. Please 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 PQS 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 2019 fishing season, 5% of the annual EQS is 590 round lb.

Bycatch allowances for other species

Full retention and reporting of rockfish *Sebastes*, excluding thornyheads, is required for internal waters (5 AAC 28.171). The allowable bycatch that may be legally landed on an NSEI sablefish permit based on round weight of both target and bycatch species is summarized in Table 5. All demersal shelf rockfish in excess of 10% of the round weight of all target species on board the vessel are weighed and reported as bycatch overage on a 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 PQS 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.adfg.alaska.gov/index.cfm?adfg=commercialbyareasoutheast.groundfish.

ACKNOWLEDGMENTS

We are grateful to the crew of the R/V *Medeia* for their work on the 2018 mark–tag survey and the crews of the F/V *Masonic*, F/V *Kaia*, and F/V *Magia* for participating in the 2018 NSEI longline survey. Thanks to Kellii Wood for contributing the management area map. Thank you to Lowell Fair and Sarah Power for reviewing and providing valuable feedback on earlier versions of this report. Finally, thank you to the scientific staff who participated in port sampling, surveys, and in ageing sablefish at the ADF&G Age Determination Unit.

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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, 1985–2018. The Equal Quota Share program was implemented in 1994.

Year	Annual Harvest Objective	Equal Quota Share	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	–	–	78	93

Table 2.–Estimated and forecasted abundance, biomass, target fishing mortality F, mortality from released sablefish in the directed fishery, and the recommended ABC for 2018 and 2019. For abundance, biomass, and ABC, the 2018 value from last year (forecasted from the 2017 tagging survey) is compared to the updated 2018 estimates.

Quantity	2018	2019	Percent change (%)
Exploited abundance (2018 value forecasted last year)	1,931,191	2,484,601	28.7
Exploited abundance (2018 value updated this year)	2,702,393	2,484,601	–8.1
Exploited biomass (round lb, 2018 value from last year)	16,454,232	20,131,204	22.3
Exploited biomass (round lb, 2018 value updated this year)	18,991,517	20,131,204	6.0
$F_{ABC} = F_{50\%}$	0.0635	0.0632	–0.4
Mortality from releases (round lb)		19,142[a]	
Recommended ABC (round lb)	965,354	1,058,037[b]	9.6

[a] Mortality from releases estimated by stock assessment model and accounted for in the decrements process (Table 3).

[b] See Equation (3) for the ABC calculation.

Table 3.–Decrement types and amounts, 2014–2019. Estimated catch is in round lb of sablefish.

Key: ADF&G = Alaska Department of Fish and Game, EQS = equal quota share, AHO = annual harvest objective.

Year	2014	2015	2016	2017	2018	2019
Acceptable Biological Catch (ABC)	952,538	986,481	807,559	850,113	965,354	1,058,037
Decrement Type (lb)			Estimated Mortality			
Bycatch mortality in halibut fishery	47,514	38,963	27,915	26,136	19,583	18,434
ADF&G longline survey removal decrement (excluding catch retained by permit holders for their EQS)	80,814	74,689	53,914	29,290	15,875	26,260
Guided sport fish harvest	35,944	51,910	44,509	43,656	41,179	33,135
Unguided sport fish harvest	7,076	5,212	7,015	3,911	5,872	11,340
Mortality from fishery deadloss	5,081	9,218	6,719	4,250	5,699	8,046
Mortality from fishery releases	–	–	–	–	–	19,142
Subsistence and personal use harvest	30,335	19,741	16,734	22,621	21,730	21,587
Total Decrements	206,764	199,733	156,805	129,863	109,938	137,944
AHO	745,774	786,748	650,754	720,250	855,416	920,093
Permit Holders	78	78	78	78	78	78
EQS	9,561	10,087	8,343	9,234	10,967	11,796

Table 4.–Sablefish harvest (round lb) from the NSEI longline survey, 1988–2018. Survey removal decrement (survey harvest minus the combined harvest allocated to the EQSs 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 the 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	–	26,260	5

Table 5.–Allowable bycatch that may be legally landed on an NSEI sablefish permit based on round weight of both target and bycatch species.

Species	Allowable Bycatch Amount
Demersal Shelf Rockfish	1%
Shortraker and Rougheye rockfish	7% in aggregate
Other rockfish & thornyheads	15% in aggregate
Lingcod	0%
Pacific cod	20%
Spiny dogfish	35%
Other groundfish	20% in aggregate

FIGURES

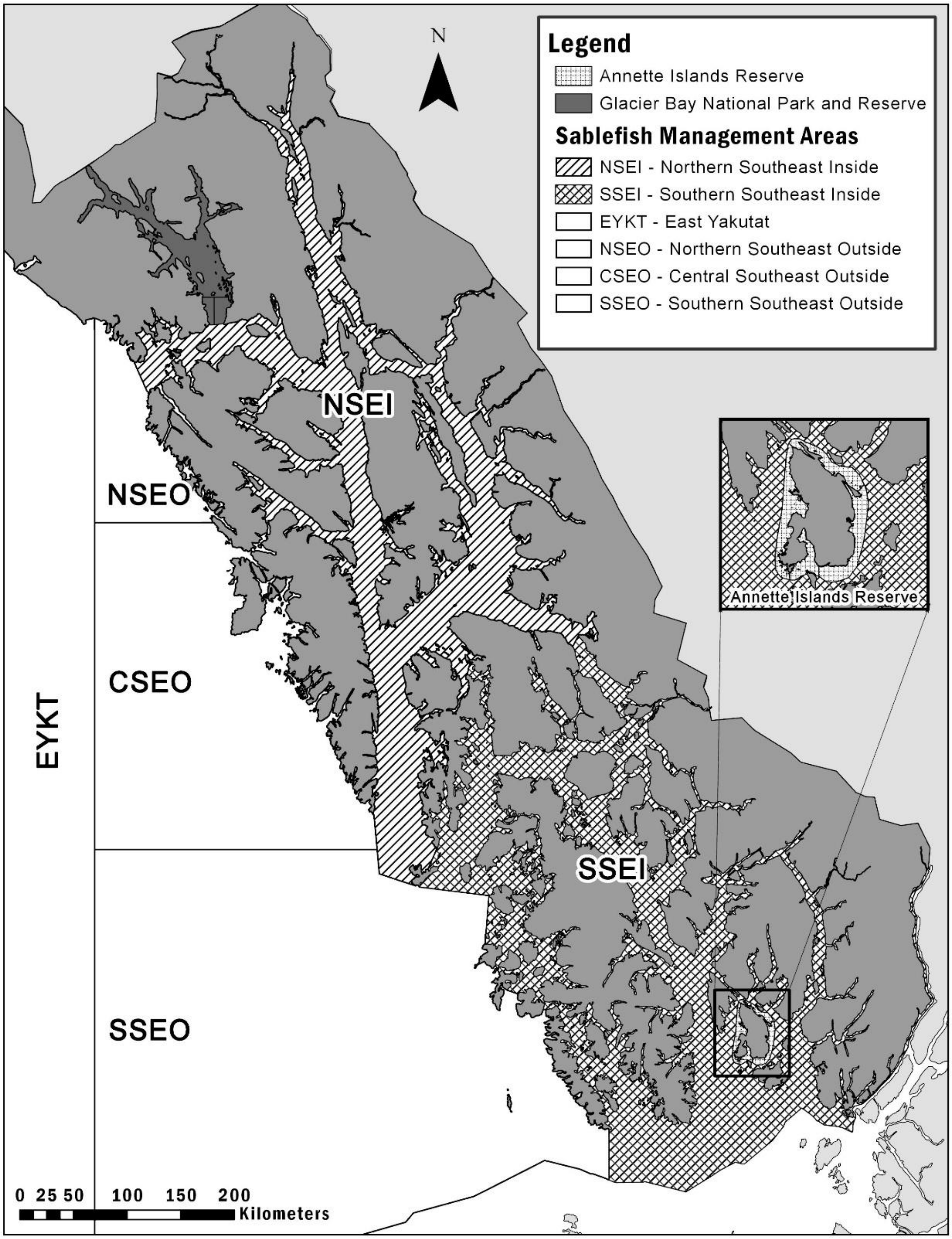

Figure 1.–NSEI and SSEI Subdistricts including restricted waters of Glacier Bay National Park and Preserve and Annette Islands Reserve.

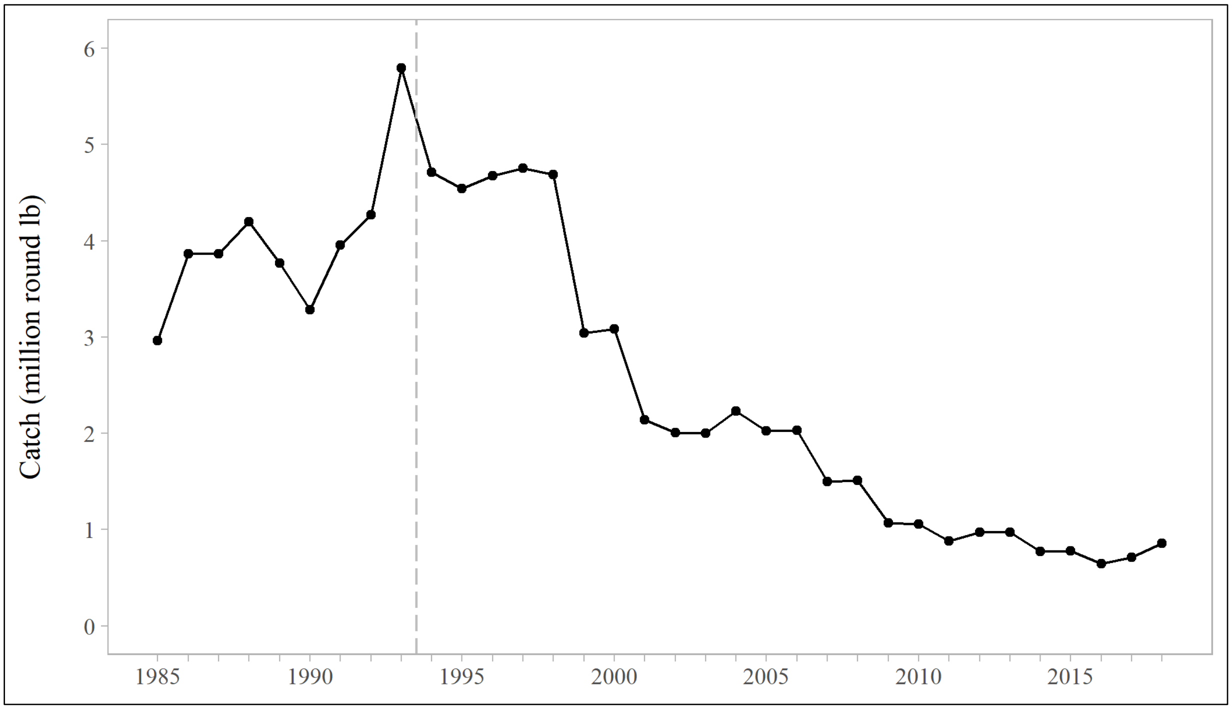

Figure 2.–Directed commercial catch in millions of round lb in NSEI, 1985–2018. The vertical dashed line marks the transition of the fishery from limited entry to equal quota share in 1994.
Source: ADF&G fish ticket database.

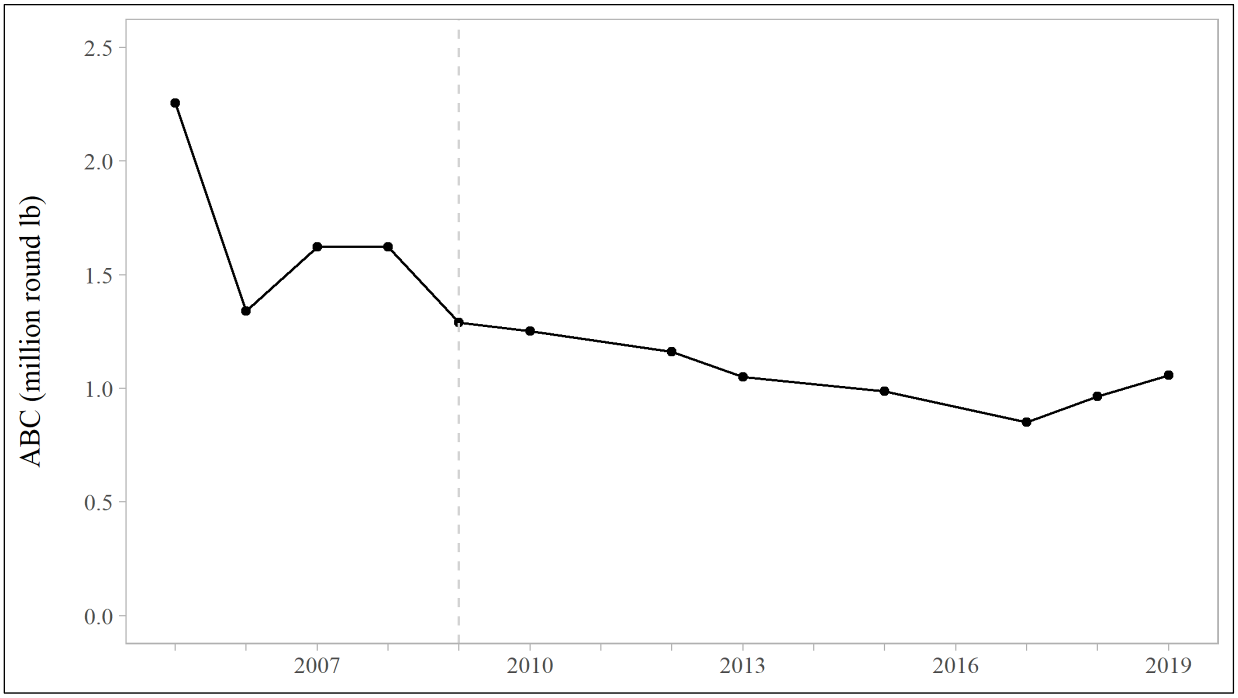

Figure 3.–ABC in millions of round lb recommended by ADF&G, 2005–2019. The grey dashed vertical line marks a change in harvest policy from $F_{40\%}$ before 2009, to $F_{45\%}$ in 2009, and $F_{50\%}$ after 2009.

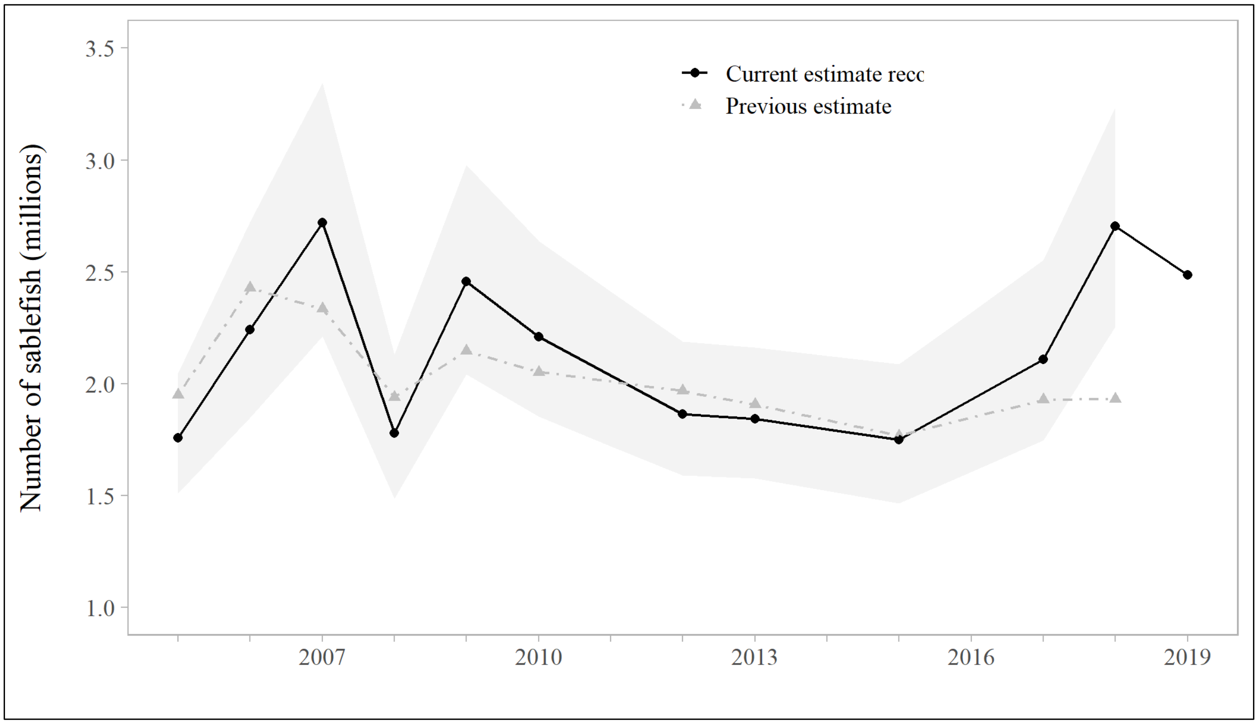

Figure 4.–Abundance estimates from the current mark–recapture model (black points) and previous model estimates of abundance that were used for management in a given year (grey triangles), 2005–2018. Shaded areas are 95% credible intervals from the current estimates' posterior distributions. The grey triangle in 2018 is the forecasted abundance from 2017.

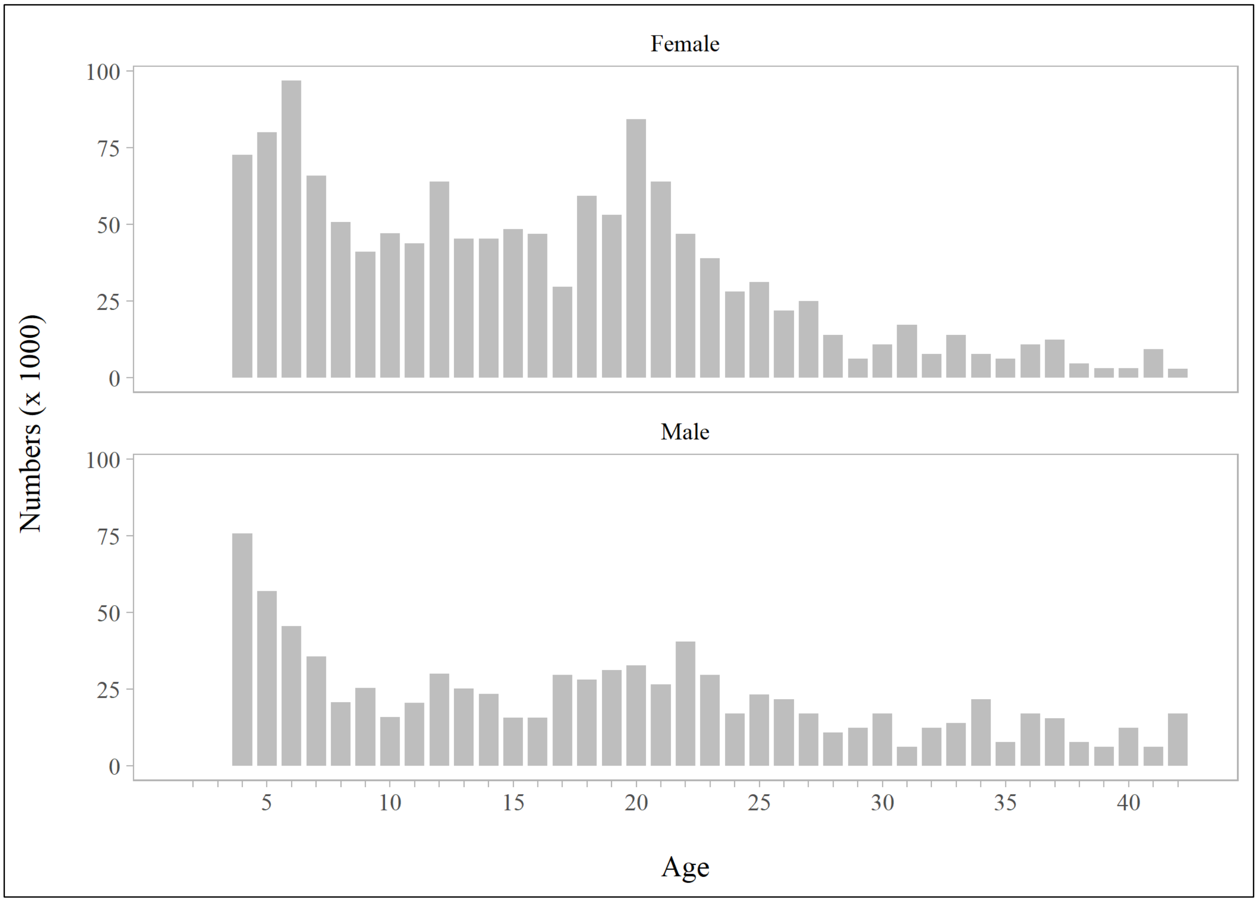

Figure 5.–Forecasted sablefish numbers-at-age by sex for 2019 using the authors-recommended abundance estimate.

