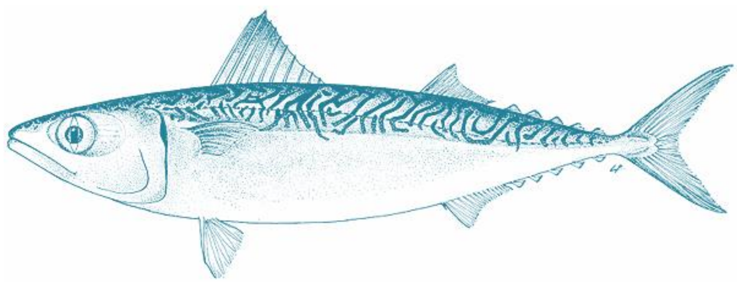
PACIFIC MACKEREL (*Scomber japonicus*) STOCK ASSESSMENT FOR U.S. MANAGEMENT IN THE 2019-20 AND 2020-21 FISHING YEARS



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PREFACE

Resource management authority for the U.S. Pacific mackerel fishery was transferred formally to the Pacific Fishery Management Council (PFMC) in January 2000. Pacific mackerel is one of five species included in the federal coastal pelagic species (CPS) fishery management plan (PFMC 1998). The most recent management stipulations and actions associated with the Pacific mackerel stock, including harvest guidelines (HG) and related metrics are presented in the CPS stock assessment and fishery evaluation (SAFE) document (PFMC 2019). Presently, the management for Pacific mackerel applies to a fishing/management season that spans from July 1st and ends on June 30th of the subsequent year (henceforth, presented as a 'fishing year'). For example, in this report, both two-year (2018-19) and single-year (2018) references indicate the same fishing year that spanned from July 1, 2018 to June 30, 2019. The primary purpose of the ongoing assessment is to provide an estimate of current abundance (in biomass), which is used in an established harvest control rule for setting respective quotas.

Beginning in 2015, the PFMC implemented an assessment/management schedule for Pacific mackerel based on: 1) conducting a full (benchmark) assessment every four years starting in 2015; 2) conducting a catch-only projection assessment every four years starting in 2017; and 3) setting harvest and management guidelines as biennial specifications that serve for two consecutive (fishing) years. In 2015, a full (benchmark) assessment was conducted for purposes of providing management advice that served for two (fishing) years, 2015-16 and 2016-17 (Crone and Hill 2015). A catch-only projection assessment was conducted in May 2017 that provided harvest guidelines (HG) for managing the Pacific mackerel resource for fishing years 2017-18 and 2018-19 (Crone and Hill 2017). The report presented here represents a benchmark assessment that was formally reviewed in April 2019 for purposes of advising management for the next two fishing years, 2019-20 and 2020-21 (STAR 2019).

This report is based on the most recent Pacific mackerel stock assessment review (STAR), which was held from April 23-25, 2019 at the Southwest Fisheries Science Center (SWFSC/NOAA/NMFS) in La Jolla, CA to evaluate the ongoing stock assessments used to provide management guidance on a systematic basis. The first draft of the assessment report (pre-STAR) was distributed prior to the review meeting in April, which served as the basis for conducting critique and discussion during the three-day meeting (Crone et al. 2019). The report here represents a final stock assessment document (post-STAR), reflecting work/discussion conducted at the review and associated recommendations from the STAR panel. The STAR panel, as well as stock assessment team (STAT), concluded that final base model ALT_19 represented the best available science for purposes of advising Pacific mackerel management in the future. The final base model ALT_19 (post-STAR) presented in this report was generally similar to the preliminary base model ALT_19 (pre-STAR), with the exception that fishery age-composition data received less emphasis (down-weighted) in the overall statistical population dynamics model.

An important conclusion from the review in April 2019 was recognition/support of the acoustic-trawl (AT) survey conducted annually by the SWFSC for providing the most scientifically sound data available for assessing abundance of the Pacific mackerel stock in any given year. It is important to note that the STAR panel's conclusions regarding the use of AT survey data for assessing abundance of Pacific mackerel also considered an important (second) review that was held in February 2018 for purposes of critically evaluating the AT survey methods in general and in particular, determining the utility of the data in ongoing assessment models used to advise management of the CPS assemblage of the California Current (PFMC 2018b). It was concluded that AT data represented the best scientific information available on an annual basis for assessing abundance of all members of the CPS assemblage (except Pacific herring), and approved the use of these data for directly (survey-based) or indirectly (model-based) assessing the status of the stock, depending on the species of interest (PFMC 2018b). Ultimately, this Pacific mackerel stock assessment report reflects these collective decisions, with the AT survey abundance index representing the foundation information for regularly providing management an estimate of stock biomass (age 1+ fish, mt) via a direct measure of abundance (survey-based, AT survey biomass index) or alternatively, as an indirect estimate using an age-structured integrated assessment model (model-based, ALT_19).

It is important to note that although the focus of this report is final base model ALT_19 supported by both the STAR panel and STAT, the STAT\SWFSC strongly feel that the most efficient scientific assessment for regularly advising management regarding the status (abundance) of any member of the CPS assemblage is the AT survey-based approach (see Assessment – AT survey\Overview and Conclusions). The survey-based assessment was generally considered the better long-term approach, recognizing a notable shortcoming of this method in the short-term, given the need to forecast stock biomass one full year after the last survey observation for purposes of providing management metrics for the current fishing year of interest. Both the STAT and STAR panel agreed that the preferred survey-based assessment could be effectively implemented by shifting the fishery start date several months to minimize the time lag between the most recent survey and the official start date of the fishery, e.g., moving the start of the fishery from July 1st to January 1st would accomplish this goal. To summarize, final base model ALT presently represents the recommended assessment approach to adopt for the upcoming fishing years 2019-20 and 2020-21, with a survey-based assessment that accommodates a more workable projection period recommended for subsequent fishing years.

The stock assessment report includes four primary sections: first, a summary (Executive summary); second, background information concerning fishery operations and management associated with the Pacific mackerel resource over time (Introduction); third, summaries of various sources of sample data used in the assessment (Assessment data); and fourth, methods/models used to conduct the assessment (Assessment). The Assessment section includes two parts based on the assessment approach (Assessment – Acoustic-trawl survey and Assessment – Model). Readers should first read the section Assessment – Acoustic-trawl survey\Overview, which presents the relative merits and related considerations for survey- vs. model-based approaches for advising CPS management. Recent Pacific sardine stock assessments (Hill et al. 2017, 2018, 2019) serve as the basis for the report style adopted here for Pacific mackerel.

Field, laboratory, and analytical work conducted in support of the ongoing Pacific mackerel assessment is the responsibility of the SWFSC and its staff, including: principal investigators (P.R. Crone, K.T. Hill, J.P. Zwolinski, M.J. Kinney); and collaborators (D.A. Demer, E. Dorval, K. Steirhoff, B. Macewicz, D. Griffith, Y. Gu, H.-H. Lee, S. Teo, K. Piner). Fishery data collection is largely the responsibility of the state fishery agencies, Washington Department of Fish and Wildlife (WDFW), Oregon Department of Fish and Wildlife (ODFW), and particularly, California Department of Fish and Wildlife (CDFW). Age determinations from sampled fish were conducted by staff from both the SWFSC (J. Taylor) and CDFW (D. Porzio and L. Laughlin). Principal investigators are responsible for developing assessments, presenting relevant background information, and addressing the merits/drawbacks of the two assessment approaches in the context of meeting the management goal (current estimate of stock biomass).

EXECUTIVE SUMMARY

Stock

The full range of Pacific mackerel (*Scomber japonicas*) in the northeastern Pacific Ocean is from southeastern Alaska to Banderas Bay (Puerto Vallarta), Mexico, including the Gulf of California. Although stock structure of this species off the Pacific coast of North America is not known definitively, it is generally hypothesized that three spawning aggregations exist currently: one in the Gulf of California; one in the vicinity of Cabo San Lucas (Baja California, Mexico); and one along the Pacific coast north of Punta Abreojos (Baja California) that extends north to areas off southern California, and even further during favorable oceanographic periods to waters off the U.S. Pacific Northwest. The latter sub-stock is harvested by fishermen in the U.S. and Mexico, and is the population considered in this assessment.

Catch

Pacific mackerel are primarily landed by commercial purse-seine vessels operating along the U.S Pacific coast, as well as off Baja California by a fleet based in Mexico (Table ES-1). A minor recreational fishery, including commercial passenger fishing vessel (CPFV), small private boat, pier, beach, etc. has traditionally operated in California waters, with strictly limited landings of Pacific mackerel relative to the commercial fishery operations (Table ES-1). Catch time series from 2008-18 were used in this assessment, based on landings from both commercial (U.S. and Mexico) and recreational (U.S.) fisheries.

Table ES-1. Landings (mt) of Pacific mackerel by fishery (2008-18). Recreational fishery proportion of total landings is also presented. A single, combined (commercial and recreational) fishery is used in final base model ALT_19.

	Commercial				Recreational		Recreational
Fishing year	**MX**	**CA**	**OR**	**WA**	**CA**	**Total**	**(prop.)**
08	803.1	4,331.6	57.6	9.0	251.1	5,452.3	0.05
09	49.3	2,956.9	53.1	4.9	231.1	3,295.3	0.07
10	1,916.8	2,052.7	49.0	1.6	187.2	4,207.3	0.04
11	2,231.8	1,753.6	201.9	83.0	112.5	4,382.7	0.03
12	7,390.0	3,171.0	1,587.8	719.2	76.0	12,944.0	0.01
13	2,552.5	11,262.5	437.8	173.2	108.9	14,535.0	0.01
14	4,098.8	4,409.7	1,214.6	502.2	197.2	10,422.5	0.02
15	9,178.8	4,395.5	7.2	1.2	203.0	13,785.8	0.01
16	11,706.8	2,490.0	3.7	21.6	149.6	14,371.8	0.01
17	2,794.3	1,309.4	45.4	4.2	167.6	4,320.8	0.04
18	6,066.3	4,773.4	341.8	140.5	165.3	11,487.2	0.02
Avg. (2008-18)	4,435.3	3,900.6	363.6	151.0	168.1	9,018.6	0.03

Data and assessment

In the past, various age-structured population dynamics models have been used to assess the status of Pacific mackerel off the U.S. Pacific coast, which were generally based on fishery landings, age/length compositions, and relative indices of abundance from fisheries and/or research surveys. The last full assessment for Pacific mackerel was conducted in 2015 for providing management advice for two consecutive (fishing, July-June) years, 2015-16 and 2016-

17. A catch-only projection assessment was conducted in 2017 that served for fishing years 2017-18 and 2018-19. The assessment report presented here represents a benchmark assessment for purposes of advising management for fishing years 2019-20 and 2020-21. Final base model ALT_19 represented the supported/recommended model from the formal review conducted in April 2019. The age-structured modeling framework Stock Synthesis was used to develop final base model ALT_19, which included the following data (2008-18): fishery landings, age-composition time series associated with the fishery and acoustic-trawl (AT) survey; fishery empirical weight-at-age data; and AT index of abundance.

Spawning stock biomass and recruitment

Recruitment was modeled using the Beverton-Holt (B-H) spawner-recruit relationship, with fixed recruitment variance (σ_R = 0.75) and steepness (h = 0.75), and estimated virgin recruitment (R_0) and recruitment deviations (2008-18). The estimated spawning stock biomass (SSB) of Pacific mackerel decreased from 2008 to 2016, with SSB increasing more recently and into the forecast period (2019-20), based on relatively high recruitment abundance estimated in 2018 (Table ES-2). Estimated recruitment time series indicated relatively high recruitment success for years 2011, 2016, and 2018 (Table ES-2). It is important to note that a major area of uncertainty associated with ongoing Pacific mackerel assessments (as well as CPS assessments in general) is estimation of highly variable recent recruitment (age-0 fish), given the contribution of widely fluctuating estimates (pulses) of age-0 fish to estimated stock biomass (age-1+ fish, mt) used for management in subsequent years, e.g., age 0-2 fish typically comprise roughly 80% of the total population biomass in any given year.

Table ES-2. Estimated stock biomass (B, age 1+ fish, mt), recruitment (R, age-0 fish, in 1,000s), spawning stock biomass (SSB, female and male), fishing mortality (F), and exploitation rate (EXP, calendar-year catch/mid-year total biomass) time series for Pacific mackerel associated with final base model ALT_19.

Fishing year	B (mt)	R (1,000s of fish)	SSB (mt)	F (yr^{-1})	EXP (catch/B)
08	63,535	265,093	26,676	0.16	0.06
09	68,289	95,052	22,774	0.10	0.07
10	42,891	158,226	19,540	0.23	0.04
11	36,826	493,683	15,288	0.14	0.05
12	69,167	121,856	14,857	0.42	0.12
13	44,439	207,560	13,842	0.69	0.21
14	35,591	151,934	11,123	0.49	0.17
15	30,702	147,110	8,236	0.93	0.24
16	22,762	336,228	5,822	0.47	0.20
17	41,237	51,942	6,280	0.21	0.12
18	25,943	620,762	7,512	0.31	0.06
19	71,099	216,893	11,071	na	na
20	56,058	222,641	13,394	na	na
Avg. (2008-20)	46,811	237,614	13,570	0.38	0.12

Stock biomass
Similar to estimated SSB, Pacific mackerel stock biomass (age 1+ fish, mt) used to advise management generally declined from 2008 to 2018, with the exception of 2012 that reflected abundance that included a large recruitment pulse estimated in 2011 (Table ES-2). Relatedly, high recruitment estimates in 2016 and 2018 translated to relatively higher estimated stock biomass in 2017 and into the forecast period (2019-20), respectively.

Exploitation status
Estimated rates of instantaneous fishing mortality (F, yr^{-1}) for Pacific mackerel have fluctuated over the last decade (2008-18), from roughly 0.1 to 0.9, with recent *F*s <0.4 (Table ES-2). Exploitation rate (calendar year catch/mid-year total biomass) time series generally followed the estimated *Fs* over time, with annual removal rates (including Mexico catches) that ranged from roughly 5 to 25% over the modeled timeframe (Table ES-2).

Ecosystem considerations
Pacific mackerel are part of the CPS assemblage of the northeastern Pacific Ocean, which represents an important forage base in the California Current. Pacific mackerel grow rapidly, feeding on plankton (plants and animals) and other CPS, including smaller northern anchovy, Pacific sardine, market squid etc. The species is prey for various larger fish (shark and tuna spp.), marine mammals, and seabirds. Pacific mackerel do not typically represent a dominant species of the CPS assemblage in most years, with absolute abundance likely less than that characterizing the more productive CPS, such as Pacific sardine and particularly, northern anchovy. However, population biomass can increase to relatively high levels during periods of favorable oceanographic conditions, which are hypothesized to be the driving mechanisms related to recruitment success and associated stock abundance of this species, as well as CPS in general.

Harvest control rules, scientific uncertainty, and management performance
Since 2000, the Pacific mackerel stock has been managed under a Federal Management Plan (FMP) harvest policy, stipulating that an optimum yield for this species be set according to the following harvest control rule (HCR):

$$\text{Harvest} = (\text{Biomass-Cutoff}) \bullet E_{MSY} \bullet \text{Distribution},$$

where Harvest is the harvest guideline (HG), Biomass is age 1+ stock biomass (mt) in the respective fishing year (71,099 mt in July 2019 and 56,058 mt in July 2020), Cutoff (18,200 mt) is the lowest level of estimated biomass above which harvest is allowed, E_{MSY} (30%, also referred to as Fraction) is the proportion of biomass above the Cutoff that can be harvested by fisheries, and Distribution (70%) is the average proportion of stock biomass (ages 1+) assumed in U.S. waters (PFMC 1998). Harvest stipulations under the federal FMP are applied to a July-June fishing year. The HG estimate associated with final base model ALT_19 for July 2019 was 11,109 mt (Table ES-3a) and 7,950 mt for July 2020 (Table ES-3b). Additional HCR statistics are also included in Tables ES-3a-b for specifying overfishing limits (OFL), as well as a range of acceptable biological catches and limits (ABCs and ACLs) based on different probability levels of overfishing using 'P-star' and associated ABC 'buffer' calculations. Final base model ALT_19 estimates of SSB uncertainty, used for calculating sigma for P-star buffers, were CV=37.6% (σ=0.363) in 2019 and

CV=45.4% (σ=0.433) in 2020, so the current default sigma (0.5) was applied to Tier 1 ABCs in Tables ES-3a-b.

Table ES-3. Pacific mackerel harvest control rules and associated management metrics for final base model ALT_19: a) 2019-20 fishing year; and b) 2020-21 fishing year.

a)

Harvest Control Rule Formulas					
OFL = BIOMASS * E_{MSY} * DISTRIBUTION					
ABC = BIOMASS * $BUFFER_{P\text{-}star}$ * E_{MSY} * DISTRIBUTION					
HG = (BIOMASS - CUTOFF) * E_{MSY} * DISTRIBUTION					
Harvest Formula Parameters					
BIOMASS (ages 1+, mt)	71,099				
P-star	0.45	0.40	0.35	0.30	0.25
ABC Buffer(Tier 1 Sigma=0.5)	0.939	0.881	0.825	0.769	0.714
ABC Buffer(Tier 2 Sigma=1.0)	0.882	0.776	0.680	0.592	0.509
E_{MSY}	0.3				
CUTOFF (mt)	18,200				
DISTRIBUTION (U.S.)	0.7				
Harvest Control Rule Values (MT)					
OFL =	**14,931**				
ABCTier 1 =	14,020	13,154	12,318	11,482	10,661
ABCTier 2 =	13,169	11,586	10,153	8,839	7,600
HG =	**11,109**				

b)

Harvest Control Rule Formulas					
OFL = BIOMASS * E_{MSY} * DISTRIBUTION					
ABC = BIOMASS * $BUFFER_{P\text{-}star}$ * E_{MSY} * DISTRIBUTION					
HG = (BIOMASS - CUTOFF) * E_{MSY} * DISTRIBUTION					
Harvest Formula Parameters					
BIOMASS (ages 1+, mt)	56,058				
P-star	0.45	0.40	0.35	0.30	0.25
ABC Buffer(Tier 1 Sigma=0.5)	0.935	0.873	0.813	0.754	0.696
ABC Buffer(Tier 2 Sigma=1.075)	0.874	0.762	0.661	0.569	0.484
E_{MSY}	0.3				
CUTOFF (mt)	18,200				
DISTRIBUTION (U.S.)	0.7				
Harvest Control Rule Values (MT)					
OFL =	**11,772**				
ABCTier 1 =	11,007	10,277	9,571	8,876	8,193
ABCTier 2 =	10,289	8,970	7,781	6,698	5,698
HG =	**7,950**				

It is important to note that management performance metrics applicable to Pacific mackerel have changed over time, including final stipulated quotas based on HGs or ACLs, depending on the year (2008-18). In 2007, the HG/ACL was increased substantially to 40,000 mt and remained at this quota until 2009, when the calculated HG (55,408 mt) was reduced by management to 10,000 mt based on limited landings in recent years, with the adjusted quota applicable through the 2010-11 fishing year that included an additional 1,000 mt incidental landing allowance (11,000 mt). Following the benchmark stock assessment conducted in 2011, a HG/ACL of roughly 31,000 mt was implemented for two consecutive fishing years. Catch-based projection assessments were used to set quotas for 2013 (~39,000 mt) and 2014 (~29,000 mt). Quotas have remained at approximately 21,000-27,000 mt since 2015. Note that from a management context, the CPS fishery has not fully utilized quotas since the late 1990s, with total landings notably below recommended catches. Landings and associated HGs/ACLs since 2008 are presented in Table ES-4.

Table ES-4. U.S. harvest guidelines/acceptable biological catches (HG/ACL, mt) and landings (mt) for Pacific mackerel since 2008. HG/ACL reflects final stipulated quotas.

Fishing year	HG/ACL (mt)	Landings (mt)
2008	40,000	4,398
2009	10,000	3,015
2010	11,000	2,103
2011	30,386	2,038
2012	30,386	5,478
2013	39,268	11,874
2014	29,170	6,127
2015	21,469	4,404
2016	21,161	2,515
2017	26,293	1,359
2018	23,840	5,256

Unresolved problems and major uncertainties

In this assessment, the most objective source of abundance data (AT survey) available presently for assessing population dynamics of the Pacific mackerel stock is used in the context of both survey- and model-based assessments. However, it is important to recognize that: 1) inherent uncertainty regarding the portion of the hypothesized stock's distribution in U.S. waters each year (i.e., availability in surveyed areas) will never be known definitively, given its extensive range dictated largely by environmental factors; and as importantly, 2) the distribution portion is necessarily not constant over time, but changing in concert with prevailing oceanographic drivers. Spatial uncertainty regarding fish vs. survey distribution each year is primarily in terms of the species' latitudinal distribution south of San Diego into waters off Baja California and less so but still not well understood, its longitudinal distribution west of the survey's offshore boundaries. Given this underlying survey catchability (q) uncertainty, AT abundance time series was modeled using an informative prior in final base model ALT_19, with plausible bounded estimates of q based on: life history assumptions; catch and larval density evaluations north-south of San Diego;

and distribution metrics previously established and used presently in harvest control rules for the stock.

The other major area of uncertainty affecting the ongoing Pacific mackerel stock assessments and related model development, as well as other CPS assessments considered in the future, is improvements needed for more efficiently producing quality age data associated with production ageing efforts in the laboratory, particularly, SWFSC's survey samples. In the interim, age-composition time series associated with the survey were developed/applied in final base model ALT_19 in a manner that minimized direct use of the age data determined from the production ageing laboratory by using survey length-composition time series with an applicable age-length key developed from fishery samples.

Research and data needs

The most important research and associated data needed for improving the quality of the ongoing Pacific mackerel stock assessments (both survey- and model-based) follow: 1) continuing/bolstering support of the AT survey operations conducted annually by the SWFSC, given its importance as the best scientific data collection program for developing a suitable index of abundance for this species and other CPS; 2) improving relations with Mexico's federal administration and related marine science institutions for purposes of expanding the present coverage of the AT survey operations for this transboundary stock, as well as to provide biological samples from both survey and fishery operations off the coast of Baja California; 3) improving production ageing programs for Pacific mackerel and other CPS, particularly, associated with survey samples processed by the SWFSC; 4) using final base model ALT_19, further evaluate important areas of uncertainty, including time-varying selectivity, recent recruitment variability/estimation assumptions, and data weighting considerations for composition time series; and finally, 5) revisiting harvest control rules for Pacific mackerel based on formal management strategy evaluations.

INTRODUCTION

Stock structure and management units

The full range of Pacific mackerel (*Scomber japonicus*, also referred to as chub or blue mackerel) in the northeastern Pacific Ocean is from southeastern Alaska to Banderas Bay (Puerto Vallarta), Mexico, including the Gulf of California (Hart 1973), Fig. 1. Although stock structure of this species off the Pacific coast of North America is not known definitively, it is generally hypothesized that three spawning aggregations exist currently: one in the Gulf of California; one in the vicinity of Cabo San Lucas (Baja California, Mexico); and one along the Pacific coast north of Punta Abreojos (Baja California) that extends north to areas off southern California, and even further during favorable oceanographic periods to waters off the U.S. Pacific Northwest. The latter sub-stock is harvested by fishermen in the U.S. and Mexico, and is the population considered in this assessment.

The Pacific Fishery Management Council (PFMC) manages the northeastern Pacific Ocean stock along the Pacific coast of North America as a single unit, with no area- or sector-specific allocations. However, the formal Fishery Management Plan (FMP) harvest control rule does include a stock distribution adjustment, based on a long-term assumption that on average, roughly 70% of this transboundary population resides in U.S. waters in any given year (PFMC 1998).

Distribution and movement

Although the northeastern Pacific Ocean stock ranges from southeastern Alaska to southern Baja California, the species is more common from Monterey Bay, CA to Cabo San Lucas, Mexico. Over the last few decades, the stock has been observed to more fully occupy the northernmost portions of its range in response to warmer oceanographic conditions that have persisted in the northeastern Pacific Ocean, being found at times as far north as British Columbia, Canada (Ware and Hargreaves 1993; Hargreaves and Hungar 1995). To date, there exists only a general understanding of the seasonal movement patterns exhibited by this species along the coast of North America (Fry and Roedel 1949; Roedel 1949; Parrish and MacCall 1978; Hill 1999), with: northerly movement from waters off Baja and southern California beginning in the late spring/summer to feed in productive areas of upwelling off Oregon and Washington (potentially, more extensive geographical range during El Niño events, MBC 1987); and southerly movement in the late fall/winter back to spawning grounds off southern and Baja California. Pacific mackerel sampled from Pacific Northwest incidental fisheries (e.g., Pacific hake and salmon spp.) during the mid-1990s indicated the fish were generally older and larger than those captured in the southern California fishery (Hill 1999). In recent years, the stock has been observed to be relatively abundant in waters off the Pacific Northwest as documented in cruise reports for the acoustic-trawl (AT) survey, conducted annually since the mid-2000s by the Southwest Fisheries Science Center (SWFSC), e.g., Stierhoff et al. 2019a; Zwolinski et al. 2019. Thus, the stock is assumed to be most abundant in U.S. waters during the summer and fall months of each year; however, determination of the exact portion of the population that occupies U.S. waters each summer/fall is necessarily problematic and subject to some level of uncertainty (see Assessment – Acoustic-trawl survey\Overview and Base model description\Catchability).

It is further hypothesized that the stock exhibits east-west (inshore-offshore) movement along the U.S. Pacific coast, with increased inshore abundance from July to November and increased offshore abundance from March to May (Cannon 1967; MBC 1987). Pacific mackerel usually occur within 30 km of shore, but have been captured as far as 400 km offshore (Fitch 1969; Frey 1971; MBC 1987; Allen et al. 1990). Pacific mackerel adults are found in water ranging from 10 to 22.2°C (MBC 1987) and larvae are found in water around 14°C (Allen et al. 1990). Adult fish are commonly found near shallow banks. Juveniles are found off sandy beaches, around kelp beds, and in open bays. Adults are found from the surface to 300 m depth (Allen et al. 1990). Pacific mackerel often school with other small pelagic species, particularly jack mackerel and Pacific sardine, and likely based on size/age attributes as well (Parrish and MacCall 1978).

Life history

Pacific mackerel found off the Pacific coast of North America are the same species found elsewhere in the Pacific, Atlantic, and Indian Oceans (Collette and Nauen 1983). Synopses regarding the biology of Pacific mackerel are presented in Kramer (1969) and Schaefer (1980). Spawning occurs from Point Conception, California to Cabo San Lucas from 3 to over 300 km offshore (Moser et al. 1993). Off California, spawning occurs from March to October (primarily, late April through August) at depths to 100 m (Knaggs and Parrish 1973). Off central Baja California, spawning can occur year round at some level, peaking from June through October. Around Cabo San Lucas, spawning occurs primarily from late fall to early spring. Although Pacific mackerel are believed to not typically spawn north of Point Conception (Fritzsche 1978; MBC 1987), relatively small, juvenile fish have been reported further north in waters off Oregon/Washington in more recent years (Stierhoff et al. 2019b).

As exhibited by similar CPS, Pacific mackerel have indeterminate fecundity and appear to spawn whenever sufficient food is available and favorable oceanographic conditions prevail. Individual fish may spawn eight times or more per year and can release batches of at least 68,000 eggs per spawning. Actively spawning fish appear capable of spawning daily or every other day (Dickerson et al. 1992). Pacific mackerel larvae eat copepods and other zooplankton, including fish larvae (Collette and Nauen 1983; MBC 1987). Juvenile and adult mackerel feed on small fish (e.g., northern anchovy), fish larvae, squid, and pelagic crustaceans, such as euphausids (Clemmens and Wilby 1961; Turner and Sexsmith 1967; Fitch 1969; Fitch and Lavenberg 1971; Frey 1971; Hart 1973; Collette and Nauen 1983). Pacific mackerel larvae are subject to predation from a number of invertebrate and vertebrate planktivores. Juveniles and adults are eaten by larger fish, marine mammals, and seabirds. Principal predators include porpoises, California sea lions, pelicans, and large piscivorous fish, such as sharks and tunas. Pacific mackerel likely school as a defense against predation, often with other CPS, such as jack mackerel and Pacific sardine.

Population dynamics of the Pacific mackerel stock off U.S. Pacific coast, particularly California, have been extensively studied in the past, with important pioneering research conducted during the 1970s and 1980s, e.g., Parrish (1974), Parrish and MacCall (1978), Mallicoate and Parrish (1981), MacCall et al. (1985), and Prager and MacCall (1988). Since the mid-1990s, various age-structured population dynamics models have been used to regularly assess the Pacific mackerel stock for providing management advice (e.g., Jacobson et al. 1994; Hill and Crone 2005; Crone et al. 2009; Crone and Hill 2015; Crone et al. 2019), see History of modeling approaches.

Pacific mackerel experience cyclical periods of notable abundance, a phenomenon exhibited by CPS in general, which are characterized by relatively short life spans and highly variable productivity/abundance driven primarily by large-scale environmental factors (e.g., Pacific Decadal Oscillation (PDO), North Pacific Gyre Oscillation (NPGO), and related oceanographic drivers, such as sea-surface temperature, sea-surface height, upwelling, chlorophyll, etc.). Analysis of mackerel scale-deposition data (Soutar and Issacs 1974) indicated that periods of high biomass, such as during the 1930s and 1980s, are relatively rare events that might be expected to occur about once every 60 years on average (MacCall et al. 1985). Results from the ongoing assessment of this stock generally support past research, with periods of high recruitment success observed no more frequently than every few decades. As presented above, recruitment is generally variable both spatially and temporally in the northeastern Pacific Ocean, and unlikely to be related strongly to spawning stock size (Parrish 1974; Parrish and MacCall 1978).

The largest recorded Pacific mackerel was 63.0 cm in length (FL) and weighed 2.9 kg (Roedel 1938; Hart 1973), but the largest Pacific mackerel harvested by commercial fishing were a 47.8 cm FL fish and a 1.72 kg fish. The oldest recorded age for a Pacific mackerel was 14 years, but most commercially caught Pacific mackerel recorded by California Department of Fish and Wildlife (CDFW) are less than 4 years old, with few living beyond age 8 and larger than 45 cm. Limited historical data of generally older and larger Pacific mackerel sampled from Pacific Northwest incidental fisheries in the 1990s exist and have been reported on previously (Hill 1999), but more current data are not available.

As addressed in earlier assessments/reviews, size-at-age relationships by sex and sex ratio data indicated no notable sexual dimorphism in growth or mortality rate is exhibited by this species. Combined sex models have been used in all past and present Pacific mackerel assessments used to advise management.

Fishery descriptions

Pacific mackerel are currently harvested by three fisheries (Table 1 and Fig. 2): the U.S. commercial fishery that primarily operates out of southern California, as well as Oregon and Washington; a sport fishery based largely in southern California; and the Mexico commercial fishery that is based in Ensenada and Magdalena Bay, Baja California. In the commercial fisheries, Pacific mackerel are landed by the same boats that catch Pacific sardine, northern anchovy, jack mackerel, and market squid (commonly referred to as the west coast ‘wetfish’ fleet). In recent years, Oregon and Washington fishermen have landed limited amounts of Pacific mackerel, with a combined annual average catch of roughly 500 mt over the last decade. Pacific mackerel are also (incidentally) harvested in small volumes by whiting trawlers and salmon trollers. Available information concerning bycatch and discard mortality of Pacific mackerel, as well as other members of the CPS assemblage of the California Current, is presented in PFMC (2019). Limited information from observer programs implemented in the past indicated little bycatch of other species and/or discard of Pacific mackerel in the commercial purse seine fishery off the U.S. Pacific coast.

The history of California’s Pacific mackerel fishery has been reviewed by Croker (1933, 1938), Roedel (1952), and Klingbeil (1983). Historically, Pacific mackerel have been landed in moderate amounts, supporting a viable fishery in California during the 1930s and 1940s and more recently, in the 1980s and early 1990s. During the early years of the fishery, Pacific mackerel were taken by lampara and pole-and-line boats, which were replaced in the 1930s by the same purse seine fleet that fished for Pacific sardine. Before 1929, Pacific mackerel were taken incidentally, in relatively small volumes with sardine and sold as a fresh product (Frey 1971). Canning of Pacific mackerel began in the late 1920s and increased as greater processing capacities and more marketable ‘packs’ were developed. Landings decreased in the early 1930s due to the economic depression and subsequent decline in demand, but increased significantly by the mid-1930s (66,400 mt in 1935-36). During this period, Pacific mackerel were second only to Pacific sardine in total (annual) landings. Subsequently, harvests underwent a long-term decline and for many years, a continued demand for canned mackerel exceeded supply. Supply reached record low levels in the early 1970s, at which time the State of California implemented a ‘moratorium’ on the directed fishery, allowing only limited amounts of incidental landings.

Following a period of ‘recovery’ that spanned from the mid to late 1970s, the moratorium was lifted. During the 1980s through mid-1990s, catches of Pacific mackerel by California fishermen supported an economically viable fishery. The market for canned mackerel during the 1980s through early 1990s fluctuated substantially due largely to economic factors. Domestic demand for canned Pacific mackerel eventually waned and the last mackerel cannery in California closed in 1992. Presently, the limited landings of Pacific mackerel caught by U.S. fishermen are used for human consumption (e.g., canned, frozen, fresh) or pet food.

Pacific mackerel are caught by recreational anglers in southern California using commercial passenger fishing vessels (CPFV), private boats, piers, beaches, etc., but are not typically considered a target species (Young 1969), with comparatively minimal catches to landings from commercial operations (Table 1). Pacific mackerel are also harvested in California's recreational fishery as bait for directed fishing on larger pelagic species, such as tunas, sharks, and billfishes. Additionally, Pacific mackerel are caught by anglers in central California, Oregon, and Washington, but typically, in only limited amounts. The sport harvest of Pacific mackerel in California comprises a very small fraction of the total landings of Pacific mackerel, e.g., over the last decade, recreational catch is less than 5% of the total weight landed (Table 1). Although some mackerel are likely discarded in some recreational fishing sectors for this non-targeted species, accurate determination of discard magnitude from available creel survey data is not straightforward, potentially subject to problematic sampling biases in the field.

In summary, Pacific mackerel landings in the U.S. have remained low over the last two decades, with total annual landings averaging ~7,000 mt since the late 1990s (Table 1). Relatedly, mackerel catches from fisheries have not realized allowable quotas via stipulated harvest guidelines imposed since the late 1990s (see Table 11, Management history, and Management performance).

The Mexico fishery for Pacific mackerel is primarily based in Ensenada and to a lesser extent, Magdalena Bay, Baja California. The Mexico purse seine fleet has slightly larger vessels, but is similar to southern California’s fleet with respect to gear (mesh size) and fishing practices. The fleet operates in the vicinity of nearby ports and also targets other CPS. Demand for Pacific mackerel in Baja California increased after World War II. Mexico landings remained fairly stable for many years, increased to over 10,000 mt in the mid-1950s, declined to under 500 mt during the mid-1970s, and remained relatively low through the late 1980s. Landings of Pacific mackerel in Ensenada peaked during the 1990s, but have remained relatively low over the last two decades. For the most part, the Ensenada fishery has been generally comparable in volume to the southern California fishery since 1990 (averaging ~10,000 mt/yr), with some differences for particular years (Table 1). In Mexico, harvested Pacific mackerel have been canned for human consumption or reduced to fish meal.

Ecosystem considerations

Pacific mackerel are part of the CPS assemblage of the northeastern Pacific Ocean, which represents an important forage base in the California Current. Pacific mackerel grow rapidly, feeding on plankton (plants and animals) and other CPS, including smaller northern anchovy, Pacific sardine, market squid etc. The species is prey for various larger fish (shark and tuna spp.), marine mammals, and seabirds. Pacific mackerel biology and trophic relationships are further described above (see Life history, and Distribution and movement).

Pacific mackerel do not typically represent a dominant species of the CPS assemblage in most years, with absolute abundance likely less than that characterizing the more productive CPS, such as Pacific sardine and particularly, northern anchovy. However, population biomass can increase to relatively high levels during periods of favorable oceanographic conditions, which are hypothesized to be the driving mechanisms related to recruitment success and associated stock abundance of this species (Parrish and MacCall 1978), as well as CPS in general (e.g., Checkley et al. 2009; Field et al. 2001; PFMC 1998; NMFS 2016a,b; PFMC 2019).

It is important to note that although there is general consensus in the marine ecology community that oceanographic factors are likely key drivers of year-to-year variation in recruitment and stock abundance dynamics exhibited by fish populations, particularly CPS, detailed understanding of the effects of particular environmental covariates on the productivity of individual species is generally lacking or refuted when evaluated over longer time periods (Walters and Collie 1988; Myers 1998; Checkley et al. 2009; Haltuch and Punt 2011; Koslow et al. 2013; Subbey et al. 2014). At this time, no environmental information is available for directly evaluating in an integrated stock assessment model specifically for Pacific mackerel, i.e., based on supportive research, whereby specific environmental factors have been shown to be correlated statistically with recent Pacific mackerel recruitment or abundance. Finally, ongoing management of Pacific sardine is illustrative of the challenges associated with using environmental data (sea-surface temperature index) that have been observed to be inconsistent indicators of recruitment success over time (Jacobson and MacCall 1995; McClatchie et al. 2010; Lindegren and Checkley 2013; Zwolinski and Demer 2014; Zwolinski and Demer 2019).

Management history

The state of California first implemented formal management associated with the Pacific mackerel stock in 1970, after the stock was thought to have declined substantially during the mid-1960s. A moratorium was placed on the fishery at this time, with a small allowance for incidental catch in mixed-fish landings. In 1972, legislation was enacted that imposed a quota based on the estimate of age-1+ biomass ($\geq$1-yr old fish) generated from formal stock assessments. A couple of very strong year classes in the late 1970s led to a brief period of moderately high stock abundance, which was followed by the fishery being reopened under a quota system in 1977. From 1977 to 1985, various adjustments were made to quotas for the directed harvest of Pacific mackerel and related incidental catch limits. It is important to note that even during the moratorium, substantial allowances were made for incidental catches associated with this species (Parrish and MacCall 1978).

State regulations enacted in 1985 imposed a moratorium on directed fishing when the total biomass was less than 18,200 mt, and limited incidental landings of Pacific mackerel to 18% (~3,000 mt) during such periods. At this time, the 'fishing year' was set to extend from July 1st to June 30th of the following year. In summary, seasonal quotas, equal to 30% of the total biomass in excess of 18,200 mt, were allowed when the biomass was between 18,200 and 136,000 mt, with no quota limitations in effect when the total biomass was estimated to be 136,000 mt or higher.

A federal fishery management plan (FMP) for CPS, including Pacific mackerel, was implemented by the PFMC in January 2000 (PFMC 1998). The FMP's harvest policy for Pacific mackerel, originally implemented by the State of California, was based on simulation analysis conducted during the mid-1980s (MacCall et al. 1985), with the addition of a proration to account nominally for the portion of the assessed stock assumed to inhabit U.S. waters (PFMC 1998). The following maximum sustainable yield (MSY) control rule for Pacific mackerel has been generally used for management from the early 2000s to the present:

$$\text{Harvest} = (\text{Biomass-Cutoff}) \bullet E_{MSY} \bullet \text{Distribution},$$

where Harvest is the harvest guideline (HG), Cutoff (18,200 mt) is the lowest level of estimated biomass above which harvest is allowed, E_{MSY} (30%, also referred to as exploitation fraction in earlier PFMC documents) is the proportion of biomass above the Cutoff that can be harvested by fisheries, and Distribution (70%) is the average proportion of total Biomass (ages 1+) assumed to reside in U.S. waters. The HGs under the federal FMP are applied to a July to June fishing year. Detailed description of the current management actions applicable to Pacific mackerel, including quotas and related fishing quantities (e.g., acceptable biological catch-ABC, acceptable catch limit-ACL, overfishing limit-OFL, etc.), can be found in the most recent CPS SAFE document (PFMC 2019). Also, see Harvest Control Rules for U.S. Management (2019-20 and 2020-21).

