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ASSESSMENT OF THE PACIFIC SARDINE RESOURCE IN 2020 for U.S. MANAGEMENT IN 2020-2021

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Assessment of the Pacific sardine resource in 2020 for U.S. management in 2020-2021

Contents

Preface

The Pacific sardine resource is assessed each year in support of the Pacific Fishery Management Council (PFMC) process of stipulating annual harvest specifications for the U.S. fishery. Presently, the assessment/management schedule for Pacific sardine is based on a full assessment conducted every three years, with an update assessment conducted in the interim years. A full stock assessment was conducted in 2017 (Hill et al. 2017, STAR 2017), and an update was conducted in 2018 (Hill et al. 2018) and 2019 (Hill et al. 2019). The following report serves as a benchmark stock assessment for purposes of advising management for the 2020-21 fishing year.

The stock assessment team's (STAT's) preferred approach for assessing the Pacific sardine (*Sardinops sagax*) is to use the acoustic-trawl (AT) survey abundance time series directly for providing management on a regular basis (survey-based approach). Past assessments (Hill et al. 2017, 2018, 2019) and reviews (STAR 2017), have presented the merits and drawbacks of using the AT survey abundance index for advising management. However, as noted by both the STAT and stock assessment review (STAR) panels, the current fishery management cycle (July-June) currently precludes using the survey-based approach in a straightforward manner to asses stock status each year. At this time, the survey-based approach would require forecasting stock biomass one full year after the last (most recent available) survey observation for purposes of providing management guidance for the upcoming fishing year. Thus, the model-based approach using the 2020 base model presented here is recommended for management purposes for the 2020-2021 fishing year.

Executive Summary

The following Pacific sardine assessment update was conducted to inform U.S. fishery management for the cycle that begins July 1, 2020 and ends June 30, 2021. The 2020 base model was reviewed at the STAR Panel in February 2020, and has many features found in the previous model ALT (2017-2019).

Stock

This assessment focuses on the northern subpopulation of Pacific sardine (NSP) that ranges from northern Baja California, México to British Columbia, Canada and extends up to 300 nm offshore. In all past assessments, the default approach has been to assume that all catches landed in ports from Ensenada (ENS) to British Columbia (BC) were from the northern subpopulation. There is now general scientific consensus that catches landed in the Southern California Bight (SCB, i.e., Ensenada and southern California) likely represent a mixture of the southern subpopulation (warm months) and northern subpopulation (cool months)

(Felix-Uraga et al. 2004, 2005, Zwolinski et al. 2011, Garcia-Morales et al. 2012, Demer and Zwolinski 2014). Although the ranges of the northern and southern subpopulations can overlap within the SCB, the adult spawning stocks likely move north and south in synchrony each year and do not occupy the same space simultaneously to any significant extent (Garcia-Morales et al. 2012). Satellite oceanography data (Demer and Zwolinski 2014) were used to partition catch data from Ensenada (ENS) and southern California (SCA) ports to exclude both landings and biological compositions attributed to the southern subpopulation.

Catches

The assessment includes sardine landings (mt) from six major fishing regions: Ensenada (ENS), southern California (SCA), central California (CCA), Oregon (OR), Washington (WA), and British Columbia (BC). Landings for each port and for the NSP over the modeled years/seasons are below in Table ES-1.

Table ES-1: Pacific sardine landings (mt) for major fishing regions off northern Baja California (Ensenada, Mexico), the United States, and British Columbia (Canada). ENS and SCA landings are presented as totals and northern subpopulation (NSP) portions. Y-S stands for year-semester for calendar and model values.

Calendar Y-S	Model Y-S	ENS Total	ENS NSP	SCA Total	SCA NSP	CCA	OR	WA	BC
2005-2	2005-1	38,000	4,397	16,615	1,581	7,825	44,316	6,605	3,231
2006-1	2005-2	17,601	11,215	18,291	17,117	2,033	102	0	0
2006-2	2006-1	39,636	0	18,556	5,016	15,710	35,547	4,099	1,575
2007-1	2006-2	13,981	13,320	27,546	20,567	6,013	0	0	0
2007-2	2007-1	22,866	11,928	22,047	5,531	28,769	42,052	4,662	1,522
2008-1	2007-2	23,488	15,618	25,099	24,777	2,515	0	0	0
2008-2	2008-1	43,378	5,930	8,980	124	24,196	22,940	6,435	10,425
2009-1	2008-2	25,783	20,244	10,167	9,874	11,080	0	0	0
2009-2	2009-1	30,128	0	5,214	109	13,936	21,482	8,025	15,334
2010-1	2009-2	12,989	7,904	20,334	20,334	2,909	437	511	422
2010-2	2010-1	43,832	9,171	11,261	699	1,404	20,415	11,870	21,801
2011-1	2010-2	18,514	11,588	13,192	12,959	2,720	0	0	0
2011-2	2011-1	51,823	17,330	6,499	182	7,359	11,023	8,008	20,719
2012-1	2011-2	10,534	9,026	12,649	10,491	3,673	2,874	2,932	0
2012-2	2012-1	48,535	0	8,621	930	598	39,744	32,510	19,172
2013-1	2012-2	13,609	12,828	3,102	973	84	149	1,421	0
2013-2	2013-1	37,804	0	4,997	110	811	27,599	29,619	0
2014-1	2013-2	12,930	412	1,495	809	4,403	0	908	0
2014-2	2014-1	77,466	0	1,601	0	1,831	7,788	7,428	0
2015-1	2014-2	16,497	0	1,543	0	728	2,131	63	0
2015-2	2015-1	20,972	0	1,421	0	6	0	66	0
2016-1	2015-2	23,537	0	423	185	1	1	0	0
2016-2	2016-1	42,532	0	964	49	234	3	170	0
2017-1	2016-2	28,212	6,936	513	145	0	0	0	0
2017-2	2017-1	99,967	0	1,205	0	170	1	0	0
2018-1	2017-2	24,534	6,032	395	198	0	2	0	0
2018-2	2018-1	43,370	0	1,424	0	35	6	2	0
2019-1	2018-2	32,169	11,210	754	551	58	2	0	0
2019-2	2019-1	46,943	0	855	0	131	8	0	0

Data and Assessment

The integrated assessment model was developed using Stock Synthesis (SS version 3.30.14), and includes fishery and survey data collected from mid-2005 through 2019. The model is based on a July-June biological year (aka 'model year'), with two semester-based seasons per year (S1=Jul- Dec and S2=Jan-Jun). Catches and biological samples for the fisheries off ENS, SCA, and CCA were pooled into a single MexCAL fleet, for which selectivity was modeled separately in each season (S1 and S2). Catches and biological samples from OR, WA, and BC were modeled by season as a single Pacific Northwest (PNW) fleet. A single AT survey index of abundance from ongoing SWFSC surveys (2006-2019) was included in the model.

The 2020 base model incoporates the following specifications:

- Sexes were combined; ages 0-8+;
- Two fisheries (MexCal and PacNW fleets), with an annual selectivity pattern for the PNW fleet and seasonal selectivity patterns (S1 and S2) for the MexCal fleet;
- MexCal fleets: age-based selectivity (time-varying and non-parametric [option 17 in Stock Synthesis]);
- PNW fleet: asymptotic age-based selectivity (time-varying for the inflection point);
- AT survey age compositions with effective sample sizes set to 1 per cluster (externally);
- Age compositions for the spring AT survey omitted;
- Fishery age compositions with effective sample sizes calculated by dividing the number of fish sampled by 25 (externally) and lambda weighting=1 (internally);
- Beverton-Holt stock-recruitment relationship with steepness set to 0.3;
- Initial equilibrium ("SR regime" parameter) estimated with the 'lambda' for this parameter set to zero (no penalty contributing to total likelihood estimate);
- Natural mortality (M) estimated with a prior;
- Recruitment deviations estimated from 2005-2018;
- Virgin recruitment estimated, and total recruitment variability (σ_R) fixed at 1.2;
- Initial fishing mortality (F) estimated for the MexCal S1 fleet and assumed to be 0 for the other fleets;
- F for the 2020-1 to 2020-2 model years set to those for the 2018 (S2) and 2019 (S1) model years.
- AT survey biomass 2006-2019, partitioned into two (spring and summer) surveys, with catchability (Q) set to 1 for 2005-2014 and 0.733 for 2015-2019;
- AT survey selectivity is assumed to be uniform (fully-selected) above age 1 and estimated annually for age-0.

Spawning Stock Biomass and Recruitment

Time series of estimated spawning stock biomass (SSB, mmt) and associated 95% confidence intervals are displayed in Figure ES-1 and Table ES-2. The initial level of SSB was estimated to be 717,077 mt. The SSB has continually declined since 2005-2006, reaching historically low levels in recent years (2014-present). The SSB was projected to be 20,623 mt (CV=19%) in January 2020.

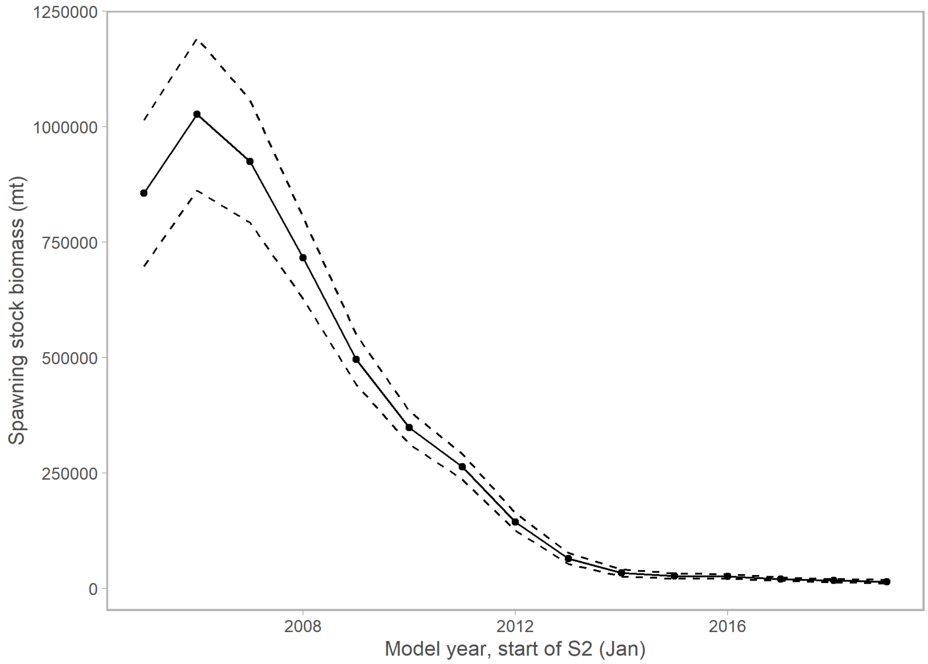

Figure ES-1: Spawning stock biomass time series (95% CI dashed lines) for 2020 base model.

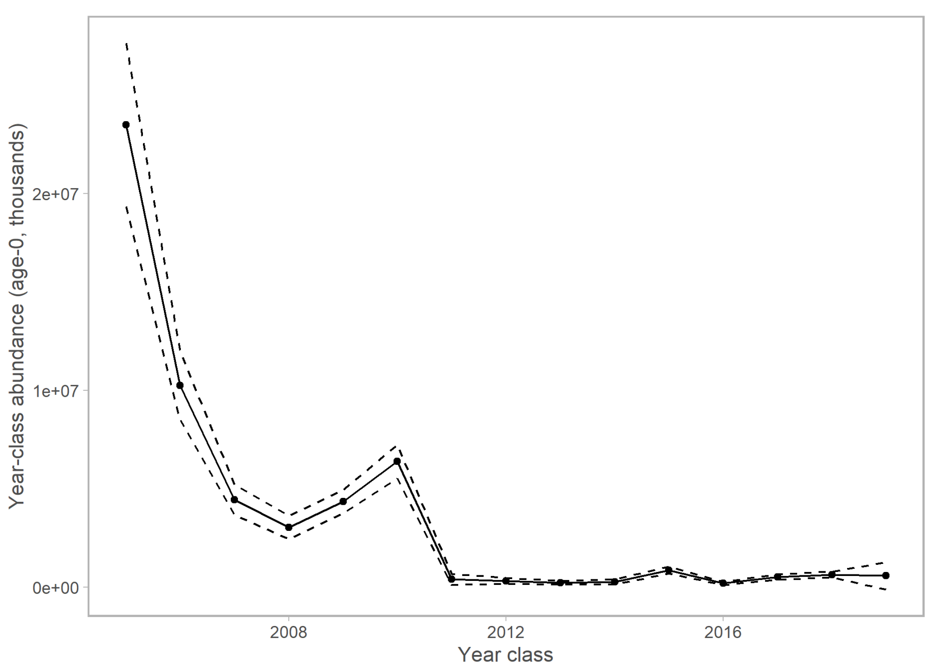

Figure ES-2: Estimated recruitment (age-0, thousands of fish) time series for 2020 base model.

Time series of estimated recruitment (age-0, thousands of fish) abundance is presented in Figure ES-2 and Table ES-2 the figure and table below. The initial level of recruitment (R_0) was estimated to be 23,481,700 age-0 thousands of fish. As indicated for SSB above, recruitment has largely declined since 2005-2006, with the exception of a brief period of modest recruitment success from 2009-1010. In particular, the 2011-2019 year classes have been among the weakest in recent history.

Table ES-2: Spawning stock biomas (SSB) and recruitment (1000s) estimates and asymptotic standard errors for 2020 base model. SSB estimates were calculated at the beginning of Season 2 (S2) of each model year (January). Recruits were age-0 fish (1000s) calculated at the beginning of each model year (July).

Calendar Y-S	Model Y-S	SSB	SSB sd	Recruits	Recruits sd
–	VIRG-1	0	0	0	0
–	VIRG-2	186,412	46,615	2,497,660	631,756
–	INIT-1	0	0	0	0
–	INIT-2	717,077	210,708	0	0
2005-2	2005-1	0	0	23,481,700	4,138,620
2006-1	2005-2	944,410	114,999	0	0
2006-2	2006-1	0	0	10,243,900	1,746,000
2007-1	2006-2	1,136,270	109,953	0	0
2007-2	2007-1	0	0	4,440,300	770,711
2008-1	2007-2	1,010,600	81,786	0	0
2008-2	2008-1	0	0	3,036,910	596,284
2009-1	2008-2	760,343	51,472	0	0
2009-2	2009-1	0	0	4,349,860	586,281
2010-1	2009-2	508,691	31,034	0	0
2010-2	2010-1	0	0	6,382,960	858,061
2011-1	2010-2	346,715	20,725	0	0
2011-2	2011-1	0	0	400,378	275,621
2012-1	2011-2	265,112	16,697	0	0
2012-2	2012-1	0	0	320,608	160,608
2013-1	2012-2	148,558	13,115	0	0
2013-2	2013-1	0	0	230,611	98,577
2014-1	2013-2	69,620	9,106	0	0
2014-2	2014-1	0	0	267,296	131,230
2015-1	2014-2	37,557	6,214	0	0
2015-2	2015-1	0	0	874,285	171,644
2016-1	2015-2	30,991	4,662	0	0
2016-2	2016-1	0	0	198,698	82,566
2017-1	2016-2	33,300	4,377	0	0
2017-2	2017-1	0	0	533,748	135,803
2018-1	2017-2	27,435	4,083	0	0
2018-2	2018-1	0	0	644,242	147,018
2019-1	2018-2	24,561	3,595	0	0
2019-2	2019-1	0	0	580,925	683,231
2020-1	2019-2	20,623	3,924	0	0
2020-2	2020-1	0	0	0	0
2021-1	2020-2	16,768	11,190	0	0

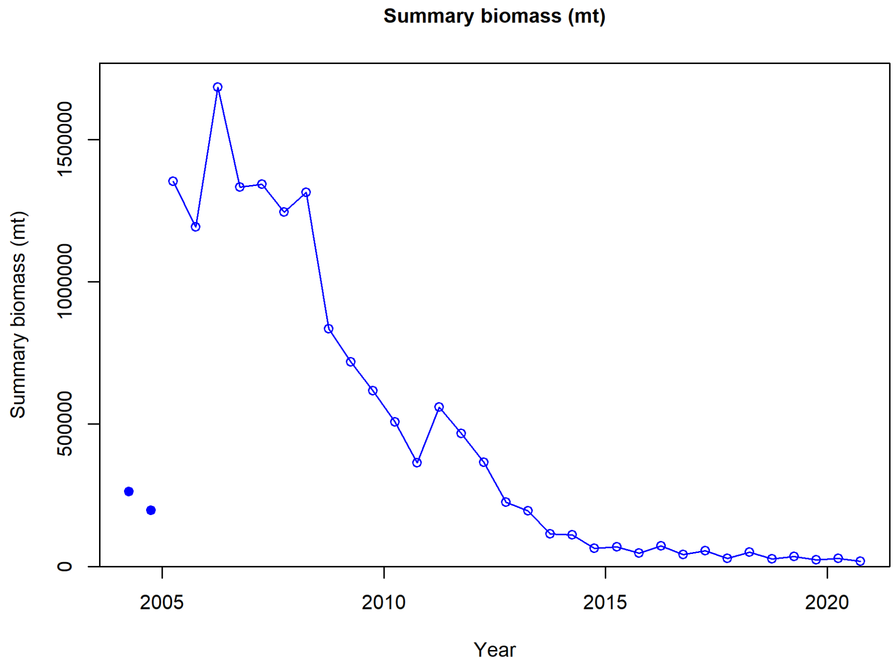

Figure ES-3: Estimated stock biomass (age 1+ fish; mt) time series for 2020 base model.

Stock Biomass for PFMC Management in 2020-21

Stock biomass, used for calculating annual harvest specifications, is defined as the sum of the biomass for sardine ages one and older (age 1+, mt) at the start of the management year. Time series of estimated stock biomass from the 2020 base model are presented in Figure ES-3. As discussed above for both SSB and recruitment, a similar trend of declining stock biomass has been observed since 2005-06. The 2020 base model stock biomass is projected to be 28,276 mt in July 2020.