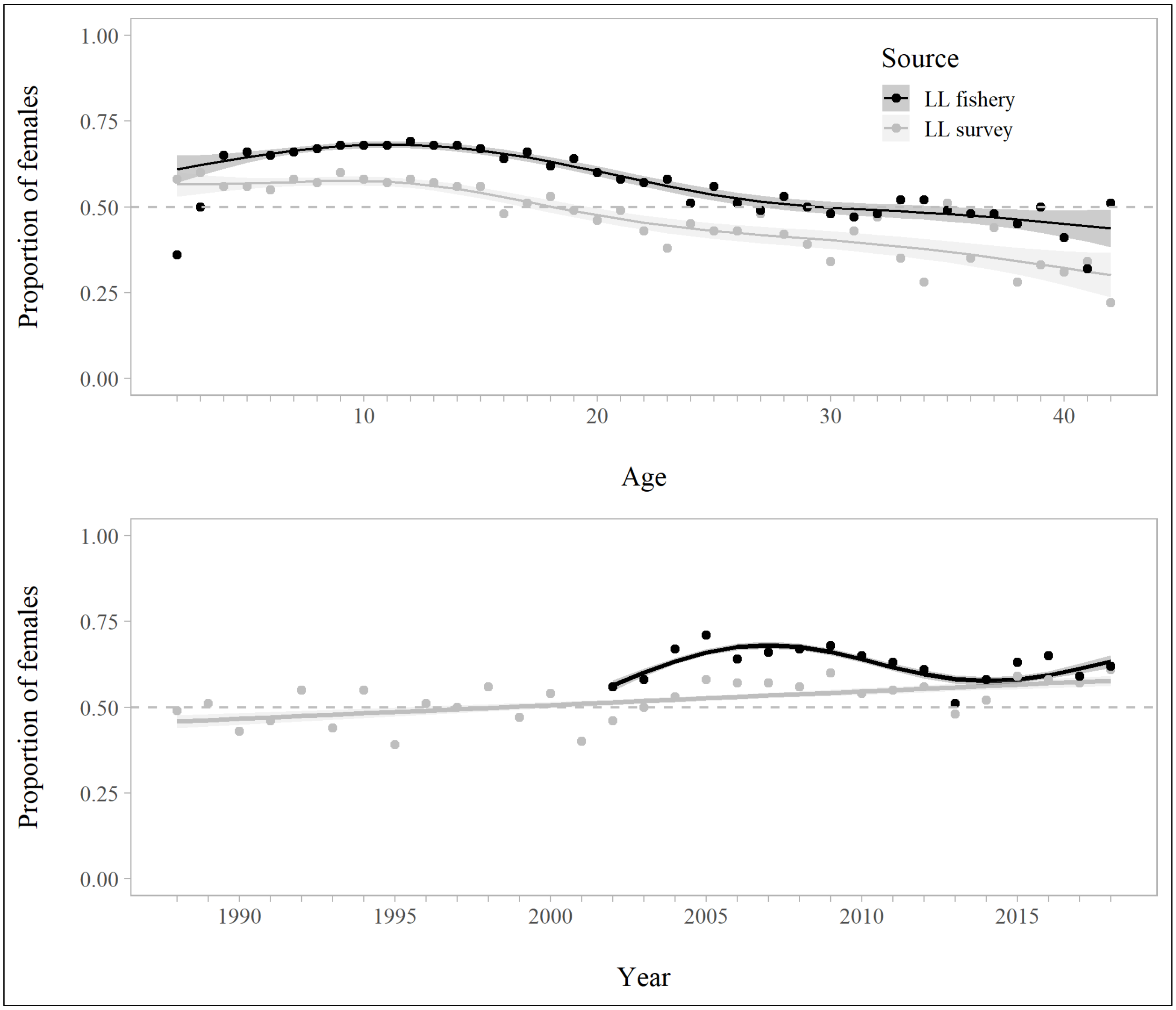

Figure 6.–Proportion of females-at-age in the commercial longline fishery (black), 2002–2018, and longline survey (grey), 1988–2018 (top panel). Proportion of females by year (all ages combined) in the fishery (black) and survey (grey) are presented for the same years (bottom panel). Shaded areas and smoothed curves are the predicted values and standard errors from a generalized additive model.

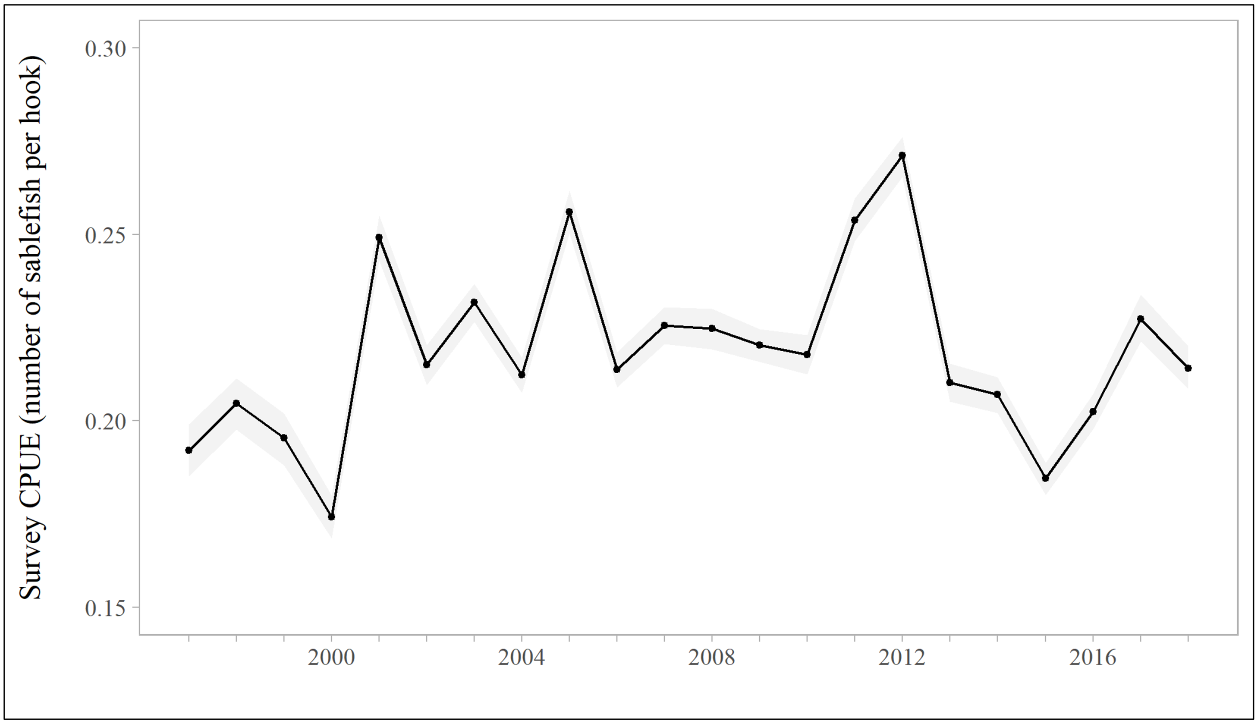

Figure 7.–Longline survey CPUE in sablefish per hook, 1997–2018. Grey shaded areas are bootstrap 95% confidence intervals.

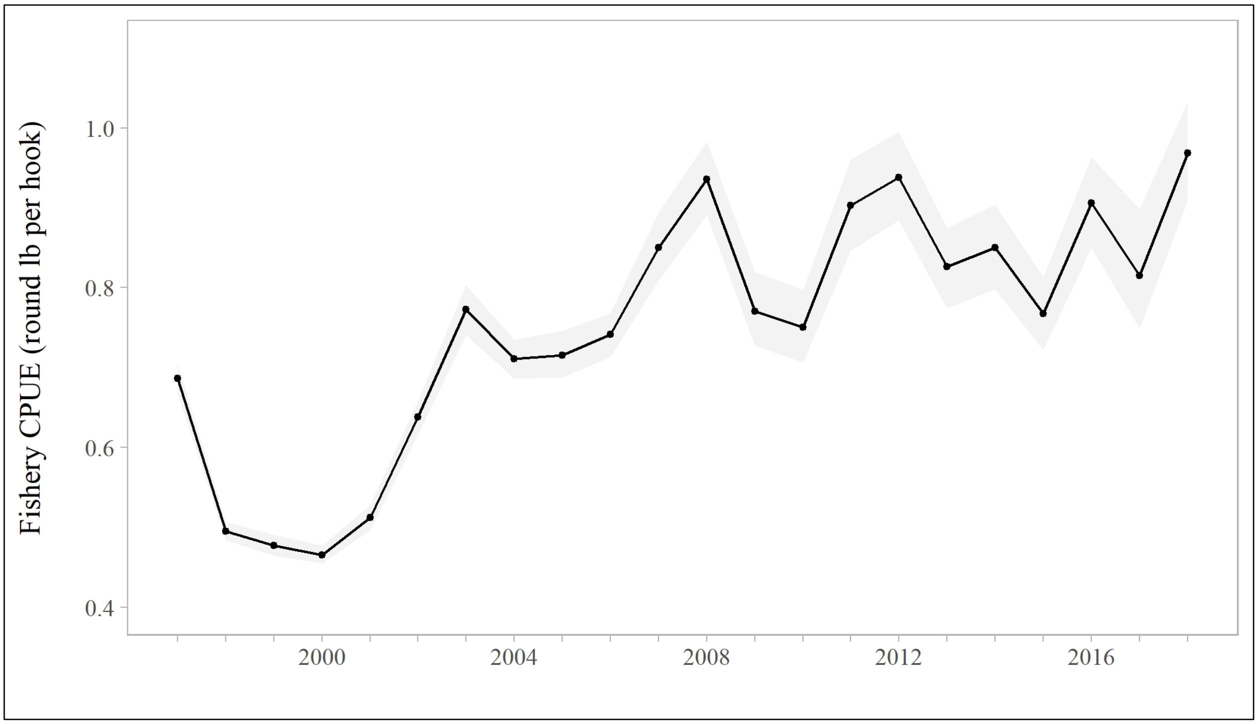

Figure 8.–Commercial longline fishery CPUE in round lb per hook, 1997–2018. Grey shaded areas are bootstrap 95% confidence intervals.

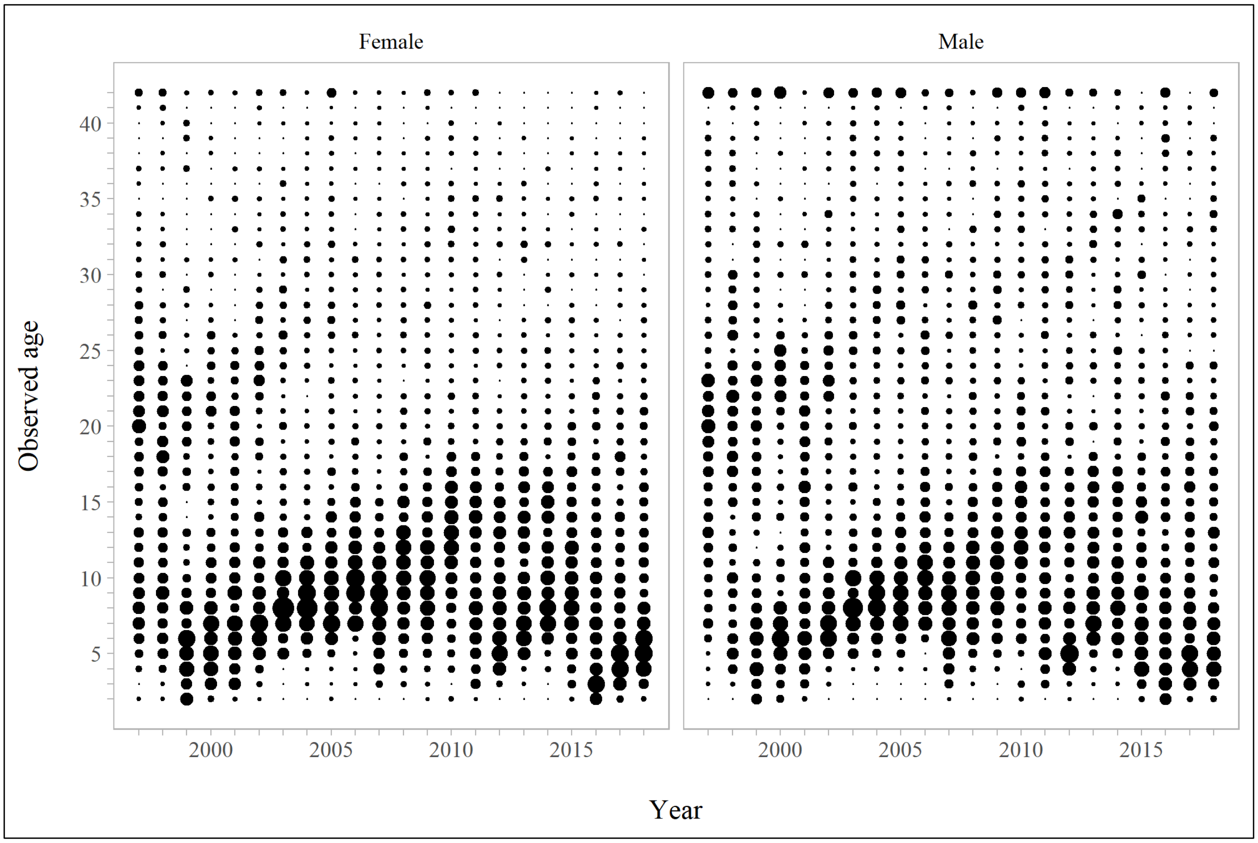

Figure 9.–Proportions-at-age for males and females in the ADF&G longline survey, 1997–2018. The size of the circle is relative to the proportion-at-age in a given year.

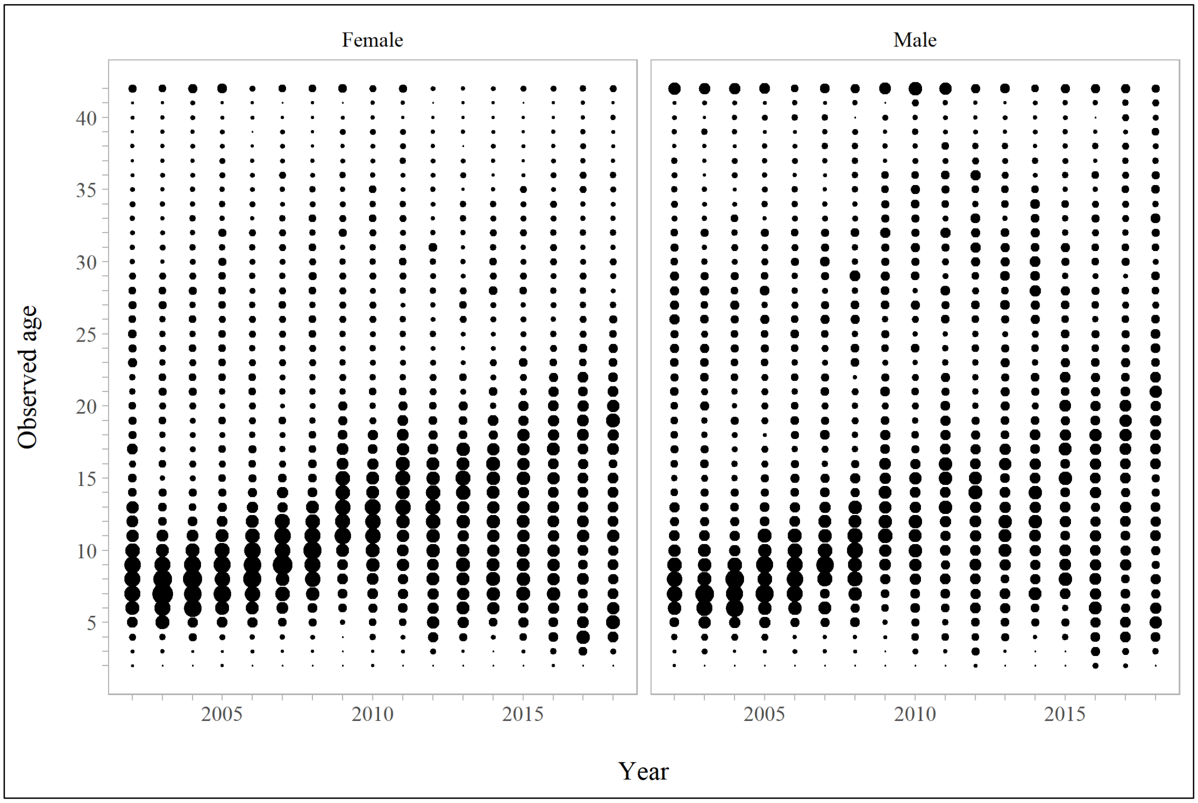

Figure 10.–Proportions-at-age for males and females in the longline fishery, 2002–2018. The size of the circle is relative to the proportion-at-age in a given year.

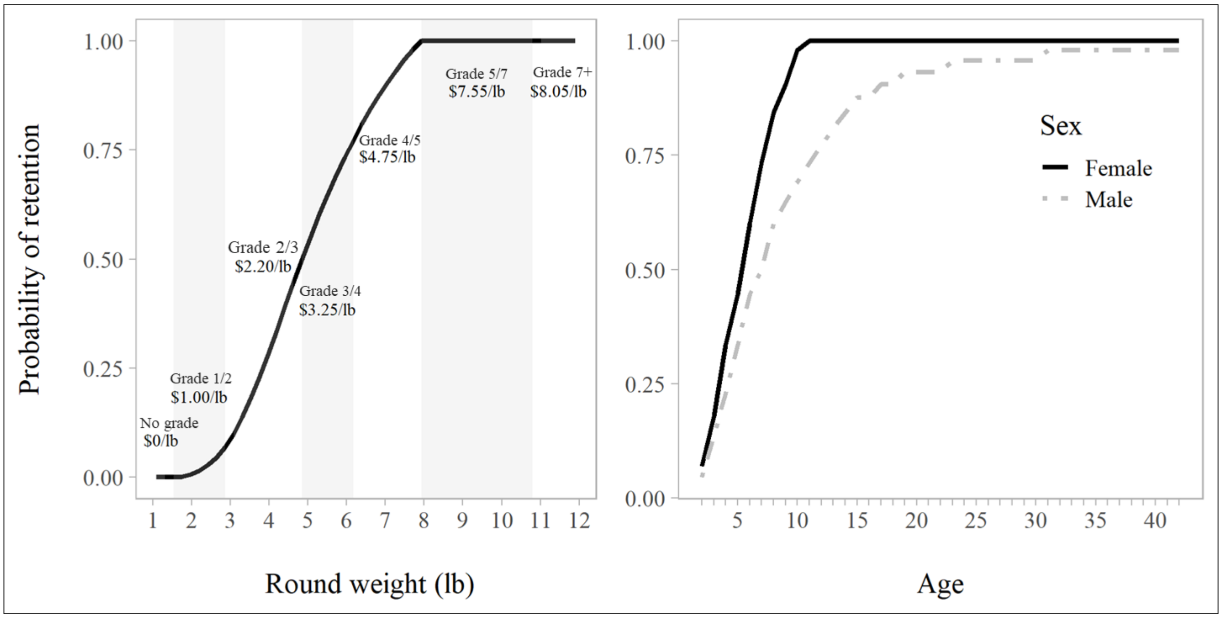

Figure 11.–The probability of retaining a fish as a function of weight in round lb (left panel), sex, and age (right panel). Shaded regions correspond to processor grade in dressed lb and price.

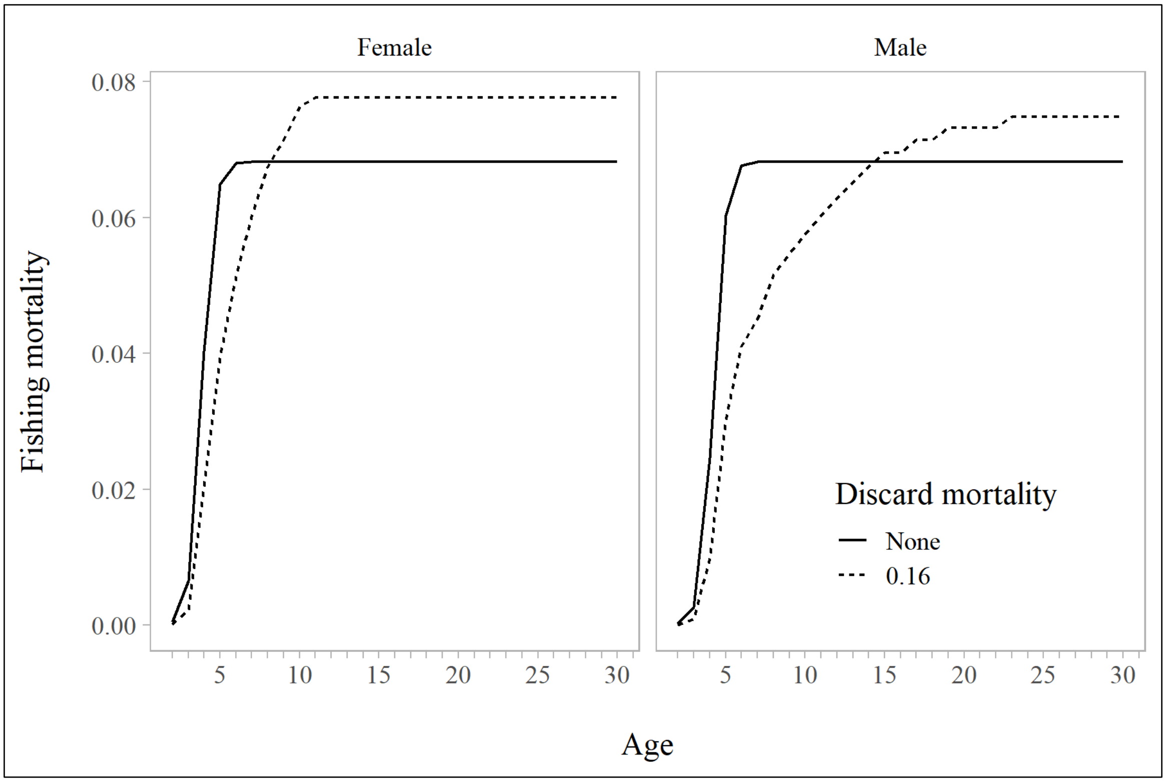

Figure 12.–A comparison of equivalent fishing mortality rates by age and sex when discard mortality is assumed to be 0 (solid line) and when it assumed to be 0.16 (dashed line).

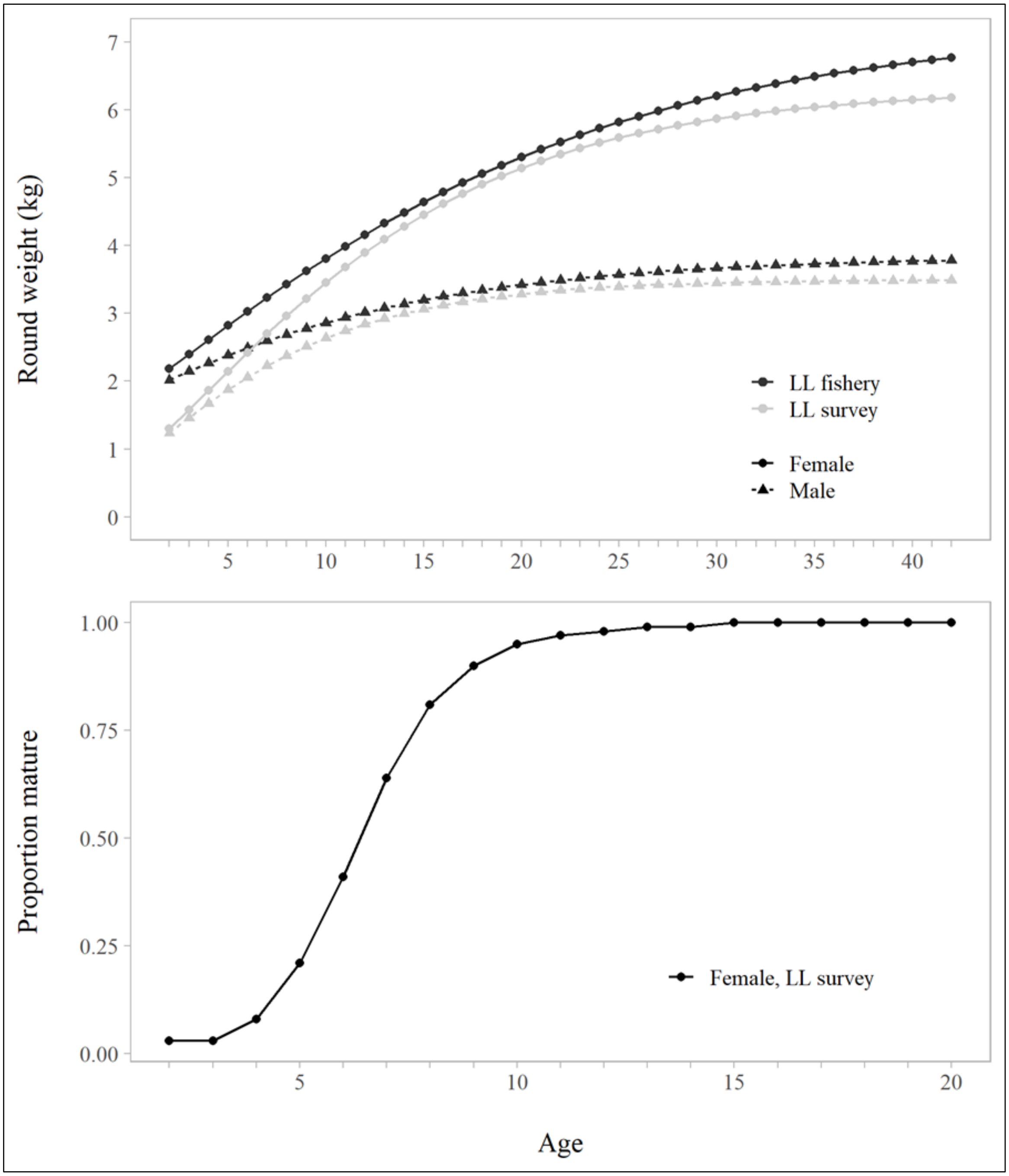

Figure 13.–Sex-specific weight-at-age (kg) from the longline fishery and survey (top panel), and proportion mature-at-age for females estimated from the longline survey (bottom panel). These values are used as inputs to the yield-per-recruit model and ABC calculation.