Total annual harvest of Pacific mackerel by the Mexico fishery is not regulated by quotas, but there has been minimum legal size limits (e.g., 25.5 cm) imposed in the past. International management agreements between the U.S. and Mexico regarding transboundary stocks, such as Pacific mackerel, have not been developed to date (see Research and data needs.

Management performance

It is important to note that management performance metrics applicable to Pacific mackerel have changed over time, including final stipulated quotas based on HGs or ACLs, depending on the year, e.g., see Table 11 for quotas from 2008-18. In 2007, the HG/ACL was increased substantially to 40,000 mt and remained at this quota until 2009, when the calculated HG (55,408 mt) was reduced by management to 10,000 mt based on limited landings in recent years, with the adjusted quota applicable through the 2010-11 fishing year that included an additional 1,000 mt incidental landing allowance (11,000 mt). Following the full stock assessment conducted in 2011, a HG/ACL of roughly 31,000 mt was implemented for two consecutive fishing years. Catch-based projection assessments were used to set quotas for 2013 (~39,000 mt) and 2014 (~29,000 mt). Quotas have remained at approximately 21,000-27,000 mt since 2015. Note that from a management context, the CPS fishery has not fully utilized quotas since the late 1990s, with total landings notably below recommended catches (see Table 11 for harvest regulations from 2008-18).

ASSESSMENT – DATA

Fishery data

Overview

Fishery data for assessing Pacific mackerel included: 1) landings from California, Oregon, and Washington commercial fisheries, California recreational fishery, and the Mexico commercial fishery; and 2) port/laboratory sample (length, weight, and age) data from California's commercial fishery. In efforts to standardize data collection, analysis, vetting, archiving, and integration into ongoing CPS assessment models, the SWFSC developed a structured query language data base (*CPS assessment data base*) that includes all fishery data (landings and biological compositions, 2000-present) typically included in ongoing assessment models used for management purposes.

Since 1929, CDFW has collected biological data for Pacific mackerel landed in the southern California fishery (primarily, San Pedro). Limited samples have also been collected from the Monterey fishery when available. In general, sample data collected from 2008 through December 2018 were used in modeling efforts conducted for this assessment. Biological samples from the commercial fishery generally included whole body weight, fork length, sex, maturity (visual), and otoliths for age determination in the laboratory. Currently, CDFW strives to collect 12 'random' (port) samples per month (typically, 25 fish per sample) to determine length/age compositions, as well as catch-at-age, weight-at-age, etc. for the directed fishery. Limited landings of Pacific mackerel are made at Oregon and Washington ports as well, although systematic biological sampling for this species has only recently begun and no processed data are available at this time.

Additionally, port sampling data for the commercial fishery in Mexico have been collected by the National Fisheries Institute (INAPESCA) since 1989; however, this information has not been made formally available to date and thus, commercial fishery data from the California purse seine fleet were assumed to be representative of the combined fisheries. Lack of data from the Pacific Northwest and Baja California fisheries is not considered a serious problem in recent years, given their respective catches have remained relatively low. However, in some recent years, Baja California catches have equaled or exceeded California landings (Table 1), which necessarily increases the likelihood of potential biases associated with the omission of (and subsequent assumptions concerning) sample data from the Mexico and Pacific Northwest fisheries (see Research and data needs).

Pacific mackerel are aged by CDFW biologists based on identification of annuli in whole sagittae (otoliths). Historically, a birth date of May 1st was used to assign year class (Fitch 1951). In 1976, ageing protocols changed to a July 1st birth date, which coincided with an increasing population, resumed fishery sampling, and a change in the management season from a May 1st opening to a July 1st start date. Fishery inputs for this assessment were compiled by 'biological year,' based on the birth date used to assign age. The biological year used in this assessment is synonymous with the 'fishing year' defined previously, as well as with 'fishing season' as reported in past PFMC and related historical literature. All landings and biological compositions included in this assessment were developed on a fishing year (July – June) basis. Sample sizes associated with biological data used in this assessment are presented in Table 2.

Landings

The assessment includes commercial and recreational landings from the *CPS assessment data base* from 2008 to 2017. Annual (fishing year) catch estimates of Pacific mackerel are presented in Table 1 and Fig. 2. The fishing year 2018 (July 2018-June 2019) landing estimate reflected average total catch from 2013-17, which was also used for both forecasted years (2019-20 and 2020-21) in the assessment model. Commercial catch statistics compiled in the *CPS assessment data base* are from the state fishery agencies California Department of Fish and Wildlife (T. Nguyen, pers. comm.), Oregon Department of Fish and Wildlife (ODFW, C. Schmitt, pers. comm.), and Washington Department of Fish and Wildlife (WDFW, L. Wargo, pers. comm.). California recreational catch (mt) time series from 2008 to the present are based on all sport fishery modes (man-made, beach/bank, party/charter, and private/rental) and obtained from CDFW (K. Lynn, pers. comm.).

As in the last assessment (Crone and Hill 2015), commercial and recreational catch have been combined into one fishery, given similar selectivity properties between the two fisheries and the limited sport-related catches. This pooling of catch data across fisheries is an important decision for developing a parsimonious assessment model that does not include unnecessary structure/process based on minimal data and information content. To date, the sport fishery has contributed only limited catches to the overall landings of this species, e.g., over the last decade, the recreational fishery has averaged roughly 3% of the total annual landings of Pacific mackerel (Table 1). For past and present assessments, discard was assumed negligible in both the commercial and recreational fisheries associated with this species (see Fishery descriptions).

Mexico landings reflect catches in Baja California from commercial purse seine fleets operating off Ensenada and in Magdalena Bay. Commercial landings from 2008 to 2017 were taken from the National Commission of Aquaculture and Fishing (CONAPESCA) website that archives Mexico's fishery yearbook statistics (CONAPESCA 2018). Preliminary catches for January-June 2018 were provided by INAPESCA (Concepción Enciso-Enciso, pers. comm.).

Age and length compositions

Presently, age data are only available from the California commercial fishery, which typically contributes the majority of fish landed at U.S. Pacific coast ports (Table 1). Biological sampling directed towards Pacific mackerel has recently begun in the states of Oregon and Washington, but only limited information is available at this time (see Research and data needs). Sample sizes (number of fishing trips) and number of measured specimens associated with biological compositions included or considered in this assessment are presented in Table 2.

To determine the proportion of each age in the total fishery landings, the nominal age composition was weighted by the total monthly landings (no. of fish). The following steps were used to develop the weighted age-composition time series (Fig. 3):

1) identified an age 'plus group' (8+) for combining older fish into a single group;
2) determined the number of individuals measured for each year, month, and age, as well as the number of samples taken (samples=fishing trips=unique combination of day/month/year/sample id);
3) calculated total and average monthly catch weights, as well as average monthly weight-at-age estimates (in mt to match fishery catch units);
4) average monthly weight-at-age estimates were then multiplied by the number of specimens measured, and the product divided by total monthly catch weight to produce age-group proportions;
5) the age-group proportions calculated in step 4 were then multiplied by the total monthly catch to produce the total weight (mt) of each age group in the fishery catch per month;
6) the numbers of fish per age group by month in the total fishery catch were calculated by taking the result of step 5 and dividing by the average monthly weight of each age group calculated in step 3;
7) the monthly calculations of numbers of fish were then aggregated into fishing years (July-June) to produce the numbers of fish-at-age per fishing year and subsequently, summed across ages to produce the total number of fish landed per fishing year; and
8) dividing the result for step 7 by the total number of fish per year produced the final weighted age-composition time series (in proportion) for each fishing year.

For the most part, weighted and un-weighted compositions were generally similar, but in some years, estimated proportions of 0- and 1-yr old fish, which typically compose the majority of the overall composition, varied substantially.

Input sample sizes associated with length-composition time series were calculated in the same manner as for the age compositions (Table 2). Length data associated with the commercial fishery were collected by CDFW and weighted following the steps presented above for age data. All length compositions (in no. of fish) were converted to proportion estimates according to 1-cm length (fork) bins from 1 to 60+ cm (Fig. 4). Note that length-composition data were not used in final base model ALT_19, but were used qualitatively in comparative evaluations with AT survey length/age data for assessing the utility of survey age data in the assessment (see Survey data\Age and length compositions).

Ageing error

In efforts to provide a realistic measure of uncertainty associated with the estimated age-composition time series, an updated 'ageing error' vector based on ager 'double-read' methods was used in all model ALT_19 configurations (Fig. 3). This vector of standard deviation-at-age (SDa) was applied to both fishery and survey age data, following methods that were reviewed and recommended for P. sardine (Hill et al. 2011; Dorval et al. 2013). Past stock assessments of Pacific mackerel (e.g., Crone and Hill 2015) relied on traditional methods to estimate and include age-reading precision information in the age-structured assessment models. The traditional methods computed SDa by averaging across all fish that were assigned a given age by one or more readers. In addition, this method assumed that all agers were unbiased, but without a means to determine whether this assumption was appropriate. In this assessment, SDa was computed using the Age-Reading Error Matrix Estimator (Agemat model) developed by Punt et al. (2008). This statistical model provides a flexible framework to compute SDa based on various assumptions and thereafter, to use information criterion (e.g., AICc) to select models that best fit the age-reading data and support associated assumptions (Hill et al. 2011, Dorval et al. 2013).

The fishery SDa vector was applied to both the fishery and AT survey age-composition time series, given very poor fits associated with Agemat models developed from survey age data, indicating notable systematic bias in age assignments. The fishery age-reading data (combined ages method) reflected estimates by two readers who have consistently participated in double-read exercises at the CDFW laboratory since 2008. A total of 1,641 Pacific mackerel specimens collected from 2008 to 2017 from the fishery landings were included in the double-read analysis. As conducted in P. sardine stock assessments (e.g., Hill et al. 2011, 2015, 2017, 2019), various scenarios were developed to compare Pacific mackerel models that assumed equal or unequal SD among agers for the fishery/survey. For the fishery, the model scenarios had generally similar fits to the age-reading data, with the model that assumed equality of SD having the lowest AICc and hence, represented the single ageing error vector applicable to both fishery and survey age-composition time series included in final base model ALT_19 (Fig. 3). Also, see Survey data\Age and length compositions.

Empirical weight-at-age

A matrix of empirically derived weight-at-age (WAA) data were used in the model to convert estimated numbers-at-age to biomass-at-age, i.e., growth processes were not estimated internally in the model, but rather, addressed using a matrix (year-age) of WAA compositions (Fig. 5). Mean WAA (ages 0-12) compositions were based on the same CDFW sampling program described above for age and length compositions. Average WAA estimates associated with weighted age-composition calculations established the baseline matrix of mean WAA. However, mean weights are required for each age (0-12 yr) included in the overall WAA matrix in the model (fish longevity, Nages in SS). Those WAA cells (year-age combinations) represented by limited (less than three) or no specimens required imputed mean WAA estimates. The following steps were used to produce imputed estimates in the overall WAA matrix:

1) first, any mean weight in the overall WAA matrix that was derived from less than 10 specimens was not used to impute values for missing cells;
2) cohorts (diagonals of mean WAA by fishing year) were extracted from the WAA matrix based on birth year;
3) if an age within a cohort was missing weight information, an average weight was calculated from the surrounding ages for that cohort (e.g., 2009 cohort with missing age-3 weight information would be imputed as the average of ages 2 and 4);
4) if step 3 was not possible, missing cells were imputed by taking the average of the weights from the same age of the two previous or two following cohorts;
5) if steps 3 and 4 were not possible, missing cells were imputed by taking the average of the weights from the same age of any three previous or following cohorts;
6) if the imputed cell in a cohort was less than the value in any previous age for that cohort, the imputed value was replaced with the largest weight in that cohort, resulting in no imputed cell reflecting a decrease in size (weight) over time;

7) beyond age 8, all mean weights were imputed by fishing year (vs. cohort), whereby mean weights for ages 9-12 equaled age-8 mean weights. Given few specimens beyond age 8 (plus group), a method for imputing weights for the older ages is an arbitrary exercise. However, imputing older ages by fishing year, rather than cohort avoids the use of weight information from outside the modeled time period (2008-18); and
8) final WAA time series for the terminal year (2018) were used for the forecast years (2019-20) in final base model ALT_19.

A single empirical WAA matrix (year/age) was applied to the fishery, survey, and population, which was based on fishery samples (Fig. 5). At this time, age data from the survey are not considered reliable for evaluating Pacific mackerel age structure and growth (see Ageing error, Unresolved problems and major uncertainties, Research and data needs, and Hill et al. 2019). Rather, results generated from experienced readers associated with the long-established CPS fishery production ageing laboratory (CDFW) were relied on in this assessment to develop the most reliable mean WAA time series applicable to Pacific mackerel inhabiting the California Current and encountered regularly by both the fishery and survey. Edwards et al. (2018) discuss applicability of a single WAA matrix to fishery, survey, and population growth assumptions in a generally similar integrated stock assessment model for P. hake. As part of sensitivity analysis, alternative WAA matrices were developed and evaluated in final base model ALT_19: using an age-length key vs. the random sample estimation method; based on missing-cell substitution using multivariate methods; and assuming a constant averaged WAA (2008-18), see Sensitivity analysis.

Average conditional age-at-length
The average age-structure of a population conditioned on its length distribution can be summarized by an age-length key (ALK). One of the uses of the ALK is to assign ages to fishes with known length, but uncertain age. An ALK for Pacific mackerel was constructed from fishery age and length data collected between July and December (2008-18) by CDFW (see Fishery data\Age and length compositions). A single ALK was constructed by aggregating all the data and fitting a multinomial log-linear model via neural networks using the R package '*nnet*.' The response in the multinomial log-linear model is a discrete probability distribution of age conditioned on length. The main advantage of using the multinomial log-linear model over an empirical ALK is that it ensures a smooth transition between ages and lengths. The ALK was used to assign ages to respective lengths for developing AT survey age-composition time series used in final base model ALT_19 (Fig. 6), see Survey data\Age and length compositions.

Survey data
Overview
Acoustic-trawl sampling of marine environments for determining abundance of fish populations is a standard practice conducted worldwide that continues to receive more focused research in fishery science, e.g., see Simmonds and MacLennan (2005) for general theory and application of fisheries acoustics, and Massé et al. (2018) for an example of a long-term program for surveying trans-national, wide-ranging small pelagic fish communities. In February 2018, an important (second) review was held for purposes of critically evaluating the AT survey methods implemented by SWFSC, as well as determining the utility of these survey data for informing abundance of CPS in both ongoing and future assessments of the CPS assemblage of the

California Current (PFMC 2018b). The panel concluded that AT data represent the best scientific information available on an annual basis for assessing abundance of all members of the CPS assemblage (except Pacific herring), and approved the use of these data for directly (survey-based) or indirectly (model-based) assessing the status of the stock, depending on the species of interest (PFMC 2018b).

Index of abundance

This assessment uses a single time-series of biomass based on the SWFSC's ongoing AT surveys. The AT time series were developed from SWFSC surveys conducted along the Pacific coast since 2006 (Cutter and Demer 2008; Zwolinski et al. 2019 and references therein). During AT surveys, multifrequency split-beam echosounders transmit sound pulses down beneath the ship and receive echoes from animals and the seabed in the path of the sound waves. The intensities of the echoes at multiple frequencies that are scattered back (the backscatter signal) normalized to the range-dependent observational volume (the volume backscatter coefficient) provide indications of the target type and behavior. Fish, particularly those with highly reflective swimbladders, create high intensity echoes. Under certain conditions, the summed intensities of the echoes from an ensemble of targets is linearly related to the density of the fish or plankton aggregations that contributed to the echoes. This attribute of the summed intensities allows animal densities to be estimated by dividing the resulting 'integrated backscatter coefficients' of the ensemble by the average echo energy from a representative animal (Simmonds and MacLennan 2005). An estimate of species' abundance is then obtained by multiplying the average estimated fish density and the survey area (Zwolinski et al. 2019).

The AT survey and estimation methods were vetted through the PFMC formal methodology review processes in February 2011 (STAR 2011; Simmonds 2011) and 2018 (PFMC 2018b). The AT survey review in 2018 concluded the summer survey was suitable for developing a relative index of abundance for purposes of using in a statistical stock assessment model (PFMC 2018b). Presently, AT survey data represent the foundation information for assessing the status of Pacific sardine for advising management on an annual basis (Hill et al. 2017, 2018, 2019).

The AT (summer) time series of Pacific mackerel biomass (2008-18) is presented in Table 3 (with figure). The biomass estimate and associated size distributions for the 2018 summer survey are further described below (Assessment – Acoustic-trawl survey) and in Stierhoff et al. (2019b). Since 2016, biomass estimates of Pacific mackerel have increased from the lowest values observed from 2013 through 2015 (Table 3). The summer 2018 survey estimate of 33,351 mt (CV=23%) was generally similar to estimates from 2016 and 2017, and is characterized by a large proportion of mackerel smaller than 22 cm, most likely age-0 fish (Fig. 3).

Age and length compositions

Together with total biomass, the standard output of the AT surveys is a vector of abundances-at-length for each member of the CPS assemblage. Biological compositions for Pacific mackerel were developed similarly as done for the ongoing Pacific sardine assessment (e.g., Hill et al. 2019), whereby the abundances-at-length were obtained by raising the length composition of each species in each trawl cluster by the respective abundance (see Zwolinski et al. 2019 for detailed computations). Also, as in Pacific sardine assessments (Hill et al. 2018, 2019), estimates of abundance-at-length of Pacific mackerel (Fig. 4, presented as proportions) were converted to abundance-at-age (Fig. 3, presented as proportions) using an age-length key (ALK, Fig. 6). In this case, the ALK was constructed from fishery data (see section Average conditional age-at-length), which was considered the most reliable basis for developing the survey age-composition time series. Age data from the survey were considered unsuitable for developing a survey-specific ALK, given potential bias indicated in age determinations associated with survey specimens revealed in otolith double-read analysis involving fishery and survey age data (see Ageing error and Empirical weight-at-age).

ASSESSMENT – ACOUSTIC-TRAWL SURVEY

Overview

Current management of the Pacific mackerel population inhabiting the California Current of the northeast Pacific Ocean relies on an estimate of stock biomass (age-1+ fish in mt), which is needed for implementing an established harvest control rule (HCR) on an annual basis. Although historically the 'actively managed' CPS (Pacific sardine and mackerel) have relied on estimated biomass from an integrated population dynamics model, in 2017, the Pacific sardine STAT recommended using biomass estimated directly from the AT survey (survey-based approach) for advising management, rather than reliance on an integrated model with additional uncertainty associated with assumed/estimated processes required in a model-based approach (Hill et al. 2017, 2019). The STAT's recommendation was founded on an efficient survey design developed using an optimal habitat index (Zwolinski et al. 2011) for sardine, which supported plausible assumptions for modeling catchability (q≈1.0), i.e., assumed uncertainty regarding stock's availability in the survey area in any given year. The underlying advantage of using biomass directly estimated by the survey is that uncertainty associated with the abundance estimate needed for management is primarily due to random sampling variability and not affected by uncertainty surrounding poorly understood population processes that must be addressed to varying degrees when fitting population dynamics models, simple or complex.

In the summer and early fall, the seasonally moving population of Pacific mackerel is most likely to reside in the more northerly regions of its hypothesized range (see Distribution and movement), and confinement to mesotrophic waters towards the coast (Zwolinski et al. 2011) may act as a barrier for the offshore excursion of the stock (PFMC 2018b). On the eastern boundary of the survey, incomplete coverage in nearshore waters has been notably reduced in 2018 (Stierhoff et al. 2019b), when compared to 2017 (Zwolinski et al. 2019). Moreover, the potential biomass of Pacific mackerel existing east of the typical survey footprint that was calculated by extrapolation was less than 4% of the biomass found in the surveyed area (Stierhoff et al. 2019b; Zwolinski et al. 2019). In the context of the horizontal domain, the extent of the stock south of the survey area is considered the most uncertain aspect of its full range in any given year. However, if Pacific mackerel movement is generally related to temperature as hypothesized, it is reasonable to assume that the availability of the stock to be sampled in U.S. waters is maximal or close to maximized during the summer and early fall. Concerns also exist about the use of target strength (TS) to length relationship derived for similar mackerel species, e.g, *Trachurus* spp. (Zwolinski et al. 2019). Because uncertainties in TS and the spatial distribution are likely conflated in the survey q for Pacific mackerel, the STAT developed model ALT_19 using an informative prior for estimating/bounding q based on the species' biology, spatial evaluations of catch and larval density, and HCR parameters presently in place for the stock (see Unresolved problems and major uncertainties, and Base model description\Catchability). It is important to note that even with the recognition of increased uncertainty for survey *q* for Pacific mackerel relative to sardine, the STAT/SWFSC recommends a similar assessment approach for both species, whereby survey-based assessments should be used to advise management on an annual basis.

The integrated model (e.g., final base model ALT_19) should be maintained along with the survey-based assessment, being used as a research vs. management model, for purposes of further evaluating stock parameters of interest other than absolute abundance, including spawner-recruit processes (particularly, recent recruitment variability), age/length structure of the population, catches and fishing intensity, etc. Finally, the model-based assessment could be used for advising management in the unlikely event that the AT survey is unable to be conducted in a particular year.

Merits of AT survey-based assessment
The AT survey employs objective sampling methods based on state-of-the-art echosounder equipment and an expansive data collection design in the field (Stierhoff et al. 2019a; Zwolinski et al. 2019**)**. The Pacific mackerel stock assessment review conducted in 2015 recommended that future assessment model development focus more attention on the utility (merits and drawbacks) of including the best available abundance data and relatedly, evaluations of survey catchability (*q*) uncertainty associated with a relative index of abundance for a widely ranging stock. The panel further concluded that management strategy evaluations (MSE) that consider AT summer survey results for Pacific mackerel, as well as spring/summer results for Pacific sardine, would allow survey- vs. model-based assessment decisions to be evaluated most efficiently in terms of advising CPS management in the future. Finally, in 2018, an AT methodology review panel concluded that the summer surveys provide abundance data using sound field design and estimation methods, and such data should be considered in future assessment model development (PFMC 2018b). Irrespective of the assessment approach adopted in the future, the AT summer surveys will continue to have the highest relevance for Pacific mackerel management. Unarguably, there exist no other scientifically collected abundance data for assessing this stock's status on a regular basis. As presented below, past assessments have included various seriously flawed 'survey' indices of abundance that have been slowly omitted from models over time (see Unresolved problems and major uncertainties).

Drawbacks of model-based assessment
In the context of meeting the management goal, a model-based assessment includes considerable additional uncertainty associated with the estimate of recent stock biomass needed for regularly advising management. This is due to the need to explicitly model critical stock parameters in the assessment that is unnecessary using a survey-based assessment approach. For example, areas of model uncertainty include natural mortality (*M*), recruitment variability (spawner-recruit relationship), biology (longevity, maturity, and growth), fishing mortality, and selectivity/catchability. The model-based assessment includes additional structural and process error not associated with a survey-based approach, given varying degrees of bias associated with sample data and parameter misspecifications in the model. Thus, using an integrated model for estimating stock biomass necessarily requires degrading the influence of the highest priority data

available (AT survey abundance information), because of inherent data/likelihood tradeoffs in the fitted model.

Additional assessment considerations
Given the survey/assessment/review/management schedule in the current resource policy framework, employing a survey-based assessment approach requires projecting estimated stock biomass from the AT survey to the beginning of the new management year (also required for the model-based approach). Currently, management stipulations are set roughly one year following the last year of sample data available for assessing the stock. The Pacific mackerel stock assessment reviews (STARs) are conducted early in the year (e.g., April 2019) for applying new management stipulations for the upcoming 'fishing year' (2019-20). Thus, under the current framework, the AT survey biomass estimated in the most recent summer would either need to be projected one full year ahead to the following summer, or the management cycle could be returned to a January start date to negate the need for predicting strength of the most recent year class required to estimate future abundance.

Presently, such projection methods for treating time lags associated with AT survey operations have not been given serious attention in similar review forums (e.g., Pacific sardine, Hill et al. 2017). That is, projected survey estimates of Pacific mackerel biomass were only generally discussed during the review in April and thus, are not presented in this assessment report. The methods available for projecting AT survey biomass from July 2018 (most recent estimate) to July 2019 (beginning of next management year) rely on sub-optimal assumptions regarding recruitment, which could be effectively circumvented by changing the start date of the fishery from the currently stipulated July 1st to January 1st. See Preface, Research and data needs, and Conclusions.

Methods
A summary of the results of the most recent AT survey cruise conducted in summer 2018 are presented in this report. Methods for this survey can be found in Stierhoff et al. (2019b). Methods and sampling designs in the field have been generally similar since the survey was first employed in 2006, noting that changes to areas surveyed occurred seasonally and annually. Since 2012 AT summer surveys have been conducted annually off the west coast of the U.S., but occasionally from Point Conception to the north (Vancouver Island, Canada). Readers should consult Zwolinski et al. (2019) and references there in for survey cruises conducted in past years.

The 2018 summer survey was conducted onboard the NOAA Fisheries Survey Vessel (FSV) Reuben Lasker. Acoustic data were collected during the day to allow sampling of fish schools aggregated throughout the surface mixed layer. Trawling was conducted during the night to sample fish dispersed near the surface. This approach was adopted in early CDFW acoustic surveys to make trawl sampling more efficient and more representative of the CPS communities (Mais 1974). The summer survey occurred between June 26 and September 23 2018, and transects spanned the west coast of the U.S. and Canada, from the northern end of Vancouver Island to San Diego (Fig. 7). Further details on echosounder calibrations, survey design, and sampling protocols are detailed in Stierhoff et al. (2019a).

Acoustic data from each transect were processed using estimates of sound speed and absorption coefficients calculated with contemporary data from Conductivity-Temperature-Depth (CTD) probes. Echoes from schooling CPS were identified with a semi-automated data processing algorithm as described in Zwolinski et al. (2019). The CPS backscatter was integrated within an observational range of 3 m below the ship's centerboard (around 10 m of absolute depth) to the bottom of the surface mixed layer or, if the seabed was shallower, to 3 m above the estimated acoustic dead zone. The vertically integrated backscatter was averaged along 100-m intervals, and the resulting nautical area backscattering coefficients (s_A; m^2 nm^{-2}) were apportioned based on the proportion and backscattering cross-section of the various CPS found in the nearest trawl cluster. The s_A were converted to biomass and numerical densities using species- and length-specific estimates of weight and individual backscattering properties (see details in Zwolinski et al. 2019).

Survey data were post-stratified to account for spatial heterogeneity in sampling effort and Pacific mackerel density. Total biomass in the survey area was estimated as the sum of the biomasses in each individual stratum. Sampling variance in each stratum was estimated from the inter-transect variance calculated using bootstrap methods (Efron 1981), and total sampling variance was calculated as the sum of the variances across strata (see Zwolinski et al. 2019 and references therein for details). The 95% confidence intervals (CIs) were estimated as the 0.025 and 0.975 percentiles of the distribution of 1,000 bootstrap biomass estimates. Coefficient of variation (CV) for each of the mean values was obtained by dividing the bootstrapped standard errors by the point estimates (Efron 1981).

For each stratum, estimates of abundance were broken down to 1-cm fork length (FL) classes. These abundance-at-length estimates were obtained by raising the length-frequency distribution from each cluster to the abundance assigned to the respective distribution based on the acoustic backscatter (see Zwolinski et al. 2019 for calculations). An age-length key was constructed using age and length data from the fisheries collected by CDFW between July and December, from 2008 onwards. Age data from the AT surveys were considered unsuitable for use in the age-length key due to the lack of recent inter-agency age calibration. Because no systematic inter-annual differences of mean length-at-age were observed in the period from 2008 through 2018, a single age-length key was constructed for all years using the function 'multinom' from the R package 'nnet.' The 'nnet' function fits a multinomial log-linear model using neural networks. The response is a discrete probability distribution of age-at-length.

For internal consistency in final base model ALT_19, the empirical weight-at-age time series for the surveys were similar to those developed from the fishery data, which was considered a reasonable assumption for purposes of addressing potential biases related to production ageing associated with survey samples (see Empirical weight-at-age and Research and data needs).

Results

The 2018 summer survey totaled 6,104 nm of daytime sampling along 107 east-west tracklines and 170 night-time surface trawls combined into 65 trawl clusters. Post-cruise strata were defined considering transect spacing, and echoes and catches of CPS (Figs. 7 and 8). Complete survey results are presented in Stierhoff et al. (2019b).

Pacific mackerel were found primarily off southern California and Oregon, and in lesser densities off Vancouver Island and Washington (Fig. 8). The entire survey area included an estimated 33,351 mt of Pacific mackerel (95% CI=19,359 to 61,076 mt, CV=22%). Fish less than roughly 20 cm (likely age-0) represented the majority of the estimated abundance and biomass.

Areas of improvement for AT survey

Continued refinement and verification of the survey working principles will continue in the future. In particular, it is necessary to continue efforts to expand the survey to cover the entire hypothesized range of the stock, which would include waters off Baja California (see Research and data needs). Currently, efforts are underway to quantify the trawl net's species and size selectivity, as well as fish avoidance behavior to both the net and daytime acoustic sampling. Concerns have been raised regarding the coherence between the age-structure and species composition from night-time trawls and the schools detected acoustically during the day. Time-permitting, localized studies will be made during the summer 2019 survey to document the CPS diel schooling behavior and vertical migrations to corroborate the validity of the method. However, it should be emphasized that unlike other strategies that rely on immediate characterization of a small number of fish schools with trawl nets followed by visual and subjective classification of the non-trawled schools, the method of night-time sampling pioneered by CDFW (Mais 1974) and adopted by SWFSC relies on the dispersion of CPS to better sample the fish aggregations near the surface. Despite the theoretical concerns of the average 12-hr lag between the acoustic school detection and associated net sampling, the trawl target identification method removes the subjectivity of echo-classification from the acoustician via reliance on the representativeness of the trawl sampling. The advanced survey technology (AST) team is also continuously working to improve target strength models to better represent the populations of interest, as was done for northern anchovy (Zwolinski et al. 2017) and Pacific herring (Zwolinski et al. 2019). Improvement of the survey design, particularly the use of more aggressive adaptive rules that will allow increasing sampling effort in areas with unusually large concentrations of CPS is being considered. The use of adaptive sampling procedures will likely reduce the uncertainty associated with estimation of species composition and associated biomass, and provide a better understanding of demography of target species.

ASSESSMENT – MODEL

History of modeling approaches

Parrish and MacCall (1978) were the first to provide stock status determinations for Pacific mackerel using an age-structured population model (virtual population analysis, VPA). Beginning in the mid-1990s, the ADEPT model, which was based on the ADAPT VPA and modified for Pacific mackerel (Jacobson 1993; Jacobson et al. 1994), was used to evaluate stock status and establish management quotas for approximately 10 years. The assessment conducted in 2004 (for 2004-05 management) represented the final ADEPT-based analysis for this stock (see Hill and Crone 2004). The forward-simulation model ASAP (Legault and Restrepo 1998) was reviewed and adopted for Pacific mackerel at the STAR conducted in 2004 (Hill and Crone 2004). The ASAP model was used for assessments and management advice from 2005 through 2008. The STAR conducted in 2009 supported decisions to begin using the Stock Synthesis (SS) model for conducting formal stock assessments of Pacific mackerel in the future (Crone et al.

2009; STAR 2009); the SS model has been used for all assessments since 2009. A full (benchmark) stock assessment and review for this species were conducted in 2011 (Crone et al. 2011; STAR 2011a), with a harvest guideline (HG) serving for two fishing years. In 2013 and 2014, catch-based projection assessments were conducted and used to set the HGs (Crone 2013; Crone and Hill 2014). In 2015, a benchmark assessment was conducted for purposes of providing management advice that served for two (fishing) years, 2015-16 and 2016-17 (Crone and Hill 2015). A catch-only projection assessment was conducted in May 2017 that provided HGs for managing the Pacific mackerel resource for fishing years 2017-18 and 2018-19 (Crone and Hill 2017). The report presented here represents a benchmark assessment that was formally reviewed in April 2019 for purposes of advising management for two consecutive fishing years, 2019-20 and 2020-21 (STAR 2019).

Responses to STAR (2015) recommendations

The two most important (high priority) recommendations from past reviews have highlighted the need for a suitable index of abundance for Pacific mackerel and relatedly, improved relations with Mexico for purposes of both extending AT survey efforts further south into waters off Baja California, Mexico and providing biological-composition data from Mexico's purse seine fishery. Also, see 'Unresolved problems and major uncertainties' and 'Research and data needs.'

General

1. Develop a way to automatically profile over current biomass. It is relatively easy to profile over parameters such as $\boldsymbol{R_0}$. However, CPS management is based on the estimate of current biomass so that quantity rather than R_0 should be the focus for likelihood profiles and sensitivity analyses.
   Response: A terminal-year biomass likelihood profile was conducted manually for final base model ALT_19 (Fig. 18). Development of a standardized software routine for profiling over terminal-year biomass is in progress at this time.

High priority

1. Improve collaboration with fishery researchers from Mexico. As noted in previous assessment reviews, a large fraction of the catch is taken off Mexico, and efforts should be made to obtain length, age and related biological data from the Mexican fisheries. Inclusion of the ATM surveys in the assessment has increased the need for Mexican data from comparable surveys because such information could be used to develop an index that is close to being a measure of the absolute abundance of the transboundary stock of Pacific mackerel.
   Response: While the fishery off Baja California has been sampled by INAPESCA in the past when catches were large, catch has been at relatively low levels in recent years, so sampling has likely been minimal. The INAPESCA has never undertaken production ageing of Pacific mackerel. Sardine biological sample data have been shared with NMFS in the past, however, Pacific mackerel data are yet to be obtained by the STAT. There is still a need to conduct AT surveys off the outer Baja Peninsula. The INAPESCA's recently built the research vessel BIPO and have conducted preliminary surveys off outer Baja Peninsula, however, that vessel has now been relocated to the Gulf of Mexico. It would be desirable to survey in Mexico with NOAA's RV *Reuben Lasker*, but a permit to operate a trawl in Mexico's waters has been problematic to date.

2. Continue to refine the indices of abundance: The Panel considers an AT survey to be the ideal way to index the abundance of CPS such as Pacific mackerel. The following should be addressed to better realize the potential of the AT survey for Pacific mackerel:
   a. STAR (2011) conducted a review of the AT surveys. Some of the recommendations of that review have been implemented. However, most of the recommendations have yet to be addressed. Given the results of the ATM surveys are likely to be used in several assessments, there may be value in conducting a second PFMC Methodology Review for these surveys. The review would follow up on the recommendations from the 2011 PFMC and any other reviews of the ATM surveys.
   Response: A second review of the AT survey was conducted in February 2018 (PFMC 2018b).

   b. Efforts should be made to ensure that future surveys cover a larger area, particularly in latitude, to reduce the effects of uncertainty regarding the proportion of the population in the surveyed area.
   Response: The SWFSC continues to conduct an annual summer AT survey for CPS, and it typically extends from northern Vancouver Island to San Diego. As noted in response 1) above, permission to trawl off the outer Baja Peninsula will be difficult to obtain, likely requiring focused political/scientific discussion in the future.

   c. The sample sizes for the ATM survey length-compositions can be very small. Further identify and implement ways to increase the number of fish caught during the trawling associated with the ATM surveys.
   Response: The SWFSC's AT survey continues to collect Pacific mackerel samples at an appropriate level of sampling when fish are captured in the trawl. Future *in-situ* studies of trawl selectivity and speed (e.g. net avoidance, extrusion) will increase our understanding of trawl efficiency and interpretation of results for all CPS sampled in the AT surveys.

   d. Refine the target strength estimates for Pacific mackerel.
   Response: No progress has been made in refining target strength for Pacific mackerel.

   e. Develop an informative prior for the relative proportion of the population in the survey area when the spring and summer surveys are conducted.
   Response: This assessment (2019) uses Pacific mackerel biomass estimates from the summer AT surveys. Rationale for developing a reasonable prior for this survey is described below ('Base model description, Catchability').

3. Continue to refine the CPFV index of abundance. The CPFV index is used in the assessment of Pacific mackerel and could be included in other assessments. This index is based on fitting a fixed-effects model to catch rates by year, quarter and spatial region. This index can be improved by:
   a. Developing a single database that includes the raw trip-level data.
   Response: Raw trip-level data are no longer made available by CDFW, precluding such an analysis. More importantly, as indicated by the STAT/SWFSC in this assessment report, as well as in past reviews (STAR 2015), the use CPFV data to assess the status of Pacific mackerel is subject to considerable bias, misleading, and not recommended, given the

numerous shortcomings of the data, particularly, for tracking trends in abundance of this species. The STAT/SWFSC support using abundance data collected from the ongoing AT survey for regularly assessing the status of the Pacific mackerel stock (see Preface, Assessment – Acoustic-trawl survey\Overview, and Conclusions).

b. Conducting analyses in which the trip is the unit of analysis and trip-within-vessel is treated as a random effect and the factors associated with blocks within region are explicitly modelled.
Response: See response 3a) above.

c. Conducting analyses in which an attempt is made to include catch-rates of other classes of target species as covariates.
Response: See response 3a) above.

4. Increase support for current port sampling and laboratory analysis programs for CPS, particularly in the Pacific Northwest.
   Response: Pacific mackerel are occasionally captured in the Pacific Northwest, however, landings are limited, making routine sampling on a regular basis difficult to implement in the field (see Research and data needs).

5. Biological (e.g. length, age, sex) data on mackerel caught in the Pacific Northwest should be collected. These data could further assist in understanding whether and to what extent selectivity for the commercial fishery is dome-shaped. The aging of Pacific mackerel in the Pacific Northwest should be coordinated with researchers conducting ageing in California.
   Response: Dome-shaped selectivity is implemented for the fishery age-composition time series in final base model ALT_19, which was not observed to be problematic during model development or sensitivity analysis (see Base model description\Selectivity).

6. Standard data processing procedures should be developed for CPS, similar to those developed for groundfish species, and a 'data document' developed that provides, in considerable detail, how the basic data sources (e.g., catches, CPFV indices, etc.) are constructed. Much of this information has been published in the past, but a single (and 'living') document describing the basic data will assist assessment authors and future review panels.
   Response: Stock assessment data applicable to Pacific mackerel are now archived in the newly established *CPS assessment data base*. Data sources and methods for constructing fishery biological-composition time series are presented in detail in this assessment report (see Fishery data\Overview).

7. Investigate the spatial distribution, especially the range, of the Pacific mackerel population over time and whether this changes with population size and/or environmental conditions. In particular, an environmentally-based index of spatial distribution might prove useful for developing priors for ATM catchability for use in future assessments.
   Response: Although the STAT considers this worthwhile research to pursue that would provide valuable information for assessing the status of CPS in general, such work would necessarily require substantial attention and long-term planning at the SWFSC level (see Research and data needs).

Medium priority

1. Revisit the basis for the current estimate of *M* and hence longevity; explore the use of historical tagging data to estimate *M*.
   Response: Natural mortality (*M*) parameterization was further evaluated in final base model ALT_19 (see Base model description\Natural mortality).

2. Examine whether parameters such as growth rate and asymptotic size have changed over time.
   Response: Pacific mackerel growth processes were simplified in final base model ALT_19, which includes empirical weight-at-age data and no internal estimation of growth parameters.