Exploitation Status

Exploitation rate is defined as the calendar year NSP catch divided by the total mid-year biomass (July-1, ages 0+). Based on 2020 base model estimates, the U.S. exploitation rate has averaged about 9% since 2005, peaking at 31% in 2013. The total exploitation rates were 23% in 2019, largely driven by catches from Mexico. Exploitation rates for the NSP, calculated from the 2020 base model, are presented in Figure ES-4 and Table ES-3.

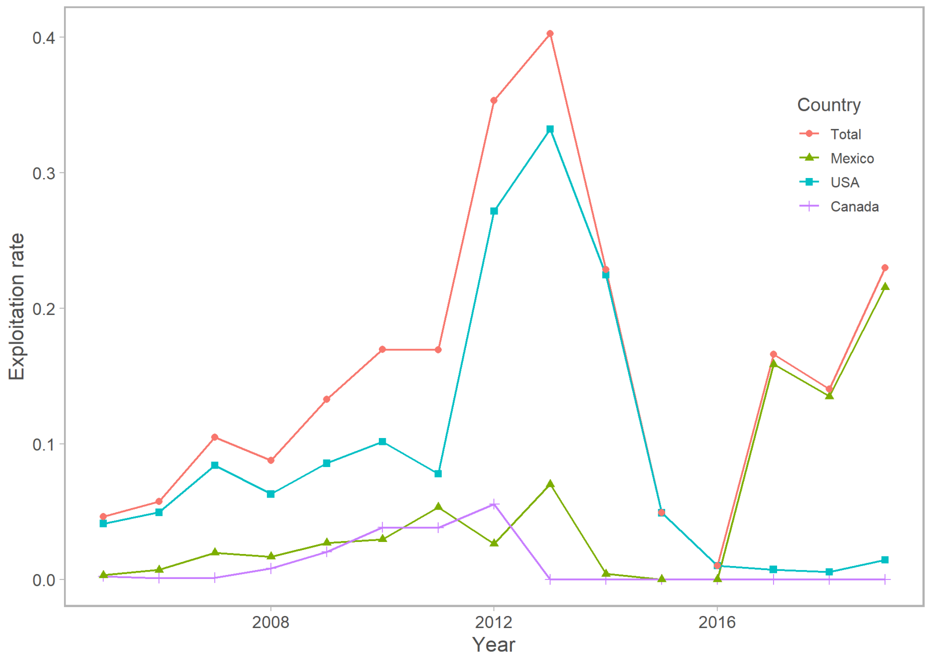

Figure ES-4: Annual exploitation rates (calendar year landings / July total biomass) for 2020 base model.

Table ES-3: Annual exploitation rate (calendar year landings / July total biomass) by country.

Calendar Year	Mexico	USA	Canada	Total
2005	0.00	0.04	0.00	0.05
2006	0.01	0.05	0.00	0.06
2007	0.02	0.08	0.00	0.10
2008	0.02	0.06	0.01	0.09
2009	0.03	0.09	0.02	0.13
2010	0.03	0.10	0.04	0.17
2011	0.05	0.08	0.04	0.17
2012	0.03	0.27	0.06	0.35
2013	0.07	0.33	0.00	0.40
2014	0.00	0.22	0.00	0.23
2015	0.00	0.05	0.00	0.05
2016	0.00	0.01	0.00	0.01
2017	0.16	0.01	0.00	0.17
2018	0.13	0.01	0.00	0.14
2019	0.22	0.01	0.00	0.23

Ecosystem Considerations

Pacific sardine represent an important forage base in the California Current Ecosystem (CCE). At times of high abundance, Pacific sardine can compose a substantial portion of biomass in the CCE. However, periods of low recruitment success driven by prevailing oceanographic conditions can lead to low population abundance over extended periods of time. Readers should consult PFMC (1998), PFMC (2017), and NMFS (2019, *Supplementary materials to the California Current integrated ecosystem assessment (CCIEA) California Current ecosystem status report* 2019) for comprehensive information regarding environmental processes generally hypothesized to influence small pelagic species that inhabit the CCE.

Harvest Control Rules

Evaluation of Scientific Uncertainty

Scientific uncertainty in the base model is based on asymptotic standard errors associated with SSB estimates from the 2020 base model. Base model SSB was projected to be 16,769 mt (SD=11,190 mt; CV=0.607) in January 2021, so the corresponding σ for calculating P-star buffers is 0.607, rather than the newly adopted default value (0.50) for Tier 1 assessments.

Harvest Guideline

The annual harvest guideline (HG) is calculated as follows:

$HG = (BIOMASS - CUTOFF) * FRACTION * DISTRIBUTION;$

where HG is the total U.S. directed harvest for the period July 1, 2020 to June 30, 2021, BIOMASS is the stock biomass (ages 1+, mt) projected as of July 1, 2020, CUTOFF (150,000 mt) is the lowest level of biomass for which directed harvest is allowed, FRACTION (EMSY bounded 0.05-0.20) is the percentage of biomass above the CUTOFF that can be harvested, and DISTRIBUTION (87%) is the average portion of BIOMASS assumed in U.S. waters. The base model estimated stock biomass is projected to be below the 150,000 mt threshold, so the HG for 2020-21 would be 0 mt.

OFL and ABC

On March 11, 2014, the PFMC adopted the use of CalCOFI sea-surface temperature (SST) data for specifying environmentally-dependent E_{msy} each year. The E_{msy} is calculated as,

$E_{msy} = -18.46452 + 3.25209(T) - 0.19723(T^2) + 0.0041863(T^3),$

where T is the three-year running average of CalCOFI SST (Table 23), and E_{msy} for OFL and ABC is bounded between 0 to 0.25. Based on recent conditions in the CCE, the average temperature for 2017-19 was 15.9965 °C, resulting in E_{msy}=0.22458.

Estimated stock biomass in July 2020 from the 2020 base model was 28,276 mt. The overfishing limit (OFL, 2019-2020) associated with that biomass was 5,525 mt. Acceptable biological catches (ABC, 2020-2021) for a range of P-star values (Tier 1 σ=0.607; Tier 2 σ=1.0) associated with the base model are presented in the table below.

Harvest Control Rule Formulas									
OFL = BIOMASS * E_{MSY} * DISTRIBUTION; where E_{MSY} is bounded 0.00 to 0.25									
$ABC_{P\text{-}star}$ = BIOMASS * $BUFFER_{P\text{-}star}$ * E_{MSY} * DISTRIBUTION; where E_{MSY} is bounded 0.00 to 0.25									
HG = (BIOMASS - CUTOFF) * FRACTION * DISTRIBUTION; where FRACTION is E_{MSY} bounded 0.05 to 0.20									
Harvest Formula Parameters									
BIOMASS (ages 1+, mt)	**28,276**								
P-star	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05
ABC $Buffer_{(Sigma\ 0.607)}$	0.92657	0.85748	0.79148	0.72742	0.66408	0.60003	0.53312	0.45943	0.36852
ABC $Buffer_{Tier\ 2}$	0.88191	0.77620	0.68023	0.59191	0.50942	0.43101	0.35472	0.27761	0.19304
CalCOFI SST (2016-2018)	15.9965								
E_{MSY}	0.224584								
FRACTION	0.200000								
CUTOFF (mt)	150,000								
DISTRIBUTION (U.S.)	0.87								
Harvest Control Rule Values (MT)									
OFL =	**5,525**								
$ABC_{(Sigma\ 0.607)}$ =	5,119	4,737	4,373	4,019	3,669	3,315	2,945	2,538	2,036
$ABC_{Tier\ 2}$ =	4,872	4,288	3,758	3,270	2,814	2,381	1,960	1,534	1,067
HG =	**0**								

Management Performance

The U.S. HG/ACL values and catches since the onset of federal management are presented in Figure ES-5.

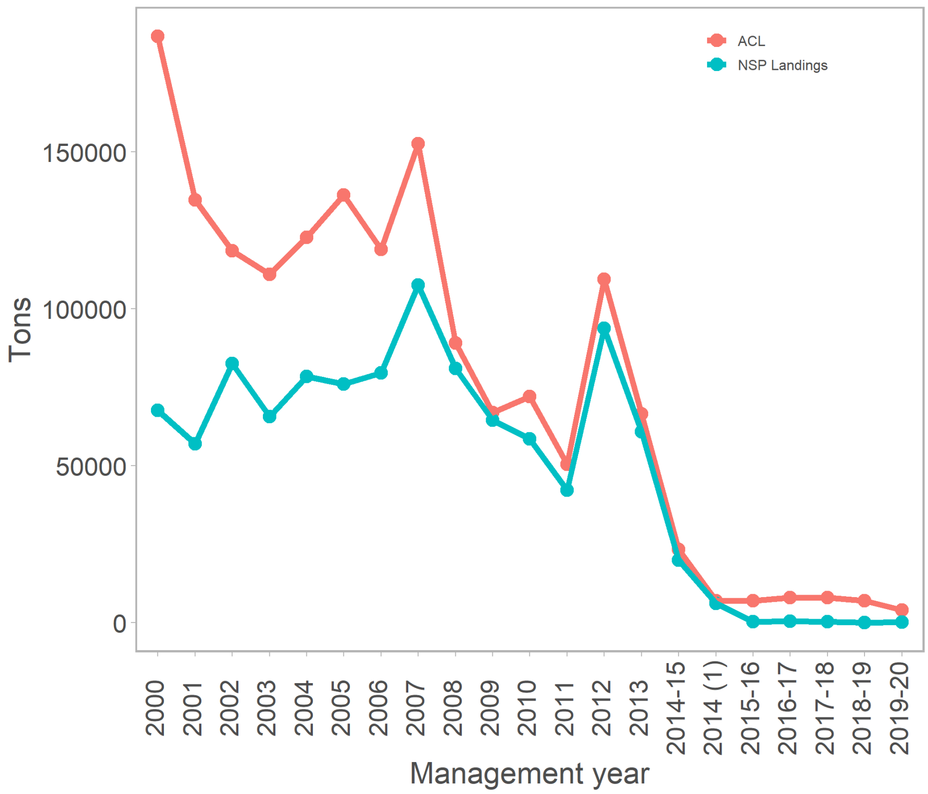

Figure ES-5: U.S. HG and ACL values and catches.

Unresolved Problems and Major Uncertainties

Two notable sources of uncertainty in this assessment are estimates of nearshore biomass and values of recent Mexican catches.

Nearshore biomass, particularly the area outside of the ongoing AT survey footprint, is a major uncertainty. The 2020 summer AT survey will make strides towards increasing nearshore coverage using acoustics in collaboration with the fishing industry.

The CCPSS aerial survey was designed to measure nearshore biomass outside of the AT survey footprint. The biomass estimate in 2019 was used to inform catchability from 2015-2019 in the 2020 base model. There are a number of research needs related to improvement of the CCPSS survey, particularly coordination of visual estimates with randomly sampled purse-seine point sets, temporal rather than spatial replication, and sufficient biological sampling on mixed anchvoy and sardine schools. Further details are included in the STAR panel report.

The assumed Mexican catches (MexCal fleet) in model year-semester 2019-2 were assumed to be the same as values from 2018-2. This assumption results in a relatively high exploitation rate which affects the trend in stock biomass and forecast biomass. The impact of this assumption is an area of future research.

Research and Data Needs

Research and data for improving stock assessments of the Pacific sardine resource in the future address areas of need that are primarily for data inputs, including nearshore biomass estimates, AT survey operations, and laboratory-based biology studies. See the research recommendations from the STAR panel report for more details.

1 Introduction

1.1 Distribution, Migration, Stock Structure, Management Units

Information regarding Pacific sardine (*Sardinops sagax*) biology and population dynamics is available in (Clark and Marr 1955, Ahlstrom 1960, Murphy 1966, MacCall 1979, Leet et al. 2001), as well as references cited below.

The Pacific sardine has at times been the most abundant fish species in the California Current Ecosystem (CCE). When the population is large, it is abundant from the tip of Baja California (23°N latitude) to southeastern Alaska (57°N latitude) and throughout the Gulf of California. Occurrence tends to be seasonal in the northern extent of its range. When abundance was low during the 1960-70s, sardines did not generally occur in significant quantities north of Baja California.

There is a longstanding consensus in the scientific community that sardines off the west coast of North America represent three subpopulations (see review by Smith 2005). A northern subpopulation ('NSP'; northern Baja California to Alaska; Figure 1), a southern subpopulation ('SSP'; outer coastal Baja California to southern California), and a Gulf of California subpopulation were distinguished on the basis of serological techniques (Vrooman 1964) and in studies of oceanography as pertaining to temperature-at-capture (Felix-Uraga et al. 2004, 2005, Garcia-Morales et al. 2012, Demer and Zwolinski 2014). An electrophoretic study (Hedgecock et al. 1989) showed, however, no genetic variation among sardines from central and southern California, the Pacific coast of Baja California, or the Gulf of California. Although the ranges of the northern and southern subpopulations can overlap within the Southern California Bight, the adult spawning stocks likely move north and south in synchrony and do not occupy the same space simultaneously to a significant extent (Garcia-Morales et al. 2012). The NSP is exploited by fisheries off Canada, the U.S., and northern Baja California 1, and represents the stock included in the CPS Fishery Management Plan (CPS-FMP; PFMC 1998). The 2014 assessment (Hill et al. 2014) addressed the above stock structure hypotheses in a more explicit manner, by partitioning southern (Ensenada and Southern California ports) fishery catches and composition data using an environment-based approach described by Demer and Zwolinski (2014) and in the following sections. The same subpopulation hypothesis is carried forward in the following assessment.

Pacific sardine migrate extensively when abundance is high, moving as far north as British Columbia in the summer and returning to southern California and northern Baja California in the fall. Early tagging studies indicated that the older and larger fish moved farther north (Jr. 1938, Clark and Jr. 1945). Movement patterns were probably complex, and the timing and extent of movement were affected by oceanographic conditions (Hart 1973) and stock biomass levels. During the 1950s to 1970s, a period of reduced stock size and unfavorably cold sea-surface temperatures together likely caused the stock to abandon the northern portion of its range. In recent decades, the combination of increased stock size and warmer sea-surface temperatures resulted in the stock re-occupying areas off Central California, Oregon, Washington, and British Columbia, as well as distant offshore waters off California. During a cooperative U.S.-U.S.S.R. research cruise for jack mackerel in 1991, several tons of sardine were collected 300 nm west of the Southern California Bight (SCB) (Macewicz and Abramenkoff 1993). Resumption of seasonal movement between the southern spawning habitat and the northern feeding habitat has been inferred by presence/absence of size classes in focused regional surveys (Lo et al. 2011) and measured directly using the acoustic-trawl method (Demer et al. 2012).

1.2 Life History Features Affecting Management

Pacific sardine may reach 41 cm in length (Eschmeyer et al. 1983), but are seldom longer than 30 cm in fishery catches and survey samples. The heaviest sardine on record weighed 0.323 kg. Oldest recorded age of sardine is 15 years, but fish in California commercial catches are usually younger than five years and fish in the PNW are less than 10 years old. Sardine are typically larger and two to three years older in regions off the Pacific Northwest than observed further south in waters off California. There is evidence for regional variation in size-at-age, with size increasing from south to north and from inshore to offshore (Phillips 1948, Hill 1999). McDaniel et al. (2016) analyzed recent fishery and survey data and found evidence for age-based (as opposed to size-based) movement from inshore to offshore and from south to north.

Historically, sardines fully recruited to the fishery when they were ages three and older (MacCall 1979). Recent fishery data indicate that sardines begin to recruit to the SCA fishery at age zero during the late winter-early spring. Age-dependent availability to the fishery depends upon the location of the fishery, with young fish unlikely to be fully available to fisheries located in the north and older fish less likely to be fully available to fisheries south of Point Conception.

Sardines spawn in loosely aggregated schools in the upper 50 meters of the water column. Sardines are oviparous, multiple-batch spawners, with annual fecundity that is indeterminate, and age- or size-dependent (Macewicz et al. 1996). Spawning of the northern subpopulation typically begins in January off northern Baja California and ends by August off the Pacific Northwest (Oregon, Washington, and Vancouver Island), typically peaking off California in April. Sardine eggs are most abundant at sea-surface temperatures of 13 to 15 °C, and larvae are most abundant at 13 to 16 °C. The spatial and seasonal distribution of spawning is influenced by temperature. During warm ocean conditions, the center of sardine spawning shifts northward and spawning extends over a longer period of time (Ahlstrom 1960, Butler 1987, Dorval et al. 2013, 2016). Spawning is typically concentrated in the region offshore and north of Point Conception (Lo et al. 1996, 2005) to areas off San Francisco. However, during April 2015 and 2016 spawning was observed in areas north of Cape Mendocino to central Oregon (Dorval et al. 2013, 2016).

1.3 Ecosystem Considerations

Pacific sardine represent an important forage base in the California Current Ecosystem (CCE). At times of high abundance, Pacific sardine can compose a substantial portion of biomass in the CCE. However, periods of low recruitment success driven by prevailing oceanographic conditions can lead to low population abundance over extended periods of time. Readers should consult PFMC (1998), PFMC (2017), and NMFS (2019, *Supplementary materials to the California Current integrated ecosystem assessment (CCIEA) California Current ecosystem status report* 2019) for comprehensive information regarding environmental processes generally hypothesized to influence small pelagic species that inhabit the CCE.

1.4 Abundance, Recruitment, and Population Dynamics

Extreme natural variability is characteristic of clupeid stocks, such as Pacific sardine (Cushing 1971). Estimates of sardine abundance from as early as 300 AD through 1970 have been reconstructed from the deposition of fish scales in sediment cores from the Santa Barbara basin off SCA (Soutar and Isaacs 1969, 1974, Baumgartner et al. 1992, McClatchie et al. 2017). Sardine populations existed throughout the period, with abundance varying widely on decadal time scales. Both sardine and anchovy populations tend to vary over periods of roughly 60 years, although sardines have varied more than anchovies. Declines in sardine populations have generally lasted an average of 36 years and recoveries an average of 30 years.

Pacific sardine spawning biomass (age 2+), estimated from virtual population analysis methods, averaged 3.5 mmt from 1932 through 1934, fluctuated from 1.2 to 2.8 mmt over the next ten years, then declined steeply from 1945 to 1965, with some short-term reversals following periods of strong recruitment success (Murphy 1966, MacCall 1979). During the 1960s and 1970s, spawning biomass levels were as low as 10,000 mt (Barnes et al. 1992). The sardine stock began to increase by an average annual rate of 27% in the early 1980s (Barnes et al. 1992).