APPENDIX A. MARK–RECAPTURE ANALYSIS

BACKGROUND

The mark–recapture study forms the foundation for current sablefish management in NSEI. The most commonly used method for abundance estimation and the model that was used for many years by ADF&G is the Chapman estimator:

$$N = \frac{(K_0 + 1)(n + 1)}{k + 1} - 1,$$

where N is the estimated population abundance, K_0 is the total number of fish tagged in the population, n is the number of fish checked for marks at the time of recapture, and k is the number of marked fish out of n. The variance of the abundance estimate is calculated as

$$\text{var}(N) = \frac{(K_0 + 1)(n + 1)(K_0 - k)(n - k)}{(k + 1)^2(k + 2)}.$$

A description of all model variables is found in Table A1, and a summary of the mark–recapture data since 2005 is found in Table A2. ADF&G did not conduct a tagging survey in 2011, 2014, or 2016 due to budget restrictions. In the equations above, n and k represent the combined observed samples and marks in the fishery and survey, and tags captured in other fisheries or outside Chatham before or during the survey (D_0 and D_{srv}) are deducted from K_0 prior to estimation (Table A2).

MODEL ASSUMPTIONS

There are 4 primary assumptions integral to the Chapman estimator that have been discussed in detail in previous iterations of this stock assessment (Dressel 2009; Mueter 2010; 2017 Memorandum[1]). Briefly, these assumptions include a closed population (no movement in or out of the study area), equal probability of recapture, sufficient time between marking and recapture to allow for marked fish to be randomly distributed throughout the unmarked population, and no tag loss or errors. Violations to these assumptions can be mitigated through study design, treatment of data, and changes to model structure. A combination of approaches was utilized to meet or relax these assumptions:

1. Potential differences in the size selectivity between the pot survey and longline survey and fishery were accounted for by (1) estimating growth between May and August using known length recaptured fish, (2) comparing the cumulative length distributions between tagged and recaptured fish, and (3) adjusting sample sizes accordingly. Despite the differences in selectivity between pot and longline gear, since 2005 minimal differences in the cumulative length distributions between marked and recaptured fish were found—suggesting that in most years the size distribution tagged in the pot survey well represents the fishery (Figure A1). The 2018 survey was a notable exception; the size distribution of the

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[1] B. Williams and K. Van Kirk. 2017 NSEI Sablefish Assessment. State of Alaska, Department of Fish and Game, Division of Commercial Fisheries Memorandum. March 16, 2017. https://github.com/commfish/seak_sablefish/blob/master/text/2017_NSEI_sablefish_stock_assessment_FINAL.pdf

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ecaptured fish was much larger than that of the released (Figure A1). A record number of fish were tagged in 2018, and catch rates were so high that the number of pots fished in a set was reduced from 40 to 20. Since a large number of small fish were tagged and none of the tags were recovered in the fishery, 518 tags were removed prior to analysis (the difference between K and K_0 in Table A2).

2. To assess the assumption that there is sufficient time between marking and recapture to allow for tagged fish to be randomly distributed, movement in the population between statistical areas was explored graphically. Results suggest that the population is sufficiently mixed across study years (Figure A2). These findings are consistent with Mueter (2010) and lend support to the current study design of the mark–recapture project.
3. A suite of alternative models that are stratified by time were developed in order to account for natural and fishing mortality, potential changes in the probability of recapture, and tag loss from other fisheries or outside the NSEI. This allows for greater precision in the estimates of abundance, as each time period compensates for changes in K, n, and k.
4. To account for potential violations of the closed population assumption, 2 of the alternative models estimate an additional parameter for migration (Models 2 and 4, Table A3).
5. To further address a potential change in capture probability through time, 2 of the alternative models incorporate fishery CPUE data to account for seasonal changes in catch rates or fish abundance (Models 3 and 4, Table A3).

MODEL DEVELOPMENT

The mark–recapture models used in this analysis are based on analyses by Mueter (2010). Population estimates from a simple Chapman estimator (Model 0) are compared with estimates from several extensions of a stratified Petersen estimator that account for changes in capture probability through time, natural and fishing mortality, migration, and seasonal trends in catch rates. These alternative model structures (Models 1–4) are implemented in the Bayesian open source software JAGS 4.3.0 (Depaoli et al. 2016). The Bayesian approach is preferred, because it allows the incorporation of prior information and additional parameter uncertainty into the model. Previous methods used arbitrary break points (e.g., 5 or 10 days) to define temporal strata throughout the fishing season (Mueter 2010; 2016 Memorandum[2]). Here cumulative catch over time is used to define temporal strata. A combination of convergence criteria, deviance information criterion (DIC; Spiegelhalter et al. 2002), and an examination of seasonal trends in abundance was used in model selection.

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[2] K. Van Kirk. 2016 NSEI Sablefish Assessment. State of Alaska, Department of Fish and Game, Division of Commercial Fisheries Memorandum. June 6, 2016. https://github.com/commfish/seak_sablefish/blob/master/text/2016_NSEI_sablefish_stock_assessment_FINAL.pdf

MODEL 1: TIME-STRATIFIED PETERSEN ESTIMATOR

The abundance of sablefish in Chatham Strait in a given time period N_i was assumed to follow a normal distribution with an uninformed prior (precision = 1×10^{-12}) centered on past assessments' forecast of abundance.

For any given time period i (see Table A1 for variable definitions),

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

and

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

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

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

The final estimate and credible interval reported for N is the mean N across all time periods.

MODEL 2: ACCOUNTING FOR MOVEMENT

Following Mueter (2010), the time-stratified Petersen estimator was extended by estimating a parameter for net migration r. If r is positive, it indicates that there was net positive movement of sablefish into Chatham Strait during the fishery. Conversely, a negative r would suggest net movement out of Chatham during the fishery. Following Mueter (2010), r was assigned a vague normal prior distribution, centered at +5,000 fish (precision = 1×10^{-12}). This parameter is incorporated into the model with the addition of r into the abundance equation from Model 1:

$$N_i = (N_{i-1} - C_{i-1}) * \exp(-M * t_i) + r * t_i.$$

MODELS 3 AND 4: INCLUDING FISHERY CPUE DATA

As an extension to the above models and to account for seasonal trends in abundance and fishing effort, fishery CPUE data was included in the model. An examination of fishery CPUE annually since 2005 (omitted for brevity), shows slight increasing or decreasing linear trends in fishery CPUE over the fishing season. This suggests a change in fish abundance or density throughout the fishing season and that the direction of this change is variable between years. Fishery CPUE in a given time period, defined as number of sablefish per 1,000 hooks, was back-calculated using mean fish weight in the fishery and weight of the landing from fish tickets.

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Versions of Models 1 and 2 were adapted to include fishery CPUE data (Appendix A3, Models 3 and 4) following the methods in Mueter (2010). Fishery CPUE was assumed proportional to total sablefish abundance in each time period

$$CPUE_i = q * N_i,$$

where catchability q is the constant of proportionality. These models were fit to the mark–recapture and fishery CPUE data by maximizing the combined likelihood—a binomial likelihood component for the mark–recapture data and a normal likelihood for the fishery CPUE data. Both likelihood components received equal weights in the combined likelihood, thus fishery CPUE and mark–recapture data contribute equally to the parameter estimation.

RESULTS AND MODEL SELECTION

A total of 32 models (4 models × 8 time periods) were fit for each tagging survey year from 2005 to 2018 (11 distinct years). Trace plots were examined visually, and a convergence diagnostic was used to test the convergence of MCMC chains (Gelman and Rubin 1992). All models converged except for versions of Models 3 and 4 with fewer than 4 time periods. Models 3 and 4 used fishery CPUE data to estimate q, so these models require more observations of CPUE (i.e., more time periods) to converge. Therefore, Models 3 and 4 with fewer than 4 time periods were omitted from further consideration.

A combination of DIC and visual examination of trends in abundance estimates were used in the remaining model selection. A tradeoff existed between the number of time periods P and the ability to accurately describe seasonal trends. Consistent with last year, a comparison of Models 1–4 across a range of time periods P showed that the final estimate of N stabilizes after $P \geq 6$ for most years.[3] Because capturing this temporal trend was a motivating factor in the development of these models, models with $P < 6$ were eliminated, and the remaining models were compared using DIC.

The models with the most support in all years were Models 1 and 2 by DIC ($\Delta DIC \leq 2$; Burnham and Anderson 2003). The point estimate and credible interval for N in the top candidate models of 2018 are found in Table A4. The simple Chapman estimator (Model 0) does not account for natural or fishing mortality or changes in abundance throughout the season but provides a comparable estimate of abundance to Models 1–4 (Table A4). Although Model 2 had statistical support via DIC, the resultant abundance estimates and variance from Model 2 were greater than Model 1 (Table A4). The estimates and credible intervals for net migration (r) were wide for all years, and the direction of net migration (positive or negative) was inconsistent across years (Figure A3). Interestingly, Model 2 results in 2018 suggest record migration into Chatham, which could account for the rapid increase in abundance since 2016. Model 4, which includes migration and CPUE data, fit better than Model 3, which was unable to capture the increasing trend in CPUE over the fishery (Figure A4).

Model 1 with $P = 6$ was selected for the 2019 forecast.

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[3] J. Sullivan, B. Williams, and A. Olson. 2018 NSEI sablefish assessment. State of Alaska, Department of Fish and Game, Division of Commercial Fisheries Memorandum. June 20, 2018. https://github.com/commfish/seak_sablefish/blob/master/text/2018_NSEI_sablefish_forecast_FINAL.pdf (Accessed August 2019).

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TABLES

Table A1.–Notation for mark–recapture models used in the 2018 stock assessment.

Variable	Definition
N_0	Number of sablefish in Chatham Strait at time of marking during the ADF&G pot survey
K_0	Number of tags released in the ADF&G pot survey
D_0	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)
i	Subscript for each time period may refer to the ADF&G longline survey (i = 1) or to 1 of the fishery time periods based on time of landing
N_i	Number of sablefish in Chatham Strait at the beginning of time period i
D_i	Number of tags lost in time period i that should be decremented from the next time period
C_i	Total catch (number of sablefish removed) during time period i
K_i	Number of tagged sablefish in Chatham Strait at the beginning of time period i
t_i	Number of days in time period i
n_i	Observed catch during period i (number of sablefish that were checked for marks)
k_i	Number of marked fish recovered in period i
p_i	Probability of recapture in time period i
M	Natural mortality decremented daily and fixed at 0.1 following Johnson and Quinn (1988)
r	Net number of tagged fish entering or leaving Chatham Strait (migration parameter)
q	Catchability coefficient for the fishery relating fishery CPUE in period i to sablefish abundance $CPUE_i = q * N_i$
P	Total number of time periods

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Table A2.–A summary of data inputs to the mark–recapture models, including total fish 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 fish in the longline survey and fishery (k_{srv} and k_{fsh}), number of sampled fish 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, 2005–2018.

Year	K	K_0	D_0	k_{srv}	n_{srv}	D_{srv}	k_{fsh}	n_{fsh}	D_{fsh}
2005	7,118	7,118	9	60	17,495	44	690	180,999	84
2006	5,325	5,325	3	26	14,481	20	503	203,878	38
2007	6,158	6,055	2	33	15,253	10	335	150,729	61
2008	5,450	5,412	4	42	15,483	12	431	156,313	43
2009	7,071	7,054	7	42	14,946	9	285	105,709	62
2010	7,443	7,307	4	54	14,764	6	331	106,201	28
2012	7,582	7,548	23	66	18,047	4	380	97,134	53
2013	7,961	7,921	24	86	13,570	3	374	99,286	113
2015	6,862	6,765	1	63	12,274	10	242	70,273	32
2017	7,096	6,933	3	39	14,200	3	197	60,409	11
2018	9,678	9,160	0	64	13,392	26	183	65,940	135

Table A3. –A description of the mark–recapture models compared in 2018.

Model	Description	Parameters
Model 0	Chapman estimator	N
Model 1	Time-stratified Petersen estimator with natural mortality	N, p
Model 2	Model 1 with migration	N, p, r
Model 3	Model 1 with fishery CPUE data	N, p, q
Model 4	Model 1 with migration and fishery CPUE data	N, p, r, q

Table A4.–Results from candidate models in 2018, including abundance estimate (median) and 95% credible intervals, deviance, parameter penalty, and Δ DIC (Δ DIC ≤ 2 are models with the most statistical support).

Model	Estimate	Upper CI	Lower CI	Deviance	Parameter penalty	Δ DIC
Model 0	2,922,204	3,280,562	2,563,846			
Model 1	2,702,394	3,234,292	2,254,476	38.79	3.64	0.00
Model 2	3,040,321	3,863,683	2,424,141	38.31	4.16	0.06
Model 3	2,690,995	3,224,577	2,250,297	80.30	7.68	45.55
Model 4	2,870,311	3,482,740	2,373,470	73.40	9.96	40.94

FIGURES

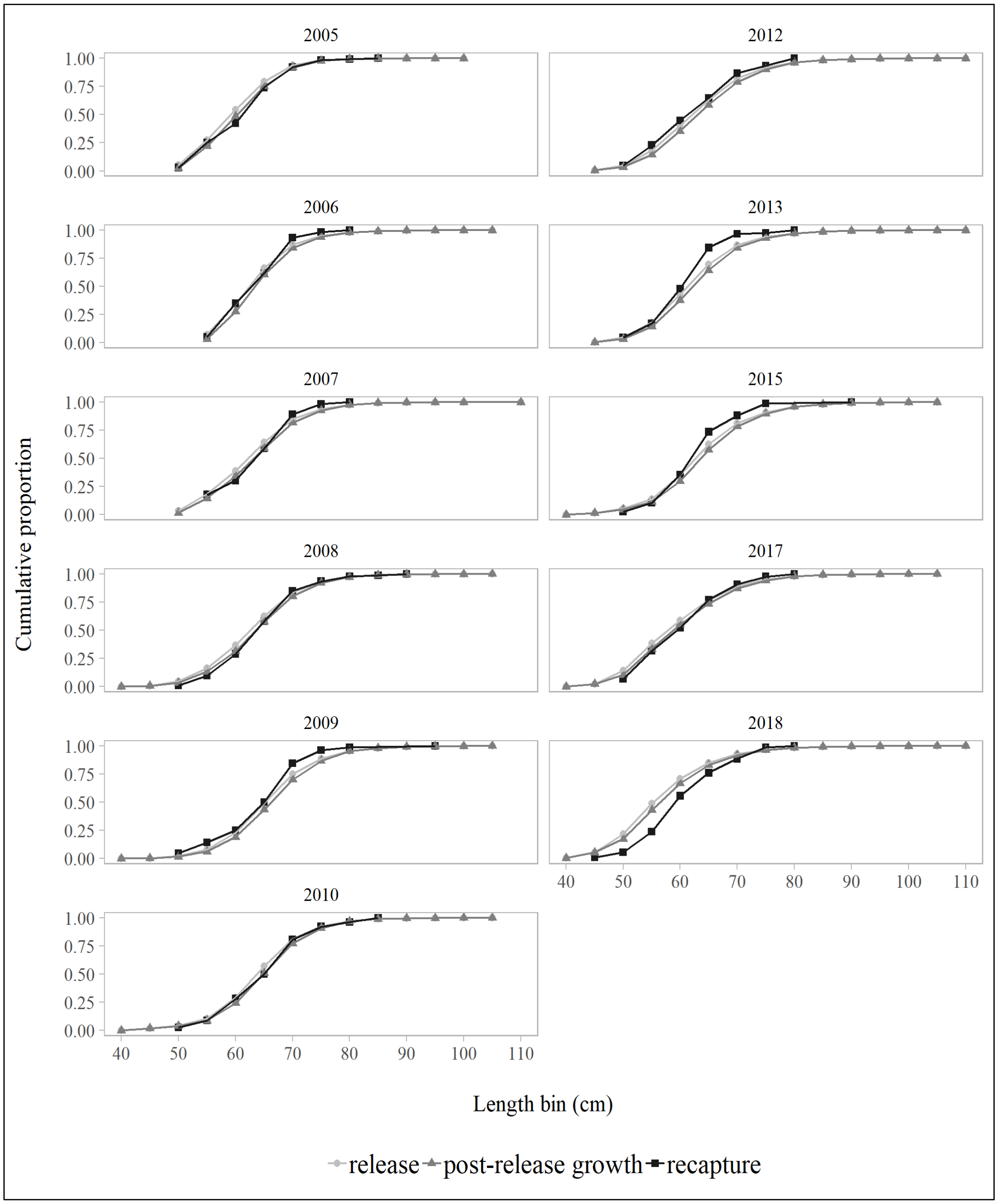

Figure A1.–The cumulative proportion at length released (light grey), predicted growth after release (dark grey), and recaptured (black) in Chatham Strait by 5 cm length bins, 2005–2018.

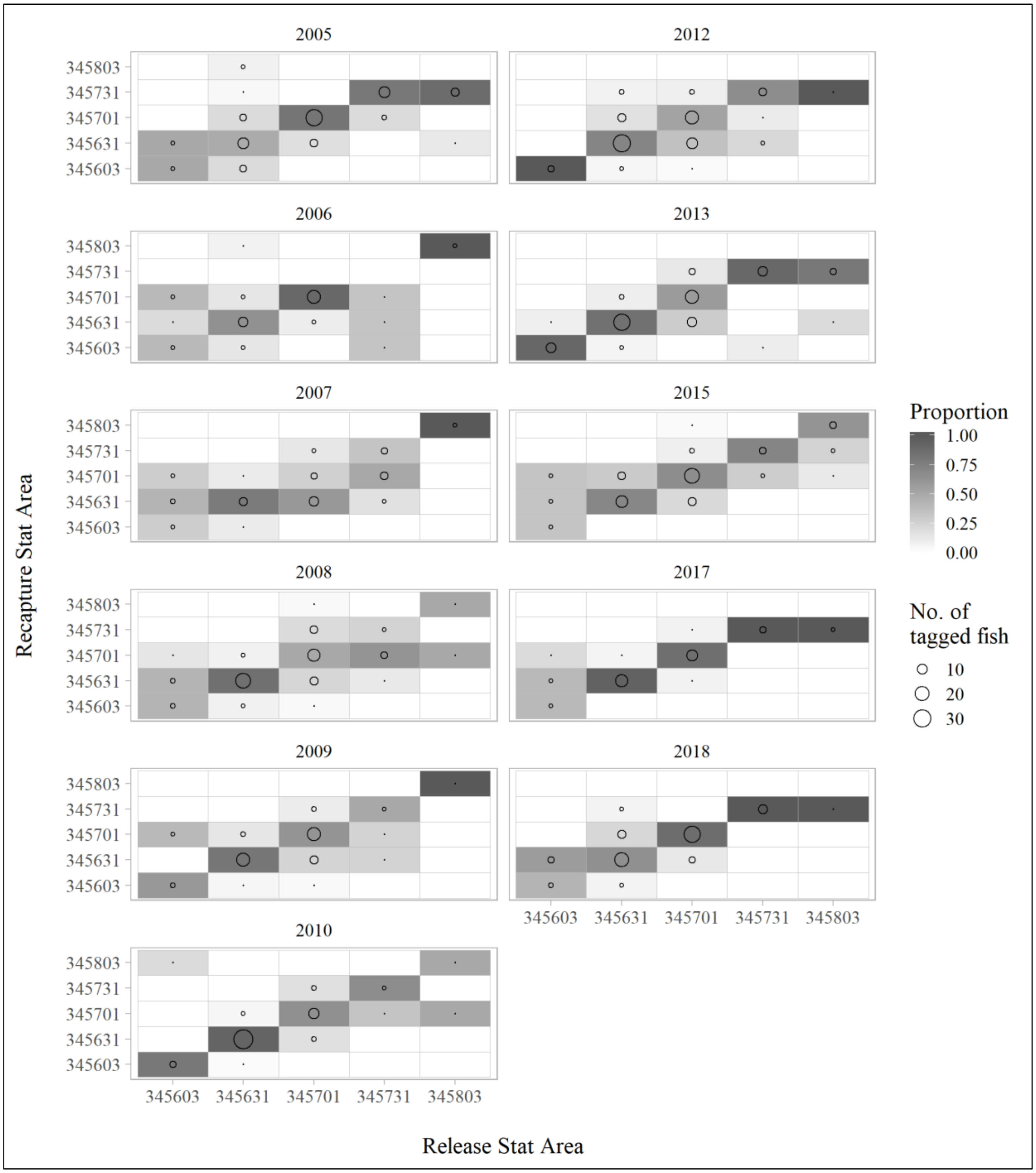

Figure A2.–The probability of being recaptured in a statistical area given release area, 2005–2018. The relative size of the circle represents the number of tagged fish recaptured in each area. Statistical areas are arranged roughly north to south along each axis.