3. Ageing error should be revisited. As noted during the 2011 STAR Panel report, few otoliths have currently been read multiple times, so additional readings need to be made. An age validation study should be conducted for Pacific mackerel. Such a study should compare age readings based on whole and sectioned otoliths and consider a marginal increment analysis and other validation methods.
   Response: An updated ageing error vector was developed for Pacific mackerel (see Ageing error).

4. Conduct a study to update the information used to determine maturity-at-length (and maturity-at-age).
   Response: No new maturity information is available for Pacific mackerel at this time, however, further maturity research for this species is being considered in the near future.

5. Compare catch rate trends of CPFV observer data and CPFV logbook data for the years 1985-89. This work may help validate trends in the logbook data.
   Response: See High priority response 3a) above.

Responses to recent STAR (2019) requests

During the review in April 2019, numerous additional model configurations were investigated, which included evaluating different combinations of data and parameterizations in particular candidate models, revising outputs and contrasting results across similar models, conducting diagnostic analysis for particular configurations, etc. Detailed requests, rationales, and responses associated with sensitivity analysis conducted during the review in April are presented under Requests to the STAT in STAR (2019). Results for several sensitivity requests during the review in April are further discussed in Sensitivity analysis and presented in Appendix A (Table A2 and Fig. A2).

Statistical modeling framework

The Stock Synthesis model (SS; Methot 2013; Methot and Wetzel 2013; Punt and Maunder 2013) is founded on the AD Model Builder software environment, which essentially represents a C++ library of automatic differentiation code for nonlinear statistical optimization (Otter Research 2001). The modeling framework is very flexible and allows full integration of both population size and age structure, with capability for explicit spatial and temporal parameterizations. The model incorporates all relevant sources of variability and estimates goodness of fit in terms of the original data, producing final estimates of precision that accurately reflect uncertainty associated with the sources of data used as input in the overall modeling effort.

The SS model comprises three sub-models: (1) a population dynamics sub-model, where abundance, mortality, and growth patterns are incorporated to create a synthetic representation of the true population; (2) an observation sub-model that defines various processes and filters to derive expected values for different types of data; and (3) a statistical sub-model that quantifies the difference between observed data and their expected values and implements algorithms to search for the set of parameters that maximizes goodness of fit. Stock assessments based on the SS modeling framework have been conducted on numerous marine fish/fishery resources throughout the world. The SS model used in the last benchmark assessment for Pacific mackerel was version 3.24s (Crone and Hill 2015; Methot 2013). The most recent SS version (3.30.12, Methot et al. 2018) was used for the assessment in 2019. All SS files for final base model ALT_19 are presented in Appendix B.

Differences between past (H3) and present (ALT) assessment models

Structure, processes, and data associated with the past (H3) and present (ALT_19) model-based assessments are compared in the following table (also, see Table 4). The primary difference between the models is the survey index of abundance used in the assessment: a fishery-dependent commercial passenger fishing vessel (CPFV) index for model H3; and a fishery-independent acoustic-trawl (AT) index of abundance for final base model ALT_19.

	H3	**ALT_19**
Model structure/processes/data		
Time period	1983-19	2008-19
Fisheries (no., type)	1, combined rec./com.	1, combined rec./com.
Surveys (no., type)	1, CPFV	1, AT
Natural mortality (M)	Fixed (0.5)	Estimated (prior)
Growth	Estimated (V-B LAA)	Fixed (WAA)
Spawner-recruit relationship	Beverton-Holt	Beverton-Holt
Virgin recruitment (R_0)	Estimated	Estimated
Steepness (h)	Estimated	Fixed (0.75)
Tot. recruitment variability (σ_R)	Fixed (0.75)	Fixed (0.75)
Init. equil. recruitment offset (R_1)	Estimated	NA
Catchability (q)	Estimated	Estimated (prior)
Selectivity (age-based)	Estimated	Estimated
Fishery	Asymptotic	Dome
Age composition	Y	Y
Mean length-at-age (LAA)	Y	N
Survey	Asymptotic	Asymptotic
Length composition	Y	N
Age composition	N	Y
Data weighting	N	Y (fishery age data down-weighted)

Unresolved problems and major uncertainties

In the past, the major area of uncertainty for assessing the status of the Pacific mackerel stock on a regular basis was identifying an appropriate index of abundance that was representative of the stock's abundance dynamics and could be used as the foundation source of data, either as a survey-based assessment or as the priority data in an integrated model-based assessment (e.g., Crone and Hill 2015; STAR 2015). That is, various indices of abundance have been used in Pacific mackerel stock assessments since the mid-1990s, including power plant impingement data, fishing industry aerial spotter data, CalCOFI larval data, AKFSC triennial shelf (bottom-trawl) survey, and CPFV logbook data (CDFW). All of these indices of abundance were eventually (and justifiably) rejected as suitable indices that could be considered representative of population abundance of Pacific mackerel, with the CPFV logbook survey lasting the longest for use in an assessment for advising management. Further, none of the above indices were subjected to rigorous methodology review as conducted to date for the SWFSC's AT survey (STAR 2011; PFMC 2018b).

In this assessment (2019), the most objective source of abundance data (AT survey) available presently for assessing population dynamics of the Pacific mackerel stock (PFMC 2018b) is used in the context of both survey- and model-based assessments. However, it is important to recognize that: 1) inherent uncertainty regarding the portion of the hypothesized stock's distribution in U.S. waters each year (i.e., availability in surveyed areas) will never be known definitively, given its extensive range dictated largely by environmental factors; and as importantly, 2) the distribution portion is necessarily not constant over time, but changing in concert with the prevailing oceanographic drivers. The AT survey design, methods, and results are presented in Assessment – Acoustic-trawl survey. Spatial uncertainty regarding fish vs. survey distribution each year is primarily in terms of the species' latitudinal distribution south of San Diego into waters off Baja California and less so but still not well understood, its longitudinal distribution west of the survey's offshore boundaries (e.g., jack mackerel of the CPS assemblage, MacCall and Stauffer 1983).

Given this underlying fish vs. survey spatial uncertainty, catchability (q, probability of capture by the survey) for AT abundance time series was modeled using an informative prior in final base model ALT_19, with plausible bounded estimates of q based on: life history assumptions; catch and larval density evaluations north-south of San Diego; and distribution metrics previously established and used presently in harvest control rules for the stock (see Base model description\Catchability). Finally, it is important to note that this general issue regarding uncertainty surrounding species' range vs. survey design was also addressed in past Pacific sardine (e.g., Hill et al. 2015) and hake (Helser et al. 2002) assessments by assuming that the AT survey provided estimates of 'absolute' abundance (fixed q=1) for the respective populations. Catchability issues associated with both assessments have evolved over time, with q now treated as an estimated parameter in the models (Hill et al. 2019; Edwards et al. 2018).

The other major area of uncertainty affecting the ongoing Pacific mackerel stock assessment and related model development, as well as other CPS assessments considered in the future (e.g., Pacific sardine, northern anchovy, jack mackerel), is improvements needed for more efficiently producing quality age data associated with production ageing efforts in the laboratory, particularly, SWFSC's survey samples. As discussed above (Ageing error, Empirical weight-at-age, and Survey data\Age and length compositions), age determinations for survey sampled specimens need to be conducted in a more structured, technical framework than in place presently, one that maximizes consistency in age reading protocols, including more systematic/coordinated double-read analysis with the most experienced ageing laboratory for CPS that is responsible for production ageing of Pacific mackerel samples collected from the fishery (see Research and data needs). In this assessment, age-based compositions associated with the survey, including fishery/survey weight-at-age and age-composition time series, were developed/applied in a manner that minimized direct use of the age data determined from the production ageing laboratory in La Jolla.

Base model description

Final base model ALT_19 represents a parsimonious model-based assessment, and includes three primary sources of data: fishery landings; fishery/survey biological compositions; and most importantly, AT survey abundance time series. Additionally, informative priors are used for evaluating key areas of uncertainty in the model, including estimation of the population's natural mortality (*M*) and survey's catchability (*q*). Many alternative model configurations were investigated based on different: data (e.g., landings, fishery/survey weight-at-age, and survey age compositions); assumptions for critical population processes (e.g., recruitment variability and deviation estimates, and spawner-recruit steepness); and fishery/survey processes (e.g., selectivity and catchability), see Sensitivity analysis and Appendix A. It is important to note that final base model ALT_19 (post-STAR) presented in this report was generally similar to the preliminary base model ALT_19 (pre-STAR), with the exception that fishery age-composition time series were down-weighted relative to other data sources in the overall statistical population dynamics model, i.e., less emphasis in calculation of the model's overall fit to the multiple sources of data and associated assumptions regarding important population processes.

Final base model ALT_19 specifications follow, with past model H3 specifications presented in brackets if different from present model. Also, see table above (Differences between past (H3) and present (ALT) assessment models). Further discussion regarding particular model specifications (fish/fishery processes) follow the summarized list below.

- Time period: 2008-18, with annual time steps [H3: 1983-15].
- Fisheries: one, commercial (U.S. and Mexico) and recreational (U.S.) fisheries were combined into a single fishery.
- Surveys: one, index of abundance from AT survey [H3: one, CPFV index of abundance].
- Sex: combined sexes.
- Longevity: 12 years.
- Natural mortality: constant, *M* estimated using prior (mean=-0.5/SD=0.32 in log-space) [H3: fixed=0.5 yr^{-1}].
- Maturity: included in maturity*fecundity-at-age vector in empirical weight-at-age (WAA) file (similar vector of maturity-at-age as used in model H3 multiplied by average (2008-18) WAA) [H3: fixed vector of maturity-at-age].
- Growth: empirical WAA (growth not internally estimated) [H3: constant, estimated von-Bertalanffy growth curve (L_∞=39 cm, k=0.39) and weight-length relationship (a=2.7e-6; b=3.4)].
- Fishing mortality: *F* calculations based on SS hybrid method and initial *F* estimate based on a non-equilibrium population assumption and set to 0.

- Selectivity (fishery): constant, age-based, dome-shaped (age-specific using SS non-parametric form) [H3: asymptotic using SS double-normal form].
- Selectivity (index): constant, age-based, asymptotic (age-specific using SS non-parametric form) [H3: asymptotic using SS logistic form].
- Catchability: constant, q estimated using prior (mean=-0.425/SD=0.32 in log-space) [H3: q estimated].
- Spawner-recruit: Beverton-Holt S-R function, with estimated virgin recruitment (R_0), fixed steepness (h=0.75), fixed recruitment variance (σ_R = 0.75) [H3: steepness estimated (h=0.49)].
    - Recruitment eras: recruitment deviations for 'early period' (2002-07), 'main period' (2008-17), 'late period (2018), and 'forecast period' (2019-20) [H3: respective year ranges similar, but based on data range=1983-14].
    - Recruitment bias adjustments implemented (2008-17) [H3: 1983-13].
- Variance adjustments (additional data weighting) for biological compositions and indices: Fishery age-composition time series down-weighted (likelihood lambda=0.5) [H3: none].

Likelihood components and model parameters
The list of estimated parameters for final base model ALT_19 is presented in Table 5. The total objective function was based on the following likelihood components and estimated parameters: 1) fit to catch; 2) fit to AT survey index of abundance; 3) fits to age compositions for fishery and survey; 4) spawner-recruit virgin recruitment, recruitment deviations, and forecast recruitment estimates; 5) prior estimates for M and q; and 6) soft-bound penalties associated with particular estimated parameters.

Initial population and fishing conditions
The modeled time period in final base model ALT_19 was from 2008-18, founded on the highest priority data (AT survey index of abundance) for meeting the management goal (recent stock biomass). A similar timeframe and prioritized data were used for developing the Pacific sardine assessment model (Hill et al. 2017, 2019). Assumptions related to initial population and fishing conditions for final base model ALT_19 were similar to past Pacific mackerel stock assessments, whereby a non-equilibrium model or rather, a model that was based on a relaxed equilibrium assumption of the virgin (unfished) age structure at the start of the model using recruitment deviation estimates prior (early era in SS) to the start of the modeled time period (e.g., Edwards et al. 2018; Hill et al. 2019). Hill et al. (2019) further discuss details for addressing initial population/fishing conditions in integrated assessment models for Pacific sardine. Initial fishing mortality was fixed (F=0) as in past assessments, noting that an alternative configuration with estimated initial F was evaluated in sensitivity analysis (F<0.01), which produced similar results as the final base model (Table A2 and Fig. A2).

Growth
Growth was estimated internally in past Pacific mackerel assessment models, based on a modified von Bertalanffy length-at-age (LAA) relationship (Methot and Wetzel 2013). Pacific mackerel exhibit relatively rapid growth as juveniles, realizing over 50% of their total growth (in length) by age 1 to 1.5 (20-25 cm) and subsequently, grow a few cm per year until death at roughly 40 cm (age 6-8+ yr). For purposes of developing a parsimonious model to meet the management goal (see Preface), internal estimation of growth implemented in past models was

essentially bypassed via a matrix of empirical weight-at-age (WAA) estimates (by year), which were used to convert estimated numbers-at-age in the model to biomass-at-age (Fig. 5). The use of empirical WAA data is a convenient method for capturing the variability in growth relationships (e.g., weight-length and length-at-age) both within and across years, without requiring parametric models to address these biological processes in the integrated assessment model (Edwards et al. 2018). Underlying assumptions for using empirical WAA data are that the age samples come from sources (e.g., fishery or survey) that can be considered generally representative of the modeled population, and that the WAA time series are not subject to strong selectivity biases associated with the respective sampling process/source (see Empirical weight-at-age). Growth was further evaluated in sensitivity analysis for final base model ALT_19, including models that included alternative WAA data (Table A2 and Fig. A2) and internally estimated growth.

Maturity

The maturity schedule (maturity-at-age, in proportion) assumed in past assessment models was used in all model ALT_19 scenarios associated with the assessment conducted in 2019 (Fig. 5). Ultimately, the underlying maturity schedule in the model reflected normalized net fecundity-at-age estimates based on predicted fraction mature, spawning frequency investigations, and batch fecundity calculations from a laboratory study conducted in the mid-1980s (Dickerson et al. 1992; Crone and Hill 2015). Note that the assumed maturity schedule is treated differently in integrated assessments that bypass internal estimation of growth parameters by using WAA data, such as final base model ALT_19 (Methot and Wetzel 2013; Methot et al. 2018). For example, in final base model ALT_19, the time-invariant maturity-at-age vector assumed in past models was multiplied by a vector of averaged WAA time series from 2008-18, which served as a constant 'maturity*fecundity' vector in the empirically-derived WAA matrix used in the integrated model (Fig. 5). Also, see Empirical weight-at-age.

Natural mortality

In past assessments, natural mortality rate (M) was assumed to be 0.5 yr^{-1} and constant over time for all ages. Parrish and MacCall (1978) estimated natural mortality for Pacific mackerel using early catch curves (M = 0.3-0.5), regression of Z on f (M = 0.5), and comparative studies of maximum age (M = 0.3-0.7; Beverton 1963) and growth rate (M = 0.4-0.6; Beverton and Holt 1959). The above research and overall conclusions considered the regression of Z on f to be the most reliable method, with the estimate M = 0.5 falling within the range of the plausible estimates.

Given past uncertainty associated with assumed rates of M considered for Pacific mackerel, as well as other members of the CPS assemblage, M was modeled in this assessment using an informative prior based generally on a meta-analysis approach recommended in Hamel (2015) and Then et al. (2014), Tables 5-6. Similar approaches for evaluating M in integrated fish stock assessments have been used in models for Pacific hake (Edwards et al. 2018) and various groundfish species (e.g., Johnson et al. 2016; Haltuch et al. 2017).

Three empirical relationships between critical life history parameters and M were examined: Hoenig (1982), based on maximum age (AgeMax); modified Pauly (1980), based on maximum size (L_∞) and growth rate (k); and Charnov and Berrigan (1990), based on age-at-50% maturity

(AgeMat), Table 6. The combined result from the analysis indicated a prior for *M* that was relatively robust to the choice of specific input parameters and yet generally uncertain: log(*M*) = -0.5/log(SD) = 0.32, translating to a median (exponentiated) value of *M* = 0.61 (SD = 1.38, 95% PI = 0.32-1.14). For this assessment, *M* was modeled using an informative prior based on a lognormal distribution (log(*M*) = -0.5/log(SD)=0.32), Table 5. Natural mortality was further evaluated in sensitivity analysis for final base model ALT_19 (Table A2 and Fig. A2), including in formal profile evaluations (Table 12). See Results\Natural mortality estimates, Profile analysis, and Sensitivity analysis.

Spawner-recruit relationship
As implemented in past assessments, a Beverton-Holt spawner-recruit (S-R) relationship was assumed in the model, based on: estimated virgin recruitment, log(R_0); fixed recruitment variability (σ_R = 0.75); and fixed steepness (*h*=0.75). In past models, steepness was estimated (*h*≈0.50) and relatively robust in sensitivity analysis across a wide range of assumed values (e.g., Crone and Hill 2015). Fixing *h* in the present model is aligned with a primary goal of the assessment to develop a parsimonious model that meets the management goal using prioritized data and model assumptions/estimated parameters most efficiently. Steepness was further evaluated in sensitivity analysis for final base model ALT_19 (Table A2 and Fig. A2), including in formal profile evaluations (Table 12). See Results\Spawner-recruit relationship estimates, Profile analysis, and Sensitivity analysis.

Recruitment deviations were modeled in final base model ALT_19 similarly as done in past assessments, using the same approach for treating recruitment eras in SS: recruitment deviations for ‘early period’ (2002-07); ‘main period’ (2008-17); ‘late period (2018), and ‘forecast period’ (2019-20). Recruitment estimation was further evaluated in sensitivity analysis for final base model ALT_19 (Table A2 and Fig. A2), including alternative assumptions for σ_R and recent recruitment estimation (estimated or assumed from underlying S-R relationship).

Selectivity
Selectivity curves were modeled as non-parametric functions, with estimated age-specific values using a random walk (Methot et al. 2018): fishery (estimated ages 0-5, ages 6+ assumed equal to age-5 fish); and survey (estimated ages 0-1, ages 2+ assumed equal to age-1 fish). This selectivity formulation has the properties that the maximum selectivity equals 1, which results in one fewer degree of freedom than the number of estimated ages and thus, one parameter should be fixed at an arbitrary (reference) value, typically minimum age included in the composition time series (Methot et al. 2018). For both the fishery and survey selectivity parameterizations in final base model ALT_19, age-0 fish were used as the reference age, so that estimated age selectivities were relative to age-0. Similar selectivity parameterizations are used for related small pelagic species in both Pacific sardine (Hill et al. 2019) and hake (Edwards et al. 2018) stock assessments. Various alternative selectivity assumptions were investigated in sensitivity analysis, including based on different underlying forms and time-varying considerations (Table A2 and Fig. A2).

Catchability
As discussed previously, survey catchability (*q*) assumptions for the CPS assemblage of the California Current are necessarily uncertain to varying degrees, given the extensive ranges

exhibited by these species dictated largely by oceanographic factors (see Assessment – Acoustic-trawl survey\Overview and Unresolved problems and major uncertainties). Uncertainty surrounding survey q for the Pacific mackerel stock was modeled in this assessment using plausible bounded estimates for q based on: life history assumptions; catch and larval density evaluations north-south of San Diego; and distribution metrics previously established and used presently in harvest control rules for the stock.

General consensus concerning life history of the Pacific mackerel stock is that the species exhibits predictable north-south seasonal movement off the Pacific coast of North America, and is most likely to occupy the more northerly regions of its range and be within the survey area (U.S. waters) from mid-summer to fall each year, which coincides with the annually conducted AT summer cruises. Catch data from summer months for various time periods were compared between U.S. and Mexico (Fig. 9) to evaluate average proportion estimates of the stock in U.S. waters relative to total landings (U.S. and Mexico fisheries). The average proportion of the stock in U.S. waters determined from summer catch data compared between the two countries (1983-17, 2000-17) indicated that roughly 61% of the total catch was caught in U.S. waters. Historical Pacific mackerel larval density data from CalCOFI surveys were evaluated similarly as catch (Fig. 9), i.e., to obtain average proportion estimates of the stock in U.S. waters relative to overall larval density (U.S. and Mexico waters). The average proportion of the stock in U.S. waters determined from summer CalCOFI data compared between the two countries (1951-84) indicated that roughly 62% of the overall larval distribution was in U.S. waters. Pacific mackerel larval density distributions off southern California and Baja California Mexico were also investigated previously (PFMC 1998) for purposes of calculating formal 'distribution' (70%) metrics for using in the harvest control rule used currently for management of the stock. Weber and McClatchie (2012) discuss general larval distribution information associated with the historical CalCOFI cruises conducted by the SWFSC, including timing issues of the cruises relative to the species' biology (spatial/temporal characteristics of the spawning aggregation). It is important to note that strict determination of the portion of the stock's 'availability' to the survey efforts each year is necessarily problematic, given the species' biology and transboundary movements across particularly the southern, as well as western regions of its hypothesized range. To varying degrees, this spatial/temporal uncertainty issue (fish distribution vs. survey design) is applicable to all CPS and not specific to Pacific mackerel. For example, catchability considerations in stock assessments associated with Pacific sardine (Hill et al. 2019) and hake (Edwards et al. 2019) have evolved over time, whereby parameterizations of q changed as additional information and subsequent model investigations led to more informed q estimation in the model.

For this assessment, AT survey q was modeled using an informative prior based on a normal distribution with mean $\log(q)$ = -0.425/log(SD)=0.32, which reflected an exponentiated assumed central tendency (0.65) and error (1.38) associated with the prior (Table 5). The catchability prior was centered around 0.65 based on the evidence presented above regarding species' biology, catch/larvae evaluations off San Diego/Mexico (~60%, 0.6), and current distribution metric (70%, 0.7) included in the current management control rule. Finally, catchability was further evaluated in sensitivity analysis for final base model ALT_19 (Table A2 and Fig. A2), including in formal profile evaluations (Table 12).

Convergence criteria and status

The iterative process for determining numerical solutions in the model was continued until the difference between successive likelihood estimates was <0.0001. The total likelihood and final gradient estimates for final base model ALT_19 were 56.4492 and 3.17e-5, respectively.

Results

Parameter estimates and errors

Parameter estimates and associated errors (SDs) for final base model ALT_19 are presented in Table 5.

Growth estimates

Empirical weight-at-age (WAA) time series used in final base model ALT_19 are presented in Fig. 5.

Natural mortality estimates

Natural mortality (*M*) estimates associated with final base model ALT_19 and development of the prior for *M* are presented in Tables 5-6. Prior estimated median and SD for *M* from the fitted model were 0.81 (instantaneous) and 0.13 (log), respectively. Also, see Profile analysis.

Selectivity fits to fishery and survey age-composition time series

Estimated age-based selectivity curves for the fishery and AT survey are presented in Fig. 10. Model fits and associated residual plots for the age-composition time series associated with the fishery and survey are presented in Figs. 11 and 12, respectively. Overall fits to the composition time series were relatively good, however, poor fits were indicated for particular survey years. As presented previously (see Baseline model description), fishery age-composition time series were down-weighted (lambda=0.5) in final base model ALT_19, which slightly degraded the fit to the fishery composition data, while improving the fit to the AT survey index of abundance that represents the highest priority data in the assessment. See Sensitivity analysis and STAR (2019) for further discussion regarding improved fits to the survey index related to decreased emphasis on fishery age-composition data.

Catchability estimates and fits to survey index of abundance

Prior estimated mean and SD for *q* from the fitted model were -0.41 (log; 0.67=exponentiated) and 0.27 (log), respectively (Table 5). Model fits to the AT index of abundance are presented in Fig. 13. Fits to the AT index were relatively good for recent years (2016-18), particularly, the terminal-year biomass estimate (2018), which is important given it represents the basis for advising management. The model was unable to fit the high (2012) or low (2013-15) years, reflecting a relatively flat estimated curve over the modeled time period (2008-18). Also, see Profile analysis and Sensitivity analysis.

Spawner-recruit relationship estimates

The Beverton-Holt spawner-recruit (S-R) relationship associated with final base model ALT_19 is presented in Fig. 14. In final base model ALT_19, virgin recruitment was estimated [log(R_0)=12.36], steepness fixed (h=0.75), and underlying total recruitment variability fixed (σ_R = 0.75). Recruitment deviations and SEs associated with S-R calculations for the early, main, and late/forecast periods for final base model ALT_19 are presented in Fig. 14. Also, see Profile analysis and Sensitivity analysis.

Population number- and biomass-at-age estimates
Estimates of population number-at-age (July 1st) are presented in Table 7. The vast majority of the Pacific mackerel population is comprised of young fish, with an annual average over the last decade (2008-18) of approximately 90% of the stock $\leq$2 years old. Estimates of population biomass-at-age (July 1st) are presented in Table 8, which indicate that roughly 80% of average annual biomass (2008-18) was composed of age 0-2 fish.

Spawning stock biomass estimates
Estimated (female) spawning stock biomass (SSB) time series along with 95% confidence intervals (CI) are presented in Fig. 15. The estimated SSB of Pacific mackerel decreased from 2008 to 2016, with SSB increasing recently and into the forecast period, based on relatively high recruitment abundance estimated in 2018.

Recruitment estimates
Estimated recruitment (age-0 fish, numbers) abundance time series is presented in Fig. 15. Estimated recruitment time series indicated relatively high recruitment success for years 2011, 2016, and 2018 (Figs. 14-15). It is important to note that a major area of uncertainty associated with ongoing Pacific mackerel assessments (as well as CPS assessments in general) is estimation of highly variable recent recruitment (age-0 fish), given the contribution of widely fluctuating estimates (pulses) of age-0 fish to estimated stock biomass (age-1+ fish, mt) used for management in subsequent years, e.g., age 0-2 fish typically comprise 80-90% of the total biomass in any given year (see Population number- and biomass-at-age estimates).

Stock biomass estimates for PFMC management
Time series of estimated stock biomass (mt, age 1+ fish) used for setting management specifications on an annual basis is presented in Fig. 16. Similar to estimated SSB, estimates of stock biomass generally declined from 2008 to 2018, with the exception of 2012 that reflected abundance that included a large recruitment pulse estimated in 2011 (Fig. 15). Similarly, high recruitment estimates in 2016 and 2018 translated to relatively higher estimated stock biomass in 2017 and into the forecast period (2019-20), respectively (Table 8, age 1+ biomass).

Fishing mortality and exploitation rates
Estimated rates of instantaneous fishing mortality (F, yr^{-1}) for this stock have fluctuated over the last decade (2008-18), from roughly 0.1 to 0.9, with recent Fs <0.4 (Fig. 17). Exploitation rate (calendar year catch/mid-year total biomass) time series generally followed the estimated Fs over time, with annual removal rates (including Mexico catches) that ranged from roughly 5 to 25% over the modeled timeframe (2008-18).

Uncertainty analysis
Convergence tests
Convergence properties of final base model ALT_19 were tested to ensure the model represented an optimal solution. Final base model ALT_19 was run over a wide range of initial starting values for virgin recruitment [$\log(R_0)$, 11.4 to 13.3]. For each run, phase order for estimating

parameter components (e.g., M, $\log(R_0)$, q, selectivity) was randomized from 1 to 3, and all parameters were jittered by 20% (Table 9). All models converged to the same total negative log likelihood estimate (56.4492) and had identical final estimates of $\log(R_0)$=12.3613. Thus, final base model ALT_19 appeared to have converged to a global minimum.

Terminal-year stock biomass likelihood profile

Likelihood profiles for terminal-year (2018) stock biomass (age 1+ fish) can provide information regarding which data components influence scale in the integrated stock assessment model. Additionally, these diagnostic analyses are useful for identifying areas of conflict among data sources and tension between particular parameterizations included in the assessment model. The terminal-year stock biomass profile is centered on the 2018 estimate of stock biomass. This profile required using a re-configured final base model ALT_19 that: included an additional 'virtual survey' that was based on a single, precise, terminal-year (2018) survey estimate of stock biomass that essentially equaled the estimated stock biomass in 2018 from final base model ALT_19; and the virtual survey received high emphasis (lambda=100) relative to other data components in the overall fitted model. A terminal-year stock biomass likelihood profile is a more useful diagnostic for this species, as well as other CPS (e.g., Pacific sardine) that are managed on the basis of a current estimate of stock biomass. Diagnostic profiles for final base model ALT_19 indicated only one area of data conflict, namely, the AT age-composition time series fitting better at lower terminal-year biomass values relative to the other model components (Fig. 18). Fishery age-composition time series had little influence on model estimates of terminal-year stock biomass. This profile indicated that the AT survey index of abundance and parameter priors (e.g., M and q) are informative in the model for determining current stock biomass, given other structure (assumptions, data, and parameterizations) included in the configuration.

Profile analysis

Sensitivity of model results associated with important underlying population and survey processes estimated/assumed in final base model ALT_19 were further evaluated via profile analysis, including natural morality (M), AT survey catchability (q), and S-R steepness (h), Table 12. Uncertainty associated with the level of M in final base model ALT_19 was examined by profiling across a range of fixed levels of M. The profile was conducted using a range of M rates from 0.5 to 1.1 yr^{-1}. Models with higher assumed levels of M resulted in: lower estimates of survey catchability (q), i.e., M and q were inversely related; lower estimates of 2018 stock biomass; and higher levels of projected (2019) stock biomass (Table 12). Model fits to most data components (e.g., AT survey abundance index and age compositions), as well as total likelihood estimates indicated better fits at higher levels of M, however, the fishery age-composition data fit better at lower M values. The range of recent and projected stock biomass associated with the overall M profile indicated estimated 2018 stock biomass ranged from 25,889 to 27,278 mt and projected (2019) stock biomass ranged from 62,150 to 86,740 mt.

Uncertainty associated with the level of survey catchability (q) in final base model ALT_19 was evaluated by profiling across a range of fixed levels of q from 0.45 to 0.85 (Table 12). As presented above, survey q was inversely related to M, with increases in q resulting in lower estimates of M, as well as lower estimates of 2018 and 2019 stock biomass. Model fits to the AT index of abundance, M prior, as well as total likelihood estimates indicated better fits to higher levels of *q*. Age-composition time series for the fishery and survey both fit better at lower *q* values, but differences were negligible. Estimated stock biomass in 2018 ranged from 20,089 to 38,693 mt and projected (2019) stock biomass ranged from 57,548 to 100,256 mt.

Uncertainty associated with the level of S-R steepness (*h*) in model ALT_19 was evaluated by profiling across a range of fixed levels of *h* from 0.3 to 1.0 (Table 12). Model fits to *h* were comparable across the full range of values (total likelihood difference = 1.11), with fits to data components and parameter estimates also generally robust to varying levels of *h*. Increases in *h* resulted in higher estimates of survey *q* and lower estimates of *M*. Alternative assumptions for *h* had minor influence on model estimates important to management, such as stock biomass in 2018, which were generally similar across the profiled range (0.5-1), Table 12.

Retrospective analysis
Retrospective analysis provides another means of examining model properties and characterizing uncertainty. A retrospective analysis was conducted on final base model ALT_19, whereby data were removed sequentially (on an annual basis) from the terminal year (2018) backwards to 2014. Estimated stock biomass time series from the four model runs are presented in Fig. 19. There was no indication of a tendency of over-estimation of terminal-year stock biomass associated with final base model ALT_19, as was the case in previous models (e.g., Crone and Hill 2015). However, the analysis does indicate that final base model ALT_19 is generally characterized by a pattern of under-estimation of terminal-year stock biomass (Fig. 19), which is likely in large part due to the inherently variable abundance time series associated with the AT survey based on highly uncertain estimates of recruitment.

Sensitivity analysis
Uncertainty associated with results generated from final base model ALT_19 necessarily reflects an underestimate of the total uncertainty associated with stock status determinations for advising management (e.g., estimates of current and projected stock biomass). That is, a single base model does not explicitly account for alternative assumptions for Pacific mackerel population dynamics and fishery processes (e.g., recruitment, selectivity, temporal/spatial structure), the effects of different data-weighting approaches, and a strict scientific basis for prior probability distributions. Thus, final base model ALT_19 received extensive sensitivity analysis for purposes of evaluating the influence of data, assumptions, estimation methods, and structural uncertainty on important model results, particularly, estimated stock biomass (age 1+, mt) required for advising management. Results from selected models associated with the sensitivity analysis are presented in Table A2 and Fig. A2. As indicated in the profile analysis that involved *M*, AT survey *q*, and spawner-recruit (S-R) *h*, sensitivity analysis that considered various important processes/parameters in final base model ALT_19 resulted in relatively robust findings across the alternative model configurations, i.e., generally similar trends of estimated stock biomass, but differences in scale for particular models (Table A2 and Fig. A2). For example, the suite of models included in the overall sensitivity analysis resulted in stock biomass estimates ranging from approximately 50,000 to 90,000 mt (final base model ALT_19=71,099 mt).

However, as revealed in past stock assessments of Pacific mackerel, as well as Pacific sardine (e.g., Hill et al. 2015, 2016) and as expected in CPS assessments in general, management metrics of interest were relatively sensitive to decisions regarding recent recruitment estimation in the model. Model ALT_19_2 (Table A2 and Fig. A2) is an example of this more influential parameterization, whereby estimates of forecasted stock biomass (2019-20) were impacted substantially when recruitment was not estimated in the terminal-year (2018, as was the case in final base model ALT_19), but rather, was assumed to strictly follow the underlying S-R relationship. Such decisions regarding what recent years should be included/omitted in recruitment estimation associated with spawner-recruit processes in the model should be standardized in the future, to some degree, noting that sensitivity analysis is warranted in any event, given the inherent recruitment variability that characterizes CPS biology.

Ultimately, final base model ALT_19 was the outcome of sensitivity analysis conducted at the review in April, whereby sequentially down-weighted fishery age-composition time series resulted in increasingly better fits to the AT survey index of abundance, considered the highest priority data in the assessment (STAR 2019); in final base model ALT_19, fishery age-composition time series were down-weighted using lambda=0.5. Another area of sensitivity analysis conducted at the review in April addressed time-varying selectivity for age-0 fish associated with the AT survey age compositions in efforts to better fit these data (ALT_19_19, Table A2 and Fig. A2), but convergence/stability issues observed with such configurations were not able to be adequately resolved given limited time and thus, not included in the recommended final base model ALT_19 for management (STAR 2019). Also, see Conclusions.

Historical analysis
Estimated stock biomass time series from previous stock assessments are presented in Fig. 20. For the most part, full/updated assessments from 2004 to 2011 were characterized by generally similar trends/scales of estimated stock biomass. The 2015 stock assessment indicated a substantially reduced level of stock biomass beginning in 2007 to the end of the modeled timeframe (2015), due primarily to the critical abundance time series (CPFV) used in the model. Stock biomass time series associated with final base model ALT_19 was similar to previously estimated stock biomass (2015) for years 2008 to 2013, with a generally lower trajectory from 2014-20, based primarily on the different index of abundance used in the past (CPFV logbook index, model H3) vs. present assessment (AT survey index, final base model ALT_19). Also, see Crone et al. (2019) for estimated stock biomass associated with the fully updated model H3 (1983-2018), which provides more relevant comparisons of estimated stock biomass time series between previous and present assessments.

Conclusions

The following are conclusions and recommendations from the STAT/SWFSC for regularly advising management regarding the abundance of Pacific mackerel (and other CPS) in the future, which is necessary for implementing harvest control rules associated with the stocks (in descending order of importance).

- Given the merits of the survey-based assessment approach and drawbacks of model-based assessments for CPS, adopt the survey-based assessment approach for formal management (move the start date of the fishery to January or secondarily, use a reasonable projection method for obtaining a current estimate of stock biomass).
- If the model-based assessment approach is adopted, final base model ALT_19 should be used as the foundation model to further develop in the future.

- ○ Final base model ALT_19 includes the best available scientific information, plausible assumptions regarding Pacific mackerel biology, internally consistent in terms of both input data and parameters/processes estimated or assumed, robust to a wide range of reasonable states of nature (model configurations), stable in terms of perturbation and sound in terms of diagnostics, and produces reasonable results given the data, assumptions, and model structure.
- ○ Future areas of sensitivity evaluations for final base model ALT_19 should include time-varying selectivity, recent recruitment variability/estimation assumptions, and data weighting considerations for composition time series. It is important to note that final base model ALT_19 represents a management (vs. research) model and as such, is parsimonious and straightforward for purposes of regularly advising management. Modifications to the ongoing model need to consider inherent tradeoffs between efficiently meeting the management goal and further complexity for purposes of addressing areas of uncertainty associated with underlying process error in the model, such as recruitment variability assumptions, survey catchability uncertainty, selectivity considerations, etc.
- ○ Develop a fully Bayesian Markov Chain Monte Carlo (MCMC) estimation/simulation for final base model ALT_19 and compare results with the current model based on maximum likelihood estimation.
- ○ Eggs/larvae surveys (e.g., DEPM time series from CalCOFI) should be evaluated and used qualitatively in CPS assessments for corroborating/improving the ongoing AT survey for members of the assemblage such as northern anchovy and Pacific sardine, but are ineffective monitoring efforts for mackerel species. At this time, no other scientific-based indices of abundance are available/suitable for using directly in ongoing CPS stock assessments.

HARVEST CONTROL RULES FOR U.S. MANAGEMENT IN 2019-20 AND 2020-21

It is important to note that harvest control rule (HCR, Table 10a-b) statistics applicable to the model-based assessment method (final base model ALT_19) are presented at this time, given lack of consensus in past CPS assessment reviews (Hill et al. 2018, 2019) regarding suitable methods for projecting the terminal-year survey biomass estimate (2018) to the current fishing year (2019), see Preface and Research and data needs. Since 2000, the Pacific mackerel stock has been managed under a Federal Management Plan (FMP) harvest policy, stipulating that an optimum yield for this species be set according to the following harvest control rule:

$$\text{Harvest} = (\text{Biomass-Cutoff}) \bullet E_{MSY} \bullet \text{Distribution},$$

where Harvest is the harvest guideline (HG), Biomass is age 1+ stock biomass (mt) in the respective fishing year (71,099 mt in July 2019 and 56,058 mt in July 2020), Cutoff (18,200 mt) is the lowest level of estimated biomass above which harvest is allowed, E_{MSY} (30%, also referred to as Fraction) is the proportion of biomass above the Cutoff that can be harvested by fisheries, and Distribution (70%) is the average proportion of stock biomass (ages 1+) assumed in U.S. waters (PFMC 1998). Harvest stipulations under the federal FMP are applied to a July-June fishing year. The HG estimate associated with final base model ALT_19 for July 2019 was 11,109 mt (Table 10a) and 7,950 mt for July 2020 (Table 10b). Note that the forecasted HG for

2020 was based on the assumption that that projected catch for 2019 was similar to estimated landings in 2018 (12,000 mt), with predicted recruitment (i.e., 2019 and 2020 cohorts) for the forecast period estimated directly from the spawner-recruit relationship as recommended in previous reviews. Landings and associated HGs since 2008 are presented in Table 11. Finally, additional HCR statistics are also included in Table 10a-b for specifying overfishing limits (OFLs), as well as a range of acceptable biological catches and limits (ABCs and ACLs) based on different probability levels of overfishing using 'P-star' and associated ABC 'buffer' calculations. Final base model ALT_19 estimates of SSB uncertainty, used for calculating sigma for P-star buffers, were CV=37.6% (σ=0.363) in 2019 and CV=45.4% (σ=0.433) in 2020, so the current default sigma (0.5) was applied to Tier 1 ABCs in Table 10a-b.

Regional management considerations
Pacific mackerel, as well as other species considered in the CPS FMP, are not managed formally on a regional basis within the U.S., due primarily to the extensive distribution and annual migration exhibited by these stocks (see Distribution and movement). Noting that a form of regional (temporal/spatial) management has been adopted for Pacific sardine, whereby seasonal allocations are stipulated in attempts to ensure regional fishing sectors have at least some access to the directed harvest each year (PFMC 2014). However, given the recent history of relatively limited landings of Pacific mackerel in California, and particularly Oregon and Washington, region-specific catch regulations would not likely provide further benefits for management of the stock at this time.