As exhibited by many members of the small pelagic fish assemblage of the CCE, Pacific sardine recruitment is highly variable, with large fluctuations observed over short timeframes. Analyses of the sardine stock-recruitment relationship have resulted in inconsistent findings, with some studies showing a strong density-dependent relationship (production of young sardine declines at high levels of spawning biomass) and others, concluding no relationship (Clark and Marr 1955, Murphy 1966, MacCall 1979). Jacobson and Maccall (1995) found both density-dependent and environmental factors to be important, as was also agreed during a sardine harvest control rule workshop held in 2013 (Council 2013).

1.5 Relevant History of the Fishery and Important Features of the Current Fishery

The sardine fishery was first developed in response to demand for food during World War I. Landings increased rapidly from 1916 to 1936, peaking at over 700,000 mt. Pacific sardine supported the largest fishery in the western hemisphere during the 1930s and 1940s, with landings in Mexico to Canada. The population and fishery soon declined, beginning in the late 1940s and with some short-term reversals, to extremely low levels in the 1970s. There was a southward shift in catch as the fishery collapsed, with landings ceasing in the Pacific Northwest in 1947 through 1948 and in San Francisco, from 1951 through 1952. The San Pedro fishery closed in the mid-1960s. Sardines were primarily reduced to fish meal, oil, and canned food, with small quantities used for bait.

In the early 1980s, sardines were taken incidentally with Pacific and jack mackerel in the SCA mackerel fishery. As sardine continued to increase in abundance, a directed purse-seine fishery was re-established. The incidental fishery for sardines ceased in 1991 when the directed fishery was offered higher quotas. The renewed fishery initiated in Ensenada and Southern California, expanded to Central California, and by the early 2000s, substantial quantities of Pacific sardine were landed at OR, WA, and BC. Volumes have reduced dramatically in the past several years. Harvest by the Mexican (Ensenada) fishery is not currently regulated by quotas, but there is a minimum legal size limit of 150 mm SL. The Canadian fishery failed to capture sardine in summer 2013, and has been under a moratorium since summer 2015. The U.S. directed fishery has been subject to a moratorium since July 1, 2015.

1.6 Recent Management Performance

Management authority for the U.S. Pacific sardine fishery was transferred to the PFMC in January 2000. The Pacific sardine was one of five species included in the federal CPS-FMP (PFMC 1998). The CPS-FMP includes harvest control rules intended to prevent Pacific sardines from being overfished and to maintain relatively high and consistent, long-term catch levels. Harvest control rules for Pacific sardine are described at the end of this report. A thorough description of PFMC management actions for sardines, including HG values, may be found in the most recent CPS SAFE document (PFMC 2017). U.S. harvest specifications and landings since 2000 are displayed in Table 1. Harvests in major fishing regions from ENS to BC are provided in Table 2 and Figure 2.

2 Data

Data used in the Pacific sardine assessments are summarized in Figure 3. The data that were added or reprocessed for this assessment are:

1. Fishery catches (MexCal updated through 2019, separated based on vessel monitoring system data from Ensenada)
2. Acoustic-trawl age compositions (re-aged fish 2017-2018; added 2019; Figure 4)
3. Acoustic-trawl index of abundance (2012-2018 re-calculated based on updated target strength; added 2019)
4. Acoustic-trawl weight-at-age values and age compositions recalculated with annual age-length keys from 2012-2019. This was done for summer AT values only
5. Spring acoustic-trawl age compositions were dropped from the 2020 base model.

2.1 Fishery-Dependent Data

Available fishery data include commercial landings and biological samples from six regional fisheries: Ensenada (ENS); Southern California (SCA); Central California (CCA); Oregon (OR); Washington (WA); and British Columbia (BC). Standard biological samples include individual weight (kg), standard length (cm), sex, maturity, and otoliths for age determination (not in all cases). A complete list of available port sample data by fishing region, model year, and season is provided in (Table 3).

All fishery catches and compositions were compiled based on the sardine's biological year ('model year') to match the July 1st birth-date assumption used in age assignments (Table 2). Each model year is labeled with the first of two calendar years spanned (e.g., model year '2005' includes data from July 1, 2005 through June 30, 2006). Further, each model year has two six-month seasons, including 'S1'=Jul-Dec and 'S2'=Jan-Jun. Major fishery regions were pooled to represent a southern 'MexCal' fleet (ENS+SCA+CCA) and a northern 'PNW' fleet (OR+WA+BC). The MexCal fleet was treated with semester-based selectivities ('MexCal_S1' and 'MexCal_S2'). Rationale for this fleet design is provided in (Hill et al. 2011).

2.1.1 Landings

Final Ensenada monthly landings from 2003-2017 were taken from CONAPESCA's web archive of Mexican fishery yearbook statistics (CONAPESCA 2017). Monthly landings for 2018 and 2019 were provided by INAPESCA (Concepción Enciso-Enciso, pers. comm.). Recently (2017-2019), the Ensenada fleet has shifted a portion of effort to catch sardine much farther south of it's customary fishing grounds. Therefore, recent Ensenada NSP landings were filtered with VMS data to exclude sardine caught south of the southern boundary of the habitat model (31°N) (Concepción Enciso-Enciso, pers. comm.).

California (SCA and CCA) commercial landings were obtained from the PacFIN database (2005-2019) and CDFW's 'Wetfish Tables' (2019). Given California's live bait industry is currently the only active sector in the U.S. sardine fishery, live bait landings were also included in this assessment. California live bait landings through 2018 are recorded on 'Live Bait Logbooks' provided to the CDFW on a voluntary basis. For logs through 2015, the CDFW compiles estimates of catch weight based on a conversion of scoop number to lbs (Kirk Lynn, CDFW, pers. comm.). Since 2016, all live bait catch has been reported in lbs. Beginning in 2019, all California live bait catch has been recorded on mandatory electronic fish tickets. Monthly live bait landings were pooled with other commercial catches in the MexCal fleet.

Oregon (OR) and Washington (WA) landings (2005-2019) were obtained from PacFIN. British Columbia (BC) monthly landing statistics (2005-2012) were provided by Fisheries and Oceans Canada (Linnea Flostrand and Jordan Mah, pers. comm.). Sardine were not landed in Canada during 2013-2019. The BC landings were pooled with OR and WA as part of the PNW fleet.

Available information concerning bycatch and discard mortality of Pacific sardine, as well as other members of the small pelagic fish assemblage of the California Current Ecosystem, is presented in NMFS (2019). Limited information from observer programs implemented in the past indicated minimal discard of Pacific sardine in the commercial purse seine fishery that targets the small pelagic fish assemblage off the USA Pacific coast.

The NSP landings by model year-season for each fishing region (ENS and SCA) are presented in Table 2 and Figure 2. The current Stock Synthesis model aggregates regional fisheries into a southern 'MexCal' fleet (separated in to two semesters, S1 and S2) and a northern 'PNW' fleet (Figure 1). Landings aggregated by model year-season and the three fleets are presented in Table 4 and Figure 5. Landings data for all fisheries are complete through December 2019 (model time step 2019-1). Landings for the model time step 2019-2 were assumed identical to those from 2018-2, and landings for the forecast were assumed equal to 2019-1 and 2019-2.

2.1.2 Empirical weight-at-age

Described below in the biological parameters section (2.4.2).

2.1.3 Age compositions

Age compositions for each fleet and season were the sums of catch-weighted age observations, with monthly landings (number of fish) within each port and season serving as the weighting unit. As indicated above, environmental criteria used to assign landings to subpopulations were also applied to monthly port samples to categorize NSP-based biological compositions. The following steps were used to develop the weighted age-composition time series:

1. Identified an 'age-plus' group (8+) for combining fish into a single group.

2. Determined the number of individuals measured for each year, semester, 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. Averaged monthly weight-at-age estimates and multiplied by the number of specimens measured. Age-group proportions were these values divided by total monthly catch weight.

5. Multiplied age-group proportions by the total monthly catch to produce the total weight (mt) of each age group in the fishery catch per month.

6. Calculated number of fish per age group by month by taking result of step 5 and dividing by the average monthly weight of each age group calculated in step 3.

7. Aggregated monthly calculations of numbers of fish to fishing semesters to produce the numbers of fish-at-age per fishing semester and subsequentlysummed across ages to produce the total number of fish landed per fishing semester.

8. Divided the result in step 7 by the total number of fish per year produced in the final weighted age-composition time series (in proportion) for each fishing year.

Total numbers for ages observed in each fleet-semester stratum were divided by the typical number of fish collected per sampled load (25 fish per sample) to set the sample sizes for compositions included in the assessment model. Semesters with fewer than three samples were excluded from the model. Age compositions were input as proportions. Age-composition time series are presented in Figures 6-8.

Oregon and Washington fishery ages from season 2 (S2, Jan-Jun), were omitted from all models due to inter-laboratory inconsistencies in the application of birth-date criteria during this semester (noting that OR and WA landings and associated samples during S2 are typically trivial). Age data were not available for the BC or ENS fisheries, so PNW and MexCal fleet compositions only represent catch-at-age by the OR-WA and CA fisheries, respectively.

While no directed fishery samples have been available since July 2015, CDFW has continued limited sampling of sardine taken incidental to other CPS finfish, e.g. northern anchovy in Monterey Bay. These few samples represent a relative small portion of incidental removals, e.g. 35-250 mt per semester. While these age composition data have not been included in the current base model, the STAT would be prepared to explore utility in the ongoing asessment if made avilable in the future.

2.1.4 Ageing error

Sardine ageing using otolith methods was first described by Walford and Mosher (1943) and extended by Yaremko (1996). Pacific sardines are routinely aged by fishery biologists in CDFW, WDFW, and SWFSC using annuli enumerated in whole sagittae. A birth date of July 1st is assumed when assigning ages.

Ageing-error vectors for fishery data were unchanged from the most recent assessment Hill et al. (2011)-(2017). Ageing error vectors (SD at true age) were linked to fishery-specific age-composition data (Figure 9). For complete details regarding age-reading data sets, model development and assumptions, see Appendix 2 in Hill et al. (2011), as well as Dorval et al. (2013).

2.2 Fishery-Independent Data: Acoustic-Trawl Survey

This assessment uses a single time series of biomass based on the SWFSC's AT survey. This survey and estimation methods were vetted through formal methodology review processes in February 2011 and January 2018 (PFMC 2011, Simmonds 2011, Council 2018).

2.2.1 Empirical weight-at-age

Described below in the biological parameters section (2.4.2).

2.2.2 Index of abundance

Revised 2012-2018 summer time-series biomass estimates

In the 2018 assessment of Pacific sardine, the estimate of sardine biomass during summer 2017 was 36,644 t (CV = 30.1%), based on an analysis of acoustic-trawl sampling. This estimate was derived using nautical area scattering coefficients (NASC) from putative coastal pelagic fishes (CPS) integrated from 10-350 m depth. By extending beyond the typical depth-range of the CPS, these vertically integrated values included backscatter from non-CPS species with swimbladders, e.g., rockfishes and hake. After replacing CPS-NASC-250 with data from only the region where CPS were indicated by echo spectra, school morphology, and potential oceanographic habitat, i.e. typically the upper mixed layer, the estimate of sardine biomass during summer 2017 was revised to 24,349 mt (CI95%=10,531 to 45,855 mt, CV = 37%) to be used in the 2018 assessment update. However, the final analysis of the 2017 summer survey, as well as those from subsequent surveys, were computed applying a new TS to length model for Pacific Herring (Zwolinski et al. 2019). The current TS model replaced the earlier

TS model which had been adopted from Pacific Sardine, by a model based on Pacific Herring measurements. Because the proportion of the integrated backscatter attributed to a given CPS species is a function of all species found in the corresponding cluster eq. 14 in (Zwolinski et al. 2019), modifications to a TS model of one of the species will change the acoustic proportion of the remaining ones. In 2017, there were a few influential trawls clusters with both sardine and herring. Upon updating the biomass with the new TS model for herring, the final estimate of Pacific sardine in 2017 was revised to 14,103 mt (CI95%=7,337 to 22,981 mt, CV = 30%, Table 5). To maximize consistency across the time-series, all summer surveys between 2012 and 2018 were re-analyzed with the new herring TS (Table 6).

2019 summer biomass estimate

The summer 2019 survey totaled 5,122 nmi of 106 daytime east-west acoustic transects and 167 night-time surface trawls combined into 64 trawl clusters. Post-cruise strata were defined, considering transect spacing and biomass density (Table 5; Figures 10 and 11).Continuous Underway Fish Egg Sampler data and catch were used to make decisions about adaptive sampling during the survey. Complete survey results are in Stierhoff et al. (2020a, 2020b).

At the time of the beginning of the summer survey, the sardine potential habitat extended beyond the north of Vancouver Island. Nonetheless, despite the availability of suitable habitat, sardine were found south of Vancouver Island. The stock was dispersed off the west coast of the US, and usually in small densities (Figure 11). The entire survey area included an estimated 33,138 mt of NSP Pacific sardine (CI95%= 21,653 to 46,051 mt, CV=21%, Table 5). The distribution of abundance-at-length was bi-modal (Tables 7 and 8). See Figure 12 for a time series of AT survey indices.

Nearshore sampling

To estimate CPS biomass nearshore, where it is too shallow to navigate NOAA ships safely, sampling from Lasker was augmented with echosounder and purse-seine sampling from two fishing vessels, and echosounder sampling from an unmanned surface vehicle (USV; Stierhoff et al. 2020). The coasts of WA and OR were surveyed by F/V *Lisa Marie*; the coasts of WA, OR, and CA (north of Pt. Conception) were surveyed by a USV; and the coasts of the Southern CA Bight (SCB), and Santa Cruz and Santa Catalina Islands were surveyed by F/V *Long Beach Carnage*. The biomass of Pacific sardine estimated to be nearshore (494 mt) amounted to ≈ 1.5% of the estimated total of 33,138 mt (Stierhoff et al. 2020b). Note, that the nearshore estimates represent observations, and there were no model-based extrapolations into areas not covered by F/V or USV sampling. For more details on nearshore sampling please refer to Stierhoff et al. (2020b).

2.2.3 Age compositions

Estimates of abundance-at-length were converted to abundance-at-age using survey-specific age-length keys for the summer (Figure 13). Spring survey values used a data-pooled age-length key. Age-length keys were constructed using ordinal generalized additive regression models from the R package mgcv (Wood 2017). More details are in Section 11. A generalized additive model with an ordinal categorical distribution fits an ordered logistic regression model in which the linear predictor provides the expected value of a latent variable following sequentially ordered logistic distributions. Unlike previous iterations in which the conditional age-at-length was modeled as a multinomial response function 'multinom' from the R package 'nnet', and hence, disregarding the order of the age classes, the order logistical framework provides a more strict structure for the conditional age-at-length, which might, arguably, be beneficial with small sample sizes.

2.2.4 Ageing error

There were two ageing error vectors for age data from 2005-2016 and 2017-2018. The standard deviations for 2017-2018 data were applied to survey age-composition time series from 2017-2019 (Figure 9).

2.3 Fishery-Independent Data: Aerial Survey

California Department of Fish and Wildlife has conducted an aerial survey off the coast of Central California. Aerial surveys were conducted on August 3, 4, and 10 in 2017 and August 6, 7, and 8 in 2019. Biomass estimates were 21,046 mt in 2017 and 12,279 mt in 2019. Length compositions were observed via point sets on August 14 and 28 in 2017 and August 13, 14, 21 and September 12 in 2019. Relating the aerial survey estimates to the length compositions was difficult due to the temporal and spatial mismatches, i.e. the point sets represent a small fraction of the overall aerial footprint. There was insufficient biological sampling to relate length compositions to age compositions for explicit integration into the 2020 base model. The aerial survey estimates of abundance were used to inform the catchability coefficient from 2015-2019 in the 2020 base model. Additional details in 3.5.8 and in Lynn et al. (2020).

2.4 Biological Parameters

2.4.1 Stock structure

We presume to model the northern sub-population of Pacific sardine (NSP) that, at times, ranges from northern Baja California, México to British Columbia, Canada. As mentioned above, there is general consensus that catches landed in ENS and SCA likely represent a mixture of SSP (during warm months) and NSP (cool months) (Felix-Uraga et al. 2004, 2005, Zwolinski et al. 2011, Garcia-Morales et al. 2012, Demer and Zwolinski 2014) (Figure 1). The approach involves analyzing satellite oceanographic data to objectively partition monthly catches and biological compositions from ENS and SCA ports to exclude data from the SSP (Demer and Zwolinski 2014). This approach was first adopted in the 2014 full assessment (Hill et al. 2014, STAR 2014) and has carried forward each year, including this assessment.

2.4.2 Growth

Previous analysis of size-at-age from fishery samples (1993-2013) provided no indication of sexual dimorphism related to growth (Figure 14; Hill et al. 2014), so combined sexes were included in the present assessment model with a sex ratio of 50:50.

Past Pacific sardine stock assessments conducted with the CANSAR and ASAP statistical catch-at-age models accounted for growth using empirical weight-at-age time series as fixed model inputs (e.g., Hill et al. 2006a, 2009). Stock synthesis models used for management from 2007 through 2016 estimated growth internally using conditional age-at-length compositions and a fixed length-weight relationship (e.g., Hill et al. 2016). Disadvantages to estimating growth internally within the stock assessment include: 1) inability to account for regional differences in age-at-size due to age-based movements (McDaniel et al. 2016); 2) difficulty in modeling cohort-specific growth patterns; 3) potential model interactions between growth estimation and selectivity; and 4) models using conditional age-at-length data require more estimable model parameters than the empirical weight-at-age approach. For these reasons, the base model was constructed to bypass growth estimation internally in SS, instead opting for use of empirical weight-at-age time series.

Fishery-dependent weight-at-age

Fishery mean weight-at-age estimates were calculated for seasons with more than two samples. Growth patterns were examined by cohort and smoothed as needed. Specifically, fish of the same cohort were not allowed to shrink unrealistically in subsequent time steps, and negative deviations were substituted by interpolation. Likewise, missing values were substituted through interpolation. Fishery-dependent weight-at-age vectors are displayed by cohorts in (Figures 15 and 16).