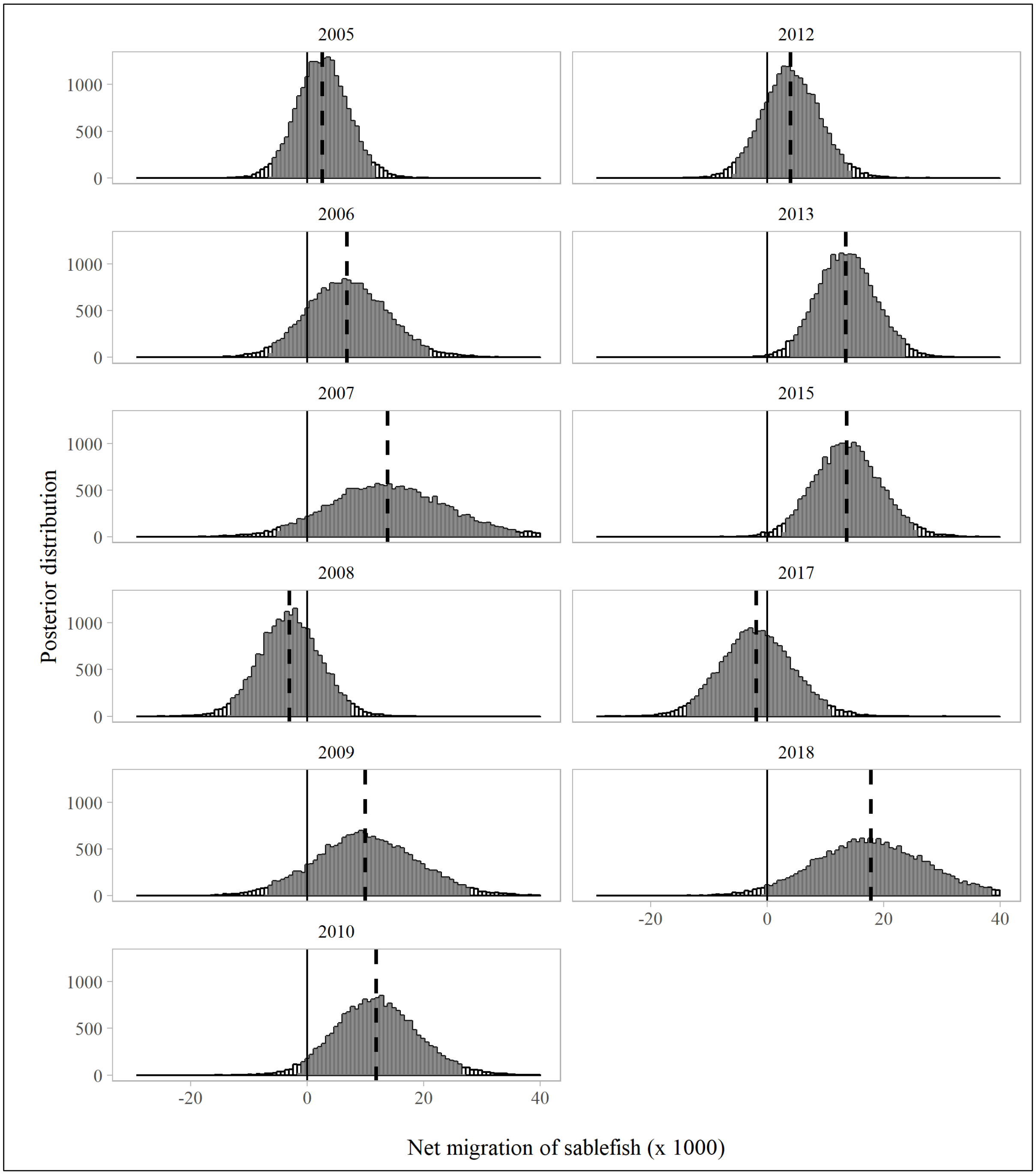

Figure A3.–Posterior distribution of net migration into Chatham Strait with 95% credible intervals shaded (Model 2, $P = 6$). The median is denoted by the dashed vertical line. The solid vertical (no migration) is to aid in comparing results across years.

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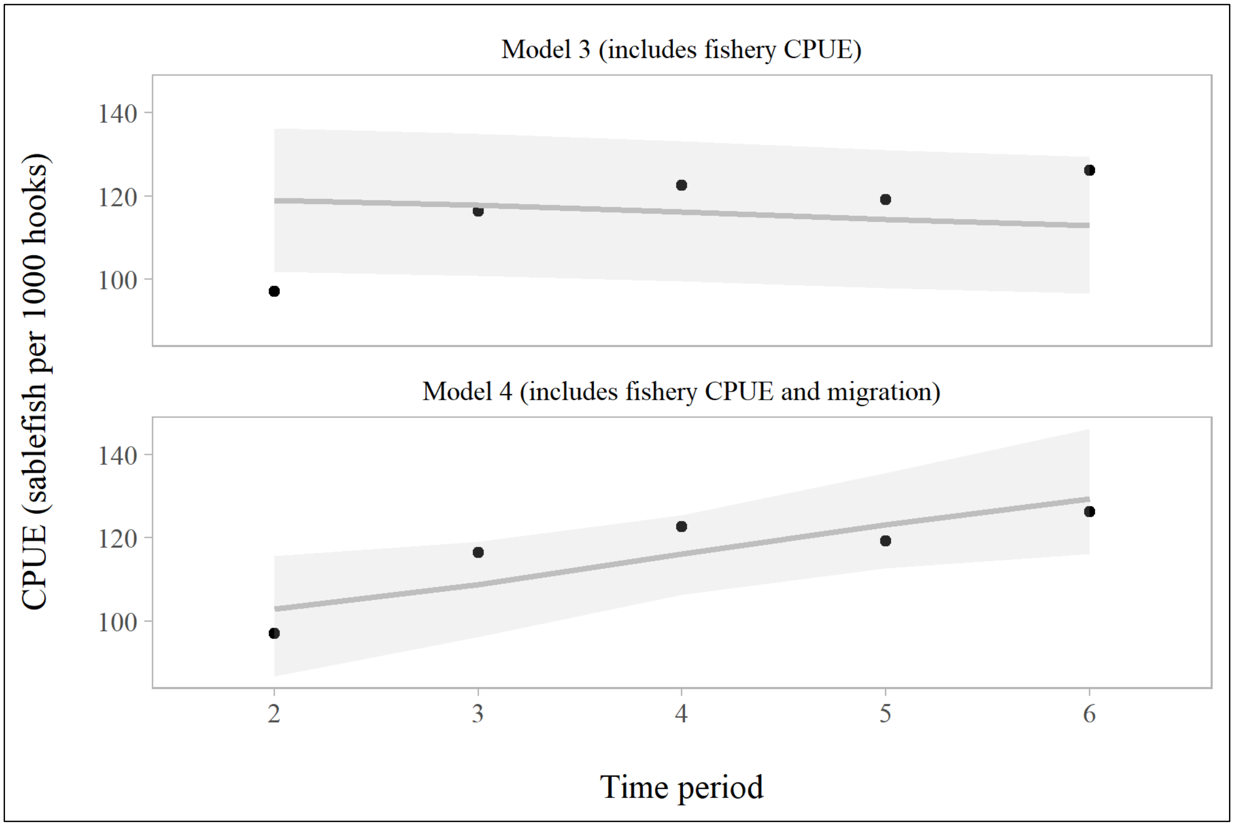

Figure A4.– Observed (black) and model-estimated (grey) CPUE (sablefish/1000 hooks) in the 2018 longline fishery for Model 3 (top panel; which included CPUE), and Model 4 (bottom panel, which included CPUE and allowed for migration). Grey shaded areas show 95% credible intervals from the posterior distribution. Models 0, 1, and 2 are not included in this comparison because they do not estimate CPUE.

APPENDIX B. PRELIMINARY RESULTS FOR A STATISTICAL CATCH-AT-AGE MODEL FOR SABLEFISH (*ANOPLOPOMA FIMBRIA*) IN THE NORTHERN SOUTHEAST INSIDE MANAGEMENT AREA

Appendix B.– Preliminary results for a statistical catch-at-age model for sablefish (*Anoplopoma fimbria*) in the Northern Southeast Inside management area.

INTRODUCTION

Sablefish have been commercially fished in Southeast Alaska inside waters since at least the early 1900s, with active management in the NSEI management area beginning in 1945 (Carlile et al. 2002, Figure 2). Early attempts to track fishery performance and estimate abundance of sablefish in NSEI included a vessel logbook program that began in 1932 and a tagging experiment in 1951 (Carlile et al. 2002). Several statistical catch-at-age models for NSEI sablefish have been developed; however, none of these models have been used to set annual harvest quotas (Carlile et al. 2002; Dressel 2009; Mueter 2010; 2017 Memorandum[1]).

Currently the Alaska Department of Fish and Game (ADF&G) conducts an annual mark–recapture survey that serves as the basis for stock assessment and management (Stahl and Holum 2010). Fish are tagged during a pot survey from May through June, with recaptures occurring in the ADF&G longline survey in July and the longline fishery from August through November (Beder and Stahl 2016). A time-stratified modified Petersen model is used to estimate abundance in a Bayesian framework using JAGS 4.3.0 (Chapman 1951; Depaoli et al. 2016; 2018 Memorandum[2]). Abundance estimates are partitioned into age classes in order to estimate biomass-at-age using age composition and weight-at-age data collected during the longline survey and fishery. ADF&G has defined Acceptable Biological Catch (ABC) as F_{ABC}=$F_{50\%}$ for the NSEI sablefish stock (Dressel 2009). A yield-per-recruit model is used to estimate $F_{50\%}$ using the optim() function in the statistical software R.[3]

Several factors motivated the development of a statistical catch-at-age model. The current ADF&G framework relies heavily on the mark–recapture experiment, which may be vulnerable to future funding reductions. Furthermore, the mark–recapture estimate provides a single snapshot in time and is susceptible to high interannual variability in abundance and biomass estimates. Consequently, it is difficult to fully integrate all available data sources, explore historical trends, or fully assess stock status or harvest strategies. A significant amount of data is collected in NSEI through multiple surveys, logbooks, and port sampling by ADF&G (Figure B1). Moving to a new modeling framework will allow better utilization of these data sources, thus making management more resilient to potential funding reductions. Additionally, the current assessment relies on federal estimates of selectivity and does not estimate recruitment for the stock. If there are differences in availability, gear selectivity, or stock dynamics between federally managed waters and NSEI, we are unable to detect them. Finally, strong recruitment from the 2014- and possibly

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[1] B. Williams and K. Van Kirk. 2017 NSEI Sablefish Assessment. State of Alaska, Department of Fish and Game, Division of Commercial Fisheries Memorandum. March 16, 2017. https://github.com/commfish/seak_sablefish/blob/master/text/2017_NSEI_sablefish_stock_assessment_FINAL.pdf

[2] J. Sullivan, B. Williams, and A. Olson. 2018 NSEI sablefish assessment. State of Alaska, Department of Fish and Game, Division of Commercial Fisheries Memorandum. June 20, 2018. https://github.com/commfish/seak_sablefish/blob/master/text/2018_NSEI_sablefish_forecast_FINAL.pdf.

[3] R Core Team. 2018. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/ (Accessed August 2019).

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2013- and 2015-year classes were reported in the federal assessment, prompting questions about how to treat uncertainty in recruitment for state management (Hanselman et al. 2017; 2018 Memorandum[4]). A statistical catch-at-age model coded in Template Model Builder (TMB) will allow more flexibility in exploring recruitment using random effects (Kristensen et al. 2016).

MODELING APPROACH

The statistical catch-at-age 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 attempt at modeling the NSEI sablefish stock (Mueter 2010); this model was based on `ADMB` code from an older federal assessment of sablefish that has also been adapted for 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 option. Variable definitions for all equations used in the statistical catch-at-age model can be found in Table B1.

DATA INPUTS

The data used as inputs to the `TMB` model, including point estimates, variance, and sample sizes for composition data, can be found at www.github.com/commfish/seak_sablefish/TMB_inputs. A summary of the available data by year can be found in Figure B1.

WEIGHT-AT-AGE

Data from the 2002–2018 longline fishery and 1997–2018 ADF&G longline surveys were used to obtain weight-at-age. A sex-specific 3-parameter weight-based von Bertalanffy growth model was fit to weight-at-age data:

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

where w_a is weight at a given age (kg), W_∞ is the mean asymptotic weight (kg), β is the power in the allometric equation and relates to the rate at which W_∞ is reached, and t_0 is the theoretical age at weight 0 (years).

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

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[4] J. Sullivan, B. Williams, and A. Olson. 2018 NSEI sablefish assessment. State of Alaska, Department of Fish and Game, Division of Commercial Fisheries Memorandum. June 20, 2018. https://github.com/commfish/seak_sablefish/blob/master/text/2018_NSEI_sablefish_forecast_FINAL.pdf.

MATURITY-AT-AGE

Data from the 1997–2018 ADF&G longline surveys were used to fit a maturity curve for females and estimate spawning stock biomass within the model (Figure B2B). Alternative length, age, and year-specific models were evaluated using Akaike Information Criterion (Akaike 1974). The length-based maturity curve fit to all years was the best-fitting model. We used a logistic regression approach in `R`, such that the probability p of being mature at a given length on the logit scale is a linear function of length (l):

$$\ln(\frac{p_l}{1-p_l}) = \beta_0 + \beta_1 \cdot l.$$

Predicted maturity-at-length was transformed to maturity-at-age using fitted values from a length-based von Bertalanffy growth curve. The length at 50% maturity is 62.3 cm and the age at 50% maturity is 6.4 years. Predicted proportions mature-at-age were used as inputs to the assessment model and in the calculation of spawning stock biomass (Figure B2B).

SEX RATIOS

A generalized additive model was fit to sex ratio information from the 1997–2018 ADF&G longline surveys using the `gam()` function in the `mgcv` R package (Wood 2011). The probability of being female-at-age r_a is modeled as a smooth function of age a

$$\ln(\frac{r_a}{1-r_a}) = s(a).$$

Fits to the data suggest that female sablefish make up the majority of catch-at-age in the survey until roughly age 18 and then decline to less than 40% by age 30 (Figure B2C). Predicted values of proportion female-at-age were used to estimate spawning stock biomass in the single-sex model. These data are not used in the sex-structured model.

CATCH

Catch data from 1980 to 2018 include harvest in the directed sablefish longline fishery, ADF&G longline survey removals, and sablefish retained in other fisheries like the IFQ halibut longline fishery (Figure B3A). Catch was assumed to be lognormally distributed, with a fixed log standard deviation of 0.05.

Changes in the management structure during this period included a move to Limited Entry in 1985 and the Equal Quota Share (EQS) Program in 1994. Additional sources of mortality that are not currently included in this model include sport, subsistence, and personal use harvest; estimated bycatch mortality in the halibut fishery; and estimated deadloss, which includes mortality from sand fleas, sharks, and whales. Currently these additional sources of mortality are accounted for in the decrements process used to calculate the annual harvest objective. Methods should be developed to incorporate these data into the model in the future.

FISHERY CPUE

Fishery CPUE in kg per hook was used as an index of abundance from 1980 to 2018 (Figure B3B). This index was assumed to be lognormally distributed, with a fixed log standard deviation of 0.1 for the historical data (1980–1996) and 0.08 for the contemporary data (1997 to present). Separate catchabilities and selectivity curves were assumed for pre-EQS and EQS time periods (Table B2).

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SURVEY CPUE

Longline survey CPUE in numbers per hook was used as an index of abundance from 1997 to 2018 (Figure B3C). This index was assumed to be lognormally distributed, with a fixed log standard deviation of 0.1. An earlier longline survey from 1988 to 1996 used a shorter soak time of 1 hr instead of the current 3–11 hr (Carlile et al. 2002). These data were omitted because the 1 hr soak time was likely too short to provide an accurate measure of relative abundance (Sigler 1993).

MARK–RECAPTURE ABUNDANCE

The mark–recapture abundance index was included for 2003–2010, 2012, 2013, 2015, 2017, and 2018 (Figure B3D). A time-stratified Petersen mark–recapture model implemented in JAGS 4.3.0 was used to estimate abundance (Depaoli et al. 2016; 2018 Memorandum[5]). Further information about how these indices were derived can also be found in the 2018 NSEI sablefish assessment (2018 Memorandum[6]). This index was assumed to be lognormally distributed, and the log standard deviation was approximated as the coefficient of variation from the posterior distribution of the mark–recapture abundance estimates.

AGE COMPOSITIONS

Fishery age compositions from the 2002–2018 longline fishery and survey age compositions from the 1997–2018 longline surveys were included in the model (Figure B4). 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. Age compositions were assumed to follow the multinomial or Dirichlet-multinomial distributions (only results for the multinomial are shown in this report). Until more sophisticated tuning methods or estimates of effective sample size can be developed for NSEI, effective sample sizes were calculated as the square root of the total sample size in a given year.

An ageing error matrix for NSEI is currently being developed in conjunction with the ADF&G Age Determination Unit. Until this has been fully developed and reviewed, the federal sablefish ageing error matrix has been made available to the State (D. Hanselman, Fisheries Research Biologist, NOAA, Juneau, personal communication April 2019; Hanselman et al. 2018; Heifetz et al. 1999; Figure B5). 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).

LENGTH COMPOSITIONS

Length data from the 2002–2018 longline fishery and 1997–2018 ADF&G longline surveys were summarized using the federal conventions for length compositions (Hanselman et al. 2018). The federal assessment uses bins ranging from 41 to 99 cm (bin size increases in 2 cm increments). 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_+). Sample sizes were adequate to separate length compositions by sex.

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[5] Ibid.

[6] Ibid.

Length distributions in fishery (Figure B6) show dramatically different patterns than the survey (Figure B7), with the fishery length distribution truncated at approximately 60 cm. Full retention is not a requirement in state waters and the length differences between the survey and fishery are attributed to discarding of small fish in the fishery. Because of the bias introduced by allowing fish to be released in the fishery, there is a question of whether fishery age and length compositions should be included in 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 B8). 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

To model the discarding behavior in the NSEI fishery, processor grade and price per lb data were used to inform retention probabilities at size (Figure B9). 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 sex- and weight-based von Bertalanffy growth curves (Figure B9).

MODEL PARAMETERS

NATURAL MORTALITY

Natural mortality M was assumed constant over time and age and fixed at 0.10, which is consistent with past state and federal assessments (Johnson and Quinn 1988; Hanselman et al. 2018).

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, do not experience barotrauma, and are known to survive well in laboratory experiments.

SELECTIVITY

The longline fishery and survey are assumed to follow a logistic selectivity pattern. Currently 2 parameterizations of logistic selectivity are available in the TMB model.

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The first parameterization uses s_{50} and s_{95}, representing the ages when 50% (s_{50}) and 95% (s_{95}) of fish are selected by the gear. Selectivity-at-age (s_a) for this parameterization is defined as

$$s_a = \frac{1}{1 + \exp\frac{-\ln(19)(a - s_{50})}{s_{95} - s_{50}}}.$$

The second parameterization uses s_{50} and δ, representing the ages when 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

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

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

Currently fishery and survey selectivity are fixed in the model using federal selectivity values for the derby (pre-EQS), contemporary fishery (EQS), and longline survey (Hanselman et al. 2018; Table B2; Figure B10).

Estimating selectivity will be challenging when accounting for fishery releases because no age or length data are available on the discarded population. One potential solution is to estimate a single selectivity for the longline survey and then apply that selectivity curve to the fishery. Further information 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, 39 (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.

Following the federal assessment, if recruitment is estimated using penalized likelihood, the parameter that describes the variability of τ and ψ, $\ln(\sigma_R)$, is fixed at 0.1823 (Sigler et al. 2002, Hanselman et al. 2018). However, if τ and ψ are estimated as random effects, $\ln(\sigma_R)$ is an estimated parameter. Results are only shown for the penalized likelihood approach.

FISHING MORTALITY

There is 1 parameter estimated for mean log-fishing mortality, μ_F, and 39 (T) log-fishing mortality deviations ϕ.

POPULATION DYNAMICS

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

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

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

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

where the total instantaneous mortality, $Z_{t,a,k}$, is the sum of natural mortality M and fishing mortality $F_{t,a,k}$.

Total annual fishing mortality F_t is defined as

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

Fishing mortality is modeled as a function of fishery selectivity $s_{t,a,k}$, retention probability $R_{a,k}$ (the age-specific probability of being landed given being caught; Figure B9), and discard mortality D:

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

PREDICTED VALUES

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

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

where $w_{a,k}^{srv}$ is mean weight-at-age by sex in the longline survey and S^{srv} is the fraction of fish in year t surviving to the beginning of the fishery in August. Survival equations include natural and fishing mortality because the model assumes continuous fishing mortality.

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

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

-continued-

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

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

Spawning biomass SSB was calculated as

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

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

Predicted survey age compositions (sexes combined) were computed as

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

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

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

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

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

where $R_{a,k}$ is the assumed probability of retention by age and sex (Figure B9).

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

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

-continued-

The biomass of discarded sablefish estimated to die (W_t) with an assumed discard mortality (D) of 0.16 is

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

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

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

Fishery length compositions were calculated as

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

LIKELIHOOD COMPONENTS

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

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

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

   where λ_Y = 1.0 and c is a small constant set at 0.0001 to allow approximately 0 catches in log-space.

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

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

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

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

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

where T_P^{age} is the number of years of data for each age composition, $\lambda_{P^{age}}$ is set to 1.0, and c prevents the composition from being 0 in the likelihood calculation. Standard methods of tuning the effective sample size or iterative reweighting have not yet been applied to this assessment model (McAllister and Ianelli 1997; Francis 2011). Alternatively, effective sample size can be calculated through the estimation of an additional parameter θ using the Dirichlet-multinomial likelihood (Thorson et al. 2017):

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

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

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

Because the implementation of the alternative Dirichlet-multinomial likelihood is currently under development, only results for the multinomial likelihood are presented here.

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

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

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

5. Annual log-fishing mortality deviations (ϕ_t) are included with a penalized lognormal likelihood, where

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

where λ_ϕ=0.1.

6. Recruitment deviations (τ_t) can be included using a penalized lognormal likelihood

$$\ln L(\tau) = \lambda_\tau \sum_{i=1}^{T+A-2} (\tau_i - 0.5\sigma_R^2)^2,$$

   where $-0.5\sigma^2$ is a bias correction needed to obtain the expected value (mean) instead of the median. The λ_ϕ=2.0 and σ_R is fixed at 1.2 as in the federal assessment (Hanselman et al. 2018). Alternatively, recruitment deviations can be estimated as a random effect, where

$$\ln L(\tau) = \sum_{i=1}^{T+A-2} \ln(\sigma_R) + \frac{(\tau_i - 0.5\sigma_R^2)^2}{2\sigma_R}.$$

   Initial numbers-at-age deviations ψ_a are implemented in the same way as recruitment deviations and are governed by the same σ_R. Only results for the penalized likelihood approach are shown.

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

PRELIMINARY RESULTS AND DISCUSSION

A summary of parameter estimates and standard errors are reported in Table B3. The objective function value (negative log likelihood) was 1,007.1. The maximum gradient component was 0.00086, barely passing the minimum convergence criteria of 0.001. A summary of the contributions of each likelihood component to the total objective function can be found in Table B4.

In particular, mean recruitment and deviations were difficult to estimate (Table B3). Initially, the weight on this likelihood component was assumed to be low ($\lambda_\tau = 0.1$), but this yielded an anomalously large spike (>40 times the mean value) in age-2 recruitment in 2016 corresponding to the 2014 year class. Increasing the λ_τ to 2.0 resulted in more reasonable parameter estimates and decreased the age-2 recruitment to approximately 8 times mean recruitment. Alternatively, it may be that the parameter governing variability in recruitment σ_R should be reduced or estimated using random effects. Currently σ_R is fixed to 1.2; however, it is possible σ_R is too high for a low-productivity species like sablefish (Sigler et al. 2002; Hanselman et al. 2018). Future work should include an analysis to evaluate assumptions about σ_R.