RESEARCH AND DATA NEEDS

See discussion presented in Unresolved problems and major uncertainties that provides the basis for the following research and data needs summarized below.

The most important research support needed for improving the quality of the ongoing stock assessments of Pacific mackerel, Pacific sardine, and other CPS assessed in the future should be directed towards the AT survey conducted annually by the SWFSC. This fishery-independent monitoring effort provides the most objective time series for measuring total biomass of CPS and regularly advising management. First, the capability to extend the AT survey operations beyond particularly the latitudinal (south) and less so longitudinal (west) extents of the current survey design would greatly benefit the quality of data provided by this survey effort, given the extensive distribution of Pacific mackerel in any given year, believed to be influenced largely by oceanographic factors. The types and priority of recommended improvements to the AT survey are presented above (Areas of improvements for AT survey). In this context, it is imperative that efforts continue for encouraging collaborative research and data exchange between NOAA Fisheries (Southwest Fisheries Science Center) and researchers from Mexico's federal and academic fishery institutions, i.e., such cooperation is necessary for providing a synoptic assessment that is based on representative sample data that have been collected using consistent methods across the full hypothesized range of this species. In summary, this species' biology is characterized by trans-boundary movements each year that cross multiple countries' marine exclusive economic zones and thus, focused political discussions will be needed to allow cooperative survey efforts that extend beyond U.S. waters. Further, it is likely that without such collaborative survey agreements in the future, very little additional information will ever be available for improving our understanding of Pacific mackerel or other CPS (e.g., Pacific sardine, jack mackerel, northern anchovy) distributions relative to the surveyed area each year (i.e., uncertainty surrounding fish availability and AT survey catchability).

Second, given the importance of age (as well as size, weight, and length) composition time series for developing a sound understanding of Pacific mackerel population dynamics, as well as being needed for using integrated model-based assessments for management purposes, it is critical that biological data collection programs at both the state (fishery) and federal (survey) levels continue to be supported in the future. Ultimately, fishery samples should be collected in the field based on the actual landings from completed fishing trips in the three states (California, Oregon, and Washington), which would allow the most representative overall age-composition time series to be developed for using in the ongoing assessments. To date, only fishery age data from California have been available for assessments, noting that: historically, the California fishery has represented the main fishery for this species, with both the Washington and Oregon fisheries contributing limited catches to the total landings each year; and recently, efforts have begun to sample/process/age landed fish from Pacific Northwest ports. As discussed above (Introduction), biological samples from the limited Pacific Northwest fisheries are needed, given hypotheses/observations regarding this species' biology and larger/older fish tending to occupy more northerly regions of its range each year (e.g., Hill 1999), before moving south to spawning areas off San Diego/Baja California. As indicated above for extending the spatial boundaries of the present AT survey design, improved relations/collaborations with Mexico are needed in terms of developing coordinated programs for purposes of exchanging biological and catch data between the countries. Relatedly, another very important issue that demands immediate attention is to revisit ageing methods/coordination of production ageing of Pacific mackerel associated with the AT survey (SWFSC) for purposes of further evaluating/correcting suspected bias associated with age determinations from this sample information. In this context, laboratory-based biological research (e.g., young-of-year tank studies) would provide valuable age/growth information for improving methods involved in production ageing efforts (e.g., first-annulus deposition and identification), which serve as the basis for developing age-composition time series used in the assessments. Finally, it is important to note that a small pelagic species age/growth working group that included researchers from the U.S., Mexico, and Canada has been established in the past, but the group is no longer formally active and meeting on a regular basis.

Third, the harvest control rule utilized in the Pacific mackerel federal CPS-FMP was developed in the mid-1980s based on estimated abundance and spawner-recruit data available at that time and thus, harvest strategies should be re-examined using updated data and simulation methods. Formal management strategy evaluations (MSE) should be undertaken in the near future, which address not only the Pacific mackerel stock alone, but also include assemblage-based management options. It is important that the MSEs consider recent market conditions and economic factors affecting the overall wetfish fleet, which necessarily will impact fishery goals and associated operations in the future. Finally, decisions regarding the utility of survey-based assessments for managing the stocks in the future would benefit from MSEs that include alternative projection methods, which could be evaluated in concert with analogous MSEs that consider model-based assessment approaches.

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TABLES

Table 1. Landings (mt) of Pacific mackerel by fishery (1983-18). Recreational fishery proportion of total landings is also presented. A single, combined (commercial and recreational) fishery is used in final base model ALT_19. Note that the model was based on 2008-18 data and extended historical time series for landings is presented for information only.

	Commercial				Recreational		Recreational
Fishing year	MX	CA	OR	WA	CA	Total	(prop.)
83	2,377.2	36,309.1	4.9	0.0	1,544.1	40,235.4	0.04
84	4,534.2	39,239.8	0.0	0.0	1,467.3	45,241.4	0.03
85	6,815.5	37,614.9	0.0	0.0	1,015.9	45,446.3	0.02
86	7,314.4	44,298.0	0.0	0.0	859.2	52,471.6	0.02
87	1,809.1	44,838.0	1.5	0.0	1,264.5	47,913.0	0.03
88	5,998.9	41,967.8	0.6	0.0	688.6	48,655.9	0.01
89	21,987.2	25,063.2	4.7	0.2	666.3	47,721.6	0.01
90	30,541.2	39,973.8	10.4	0.1	705.3	71,230.9	0.01
91	33,871.1	30,268.1	41.1	0.2	705.3	64,885.8	0.01
92	5,780.8	25,583.6	470.5	5.6	705.8	32,546.3	0.02
93	9,108.3	10,787.1	271.0	30.6	608.8	20,805.8	0.03
94	13,302.3	9,372.1	355.0	32.9	1,037.8	24,100.1	0.04
95	3,367.7	7,614.7	48.1	42.2	1,013.4	12,086.1	0.08
96	14,089.3	9,787.9	118.2	6.2	685.6	24,687.1	0.03
97	26,859.5	23,412.8	1,638.3	155.9	804.0	52,870.4	0.02
98	42,815.0	19,578.0	454.5	42.3	429.6	63,319.4	0.01
99	8,587.0	7,170.2	256.9	46.0	152.6	16,212.7	0.01
00	6,530.2	20,936.4	138.5	48.5	325.3	27,978.9	0.01
01	4,003.5	8,435.9	302.5	270.7	571.0	13,583.7	0.04
02	10,327.6	3,541.1	127.4	248.8	254.1	14,499.0	0.02
03	2,617.7	5,972.1	159.1	53.2	323.3	9,125.3	0.04
04	1,711.4	5,011.8	110.4	23.7	544.0	7,401.3	0.07
05	3,084.9	4,572.1	314.3	22.3	412.0	8,405.5	0.05
06	1,986.1	7,870.2	669.4	41.8	372.0	10,939.5	0.03
07	2,218.4	6,208.4	697.8	37.5	310.4	9,472.5	0.03
08	803.1	4,331.6	57.6	9.0	251.1	5,452.3	0.05
09	49.3	2,956.9	53.1	4.9	231.1	3,295.3	0.07
10	1,916.8	2,052.7	49.0	1.6	187.2	4,207.3	0.04
11	2,231.8	1,753.6	201.9	83.0	112.5	4,382.7	0.03
12	7,390.0	3,171.0	1,587.8	719.2	76.0	12,944.0	0.01
13	2,552.5	11,262.5	437.8	173.2	108.9	14,535.0	0.01
14	4,098.8	4,409.7	1,214.6	502.2	197.2	10,422.5	0.02
15	9,178.8	4,395.5	7.2	1.2	203.0	13,785.8	0.01
16	11,706.8	2,490.0	3.7	21.6	149.6	14,371.8	0.01
17	2,794.3	1,309.4	45.4	4.2	167.6	4,320.8	0.04
18	6,066.3	4,773.4	341.8	140.5	165.3	11,487.2	0.02
Avg. (2008-18)	4,435.3	3,900.6	363.6	151.0	168.1	9,018.6	0.03

Table 2. Age and length sample (no. fish and fishing trips) information from: CDFW port sampling and laboratory programs for Pacific mackerel (2008-18); and AT survey (2008-18), noting that survey age data were not used in final base model ALT_19. Number of fishing trips for fishery are applicable to both age and length samples.

Fishing year	Age			Length	
	Fishery (no. fish)	Fishery (no. trips)	AT survey (no. fish)	Fishery (no. fish)	AT survey (no. fish)
2008	723	29		725	
2009	422	17		440	
2010	497	20		512	
2011	771	31		775	
2012	1,195	48	165	1,198	165
2013	1,793	72	94	1,800	94
2014	1,396	56	213	1,396	213
2015	447	18	123	447	123
2016	494	20	357	494	357
2017	222	9	616	222	619
2018	148	6		148	904

Table 3. AT survey index of abundance for Pacific mackerel included in final base model ALT_19. Figure of AT survey index of abundance is presented below.

Year	AT survey	
	B (mt)	*CV* (%)
2008	55,000	38
2009		
2010		
2011		
2012	109,951	34
2013	8,245	61
2014	8,159	56
2015	7,146	52
2016	32,782	52
2017	41,139	26
2018	33,351	22

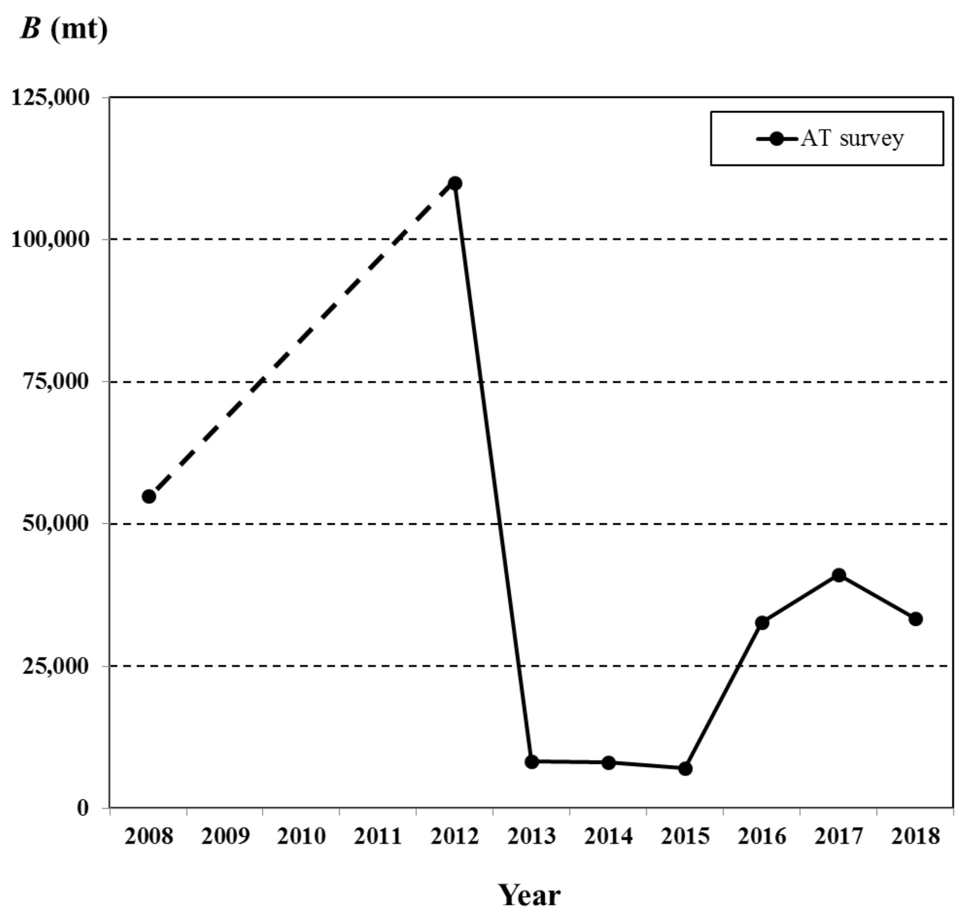


Table 4. Model structure (data and processes) and results (likelihood and parameter estimates) for final base model ALT_19. See Fig. 16 for estimated stock biomass (*B*) time series.

MODEL STRUCTURE	**ALT_19**
Time period (annual time step)	2008-19
Fishery (no.)	1
Survey (no.)	1=AT
Natural mortality (*M*)	Est (Prior)
Growth	WAA
S-R steepness (*h*)	Fixed
Catchability (*q*)	Est (Prior)
Selectivity	
Fishery (lambda=0.5)	Est (Dome)
Survey	Est (Asymptotic)

LIKELIHOODS	**ALT_19**
Catch	<0.0001
Fishery age composition	24.83
AT age composition	24.33
Age composition subtotal	49.17
At index of abundance	4.69
Recruitment	0.78
Forecast recruitment	1.40
Priors	0.41
Parm_softbounds	0.0007
Total -log(*L*)	56.45
Number of est. pars.	28

ESTIMATES	**ALT_19**
M	0.81
$\ln(R_0)$	12.36
S-R *h*	0.75
AT survey *q*	0.67
B (mt) - 2018	25,943
B (mt) - 2019	71,099

Table 5. Summary tables of estimated parameters (S-R and selectivity) and priors (natural mortality and catchability) for final base model ALT_19: a) estimate/prior values presented for *M* and *q* are parameterized in log space; and b) final value for *q*=log (SD=log), and *M*=instantaneous (SD=log). Distribution plots associated with prior-based *M* and *q* are presented below.

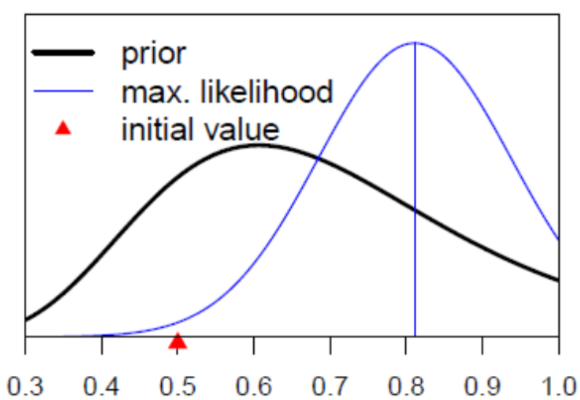
a)

Parameter	Estimated pars. (no.)	Bounds (low, high)	Estimate/Prior (mean, SD) / Single value=fixed
Population processes			
S-R_virgin recruitment_log(R_0)	1	(5, 20)	Uniform
S-R_steepness (*h*)	na	na	0.75
S-R_recruitment variability_σ_R	na	na	0.75
S-R_recruitment deviations_log(rec-devs), 2002-20	19	(-6, 6)	Lognormal (0, σ_R)
Natural mortality (*M*)_*Prior*	1	(0.3, 1)	Lognormal (0.61, 1.38)
Fishery/survey processes			
Fishery			
Selectivity (age-based, non-parametric, ages 1-5)	5	(-5, 9)	Uniform
AT survey			
Catchability (*q*)_*Prior*	1	(-5, 5)	Normal (0.65, 1.38)
Selectivity (age-based, non-parametric, ages 0-1)	1	(-5, 9)	Uniform

b)

Parameter	Phase	Min	Max	Initial/Prior value	Final value	SD
Natural mortality (*M*)_*Prior*	3	0.3	1	-0.5	0.811	0.127
S-R_virgin recruitment_log(R_0)	1	5	20	11	12.361	0.306
Catchability (*q*)_*Prior*	1	-5	5	-0.425	-0.408	0.265
AgeSel_P1_Fishery (age-0)	-2	-5	9	0	0	--
AgeSel_P2_Fishery (age-1)	2	-5	9	0.1	0.338	0.288
AgeSel_P3_Fishery (age-2)	2	-5	9	0.1	-0.502	0.694
AgeSel_P4_Fishery (age-3)	2	-5	9	0.1	0.882	0.946
AgeSel_P5_Fishery (age-4)	2	-5	9	0.1	-0.698	2.111
AgeSel_P6_Fishery (age-5)	2	-5	9	0.1	-1.587	3.898
AgeSel_P1_AT survey (age-0)	-2	-5	9	0	0	--
AgeSel_P2_AT survey (age-1)	2	-5	9	0.1	1.032	0.317

Natural mortality_*M*



AT survey catchability_ln(*q*)

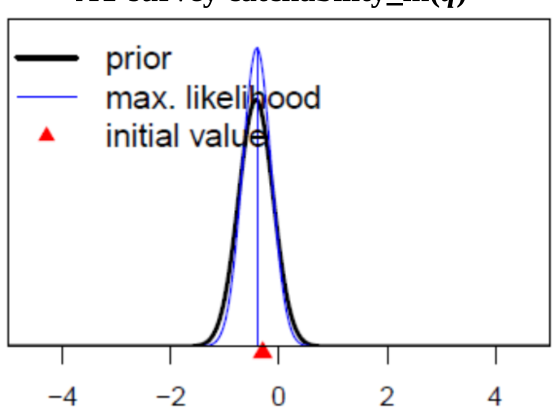


Table 6. Empirical relationships (Method) used in meta-analysis to evaluate rates of natural mortality (*M*) for Pacific mackerel. Three empirical relationships between critical life history parameters and *M* were examined: Hoenig (1982), based on maximum age (AgeMax); modified Pauly (1980), based on maximum size (L_∞) and growth rate (*k*); and Charnov and Berrigan (1990), based on age-at-50% maturity (AgeMat).

Method	Equation	Regression type	Log intercept	Parameter value	Parameter source	log(*M*)	SD
Charnov and Berrigan (1990)	M = 1.78 /AgeMat	log–log reg. (fixed slope = -1)	0.53	2.2	P. mackerel assmt. (2015)	-0.26	0.84
Hoenig (1982)	M = 5.40/AgeMax	log–log reg. (fixed slope = -1)	1.69	12	P. mackerel assmt. (2015)	-0.80	0.43
Hoenig (1982)	M = 5.40/AgeMax	log–log reg. (fixed slope = -1)	1.69	15	P. mackerel assmt. (2015)	-1.02	0.43
Hoenig (1982)	M = 5.40/AgeMax	log–log reg. (fixed slope = -1)	1.69	10	P. mackerel assmt. (2015)	-0.62	0.43
Hoenig (1982)	M = 5.40/AgeMax	log–log reg. (fixed slope = -1)	1.69	11	Fitch (1951)	-0.71	0.43
Pauly (1980)	$M = 6.50 * L_\infty^{(-0.35)} * k^{(0.56)}$	log–log regression	1.87	L_∞=39.2; k=0.39	P. mackerel assmt. (2015)	-0.07	0.86
Pauly (1980)	$M = 6.50 * L_\infty^{(-0.35)} * k^{(0.56)}$	log–log regression	1.87	L_∞=40.46; k=0.24	Parrish and MacCall (1978) Knaggs and Parrish (1973)	-0.26	0.86
Combined result						**-0.50**	**0.32**

Table 7. Pacific mackerel population numbers-at-age (1,000s of fish) for model ALT_19.

Fishing year	Population numbers-at-age (1,000s of fish)												
	0	1	2	3	4	5	6	7	8	9	10	11	12
Virgin	233,577	103,793	46,122	20,495	9,107	4,047	1,798	799	355	158	70	31	25
2008	265,093	72,099	47,846	41,067	10,016	4,142	1,815	799	355	158	70	31	25
2009	95,052	108,978	28,727	19,903	15,558	4,111	1,811	793	349	155	69	31	25
2010	158,226	40,138	45,085	12,225	7,966	6,563	1,808	796	349	154	68	30	24
2011	493,683	62,964	15,280	18,244	4,333	3,163	2,850	785	346	151	67	30	24
2012	121,856	205,266	25,489	6,417	7,074	1,799	1,386	1,249	344	152	66	29	23
2013	207,560	44,012	68,213	9,501	1,865	2,545	766	590	532	146	64	28	22
2014	151,934	65,867	12,199	22,782	2,118	588	1,054	317	244	220	61	27	21
2015	147,110	53,157	20,933	4,426	6,202	737	249	446	134	103	93	26	20
2016	336,228	41,579	12,526	6,337	778	1,737	298	100	180	54	42	38	19
2017	51,942	118,859	13,407	4,585	1,762	274	736	126	43	76	23	18	24
2018	620,762	20,811	45,680	5,457	1,648	705	119	320	55	19	33	10	18
2019	216,893	237,485	7,497	17,878	1,784	628	303	51	138	24	8	14	12
2020	222,641	83,738	86,650	2,957	5,955	687	271	131	22	59	10	3	11
Avg. (2008-18	240,859	75,794	30,489	13,722	5,393	2,397	1,172	575	266	126	60	27	22

Table 8. Pacific mackerel population biomass-at-age (mt) for model ALT_19. Age 1+ represents stock biomass estimate used for advising management.

Fishing year	Biomass-at-age (mt)												
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**1+**
Virgin	20,204	20,593	14,279	10,629	6,133	3,408	1,566	709	332	148	66	29	23	57,914
2008	22,931	14,304	14,813	21,297	6,745	3,488	1,580	709	332	148	66	29	23	63,535
2009	11,520	26,885	11,657	12,519	11,017	3,387	1,577	691	310	138	61	27	22	68,289
2010	14,620	8,236	13,868	6,759	5,392	5,824	1,574	693	304	134	59	26	21	42,890
2011	52,034	13,027	3,603	10,780	3,000	2,665	2,529	683	301	132	58	26	21	36,826
2012	14,745	47,827	8,595	3,609	4,828	1,457	1,207	1,108	299	132	58	25	20	69,166
2013	27,273	11,122	23,963	4,301	1,201	2,031	624	494	472	130	57	25	20	44,439
2014	21,332	16,131	4,270	11,796	1,337	470	832	256	213	192	53	23	18	35,591
2015	18,727	15,479	8,116	2,257	3,378	600	209	356	109	84	76	21	16	30,702
2016	73,264	11,933	4,776	3,579	459	1,413	251	85	144	43	33	30	15	22,762
2017	9,734	31,771	4,930	2,384	1,047	223	620	106	36	64	19	15	20	41,237
2018	91,873	4,938	15,933	3,103	911	573	100	270	46	16	28	8	15	25,943
2019	32,100	56,355	2,615	10,167	987	511	256	43	116	20	7	12	10	71,099
2020	32,951	19,871	30,224	1,681	3,295	559	229	110	19	50	9	3	10	56,058
Avg. (2008-18)	32,550	18,332	10,411	7,490	3,574	2,012	1,009	495	233	110	52	23	19	43,762

Table 9. Convergence tests for final base model ALT_19, whereby randomized parameter phase orders and 20% jittering were applied over a wide range of virgin recruitment values, $\log(R_0)$. Model ALT_19: $\log(R_0) = 12.3613$ and total $-\log(L) = 56.4492$.

	PHASE ORDER BY COMPONENT				RESULTS	
Initial log(R_0)	***M***	**R_0**	***q***	**Selectivity**	**Final log(R_0)**	**Total -log(*L*)**
11.4	3	1	2	1	12.3613	56.4492
11.5	1	2	1	3	12.3613	56.4492
11.6	1	3	2	2	12.3613	56.4492
11.7	2	1	3	1	12.3613	56.4492
11.8	3	3	2	1	12.3613	56.4492
11.9	1	3	1	2	12.3613	56.4492
12.0	2	1	1	3	12.3613	56.4492
12.1	3	1	2	3	12.3613	56.4492
12.2	1	2	3	2	12.3613	56.4492
12.3	3	2	1	2	12.3613	56.4492
12.4	2	2	1	3	12.3613	56.4492
12.5	2	1	3	1	12.3613	56.4492
12.6	3	1	2	3	12.3613	56.4492
12.7	3	1	1	2	12.3613	56.4492
12.8	3	2	1	3	12.3613	56.4492
12.9	3	1	2	2	12.3613	56.4492
13.0	2	1	2	3	12.3613	56.4492
13.1	2	3	3	1	12.3613	56.4492
13.2	3	2	3	1	12.3613	56.4492
13.3	1	3	2	1	12.3613	56.4492

Table 10. Pacific mackerel harvest control rules and associated management metrics for final base model ALT_19: a) 2019-20 fishing year; and b) 2020-21 fishing year.

a)

Harvest Control Rule Formulas					
OFL = BIOMASS * E_{MSY} * DISTRIBUTION					
ABC = BIOMASS * $BUFFER_{P\text{-}star}$ * E_{MSY} * DISTRIBUTION					
HG = (BIOMASS - CUTOFF) * E_{MSY} * DISTRIBUTION					
Harvest Formula Parameters					
BIOMASS (ages 1+, mt)	71,099				
P-star	0.45	0.40	0.35	0.30	0.25
ABC Buffer(Tier 1 Sigma=0.5)	0.939	0.881	0.825	0.769	0.714
ABC Buffer(Tier 2 Sigma=1.0)	0.882	0.776	0.680	0.592	0.509
E_{MSY}	0.3				
CUTOFF (mt)	18,200				
DISTRIBUTION (U.S.)	0.7				
Harvest Control Rule Values (MT)					
OFL =	**14,931**				
ABCTier 1 =	14,020	13,154	12,318	11,482	10,661
ABCTier 2 =	13,169	11,586	10,153	8,839	7,600
HG =	**11,109**				

b)

Harvest Control Rule Formulas					
OFL = BIOMASS * E_{MSY} * DISTRIBUTION					
ABC = BIOMASS * $BUFFER_{P\text{-}star}$ * E_{MSY} * DISTRIBUTION					
HG = (BIOMASS - CUTOFF) * E_{MSY} * DISTRIBUTION					
Harvest Formula Parameters					
BIOMASS (ages 1+, mt)	56,058				
P-star	0.45	0.40	0.35	0.30	0.25
ABC Buffer(Tier 1 Sigma=0.5)	0.935	0.873	0.813	0.754	0.696
ABC Buffer(Tier 2 Sigma=1.075)	0.874	0.762	0.661	0.569	0.484
E_{MSY}	0.3				
CUTOFF (mt)	18,200				
DISTRIBUTION (U.S.)	0.7				
Harvest Control Rule Values (MT)					
OFL =	**11,772**				
ABCTier 1 =	11,007	10,277	9,571	8,876	8,193
ABCTier 2 =	10,289	8,970	7,781	6,698	5,698
HG =	**7,950**				

Table 11. U.S. harvest guidelines/acceptable biological catches (HG/ACL, mt) and landings (mt) for Pacific mackerel since 2008. HG/ACL reflects final stipulated quotas. Accompanying figure is also presented below.

Fishing year	HG/ACL (mt)	Landings (mt)
2008	40,000	4,398
2009	10,000	3,015
2010	11,000	2,103
2011	30,386	2,038
2012	30,386	5,478
2013	39,268	11,874
2014	29,170	6,127
2015	21,469	4,404
2016	21,161	2,515
2017	26,293	1,359
2018	23,840	5,256

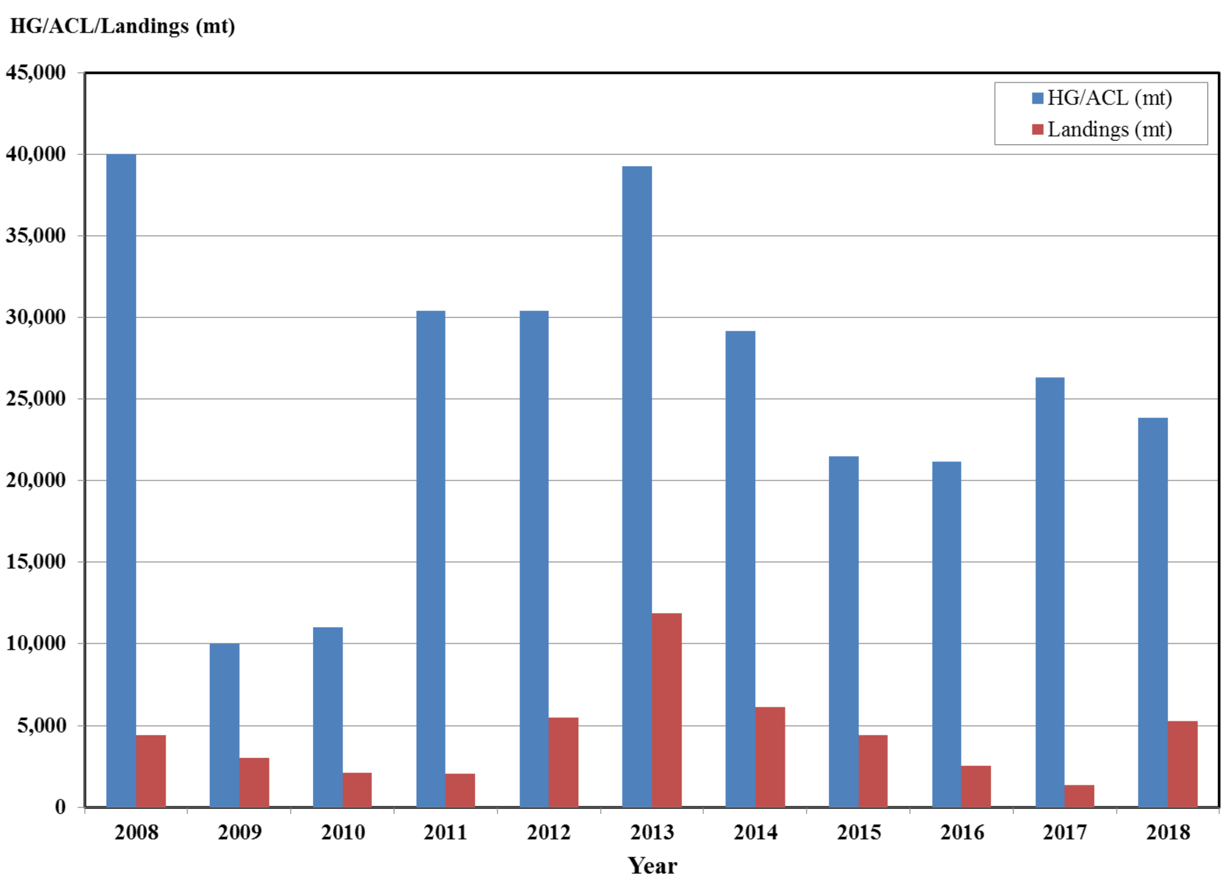


Table 12. Uncertainty analysis profiles for natural mortality (*M*, top), catchability (*q*, middle), and S-R steepness (*h*, bottom) associated with final base model ALT_19. Best likelihood (*L*) values for model components and total likelihood are shaded grey. Model ALT_19 likelihood values and model estimates are bold-face type.

Likelihood components (*L*)	Natural mortality (*M*)							
	0.50	**0.60**	**0.70**	**0.80**	**0.8111**	**0.90**	**1.00**	**1.10**
AT survey index of abundance	6.372	5.782	5.241	4.745	**4.693**	4.295	3.887	3.520
AT survey age composition	27.533	25.837	24.844	24.361	**24.333**	24.279	24.524	25.035
Fishery age composition	23.770	24.133	24.481	24.799	**24.832**	25.085	25.343	25.579
q prior	0.0427	0.0390	0.0189	0.0024	**0.0014**	0.0031	0.0282	0.0802
Total	60.794	58.231	56.782	56.079	**56.037**	55.914	56.159	56.730
Model estimates								
AT survey *q*	0.718	0.715	0.696	0.668	**0.665**	0.638	0.606	0.575
Stock biomass 2018 (mt)	27,278	26,235	25,889	25,924	**25,943**	26,174	26,546	26,984
Stock biomass 2019 (mt)	62,150	63,837	66,753	70,618	**71,099**	75,290	80,683	86,740

Likelihood components (*L*)	AT survey catchability (*q*)									
	0.45	**0.50**	**0.55**	**0.60**	**0.65**	**0.665**	**0.70**	**0.75**	**0.80**	**0.85**
AT survey index of abundance	4.896	4.828	4.772	4.729	4.699	**4.693**	4.683	4.681	4.693	4.717
AT survey age composition	24.162	24.202	24.243	24.283	24.322	**24.333**	24.360	24.397	24.434	24.469
Fishery age composition	24.748	24.763	24.781	24.802	24.825	**24.832**	24.849	24.875	24.901	24.928
M prior	0.5648	0.5224	0.4845	0.4508	0.4208	**0.4125**	0.3942	0.3704	0.3493	0.3304
Total	56.760	56.640	56.549	56.487	56.453	**56.448**	56.445	56.463	56.506	56.570
Model estimates										
M	0.852	0.841	0.831	0.822	0.813	**0.811**	0.806	0.799	0.793	0.787
Stock biomass 2018 (mt)	38,693	34,758	31,534	28,843	26,562	**25,943**	24,603	22,902	21,409	20,089
Stock biomass 2019 (mt)	100,256	91,262	83,897	77,745	72,520	**71,099**	68,018	64,091	60,628	57,548

Likelihood components (*L*)	S-R steepness (*h*)								
	0.30	**0.40**	**0.50**	**0.60**	**0.70**	**0.75**	**0.80**	**0.90**	**1.00**
AT survey index of abundance	4.855	4.757	4.714	4.695	4.692	**4.693**	4.696	4.706	4.719
AT survey age composition	23.854	24.106	24.217	24.279	24.318	**24.333**	24.346	24.367	24.384
Fishery age composition	24.902	24.821	24.814	24.823	24.831	**24.832**	24.832	24.828	24.819
Parameter priors	0.8310	0.6075	0.5085	0.4562	0.4250	**0.4139**	0.4048	0.3909	0.3810
Total	57.551	56.940	56.662	56.527	56.465	**56.449**	56.441	56.438	56.448
Model estimates									
AT survey *q*	0.552	0.601	0.631	0.650	0.661	**0.665**	0.668	0.672	0.673
M	0.884	0.854	0.836	0.823	0.814	**0.811**	0.808	0.804	0.801
Stock biomass 2018 (mt)	29,185	27,511	26,642	26,189	25,984	**25,943**	25,932	25,974	26,071
Stock biomass 2019 (mt)	75,325	72,675	71,550	71,113	71,046	**71,099**	71,191	71,455	71,780

FIGURES

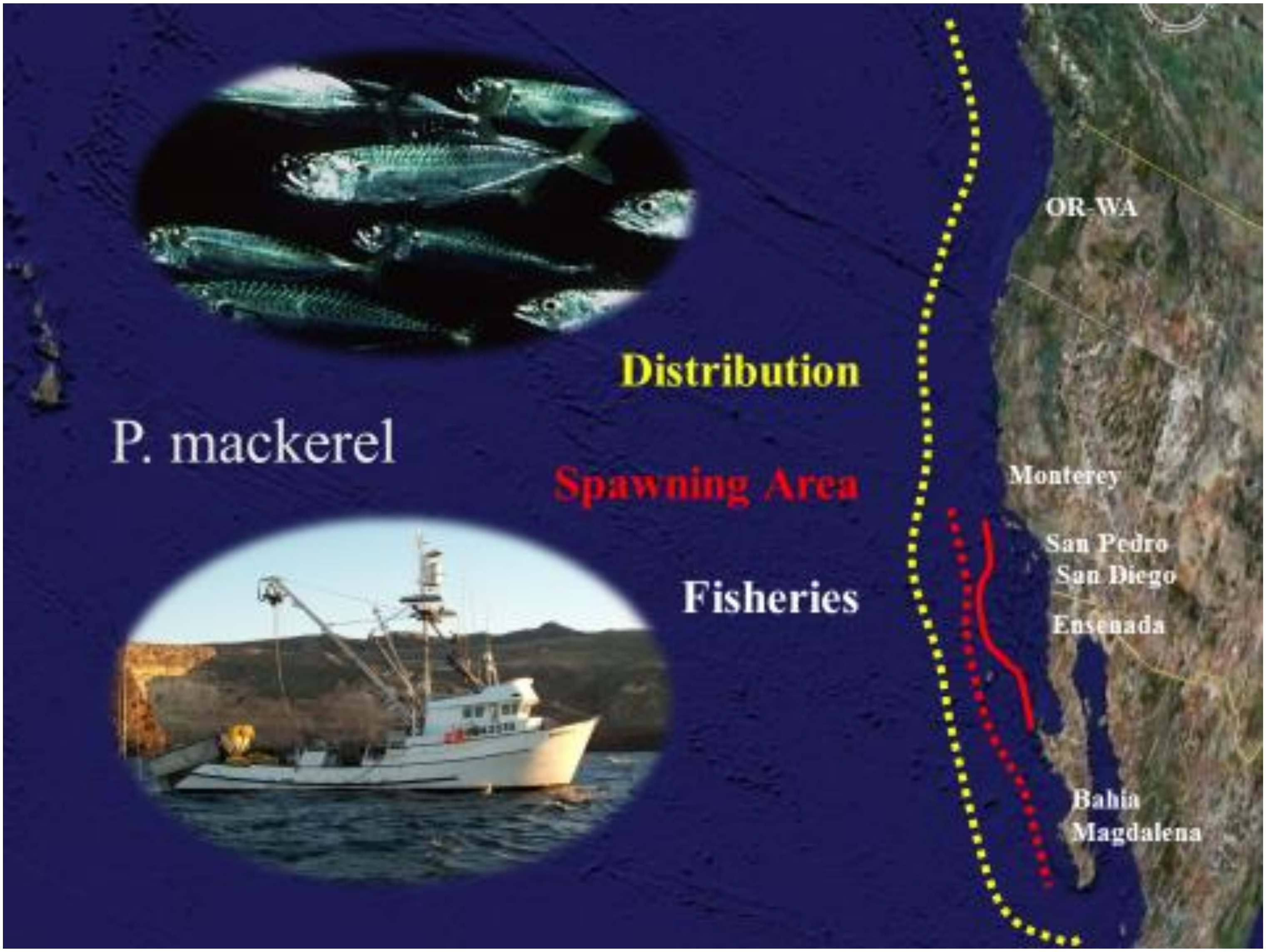


Fig. 1. Map of Pacific mackerel stock distribution, spawning range, and fisheries.