Fishery-independent weight-at-age

AT survey weight-at-age time series (Figure 17) were calculated for every survey using the following process: 1) the AT-derived abundance-at-length was converted to biomass-at-length using a time-invariant length-to-weight relationship; 2) the biomass- and numbers-at-length were converted to biomass-at-age and numbers-at-age, respectively, using the above-mentioned age-length keys; and 3) mean weights-at-age were calculated by dividing biomass-at-age by the respective numbers-at-age. Missing values were substituted through interpolation. In some cases, fish of the same cohort were allowed to shrink (albeit in relatively small increments) in subsequent time steps. The few cases of shrinking fish were likely due to small sample sizes at older ages (>5).

Empirical weight-at-age data were included as fixed inputs in the 2020 base model. Empirical weight-at-age models require population weight-at-age vectors to convert population number-at-age to biomass-at-age. The 2017 benchmark assessment (Hill et al. 2017) used population weight-at-age vectors that were derived from growth parameter estimates for the beginning and middle of each semester. For the 2020 benchmark assessment, the weight-at-age vectors derived from growth estimates were replaced with empirical weight-at-age values from the AT survey. Beginning and middle semester values are identical, and the assumption here is that there is no within semester variability in weight-at-age values. This change in the 2020 benchmark assessment prioritizes recent empirical values over time-invariant estimates of growth.

2.4.3 Maturity

Maturity was modeled using a fixed vector of fecundity × maturity by age. The vector was derived from the 2016 assessment model after it was updated with newly available information (Hill et al. 2017). In addition to other data sources, this model was updated with new parameters for the logistic maturity-at-length function using female sardine sampled from survey trawls conducted from 1994 to 2016 (n=4,561 Hill et al. 2017). Reproductive state was primarily established through histological examination, although some immature individuals were simply identified through gross visual inspection. Parameters for the logistic maturity function were estimated as follows:

$$Maturity = \frac{1}{1 + exp(slope * L - L_{inflection})}$$

where slope = -0.9051 and $L_{inflection}$ = 16.06 cm-SL. Maturity-at-length parameters were fixed in the updated assessment model (T_2017) and fecundity was fixed at 1 egg/gram body weight. The fecundity × maturity-at-age vector was extracted and used in the 2020 base model.

2.4.4 Natural mortality

A prior for natural mortality (M) was derived with a meta-analysis using methods described in Then et al. (2015) and Hamel (2015). Pacific sardine had an assumed maximum age of 10 and six estimates of von Bertlanffy k (Table 9) from previous assessments (Conser et al. 2004, Hill et al. 2007, 2008, 2011, 2012, 2014). The resulting prior was modeled using a lognormal distribution with a mean=-0.59 and sd=0.39 (Figure 18).

The prior on M is generally consistent with values (either fixed or estimated) in previous assessments and studies. The adult natural mortality rate has been estimated to be M=0.4-0.8 yr^{-1} (Murphy 1966, MacCall 1979) and 0.51 yr^{-1} (Clark and Marr 1955). Murphy's (1966) virtual population analysis of the Pacific sardine used M=0.4 yr^{-1} to fit data from the 1930s and 1940s, but M was doubled to 0.8 yr^{-1} from 1950 to 1960 to better fit the trend in CalCOFI egg and larval data (Murphy 1966). Zwolinski and Demer (2013) studied natural mortality using trends in abundance from the acoustic-trawl method (AT) surveys (2006-2011), accounting for fishery removals, and estimated M=0.52 yr^{-1}. Age-specific mortality estimates are available for the entire suite of life history stages (Butler et al. 1993). Mortality is high at the egg and yolk sac larvae stages (instantaneous rates in excess of 0.66 d-1). Until 2017, Pacific sardine stock assessments for PFMC management used M=0.4 yr-1. The 2017 benchmark assessment (Hill et al. 2017) used M=0.6 yr^{-1}, which translated to an annual death rate of 45% in adult sardine stock.

2.5 Available Data Sets Not Used in Assessment

Past sardine stock assessments have included a time series of daily egg production method (DEPM) spawning stock biomass (SSB). The time series was included in the assessments as an index of relative female SSB (Q estimated) and has always been considered an underestimate of true SSB (Deriso et al. 1996). The DEPM time series has been described in numerous publications and stock assessment reports. The DEPM time series was excluded from the 2020 benchmark assessment. As indicated in past assessments, exclusion of the DEPM time series continues to have negligible impact on the stock assessment outcome. Nonetheless, DEPM estimates are still considered useful to corroborate/refute results from the AT survey.

3 Assessment

3.1 History of Modeling Approaches

The population's dynamics and status of Pacific sardine prior to the collapse in the mid-1900s was first modeled by Murphy (1966). MacCall (1979) refined Murphy's virtual population analysis (VPA) model using additional data and prorated portions of Mexican landings to exclude the southern subpopulation. Deriso et al. (1996) modeled the recovering population (1982 forward) using CANSAR, a modification of Deriso's (1985) CAGEAN model. The CANSAR was subsequently modified by Jacobson (Hill et al. 1999) into a quasi, two-area model CANSAR-TAM to account for net losses from the core model area. The CANSAR and CANSAR-TAM models were used for annual stock assessments and management advice from 1996 through 2004 (e.g. Hill et al. 1999, Conser et al. 2003). In 2004, a STAR Panel endorsed the use of an Age Structured Assessment Program (ASAP) model for routine assessments. The ASAP model was used for sardine assessment and management advice from 2005 to 2007 (Conser et al. 2003, 2004, Hill et al. 2006b, 2006a). In 2007, a STAR Panel reviewed and endorsed an assessment using Stock Synthesis (SS) 2 (Methot 2005), and the results were adopted for management in 2008 (Hill et al. 2007), as well as an update for 2009 management

(Hill et al. 2008). The sardine model was transitioned to SS version 3.03a in 2009 (Methot 2009) and was again used for an update assessment in 2010 (Hill et al. 2009, 2010). Stock Synthesis version 3.21d was used for the 2011 full assessment (Hill et al. 2011), the 2012 update assessment (Hill et al. 2012). The 2014 sardine full assessment (Hill et al. 2014), 2015 update assessment (Hill et al. 2015), and 2016 update assessment (Hill et al. 2016) were based on SS version 3.24s.

The 2017 full assessment (model ALT; Hill et al. 2017) and the 2018 (Hill et al. 2018) and 2019 (Hill et al. 2019) update assessments were based on SS version 3.24aa. SS version 3.24aa corrected errors associated with empirical weight-at-age models having multiple seasons. These past assessments relied solely on the AT survey to provide an index of abundance and did not incorporate daily egg-production time series. As a result, the modeled timeframe in model ALT was shortened to begin in 2005. The 2005 start date coincides with the first available biomass estimate from the AT survey. Natural mortality was fixed at 0.6 and catchability was freely estimated. AT survey age compositions were derived using pooled, seasonal age-length keys, but survey weight-at-age values were based on survey-specific vectors as described in section 2.2.1 (biomass-at-age divided by numbers-at-age). Selectivity was age-based and estimated with a flexibile selectivity pattern which is based on age-specific estimated selectivity parameters rather than fitting a dome-shaped functional form (e.g. 'double-normal'). See section 3.5.7 for a deeper explanation.

3.2 2017 STAR Panel Recommendations

Below are the recommendations from the STAR panel review of the 2017 benchmark assessment. Responses to comments are below

High Priority

1. Conduct an analysis of effect of fish sample size on the uncertainty in the AT Survey biomass estimates and model outputs. Use this information to re-evaluate and revise the sampling strategy for size and age data that includes target sample sizes for strata.

- This analysis has not been conducted because there is no room for revising the trawl sampling strategy. The current protocol already maximizes the time available for trawl sampling, which comprises typically 3, and occasionally 4 trawls per night when the surveys are conducted on NOAA Fisheries Survey Vessels (FSV). Considering that 2.5 to 3 hour are spent during a single trawl operation, increasing the numbers of trawls per night to more than 3 is virtually impossible. Increasing the trawl duration from 45 minutes to 60 minutes or more will be considered for 2020.

2. The clusters (the Primary Sampling Units, PSUs) with age-length data should be grouped into spatial strata (post-strata, or collapsed post-strata used in AT Survey

biomass estimators). The variance in estimates of age-length compositions can then be estimated by bootstrapping of PSUs, where age-length keys are constructed for each bootstrap replicate. The sub-sample size of fish within clusters that are measured for lengths should be increased, and length-stratified age-sampling should be implemented. This approach would likely increase coverage of age samples per length class and reduce data gaps.

- This recommendation pertains to the traditional analysis of acoustic-trawl survey data on which multiple PSU are combined into strata based on similarity of the targets species lengths. However, this is not the method used on SWFSC AT Surveys that was reviewed favorably in 2018. We agree that evaluating rigorously the number of measured individuals per trawl is necessary and SWFSC will undertake that task with samples collected in 2020.

3. The survey projection method should be developed further. Specifically, the survey age composition should be based on annual age-length keys, and the uncertainty associated with population age-composition, weight-at-age and maturity-at-age needs to be quantified and included in the calculation of CVs. A bootstrappping procedure could be used to quantify the uncertainty associated with population age-composition and projected weight-at-age. Uncertainty in weight-at-age could also be evaluated using a retrospective analysis in which the difference between observed and predicted weight-at-age for past years was calculated. Ultimately, improved estimates of weight-at-age and measures of precision of such estimates could be obtained by fitting a model to the empirical data on weight-at-age.

- This recommendation relates to projections used for AT-based management. Addressing this recommendation cannot be completed until it is decided that an MSE is necessary to explore survey-based management and that MSE is completed.

4. The methods for estimating 1 July age 1+ biomass based on the results of the AT Survey during the previous year currently use only the results of the summer survey. Improved precision is likely if the results from the spring and summer surveys were combined. This may become more important if the number of days for surveying is reduced in future. Consideration should be given to fish born after 1 July.

- This recommendation relates to projections used for AT-based management. Addressing this recommendation cannot be completed until it is decided that an MSE is necessary to explore survey-based management and that MSE is completed.

5. Investigate alternative approaches for dealing with highly uncertain estimates of recruitment that have an impact on the most recent estimate of age-1+ biomass that is important for management.

- The STAT presented a model sensitivity including recruitment autocorrelation to the STAR panel. Autocorrelation had essentially no impact on model output and management quantities.

6. Modify Stock Synthesis so that the standard errors of the logarithms of age-1+ biomass can be reported. These biomasses are used when computing OFLs, ABCs and HGs, but the CV used when applying the ABC control rule is currently that associated with spawning biomass and not age-1+ biomass.

- This request cannot by completed by the STAT, it must be done by Stock Synthesis (SS) developers.

7. The approach of basing OFLs, ABCs and HGs for a year on the biomass estimate from the AT survey for the previous year should be examined using MSE so the anticipated effects of larger CVs and a possible time-lag between when the survey was conducted and when catch limits are implemented on risk, catch and catch variation statistics can be quantified.

- The STAT is supportive of conducting an MSE to answer questions about the differences between stock assessment model-based management and survey-based management. Such an MSE has not yet been conducted and would require years of work.

8. The assessment would benefit not only from data from Mexico and Canada, but also from joint assessment activities, which would include assessment team members from both countries during assessment development.

- Multilateral science, including stock assessments, has long been considered a worthwhile goal. Completion of multilateral science faces many obstacles, many of which are beyond the STAT or even the SWFSC control. As an example, synoptic CPS surveys are discussed each year at the Trinational Sardine Forum and U.S.-Mexico bilateral meetings, yet such surveys have yet to become reality.

9. The assessment would benefit from the availability of estimates of 1+ biomass that include quantification of the biomass inshore of the survey area and in the upper water column.

- Three different approaches were tested and presented during the 2018 AT Survey CIE review. Direct measurements using a dedicated small boat with acoustic capability was considered the best option, and the SWFSC has made strides towards measuring nearshore abundance with acoustics since 2017 in collaboration with fishing industry and using saildrones as well. Currently, the plan is to have the 2020 summer AT survey comprehensively sample nearshore areas with this method in collaboration with industry. In this 2020 stock assessment, the nearshore biomass has been incorporated through acoustic measurements from industry vessels and saildrones, and also from a CDFW aerial survey through adjusting the catchability.

10. It is unclear how the habitat model is applied to determine survey design. Is this an ad hoc decision or is there a formal procedure? The next Panel should be provided with comprehensive documentation on how the habitat model is applied.

- This topic was addressed during the 2018 AT Survey CIE review.

11. Consider future research on natural mortality. Note that changes to the assumed value for natural mortality may lead to a need for further changes to harvest control rules.

- The STAT has conducted a meta-analysis to develop a prior for natural mortality using growth parameters estimated in previous assessments. The prior lognormally distributed with a mean=-0.59 and sd=0.39 (Figure 18).

12. Explore the potential of collaborative efforts to increase sample sizes and/or gather data relevant to quantifying effects of ship avoidance, problems sampling near-surface schools, and currently unsampled nearshore areas.

- Collaboration with the fishing industry to implement a nearshore survey started in 2017 and is undergoing. Currently, the 2020 summer survey is expected to have coastwide coverage of the nearshore, conducted collaboratively with industry, both acoustically and biologically.

13. Reduce aging error and bias by coordinating and standardizing aging techniques and performing an aging exchange (double blind reading) to validate aging and estimate error. Standardization might include establishing a standard "birth month" and criteria for establishing the presence of an outer annuli. If this has already been established, identify labs, years, or sample lots where there is deviation from the criteria. The outcome of comparative studies should be provided with every assessment.

- The SWFSC regularly exchanges survey otolith samples with key personnel with the CDFW for double-reading evaluations. In addition, the SWFSC has recently brought on new staff to work on CPS ageing which is expected to result in more consistency and coordination internally and with other readers. The STAT welcomes this needed effort.

Medium Priority

14. Continue to explore possible additional fishery-independent data sources such as the SWFSC juvenile rockfish survey and the CDFW/CWPA cooperative efforts (additional sampling and aerial surveys). Inclusion of a substantial new data source would likely require review, which would not be easily accomplished during a standard STAR Panel meeting and would likely need to be reviewed during a Council-sponsored Methodology Review.

- While other potential fishery-independent data sources may exist for Pacific sardine, none have been vetted through a Council-sponsored methodology review. The STAT continues to support and promote use of the single, most objective survey tool available for estimating abundance of CPS, which has been approved by multiple Council-sponsored methodology reviews, i.e., the SWFSC's AT survey.

15. Consider spatial models for Pacific sardine that can be used to explore the implications of regional recruitment patterns and region-specific biological parameters. These models could be used to identify critical biological data gaps as well as better represent the latitudinal variation in size-at-age; this should include an analysis of age-structure on the mean distribution of sardine in terms of inshore-offshore (especially if industry partner-derived data were available).

- No progress has been made toward spatial modeling. Some of the concerns raised regarding regional size-at-age have been accounted for by the use of empirical weight-at-age data and age-based selectivity in model ALT.

16. Consider a model that has separate fleets for Mexico, California, Oregon-Washington and Canada.

- In the past, the STAT has modeled each of these regional fisheries as fleet, which resulted in an unstable, over-parameterized model. That is, the goal of current model development is to construct a parsimonious assessment model that meets the overriding management objective using/emphasizing the highest quality data available (AT survey abundance time series) in the most straightforward manner (not developed around fine-scale fishery catch and selectivity data).

17. Compare annual length-composition data for the Ensenada fishery that are included in the MexCal data sets for the northern sub-population with the corresponding southern California length compositions. Also, compare the annual length-composition data for the Oregon-Washington catches with those from the British Columbia fishery. This is particularly important if a future age data/age-based selectivity model scenario is further developed and presented for review.

- This recommendation is an artifact from the 2014 STAR Panel report. Fishery length compositions were replaced with age compositions in 2017.

3.3 2019 SSC CPS Subcommittee Report:

The SSC CPSSC requested two additional model runs to inform on the potential magnitude of sensitivity in assessment outcomes associated with some of the key uncertainties. Other issues that should be examined during the 2020 benchmark assessment are listed in the notes.

1. AT survey catchability (q) is estimated to be 1.17 in the 2019 update assessment (up from 1.15 in the 2018 assessment update). Although there are various factors, including acoustic target strength, that are uncertain and could cause q to be greater than 1.0, it is also true that the survey misses some portion of the sardine population, notably inshore of the survey area. In order to explore the sensitivity of the model to q, the CPSSC requested a model run with q fixed at 1.0 (Table 1; Figure 1).

- The STAT has fixed values of q at 1 for 2005-2014 and 0.73 for 2015-2019. The value of 0.73 represents the proportion of nearshore biomass (2019 CPSSC aerial estimate; 12,279 mt) assumed to not be represented in the 2019 AT survey biomass estimate (33,632 mt). Additionally, the AT survey was extended to nearshore waters in 2017 off of Washington/Oregon and in 2019 off California using saildrones and sonar-equipped fishing vessels (Stierhoff et al. 2020a).

2. Recent Catches of Northern Subpopulation of Pacific Sardine Catch in the Ensenada (ENS) area of Mexico is apportioned to the NSP and the SSP based on the location of the port of landing and the oceanography at the time, indicating the likely geographic boundary between the two stocks. However, evidence suggests that vessels often fish far south of the northern Mexican ports, and therefore the partitioning by location of port of landing may not be correct. The very high exploitation rates estimated for the ENS fleets in the past two years (23-35 percent) are ten times the mean rates during 2005-2014 (2.8 percent; 2015 and 2016 had 0.0 percent exploitation rates). In addition, in forecasts, the 2019 and2020 catches are assumed equal to those estimated for 2018. The CPSSC requested a run with estimated catches in ENS from 2017 and 2018 (and in forecasts) multiplied by 0.1, to reflect exploitation rates more consistent with those estimated in the recent past. Results of a run with 2017/2018 catches in the MexCal fleet multiplied by 0.1 (which achieves the aim of the sensitivity examination, since over 98 percent of estimated NSP landings by the MexCal fleet were from ENS in both 2017 and 2018) are shown in Table 1 and Figure 1.

- The Mexican catches (incorporated into MexCal fishing fleets in the model) have been revised based on data collected with vessel monitoring systems for vessels from Ensenada.