Preliminary fits to catch and indices of abundance are shown in Figure B11. Results suggest that the model fits catch, pre-EQS fishery CPUE, and mark–recapture abundance reasonably well in most years. Contemporary fishery CPUE (EQS) does not fit well, with long runs of positive or negative residuals (Figure B12). The model performs poorly during the period directly following the implementation of EQS in 1994 for all indices, including catch (Figure B12). Prior to implementing this model for management, further consideration should be given to which abundance indices should be used in the model. For example, because discarding is legal in NSEI

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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 will be required to provide an estimate of number of released sablefish by set; however, there will still be no record of length or weight of these releases. Finally, variability in catch, survey, and fishery CPUE indices was assumed (Figure B3). Future enhancements could include estimating this variability using available data.

Preliminary fits to fishery are shown in Figure B13, and survey age compositions are shown in Figure B14. Although the model fits the general shape of the age compositions in most years, there are poor residual patterns (Figure B15). Fits to male fishery length compositions are shown in Figure B16; fits to female fishery length compositions are shown in Figure B17. Fits to male survey length compositions are shown in Figure B18; fits to female survey length compositions are shown in Figure B19. 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 (Figure B20).

There are several caveats to the preliminary fits to composition data. First, no efforts have been made to externally estimate, tune, or iteratively reweight the input effective samples sizes for the composition data (McAllister and Ianelli 1997; Francis 2011). This exercise should be completed prior to implementation of this model. Second, results presented here assume fixed selectivity equal to the federal fishery. Because no data on fishery releases exist, it may not be possible to estimate fishery selectivity and 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 for discarded catch. An alternative approach is to estimate survey selectivity and then assume fishery and survey selectivity are equal. Finally, fishery size-at-age is larger than survey size-at-age, especially at younger ages. Consequently, fits to fishery length compositions may benefit from the development of separate age-length keys for the NSEI survey and fishery.

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 B21). Recruitment trends are comparable with federal values, and estimates of spawning stock biomass, exploitable biomass, and exploitable abundance are in par with past and current ADF&G estimates (Hanselman et al 2018; 2018 Memorandum[7]). A time series of fishing mortality and harvest rate (defined as 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 B22). The model suggests that harvest rates were more than 4 times what they are today during this time period.

Although not currently ready to be considered for management, the statistical catch-at-age model outlined here is planned to be presented as a management alternative in 2020. Planned future developments to this model are summarized by priority level in the following sections.

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[7] Ibid.

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HIGH PRIORITY

The following tasks must be completed for this model to be considered for management:

- Complete the development and estimation of management reference points.
- Develop rationale for the choice of fishery-dependent data sources to include in the model and whether fishery selectivity should be fixed or estimated. This relates to the challenge of accounting for unobserved fishery releases and estimating fishery selectivity and fitting to landed catch compositions.
- Improve weighting methods and tune model to composition data.

SHORT TERM

These tasks should be completed within 1–2 years of implementation. They are critical components of a well-developed statistical catch-at-age model.

- Implement Bayesian analysis to evaluate posterior densities of estimated and derived quantities of interest.
- Evaluate estimation and assumptions about recruitment variability.
- Conduct retrospective analysis to determine model performance over time.
- Develop framework to conduct projections to evaluate stock status and assess risk.

LONG TERM

These tasks should be completed within 2–4 years of implementation. While they are not critical to the implementation of the model, they will improve model-based inference, understanding of stock dynamics, and data quality.

- Develop ageing error matrices and age-length keys for NSEI.
- Review indices of abundance. The fishery and survey CPUE have little contrast and may not be useful indices of abundance. This may include standardizing CPUE through generalized linear or addition modeling to account for variables to affect CPUE. It may also include developing algorithms to identify trip and set targets and allocating total trip landings to set effort.
- Evaluate alternative harvest policies and biological reference points.
- Improve methods for accounting for fishery releases, including conducting research to better understand discarding behavior and how it has changed over time.
- Develop priors for catchability and other relevant parameters.
- Assess alternative sources of data, especially historical biological and catch data (Carlile et al. 2002).
- Develop methods to account for additional sources of mortality, including sport, subsistence and personal use harvest; estimated bycatch mortality in the halibut fishery; and estimated deadloss, which includes mortality from sand fleas, sharks, and whales.

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TABLES

Table B1.–Variable definitions for the statistical catch-at-age 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 when 50% of fish are selected to the gear
s_{95}	Age when 95% of fish are selected to the gear
δ	Slope parameter in the logistic selectivity curve
q	Catchability
μ_R	Mean log recruitment
τ_t	Log recruitment deviations
μ_N	Mean log initial numbers-at-age
ψ_a	Log deviations of initial numbers-at-age
σ_R	Variability in recruitment and initial numbers-at-age
μ_F	Mean log fishing mortality
ϕ_t	Log fishing mortality deviations
θ	Dirichlet-multinomial parameter related to effective sample size
Data and predicted variable	
w_a	Weight-at-age
p_a	Proportion mature-at-age
r_a	Proportion female-at-age

-continued-

Table B1.–Page 2 of 2.

Variable	Definitions
Data and predicted variable	
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)

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Table B2.–Assumed selectivity parameters for the fishery before the Equal Quota Share program started in 1994 (pre-EQS), the fishery since the implementation of EQS, and the ADF&G longline survey.

	Male		Female	
	s_{50}	δ_{50}	s_{50}	δ_{50}
Pre-EQS Fishery	5.12	2.57	2.87	2.29
EQS Fishery	4.22	2.61	3.86	2.61
Longline survey	3.72	2.21	3.75	2.21

Source: These parameters estimates were borrowed from the federal stock assessment, where the federal derby fishery, IFQ fishery, and NMFS Cooperative Longline Survey were assumed to represent pre-EQS, EQS, and the ADF&G longline survey (Hanselman et al. 2018).

Table B3.–Parameter estimates from the statistical catch-at-age model. Estimates of recruitment, initial numbers-at-age, and fishing mortality deviations were excluded for brevity.

Parameter	Estimate	Standard error
Pre-EQS catchability, $\ln(q_{fsh,pre-EQS})$	–17.618	0.044
EQS catchability, $\ln(q_{fsh,EQS})$	–16.911	0.024
Survey catchability, $\ln(q_{srv})$	–16.276	0.023
Mark–recapture catchability, $\ln(q_{MR})$	-0.038	0.010
Mean log recruitment, μ_R	6.224	0.093
Mean log initial numbers-at-age, μ_N	6.561	0.127
Mean log fishing mortality, μ_F	–2.601	0.359

Table B4.–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 difference between the total likelihood and the data likelihood is the contribution of penalized likelihoods, including recruitment and fishing mortality.

Likelihood component	Likelihood	% of Total Likelihood
Catch	13.1	1.3
Fishery CPUE	133.6	13.3
Survey CPUE	52.0	5.2
Mark–recapture abundance	52.0	5.2
Survey ages	181.1	18.0
Fishery ages	146.2	14.5
Survey lengths	107.7	10.7
Fishery lengths	284.7	28.3
Data likelihood	970.5	96.4
Total likelihood	1007.1	100.0

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FIGURES

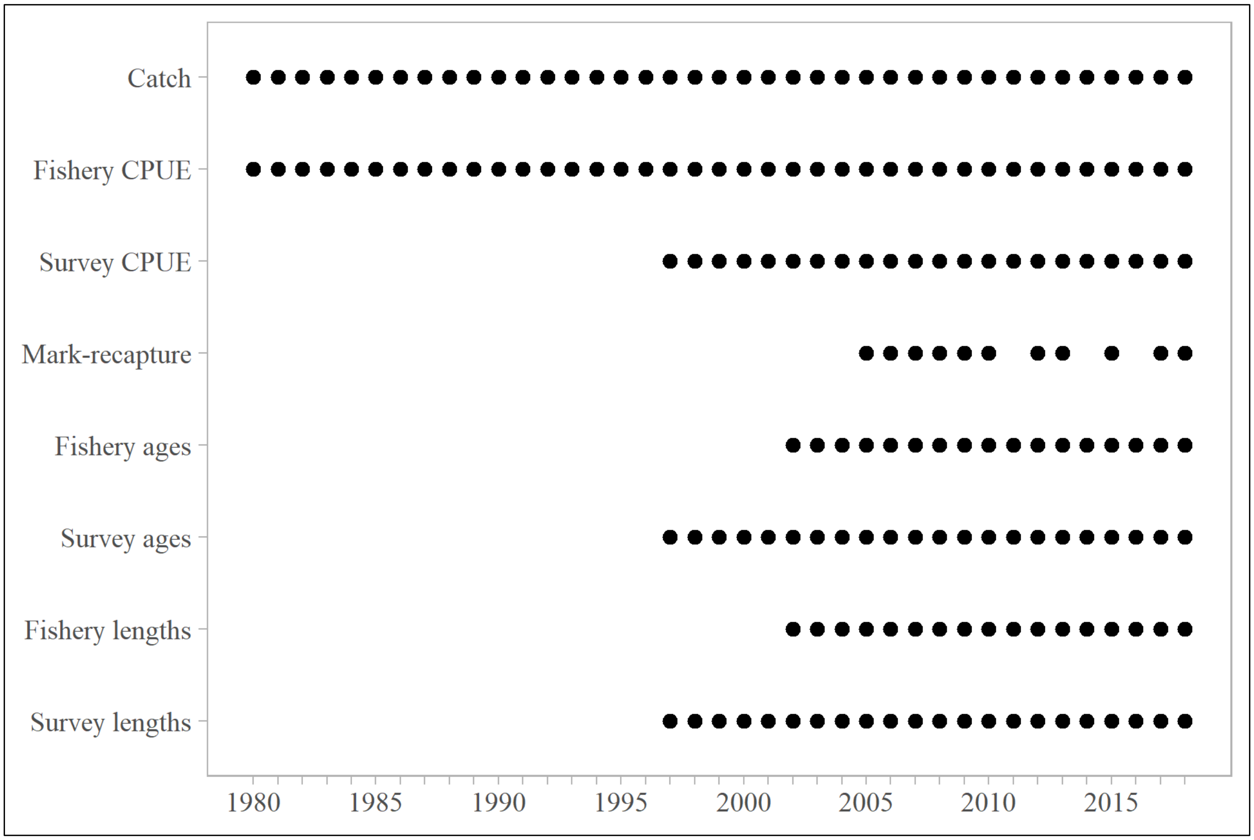

Figure B1.–A summary of the available data sources in NSEI by year.

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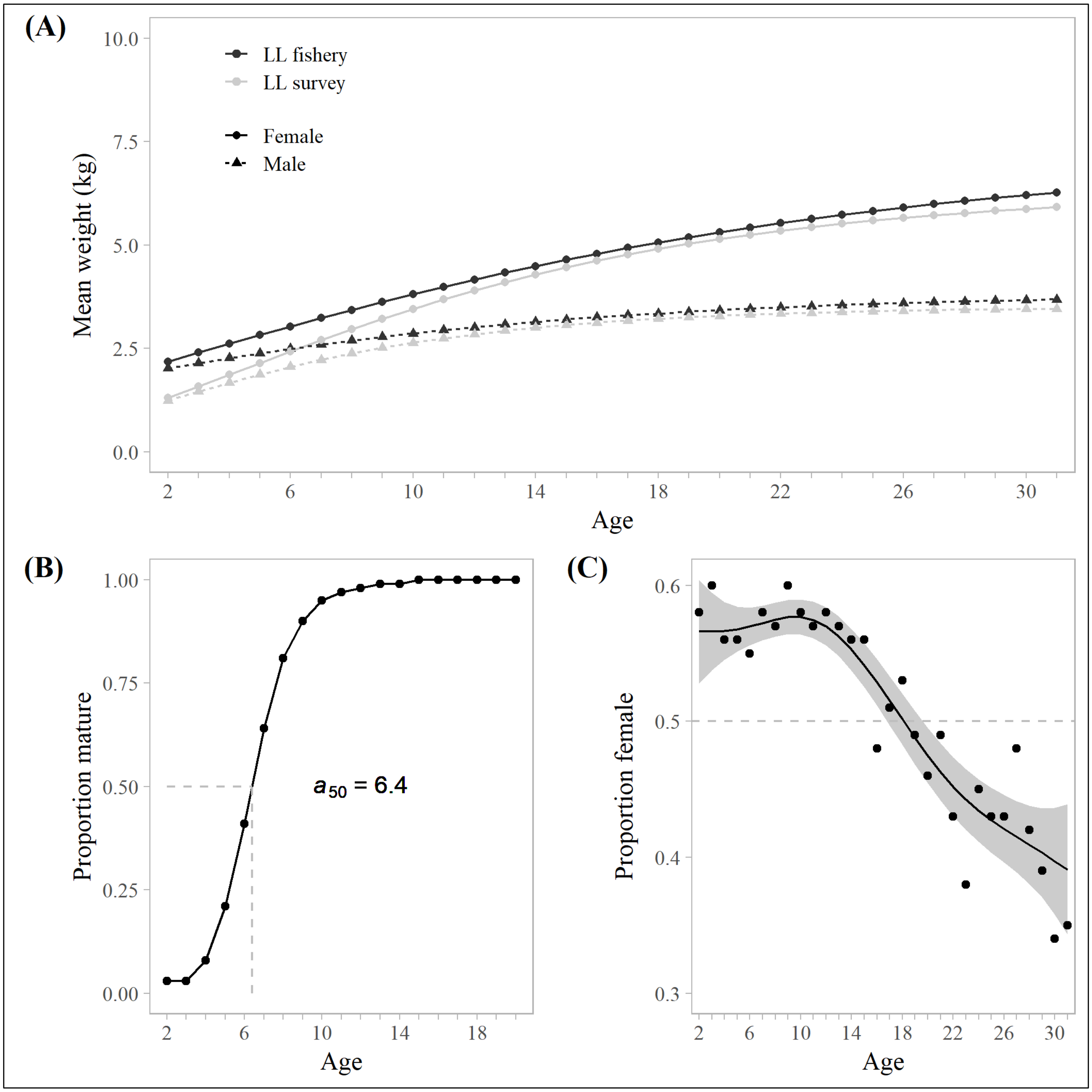

Figure B2.–Biological inputs to the statistical catch-at-age model, including (A) von Bertalanffy growth model predictions of weight-at-age (kg) by sex from the longline fishery (black) and ADF&G longline survey (grey); (B) proportion mature-at-age females estimated from the longline survey with the age at 50% maturity (a_{50}=6.4 yr); and (C) proportion female in the longline survey, where the curve is the fitted line from a generalized additive model +/–2 standard error.

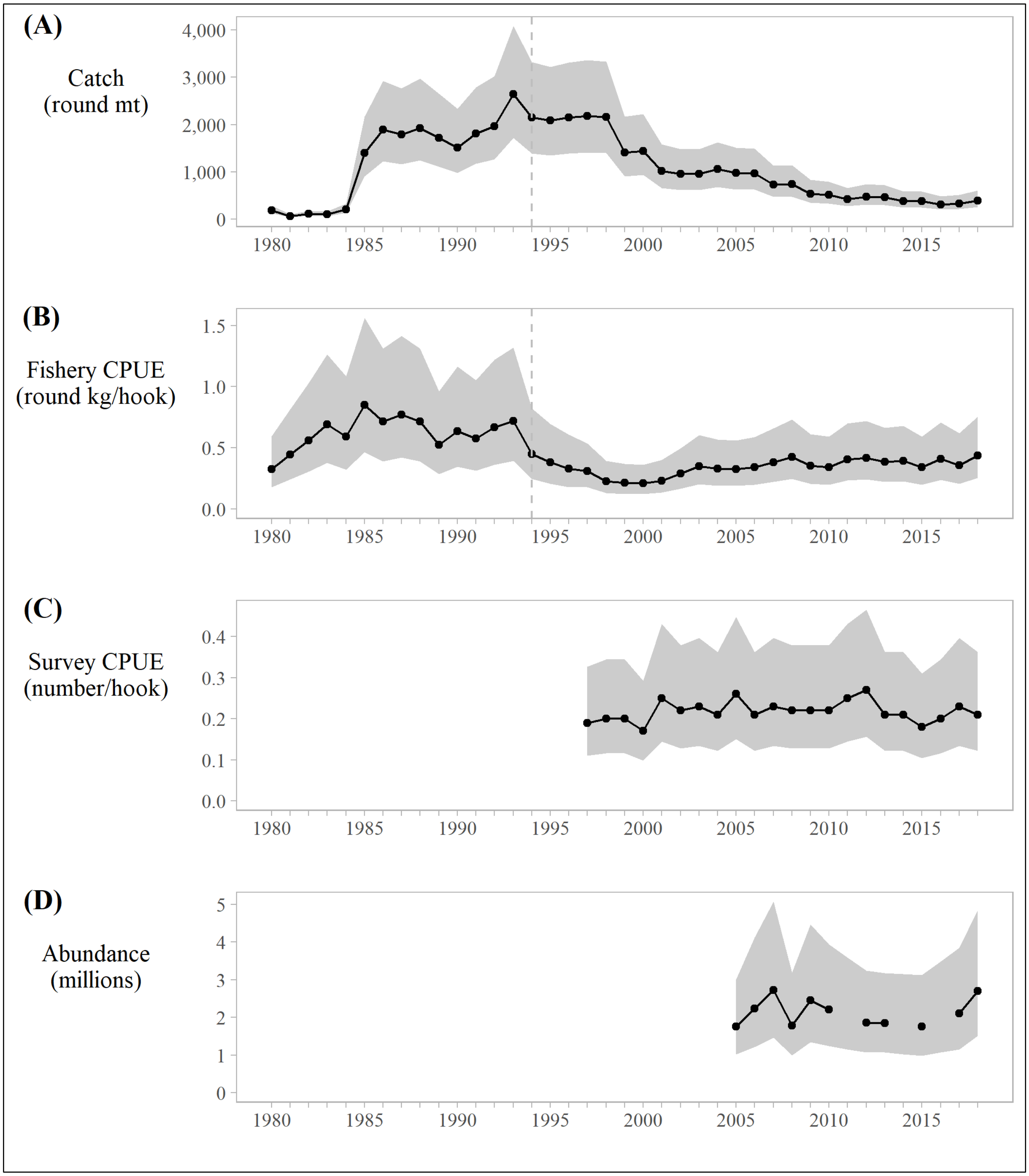

Figure B3.–Indices of catch and abundance with the assumed error distribution, including (A) harvest (round mt), (B) fishery catch per unit effort in round kg per hook, (C) survey catch per unit effort in number of fish per hook, and (D) mark–recapture abundance estimates in millions. The dashed vertical line in 1994 mark the transition to the Equal Quota Share program.

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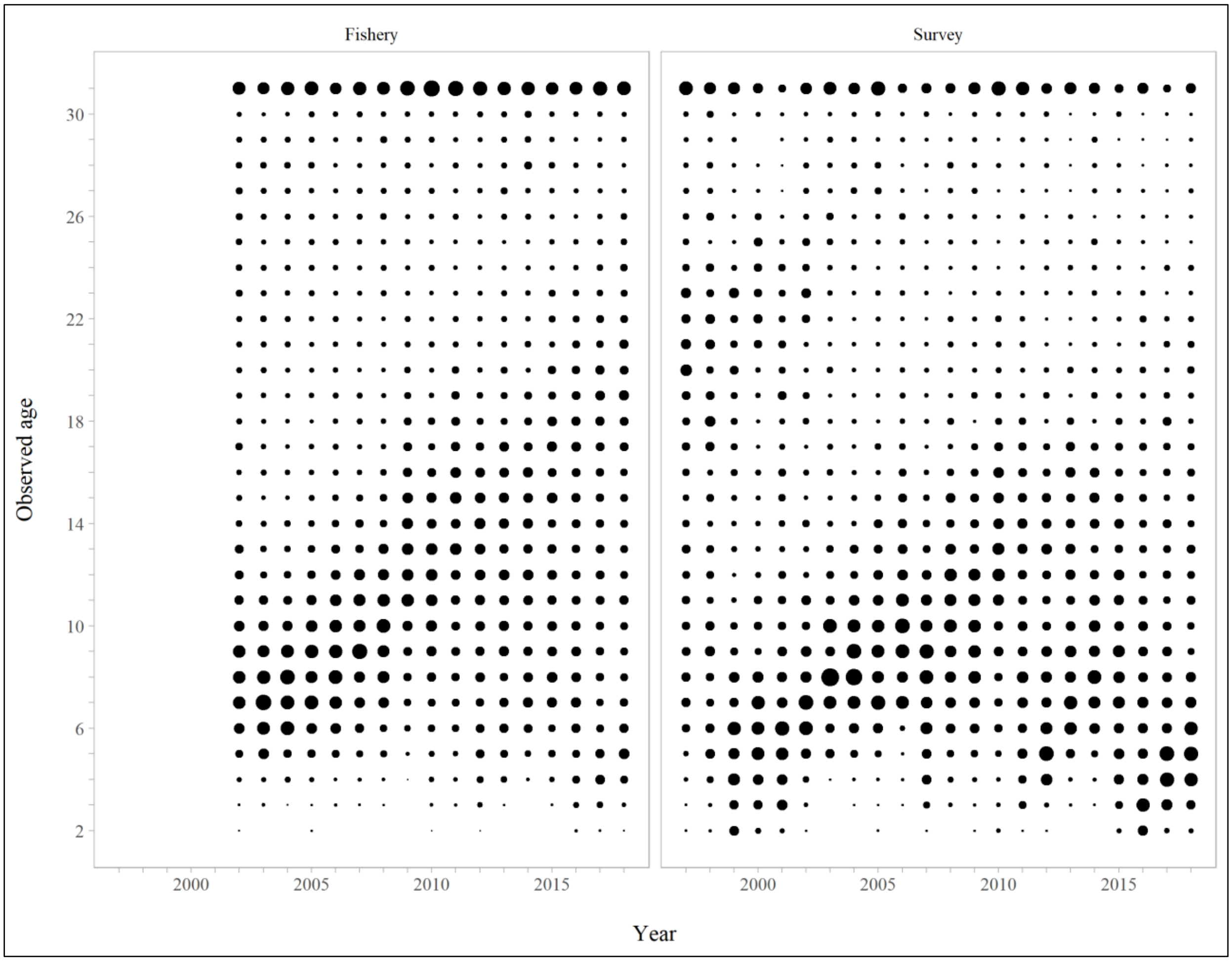

Figure B4.–Proportions-at-age for the NSEI longline fishery (2002–2018) and ADF&G longline survey (1997–2018). The size of the circle is relative to the proportion-at-age in a given year.