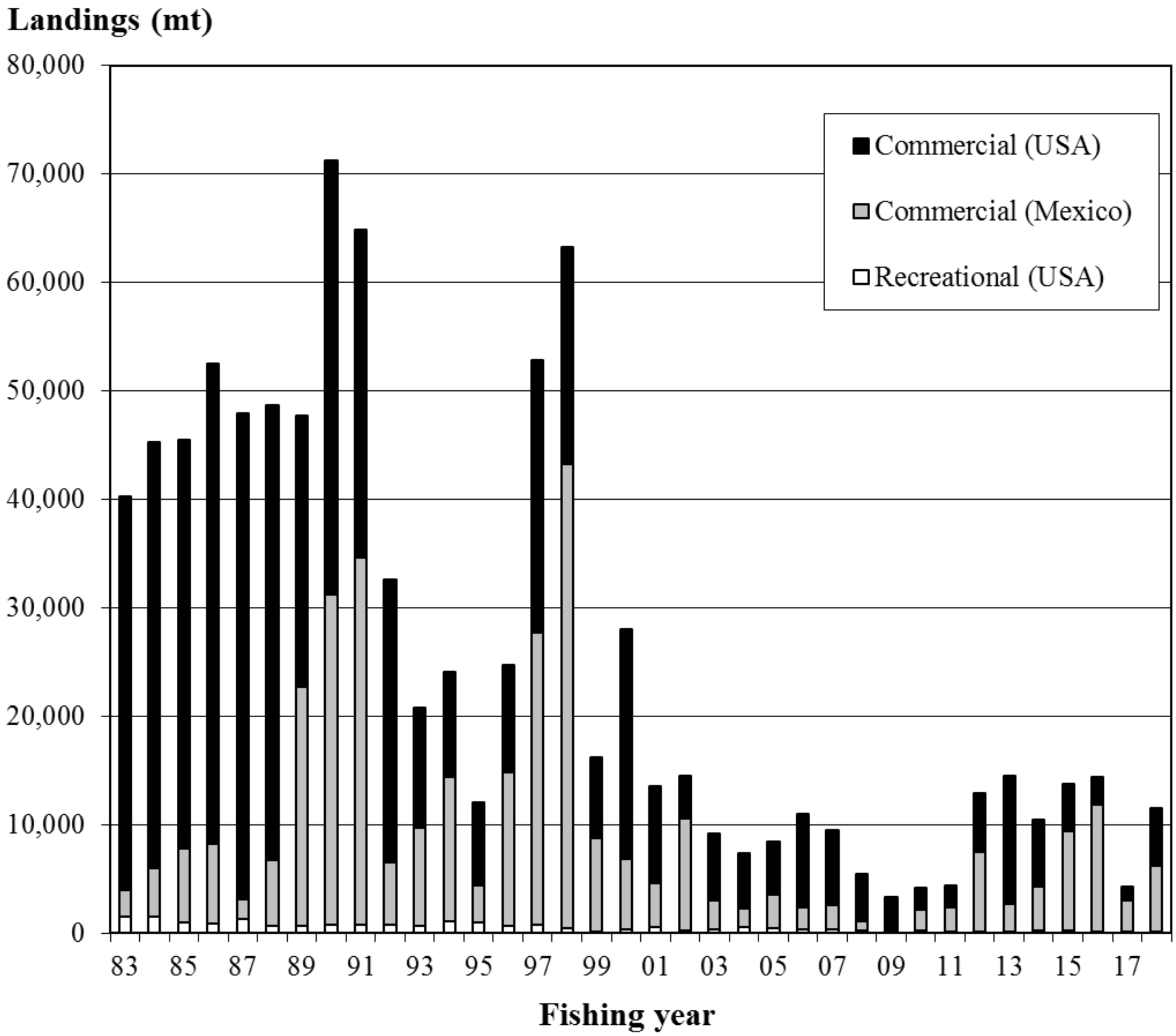
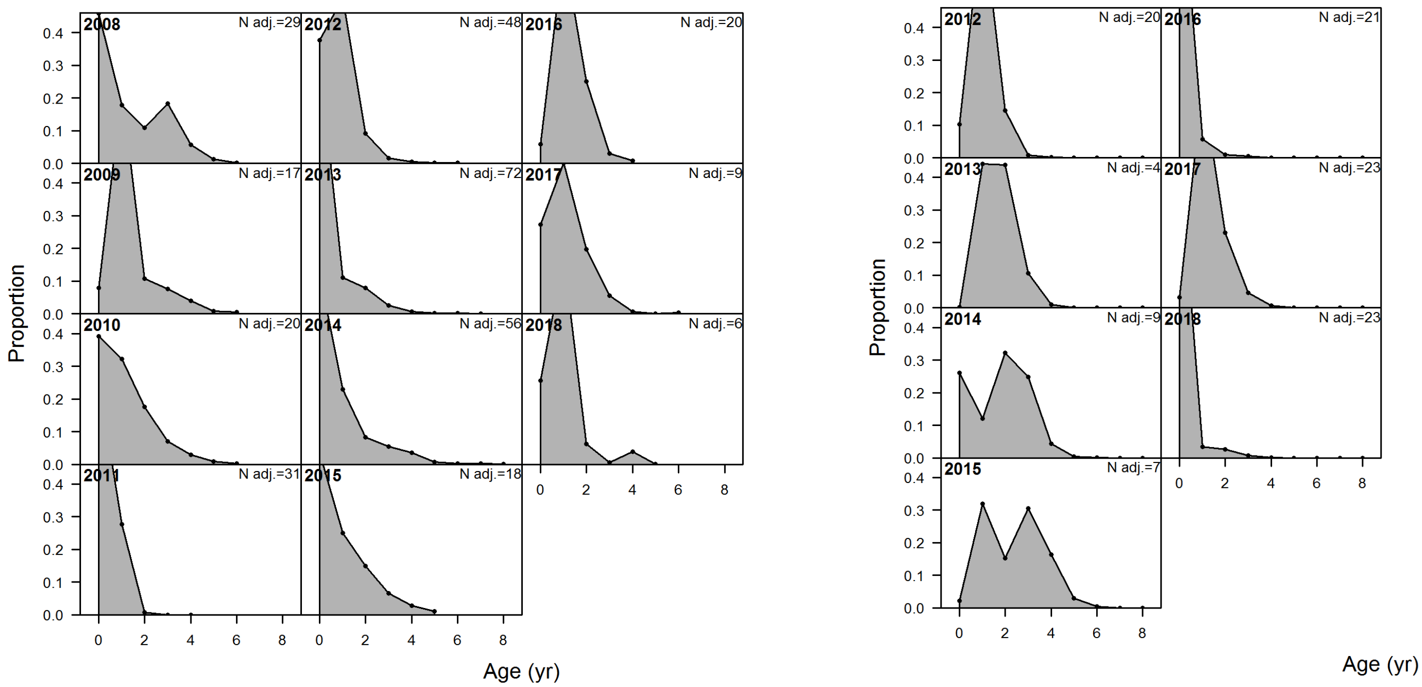


Fig. 2. Landings of Pacific mackerel by fishery (1983-18). Landings in fishing year 2018 represent average values from 2013-17. Model ALT_19 is based a single, combined (commercial and recreational) fishery.



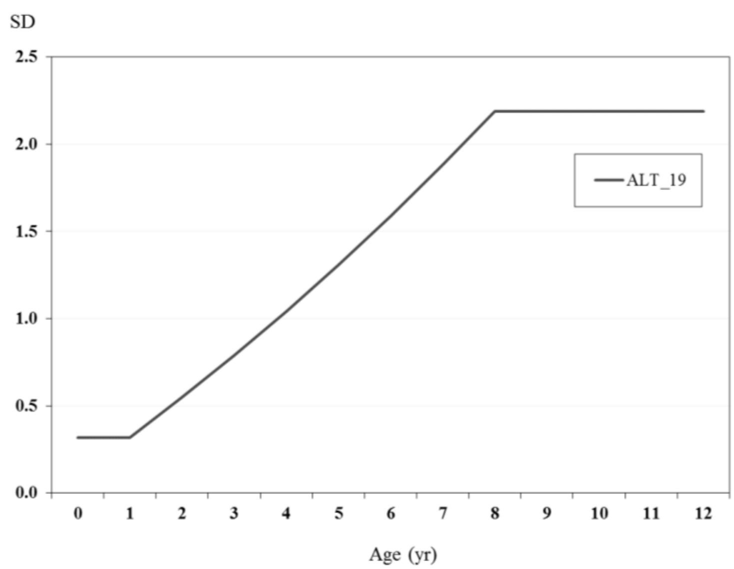


Fig. 3. Pacific mackerel age-composition time series for fishery (top, left) and AT survey (top, right), and ageing error vector (bottom) used in final base model ALT_19.

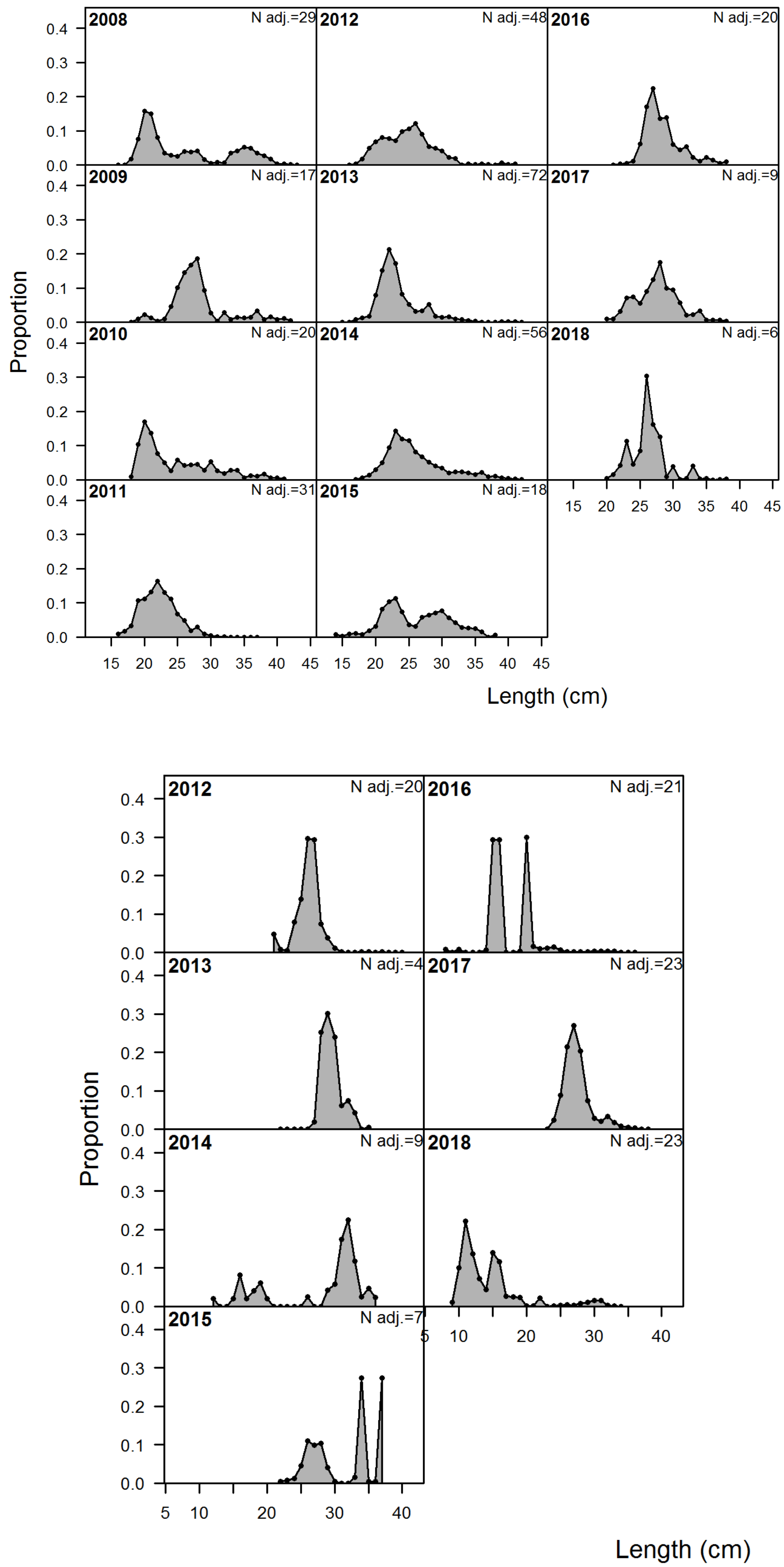
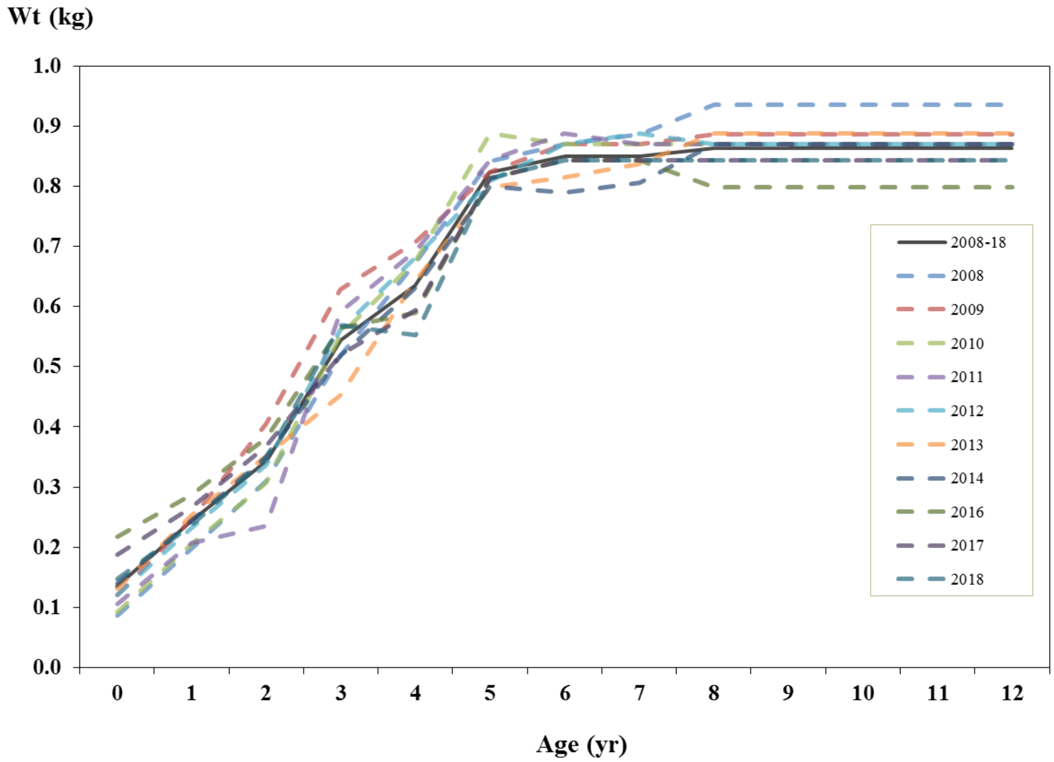


Fig. 4. Pacific mackerel length-composition time series for fishery (top) and AT survey (bottom). Length data were not used in final base model ALT_19.



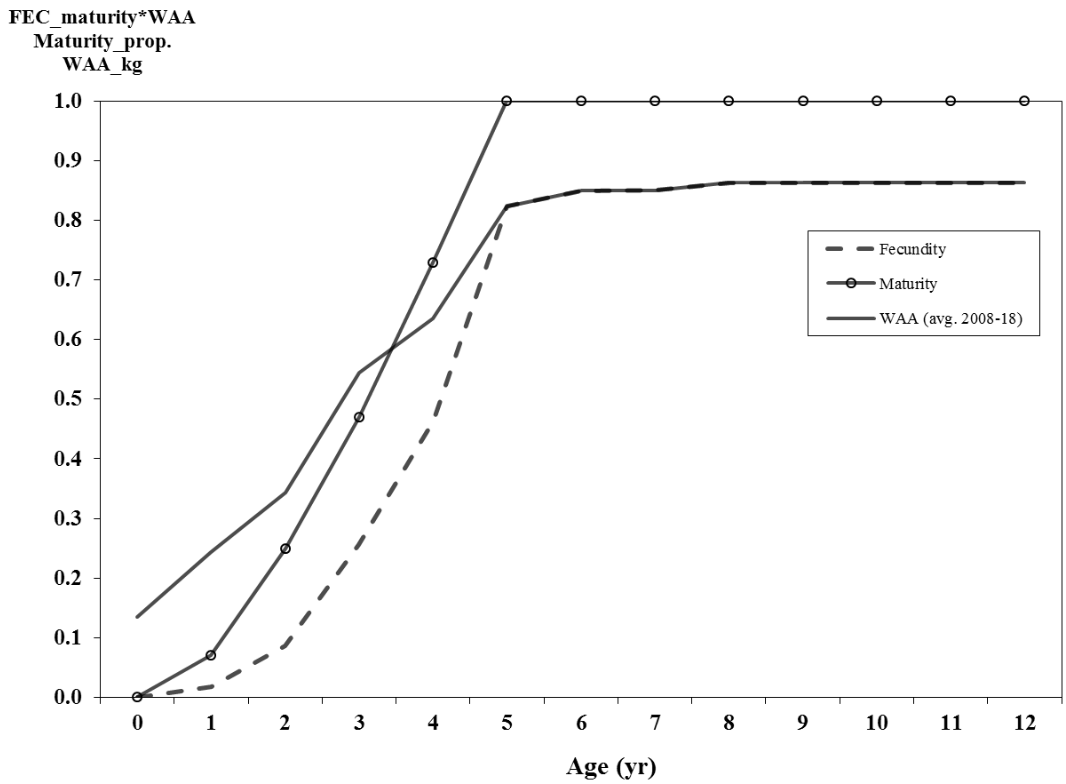


Fig. 5. Pacific mackerel mean weight-at-age (WAA, kg) time series used in final base model ALT_19 (avg. 2008-18 also presented, top). Associated maturity (prop.) and fecundity (FEC, maturity*WAA avg. 2008-18) time series used in model ALT_19 are also presented, bottom.

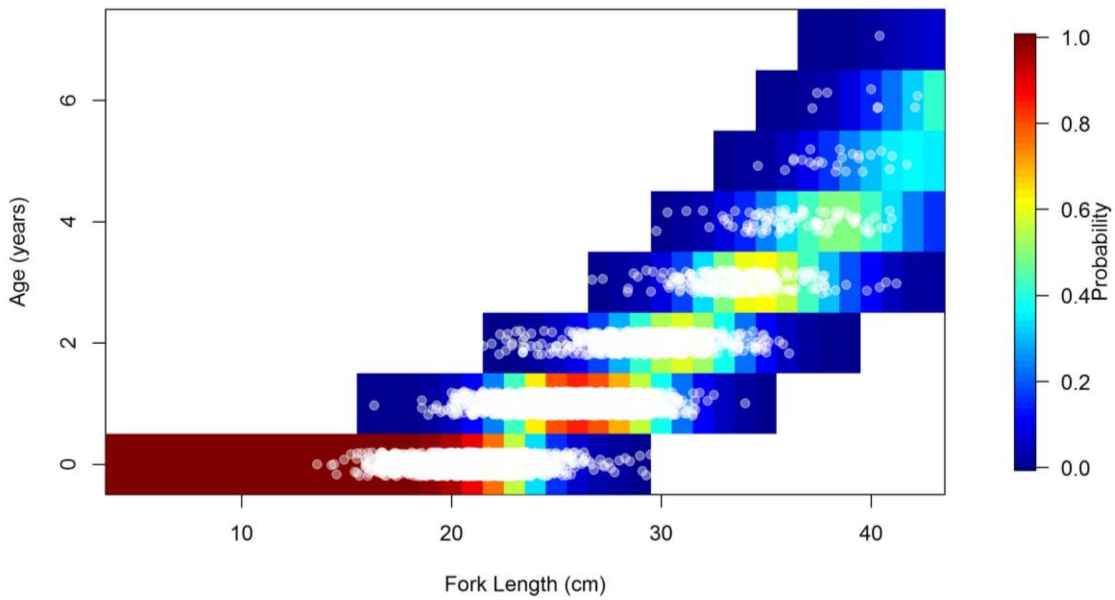


Fig. 6. Aggregate age-length key (ALK) derived from fishery samples collected from July to December (2008-18). ALK used to develop AT survey age-composition time series used in model ALT_19 (see Fig. 3).

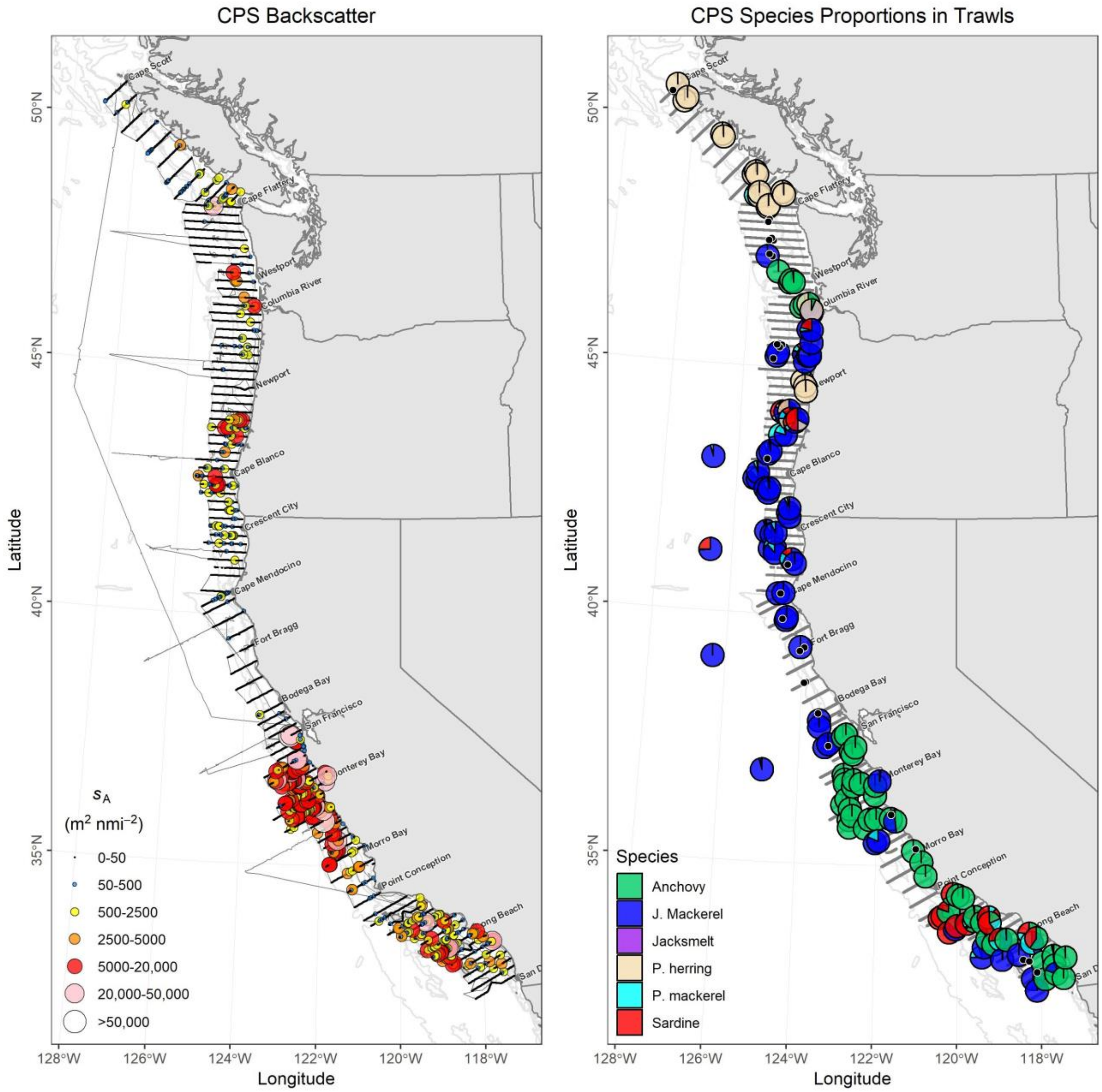


Fig. 7. Results from the AT survey for summer 2018 (Stierhoff et al. 2019b). A map of the distribution of 38-kHz integrated backscattering coefficients (s_A, m^2 nmi^{-2}) averaged over 2,000-m distance intervals and from 5 to 70-m deep ascribed to CPS (left), and proportions of CPS in trawls (black points indicate trawls with no CPS (right).

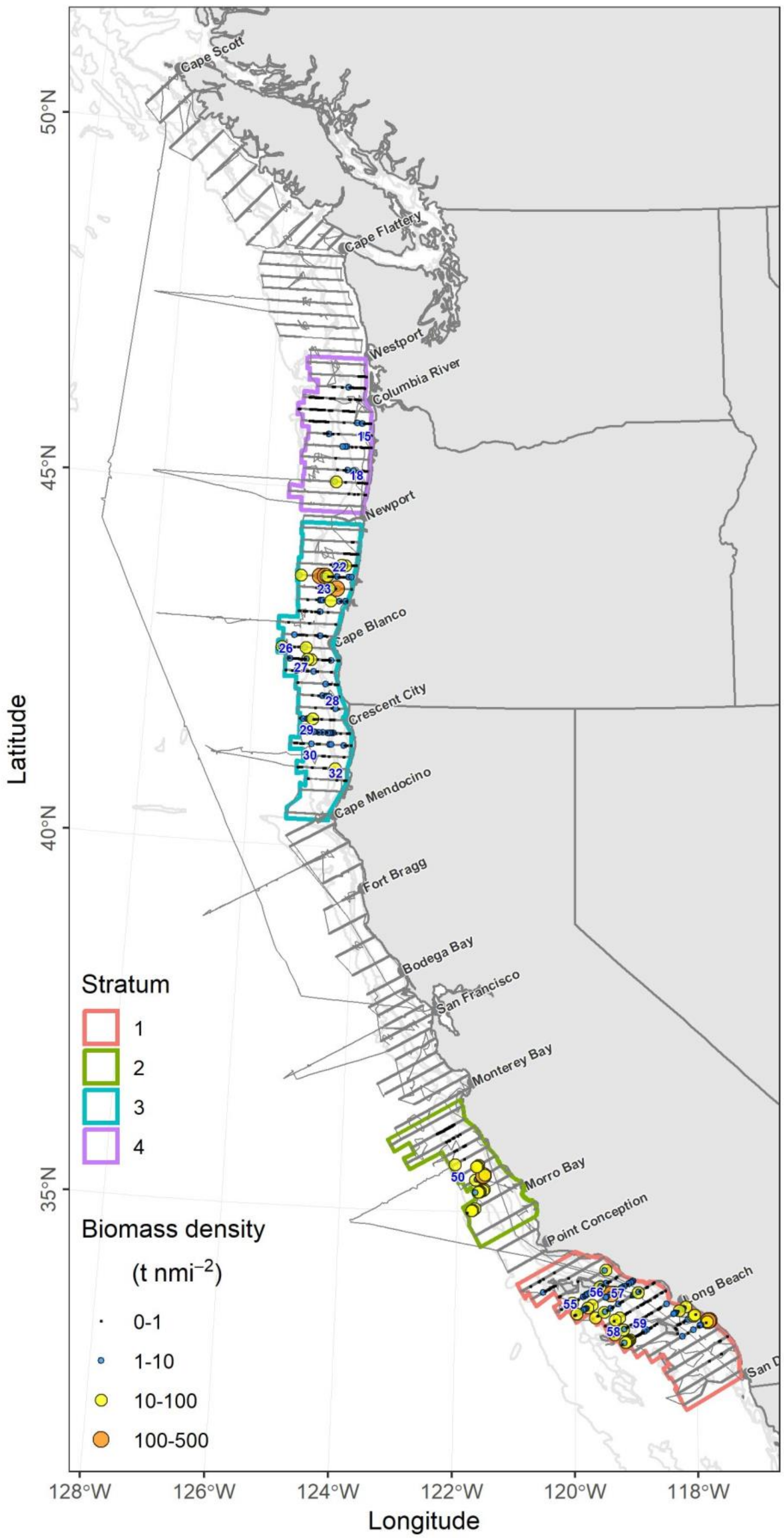


Fig. 8. Biomass densities of Pacific mackerel throughout the summer from the AT survey cruise in 2018 estimated using the acoustic-trawl method (Stierhoff et al. 2019b). The blue numbers represent the locations of trawl clusters with at least one mackerel. The gray line represents the vessel track.

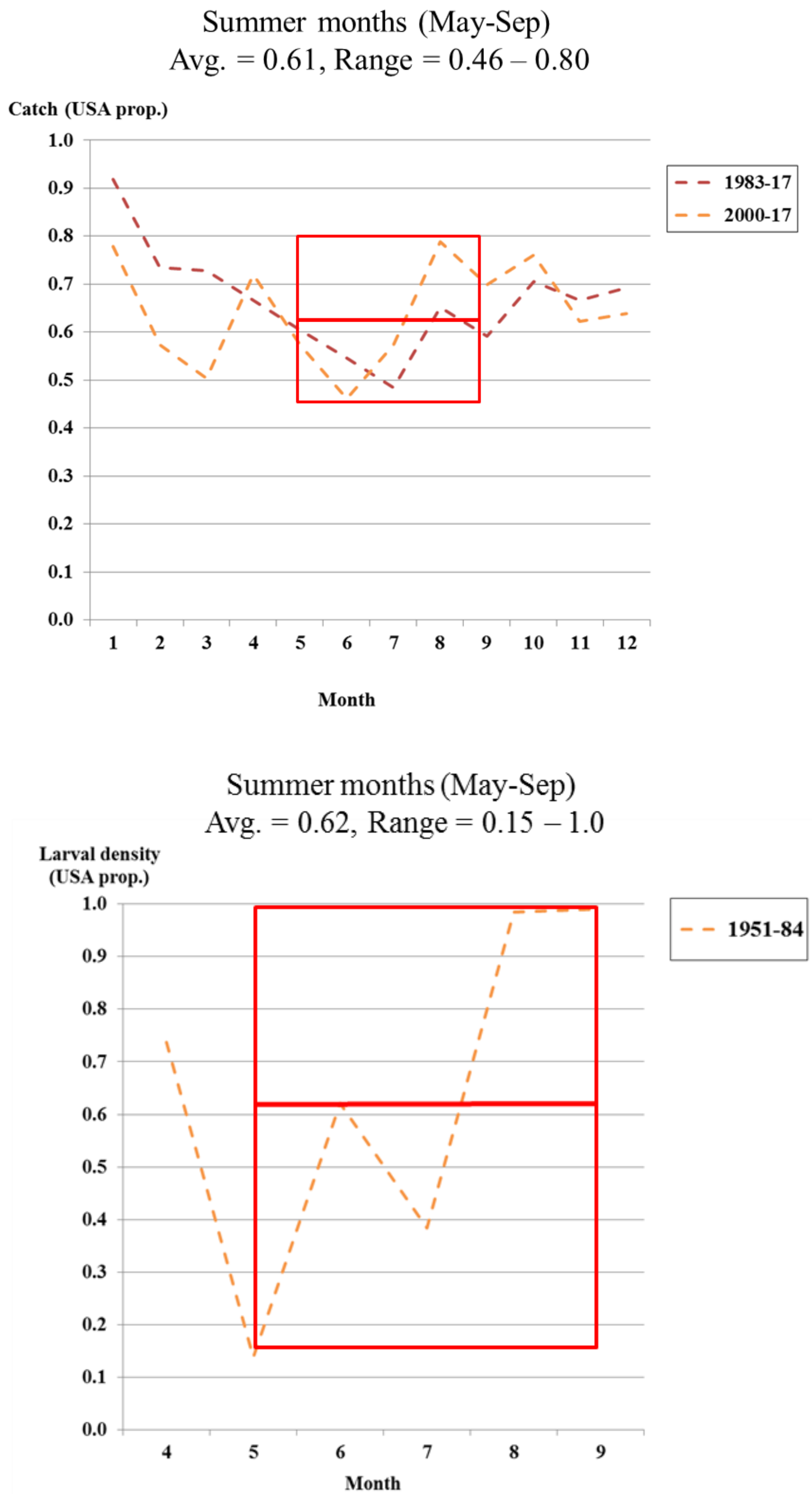


Fig. 9. Pacific mackerel landings (top) and larval densities (bottom) compared between U.S. and Mexico. Comparisons presented as proportion landings/larvae in U.S. waters during summer months for various time periods. Presence data used for informing prior distribution for AT survey index catchability (*q*) estimation in final base model ALT_19.

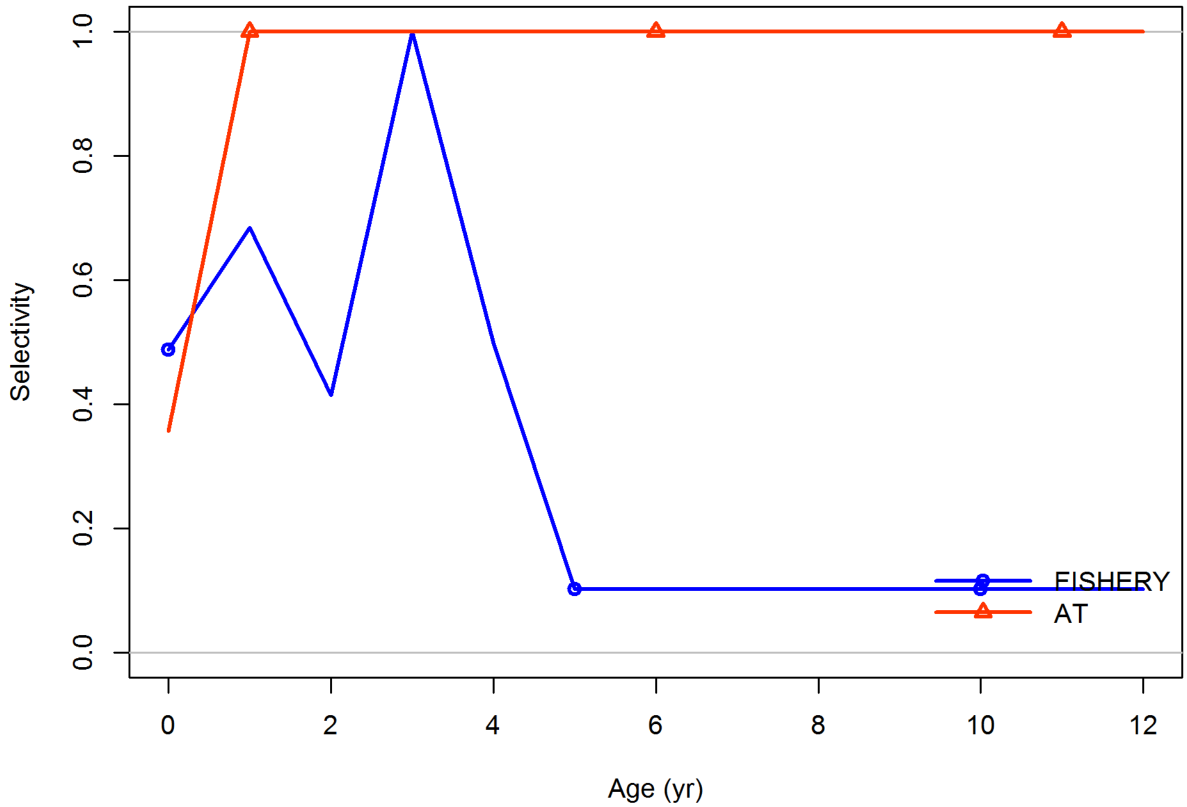


Fig. 10. Estimated age-based selectivity curves for the fishery and AT survey for final base model ALT_19.

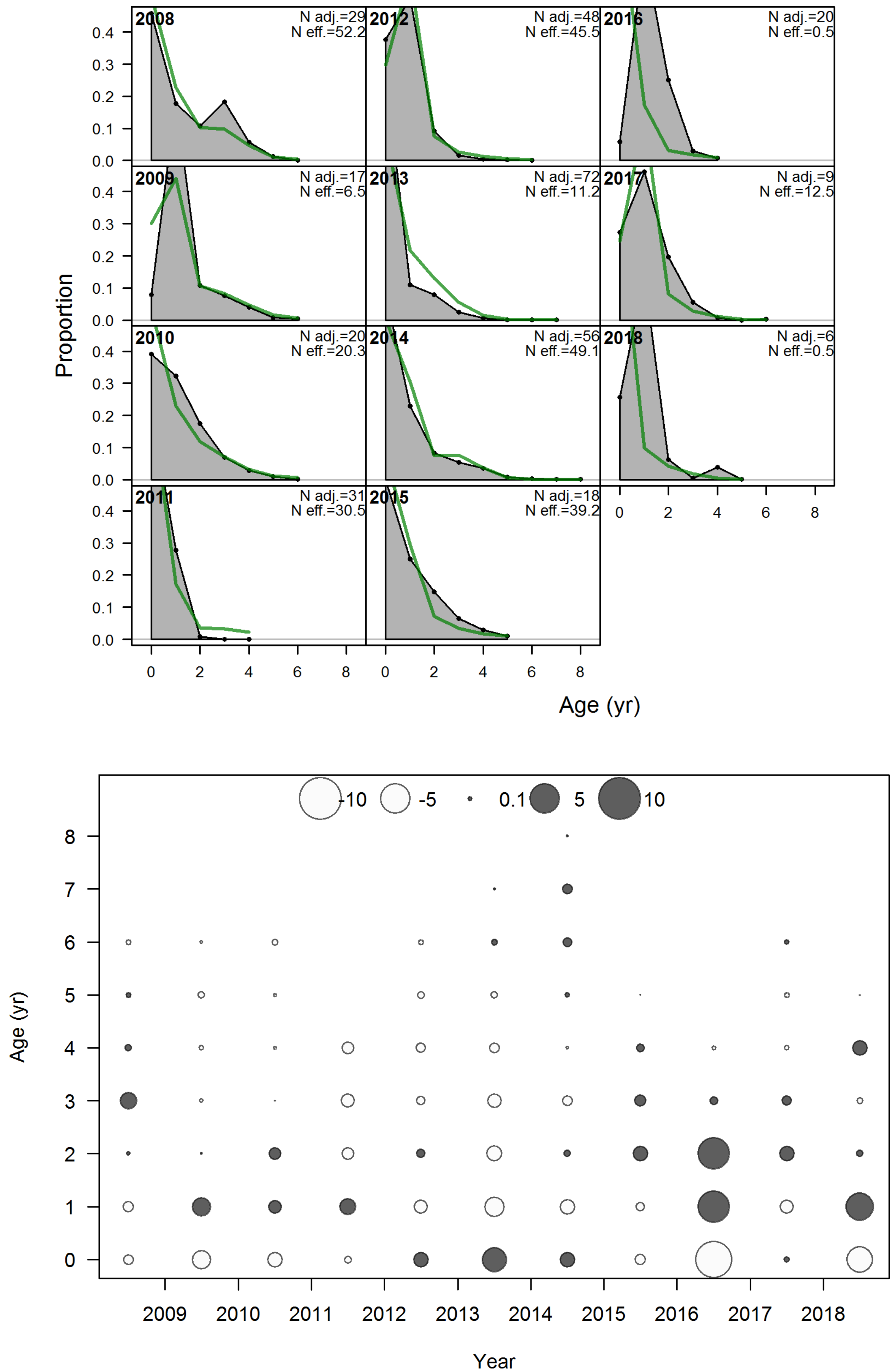


Fig. 11. Fits (top) and Pearson residual (bottom) plots associated with fishery age-composition time series for final base model ALT_19.