3.4 Changes between Model ALT (2017-19) and the 2020 Base Model

The 2020 base model is an extension of model ALT that incorporates re-calculated and updated data through 2019. The 2020 base also includes structural changes such as time-varying age-based selectivities and priors on natural mortality and catchability. Descriptions and motivations for the addition of new features are below.

1. Transitioned to most recent SS software (v3.30.14).
2. Re-calculated AT survey weight-at-age values based on annual age-length keys.
3. Used AT survey weight-at-age as population weight-at-age.
4. Updated AT survey index of abundance with re-aged 2017 and 2018 otoliths and values re-calculated to adjust for herring target strength.
5. Added AT survey age compositions for 2019.
6. Added fishery catches with newly split VMS data from Ensenada. Described in section 2.1.1.
7. Fixed stock-recruitment relationship steepness at 0.3.
8. Fixed catchability (Q) at 1 for 2005-2014, and fixed Q=0.73 for 2015-2019 to account for nearshore biomass.
9. Estimated time-varying age-0 selectivity for the AT survey.
10. Estimated time-varying age-based selectivity for the three fishing fleets/
11. Tuned recruitment deviations to new data (e.g., increase σ_R; changed bias adjustment parameters).
12. Omitted spring AT survey age composition from model.

This information is presented in Table 10 and the changes in estimated likelihood values and forecast stock biomasses (age 1+; mt) are shown in Table 11.

3.5 Model Description

Overview

Many characteristics of the general model ALTs used in the past (Hill et al. 2017, 2018, 2019) remain in the 2020 base model. Notable changes are fixing steepness (h) at 0.3, fixed catchability (q) at 1 for 2005-2014 and 0.73 for 2015-2019 (scaled using the aerial survey nearshore estimates), addition of a prior for natural mortality (M), estimation of time-varying age-0 selectivity for the AT survey, estimation of time-varying age selectivity for the fishing fleets, and ommission of AT survey spring age compositions from the model.

3.5.1 Time period and time step

The modeled timeframe begins in 2005, as in past model ALT, and extends through 2020. Time steps remain based on two, six-month semester blocks for each fishing year (semester 1= July-December and semester 2=January-June). The need for an extended time period in the model is not supported by the management goal, given that years prior to the start of the AT survey time series provide limited additional information for evaluating terminal stock biomass in the integrated model. Further, although a longer time series of catch may be helpful in a model for accurately determining the scale in estimated quantities of interest, estimated trend and scale were not sensitive to changes in start year for the 2020 base model. Finally, Pacific sardine biology (relatively few fish >5 years old observed in fisheries or surveys) further negates the utility of an extended time period in a population dynamics model employed for estimating terminal stock biomass of a short-lived species.

3.5.2 Surveys

The 2020 base model includes only the AT survey index of abundance, similar to past model ALTs. Associated age compositions and weight-at-age values from the AT survey are included in the 2020 base model. The spring age compositions were not used in the 2020 base model.

3.5.3 Fisheries

Fishery structure in the 2020 base model is the same as implemented in past assessments. Three fisheries are included in the model, including two Mexico-California fleets separated into semesters (MexCal_S1 and MexCal_S2) and one fleet representing Pacific Northwest fisheries (Canada-WA-OR, PNW). Also, because the California live bait industry currently reflects the only active sector in the U.S. sardine fishery, minor amounts of live bait landings were included in the current assessment.

Definitions of fleets and areas

Data from major fishing regions are aggregated to represent southern and northern fleets (fisheries). The southern 'MexCal' fleet includes data from three major fishing areas at the southern end of the stock's distribution: northern Baja California (Ensenada, Mexico), southern California (Los Angeles to Santa Barbara), and central California (Monterey Bay).

Fishing can occur throughout the year in the southern region, however, availability-at-size/age changes due to migration. Selectivity for the southern MexCal fleet was modeled separately for seasons 1 and 2 (semesters, S1 and S2).

The 'PNW' fleet (fishery) includes data from the northern range of the stock's distribution, where sardine are typically abundant between late spring and early fall. The PNW fleet includes aggregate data from Oregon, Washington, and Vancouver Island (British Columbia, Canada). The majority of fishing in the northern region typically occurs between July and October (S1).

3.5.4 Longevity and natural mortality

Biology assumptions for the Pacific sardine in the 2020 base model were similar to those in past model ALTs. There were 9 age bins, representing ages 0 to 8+. A meta-analysis of natural mortality based on a maximum age of 10 and past von Bertalanffy growth rate (k) estimates were used to develop an informed prior for M. See the section 2.4.4 for details regarding the parameterization for M in the 2020 base model (Figure 18)

3.5.5 Growth

A mix of empirical weight-at-age estimates by year/semester were used in the 2020 base model to translate derived numbers-at-age into biomass-at-age for both input data (catch time series) and output estimates (population numbers-at-age). Treatment of growth using empirical weight-at-age matrices associated with the fisheries, survey, and population greatly simplifies the overall assessment, while allowing growth to vary across time and minimizing potential conflicts with selectivity parameterizations. The previous "Growth" section contains details on weight-at-age calculations for the fisheries and the AT survey (Section 2.4.2).

3.5.6 Stock-recruitment relationship

Equilibrium recruitment (R_0) and initial equilibrium offset (SR_{regime}) were estimated in the 2020 base model, and steepness (h) was fixed at 0.3. In previous model ALTs, all three of these parameters were estimated (Table 10). Steepness was not estimable from the data, and thus fixed.

Following recommendations from past assessment reviews, the estimate of average recruitment variability (σ_R) assumed in the stock-recruitment (S-R) relationship was set to 1.2. Past model ALTs used a value of 0.75, but the value was increased as part of the model tuning process. Specifically, σ_R was increased to reflect the estimated root mean square error values in the modeled recruitment deviations. Recruitment deviations were estimated as separate vectors for the early and main data periods in the overall model. Early recruitment deviations for the initial population were estimated from 1999-2004 (six years before the start of the model). A recruitment bias adjustment ramp (Methot and Taylor 2011) was applied to the early period and bias-adjusted recruitment estimated in the main period of the model. Main period recruitment deviations were advanced one year from that used in the last assessment, i.e., estimated from 2005-18 (S2 of each model year), which translated to the 2019 year class being freely estimated in the model.

Pacific sardines are believed to have a broad spawning season, beginning in January off northern Baja California and ending by July off the Pacific Northwest. In the semester-based model, spawning stock biomass (SSB) is calculated at the beginning of S2 (January). Recruitment was specified to occur in S1 of the following model year (consistent with the July 1st birth-date assumption). In earlier assessments, a Ricker stock-recruitment (S-R) relationship had been assumed following Jacobson and MacCall (1995), however, following recommendations from past reviews, a Beverton-Holt S-R has been implemented in all assessments since 2014.

It is important to note that there exists little information in the assessment to directly evaluate recent recruitment strength (e.g., absolute numbers of age-0, 6-9 cm fish in the most recent year), with the exception of age data from the southern fisheries, which have caught these juveniles infrequently in past years in low volume during their first semester of life (S1), but in greater amounts during the second semester (MexCal_S2) in some years. Age-0 recruits are rarely observed in the PNW fishery. Age-0 fish are not typically encountered by the AT survey, except for limited occurrences in particular years and in relatively high numbers observed in one cruise (summer 2015).

3.5.7 Selectivity

Age-based selectivity was assumed in the 2020 base model using age compositions from the respective fisheries and AT survey, rather than relying on length compositions and associated length-based selectivity. Time-varying selectivity was generally implemented in the 2020 base model for both the fisheries and survey, whereas, selectivity in past model ALTs was time invariant. Pacific sardine migrate north in summers, and then back to southern waters in late fall and winter to spawning grounds (McDaniel et al. 2016). Time-varying selectivity was adopted in this assessment to better capture interannual variations in these migrations and to provide better model fits to age compositions from the fisheries and AT survey.

Selectivities for the MexCal fisheries were modeled as non-parametric functions with estimated age-specific values using a random walk (Option 17; Methot 2019). Selectivity patterns from 2005-2014 were freely estimated because age compositions showed year-to-year variability across some years. Technically, we used the replacement block function (option 2) instead of alternative options that require specifying a base selectivity pattern and estimation of subsequent deviations from this base pattern. Ages 1-5 for MexCal S1 and ages 1-3 for MexCal

S2 were estimated using time-varying annual blocks. Time-varying selectivity increased the number of estimated parameters in the model and also improved fits to the fishery age compositions. The selectivity pattern estimated in 2014 was assumed to be constant through 2019 given the absence of age-composition data from the fisheries.

The PNW fleet was modeled using a two-parameter logistic selectivity form as implemented in past model ALTs. Asymptotic selectivity captured the stock's biology and evidence that larger, older sardines typically migrate to northern feeding habitats each summer (McDaniel et al. 2016). The age-at-inflection estimate was modeled as a time-varying parameter. The block treatment was the same as for the MexCal fleets, in that annual blocks were used from 2005-2014, and the 2014 pattern was constant through 2019.

Following recommendations from the most recent review, the AT survey selectivity was modeled with time-varying age-0 selectivity and time-invariant full selectivity for ages 1+ fish. The AT survey is based on sound technical methods and an expansive sampling operation in the field using an optimal habitat index for efficiently encountering all adult fish in the stock (Demer and Zwolinski 2014); observations of age-1 fish in length- and age-composition time series, to some degree, in every year; recognition of some level of ageing bias in the laboratory that may confound explicit interpretation of estimated age compositions, e.g., low probability of selection of age-1 fish in a particular year may be attributed to incorrectly assigned ages for age-0 or age-2 fish; and minor constraints to selectivity estimation, which typically reflects a sensitive parameterization that can substantially impact model results, supports the overriding goal of the assessment, i.e., parsimonious model that is developed around the AT survey abundance index. Finally, in addition to potential biases associated with the trawling and ageing processes, the age-1+ selectivity assumption recognizes the vulnerability of adult sardine with fully-developed swim bladders to echosounder energy in the acoustic sampling process. That is, there are three selectivity components to consider with the acoustic-trawl method: 1) fish availability with regard to the actual area surveyed each year; 2) vulnerability of fish to the acoustic sampling gear; and 3) vulnerability of fish to the mid-water trawl (avoidance and/or extrusion). No evidence exists that sardine with fully-developed swim bladders (i.e., greater than age 0) are missed by the acoustic equipment, further supporting the assumption that age-1+ fish are fully-selected by the survey in any given year.

3.5.8 Catchability

The STAT considered several approaches related to accounting for the biomass inshore of the AT survey including: (a) ignoring it; (b) adding the estimate of biomass from the 2019 CCPSS survey to the estimate of biomass from the assessment; (c) specifying a change in the acoustic catchability (Q) for recent years using the estimates of AT and aerial survey biomass for 2019; and (d) fully integrating the CCPSS data into the assessment. The first of these options would ignore observed biomass not surveyed acoustically, while the second would lead to difficulties when conducting projections for rebuilding analyses. The fourth option is ideal in principle, but there remains considerable uncertainty about how to achieve this given there are only estimates of biomass from the CCPSS for 2017 and 2019 and uncertainty about what selectivity pattern to assume for the CCPSS data were it to be fit as a separate fleet. The 2020 base model therefore specified Q for two periods 2005-2014 and 2015-onwards, with Q for the first period set to 1 and that for second period set to 0.733 to account for an increase in the proportion of sardine biomass inshore of the AT survey since 2015. The value of 0.733 was calculated from the 2019 AT survey estimate (33,632 mt) and 2019 aerial survey estimate (12,279 mt), specifically $\frac{33{,}632}{33{,}632+12{,}279}$.

3.5.9 Likelihood components and model parameters

A complete list of model parameters for the 2020 base model is presented in Table 13. The total objective function was based on the following individual likelihood components: 1) fits to catch time series; 2) fits to the AT survey abundance index; 3) fits to age compositions from the three fleets and AT survey; 4) estimated parameters and deviations associated with the stock-recruitment relationship; and 5) minor contributions from soft-bound penalties associated with particular estimated parameters.

3.5.10 Initial population and fishing conditions

Given the Pacific sardine stock has been exploited since the early 20th Century (i.e., well before the start year used in the model), further information is needed to address equilibrium assumptions related to starting population dynamics calculations in the assessment model. One approach is to extend the modeled time period backwards in time to the start of the small pelagic fisheries off the U.S. west coast and in effect, ensure no fishing occurred prior to the start year in the model. In an integrated model, this method can be implemented by: 1) extending the catch time series back in time and confirming that harvest continues to decline generally as the onset of the fishery is approached; or 2) estimating additional parameters regarding initial population and fishing conditions in the model. Given assumptions regarding initial equilibrium for Pacific sardine (a shorter-lived species with relatively high intrinsic rates of increase) are necessarily difficult to support regardless of when the modeled time period begins, as well as the extreme length of an extended catch time series (early 1900s) that would be needed in this case, the approach above was adopted in this assessment, as conducted in all previous assessments to date.

The initial population was defined by estimating 'early' recruitment deviations from 1999-2004, i.e., six years prior to the start year in the model. Initial fishing mortality (F) was estimated for the MexCal S1 fishery and fixed=0 for MexCal S2 and PNW fisheries, noting that results were robust to different combinations of estimated vs. fixed initial F for the three fisheries. In effect, the initial equilibrium age composition in the model is adjusted via application of early recruitment deviations prior to the start year of the model, whereby the model applies the initial F level to an equilibrium age composition to get a preliminary number-at-age time series, then applies the recruitment deviations for the specified number of younger ages in this initial vector. If the number of estimated ages in the initial age composition is less than the total number of age groups assumed in the model (as is the case here), then the older ages will retain their equilibrium levels. Because the older ages in the initial age composition will have progressively less information from which to estimate their true deviation, the start of the bias adjustment was set accordingly (Methot 2011, Methot and Wetzel 2013). Ultimately, this parsimonious approach reflects a non-equilibrium analysis or rather, allows for a relaxed equilibrium assumption of the virgin (unfished) age structure at the start of the model as implied by the assumed natural mortality rate (M). Finally, an equilibrium 'offset' from the stock-recruitment relationship (R_1) was estimated (with no contribution to the likelihood) and along with the early recruitment deviation estimates, allowed the most flexibility for matching the population age structure to the initial age-composition data at the start of the modeled time period.

3.5.11 Assessment program with last revision date

For the 2020 base model, the stock assessment team (STAT) transitioned from Stock Synthesis (SS) version 3.24s to version 3.30.14. The SS model is comprised of 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. The modeling framework allows for the full integration of both population size and age structure, with explicit parameterization both spatially and temporally. The model incorporates all relevant sources of variability and estimates goodness of fit in terms of the original data, allowing for final estimates of precision that accurately reflect uncertainty associated with the sources of data used as input in the modeling effort.

3.5.12 Bridging analysis

The exploration of models began by bridging the 2019 model ALT to Stock Synthesis version 3.30.14. Resulting time series in stock biomass had negligible differences (Figure 19). The effects of implementing each change of the 2020 base model are shown in Figures 20 and 22. Visually, time series of stock biomass and recruitment were very similar, with the exception of the model run with the prior on natural mortality and estimated catchability (no model convergence). This change resulted in a high catchability and scaling down of the AT indices of abundance. Likelihoods and 2020 stock biomasses associated with each of the changes are shown in Table 11.

3.5.13 Convergence criteria and status

The iterative process for determining numerical solutions in the model was continued until the difference between successive likelihood estimates was <0.00001. The total likelihood and final gradient estimates for the 2020 base model were 91.69 and 5.72e-06, respectively.

3.6 Base Model Results

3.6.1 Likelihoods and derived quantities of interest

The 2020 base model total likelihood was 91.685 (Table 12). Likelihood values from the AT survey and PNW fishery age compositions made up the majority of the total likelihood. The forecasted stock biomass for July 2020 was 28,276 (age 1+; mt).

3.6.2 Parameter estimates and errors

Parameter estimates and standard errors for the 2020 base model are presented in Table 13.

3.6.3 Growth

Growth parameters were not estimated in the 2020 base model. Rather, empirical weight-at-age estimates by year were used to convert estimated numbers into weight of fish for calculating biomass quantities relevant to management (Figures 15-17).

3.6.4 Selectivity estimates and fits to fishery and survey age compositions

Time-varying age-based selectivities were estimated for the three fisheries (Figures 23-25) and AT survey (Figure 26). Time-varying selectivities resulted in good fits to fishery age compositions (Figures 27, 28, and 29), and residuals of the fits to age compositions had a maximum absolute scale of about two (Figures 30, 31, and 32).

Time-varying age-0 parameters for the AT survey improved age-composition fits, relative to estimates from previous model ALTs. However, there were poor fits in some years (Figures 33 and 34).

3.6.5 Fit to survey index of abundance

Model fits to the AT survey abundance index in arithmetic and log scale are presented in Figures 35 and 36. The predicted fit to the survey index was generally good (near mean estimates and within error bounds), particularly for the two most recent years of the time series.

3.6.6 Stock-recruitment relationship

Recruitment was modeled using a Beverton-Hold stock-recruitment relationship (Figure 37). The assumed level of underlying recruitment deviation error was fixed (σ_R=1.2), equilibrium recruitment was estimated ($log(R_0)$=14.731) and steepness (h) was fixed at 0.3. Recruitment deviations for the early (1999-2004), main (2005-2017), and forecast (2018-2020) periods in the model are presented in Figure 38. Asymptotic standard errors for recruitment deviations are shown in Figure 39, and the recruitment bias adjustment plot for the three periods are shown in Figure 40.

3.6.7 Population number- and biomass-at-age estimates

Population number-at-age estimates for 2020 base model are presented in Table 14. Corresponding estimates of population biomass-at-age, total biomass (age-0+, mt) and stock biomass (age-1+ fish, mt) are shown in Table 15. Age 0-3 fish have comprised about 73% of the total population biomass from 2005-2019.

3.6.8 Spawning stock biomass

Time series of estimated spawning stock biomass (SSB; mt) and associated 95% confidence intervals are presented in Table 16 and Figure 41. The initial level of SSB was estimated to be 717,077 mt. The SSB has continually declined since 2005-2006, reaching low levels in recent years (2014-present). The SSB was projected to be 16,768 mt in January 2021.