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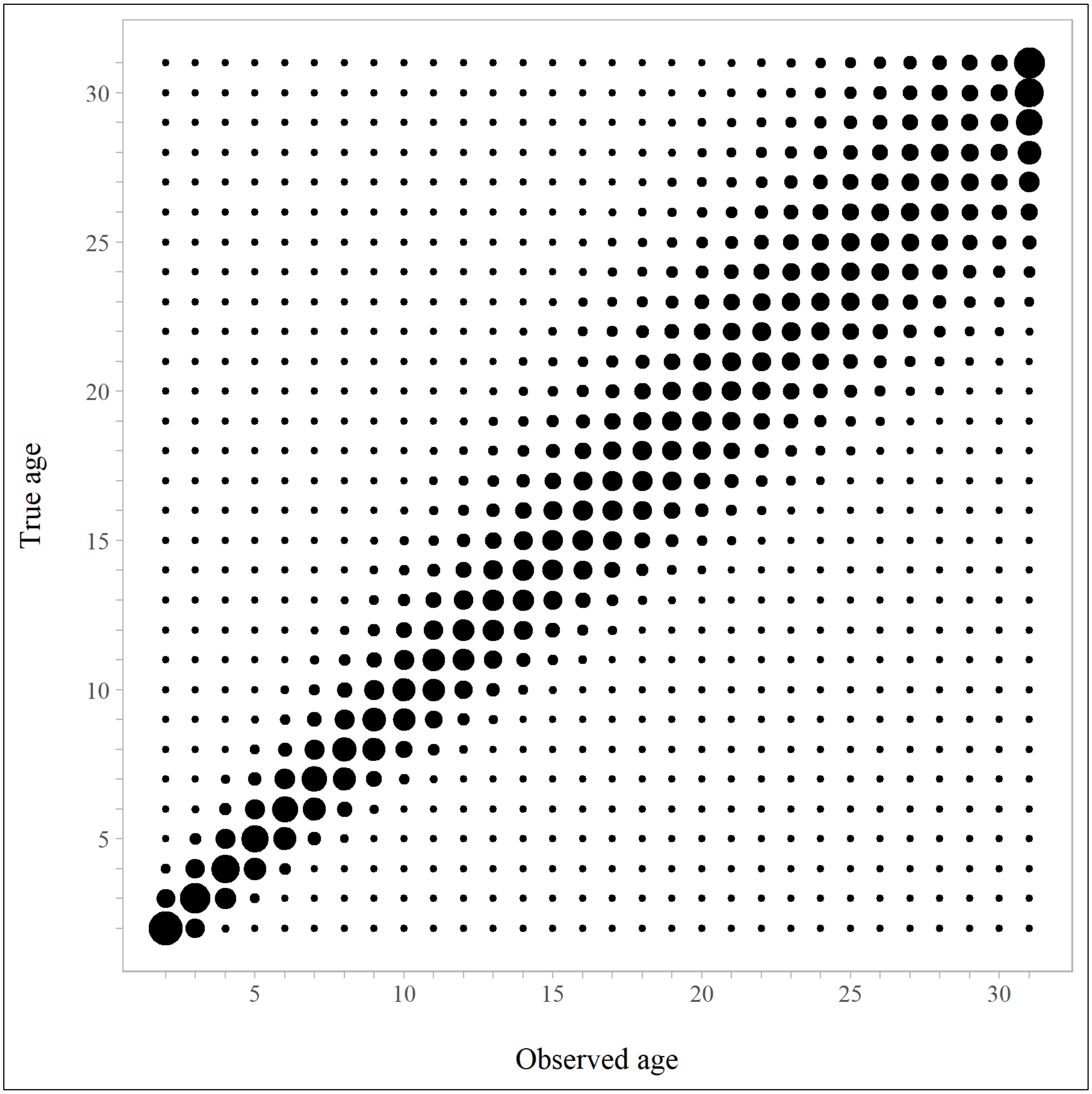

Figure B5.–Ageing error matrix used in the model, showing the probability of observing an age given the true age.

Source: Heifetz et al. 1999.

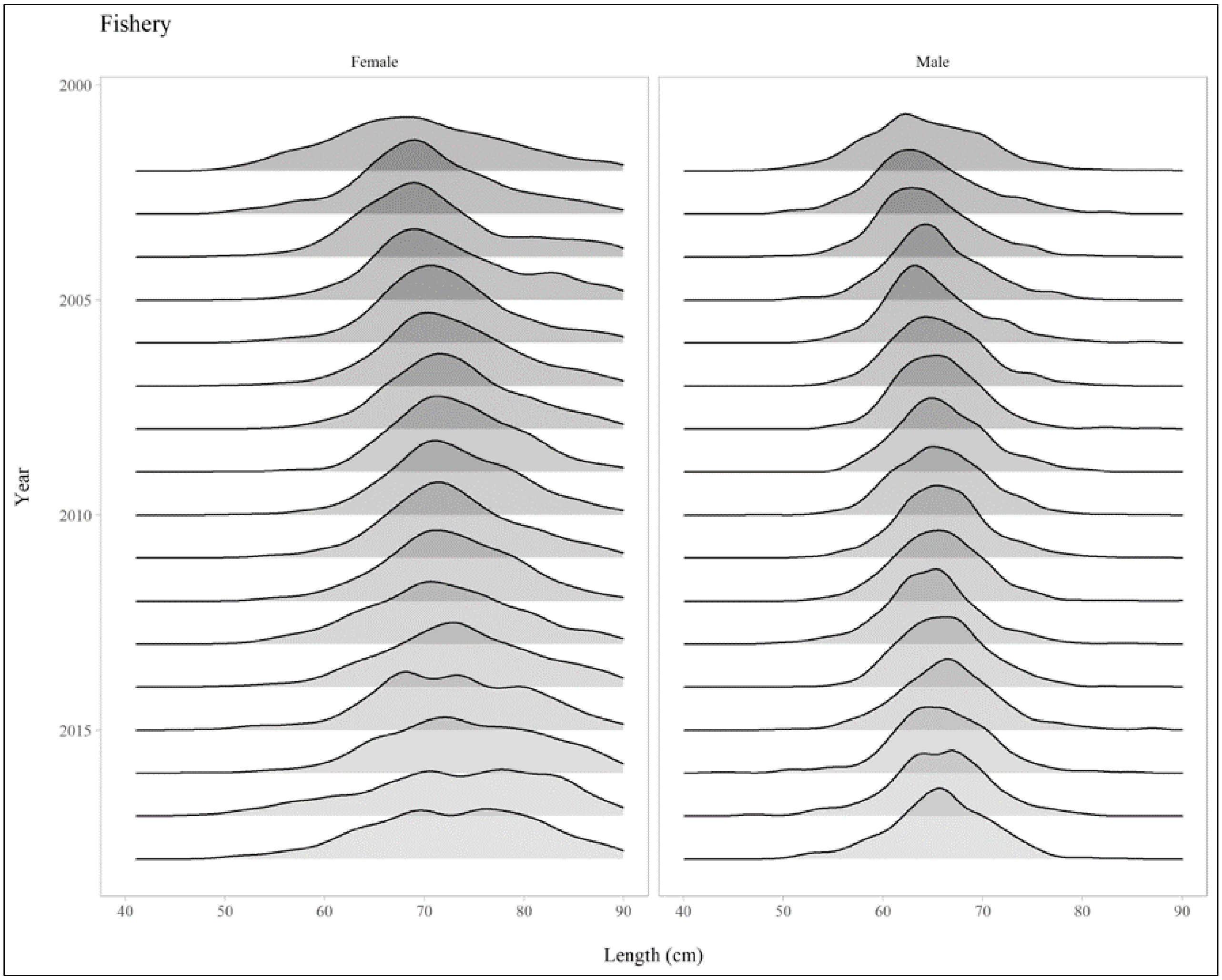

Figure B6.–Fishery length distributions by sex, 2002–2018.

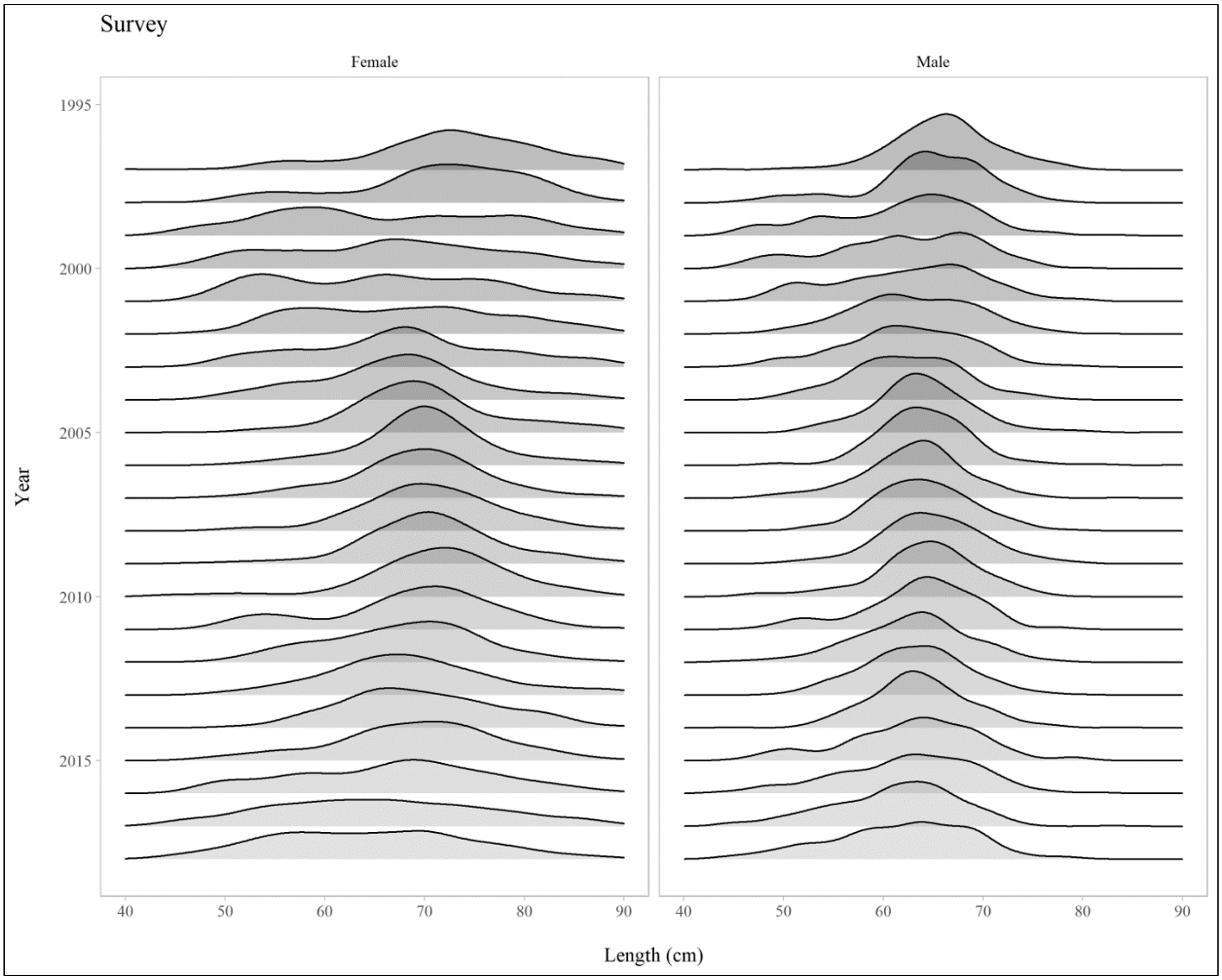

Figure B7.–Longline survey length distributions by sex, 1997–2018.

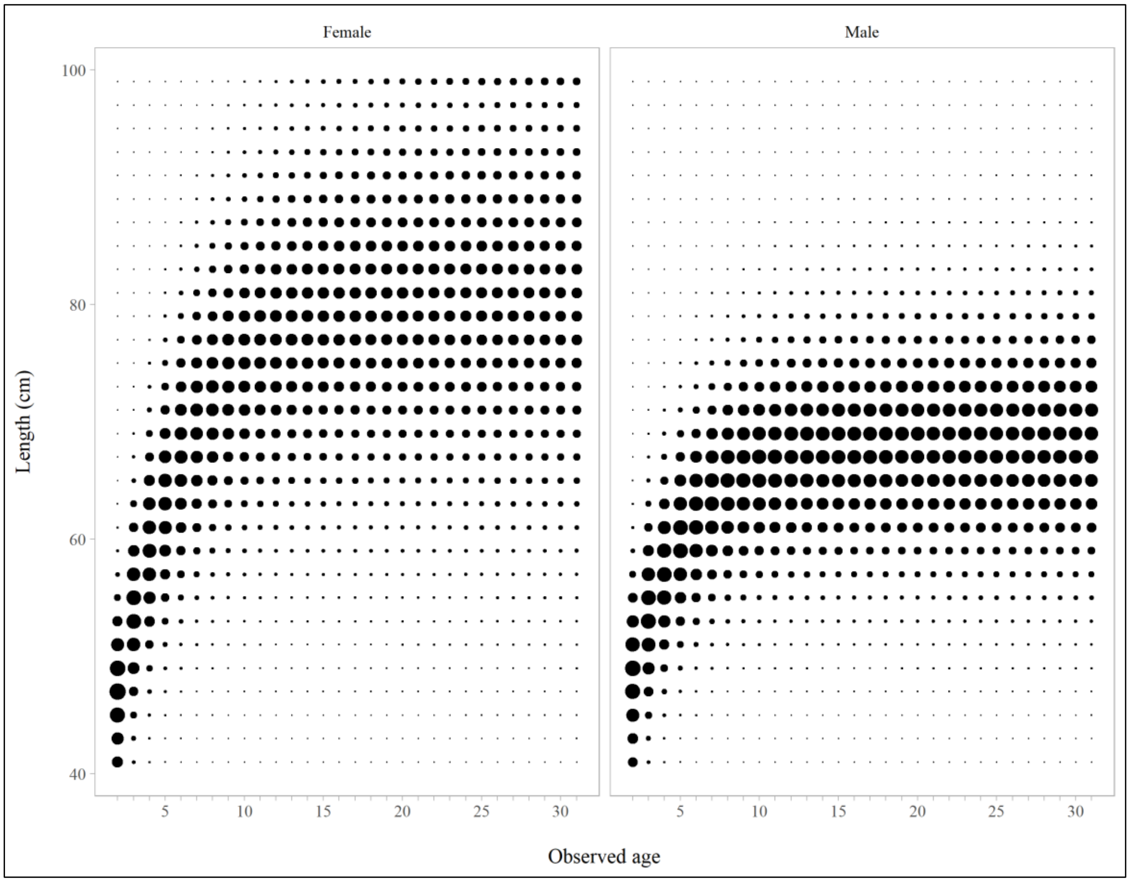

Figure B8.–Age-length key used in the model, with the relative size of the bubbles reflecting the probability that a fish of a given age falls within a certain length bin. The probabilities sum to 1 across each age.

Source: Echave et al. 2012.

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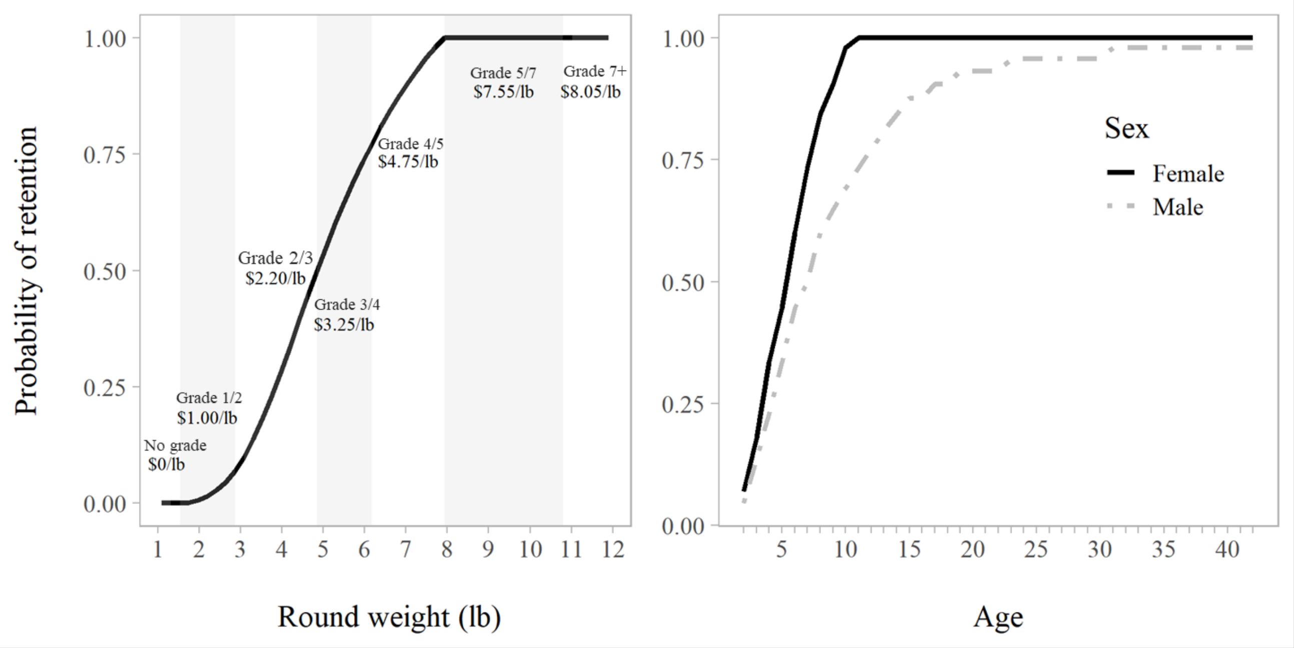

Figure B9.– The probability of retaining a fish as a function of weight in round lb (left panel), sex, and age (right panel). Shaded regions correspond to processor grade and price in dressed lb.

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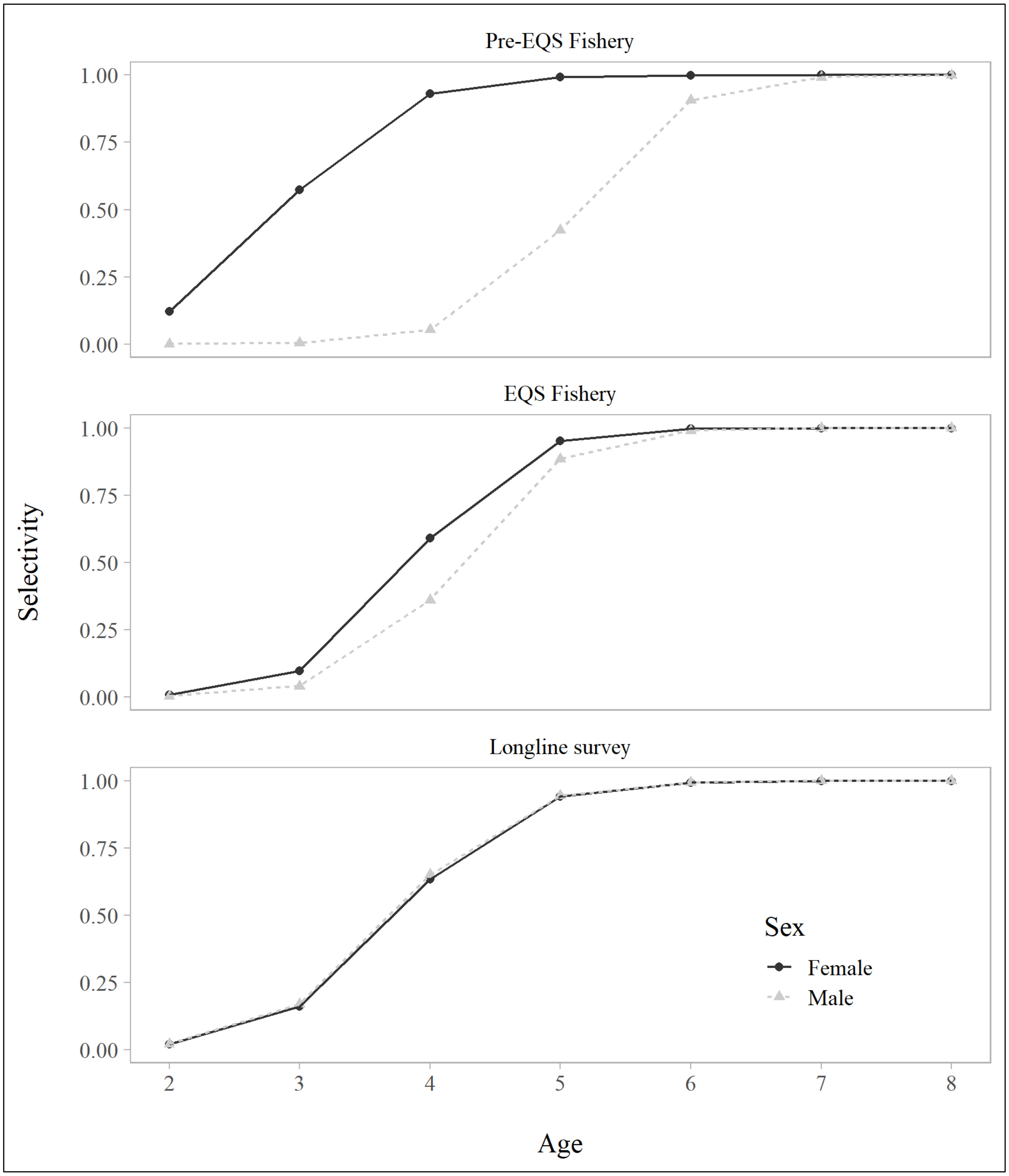

Figure B10.–Fixed age-based selectivity curves for the fishery before the Equal Quota Share program started in 1994 (pre-EQS), the fishery since the implementation of EQS, and the ADF&G longline survey for females (black points) and males (grey triangles).

Source: These parameter estimates were borrowed from the federal stock assessment for the derby fishery (pre-EQS), IFQ fishery (EQS), and NMFS Cooperative longline survey (Hanselman et al. 2018).