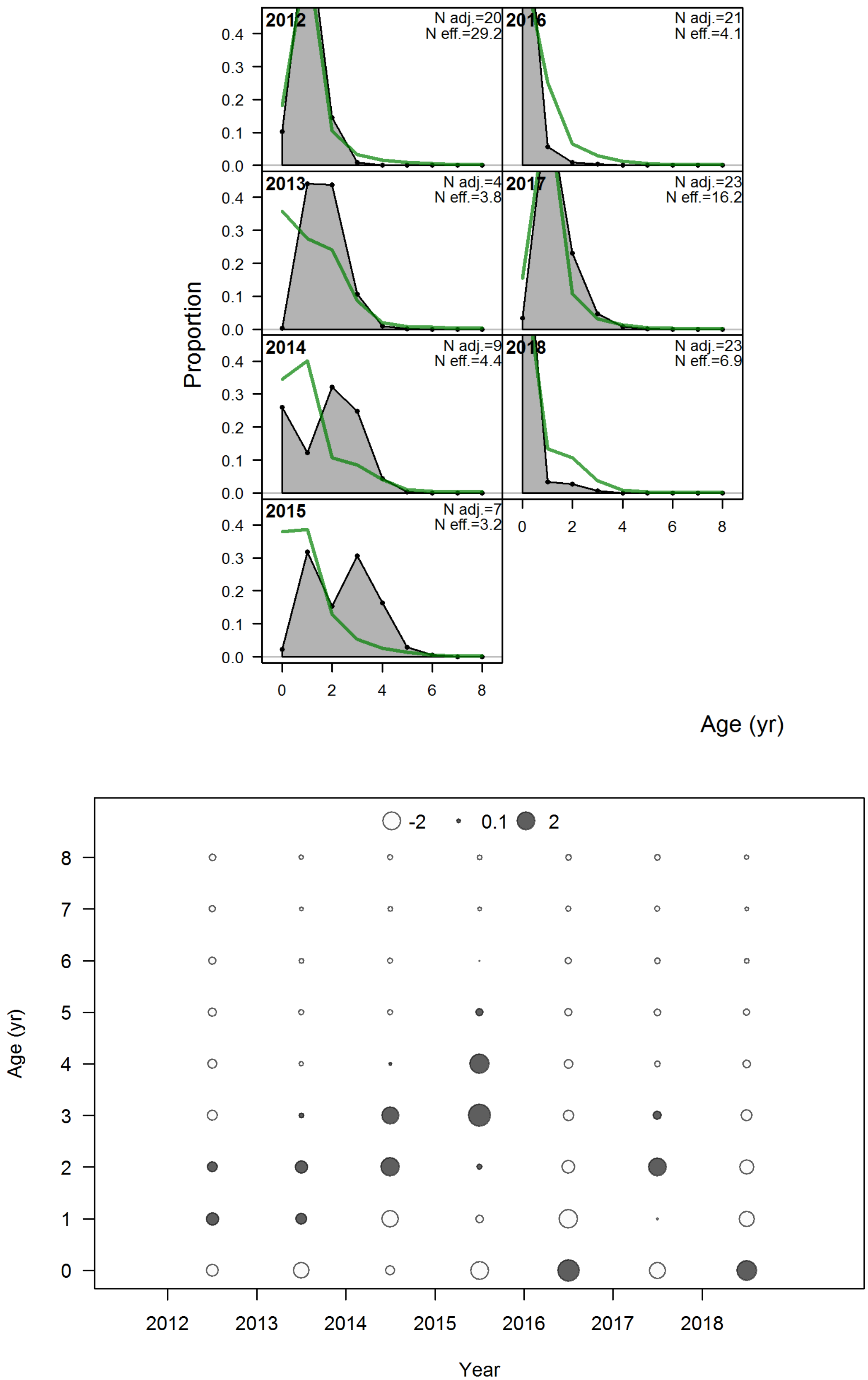


Fig. 12. Fits (top) and Pearson residual (bottom) plots associated with AT survey age-composition time series for final base model ALT_19.

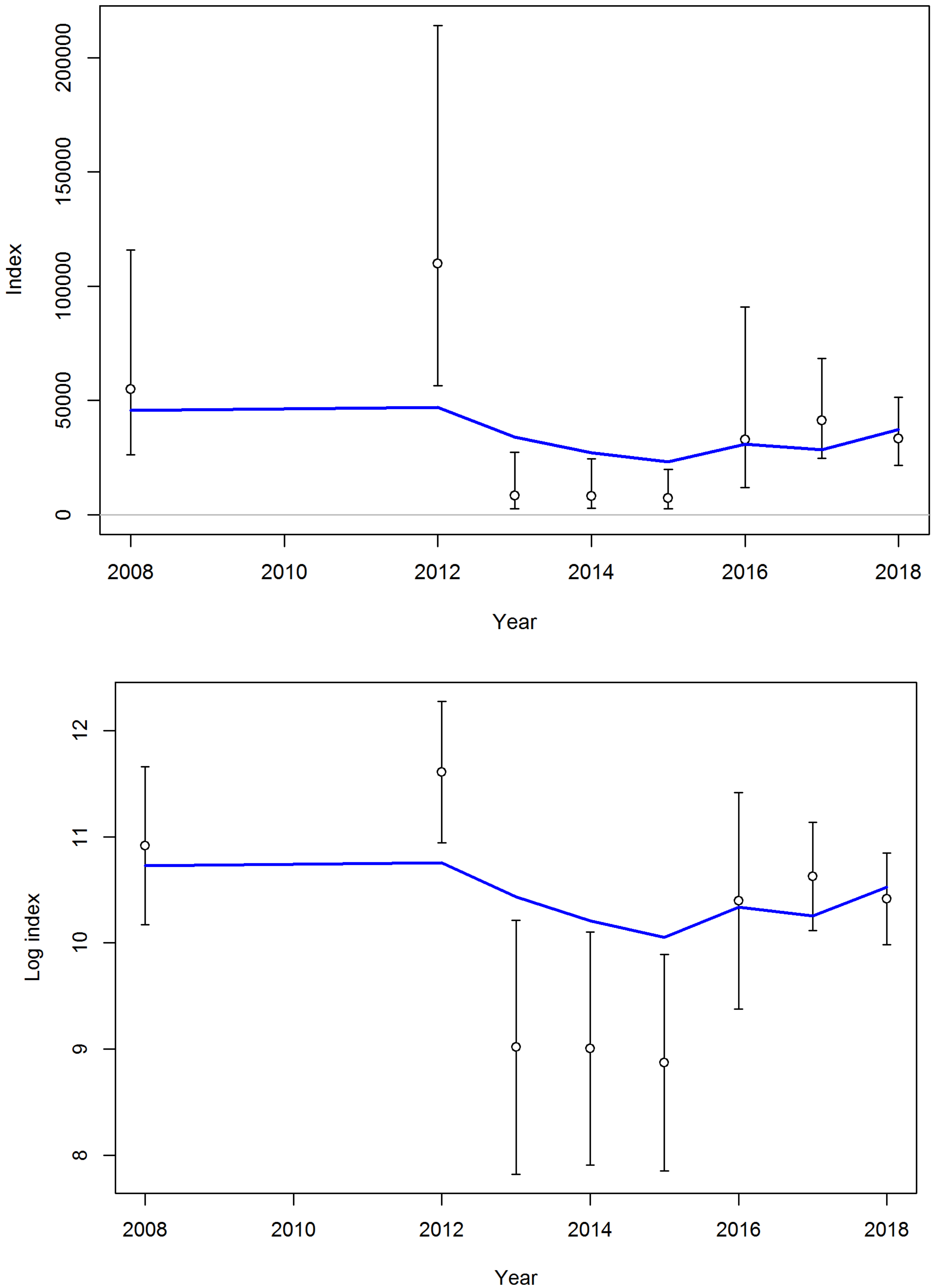
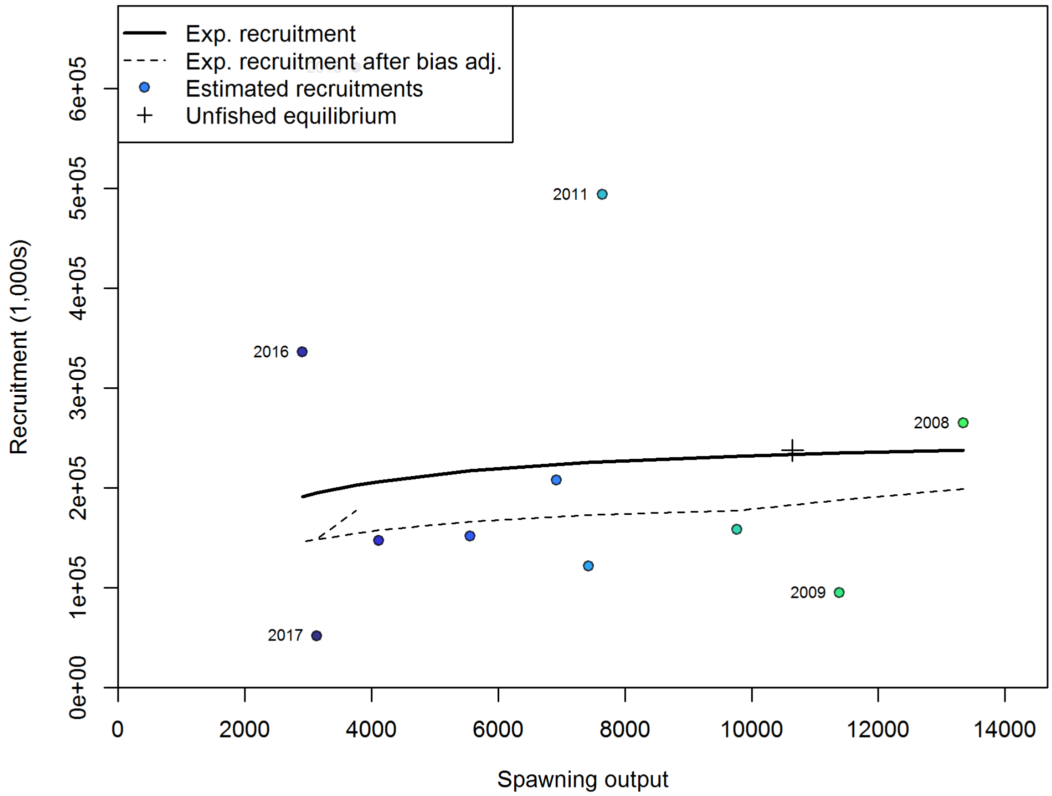


Fig. 13. Fits (arithmetic_top, log_bottom) to AT survey index of abundance for final base model ALT_19.



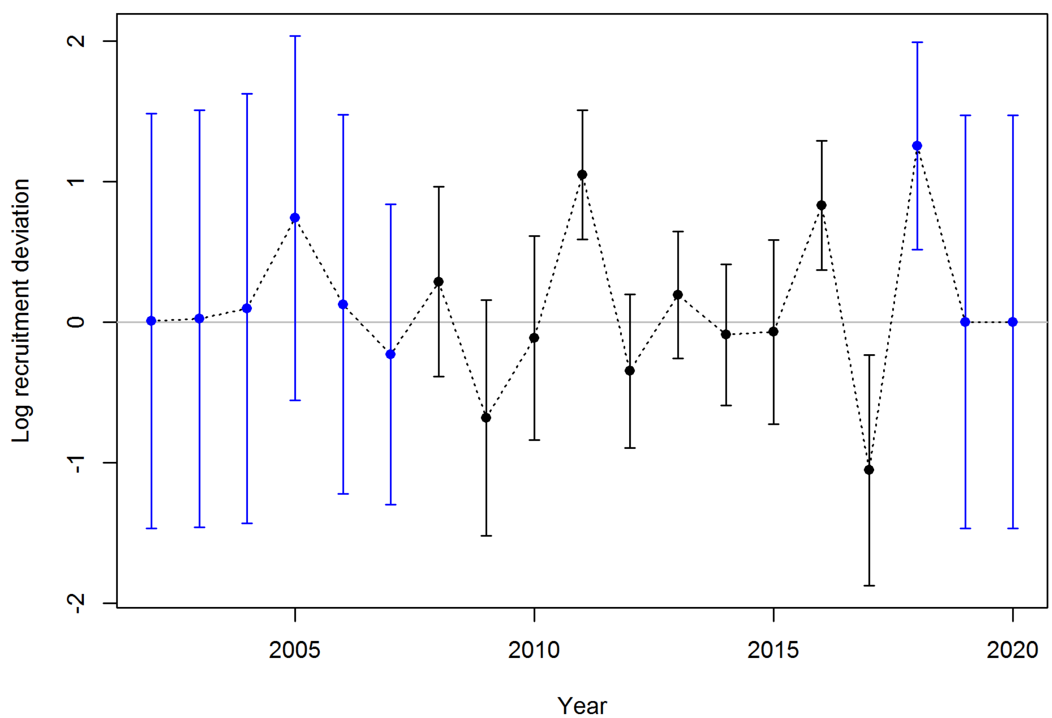


Fig. 14. Beverton-Holt stock-recruitment relationship (top), and estimated recruitment deviations and associated standard errors (bottom) for final base model ALT_19. Note that estimated recruitment in 2018 is hidden behind the legend (top).

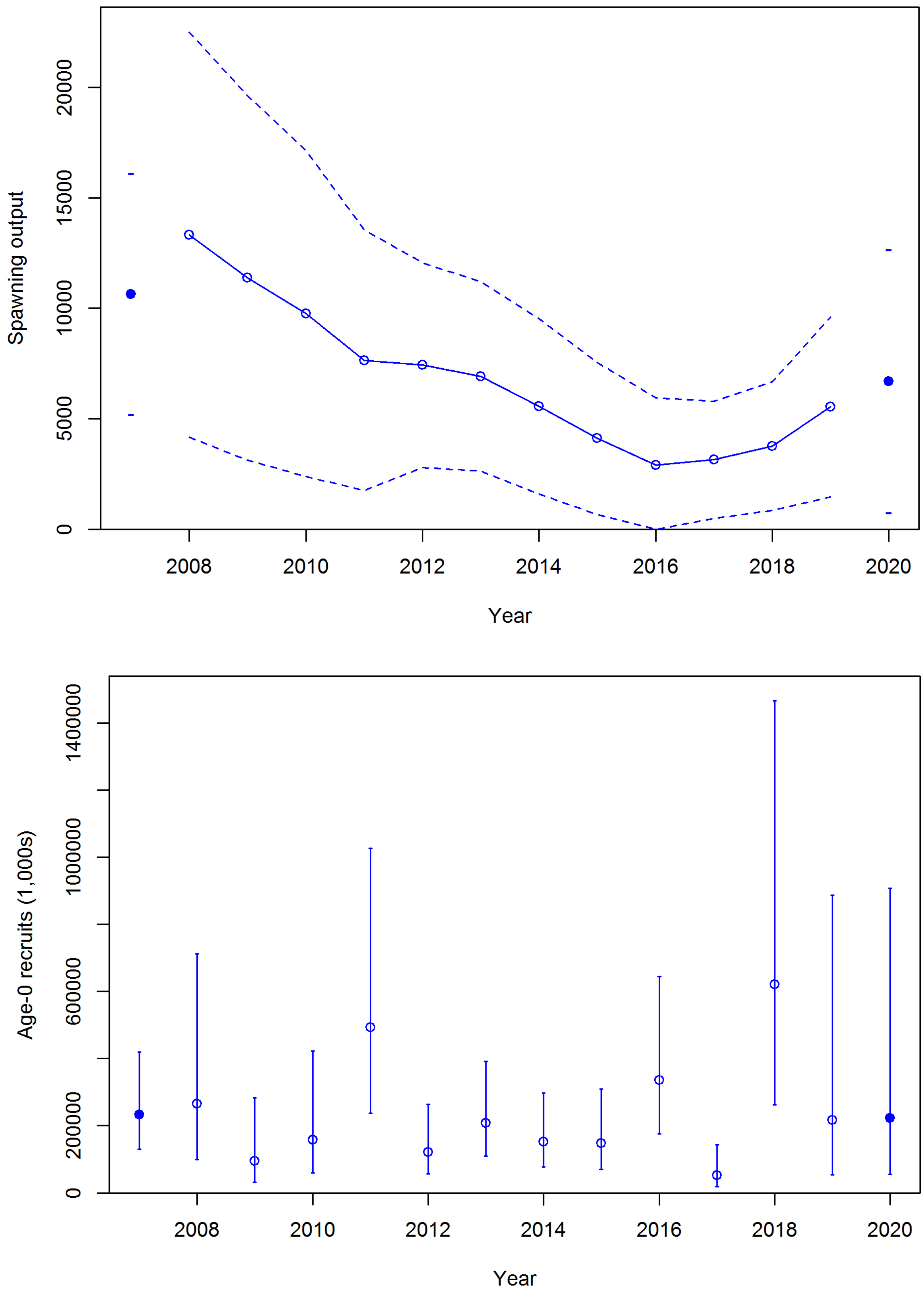


Fig. 15. Estimated spawning stock biomass (female *SSB*, mt, top) and recruitment age-0 fish in 1,000s, bottom) time series with 95% CIs) for final base model ALT_19. Solid dots represent virgin-unfished and forecast year (2020) estimates.

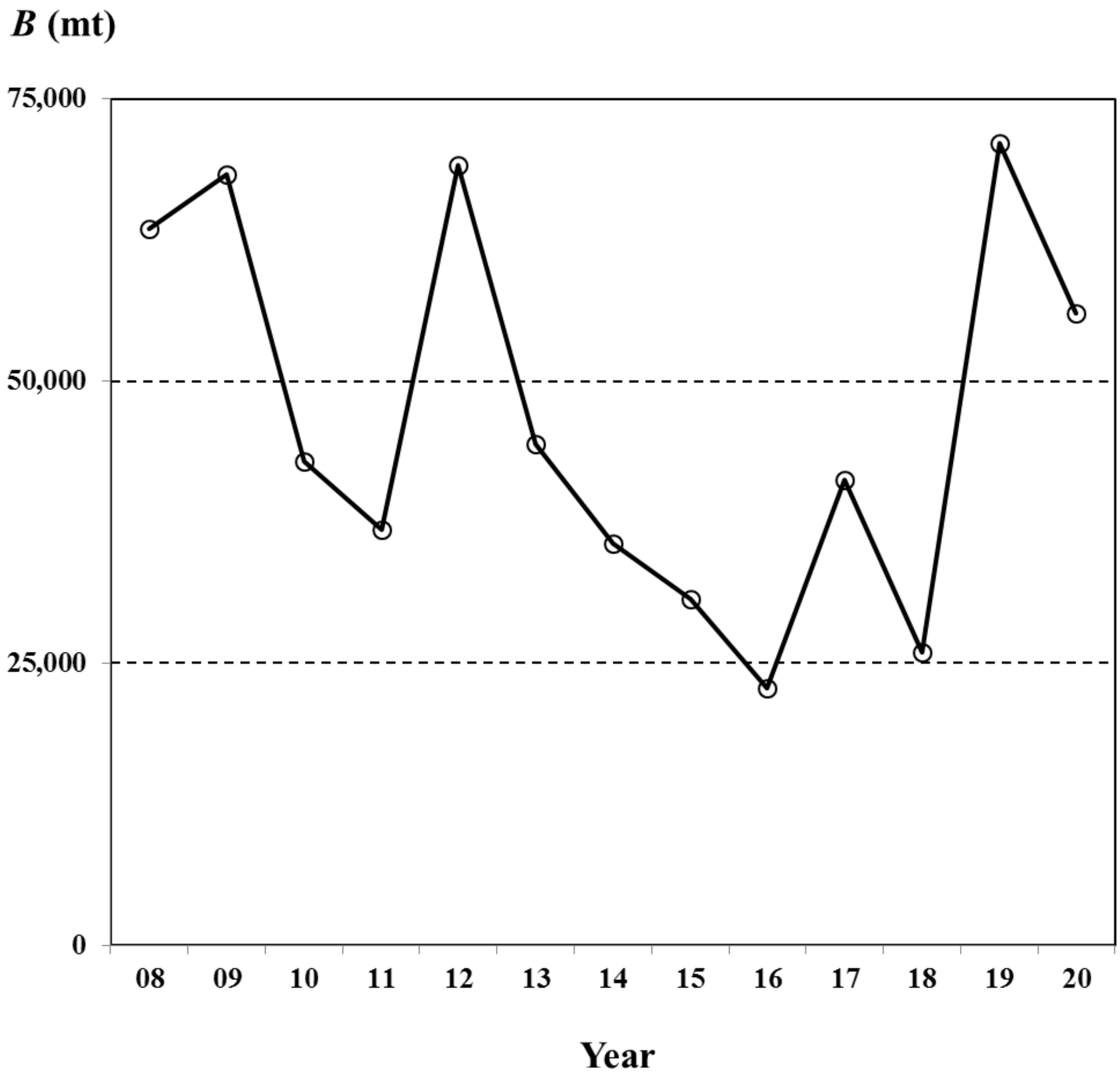


Fig. 16. Estimated stock biomass (*B*, age 1+ fish, mt) time series for final base model ALT_19. Also, see Table 4.

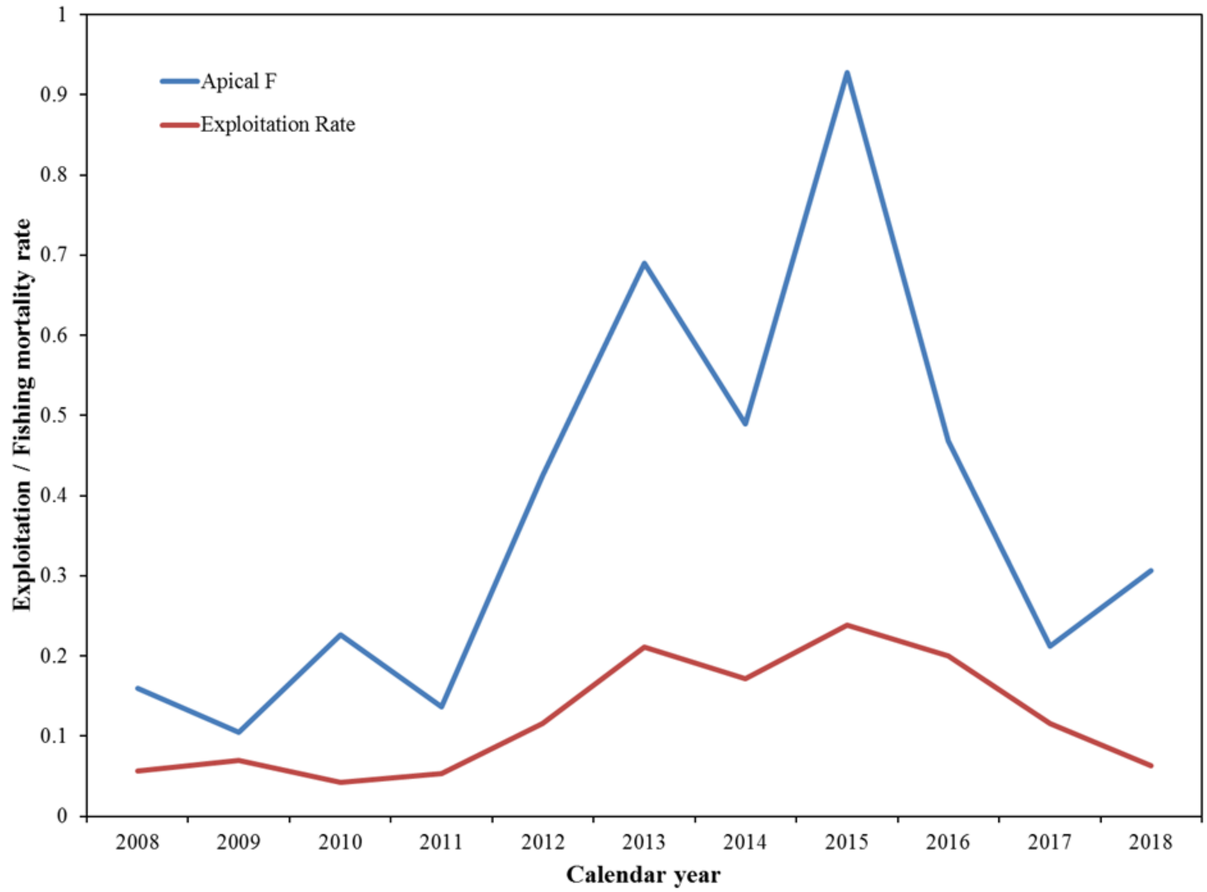


Fig. 17. Estimated fishing mortality (*F*) and total exploitation rate (calendar-year catch/mid-year total biomass) time series for final base model ALT_19. Note that higher *F* values for the fishery (2012-16) reflect rates at the fully-selected age (age-3). Annual exploitation rate is calculated as total calendar year landings divided by total estimated population biomass (age-0+ fish) in July.

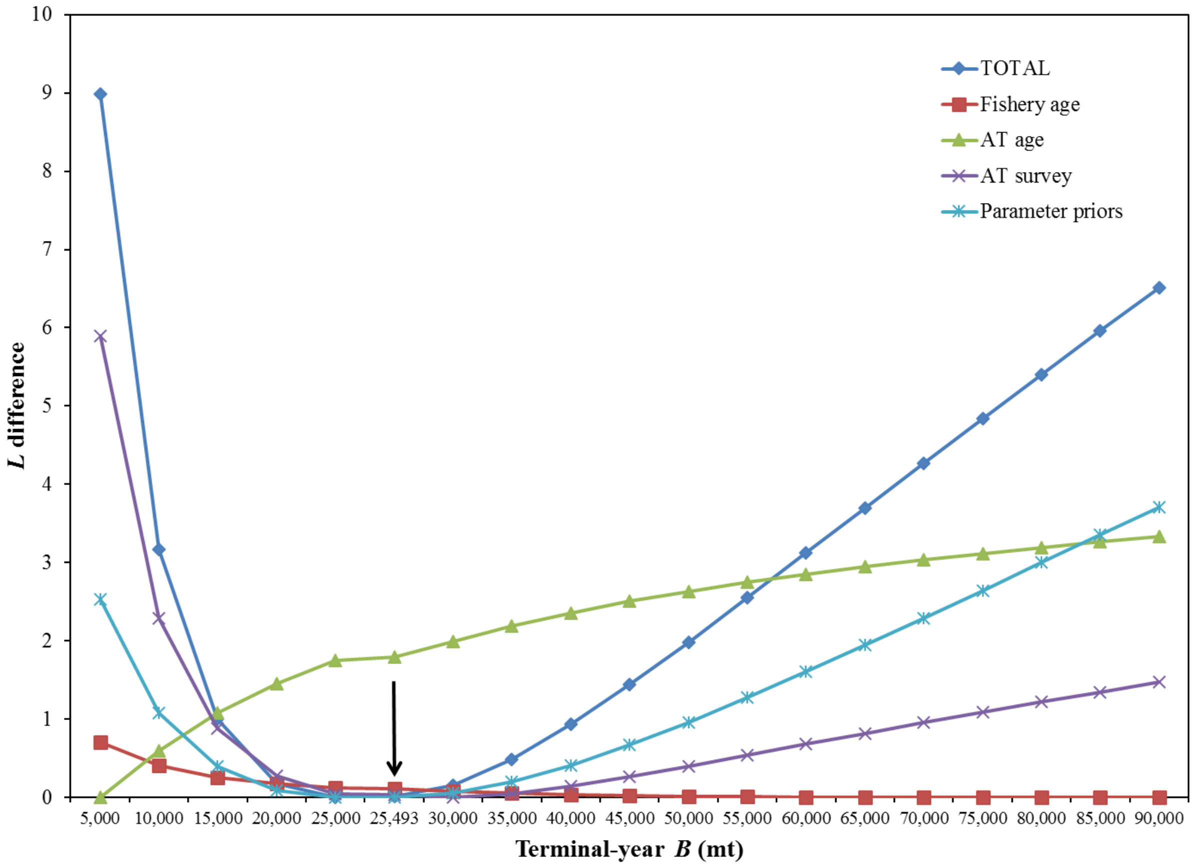


Fig. 18. Likelihood (*L*) differences for key model components profiled over a range of fixed terminal-year stock biomass (*B*, age 1+ fish, mt) values (5,000-90,000 mt) for final base model ALT_19. Vertical arrow indicates *B* estimate (25,493 mt) in 2018 for model ALT_19.

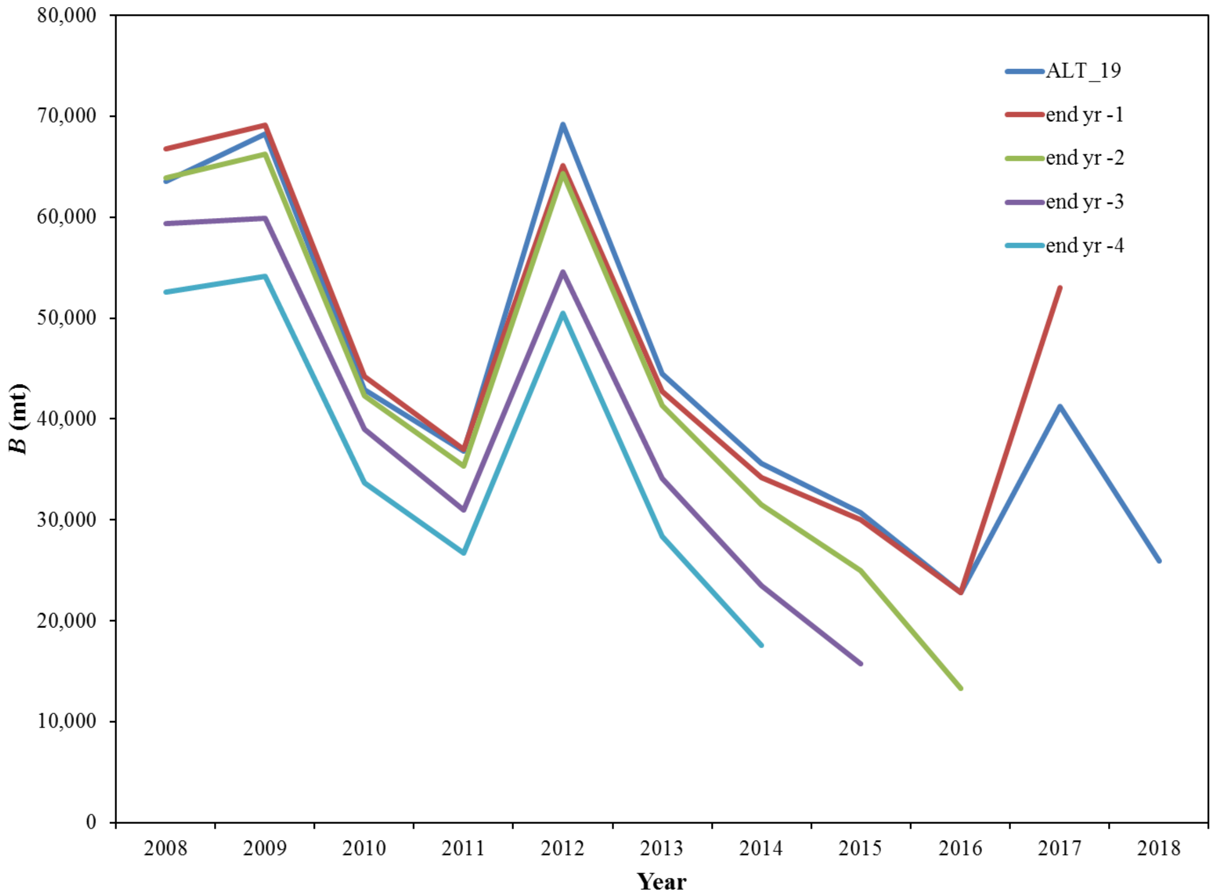


Fig. 19. Estimated stock biomass (*B*, age 1+ fish, mt) time series associated with retrospective analysis (2014-18) for final base model ALT_19.

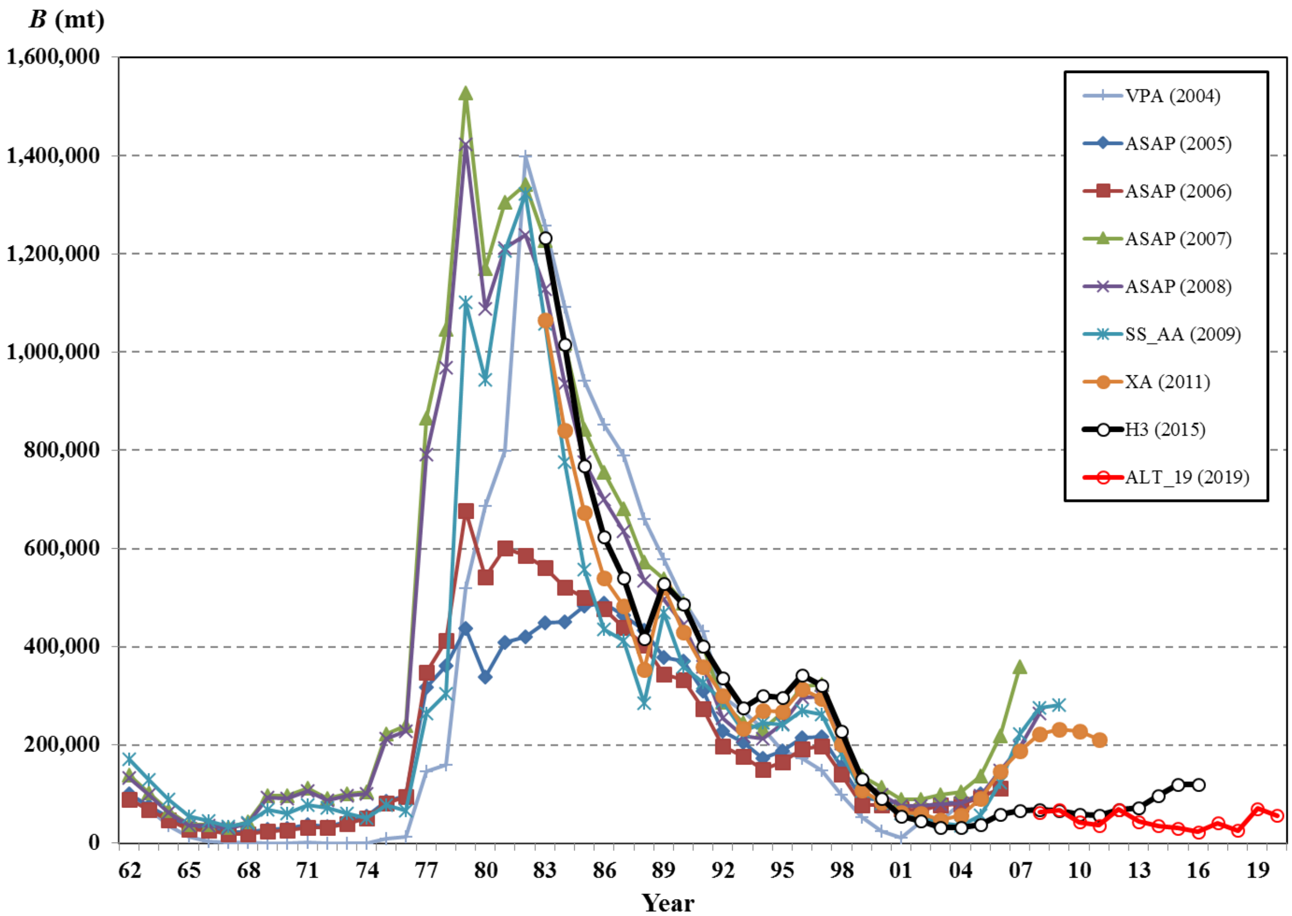


Fig. 20. Estimated (historical) stock biomass (*B,* age 1+ fish, mt) time series used for Pacific mackerel management since 2004.

APPENDIX A
Sensitivity analysis for final base model ALT_19

Table A1. Model structure (data and processes) and results (likelihood and parameter estimates) for alternative assessment models associated with sensitivity analysis for base model ALT_19. **Suite of models included in general sensitivity analysis for conducting initial discussion at the review meeting in April**. Also, see Fig. A1 for model descriptions and associated estimated stock biomass time series (models 1-13 reflect single change made to base model ALT_19).

MODEL STRUCTURE	MODEL							
	ALT_19	ALT_19_1	ALT_19_2	ALT_19_3	ALT_19_4	ALT_19_5	ALT_19_6	ALT_19_7
Time period (annual time step)	2008-19	2008-19	2008-19	2008-19	2008-19	2008-19	2008-19	2008-19
Fishery (no.)	1	1	1	1	1	1	1	1
Survey (no.)	1=AT	1=AT	1=AT	1=AT	1=AT	1=AT	1=AT	1=AT
Natural mortality (*M*)	Est (Prior)	Est (Prior)	Est (Prior)	Est (Prior)	Est (Prior)	Est (Prior)	Est (Prior)	Est (Prior)
Growth	WAA	WAA	WAA	WAA	WAA	WAA	WAA	WAA
S-R steepness (*h*)	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed
Catchability (*q*)	Est (Prior)	Est (Prior)	Est (Prior)	Est (Prior)	Est (Prior)	Est (Prior)	Est (Prior)	Est (Prior)
Selectivity								
Fishery	Est (Dome)	Est (Dome)	Est (Dome)	Est (Dome)	Est (Dome)	Est (Dome)	Est (Dome)	Est (Dome)
Survey	Est (Asymptotic)	Est (Asymptotic)	Est (Asymptotic)	Est (Asymptotic)	Est (Asymptotic)	Est (Asymptotic)	Est (Asymptotic)	Est (Asymptotic)

LIKELIHOODS	ALT_19	ALT_19_1	ALT_19_2	ALT_19_3	ALT_19_4	ALT_19_5	ALT_19_6	ALT_19_7
Catch	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Fishery age composition	36.65	36.50	34.51	36.65	36.97	14.50	36.88	36.50
AT age composition	31.34	31.50	36.14	31.34	31.54	9.26	31.04	31.49
Age composition subtotal	67.99	67.99	70.65	67.99	68.51	23.76	67.92	67.99
At index of abundance	7.42	7.46	8.74	7.42	7.57	4.74	7.43	7.46
Recruitment	0.69	0.71	0.65	0.69	0.76	-1.15	0.75	0.71
Forecast recruitment	0.80	0.74	0.00	0.80	0.82	0.27	0.95	0.74
Priors	0.27	0.24	0.40	0.27	0.23	0.23	0.37	0.24
Parm_softbounds	0.0007	0.0007	0.0007	0.0007	0.0010	0.0008	0.0007	0.0007
Total -log(*L*)	77.17	77.14	80.44	77.17	77.89	27.85	77.42	77.14
Number of est. pars.	28	28	25	29	28	28	28	28

ESTIMATES	ALT_19	ALT_19_1	ALT_19_2	ALT_19_3	ALT_19_4	ALT_19_5	ALT_19_6	ALT_19_7
M	0.77	0.75	0.81	0.77	0.75	0.74	0.8	0.76
$\ln(R_0)$	12.32	12.22	12.46	12.32	12.30	12.37	12.56	12.22
S-R *h*	0.75	1.00	0.75	0.75	0.75	0.75	0.50	1.00
AT survey *q*	0.66	0.67	0.66	0.66	0.66	0.72	0.63	0.67
B (mt) - 2018	26,829	26,909	27,888	26,829	27,000	32,855	27,380	26,901
B (mt) - 2019	62,232	62,549	30,821	62,232	62,276	50,577	62,900	62,531

Table A1. Continued.