3.6.9 Recruitment

Time series of estimated recruitment abundance are presented in Tables 14 and 16 and Figure 42. The equilibrium level of recruitment R_0 was estimated to be 2,497,997 age-0 fish. As indicated for SSB above, recruitment has declined since 2005-2006 with the exception of a brief period of modest recruitment success in 2009-2010. In particular, the 2011-2018 year classes have been among the weakest in recent history.

3.6.10 Stock biomass for PFMC management

Stock biomass, used for calculating annual harvest specifications, is defined as the sum of the biomass for sardine ages one and older (age 1+) at the start of the management year (July). Time series of estimated stock biomass are presented in Table 15 and Figure 43. As discussed above for both SSB and recruitment, a similar trend of declining stock biomass has been observed since 2005-2006, peaking in 2006, and plateauing at recent low levels since 2014. The 2020 base model stock biomass is projected to be 28,276 mt in July 2020. Pacific sardine NSP biomass remains below the 50,000 mt minimum stock size threshold as defined in the CPS-FMP.

3.6.11 Fishing mortality

Estimated fishing mortality (apical F) time series by fishery are presented in Figure 44. In recent years (2015-2020), fishing mortality estimates are high due to harvest on NSP sardine in Ensenada. Exploitation rate has been around 20% for 2017-2019 Table 17 and Figure 45. Note that landings from Ensenada in 2019 were assumed to be the same as in 2018.

3.7 Modeling Diagnostics

3.7.1 Convergence

Convergence was evaluated by starting model parameters from values jittered from the maximum likelihood estimates. Starting parameters were jittered by 5% and 10%, 50 replicates for each percentage, and a better minimum was not found. Rephasing of parameter estimation order did not result in a better fit to the data. There were no difficulties in inverting the Hessian to obtain estimates of variability, and the STAT feels that the base model represents the best fit to the data given the modeling assumptions.

3.7.2 Retrospective analysis

A five-year retrospective analysis was conducted by running the model by using data only through 2014, 2015, 2016, 2017, and 2018. Trends and scale in stock biomasses were similar through the retrospective years (Figure 46). The lack of retrospective pattern is likely attributable to priors on natural mortality, fixed catchability, and fixed steepness values that provide model stability.

3.7.3 Historical analysis

Estimates of stock biomass (Figure 47; age 1+ fish, mt) and recruitment (Figure 48; age-0 fish, billions) for the 2020 base model were compared to recently conducted assessments. Full and updated stock assessments since 2014 (Hill et al. 2014-2019) are included in the comparison. Stock biomass and recruitment trends were generally similar, with notable differences in scale between particular years. It is important to note that previous (2014-16) assessments were structured very similarly (e.g., similar model dimensions, data, assumptions, and parameterizations). Whereas, the model ALTs and 2020 base model reflect much simpler versions of past assessments models, which necessarily confounds direct comparisons between results from this year's model with past assessments.

3.7.4 Likelihood profiles

Likelihood profiles were conducted for terminal year biomass, natural mortality (no prior), catchability (no prior), and steepness. In these profiles, specific parameter values were fixed and the remaining parameters estimated. Sensitivities had the same configuration as the 2020 base model, with the exception of natural mortality and catchability. In these two cases, there were no priors associated with the fixed values.

The terminal-year stock biomass likelihood profile was implemented as follows:

1. Create dummy survey for 2019 (in addition to the current AT survey 2019 value).
2. Fix dummy survey log-catchability at 0 (1 in exponentiated space).
3. Mirror the weight-at-age and age compositions associated with the 2019 summer AT survey.
4. Force the model through the dummy survey estimate. Technically, this was achieved by heavily weighting the dummy survey value in the likelihood calculation (lambda=3, compared to lambda=1 for the AT survey). Weighting for the AT survey was not decreased for this sensitivity.

Dummy values between 30,000-60,000 mt had the highest support (Figure 49), and this was largely driven by the AT survey index of abundance. This range of terminal year biomass values resulted in forecast stock biomass values of 18,983-38,370 mt (Table 18).

Natural mortality estimates between 0.5 and 0.6 (Figure 50) were supported by profiles. Age compositions from the PNW fishery and AT survey supported low values of M (≈ 0.4; Figure 50), whereas the MexCal S2 fishery supported a higher value. The changes in select parameter estimates and stock biomass estimates at fixed values of natural mortality are shown in Table 19. Generally, increases in natural mortality values resulted in decreased estimates of initial F, catchability (Q), and R_0 (Table 19). Stock biomass values in 2019 and 2020 increased with increasing natural mortality, due to the negative correlation with catchability (Table 19).

Data from the AT survey and PNW fishery (to a lesser extent) support higher catchability values than those used in the 2020 base model (Figure 51). Percentage increases in catchability values resulted in increased estimates of initial F and decreased estimates of natural mortality and R_0 (Table 20). Increased catchability values resulted in decreased 2019 and 2020 stock biomass estimates.

Recruitment estimates support low values of steepness (Figure 52). There is relatively little information on steepness in the age compositions. One explanation for the low steepness values is the timeframe of the assessment. From 2005-2019, the fishery has undergone a "one-way trip", in which the population has declined. As a result, it follows that estimates of steepness are low given that the biomass has declined by orders of magnitude without any notable increases in the time period. Increasing values of steepness had relatively small changes on 2019 stock biomass but large changes in the 2020 forecast stock biomass estimates (Table 21).

4 Harvest Control Rules

4.1 Evaluation of Scientific Uncertainty

Scientific uncertainty in the 2020 base model is based on asymptotic standard errors associated with SSB estimates derived in the model. The 2020 base model SSB was projected to be 16,769 mt (SD=11,190 mt; CV=0.607) in January 2021, so the corresponding σ for calculating P-star buffers is 0.607, rather than the newly adopted default value (0.50) for Tier 1 assessments.

4.2 Harvest Guideline

The annual harvest guideline (HG) is calculated as follows:

$HG = (BIOMASS - CUTOFF) * FRACTION * DISTRIBUTION;$

where HG is the total U.S. directed harvest for the period July 1, 2020 to June 30, 2021, BIOMASS is the stock biomass (ages 1+, mt) projected as of July 1, 2020, CUTOFF (150,000 mt) is the lowest level of biomass for which directed harvest is allowed, FRACTION (EMSY bounded 0.05-0.20) is the percentage of biomass above the CUTOFF that can be harvested, and DISTRIBUTION (87%) is the average portion of BIOMASS assumed in U.S. waters. The

2020 base model estimated stock biomass is projected to be below the 150,000 mt threshold, so the HG for 2020-2021 would be 0 mt. Harvest estimates for the base model are presented in Figure 22.

4.3 OFL and ABC

On March 11, 2014, the PFMC adopted the use of CalCOFI sea-surface temperature (SST) data for specifying environmentally-dependent E_{msy} each year. The E_{msy} is calculated as,

$$E_{msy} = -18.46452 + 3.25209(T) - 0.19723(T^2) + 0.0041863(T^3)$$

where T is the three-year running average of CalCOFI SST (Table 23), and E_{msy} for OFL and ABC is bounded between 0 to 0.25. Based on recent conditions in the CCE, the average temperature for 2017-2019 was 15.9965 °C, resulting in E_{msy}=0.22458.

Estimated stock biomass in July for the 2020 base model was 28,276 mt Figure 22. The overfishing limit (OFL, 2019-2020) associated with that biomass was 5,525 mt (Figure 22). Acceptable biological catches (ABC, 2020-2021) for a range of P-star values (Tier 1 σ=0.607; Tier 2 σ=1.0) associated with the base model are presented in Figure 22.

5 Regional Management Considerations

Pacific sardine, as well as other species considered in the CPS FMP, are not managed formally on a regional basis within the USA, due primarily to the extensive distribution and annual migration exhibited by these small pelagic stocks. A form of regional (spatial/temporal) 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).

6 Research and Data Needs

Nearshore biomass, particularly the area inshore of the past AT survey footprint, is a major uncertainty. The CCPSS aerial survey estimate of biomass was incorporated into the assessment by adjusting catchability. There are a number of research needs related to improvement of the CCPSS survey, particularly coordination of visual estimates with randomly sampled purse-seine point sets, temporal rather than spatial replication, and sufficient biological sampling on mixed anchovy and sardine schools. Further details are included in the STAR panel report. The 2020 summer AT survey will make strides towards increasing nearshore coverage using acoustics in collaboration with the fishing industry.

Ageing consistency remains a research need that the SWFSC and CDFW are committed to working on in the future.

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9 Tables

Table 1: U.S. Pacific sardine harvest specifications and landings (mt) since the onset of federal management. US. harvest limits and closures are based on total catch, regardless of subpopulation source. Landings for the 2019-20 management year are preliminary and incomplete.

Mgmt. Year	OFL	ABC	HG or ACL	Tot. Landings	NSP Landings
2000	-	-	186,791	73,766	67,691
2001	-	-	134,737	79,746	57,019
2002	-	-	118,442	103,134	82,529
2003	-	-	110,908	77,728	65,692
2004	-	-	122,747	96,513	78,430
2005	-	-	136,179	92,906	76,047
2006	-	-	118,937	94,337	79,623
2007	-	-	152,564	131,090	107,595
2008	-	-	89,093	90,164	80,986
2009	-	-	66,932	69,903	64,506
2010	-	-	72,039	69,140	58,578
2011	92,767	84,681	50,526	48,802	42,253
2012	154,781	141,289	109,409	103,600	93,751
2013	103,284	94,281	66,495	67,783	60,767
2014 (1)	59,214	54,052	6,966	6,806	6,121
2014-15	39,210	35,792	23,293	23,113	19,969
2015-16	13,227	12,074	7,000	1,919	260
2016-17	23,085	19,236	8,000	1,800	516
2017-18	16,957	15,479	8,000	1,775	372
2018-19	11,324	9,436	7,000	1,507	43
2019-20	5,816	4,514	4,000	994	139

Table 2: Pacific sardine landings (mt) for major fishing regions off northern Baja California (Ensenada, Mexico), the United States, and British Columbia (Canada). ENS and SCA landings are presented as totals and northern subpopulation (NSP) portions. Y-S stands for year-semester for calendar and model values.

Calendar Y-S	Model Y-S	ENS Total	ENS NSP	SCA Total	SCA NSP	CCA	OR	WA	BC
2005-2	2005-1	38,000	4,397	16,615	1,581	7,825	44,316	6,605	3,231
2006-1	2005-2	17,601	11,215	18,291	17,117	2,033	102	0	0
2006-2	2006-1	39,636	0	18,556	5,016	15,710	35,547	4,099	1,575
2007-1	2006-2	13,981	13,320	27,546	20,567	6,013	0	0	0
2007-2	2007-1	22,866	11,928	22,047	5,531	28,769	42,052	4,662	1,522
2008-1	2007-2	23,488	15,618	25,099	24,777	2,515	0	0	0
2008-2	2008-1	43,378	5,930	8,980	124	24,196	22,940	6,435	10,425
2009-1	2008-2	25,783	20,244	10,167	9,874	11,080	0	0	0
2009-2	2009-1	30,128	0	5,214	109	13,936	21,482	8,025	15,334
2010-1	2009-2	12,989	7,904	20,334	20,334	2,909	437	511	422
2010-2	2010-1	43,832	9,171	11,261	699	1,404	20,415	11,870	21,801
2011-1	2010-2	18,514	11,588	13,192	12,959	2,720	0	0	0
2011-2	2011-1	51,823	17,330	6,499	182	7,359	11,023	8,008	20,719
2012-1	2011-2	10,534	9,026	12,649	10,491	3,673	2,874	2,932	0
2012-2	2012-1	48,535	0	8,621	930	598	39,744	32,510	19,172
2013-1	2012-2	13,609	12,828	3,102	973	84	149	1,421	0
2013-2	2013-1	37,804	0	4,997	110	811	27,599	29,619	0
2014-1	2013-2	12,930	412	1,495	809	4,403	0	908	0
2014-2	2014-1	77,466	0	1,601	0	1,831	7,788	7,428	0
2015-1	2014-2	16,497	0	1,543	0	728	2,131	63	0
2015-2	2015-1	20,972	0	1,421	0	6	0	66	0
2016-1	2015-2	23,537	0	423	185	1	1	0	0
2016-2	2016-1	42,532	0	964	49	234	3	170	0
2017-1	2016-2	28,212	6,936	513	145	0	0	0	0
2017-2	2017-1	99,967	0	1,205	0	170	1	0	0
2018-1	2017-2	24,534	6,032	395	198	0	2	0	0
2018-2	2018-1	43,370	0	1,424	0	35	6	2	0
2019-1	2018-2	32,169	11,210	754	551	58	2	0	0
2019-2	2019-1	46,943	0	855	0	131	8	0	0

Table 3: Pacific sardine length and age samples available for major fishing regions off northern Baja California (Mexico), the United States, and Canada. Samples from model year-semester 2015-1 onward were from incidental catches so were not included in the model. Values shown are number of sample lengths-number of sample ages. Note, one sample corresponds to 25 fish (e.g., a sample size of 3 corresponds to 75 fish).

Calendar Y-S	Model Y-S	ENS	SCA	CCA	OR	WA	BC
2005-2	2005-1	115-0	73-72	24-23	14-14	54-27	65-0
2006-1	2005-2	53-0	67-66	32-31	0-0	0-0	0-0
2006-2	2006-1	46-0	61-61	58-58	12-12	15-15	0-0
2007-1	2006-2	22-0	74-72	47-46	3-3	0-0	0-0
2007-2	2007-1	46-0	72-72	68-68	80-80	10-10	23-0
2008-1	2007-2	43-0	53-53	15-15	0-0	0-0	0-0
2008-2	2008-1	83-0	25-25	30-30	80-80	14-14	229-0
2009-1	2008-2	50-0	20-20	20-20	0-0	0-0	0-0
2009-2	2009-1	0-0	13-12	23-23	82-81	12-12	285-0
2010-1	2009-2	0-0	62-62	37-36	3-1	2-2	2-0
2010-2	2010-1	0-0	25-25	13-13	64-26	8-8	287-0
2011-1	2010-2	0-0	22-21	11-11	0-0	0-0	0-0
2011-2	2011-1	0-0	22-22	22-22	34-33	10-10	362-0
2012-1	2011-2	0-0	48-47	16-16	8-8	8-8	0-0
2012-2	2012-1	0-0	44-41	18-17	83-82	37-37	106-0
2013-1	2012-2	0-0	16-16	2-2	0-0	3-3	0-0
2013-2	2013-1	0-0	39-39	5-5	75-74	66-65	0-0
2014-1	2013-2	0-0	27-26	14-13	0-0	1-1	0-0
2014-2	2014-1	0-0	8-8	6-6	27-27	24-23	0-0
2015-1	2014-2	0-0	18-18	14-14	15-15	1-0	0-0
2015-2	2015-1	0-0	0-0	2-2	0-0	1-0	0-0
2016-1	2015-2	0-0	8-8	0-0	4-0	0-0	0-0
2016-2	2016-1	0-0	3-3	4-3	4-0	0-0	0-0
2017-1	2016-2	0-0	3-3	0-0	0-0	0-0	0-0
2017-2	2017-1	0-0	1-1	4-4	0-0	0-0	0-0
2018-1	2017-2	0-0	2-2	0-0	0-0	0-0	0-0
2018-2	2018-1	0-0	2-2	4-4	0-0	0-0	0-0
2019-1	2018-2	0-0	1-0	6-0	0-0	0-0	0-0
2019-2	2019-1	0-0	1-0	2-0	0-0	0-0	0-0

Table 4: Pacific sardine NSP landings (mt) by year-semester and fleet for the 2020 base model. For forecast model year-semesters (2020-1, 2020-2), fishing mortality values estimated from 2019-1 and 2019-2 landings were used.

Calendar Y-S	Model Y-S	MexCal S1	MexCal S2	PNW
2005-2	2005-1	13,803.0	0.0	54,152.6
2006-1	2005-2	0.0	30,364.2	101.7
2006-2	2006-1	20,726.2	0.0	41,220.9
2007-1	2006-2	0.0	39,900.3	0.0
2007-2	2007-1	46,228.1	0.0	48,237.1
2008-1	2007-2	0.0	42,910.1	0.0
2008-2	2008-1	30,249.2	0.0	39,800.1
2009-1	2008-2	0.0	41,198.5	0.0
2009-2	2009-1	14,044.9	0.0	44,841.2
2010-1	2009-2	0.0	31,146.5	1,369.7
2010-2	2010-1	11,274.0	0.0	54,085.9
2011-1	2010-2	0.0	27,267.6	0.1
2011-2	2011-1	24,871.4	0.0	39,750.5
2012-1	2011-2	0.0	23,189.9	5,805.6
2012-2	2012-1	1,528.4	0.0	91,425.6
2013-1	2012-2	0.0	13,884.9	1,570.8
2013-2	2013-1	921.6	0.0	57,218.0
2014-1	2013-2	0.0	5,625.0	908.0
2014-2	2014-1	1,830.9	0.0	15,216.8
2015-1	2014-2	0.0	727.7	2,193.9
2015-2	2015-1	6.1	0.0	66.3
2016-1	2015-2	0.0	185.8	1.3
2016-2	2016-1	283.5	0.0	173.2
2017-1	2016-2	0.0	7,080.5	0.0
2017-2	2017-1	170.4	0.0	1.2
2018-1	2017-2	0.0	6,229.4	2.2
2018-2	2018-1	35.3	0.0	7.9
2019-1	2018-2	0.0	11,819.4	2.5
2019-2	2019-1	130.9	0.0	7.7
2020-1	2019-2	0.0	11,819.4	2.5
2020-2	2020-1	0.0	0.0	0.0
2021-1	2020-2	0.0	1.9	0.0

Table 5: Revised Pacific sardine (NSP) biomass estimates by stratum during the summer 2017-2019 AT surveys. Estimates (mt), 95 percent confidence intervals, standard deviations and coefficients of variation are shown. Point biomass estimates are mean values and stratum areas are nmi^2.