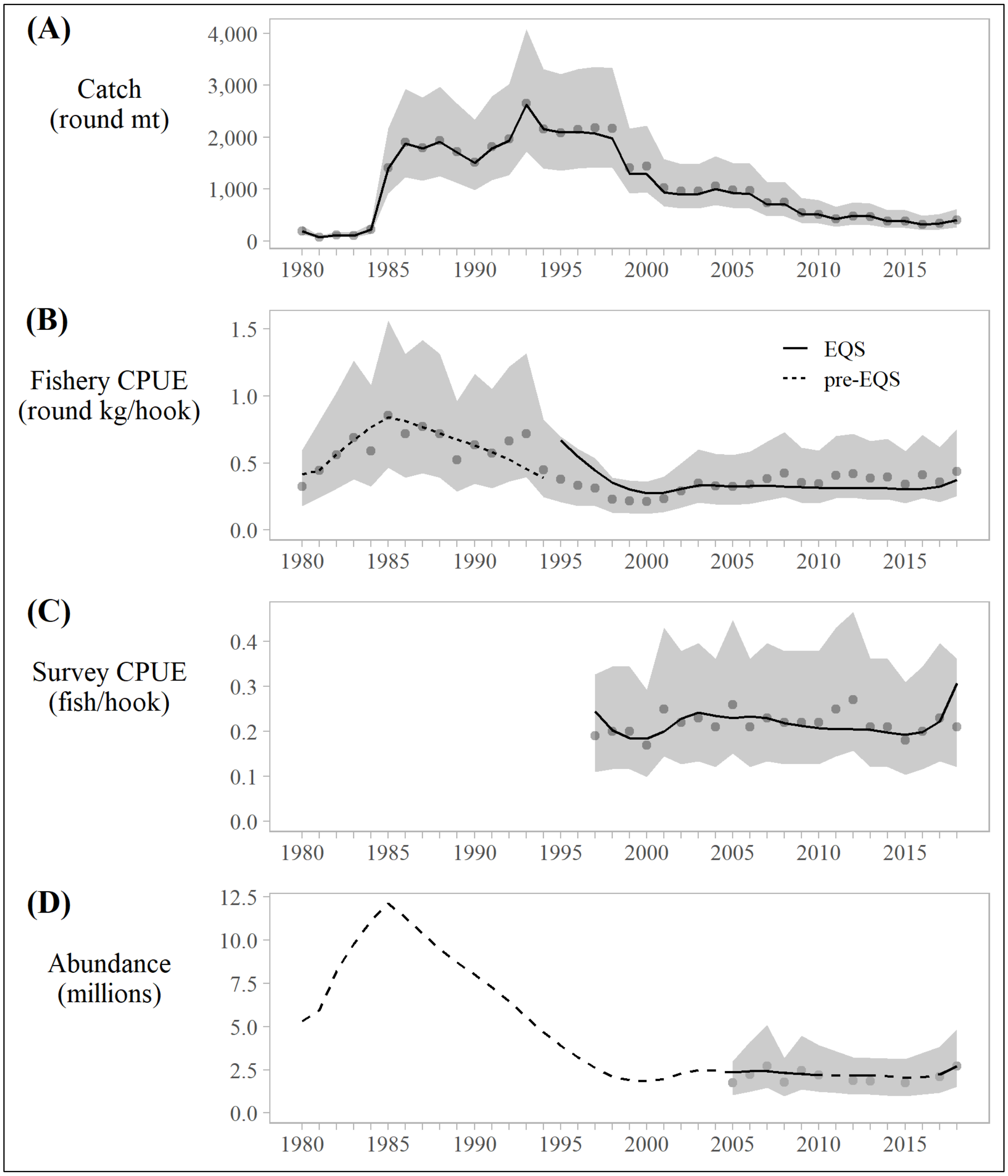

Figure B11.–Fits to indices of catch and abundance with the assumed error distribution shown as shaded grey polygons. Input data are shown as grey points and model fits are shown in black. Indices include (A) harvest (round mt); (B) fishery catch per unit effort in round kg per hook with separate selectivity and catchability time periods before and after the implementation of the Equal Quota Share program in 1994; (C) survey catch per unit effort in number of fish per hook; and (D) mark–recapture abundance estimates in millions. Solid lines and dashed lines in panel D reflect years that data were available (solid lines) and were not available (dashed lines).

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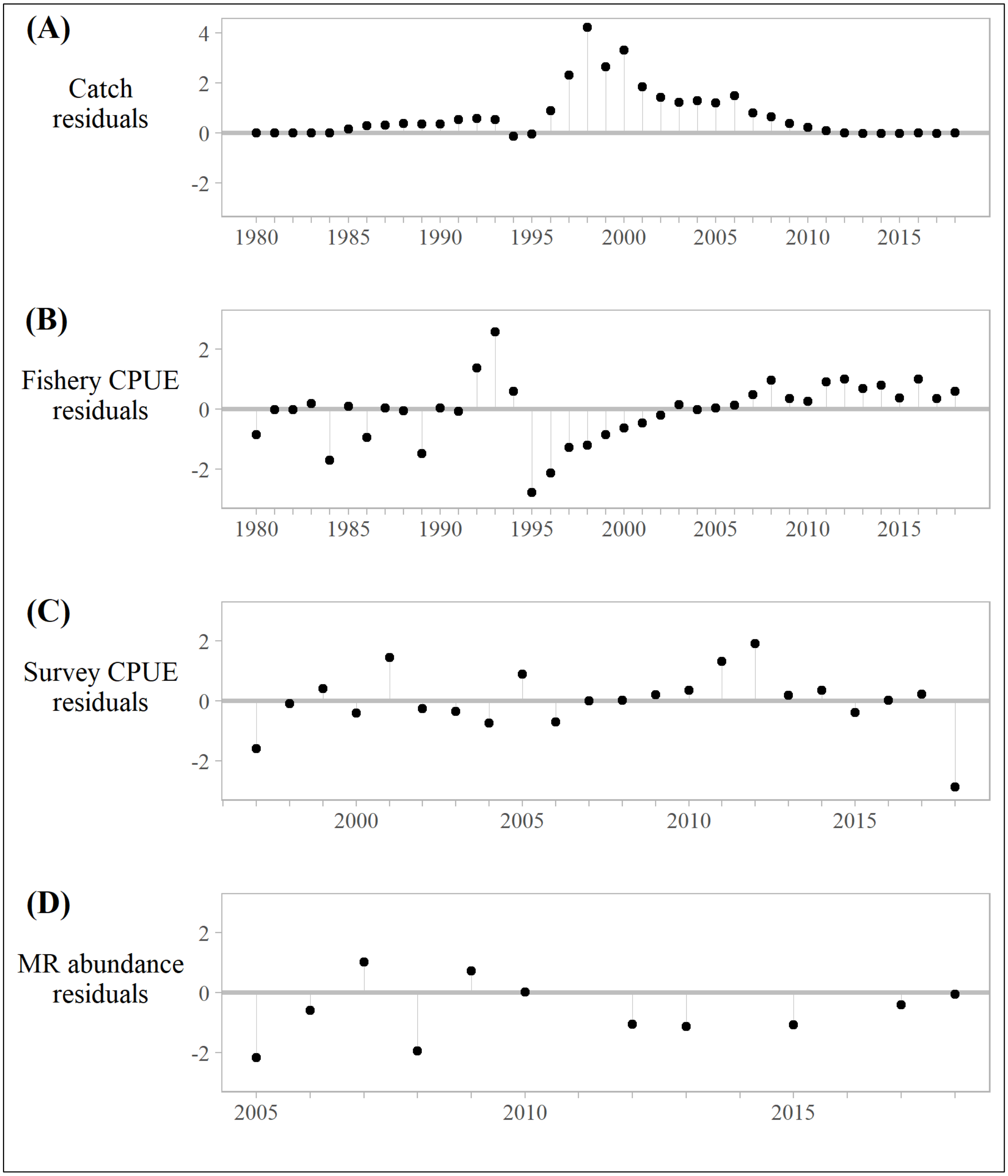

Figure B12.–Standardized residuals of fits to indices of catch and abundance, including (A) harvest, (B) fishery catch per unit effort, (C) survey catch per unit effort, and (D) mark–recapture (MR) abundance.

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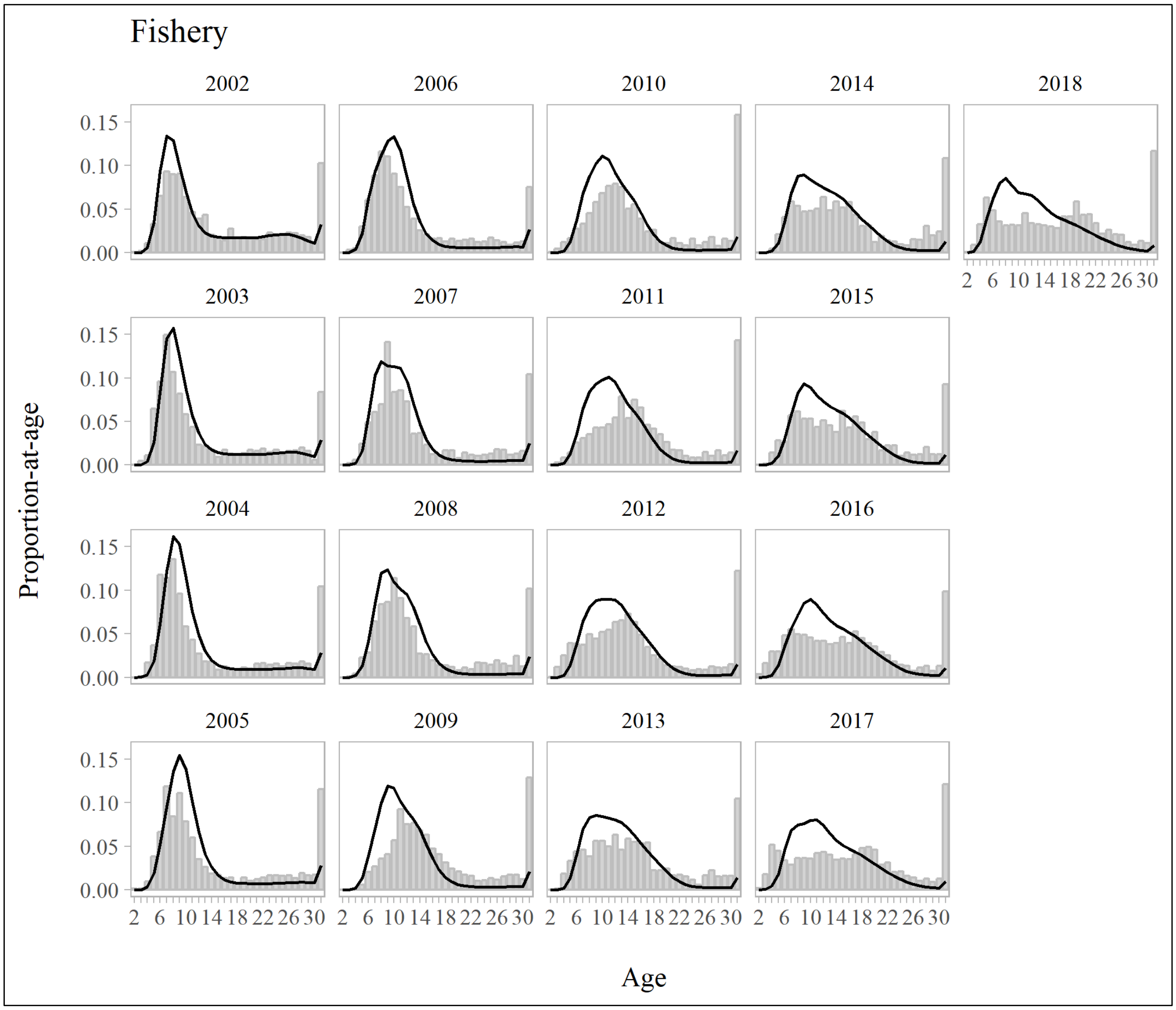

Figure B13.–Fits to fishery age compositions, 2002–2018. Observed (gray bars) and predicted proportions-at-age (black lines) shown.

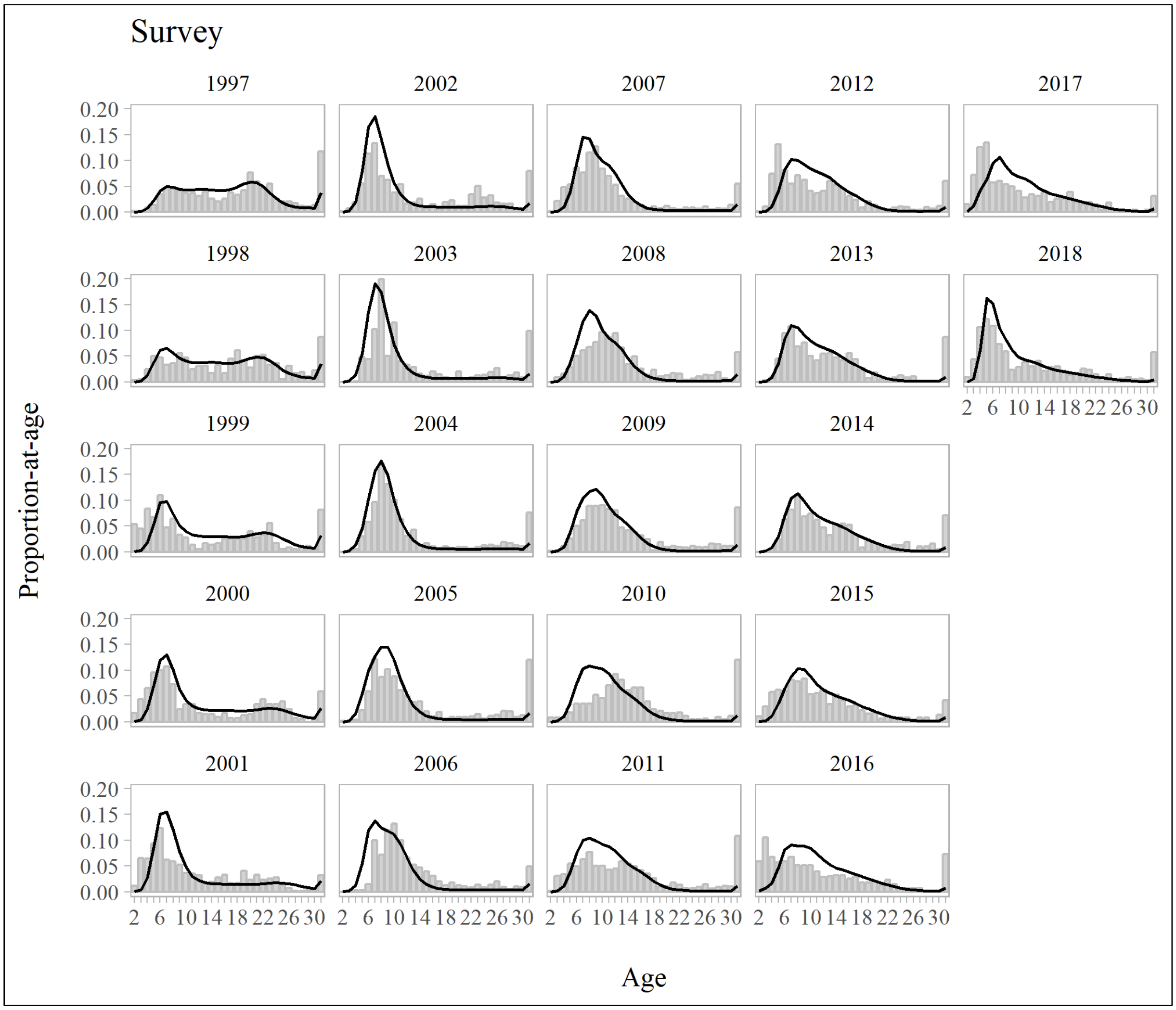

Figure B14.–Fits to survey age compositions, 1997–2018. Observed (gray bars) and predicted proportions-at-age (black lines) shown.

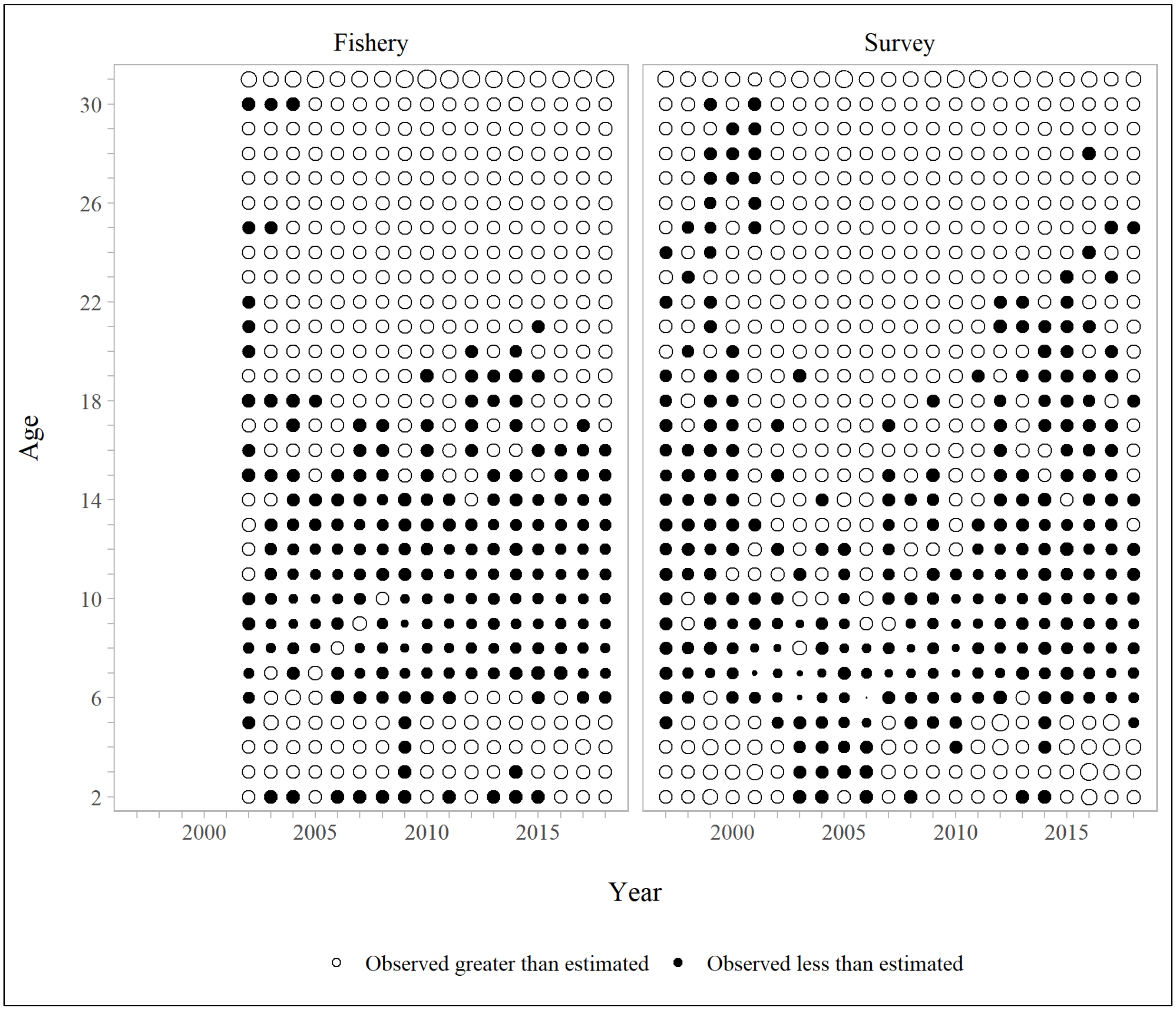

Figure B15.–Standardized residuals of fits to fishery (2002–2018) and survey (1997–2018) age compositions. Size of residual scales to point size. Black points represent negative residuals (observed < predicted); white points represent positive residuals (observed > predicted).

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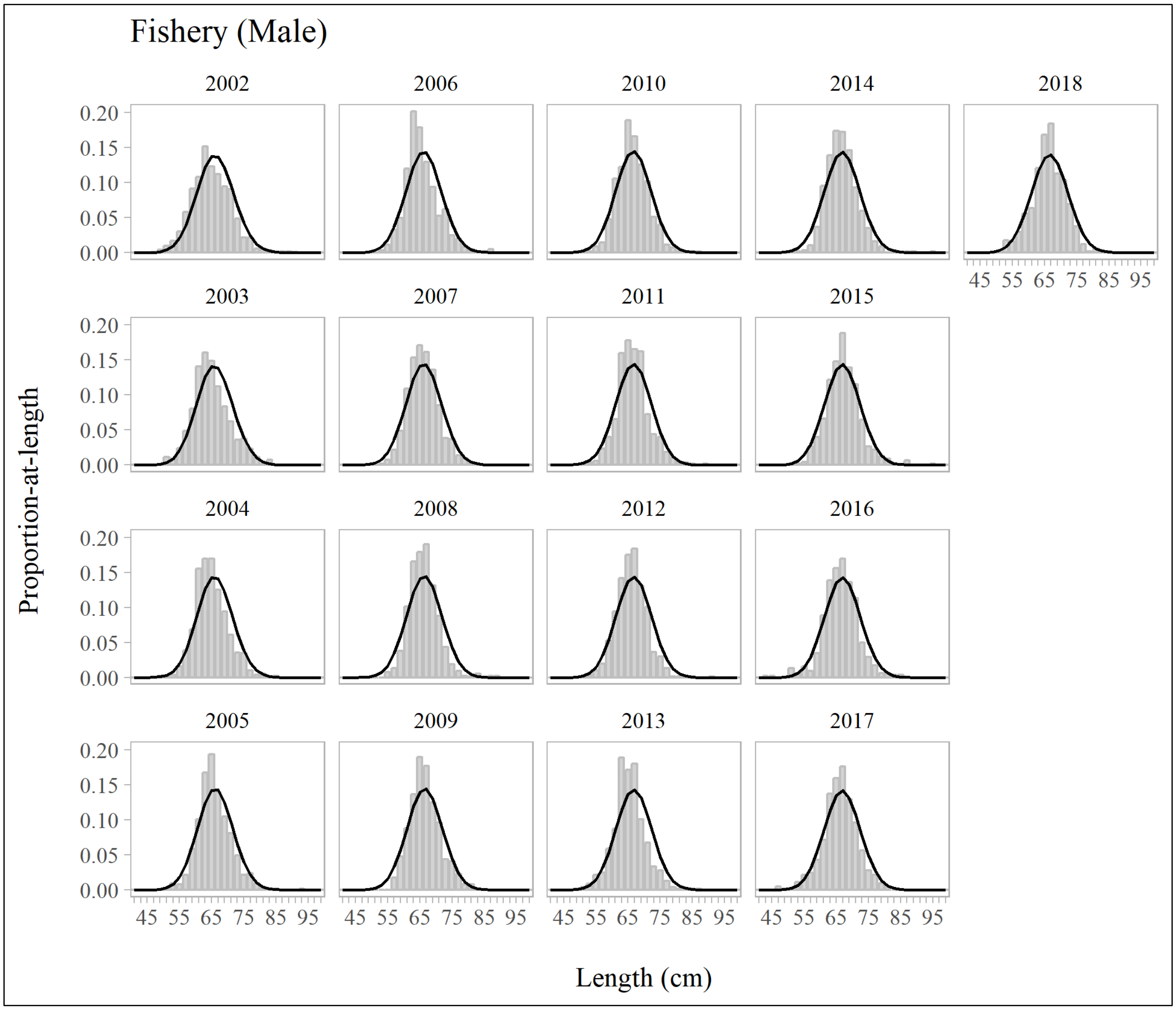

Figure B16.–Fits to male fishery length compositions, 2002–2018. Observed (gray bars) and predicted proportions-at-age (black lines) shown.