MODEL STRUCTURE	MODEL						
	ALT_19	**ALT_19_8**	**ALT_19_9**	**ALT_19_10**	**ALT_19_11**	**ALT_19_12**	**ALT_19_13**
Time period (annual time step)	2008-19	2008-19	2008-19	2008-19	2008-19	2008-19	2008-19
Fishery (no.)	1	1	1	1	1	1	1
Survey (no.)	1=AT	1=AT	1=AT	1=AT	1=AT	1=AT	1=AT
Natural mortality (*M*)	Est (Prior)	Est (Prior)	Est	Fixed	Est (Prior)	Est	Est (Prior)
Growth	WAA	WAA	WAA	WAA	WAA	WAA	WAA
S-R steepness (*h*)	Fixed	Est (Prior)	Fixed	Fixed	Fixed	Fixed	Fixed
Catchability (*q*)	Est (Prior)	Est (Prior)	Est (Prior)	Est (Prior)	Est	Est	Est (Prior)
Selectivity							
Fishery	Est (Dome)	Est (Dome)	Est (Dome)	Est (Dome)	Est (Dome)	Est (Dome)	Est (Dome)
Survey	Est (Asymptotic)	Est (Asymptotic)	Est (Asymptotic)	Est (Asymptotic)	Est (Asymptotic)	Est (Asymptotic)	Est (Asymptotic)

LIKELIHOODS	ALT_19	ALT_19_8	ALT_19_9	ALT_19_10	ALT_19_11	ALT_19_12	ALT_19_13
Catch	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Fishery age composition	36.65	36.61	36.85	35.46	36.66	36.85	36.55
AT age composition	31.34	31.39	31.15	34.68	31.36	31.13	31.31
Age composition subtotal	67.99	68.00	68.00	70.14	68.02	67.98	67.86
At index of abundance	7.42	7.43	7.30	8.03	7.41	7.31	7.55
Recruitment	0.69	0.69	0.75	1.19	0.68	0.77	0.78
Forecast recruitment	0.80	0.78	0.76	1.07	0.81	0.76	0.84
Priors	0.27	0.19	0.00	0.03	0.26	0.00	0.36
Parm_softbounds	0.0007	0.0007	0.0007	0.0011	0.0007	0.0006	0.0007
Total -log(*L*)	77.17	77.09	76.81	80.46	77.18	76.82	77.39
Number of est. pars.	28	29	28	27	28	28	28

ESTIMATES	ALT_19	ALT_19_8	ALT_19_9	ALT_19_10	ALT_19_11	ALT_19_12	ALT_19_13
M	0.77	0.76	0.83	0.5	0.76	0.83	0.79
$\ln(R_0)$	12.32	12.29	12.45	11.79	12.30	12.47	12.43
S-R *h*	0.75	0.81	0.75	0.75	0.75	0.75	0.75
AT survey *q*	0.66	0.67	0.65	0.71	0.69	0.63	0.62
B (mt) - 2018	26,829	26,822	26,892	28,369	25,991	27,651	29,832
B (mt) - 2019	62,232	62,275	64,622	56,539	60,514	66,304	71,460

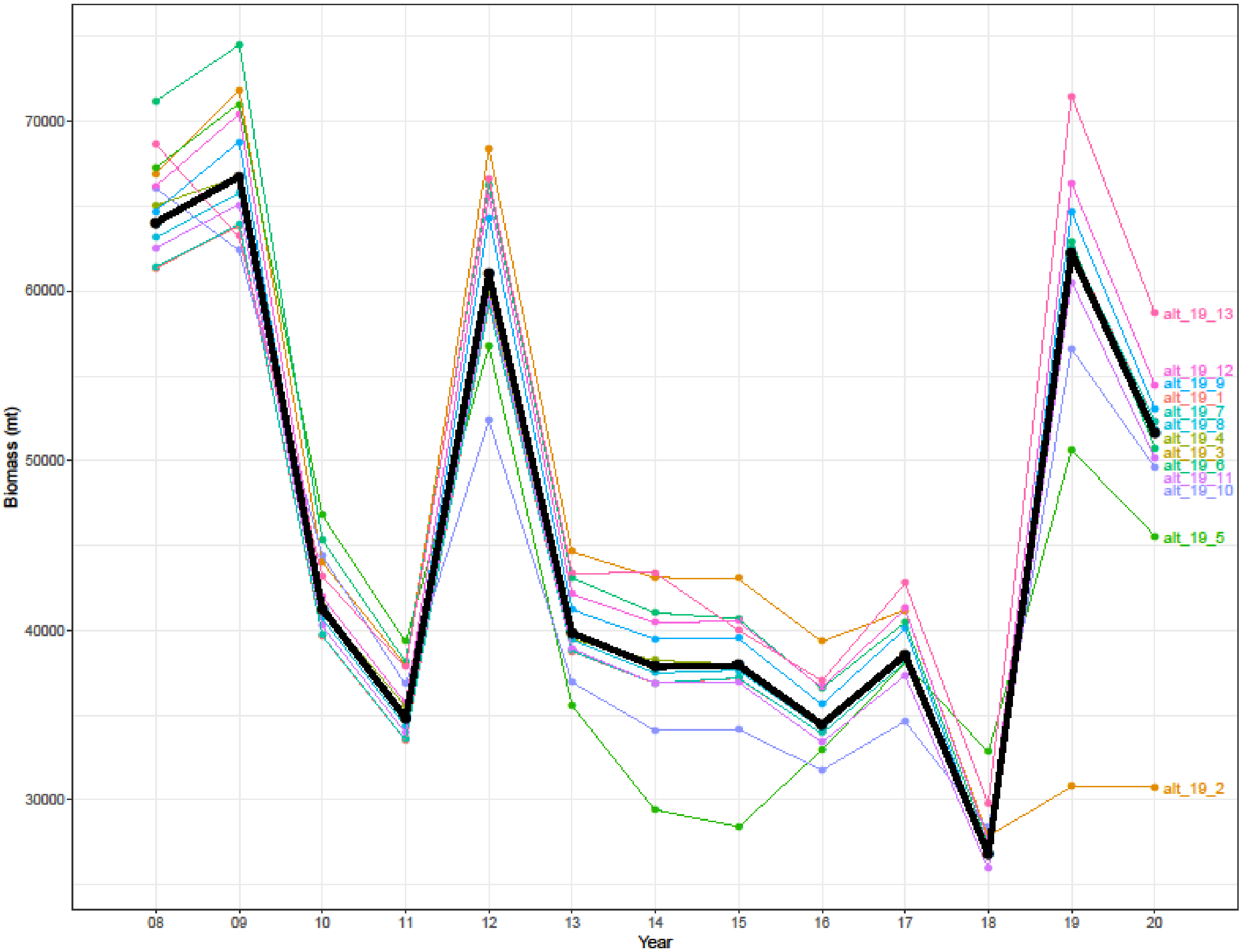


Fig. A1. Estimated stock biomass (*B*, age 1+ fish, mt) time series for alternative assessment models associated with sensitivity analysis for base model ALT_19. **Suite of models included in sensitivity analysis for conducting initial discussion at the review meeting in April**. Also, see Table A1 for further model details (models 1-13 reflect single change made to base model ALT_19).

ALT_19: Base model (preliminary, black line)
ALT_19_1: $\sigma_R = 1.0$
ALT_19_2: Rec-devs estimated (2008-17)
ALT_19_3: Initial *F* estimated
ALT_19_4: Fishery selectivity (doub.-norm.)
ALT_19_5: Fishery/survey comp. weighting (Francis)
ALT_19_6: $h = 0.5$
ALT_19_7: $h = 1.0$
ALT_19_8: *h* (prior)
ALT_19_9: *M* estimated
ALT_19_10: $M = 0.5$
ALT_19_11: *q* estimated
ALT_19_12: $M + q$ estimated
ALT_19_13: WAA (fixed, avg. 2008-18)

Table A2. Model structure (data and processes) and results (likelihood and parameter estimates) for alternative assessment models associated with sensitivity analysis for base model ALT_19. **Suite of models included in general sensitivity analysis associated with the final base model ALT_19 selected at the review meeting in April**. Also, see Fig. A2 for model descriptions and associated estimated stock biomass time series (models 1-19 reflect single change made to base model ALT_19).

MODEL STRUCTURE	**MODEL**										
	ALT_19	**ALT_19_1**	**ALT_19_2**	**ALT_19_3**	**ALT_19_4**	**ALT_19_5**	**ALT_19_6**	**ALT_19_7**	**ALT_19_8**	**ALT_19_9**	**ALT_19_10**
Time period (annual time step)	2008-19	2008-19	2008-19	2008-19	2008-19	2008-19	2008-19	2008-19	2008-19	2008-19	2008-19
Fishery (no.)	1	1	1	1	1	1	1	1	1	1	1
Survey (no.)	1=AT	1=AT	1=AT	1=AT	1=AT	1=AT	1=AT	1=AT	1=AT	1=AT	1=AT
Natural mortality (*M*)	Est (Prior)	Est (Prior)	Est (Prior)	Est (Prior)	Est (Prior)	Est (Prior)	Est (Prior)	Est (Prior)	Est (Prior)	Est	Fixed
Growth	WAA	WAA	WAA	WAA	WAA	WAA	WAA	WAA	WAA	WAA	WAA
S-R steepness (*h*)	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed	Est (Prior)	Fixed	Fixed
Catchability (*q*)	Est (Prior)	Est (Prior)	Est (Prior)	Est (Prior)	Est (Prior)	Est (Prior)	Est (Prior)	Est (Prior)	Est (Prior)	Est (Prior)	Est (Prior)
Selectivity											
Fishery	Est (Dome)	Est (Dome)	Est (Dome)	Est (Dome)	Est (Dome)	Est (Dome)	Est (Dome)	Est (Dome)	Est (Dome)	Est (Dome)	Est (Dome)
Survey	Est (Asymptotic)	Est (Asymptotic)	Est (Asymptotic)	Est (Asymptotic)	Est (Asymptotic)	Est (Asymptotic)	Est (Asymptotic)	Est (Asymptotic)	Est (Asymptotic)	Est (Asymptotic)	Est (Asymptotic)

LIKELIHOODS	**ALT_19**	**ALT_19_1**	**ALT_19_2**	**ALT_19_3**	**ALT_19_4**	**ALT_19_5**	**ALT_19_6**	**ALT_19_7**	**ALT_19_8**	**ALT_19_9**	**ALT_19_10**
Catch	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Fishery age composition	24.83	25.29	23.36	24.83	25.08	10.84	24.81	24.82	24.83	25.05	23.77
AT age composition	24.33	22.64	29.99	24.33	24.49	9.37	24.22	24.38	24.35	24.27	27.53
Age composition subtotal	49.17	47.93	53.35	49.17	49.57	20.21	49.03	49.20	49.18	49.32	51.30
At index of abundance	4.69	4.37	6.14	4.69	4.88	2.58	4.71	4.72	4.70	4.35	6.37
Recruitment	0.78	2.81	0.86	0.78	0.72	-0.76	0.80	0.85	0.79	0.91	1.28
Forecast recruitment	1.40	0.93	0.00	1.40	1.40	0.61	1.60	1.29	1.36	1.33	1.79
Priors	0.41	0.49	0.60	0.41	0.39	0.47	0.51	0.38	0.34	0.00	0.04
Parm_softbounds	0.0007	0.0007	0.0007	0.0007	0.0010	0.0007	0.0007	0.0007	0.0007	0.0006	0.0012
Total -log(*L*)	56.45	56.53	60.94	56.45	56.96	23.11	56.66	56.45	56.37	55.91	60.79
Number of est. pars.	28	28	25	29	28	28	28	28	29	28	27

ESTIMATES	**ALT_19**	**ALT_19_1**	**ALT_19_2**	**ALT_19_3**	**ALT_19_4**	**ALT_19_5**	**ALT_19_6**	**ALT_19_7**	**ALT_19_8**	**ALT_19_9**	**ALT_19_10**
M	0.81	0.83	0.86	0.81	0.80	0.82	0.84	0.80	0.81	0.89	0.50
$\ln(R_0)$	12.36	12.59	12.54	12.36	12.35	12.46	12.58	12.26	12.33	12.51	11.74
S-R *h*	0.75	0.75	0.75	0.75	0.75	0.75	0.50	1.00	0.81	0.75	0.75
AT survey *q*	0.67	0.63	0.64	0.67	0.67	0.71	0.63	0.67	0.67	0.64	0.72
B (mt) - 2018	25,943	25,702	27,470	25,943	25,962	30,423	26,642	26,071	25,933	26,131	27,278
B (mt) - 2019	71,099	83,398	30,988	71,099	71,076	54,914	71,550	71,780	71,214	74,599	62,150

Table A2. Continued.

MODEL STRUCTURE	MODEL									
	ALT_19	**ALT_19_11**	**ALT_19_12**	**ALT_19_13**	**ALT_19_14**	**ALT_19_15**	**ALT_19_16**	**ALT_19_17**	**ALT_19_18**	**ALT_19_19**
Time period (annual time step)	2008-19	2008-19	2008-19	2008-19	2008-19	2008-19	2008-19	2008-19	2008-19	2008-19
Fishery (no.)	1	1	1	1	1	1	1	1	1	1
Survey (no.)	1=AT	1=AT	1=AT	1=AT	1=AT	1=AT	1=AT	1=AT	1=AT	1=AT
Natural mortality (*M*)	Est (Prior)	Est (Prior)	Est	Est (Prior)	Est	Est (Prior)	Est (Prior)	Est (Prior)	Est (Prior)	Est (Prior)
Growth	WAA	WAA	WAA	WAA	WAA	WAA	WAA	WAA	WAA	WAA
S-R steepness (*h*)	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed
Catchability (*q*)	Est (Prior)	Est	Est	Est (Prior)	Est	Est (Prior)	Est (Prior)	Est (Prior)	Est (Prior)	Est (Prior)
Selectivity										
Fishery	Est (Dome)	Est (Dome)	Est (Dome)	Est (Dome)	Est (Dome)	Est (Dome)	Est (Dome)	Est (Dome)	Est (Dome)	Est (Dome)
Survey	Est (Asymptotic)	Est (Asymptotic)	Est (Asymptotic)	Est (Asymptotic)	Est (Asymptotic)	Est (Asymptotic)	Est (Asymptotic)	Est (Asymptotic)	Est (Asymptotic)	Est (Asymptotic)

LIKELIHOODS	ALT_19	ALT_19_11	ALT_19_12	ALT_19_13	ALT_19_14	ALT_19_15	ALT_19_16	ALT_19_17	ALT_19_18	ALT_19_19
Catch	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Fishery age composition	24.83	24.84	25.04	24.85	0.00	16.13	36.62	25.60	22.77	22.25
AT age composition	24.33	24.35	24.24	24.34	16.59	19.99	31.38	22.49	22.21	21.14
Age composition subtotal	49.17	49.20	49.28	49.18	16.59	36.12	68.00	48.09	44.97	43.39
At index of abundance	4.69	4.69	4.36	5.00	1.28	2.99	7.20	3.62	4.70	4.91
Recruitment	0.78	0.76	0.95	0.83	2.83	1.11	0.99	1.01	0.45	0.40
Forecast recruitment	1.40	1.40	1.32	1.41	1.86	1.65	1.01	1.56	1.58	0.81
Priors	0.41	0.40	0.00	0.50	0.77	0.51	0.30	0.02	0.43	0.39
Parm_softbounds	0.0007	0.0007	0.0006	0.0007	0.0000	0.0007	0.0007	0.0021	0.0008	0.0007
Total -log(*L*)	56.45	56.44	55.90	56.92	23.33	42.38	77.50	54.30	52.12	49.89
Number of est. pars.	28	28	28	28	23	28	28	32	28	35

ESTIMATES	ALT_19	ALT_19_11	ALT_19_12	ALT_19_13	ALT_19_14	ALT_19_15	ALT_19_16	ALT_19_17	ALT_19_18	ALT_19_19
M	0.81	0.81	0.89	0.83	0.90	0.84	0.78	0.63	0.81	0.80
$\ln(R_0)$	12.36	12.34	12.55	12.47	12.46	12.38	12.33	12.16	12.38	12.36
S-R *h*	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
AT survey *q*	0.67	0.69	0.61	0.62	0.63	0.67	0.66	0.69	0.68	0.67
B (mt) - 2018	25,943	25,007	27,441	29,369	27,101	25,580	26,587	37,586	25,838	25,408
B (mt) - 2019	71,099	68,948	77,892	81,387	87,494	77,156	60,749	86,319	76,868	53,975

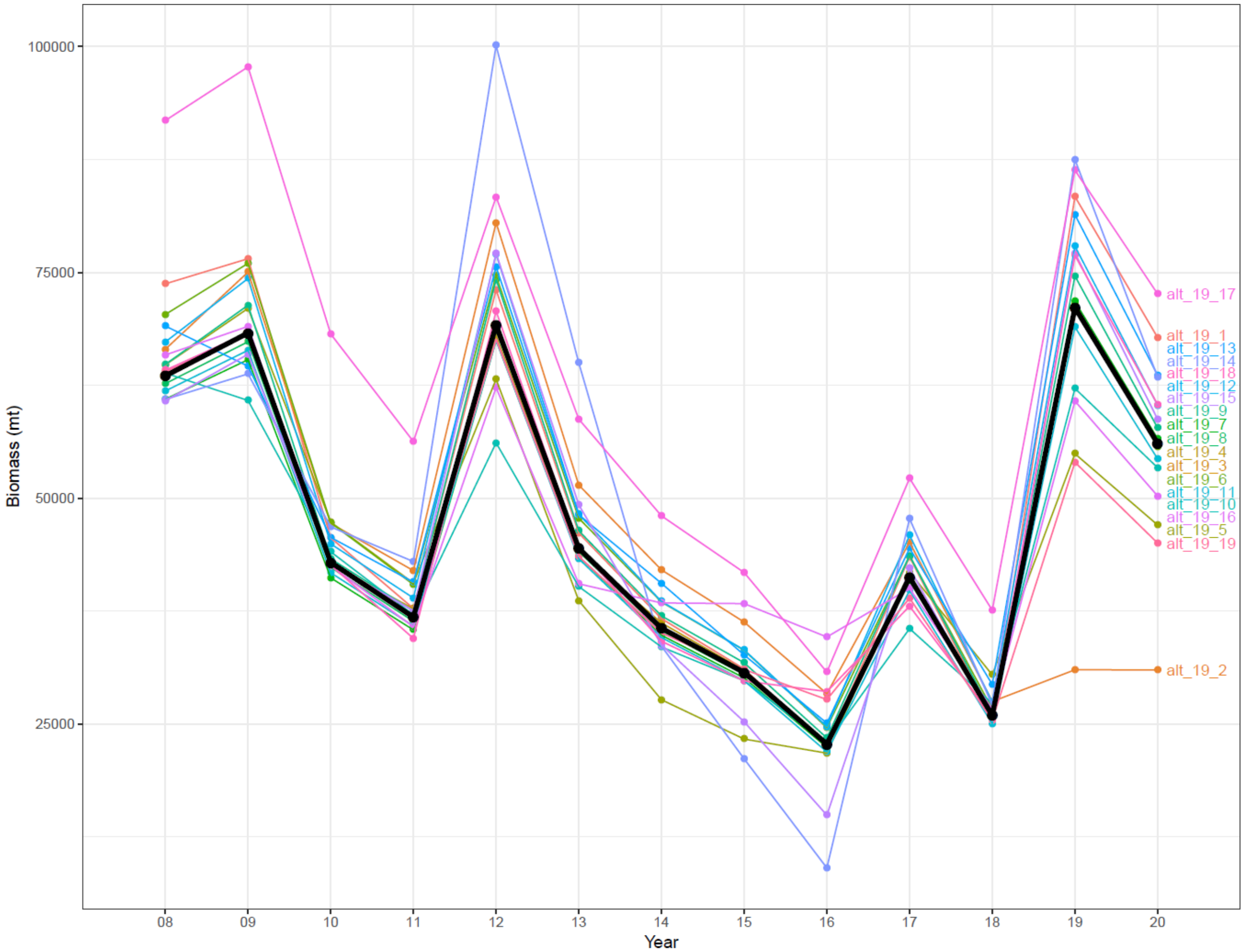


Fig. A2. Estimated stock biomass (*B*, age 1+ fish, mt) time series for alternative assessment models associated with sensitivity analysis for base model ALT_19. **Suite of models included in general sensitivity analysis associated with the final base model ALT_19 selected at the review meeting in April**. Also, see Table A2 for further model details (models 1-19 reflect single change made to base model ALT_19).

ALT_19: Base model (final, black line)
ALT_19_1: $\sigma_R = 1.0$
ALT_19_2: Rec-devs estimated (2008-17)
ALT_19_3: Initial F estimated
ALT_19_4: Fishery selectivity (doub.-norm.)
ALT_19_5: Fishery/survey comp. weighting (Francis)
ALT_19_6: $h = 0.5$
ALT_19_7: $h = 1.0$
ALT_19_8: h (prior)
ALT_19_9: M estimated
ALT_19_10: $M = 0.5$
ALT_19_11: q estimated
ALT_19_12: $M + q$ estimated
ALT_19_13: WAA (fixed, avg. 2008-18)
ALT_19_14: Fishery comp. weighting = 0
ALT_19_15: Fishery comp. weighting = 0.25
ALT_19_16: Fishery comp. weighting = 1
ALT_19_17: Survey selectivity (dome-shaped)
ALT_19_18: Survey comp. (yr.-specific ALK)
ALT_19_19: Survey selectivity (time vary, age-0)

APPENDIX B
SS files for final base model ALT_19

STARTER FILE

#V3.30.12.00-safe;_2018_09_13;_Stock_Synthesis_by_Richard_Methot_(NOAA)_using_ADMB_12.0
#Stock Synthesis (SS) is a work of the U.S. Government and is not subject to copyright protection in the United States.
#Foreign copyrights may apply. See copyright.txt for more information.
#_user_support_available_at:NMFS.Stock.Synthesis@noaa.gov
#_user_info_available_at:https://vlab.ncep.noaa.gov/group/stock-synthesis
Stock Synthesis (Ver. 3.30.12)
#
P. mackerel stock assessment (May 2019)
Model ALT_19: number of fisheries = 1 / surveys = 1 / time-step = annual / biological distributions = age / growth = WAA / selectivity = age-based
#
STARTER FILE
ALT.dat
ALT.ctl
0 # 0=use init values in control file; 1=use ss.par
1 # run display detail (0,1,2)
1 # detailed output (0=minimal for data-limited, 1=high (w/ wtatage.ss_new), 2=brief)
0 # write 1st iteration details to echoinput.sso file (0,1)
3 # write parm values to ParmTrace.sso (0=no,1=good,active; 2=good,all; 3=every_iter,all_parms; 4=every,active)
2 # write to cumreport.sso (0=no,1=like&timeseries; 2=add survey fits)
0 # Include prior_like for non-estimated parameters (0,1)
1 # Use Soft Boundaries to aid convergence (0,1) (recommended)
1 # Number of datafiles to produce: 1st is input, 2nd is estimates, 3rd and higher are bootstrap
10 # Turn off estimation for parameters entering after this phase
10 # MCeval burn interval
2 # MCeval thin interval
0 # jitter initial parm value by this fraction
2006 # min yr for sdreport outputs (-1 for styr)
2020 # max yr for sdreport outputs (-1 for endyr; -2 for endyr+Nforecastyrs
0 # N individual STD years
#vector of year values
0.0001 # final convergence criteria (e.g. 1.0e-04)
0 # retrospective year relative to end year (e.g. -4)
1 # min age for calc of summary biomass
1 # Depletion basis: denom is: 0=skip; 1=rel X*SPB0; 2=rel SPBmsy; 3=rel X*SPB_styr; 4=rel X*SPB_endyr
0.6 # Fraction (X) for Depletion denominator (e.g. 0.4)
4 # SPR_report_basis: 0=skip; 1=(1-SPR)/(1-SPR_tgt); 2=(1-SPR)/(1-SPR_MSY); 3=(1-SPR)/(1-SPR_Btarget); 4=rawSPR
1 # F_report_units: 0=skip; 1=exploitation(Bio); 2=exploitation(Num); 3=sum(Frates); 4=true F for range of ages; 5=unweighted avg. F for range of ages
#COND 10 15 #_min and max age over which average F will be calculated with F_reporting=4 or 5
2 # F_report_basis: 0=raw_F_report; 1=F/Fspr; 2=F/Fmsy ; 3=F/Fbtgt
0 # MCMC output detail: integer part (0=default; 1=adds obj func components); and decimal part (added to SR_LN(R0) on first call to mcmc)
0 # ALK tolerance (example 0.0001)
3.30 # check value for end of file and for version control

FORECAST FILE

#V3.30.12.00-safe;_2018_09_13;_Stock_Synthesis_by_Richard_Methot_(NOAA)_using_ADMB_12.0

for all year entries except rebuilder; enter either: actual year, -999 for styr, 0 for endyr, neg number for rel. endyr
#
P. mackerel stock assessment (May 2019)
Stock Synthesis (Ver. 3.30.12)
Model ALT_19: number of fisheries = 1 / surveys = 1 / time-step = annual / biological distributions = age / growth = WAA / selectivity = age-based
#
FORECAST FILE
1 # Benchmarks: 0=skip; 1=calc F_spr,F_btgt,F_msy; 2=calc F_spr,F0.1,F_msy
2 # MSY: 1= set to F(SPR); 2=calc F(MSY); 3=set to F(Btgt) or F0.1; 4=set to F(endyr)
0.5 # SPR target (e.g. 0.40)
0.5 # Biomass target (e.g. 0.40)
#_Bmark_years: beg_bio, end_bio, beg_selex, end_selex, beg_relF, end_relF, beg_recr_dist, end_recr_dist, beg_SRparm, end_SRparm (enter actual year, or values of 0 or -integer to be rel. endyr)
 2018 2018 2018 2018 2018 2018 2018 2018 2018 2018
1 #Bmark_relF_Basis: 1 = use year range; 2 = set relF same as forecast below
#
1 # Forecast: 0=none; 1=F(SPR); 2=F(MSY) 3=F(Btgt) or F0.1; 4=Ave F (uses first-last relF yrs); 5=input annual F scalar
2 # N forecast years
0 # F scalar (only used for Do_Forecast==5)
#_Fcast_years: beg_selex, end_selex, beg_relF, end_relF, beg_mean recruits, end_recruits (enter actual year, or values of 0 or -integer to be rel. endyr)
 0 0 0 0 0 0
0 # Forecast selectivity (0=fcast selex is mean from year range; 1=fcast selectivity from annual time-vary parms)
1 # Control rule method (1: ramp does catch=f(SSB), buffer on F; 2: ramp does F=f(SSB), buffer on F; 3: ramp does catch=f(SSB), buffer on catch; 4: ramp does F=f(SSB), buffer on catch)
0.5 # Control rule Biomass level for constant F (as frac of Bzero, e.g. 0.40); (Must be > the no F level below)
0.1 # Control rule Biomass level for no F (as frac of Bzero, e.g. 0.10)
0.75 # Control rule target as fraction of Flimit (e.g. 0.75)
3 #_N forecast loops (1=OFL only; 2=ABC; 3=get F from forecast ABC catch with allocations applied)
3 #_First forecast loop with stochastic recruitment
0 #_Forecast recruitment: 0= spawn_recr; 1=value*spawn_recr_fxn; 2=value*VirginRecr; 3=recent mean from yr range above
1 # value is ignored
0 #_Forecast loop control #5 (reserved for future bells&whistles)
2030 #FirstYear for caps and allocations (should be after years with fixed inputs)
0 # stddev of log(realized catch/target catch) in forecast (set value>0.0 to cause active impl_error)
0 # Do West Coast gfish rebuilder output (0/1)
0 # Rebuilder: first year catch could have been set to zero (Ydecl)(-1 to set to 1999)
0 # Rebuilder: year for current age structure (Yinit) (-1 to set to endyear+1)
1 # fleet relative F: 1=use first-last alloc year; 2=read seas, fleet, alloc list below
Note that fleet allocation is used directly as average F if Do_Forecast=4
2 # basis for fcast catch tuning and for fcast catch caps and allocation (2=deadbio; 3=retainbio; 5=deadnum; 6=retainnum)
Conditional input if relative F choice = 2
enter list of: season, fleet, relF; if used, terminate with season=-9999

1 1 1
-9999 0 0 # terminator for list of relF
enter list of: fleet number, max annual catch for fleets with a max; terminate with fleet=-9999
-9999 -1
enter list of area ID and max annual catch; terminate with area=-9999
-9999 -1
enter list of fleet number and allocation group assignment, if any; terminate with fleet=-9999
-9999 -1
#_if N allocation groups >0, list year, allocation fraction for each group
list sequentially because read values fill to end of N forecast
terminate with -9999 in year field
no allocation groups
3 # basis for input Fcast catch: -1=read basis with each obs; 2=dead catch; 3=retained catch; 99=input Hrate(F)
#enter list of Fcast catches; terminate with line having year=-9999
#_Yr Seas Fleet Catch(or_F)
 2019 1 1 12000
 2020 1 1 12000
-9999 1 1 0
#
999 # verify end of input

CONTROL FILE

#V3.30.12.00-safe;_2018_09_13;_Stock_Synthesis_by_Richard_Methot_(NOAA)_using_ADMB_12.0
#Stock Synthesis (SS) is a work of the U.S. Government and is not subject to copyright protection in the United States.
#Foreign copyrights may apply. See copyright.txt for more information.
#_user_support_available_at:NMFS.Stock.Synthesis@noaa.gov
#_user_info_available_at:https://vlab.ncep.noaa.gov/group/stock-synthesis
#_data_and_control_files: ALT.dat // ALT.ctl
#
P. mackerel stock assessment (May 2019)
Stock Synthesis (Ver. 3.30.12)
Model ALT_19: number of fisheries = 1 / surveys = 1 / time-step = annual / biological distributions = age / growth = WAA / selectivity = age-based
#
CONTROL FILE
#
1 # 0 means do not read wtatage.ss; 1 means read and use wtatage.ss and also read and use growth parameters
1 #_N_Growth_Patterns
1 #_N_platoons_Within_GrowthPattern
#_Cond 1 #_Morph_between/within_stdev_ratio (no read if N_morphs=1)
#_Cond 1 #vector_Morphdist_(-1_in_first_val_gives_normal_approx)
#
4 # recr_dist_method for parameters: 2=main effects for GP, Area, Settle timing; 3=each Settle entity; 4=none (only when N_GP*Nsettle*pop==1)
1 # not yet implemented; Future usage: Spawner-Recruitment: 1=global; 2=by area
1 # number of recruitment settlement assignments
0 # unused option
#GPattern month area age (for each settlement assignment)
 1 1 1 0
#
#_Cond 0 # N_movement_definitions goes here if Nareas > 1

```
#_Cond 1.0 # first age that moves (real age at begin of season, not integer) also cond on do_migration>0
#_Cond 1 1 1 2 4 10 # example move definition for seas=1, morph=1, source=1 dest=2, age1=4, age2=10
#
2 #_Nblock_Patterns
 2 1 #_blocks_per_pattern
# begin and end years of blocks
 2008 2010 2011 2018
 2008 2008
#
# controls for all timevary parameters
1 #_env/block/dev_adjust_method for all time-vary parms (1=warn relative to base parm bounds; 3=no bound
check)
#  autogen
0 0 0 0 0 # autogen: 1st element for biology, 2nd for SR, 3rd for Q, 4th reserved, 5th for selex
# where: 0 = autogen all time-varying parms; 1 = read each time-varying parm line; 2 = read then autogen if parm
min==-12345
#
#_Available timevary codes
#_Block types: 0: Pblock=Pbase*exp(TVP); 1: Pblock=Pbase+TVP; 2: Pblock=TVP; 3: Pblock=Pblock(-1) + TVP
#_Block_trends: -1: trend bounded by base parm min-max and parms in transformed units (beware); -2: endtrend
and infl_year direct values; -3: end and infl as fraction of base range
#_EnvLinks:  1: P(y)=Pbase*exp(TVP*env(y));  2: P(y)=Pbase+TVP*env(y);  3: null;  4: P(y)=2.0/(1.0+exp(-
TVP1*env(y) - TVP2))
#_DevLinks:  1: P(y)*=exp(dev(y)*dev_se;  2: P(y)+=env(y)*dev_se;  3: random walk;  4: zero-reverting random walk
with rho
#
# setup for M, growth, maturity, fecundity, recruitment distibution, movement
#
0 #_natM_type:_0=1Parm; 1=N_breakpoints;_2=Lorenzen;_3=agespecific;_4=agespec_withseasinterpolate
  #_no additional input for selected M option; read 1P per morph
#
1 # GrowthModel: 1=vonBert with L1&L2; 2=Richards with L1&L2; 3=age_specific_K_incr; 4=age_specific_K_decr;
5=age_specific_K_each; 6=not implemented
0.5 #_Age(post-settlement)_for_L1;linear growth below this
12 #_Growth_Age_for_L2 (999 to use as Linf)
-999 #_exponential decay for growth above maxage (value should approx initial Z; -999 replicates 3.24; -998 to not
allow growth above maxage)
0  #_placeholder for future growth feature
#
0 #_SD_add_to_LAA (set to 0.1 for SS2 V1.x compatibility)
0 #_CV_Growth_Pattern:  0 CV=f(LAA); 1 CV=F(A); 2 SD=F(LAA); 3 SD=F(A); 4 logSD=F(A)
#
5 #_maturity_option:  1=length logistic; 2=age logistic; 3=read age-maturity matrix by growth_pattern; 4=read age-
fecundity; 5=disabled; 6=read length-maturity
#_Age_Fecundity by growth pattern from wt-at-age.ss now invoked by read bodywt flag
1 #_First_Mature_Age
1 #_fecundity option:(1)eggs=Wt*(a+b*Wt);(2)eggs=a*L^b;(3)eggs=a*Wt^b; (4)eggs=a+b*L; (5)eggs=a+b*W
0 #_hermaphroditism option:  0=none; 1=female-to-male age-specific fxn; -1=male-to-female age-specific fxn
1 #_parameter_offset_approach (1=none, 2= M, G, CV_G as offset from female-GP1, 3=like SS2 V1.x)
#
#_growth_parms
#_ LO HI INIT PRIOR PR_SD PR_type PHASE env_var&link dev_link dev_minyr dev_maxyr dev_PH Block Block_Fxn
# Sex: 1  BioPattern: 1  NatMort
```

0.3 1 0.81111 -0.5 0.32 3 3 0 0 0 0 0 0 0 # NatM_p_1_Fem_GP_1
Sex: 1 BioPattern: 1 Growth
4 35 20.55 0 0 0 -3 0 0 0 0 0 0 0 # L_at_Amin_Fem_GP_1
30 70 39.09 0 0 0 -3 0 0 0 0 0 0 0 # L_at_Amax_Fem_GP_1
0.1 0.7 0.395 0 0 0 -3 0 0 0 0 0 0 0 # VonBert_K_Fem_GP_1
0.01 0.5 0.1 0 0 0 -3 0 0 0 0 0 0 0 # CV_young_Fem_GP_1
0.01 0.5 0.1 0 0 0 -3 0 0 0 0 0 0 0 # CV_old_Fem_GP_1
Sex: 1 BioPattern: 1 WtLen
-1 5 3.4e-06 0 0 0 -3 0 0 0 0 0 0 0 # Wtlen_1_Fem_GP_1
1 5 3.379 0 0 0 -3 0 0 0 0 0 0 0 # Wtlen_2_Fem_GP_1
Sex: 1 BioPattern: 1 Maturity&Fecundity
-3 3 3 0 0 0 -3 0 0 0 0 0 0 0 # Mat50%_Fem_GP_1
-3 3 3 0 0 0 -3 0 0 0 0 0 0 0 # Mat_slope_Fem_GP_1
-3 3 1 0 0 0 -3 0 0 0 0 0 0 0 # Eggs/kg_inter_Fem_GP_1
-3 3 0 0 0 0 -3 0 0 0 0 0 0 0 # Eggs/kg_slope_wt_Fem_GP_1
Hermaphroditism
Recruitment Distribution
Cohort growth dev base
0.1 10 1 1 1 0 -1 0 0 0 0 0 0 0 # CohortGrowDev
Movement
Age Error from parameters
catch multiplier
fraction female, by GP
1e-06 0.999999 0.5 0 0 0 -1 0 0 0 0 0 0 0 # FracFemale_GP_1
#
#_no timevary MG parameters
#
#_seasonal_effects_on_biology_parms
0 0 0 0 0 0 0 0 0 0 #_femwtlen1,femwtlen2,mat1,mat2,fec1,fec2,Malewtlen1,malewtlen2,L1,K
#_ LO HI INIT PRIOR PR_SD PR_type PHASE
#_Cond -2 2 0 0 -1 99 -2 #_placeholder when no seasonal MG parameters
#
3 #_Spawner-Recruitment; Options: 2=Ricker; 3=std_B-H; 4=SCAA; 5=Hockey; 6=B-H_flattop; 7=survival_3Parm; 8=Shepherd_3Parm; 9=RickerPower_3parm
0 # 0/1 to use steepness in initial equ recruitment calculation
0 # future feature: 0/1 to make realized sigmaR a function of SR curvature
#_ LO HI INIT PRIOR PR_SD PR_type PHASE env-var use_dev dev_mnyr dev_mxyr dev_PH Block Blk_Fxn # parm_name
5 20 12.3613 0 0 0 1 0 0 0 0 0 0 0 # SR_LN(R0)
0.1 1 0.75 0 0 0 -4 0 0 0 0 0 0 0 # SR_BH_steep
0 2 0.75 0 0 0 -1 0 0 0 0 0 0 0 # SR_sigmaR
-15 15 0 0 0 0 -1 0 0 0 0 0 0 0 # SR_regime
0 2 0 0 0 0 -1 0 0 0 0 0 0 0 # SR_autocorr
1 #do_recdev: 0=none; 1=devvector; 2=simple deviations
2008 # first year of main recr_devs; early devs can preceed this era
2017 # last year of main recr_devs; forecast devs start in following year
1 #_recdev phase
1 # (0/1) to read 13 advanced options

-6 #_recdev_early_start (0=none; neg value makes relative to recdev_start)
3 #_recdev_early_phase
0 #_forecast_recruitment phase (incl. late recr) (0 value resets to maxphase+1)
1 #_lambda for Fcast_recr_like occurring before endyr+1
2004 #_last_yr_nobias_adj_in_MPD; begin of ramp
2010 #_first_yr_fullbias_adj_in_MPD; begin of plateau
2017 #_last_yr_fullbias_adj_in_MPD
2019 #_end_yr_for_ramp_in_MPD (can be in forecast to shape ramp, but SS sets bias_adj to 0.0 for fcast yrs)
0.95 #_max_bias_adj_in_MPD (-1 to override ramp and set biasadj=1.0 for all estimated recdevs)
0 #_period of cycles in recruitment (N parms read below)
-6 #min rec_dev
6 #max rec_dev
0 #_read_recdevs
#_end of advanced SR options
#
#_placeholder for full parameter lines for recruitment cycles
read specified recr devs
#_Yr Input_value
#
all recruitment deviations
2002E 2003E 2004E 2005E 2006E 2007E 2008R 2009R 2010R 2011R 2012R 2013R 2014R 2015R 2016R 2017R 2018F 2019F 2020F
0.00912181 0.0232112 0.0951539 0.739554 0.125751 -0.230771 0.287725 -0.681879 -0.114863 1.04776 -0.34804 0.19296 -0.08946 -0.0710795 0.831454 -1.05458 1.25325 0 0
implementation error by year in forecast: 0 0
#
#Fishing Mortality info
0.1 # F ballpark
-2000 # F ballpark year (neg value to disable)
3 # F_Method: 1=Pope; 2=instan. F; 3=hybrid (hybrid is recommended)
4 # max F or harvest rate, depends on F_Method
no additional F input needed for Fmethod 1
if Fmethod=2; read overall start F value; overall phase; N detailed inputs to read
if Fmethod=3; read N iterations for tuning for Fmethod 3
5 # N iterations for tuning F in hybrid method (recommend 3 to 7)
#
#_initial_F_parms; count = 0
#_ LO HI INIT PRIOR PR_SD PR_type PHASE
#2020 2039
F rates by fleet
Yr: 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020
seas: 1 1 1 1 1 1 1 1 1 1 1 1 1
FISHERY 0.159493 0.104508 0.226129 0.136233 0.424743 0.689948 0.489975 0.927245 0.468759 0.2122 0.30685 0.288139 0.423372
#
#_Q_setup for fleets with cpue or survey data
#_1: fleet number
#_2: link type: (1=simple q, 1 parm; 2=mirror simple q, 1 mirrored parm; 3=q and power, 2 parm)
#_3: extra input for link, i.e. mirror fleet# or dev index number
#_4: 0/1 to select extra sd parameter
#_5: 0/1 for biasadj or not
#_6: 0/1 to float
#_ fleet link link_info extra_se biasadj float # fleetname

```
    2    1    0    0    0    0  #  AT
-9999 0 0 0 0 0
#
#_Q_parms(if_any);Qunits_are_ln(q)
#_     LO     HI     INIT     PRIOR     PR_SD     PR_type     PHASE   env-var   use_dev   dev_mnyr
dev_mxyr    dev_PH     Block    Blk_Fxn  #  parm_name
      -5      5   -0.407936     -0.425      0.32      6     1     0     0     0     0     0     0     0
#  LnQ_base_AT(2)
#_no timevary Q parameters
#
#_size_selex_patterns
#Pattern:_0; parm=0; selex=1.0 for all sizes
#Pattern:_1; parm=2; logistic; with 95% width specification
#Pattern:_5; parm=2; mirror another size selex; PARMS pick the min-max bin to mirror
#Pattern:_15; parm=0; mirror another age or length selex
#Pattern:_6; parm=2+special; non-parm len selex
#Pattern:_43; parm=2+special+2;  like 6, with 2 additional param for scaling (average over bin range)
#Pattern:_8; parm=8; New doublelogistic with smooth transitions and constant above Linf option
#Pattern:_9; parm=6; simple 4-parm double logistic with starting length; parm 5 is first length; parm 6=1 does desc
as offset
#Pattern:_21; parm=2+special; non-parm len selex, read as pairs of size, then selex
#Pattern:_22; parm=4; double_normal as in CASAL
#Pattern:_23; parm=6; double_normal where final value is directly equal to sp(6) so can be >1.0
#Pattern:_24; parm=6; double_normal with sel(minL) and sel(maxL), using joiners
#Pattern:_25; parm=3; exponential-logistic in size
#Pattern:_27; parm=3+special; cubic spline
#Pattern:_42; parm=2+special+3; // like 27, with 2 additional param for scaling (average over bin range)
#_discard_options:_0=none;_1=define_retention;_2=retention&mortality;_3=all_discarded_dead;_4=define_dom
e-shaped_retention
#_Pattern Discard Male Special
 0 0 0 0 # 1 FISHERY
 0 0 0 0 # 2 AT
#
#_age_selex_patterns
#Pattern:_0; parm=0; selex=1.0 for ages 0 to maxage
#Pattern:_10; parm=0; selex=1.0 for ages 1 to maxage
#Pattern:_11; parm=2; selex=1.0  for specified min-max age
#Pattern:_12; parm=2; age logistic
#Pattern:_13; parm=8; age double logistic
#Pattern:_14; parm=nages+1; age empirical
#Pattern:_15; parm=0; mirror another age or length selex
#Pattern:_16; parm=2; Coleraine - Gaussian
#Pattern:_17; parm=nages+1; empirical as random walk  N parameters to read can be overridden by setting special
to non-zero
#Pattern:_41; parm=2+nages+1; // like 17, with 2 additional param for scaling (average over bin range)
#Pattern:_18; parm=8; double logistic - smooth transition
#Pattern:_19; parm=6; simple 4-parm double logistic with starting age
#Pattern:_20; parm=6; double_normal,using joiners
#Pattern:_26; parm=3; exponential-logistic in age
#Pattern:_27; parm=3+special; cubic spline in age
#Pattern:_42; parm=2+nages+1; // cubic spline; with 2 additional param for scaling (average over bin range)
#_Pattern Discard Male Special
 17 0 0 12 # 1 FISHERY
```