	Stratum		Transect		Trawls		Biomass (mt)				
Year	Number	Area	Number	Distance	Cluster num.	Num. of Sardine	Point	Lower CI	Upper CI	SD	CV (%)
2017	1	5,078	7	260	2	10	847	20	2,910	771	91
	2	12,622	12	621	5	296	769	39	1,459	385	50
	3	17,221	31	1,714	12	2,320	12,337	5,524	21,648	4,195	34
	4	399	14	81	4	102	149	11	345	89	60
	All	35,320	64	2,676	19	2,728	14,103	7,337	22,981	4,231	30
2018	2	6,091	12	610	7	202	1,803	307	3,315	811	45
	3	16,661	36	1,696	13	2,324	23,345	3,310	59,124	16,808	72
	All	22,702	48	2,307	20	2,526	25,148	4,480	60,551	40,569	67
2019	2	5,972	14	611	6	1,183	1,443	484	2,733	620	43
	3	22,615	51	2,286	16	3,758	31,695	19,946	44,635	6,022	20
	All	28,587	65	2,898	22	4,941	33,138	21,653	46,051	6,296	19

Table 6: Fishery-independent indices of Pacific sardine relative abundance. ALT columns show the acoustic estimates and SEs used in the previous model ALT. The updated estimates account for an updated herring target strength value.

Model Y-S	Acoustic	SE	ALT-Acoustic	ALT-SE
2005-2	1,947,063	0.3	1,947,063	0.3
2006-1	-	-	-	-
2006-2	-	-	-	-
2007-1	-	-	-	-
2007-2	751,075	0.09	751,075	0.09
2008-1	801,000	0.3	801,000	0.3
2008-2	-	-	-	-
2009-1	-	-	-	-
2009-2	357,006	0.41	357,006	0.41
2010-1	-	-	-	-
2010-2	493,672	0.3	493,672	0.3
2011-1	-	-	-	-
2011-2	469,480	0.28	469,480	0.28
2012-1	340,831	0.33	340,831	0.33
2012-2	305,146	0.24	305,146	0.24
2013-1	306,191	0.29	313,746	0.27
2013-2	35,339	0.38	35,339	0.38
2014-1	26,279	0.7	26,280	0.63
2014-2	29,048	0.29	29,048	0.29
2015-1	16,375	0.94	15,870	0.7
2015-2	83,030	0.47	83,030	0.47
2016-1	72,867	0.5	78,770	0.51
2016-2	-	-	-	-
2017-1	14,103	0.3	24,349	0.36
2017-2	-	-	-	-
2018-1	25,148	0.67	35,501	0.65
2018-2	-	-	-	-
2019-1	33,632	0.19	-	-

Table 7: Abundance by standard length (cm) for AT summer surveys 2017-2019.

SL (cm)	2017	2018	2019
4	0	0	0
5	0	0	0
6	938,376	0	0
7	1,407,563	0	0
8	1,407,563	1,003,181	0
9	37,458,127	2,161,093	0
10	37,458,127	19,630,447	0
11	0	36,669,350	0
12	0	31,232,681	0
13	0	9,479,509	0
14	0	0	4,739,631
15	0	9,445,972	41,539,498
16	0	17,575,747	59,579,268
17	90	17,297,285	90,576,517
18	2,646,754	2,571,115	32,295,316
19	1,155,073	488,532	14,385,176
20	10,902,914	257,930	6,519,870
21	19,682,611	663,480	6,730,283
22	32,775,963	1,151,296	2,482,943
23	16,389,747	13,531,991	9,275,903
24	2,446,053	41,917,903	30,709,103
25	2,597,826	37,951,826	30,803,378
26	4,135,409	8,601,750	10,187,719
27	292,821	246,290	2,374,336
28	0	1,588,705	907,076
29	0	0	9,303
30	0	0	0

Table 8: Abundance by age for AT summer surveys 2017-2019.

Age	2017	2018	2019
0	73,396,745	99,944,046	6,691,458
1	14,901,610	45,052,881	170,804,789
2	51,900,132	31,015,046	64,803,847
3	18,842,033	52,569,410	31,729,973
4	4,891,566	9,776,712	43,653,627
5	3,080,789	3,941,948	13,763,278
6	3,274,101	4,647,299	5,468,442
7	1,408,040	5,233,944	2,361,582
8+	0	1,284,797	3,838,323

Table 9: Values used for meta-analysis for prior on natural mortality. The estimates of von Bertalanffy growth rates (k) were weighted equally in the meta-analysis.

Parameter	Value	Reference	Weight
MaxAge	10.00		1
k	0.32	Conser et al. 2004	1/6
k	0.60	Hill et al. 2007	1/6
k	0.55	Hill et al. 2008	1/6
k	0.40	Hill et al. 2011	1/6
k	0.45	Hill et al. 2012	1/6
k	0.39	Hill et al. 2014	1/6

Table 10: Differences between previous model ALT (2017-2019) and 2020 base model.

		ALT (2017-2019)	2020 Base
Time period		2005-2018	2005-2019
Fisheries (no., type)		3, commercial	3, commercial
Surveys (no., type)		1, AT	1, AT
Natural mortality (M)		Fixed (0.6)	Estimated (prior)
Growth		Fixed (WAA)	Fixed (WAA)
Spawner-recruit relationship		Beverton-Holt	Beverton-Holt
	Equilibrium recruitment (R_0)	Estimated	Estimated
	Steepness (h)	Estimated	Fixed (0.3)
	Tot. recruitment variability (σ_R)	Fixed (0.75)	Fixed (1.2)
	Init. Equilibrium recruitment offset	Estimated	Estimated (now called SR regime)
Catchability (Q)		Estimated	Fixed (1 for 2005-2014; 0.73 for 2015-2019)
Selectivity (age-based)		Estimated	Estimated
Fishery selectivity		Dome-shaped and asymptotic	Dome-shaped and asymptotic
	Age composition	Yes	Yes
	Form	Age-specifc, random walk (MexCal) / Logistic (PNW)	Age-specifc, random walk (MexCal) / Logistic (PNW)
	Time-varying	No	Yes
Survey selectivity		Asymptotic	Asymptotic
	Age Composition	Yes	Yes
	Form	Age-specific, asymptotic	Age-specific, asymptotic
	Time-varying	No	Yes (age-0)
Fishery selectivity		Random walk (option 17)	Random walk (option 17)
Data weighting		No	No

Table 11: Model structure (data and processes) and results (likelihood and forecast stock biomass) for 2020 base model. The model ALT values show the results of updating model using SS version 3.30.14. The addition of features was cumulative.

Model descriptions	# pars.	Likelihood	Forecast year	Age 1+ biomass (mt)
2019 update	46	350.49	2019	27,547
SS v3.30.14	46	350.66	2019	27,118
Add 2020 data	47	374.27	2020	24,292
Fix h=0.3	46	374.33	2020	23,297
Set SR_regime lambda=0	46	362.12	2020	13,890
Fix Q=1; recent Q=0.73	45	362.06	2020	26,377
Add M prior	46	361.91	2020	26,700
Time-vary AT age-0 selex	60	310.43	2020	23,412
Time-vary fishery selectivity	140	141.91	2020	27,721
Tune sigma_R and recdev ramp	140	139.37	2020	26,728
Remove spring AT agecomps	140	91.69	2020	28,276
2020 base	140	91.69	2020	28,276

Table 12: Likelihood components, parameters, and stock biomass estimates for the 2020 base model. Total age-composition likelihoods and age-composition likelihoods by fleet are shown.

Likelihood	TOTAL	91.685
	Age_comp	78.641
	Age_like_AT_Survey	49.050
	Age_like_PNW	19.549
	Recruitment	8.690
	Age_like_MexCal_S1	5.303
	Age_like_MexCal_S2	4.739
	Survey	4.264
	Parm_softbounds	0.077
	Parm_priors	0.012
	Catch	0.000
Parameter	NatM_p_1_Fem_GP_1	0.585
	SR_LN(R0)	14.731
	SR_regime_BLK1repl_2004	2.241
	InitF_seas_1_flt_1MexCal_S1	1.362
Biomass	2019 Stock Biomass	35,186
	2020 Stock Biomass	28,276

Table 13: Parameter estimates in the 2020 base model. Estimated values, standard deviations (SDs), bounds (minimum and maximum), estimation phase (negative values not included), status (indicates if parameters are near bounds), and prior type information (mean, SD) are shown.

Parameter	Value	Phase	Bounds	Status	SD	Prior (Exp.Val, SD)
NatM_p_1_Fem_GP_1	0.5852	2	(0.2,0.94)	OK	0.0260	Log_Norm(-0.597559,0.394758)
SR_LN(R0)	14.7309	1	(3,25)	OK	0.2529	
SR_regime_BLK1repl_2004	2.2409	4	(-15,15)	OK	0.2948	
Early_InitAge_6	-0.4751	2	(-5,5)	act	0.7784	
Early_InitAge_5	-0.5845	2	(-5,5)	act	0.6835	
Early_InitAge_4	-0.3959	2	(-5,5)	act	0.7058	
Early_InitAge_3	-0.6585	2	(-5,5)	act	0.7013	
Early_InitAge_2	0.8944	2	(-5,5)	act	0.2584	
Early_InitAge_1	0.8315	2	(-5,5)	act	0.2174	
Main_RecrDev_2005	1.4346	1	(-5,5)	act	0.2361	
Main_RecrDev_2006	0.5614	1	(-5,5)	act	0.2504	
Main_RecrDev_2007	0.2044	1	(-5,5)	act	0.2580	
Main_RecrDev_2008	0.6291	1	(-5,5)	act	0.2221	
Main_RecrDev_2009	1.1316	1	(-5,5)	act	0.2195	
Main_RecrDev_2010	-1.4903	1	(-5,5)	act	0.6503	
Main_RecrDev_2011	-1.5883	1	(-5,5)	act	0.4953	
Main_RecrDev_2012	-1.5891	1	(-5,5)	act	0.4157	
Main_RecrDev_2013	-0.8977	1	(-5,5)	act	0.4844	
Main_RecrDev_2014	0.8025	1	(-5,5)	act	0.2318	
Main_RecrDev_2015	-0.5092	1	(-5,5)	act	0.4252	
Main_RecrDev_2016	0.4150	1	(-5,5)	act	0.2746	
Main_RecrDev_2017	0.7768	1	(-5,5)	act	0.2933	
Main_RecrDev_2018	0.1192	1	(-5,5)	act	1.1506	
Late_RecrDev_2019	0.0000	5	(-5,5)	act	1.2000	
ForeRecr_2020	0.0000	5	(-5,5)	act	1.2000	
InitF_seas_1_flt_1MexCal_S1	1.3624	1	(0,3)	OK	0.9236	
AgeSel_P1_MexCal_S1(1)	0.9996	3	(-7,9)	OK	178.8820	
AgeSel_P2_MexCal_S1(1)	0.8932	3	(-7,9)	OK	0.6593	
AgeSel_P3_MexCal_S1(1)	1.3085	3	(-7,9)	OK	0.4712	
AgeSel_P4_MexCal_S1(1)	-0.3337	3	(-7,9)	OK	2.1438	
AgeSel_P5_MexCal_S1(1)	-2.4927	3	(-7,9)	OK	16.3552	
AgeSel_P6_MexCal_S1(1)	-4.4089	3	(-7,9)	OK	48.3264	
AgeSel_P7_MexCal_S1(1)	-0.0697	3	(-7,9)	OK	2.1492	
AgeSel_P8_MexCal_S1(1)	-1.4830	3	(-7,9)	OK	5.1603	
AgeSel_P9_MexCal_S1(1)	-2.1138	3	(-7,9)	OK	8.2680	
AgeSel_P2_MexCal_S2(2)	0.0479	3	(-7,9)	OK	0.3300	
AgeSel_P3_MexCal_S2(2)	-0.4405	3	(-7,9)	OK	0.4578	
AgeSel_P4_MexCal_S2(2)	-0.4634	3	(-7,9)	OK	1.7500	
AgeSel_P5_MexCal_S2(2)	0.3509	3	(-7,9)	OK	0.5972	
AgeSel_P6_MexCal_S2(2)	-0.1994	3	(-7,9)	OK	0.6512	
AgeSel_P7_MexCal_S2(2)	-1.1086	3	(-7,9)	OK	1.1027	
AgeSel_P8_MexCal_S2(2)	-0.0559	3	(-7,9)	OK	1.6901	
AgeSel_P9_MexCal_S2(2)	-1.4954	3	(-7,9)	OK	4.0644	
Age_inflection_PNW(3)	2.4368	4	(0,10)	OK	0.1883	
Age_95%width_PNW(3)	0.6834	4	(-5,15)	OK	0.1593	
AgeSel_P2_AT_Survey(4)	0.0006	4	(0,9)	LO	0.0232	
AgeSel_P2_MexCal_S1(1)_BLK3repl_2006	8.6583	3	(-7,9)	OK	9.3543	
AgeSel_P2_MexCal_S1(1)_BLK3repl_2007	1.2404	3	(-7,9)	OK	0.9112	
AgeSel_P2_MexCal_S1(1)_BLK3repl_2008	1.5006	3	(-7,9)	OK	1.7193	
AgeSel_P2_MexCal_S1(1)_BLK3repl_2009	7.6079	3	(-7,9)	OK	29.2499	
AgeSel_P2_MexCal_S1(1)_BLK3repl_2010	8.5253	3	(-7,9)	OK	12.4025	
AgeSel_P2_MexCal_S1(1)_BLK3repl_2011	6.9760	3	(-7,9)	OK	38.5871	
AgeSel_P2_MexCal_S1(1)_BLK3repl_2012	6.2259	3	(-7,9)	OK	36.1066	
AgeSel_P2_MexCal_S1(1)_BLK3repl_2013	-0.2401	3	(-7,9)	OK	3.5103	
AgeSel_P2_MexCal_S1(1)_BLK3repl_2014	1.1096	3	(-7,9)	OK	164.6170	

Table 13: Parameter estimates in the 2020 base model. Estimated values, standard deviations (SDs), bounds (minimum and maximu *(continued)*

Parameter	Value	Phase	Bounds	Status	SD	Prior (Exp.Val, SD)
AgeSel_P3_MexCal_S1(1)_BLK3repl_2006	-0.4314	3	(-7,9)	OK	0.3819	
AgeSel_P3_MexCal_S1(1)_BLK3repl_2007	1.4268	3	(-7,9)	OK	0.4532	
AgeSel_P3_MexCal_S1(1)_BLK3repl_2008	1.2125	3	(-7,9)	OK	0.8453	
AgeSel_P3_MexCal_S1(1)_BLK3repl_2009	3.5393	3	(-7,9)	OK	2.1809	
AgeSel_P3_MexCal_S1(1)_BLK3repl_2010	-0.5793	3	(-7,9)	OK	0.9676	
AgeSel_P3_MexCal_S1(1)_BLK3repl_2011	1.7492	3	(-7,9)	OK	0.5638	
AgeSel_P3_MexCal_S1(1)_BLK3repl_2012	-0.9270	3	(-7,9)	OK	1.1488	
AgeSel_P3_MexCal_S1(1)_BLK3repl_2013	2.9614	3	(-7,9)	OK	3.0817	
AgeSel_P3_MexCal_S1(1)_BLK3repl_2014	1.8358	3	(-7,9)	OK	120.0290	
AgeSel_P4_MexCal_S1(1)_BLK3repl_2006	-1.2999	3	(-7,9)	OK	1.1199	
AgeSel_P4_MexCal_S1(1)_BLK3repl_2007	-1.3412	3	(-7,9)	OK	0.6501	
AgeSel_P4_MexCal_S1(1)_BLK3repl_2008	-6.7386	3	(-7,9)	OK	7.3464	
AgeSel_P4_MexCal_S1(1)_BLK3repl_2009	-3.7008	3	(-7,9)	OK	3.3215	
AgeSel_P4_MexCal_S1(1)_BLK3repl_2010	-1.4760	3	(-7,9)	OK	2.8960	
AgeSel_P4_MexCal_S1(1)_BLK3repl_2011	0.1598	3	(-7,9)	OK	0.6756	
AgeSel_P4_MexCal_S1(1)_BLK3repl_2012	1.0494	3	(-7,9)	OK	0.6117	
AgeSel_P4_MexCal_S1(1)_BLK3repl_2013	-1.9513	3	(-7,9)	OK	1.5618	
AgeSel_P4_MexCal_S1(1)_BLK3repl_2014	7.1185	3	(-7,9)	OK	36.7615	
AgeSel_P5_MexCal_S1(1)_BLK3repl_2006	-5.1566	3	(-7,9)	OK	37.2324	
AgeSel_P5_MexCal_S1(1)_BLK3repl_2007	-6.6346	3	(-7,9)	OK	9.9454	
AgeSel_P5_MexCal_S1(1)_BLK3repl_2008	2.9368	3	(-7,9)	OK	7.8024	
AgeSel_P5_MexCal_S1(1)_BLK3repl_2009	-3.8179	3	(-7,9)	OK	35.4613	
AgeSel_P5_MexCal_S1(1)_BLK3repl_2010	-6.0284	3	(-7,9)	OK	22.5069	
AgeSel_P5_MexCal_S1(1)_BLK3repl_2011	-6.4820	3	(-7,9)	OK	13.4541	
AgeSel_P5_MexCal_S1(1)_BLK3repl_2012	-1.2854	3	(-7,9)	OK	2.0595	
AgeSel_P5_MexCal_S1(1)_BLK3repl_2013	2.2521	3	(-7,9)	OK	1.0774	
AgeSel_P5_MexCal_S1(1)_BLK3repl_2014	0.9322	3	(-7,9)	OK	3.6924	
AgeSel_P6_MexCal_S1(1)_BLK3repl_2006	-1.2270	3	(-7,9)	OK	96.3362	
AgeSel_P6_MexCal_S1(1)_BLK3repl_2007	-1.2193	3	(-7,9)	OK	93.6115	
AgeSel_P6_MexCal_S1(1)_BLK3repl_2008	-5.1867	3	(-7,9)	OK	35.5619	
AgeSel_P6_MexCal_S1(1)_BLK3repl_2009	-3.3635	3	(-7,9)	OK	65.4092	
AgeSel_P6_MexCal_S1(1)_BLK3repl_2010	-1.5192	3	(-7,9)	OK	78.4380	
AgeSel_P6_MexCal_S1(1)_BLK3repl_2011	-2.8006	3	(-7,9)	OK	60.4925	
AgeSel_P6_MexCal_S1(1)_BLK3repl_2012	-1.8037	3	(-7,9)	OK	4.5241	
AgeSel_P6_MexCal_S1(1)_BLK3repl_2013	-0.9744	3	(-7,9)	OK	1.9505	
AgeSel_P6_MexCal_S1(1)_BLK3repl_2014	1.4459	3	(-7,9)	OK	1.3166	
AgeSel_P2_MexCal_S2(2)_BLK3repl_2006	1.3806	3	(-7,9)	OK	0.3950	
AgeSel_P2_MexCal_S2(2)_BLK3repl_2007	-0.2772	3	(-7,9)	OK	0.3633	
AgeSel_P2_MexCal_S2(2)_BLK3repl_2008	1.9461	3	(-7,9)	OK	0.7279	
AgeSel_P2_MexCal_S2(2)_BLK3repl_2009	0.8361	3	(-7,9)	OK	0.3710	
AgeSel_P2_MexCal_S2(2)_BLK3repl_2010	0.5897	3	(-7,9)	OK	0.5187	
AgeSel_P2_MexCal_S2(2)_BLK3repl_2011	-1.5062	3	(-7,9)	OK	0.9162	
AgeSel_P2_MexCal_S2(2)_BLK3repl_2012	3.7226	3	(-7,9)	OK	6.1909	
AgeSel_P2_MexCal_S2(2)_BLK3repl_2013	2.2524	3	(-7,9)	OK	3.1107	
AgeSel_P2_MexCal_S2(2)_BLK3repl_2014	0.7133	3	(-7,9)	OK	0.7344	
AgeSel_P3_MexCal_S2(2)_BLK3repl_2006	-0.9642	3	(-7,9)	OK	0.3895	
AgeSel_P3_MexCal_S2(2)_BLK3repl_2007	-1.2956	3	(-7,9)	OK	0.5324	
AgeSel_P3_MexCal_S2(2)_BLK3repl_2008	-1.2453	3	(-7,9)	OK	0.6042	
AgeSel_P3_MexCal_S2(2)_BLK3repl_2009	-1.0360	3	(-7,9)	OK	0.7915	
AgeSel_P3_MexCal_S2(2)_BLK3repl_2010	-1.8725	3	(-7,9)	OK	2.4887	
AgeSel_P3_MexCal_S2(2)_BLK3repl_2011	1.0269	3	(-7,9)	OK	0.4368	
AgeSel_P3_MexCal_S2(2)_BLK3repl_2012	-0.6996	3	(-7,9)	OK	1.5213	
AgeSel_P3_MexCal_S2(2)_BLK3repl_2013	2.2189	3	(-7,9)	OK	1.7916	
AgeSel_P3_MexCal_S2(2)_BLK3repl_2014	-1.3578	3	(-7,9)	OK	1.0377	
AgeSel_P4_MexCal_S2(2)_BLK3repl_2006	-1.7581	3	(-7,9)	OK	1.4688	
AgeSel_P4_MexCal_S2(2)_BLK3repl_2007	-1.3883	3	(-7,9)	OK	1.2297	
AgeSel_P4_MexCal_S2(2)_BLK3repl_2008	-4.5123	3	(-7,9)	OK	3.4178	
AgeSel_P4_MexCal_S2(2)_BLK3repl_2009	-5.5923	3	(-7,9)	OK	3.0961	
AgeSel_P4_MexCal_S2(2)_BLK3repl_2010	1.9650	3	(-7,9)	OK	2.4864	