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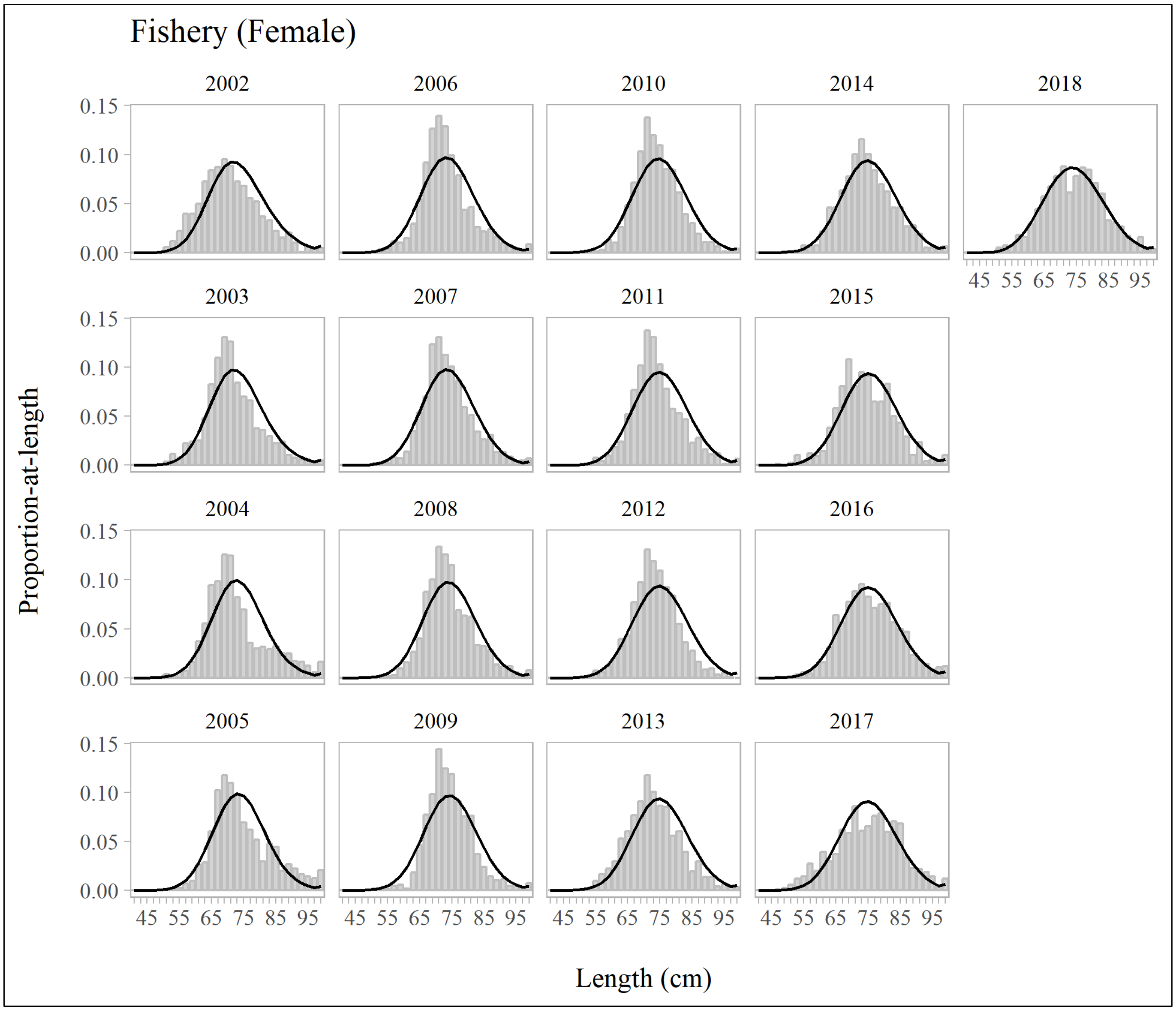

Figure B17.–Fits to female fishery length compositions, 2002–2018. Observed (gray bars) and predicted proportions-at-age (black lines) shown.

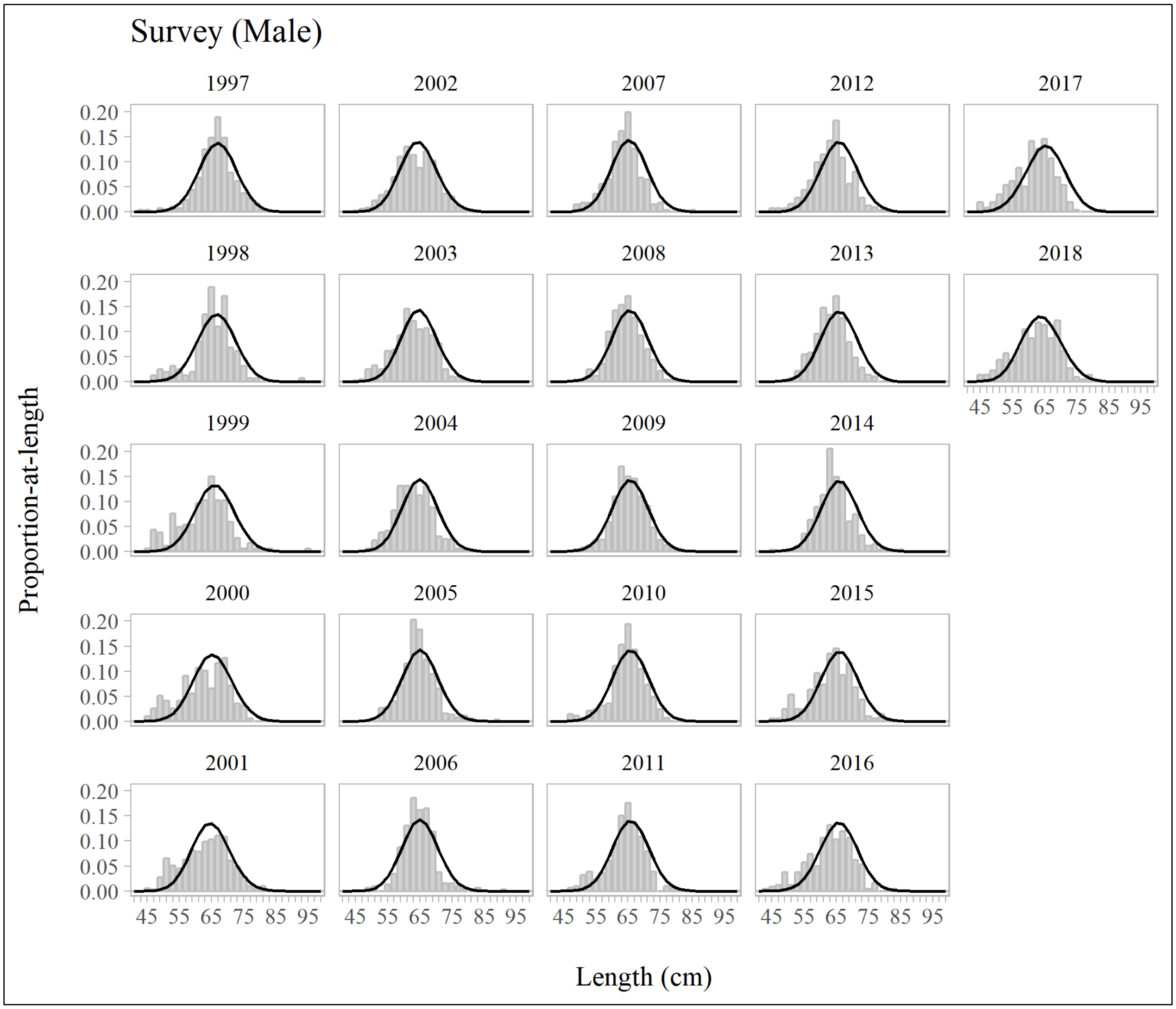

Figure B18.–Fits to male survey length compositions, 1997–2018. Observed (gray bars) and predicted proportions-at-age (black lines) shown.

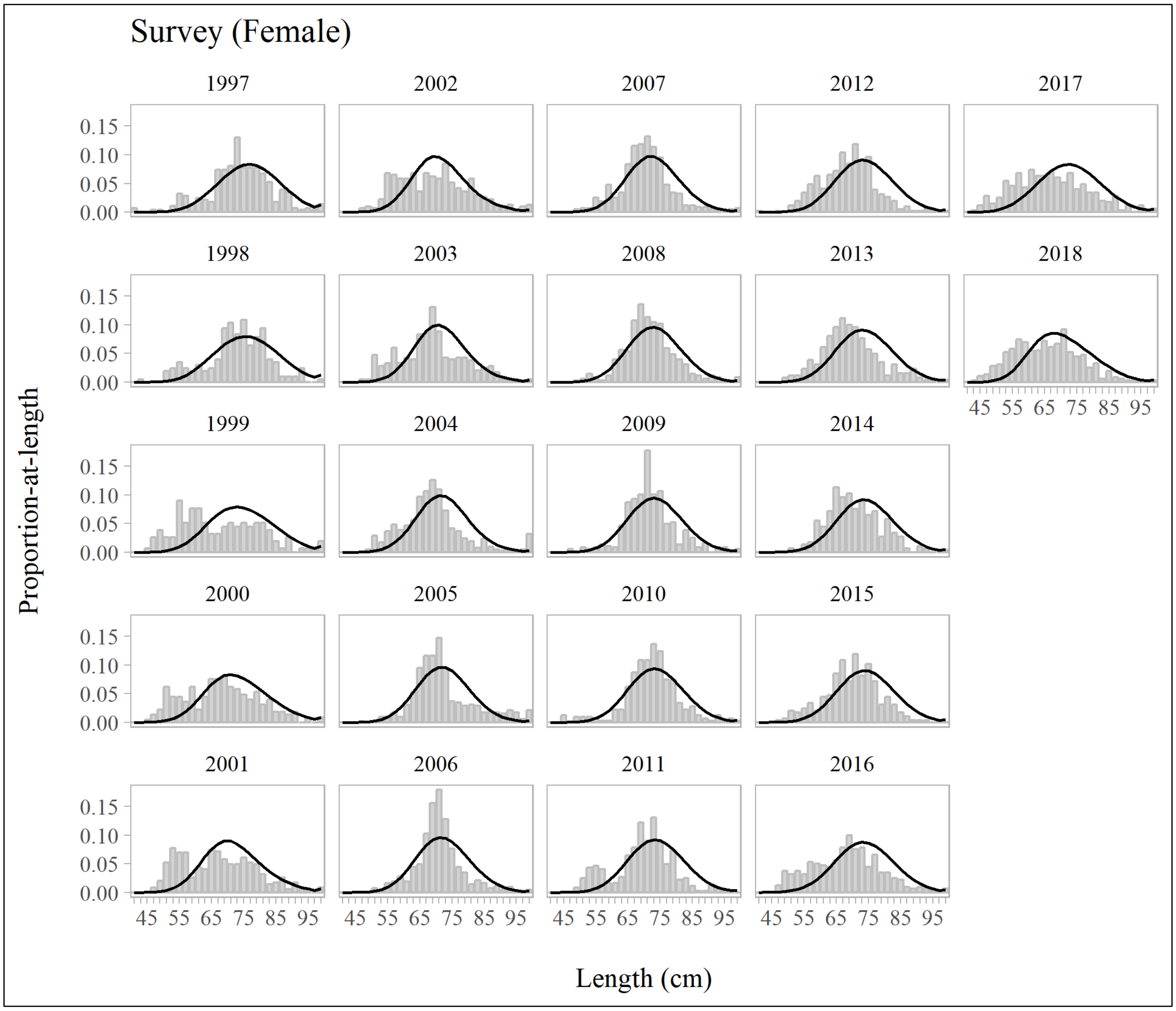

Figure B19.–Fits to female survey length compositions, 1997–2018. Observed (gray bars) and predicted proportions-at-age (black lines) shown.

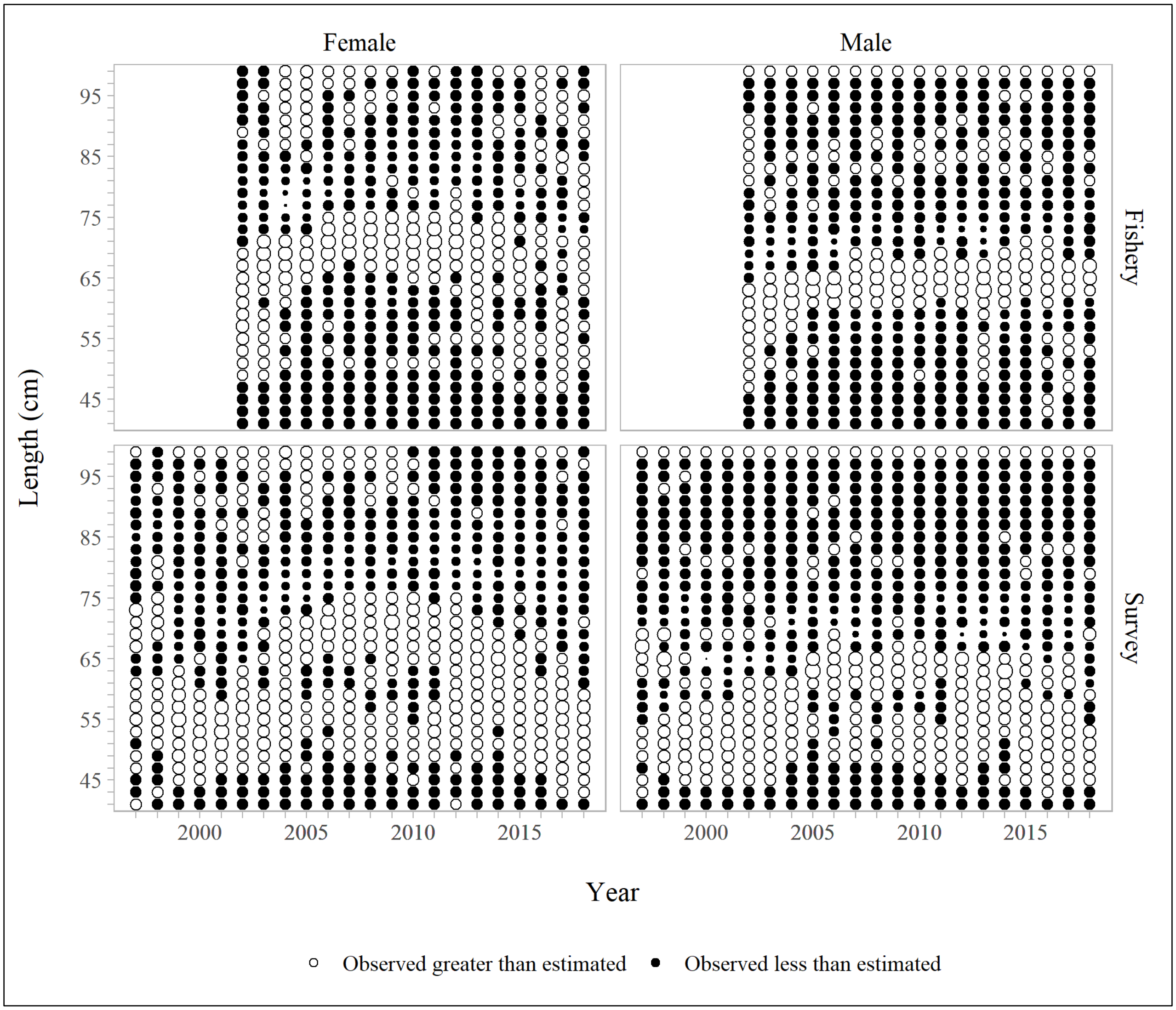

Figure B20.–Standardized residuals of fits to fishery (2002–2018) and survey (1997–2018) length compositions for males and females. Size of circle is relative to the size of the residual. Black points represent negative residuals (observed < predicted); white points represent positive residuals (observed < predicted).

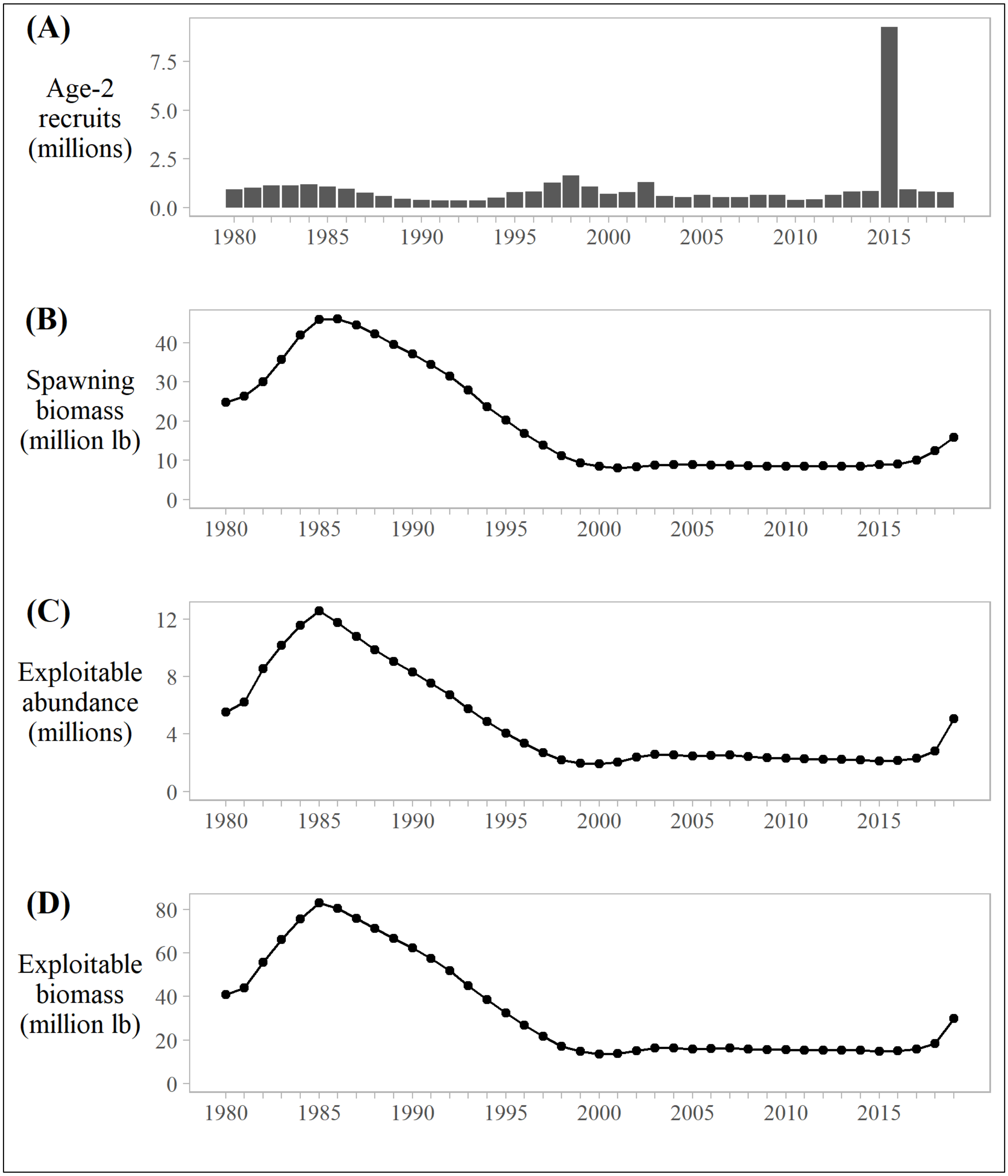

Figure B21.–Model predictions of (A) age-2 recruitment (millions), (B) female spawning stack biomass (million lb), (C) exploitable abundance (millions), and (D) exploitable biomass (million lb).

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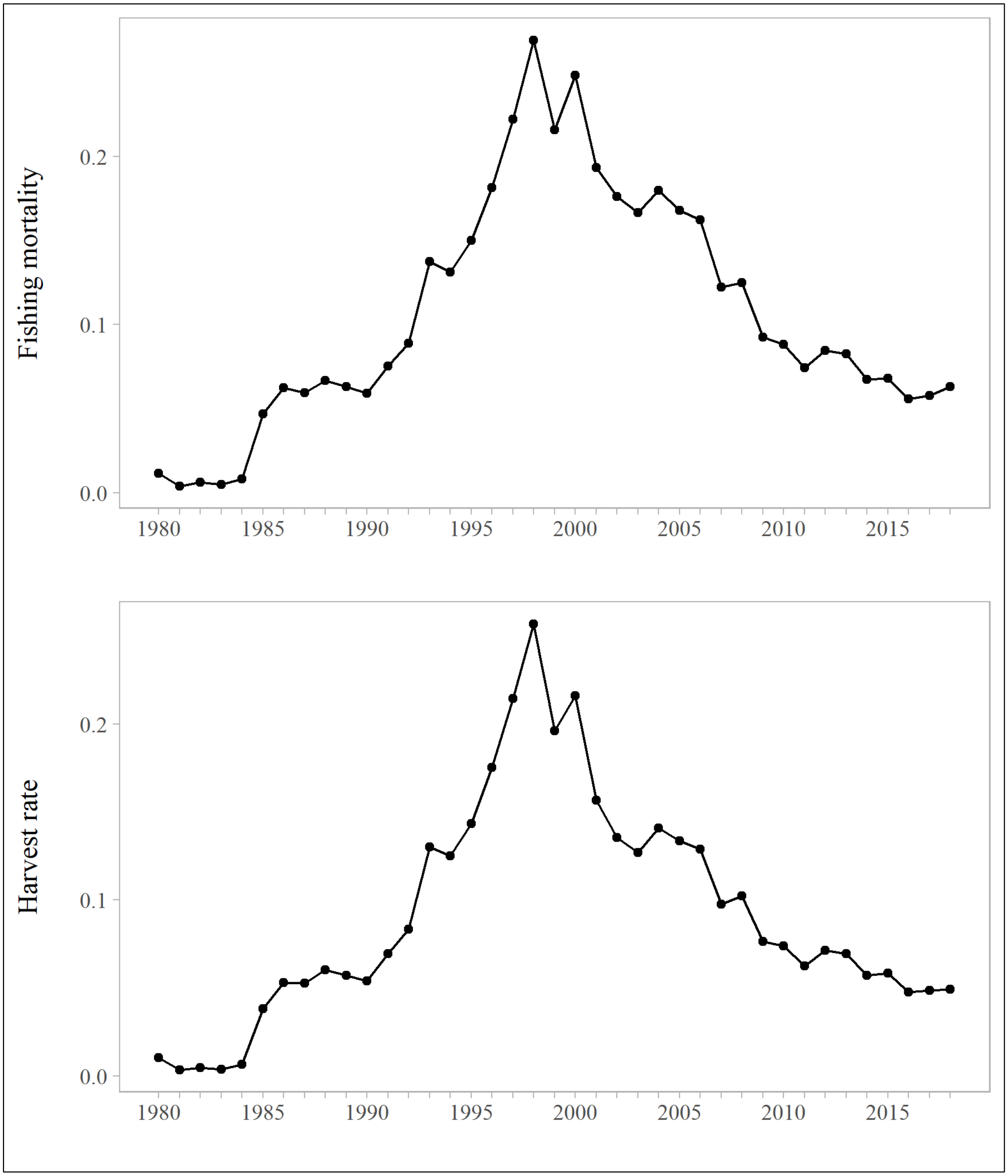

Figure B22.–Model-estimated fishing mortality rate (top) and realized harvest rate (bottom), defined as the ratio of total predicted catch to exploitable biomass. Total predicted catch is the sum of landed catch and discarded biomass assumed to die postrelease.