17 0 0 12 # 2 AT
#
#_ LO HI INIT PRIOR PR_SD PR_type PHASE env-var use_dev dev_mnyr dev_mxyr dev_PH Block Blk_Fxn # parm_name
1 FISHERY LenSelex
2 AT LenSelex
1 FISHERY AgeSelex
-5 9 0 0 0 0 -2 0 0 0 0 0 0 0 # AgeSel_P1_FISHERY(1)
-5 9 0.337838 0 0 0 2 0 0 0 0 0 0 0 # AgeSel_P2_FISHERY(1)
-5 9 -0.502497 0 0 0 2 0 0 0 0 0 0 0 # AgeSel_P3_FISHERY(1)
-5 9 0.882151 0 0 0 2 0 0 0 0 0 0 0 # AgeSel_P4_FISHERY(1)
-5 9 -0.697966 0 0 0 2 0 0 0 0 0 0 0 # AgeSel_P5_FISHERY(1)
-5 9 -1.58687 0 0 0 2 0 0 0 0 0 0 0 # AgeSel_P6_FISHERY(1)
-1 1 0 0 0 0 -2 0 0 0 0 0 0 0 # AgeSel_P7_FISHERY(1)
-1 1 0 0 0 0 -2 0 0 0 0 0 0 0 # AgeSel_P8_FISHERY(1)
-1 1 0 0 0 0 -2 0 0 0 0 0 0 0 # AgeSel_P9_FISHERY(1)
-1 1 0 0 0 0 -2 0 0 0 0 0 0 0 # AgeSel_P10_FISHERY(1)
-1 1 0 0 0 0 -2 0 0 0 0 0 0 0 # AgeSel_P11_FISHERY(1)
-1 1 0 0 0 0 -2 0 0 0 0 0 0 0 # AgeSel_P12_FISHERY(1)
-1 1 0 0 0 0 -2 0 0 0 0 0 0 0 # AgeSel_P13_FISHERY(1)
2 AT AgeSelex
-5 9 0 0 0 0 -2 0 0 0 0 0 0 0 # AgeSel_P1_AT(2)
-5 9 1.03234 0 0 0 2 0 0 0 0 0 0 0 # AgeSel_P2_AT(2)
-5 9 0 0 0 0 -2 0 0 0 0 0 0 0 # AgeSel_P3_AT(2)
-5 9 0 0 0 0 -2 0 0 0 0 0 0 0 # AgeSel_P4_AT(2)
-5 9 0 0 0 0 -2 0 0 0 0 0 0 0 # AgeSel_P5_AT(2)
-5 9 0 0 0 0 -2 0 0 0 0 0 0 0 # AgeSel_P6_AT(2)
-5 9 0 0 0 0 -2 0 0 0 0 0 0 0 # AgeSel_P7_AT(2)
-5 9 0 0 0 0 -2 0 0 0 0 0 0 0 # AgeSel_P8_AT(2)
-5 9 0 0 0 0 -2 0 0 0 0 0 0 0 # AgeSel_P9_AT(2)

```
        -5        9        0        0        0        0       -2        0        0        0        0        0        0        0  #
AgeSel_P10_AT(2)
        -5        9        0        0        0        0       -2        0        0        0        0        0        0        0  #
AgeSel_P11_AT(2)
        -5        9        0        0        0        0       -2        0        0        0        0        0        0        0  #
AgeSel_P12_AT(2)
        -5        9        0        0        0        0       -2        0        0        0        0        0        0        0  #
AgeSel_P13_AT(2)
#_no timevary selex parameters
#
0   #  use 2D_AR1 selectivity(0/1):  experimental feature
#_no 2D_AR1 selex offset used
#
# Tag loss and Tag reporting parameters go next
0  # TG_custom:  0=no read; 1=read if tags exist
#_Cond -6 6 1 1 2 0.01 -4 0 0 0 0 0 0 0  #_placeholder if no parameters
#
# no timevary parameters
#
#
# Input variance adjustments factors:
 #_1=add_to_survey_CV
 #_2=add_to_discard_stddev
 #_3=add_to_bodywt_CV
 #_4=mult_by_lencomp_N
 #_5=mult_by_agecomp_N
 #_6=mult_by_size-at-age_N
 #_7=mult_by_generalized_sizecomp
#_Factor  Fleet  Value
 -9999   1    0  # terminator
#
1 #_maxlambdaphase
1 #_sd_offset; must be 1 if any growthCV, sigmaR, or survey extraSD is an estimated parameter
# read 8 changes to default Lambdas (default value is 1.0)
# Like_comp codes:  1=surv; 2=disc; 3=mnwt; 4=length; 5=age; 6=SizeFreq; 7=sizeage; 8=catch; 9=init_equ_catch;
# 10=recrdev; 11=parm_prior; 12=parm_dev; 13=CrashPen; 14=Morphcomp; 15=Tag-comp; 16=Tag-negbin;
17=F_ballpark; 18=initEQregime
#like_comp fleet  phase  value  sizefreq_method
 1 2 1 1 1
 4 1 1 0 1
 4 2 1 0 1
 5 1 1 0.5 1
 5 2 1 1 1
 7 1 1 0 1
 9 1 1 0 1
 11 1 1 1 1
-9999  1  1  1  1  #  terminator
#
# lambdas (for info only; columns are phases)
#  0 #_CPUE/survey:_1
#  1 #_CPUE/survey:_2
#  0 #_lencomp:_1
#  0 #_lencomp:_2
```

0.5 #_agecomp:_1
1 #_agecomp:_2
0 #_init_equ_catch
1 #_recruitments
1 #_parameter-priors
1 #_parameter-dev-vectors
1 #_crashPenLambda
0 # F_ballpark_lambda
0 # (0/1) read specs for more stddev reporting
 # 0 0 0 0 0 0 0 0 0 # placeholder for # selex_fleet, 1=len/2=age/3=both, year, N selex bins, 0 or Growth pattern, N growth ages, 0 or NatAge_area(-1 for all), NatAge_yr, N Natages
 # placeholder for vector of selex bins to be reported
 # placeholder for vector of growth ages to be reported
 # placeholder for vector of NatAges ages to be reported
999

DATA FILE

#V3.30.12.00-safe;_2018_09_13;_Stock_Synthesis_by_Richard_Methot_(NOAA)_using_ADMB_12.0
#Stock Synthesis (SS) is a work of the U.S. Government and is not subject to copyright protection in the United States.
#Foreign copyrights may apply. See copyright.txt for more information.
#_user_support_available_at:NMFS.Stock.Synthesis@noaa.gov
#_user_info_available_at:https://vlab.ncep.noaa.gov/group/stock-synthesis
#_Start_time: Mon Apr 29 12:47:40 2019
#_Number_of_datafiles: 1

#_observed data:
#V3.30.12.00-safe;_2018_09_13;_Stock_Synthesis_by_Richard_Methot_(NOAA)_using_ADMB_12.0
#Stock Synthesis (SS) is a work of the U.S. Government and is not subject to copyright protection in the United States.
#Foreign copyrights may apply. See copyright.txt for more information.
#
P. mackerel stock assessment (May 2019)
Stock Synthesis (Ver. 3.30.12)
Model ALT_19: number of fisheries = 1 / surveys = 1 / time-step = annual / biological distributions = age / growth = WAA / selectivity = age-based
#
DATA FILE
#
2008 #_StartYr
2018 #_EndYr
1 #_Nseas
12 #_months/season
2 #_Nsubseasons (even number, minimum is 2)
1 #_spawn_month
1 #_Ngenders
12 #_Nages=accumulator age
1 #_Nareas
2 #_Nfleets (fisheries/surveys)
#_fleet_type: 1=catch fleet; 2=bycatch only fleet; 3=survey; 4=ignore
#_survey_timing: -1 for fishing fleet to midseason catch-at-age for observations, or 1 to use observation month; (always 1 for surveys)

#_fleet_area: area the fleet/survey operates in
#_units of catch: 1=bio; 2=num (ignored for surveys; their units read later)
#_catch_mult: 0=no; 1=yes
#_rows are fleets
#_fleet_type fishery_timing area catch_units need_catch_mult fleetname
 1 -1 1 1 0 FISHERY # 1
 3 1 1 1 0 AT # 2
#Bycatch_fleet_input_goes_next
#a: fleet index
#b: 1=include dead bycatch in total dead catch for F0.1 and MSY optimizations and forecast ABC; 2=omit from total catch for these purposes (but still include the mortality)
#c: 1=Fmult scales with other fleets; 2=bycatch F constant at input value; 3=bycatch F from range of years
#d: F or first year of range
#e: last year of range
#f: not used
a   b   c   d   e   f
#_Catch data: yr, seas, fleet, catch, catch_se
#_catch_se: standard error of log(catch)
#_NOTE: catch data is ignored for survey fleets
-999 1 1 0 0.01 # Equil. catch prior to initial year
#
2008 1 1 5452.3 0.01
2009 1 1 3295.3 0.01
2010 1 1 4207.3 0.01
2011 1 1 4382.7 0.01
2012 1 1 12944 0.01
2013 1 1 14535 0.01
2014 1 1 10422.5 0.01
2015 1 1 13785.8 0.01
2016 1 1 14371.8 0.01
2017 1 1 4320.8 0.01
2018 1 1 11487.2 0.01
-9999 0 0 0 0
#
#_CPUE_and_surveyabundance_observations
#_Units: 0=numbers; 1=biomass; 2=F; >=30 for special types
#_Errtype: -1=normal; 0=lognormal; >0=T
#_SD_Report: 0=no sdreport; 1=enable sdreport
#_Fleet Units Errtype SD_Report
1 1 0 0 # FISHERY
2 1 0 0 # AT
#_yr month fleet obs stderr
2008 1.6 2 55000 0.38 #_ AT
2012 1.6 2 109951 0.34 #_ AT
2013 1.6 2 8245 0.61 #_ AT
2014 1.6 2 8159 0.56 #_ AT
2015 1.6 2 7146 0.52 #_ AT
2016 1.6 2 32782 0.52 #_ AT
2017 1.6 2 41139 0.26 #_ AT
2018 1.6 2 33351 0.22 #_ AT
-9999 1 1 1 1 # terminator for survey observations
#
0 #_N_fleets_with_discard

#_discard_units (1=same_as_catchunits(bio/num); 2=fraction; 3=numbers)
#_discard_errtype: >0 for DF of T-dist(read CV below); 0 for normal with CV; -1 for normal with se; -2 for lognormal; -3 for trunc normal with CV
note, only have units and errtype for fleets with discard
#_Fleet units errtype
-9999 0 0 0.0 0.0 # terminator for discard data
#
0 #_use meanbodysize_data (0/1)
#_COND_0 #_DF_for_meanbodysize_T-distribution_like
note: type=1 for mean length; type=2 for mean body weight
#_yr month fleet part type obs stderr
-9999 0 0 0 0 0 0 # terminator for mean body size data
#
set up population length bin structure (note - irrelevant if not using size data and using empirical wtatage
1 # length bin method: 1=use databins; 2=generate from binwidth,min,max below; 3=read vector
no additional input for option 1
read binwidth, minsize, lastbin size for option 2
read N poplen bins, then vector of bin lower boundaries, for option 3
1 # use length composition data (0/1)
#_mintailcomp: upper and lower distribution for females and males separately are accumulated until exceeding this level.
#_addtocomp: after accumulation of tails; this value added to all bins
#_males and females treated as combined gender below this bin number
#_compressbins: accumulate upper tail by this number of bins; acts simultaneous with mintailcomp; set=0 for no forced accumulation
#_Comp_Error: 0=multinomial, 1=dirichlet
#_Comp_Error2: parm number for dirichlet
#_minsamplesize: minimum sample size; set to 1 to match 3.24, minimum value is 0.001
#_mintailcomp addtocomp combM+F CompressBins CompError ParmSelect minsamplesize
0 0.0001 0 0 0 0 1 #_fleet:1_FISHERY
0 0.0001 0 0 0 0 1 #_fleet:2_AT
sex codes: 0=combined; 1=use female only; 2=use male only; 3=use both as joint sexxlength distribution
partition codes: (0=combined; 1=discard; 2=retained
60 #_N_LengthBins; then enter lower edge of each length bin
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60
#_yr month fleet sex part Nsamp datavector(female-male)
2008 7 1 0 0 29 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0.00075 0 0.01764 0.07592 0.15844 0.15044 0.08108 0.03531 0.02836 0.02561 0.04044 0.03837 0.04201 0.01616 0.00445 0.00895 0.00625 0.03522 0.04151 0.05247 0.05 0.03525 0.0267 0.01747 0.00368 0.00382 0.00253 0.00116 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
2009 7 1 0 0 17 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0.00089 0.01021 0.02303 0.01305 0.00459 0.00959 0.04608 0.10102 0.1461 0.16771 0.18628 0.09402 0.02677 0.00388 0.02953 0.00934 0.0155 0.01273 0.01457 0.03437 0.00859 0.01579 0.00935 0.01191 0.00511 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
2010 7 1 0 0 20 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0.00927 0.10281 0.16911 0.13639 0.07633 0.05018 0.02683 0.05798 0.04249 0.04309 0.04565 0.02798 0.05305 0.02557 0.01823 0.02856 0.02793 0.00566 0.01196 0.0102 0.01649 0.00626 0.00566 0.00232 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
2011 7 1 0 0 31 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0.00988 0.0173 0.03284 0.10697 0.11252 0.13201 0.16368 0.13141 0.11242 0.06713 0.04928 0.0182 0.03042 0.00889 0.00523 0.00056 0.00075 0 0.00024 9e-05 0 0.00019 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
2012 7 1 0 0 48 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0.00064 0.00325 0.01704 0.04912 0.06862 0.08154 0.07796 0.07217 0.09883 0.10627 0.12257 0.09057 0.05368 0.04972 0.04219 0.02226 0.0194 0.00075 0.00384 0.00139 0.00303 0.00231 0.00075 0.00679 0.0015 0.00378 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

2013 7 1 0 0 72 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0.00032 0.00049 0.00855 0.0137 0.01812 0.07897 0.15219 0.21373
0.1721 0.08337 0.05253 0.03204 0.03379 0.05281 0.01809 0.01494 0.01587 0.01062 0.00896 0.00498 0.00446
0.00138 0.00088 0.00095 0.00186 0.00251 0.00154 0.00025 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
2014 7 1 0 0 56 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0.00122 0.00558 0.01434 0.02892 0.04989 0.09459 0.14249 0.11898
0.11389 0.08129 0.06712 0.0514 0.04052 0.03446 0.02042 0.02322 0.02373 0.01933 0.01451 0.02083 0.00929
0.00972 0.00594 0.00486 0.00304 0.00041 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
2015 7 1 0 0 18 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0.00732 0.00244 0.00877 0.0106 0.00814 0.01908 0.03066 0.08161 0.1038
0.11414 0.07376 0.03623 0.03171 0.05808 0.06474 0.07065 0.07687 0.05663 0.04164 0.02819 0.02652 0.02577
0.01621 0 0.00646 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
2016 7 1 0 0 20 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0.0011 0.0033 0.00563 0.01207 0.06116 0.1701 0.22511
0.13534 0.13949 0.06087 0.04523 0.05477 0.0223 0.01173 0.02212 0.01466 0.00501 0.01002 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0
2017 7 1 0 0 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0.00985 0.00985 0.03272 0.07214 0.07535 0.05535 0.09041
0.12501 0.17603 0.09975 0.09465 0.05751 0.02116 0.02313 0.03356 0.00632 0.00765 0.00632 0.00324 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
2018 7 1 0 0 6 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0.00406 0.0149 0.04144 0.11349 0.0455 0.08424 0.30443 0.1617
0.12568 0.00948 0.03873 0.00135 0.00406 0.04009 0.00271 0.00406 0 0.00135 0.00271 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0
2012 1.6 2 0 0 20 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0.0477548 0.00803657 0.00490646 0.0793673 0.138929
0.296216 0.294028 0.0744623 0.0379671 0.0110702 0.00220459 0.000264506 0.000449062 0.00155601
0.00155601 0 0.00117879 0 0 5.37e-05 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
2013 1.6 2 0 0 4 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0.000172688 0 0 0 0.000172688 0.0194146 0.252638
0.302348 0.240208 0.0617972 0.0748952 0.0429007 0 0.00545308 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
2014 1.6 2 0 0 9 0 0 0 0 0 0 0 0 0 0 0 0.0202399 0 0 0.0202399 0.0809594 0.0202399 0.0404797 0.0607196
0.0202399 0 0 0 0 0 0.0242842 0 0 0.0420602 0.0570677 0.175368 0.225113 0.117858 0.0243424 0.0471919
0.023596 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
2015 1.6 2 0 0 7 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0.00419777 0.00799099 0.0118485 0.0462103 0.110843
0.0983561 0.103311 0.0411689 0.00418472 0.000106225 0 0.0153015 0.274322 0.0040785 0.00397227 0.274109
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
2016 1.6 2 0 0 21 0 0 0 0 0 0 0 0.00802703 0 0.00796016 0.000985515 2.76e-05 0.00103852 0.00705224 0.293424
0.294083 0.00112344 0.000422958 0.00419566 0.300302 0.0168674 0.0105026 0.0116899 0.0148874 0.00660147
0.00186749 0.00117859 0.00122465 0.00221022 0.00286921 0.00368347 0.00412499 0.002943 0 0.000235741
0.000471482 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
2017 1.6 2 0 0 23 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0.000362465 0.0244153 0.0888798 0.215901 0.270898
0.20421 0.075548 0.029656 0.0210192 0.033544 0.0178014 0.00826337 0.00487989 0.00326266 0.000854618
0.000505008 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
2018 1.6 2 0 0 23 0 0 0 0 0 0 0 0 0.0111029 0.0999261 0.2225 0.136313 0.0727849 0.0428998 0.139902 0.116309
0.0254955 0.0240865 0.023844 0.00161213 0.00166453 0.0219069 0 0.000317567 0.0020768 0.00403304
0.00266161 0.00655706 0.0109225 0.0148849 0.0150308 0.00200947 0.00101155 0.000147947 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
-9999 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0
#
9 #_N_age_bins
0 1 2 3 4 5 6 7 8
1 #_N_ageerror_definitions
0.5 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5 9.5 10.5 11.5 12.5
0.32 0.32 0.55 0.79 1.04 1.31 1.59 1.88 2.19 2.19 2.19 2.19 2.19
#_mintailcomp: upper and lower distribution for females and males separately are accumulated until exceeding this level.
#_addtocomp: after accumulation of tails; this value added to all bins
#_males and females treated as combined gender below this bin number

```
#_compressbins: accumulate upper tail by this number of bins; acts simultaneous with mintailcomp; set=0 for no
forced accumulation
#_Comp_Error:  0=multinomial, 1=dirichlet
#_Comp_Error2:  parm number  for dirichlet
#_minsamplesize: minimum sample size; set to 1 to match 3.24, minimum value is 0.001
#_mintailcomp addtocomp combM+F CompressBins CompError ParmSelect minsamplesize
0 0.0001 -1 0 0 0 1 #_fleet:1_FISHERY
0 0.0001 -1 0 0 0 1 #_fleet:2_AT
2 #_Lbin_method_for_Age_Data: 1=poplenbins; 2=datalenbins; 3=lengths
# sex codes:  0=combined; 1=use female only; 2=use male only; 3=use both as joint sexxlength distribution
# partition codes:  (0=combined; 1=discard; 2=retained
#_yr month fleet sex part ageerr Lbin_lo Lbin_hi Nsamp datavector(female-male)
 2008 7 1 0 0 1 -1 -1 29 0.45884 0.17836 0.10869 0.18265 0.05649 0.01347 0.0015 0 0
 2009 7 1 0 0 1 -1 -1 17 0.07875 0.68272 0.10833 0.07652 0.04062 0.00783 0.00522 0 0
 2010 7 1 0 0 1 -1 -1 20 0.39097 0.32225 0.17552 0.07028 0.02935 0.00965 0.00199 0 0
 2011 7 1 0 0 1 -1 -1 31 0.7146 0.27722 0.00775 0.00019 0.00024 0 0 0 0
 2012 7 1 0 0 1 -1 -1 48 0.37721 0.5057 0.09232 0.01647 0.00453 0.00225 0.0015 0 0
 2013 7 1 0 0 1 -1 -1 72 0.77396 0.11062 0.07914 0.02516 0.00626 0.00173 0.0019 0.00124 0
 2014 7 1 0 0 1 -1 -1 56 0.58389 0.2296 0.08349 0.05492 0.03509 0.00735 0.00304 0.00197 0.00065
 2015 7 1 0 0 1 -1 -1 18 0.4965 0.25024 0.14868 0.06543 0.02881 0.01033 0 0 0
 2016 7 1 0 0 1 -1 -1 20 0.05923 0.65227 0.25027 0.03033 0.0079 0 0 0 0
 2017 7 1 0 0 1 -1 -1 9 0.27395 0.46183 0.19735 0.05614 0.00757 0 0.00316 0 0
 2018 7 1 0 0 1 -1 -1 6 0.25677 0.63461 0.06312 0.00542 0.03873 0.00135 0 0 0
 2012 1.6 2 0 0 1 -1 -1 20 0.103072 0.741523 0.145328 0.00851106 0.00133906 0.00018862 3.433e-05 1.98e-06
1.98e-06
 2013 1.6 2 0 0 1 -1 -1 4 0.00266553 0.441249 0.439054 0.10684 0.00973755 0.00042323 2.785e-05 1.38e-06
1.38e-06
 2014 1.6 2 0 0 1 -1 -1 9 0.260402 0.121533 0.321908 0.248336 0.0440051 0.00342914 0.00034919 1.832e-05
1.832e-05
 2015 1.6 2 0 0 1 -1 -1 7 0.0223516 0.319004 0.153189 0.305893 0.164198 0.0295627 0.00521346 0.00029386
0.00029386
 2016 1.6 2 0 0 1 -1 -1 21 0.92776 0.0571563 0.00966868 0.00468546 0.00067684 4.769e-05 4.88e-06 2.6e-07
2.6e-07
 2017 1.6 2 0 0 1 -1 -1 23 0.032665 0.681361 0.23077 0.0470267 0.0074269 0.00065699 8.429e-05 4.62e-06 4.62e-
06
 2018 1.6 2 0 0 1 -1 -1 23 0.932054 0.0343783 0.0264801 0.00662372 0.00044999 1.304e-05 5.9e-07 3e-08 3e-08
-9999  0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
#
0 #_Use_MeanSize-at-Age_obs (0/1)
#
0 #_N_environ_variables
#Yr Variable Value
#
0 # N sizefreq methods to read
#
0 # do tags (0/1)
#
0 #    morphcomp data(0/1)
#  Nobs, Nmorphs, mincomp
#  yr, seas, type, partition, Nsamp, datavector_by_Nmorphs
#
0  #  Do dataread for selectivity priors(0/1)
# Yr, Seas, Fleet,  Age/Size,  Bin,  selex_prior,  prior_sd
```

feature not yet implemented
#
999
ENDDATA

WEIGHT-AT-AGE FILE

P. mackerel stock assessment (Mar 2019)
Stock Synthesis (Ver. 3.30.12)
Model ALT_19: number of fisheries = 1 / surveys = 1 / time-step = annual / biological distributions = age / growth = WAA / selectivity = age-based
#
WAA FILE
#
12 # maxage
if Yr is negative, then fill remaining years for that Seas, growpattern, Bio_Pattern, Fleet
if season is negative, then fill remaining fleets for that Seas, Bio_Pattern, Sex, Fleet
will fill through forecast years, so be careful
fleet 0 contains begin season pop WT
fleet -1 contains mid season pop WT
fleet -2 contains maturity*fecundity
#Yr Seas Sex Bio_Pattern BirthSeas Fleet 0 1 2 3 4 5 6 7 8 9 10 11 12
2008 1 1 1 1 1 0.0865 0.1984 0.3096 0.5186 0.6734 0.8422 0.8706 0.8869 0.9358 0.9358 0.9358 0.9358 0.9358 #wt_flt_1
2008 1 1 1 1 2 0.0865 0.1984 0.3096 0.5186 0.6734 0.8422 0.8706 0.8869 0.9358 0.9358 0.9358 0.9358 0.9358 #wt_flt_2
2008 1 1 1 1 -2 0 0.017 0.086 0.2558 0.464 0.8234 0.8495 0.8505 0.8628 0.8628 0.8628 0.8628 0.8628 #fecundity
2008 1 1 1 1 0 0.0865 0.1984 0.3096 0.5186 0.6734 0.8422 0.8706 0.8869 0.9358 0.9358 0.9358 0.9358 0.9358 #popwt_beg
2008 1 1 1 1 -1 0.0865 0.1984 0.3096 0.5186 0.6734 0.8422 0.8706 0.8869 0.9358 0.9358 0.9358 0.9358 0.9358 #popwt_mid
2009 1 1 1 1 1 0.1212 0.2467 0.4058 0.629 0.7081 0.8237 0.8706 0.8706 0.8869 0.8869 0.8869 0.8869 0.8869 #wt_flt_1
2009 1 1 1 1 2 0.1212 0.2467 0.4058 0.629 0.7081 0.8237 0.8706 0.8706 0.8869 0.8869 0.8869 0.8869 0.8869 #wt_flt_2
2009 1 1 1 1 -2 0 0.017 0.086 0.2558 0.464 0.8234 0.8495 0.8505 0.8628 0.8628 0.8628 0.8628 0.8628 #fecundity
2009 1 1 1 1 0 0.1212 0.2467 0.4058 0.629 0.7081 0.8237 0.8706 0.8706 0.8869 0.8869 0.8869 0.8869 0.8869 #popwt_beg
2009 1 1 1 1 -1 0.1212 0.2467 0.4058 0.629 0.7081 0.8237 0.8706 0.8706 0.8869 0.8869 0.8869 0.8869 0.8869 #popwt_mid
2010 1 1 1 1 1 0.0924 0.2052 0.3076 0.5529 0.6768 0.8874 0.8706 0.8706 0.8706 0.8706 0.8706 0.8706 0.8706 #wt_flt_1
2010 1 1 1 1 2 0.0924 0.2052 0.3076 0.5529 0.6768 0.8874 0.8706 0.8706 0.8706 0.8706 0.8706 0.8706 0.8706 #wt_flt_2
2010 1 1 1 1 -2 0 0.017 0.086 0.2558 0.464 0.8234 0.8495 0.8505 0.8628 0.8628 0.8628 0.8628 0.8628 #fecundity
2010 1 1 1 1 0 0.0924 0.2052 0.3076 0.5529 0.6768 0.8874 0.8706 0.8706 0.8706 0.8706 0.8706 0.8706 0.8706 #popwt_beg
2010 1 1 1 1 -1 0.0924 0.2052 0.3076 0.5529 0.6768 0.8874 0.8706 0.8706 0.8706 0.8706 0.8706 0.8706 0.8706 #popwt_mid
2011 1 1 1 1 1 0.1054 0.2069 0.2358 0.5909 0.6925 0.8426 0.8874 0.8706 0.8706 0.8706 0.8706 0.8706 0.8706 #wt_flt_1
2011 1 1 1 1 2 0.1054 0.2069 0.2358 0.5909 0.6925 0.8426 0.8874 0.8706 0.8706 0.8706 0.8706 0.8706 0.8706 #wt_flt_2

2011 1 1 1 1 -2 0 0.017 0.086 0.2558 0.464 0.8234 0.8495 0.8505 0.8628 0.8628 0.8628 0.8628 0.8628 #fecundity
2011 1 1 1 1 0 0.1054 0.2069 0.2358 0.5909 0.6925 0.8426 0.8874 0.8706 0.8706 0.8706 0.8706 0.8706 0.8706 #popwt_beg
2011 1 1 1 1 -1 0.1054 0.2069 0.2358 0.5909 0.6925 0.8426 0.8874 0.8706 0.8706 0.8706 0.8706 0.8706 0.8706 #popwt_mid
2012 1 1 1 1 1 0.121 0.233 0.3372 0.5624 0.6825 0.8097 0.8706 0.8874 0.8706 0.8706 0.8706 0.8706 0.8706 #wt_flt_1
2012 1 1 1 1 2 0.121 0.233 0.3372 0.5624 0.6825 0.8097 0.8706 0.8874 0.8706 0.8706 0.8706 0.8706 0.8706 #wt_flt_2
2012 1 1 1 1 -2 0 0.017 0.086 0.2558 0.464 0.8234 0.8495 0.8505 0.8628 0.8628 0.8628 0.8628 0.8628 #fecundity
2012 1 1 1 1 0 0.121 0.233 0.3372 0.5624 0.6825 0.8097 0.8706 0.8874 0.8706 0.8706 0.8706 0.8706 0.8706 #popwt_beg
2012 1 1 1 1 -1 0.121 0.233 0.3372 0.5624 0.6825 0.8097 0.8706 0.8874 0.8706 0.8706 0.8706 0.8706 0.8706 #popwt_mid
2013 1 1 1 1 1 0.1314 0.2527 0.3513 0.4527 0.6441 0.798 0.8153 0.8368 0.8874 0.8874 0.8874 0.8874 0.8874 #wt_flt_1
2013 1 1 1 1 2 0.1314 0.2527 0.3513 0.4527 0.6441 0.798 0.8153 0.8368 0.8874 0.8874 0.8874 0.8874 0.8874 #wt_flt_2
2013 1 1 1 1 -2 0 0.017 0.086 0.2558 0.464 0.8234 0.8495 0.8505 0.8628 0.8628 0.8628 0.8628 0.8628 #fecundity
2013 1 1 1 1 0 0.1314 0.2527 0.3513 0.4527 0.6441 0.798 0.8153 0.8368 0.8874 0.8874 0.8874 0.8874 0.8874 #popwt_beg
2013 1 1 1 1 -1 0.1314 0.2527 0.3513 0.4527 0.6441 0.798 0.8153 0.8368 0.8874 0.8874 0.8874 0.8874 0.8874 #popwt_mid
2014 1 1 1 1 1 0.1404 0.2449 0.35 0.5178 0.6315 0.7997 0.7893 0.8064 0.8706 0.8706 0.8706 0.8706 0.8706 #wt_flt_1
2014 1 1 1 1 2 0.1404 0.2449 0.35 0.5178 0.6315 0.7997 0.7893 0.8064 0.8706 0.8706 0.8706 0.8706 0.8706 #wt_flt_2
2014 1 1 1 1 -2 0 0.017 0.086 0.2558 0.464 0.8234 0.8495 0.8505 0.8628 0.8628 0.8628 0.8628 0.8628 #fecundity
2014 1 1 1 1 0 0.1404 0.2449 0.35 0.5178 0.6315 0.7997 0.7893 0.8064 0.8706 0.8706 0.8706 0.8706 0.8706 #popwt_beg
2014 1 1 1 1 -1 0.1404 0.2449 0.35 0.5178 0.6315 0.7997 0.7893 0.8064 0.8706 0.8706 0.8706 0.8706 0.8706 #popwt_mid
2015 1 1 1 1 1 0.1273 0.2912 0.3877 0.51 0.5447 0.8135 0.8426 0.798 0.8153 0.8153 0.8153 0.8153 0.8153 #wt_flt_1
2015 1 1 1 1 2 0.1273 0.2912 0.3877 0.51 0.5447 0.8135 0.8426 0.798 0.8153 0.8153 0.8153 0.8153 0.8153 #wt_flt_2
2015 1 1 1 1 -2 0 0.017 0.086 0.2558 0.464 0.8234 0.8495 0.8505 0.8628 0.8628 0.8628 0.8628 0.8628 #fecundity
2015 1 1 1 1 0 0.1273 0.2912 0.3877 0.51 0.5447 0.8135 0.8426 0.798 0.8153 0.8153 0.8153 0.8153 0.8153 #popwt_beg
2015 1 1 1 1 -1 0.1273 0.2912 0.3877 0.51 0.5447 0.8135 0.8426 0.798 0.8153 0.8153 0.8153 0.8153 0.8153 #popwt_mid
2016 1 1 1 1 1 0.2179 0.287 0.3813 0.5648 0.5901 0.8135 0.8426 0.8426 0.798 0.798 0.798 0.798 0.798 #wt_flt_1
2016 1 1 1 1 2 0.2179 0.287 0.3813 0.5648 0.5901 0.8135 0.8426 0.8426 0.798 0.798 0.798 0.798 0.798 #wt_flt_2
2016 1 1 1 1 -2 0 0.017 0.086 0.2558 0.464 0.8234 0.8495 0.8505 0.8628 0.8628 0.8628 0.8628 0.8628 #fecundity
2016 1 1 1 1 0 0.2179 0.287 0.3813 0.5648 0.5901 0.8135 0.8426 0.8426 0.798 0.798 0.798 0.798 0.798 #popwt_beg
2016 1 1 1 1 -1 0.2179 0.287 0.3813 0.5648 0.5901 0.8135 0.8426 0.8426 0.798 0.798 0.798 0.798 0.798 #popwt_mid
2017 1 1 1 1 1 0.1874 0.2673 0.3677 0.5201 0.5944 0.8135 0.8426 0.8426 0.8426 0.8426 0.8426 0.8426 0.8426 #wt_flt_1
2017 1 1 1 1 2 0.1874 0.2673 0.3677 0.5201 0.5944 0.8135 0.8426 0.8426 0.8426 0.8426 0.8426 0.8426 0.8426 #wt_flt_2
2017 1 1 1 1 -2 0 0.017 0.086 0.2558 0.464 0.8234 0.8495 0.8505 0.8628 0.8628 0.8628 0.8628 0.8628 #fecundity

2017 1 1 1 1 0 0.1874 0.2673 0.3677 0.5201 0.5944 0.8135 0.8426 0.8426 0.8426 0.8426 0.8426 0.8426 0.8426
#popwt_beg
2017 1 1 1 1 -1 0.1874 0.2673 0.3677 0.5201 0.5944 0.8135 0.8426 0.8426 0.8426 0.8426 0.8426 0.8426 0.8426
#popwt_mid
2018 1 1 1 1 1 0.148 0.2373 0.3488 0.5687 0.5532 0.8135 0.8426 0.8426 0.8426 0.8426 0.8426 0.8426 0.8426
#wt_flt_1
2018 1 1 1 1 2 0.148 0.2373 0.3488 0.5687 0.5532 0.8135 0.8426 0.8426 0.8426 0.8426 0.8426 0.8426 0.8426
#wt_flt_2
2018 1 1 1 1 -2 0 0.017 0.086 0.2558 0.464 0.8234 0.8495 0.8505 0.8628 0.8628 0.8628 0.8628 0.8628 #fecundity
2018 1 1 1 1 0 0.148 0.2373 0.3488 0.5687 0.5532 0.8135 0.8426 0.8426 0.8426 0.8426 0.8426 0.8426 0.8426
#popwt_beg
2018 1 1 1 1 -1 0.148 0.2373 0.3488 0.5687 0.5532 0.8135 0.8426 0.8426 0.8426 0.8426 0.8426 0.8426 0.8426
#popwt_mid
2019 1 1 1 1 1 0.148 0.2373 0.3488 0.5687 0.5532 0.8135 0.8426 0.8426 0.8426 0.8426 0.8426 0.8426 0.8426
#wt_flt_1
2019 1 1 1 1 2 0.148 0.2373 0.3488 0.5687 0.5532 0.8135 0.8426 0.8426 0.8426 0.8426 0.8426 0.8426 0.8426
#wt_flt_2
2019 1 1 1 1 -2 0 0.017 0.086 0.2558 0.464 0.8234 0.8495 0.8505 0.8628 0.8628 0.8628 0.8628 0.8628 #fecundity
2019 1 1 1 1 0 0.148 0.2373 0.3488 0.5687 0.5532 0.8135 0.8426 0.8426 0.8426 0.8426 0.8426 0.8426 0.8426
#popwt_beg
2019 1 1 1 1 -1 0.148 0.2373 0.3488 0.5687 0.5532 0.8135 0.8426 0.8426 0.8426 0.8426 0.8426 0.8426 0.8426
#popwt_mid
2020 1 1 1 1 1 0.148 0.2373 0.3488 0.5687 0.5532 0.8135 0.8426 0.8426 0.8426 0.8426 0.8426 0.8426 0.8426
#wt_flt_1
2020 1 1 1 1 2 0.148 0.2373 0.3488 0.5687 0.5532 0.8135 0.8426 0.8426 0.8426 0.8426 0.8426 0.8426 0.8426
#wt_flt_2
2020 1 1 1 1 -2 0 0.017 0.086 0.2558 0.464 0.8234 0.8495 0.8505 0.8628 0.8628 0.8628 0.8628 0.8628 #fecundity
2020 1 1 1 1 0 0.148 0.2373 0.3488 0.5687 0.5532 0.8135 0.8426 0.8426 0.8426 0.8426 0.8426 0.8426 0.8426
#popwt_beg
2020 1 1 1 1 -1 0.148 0.2373 0.3488 0.5687 0.5532 0.8135 0.8426 0.8426 0.8426 0.8426 0.8426 0.8426 0.8426
#popwt_mid
-9999 1 1 1 1 0 0.148 0.2373 0.3488 0.5687 0.5532 0.8135 0.8426 0.8426 0.8426 0.8426 0.8426 0.8426 0.8426
#terminator