Table 13: Parameter estimates in the 2020 base model. Estimated values, standard deviations (SDs), bounds (minimum and maximu *(continued)*

Parameter	Value	Phase	Bounds	Status	SD	Prior (Exp.Val, SD)
AgeSel_P4_MexCal_S2(2)_BLK3repl_2011	-0.1931	3	(-7,9)	OK	0.6185	
AgeSel_P4_MexCal_S2(2)_BLK3repl_2012	-0.1218	3	(-7,9)	OK	1.0507	
AgeSel_P4_MexCal_S2(2)_BLK3repl_2013	-0.8163	3	(-7,9)	OK	1.3558	
AgeSel_P4_MexCal_S2(2)_BLK3repl_2014	-1.9224	3	(-7,9)	OK	1.8698	
Age_inflection_PNW(3)_BLK3repl_2006	3.1883	4	(0,10)	OK	0.2199	
Age_inflection_PNW(3)_BLK3repl_2007	3.1092	4	(0,10)	OK	0.1380	
Age_inflection_PNW(3)_BLK3repl_2008	3.5559	4	(0,10)	OK	0.2059	
Age_inflection_PNW(3)_BLK3repl_2009	4.0469	4	(0,10)	OK	0.1572	
Age_inflection_PNW(3)_BLK3repl_2010	3.9299	4	(0,10)	OK	0.3017	
Age_inflection_PNW(3)_BLK3repl_2011	3.2315	4	(0,10)	OK	0.2199	
Age_inflection_PNW(3)_BLK3repl_2012	2.2609	4	(0,10)	OK	0.1134	
Age_inflection_PNW(3)_BLK3repl_2013	2.9096	4	(0,10)	OK	0.1777	
Age_inflection_PNW(3)_BLK3repl_2014	3.6542	4	(0,10)	OK	0.4233	
AgeSel_P2_AT_Survey(4)_BLK2repl_2007	7.1577	4	(0,9)	OK	37.3381	
AgeSel_P2_AT_Survey(4)_BLK2repl_2008	0.7779	4	(0,9)	OK	1.4657	
AgeSel_P2_AT_Survey(4)_BLK2repl_2009	5.3100	4	(0,9)	OK	72.0467	
AgeSel_P2_AT_Survey(4)_BLK2repl_2010	0.4686	4	(0,9)	OK	0.8724	
AgeSel_P2_AT_Survey(4)_BLK2repl_2011	0.0240	4	(0,9)	LO	0.7727	
AgeSel_P2_AT_Survey(4)_BLK2repl_2012	0.0106	4	(0,9)	LO	0.3355	
AgeSel_P2_AT_Survey(4)_BLK2repl_2013	7.5648	4	(0,9)	OK	30.6067	
AgeSel_P2_AT_Survey(4)_BLK2repl_2014	7.9343	4	(0,9)	OK	24.1923	
AgeSel_P2_AT_Survey(4)_BLK2repl_2015	0.0001	4	(0,9)	LO	0.0055	
AgeSel_P2_AT_Survey(4)_BLK2repl_2016	7.4183	4	(0,9)	OK	33.0539	
AgeSel_P2_AT_Survey(4)_BLK2repl_2017	0.0005	4	(0,9)	LO	0.0180	
AgeSel_P2_AT_Survey(4)_BLK2repl_2018	0.0022	4	(0,9)	LO	0.0723	
AgeSel_P2_AT_Survey(4)_BLK2repl_2019	8.1485	4	(0,9)	OK	20.1864	

Table 14: Pacific sardine numbers-at-age (thousands) for 2020 base model year-semesters.

Calendar Y-S	Model Y-S	Age0	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9	Age10+
–	VIRG	2,497,660	1,391,150	774,848	431,577	240,381	133,888	74,573	41,536	23,135	12,886	16,201
–	VIRG	1,864,030	1,038,230	578,279	322,091	179,399	99,922	55,655	30,999	17,266	9,617	12,091
–	INIT	23,481,700	12,129,600	5,620,100	1,583,980	541,620	289,745	161,304	89,802	50,013	27,856	35,021
–	INIT	16,252,700	7,530,480	2,122,410	725,727	388,235	216,134	120,328	67,014	37,325	20,789	26,136
2005-2	2005-1	23,481,700	14,475,300	7,458,090	469,594	220,413	103,071	67,570	89,802	50,013	27,856	35,021
2006-1	2005-2	17,482,000	10,732,500	5,230,280	260,728	121,165	56,713	37,179	49,412	27,519	15,327	19,270
2006-2	2006-1	10,243,900	12,735,300	7,809,140	3,839,800	192,458	89,048	41,790	27,616	36,711	20,505	25,779
2007-1	2006-2	7,645,090	9,274,650	5,727,840	2,646,520	113,283	52,046	24,422	16,139	21,454	11,983	15,065
2007-2	2007-1	4,440,300	5,617,360	6,505,610	4,174,880	1,967,100	84,057	38,659	18,198	12,027	16,006	20,180
2008-1	2007-2	3,293,000	4,101,720	4,427,960	2,879,950	1,276,430	54,383	25,010	11,774	7,781	10,356	13,056
2008-2	2008-1	3,036,910	2,152,590	2,768,640	3,215,020	2,134,650	943,384	40,264	18,616	8,765	5,804	17,462
2009-1	2008-2	2,245,580	1,541,100	1,796,540	2,374,160	1,424,670	621,685	26,527	12,265	5,775	3,824	11,505
2009-2	2009-1	4,349,860	1,602,630	841,041	1,225,260	1,770,120	1,061,760	463,438	19,790	9,150	4,309	11,439
2010-1	2009-2	3,246,340	1,187,060	483,904	906,721	1,214,160	659,034	286,796	12,247	5,662	2,667	7,079
2010-2	2010-1	6,382,960	2,169,740	686,836	329,953	676,411	902,475	487,820	212,317	9,066	4,192	7,215
2011-1	2010-2	4,763,610	1,490,640	489,329	242,542	435,879	523,068	282,037	122,749	5,242	2,424	4,171
2011-2	2011-1	400,378	3,435,340	1,045,790	361,739	169,145	295,435	360,756	205,078	89,381	3,890	4,895
2012-1	2011-2	298,799	2,487,600	655,309	204,648	96,997	167,872	204,963	116,516	50,782	2,210	2,781
2012-2	2012-1	320,608	182,354	1,775,510	431,640	135,534	58,925	104,481	138,196	78,729	35,321	3,472
2013-1	2012-2	239,258	133,795	1,131,790	174,808	54,204	23,646	41,929	55,489	31,616	14,184	1,394
2013-2	2013-1	230,611	177,816	83,980	771,804	118,904	35,685	15,874	29,869	39,591	23,047	11,356
2014-1	2013-2	171,845	132,524	60,473	390,408	45,304	13,784	6,136	11,645	15,469	9,005	4,437
2014-2	2014-1	267,296	128,004	97,114	38,137	267,611	29,886	9,267	4,371	8,308	11,270	9,793
2015-1	2014-2	199,486	95,531	72,454	27,483	140,604	13,140	4,108	2,145	4,185	5,677	4,933
2015-2	2015-1	874,285	143,786	66,408	53,090	20,347	96,725	8,891	2,785	1,454	2,839	7,198
2016-1	2015-2	652,490	107,310	49,561	39,614	15,147	71,947	6,614	2,072	1,082	2,113	5,356
2016-2	2016-1	198,698	484,317	79,201	36,882	29,552	11,297	53,665	4,935	1,546	807	5,574
2017-1	2016-2	148,291	361,452	59,108	27,440	21,726	8,119	38,635	3,623	1,141	596	4,113
2017-2	2017-1	533,748	92,298	186,243	40,104	20,195	15,897	5,961	28,680	2,690	851	3,510
2018-1	2017-2	398,343	68,883	138,995	29,840	14,957	11,487	4,317	21,257	2,006	634	2,617
2018-2	2018-1	644,242	222,962	28,579	89,193	21,783	10,816	8,353	3,194	15,734	1,494	2,422
2019-1	2018-2	480,806	166,399	21,329	66,517	16,219	8,007	6,187	2,378	11,731	1,114	1,806
2019-2	2019-1	580,925	222,512	46,833	12,386	47,854	11,487	5,724	4,551	1,751	8,726	2,172
2020-1	2019-2	433,552	166,064	34,952	9,219	35,447	8,318	4,153	3,373	1,305	6,503	1,619
2020-2	2020-1	438,996	194,984	44,088	19,995	6,617	25,027	5,931	3,053	2,481	970	6,041
2021-1	2020-2	327,629	145,519	32,903	14,912	4,927	18,527	4,393	2,273	1,850	724	4,504

Table 15: Pacific sardine biomass-at-age for 2020 base model year-semesters.

Calendar Y-S	Model Y-S	Age0	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9	Age10+	Total Age0+	Total Age1+
–	VIRG	31,221	61,906	56,874	55,156	34,687	22,440	13,259	7,975	4,634	2,502	3,232	293,885	262,665
–	VIRG	108,860	70,289	43,718	28,956	19,070	12,800	8,994	6,194	3,370	1,644	2,066	305,960	197,100
–	INIT	293,521	539,768	412,515	202,433	78,156	48,561	28,680	17,242	10,018	5,410	6,987	1,643,290	1,349,769
–	INIT	949,159	509,814	160,454	65,243	41,269	27,687	19,445	13,389	7,286	3,553	4,467	1,801,766	852,607
2005-2	2005-1	293,521	644,149	547,424	60,014	31,806	17,275	12,014	17,242	10,018	5,410	6,987	1,645,858	1,352,337
2006-1	2005-2	1,020,950	726,590	395,409	23,440	12,880	7,265	6,008	9,873	5,372	2,619	3,293	2,213,698	1,192,748
2006-2	2006-1	128,048	717,000	585,685	313,712	25,270	13,411	7,330	5,090	7,060	4,107	5,143	1,811,854	1,683,806
2007-1	2006-2	446,473	627,894	433,025	237,922	12,042	6,667	3,947	3,225	4,188	2,048	2,575	1,780,005	1,333,532
2007-2	2007-1	55,504	253,343	458,646	404,546	195,923	11,331	6,066	3,354	2,289	3,108	4,042	1,398,151	1,342,647
2008-1	2007-2	231,168	330,599	407,372	324,858	163,256	7,445	3,629	1,815	1,555	2,021	1,920	1,475,639	1,244,471
2008-2	2008-1	46,465	190,074	288,216	399,949	288,178	132,640	5,661	2,617	1,659	1,104	3,391	1,359,955	1,313,490
2009-1	2008-2	157,639	124,213	165,281	267,805	182,216	85,109	3,849	1,891	883	764	2,246	991,896	834,257
2009-2	2009-1	54,373	71,477	74,853	144,826	222,504	134,206	63,398	3,062	1,741	837	2,282	773,559	719,186
2010-1	2009-2	129,529	104,936	57,923	125,218	178,117	100,437	45,285	2,011	925	425	1,414	746,220	616,691
2010-2	2010-1	79,787	104,147	48,628	35,899	91,180	123,459	68,392	31,062	1,725	814	1,439	586,534	506,747
2011-1	2010-2	290,104	95,997	33,470	33,362	53,526	77,676	46,113	21,420	907	403	694	653,671	363,567
2011-2	2011-1	5,245	247,345	115,142	42,649	20,703	40,445	51,191	28,485	12,871	740	951	565,768	560,523
2012-1	2011-2	23,665	252,740	75,623	27,914	15,073	28,018	35,971	21,287	9,232	392	493	490,408	466,743
2012-2	2012-1	4,200	20,506	205,959	52,315	17,335	8,909	17,354	22,498	13,967	6,312	661	370,015	365,815
2013-1	2012-2	27,299	16,577	146,454	24,228	8,071	3,748	7,103	10,154	5,726	2,445	240	252,046	224,747
2013-2	2013-1	3,021	19,995	12,580	117,468	18,406	6,487	3,100	4,979	6,833	3,715	1,831	198,417	195,396
2014-1	2013-2	26,739	21,111	9,791	64,964	7,733	2,401	1,091	2,118	2,805	1,609	793	141,155	114,416
2014-2	2014-1	2,593	22,490	17,345	6,971	49,401	5,777	1,897	878	1,669	2,264	1,967	113,252	110,660
2015-1	2014-2	18,233	14,865	12,491	3,952	25,717	2,569	828	441	859	1,150	1,000	82,104	63,871
2015-2	2015-1	3,497	18,247	10,340	10,496	4,189	20,090	1,820	560	304	594	1,507	71,644	68,147
2016-1	2015-2	23,424	11,325	7,712	6,829	2,810	14,713	1,413	455	237	455	1,153	70,526	47,102
2016-2	2016-1	9,220	33,902	10,724	5,853	5,733	2,213	10,851	1,115	338	180	1,167	81,296	72,077
2017-1	2016-2	5,324	15,326	6,656	3,671	4,030	1,660	8,256	796	250	128	886	46,982	41,659
2017-2	2017-1	5,711	10,051	23,448	5,771	3,266	3,025	1,278	6,783	636	201	830	61,000	55,289
2018-1	2017-2	14,300	2,921	8,868	3,993	2,775	2,349	923	4,668	439	137	564	41,935	27,634
2018-2	2018-1	12,563	12,241	5,110	17,205	4,259	2,212	1,837	723	4,695	446	723	62,012	49,449
2019-1	2018-2	17,261	7,055	1,361	8,900	3,009	1,637	1,322	522	2,568	240	389	44,264	27,003
2019-2	2019-1	25,503	13,039	3,484	1,826	9,164	2,363	1,053	996	451	2,250	560	60,689	35,186
2020-1	2019-2	15,564	7,041	2,230	1,233	6,575	1,701	887	741	286	1,400	348	38,008	22,443
2020-2	2020-1	19,272	11,426	3,280	2,947	1,267	5,148	1,091	668	640	250	1,557	47,547	28,275
2021-1	2020-2	11,762	6,170	2,099	1,995	914	3,789	939	499	405	156	970	29,698	17,936

Table 16: Spawning stock biomas (SSB) and recruitment (1000s of fish) estimates and asymptotic standard errors for base model. SSB estimates were calculated at the beginning of semester 2 of each model year (January). Recruits were age-0 fish calculated at the beginning of each model year (July).

Calendar Y-S	Model Y-S	SSB	SSB sd	Recruits	Recruits sd
–	VIRG-1	0	0	0	0
–	VIRG-2	186,412	46,615	2,497,660	631,756
–	INIT-1	0	0	0	0
–	INIT-2	717,077	210,708	0	0
2005-2	2005-1	0	0	23,481,700	4,138,620
2006-1	2005-2	944,410	114,999	0	0
2006-2	2006-1	0	0	10,243,900	1,746,000
2007-1	2006-2	1,136,270	109,953	0	0
2007-2	2007-1	0	0	4,440,300	770,711
2008-1	2007-2	1,010,600	81,786	0	0
2008-2	2008-1	0	0	3,036,910	596,284
2009-1	2008-2	760,343	51,472	0	0
2009-2	2009-1	0	0	4,349,860	586,281
2010-1	2009-2	508,691	31,034	0	0
2010-2	2010-1	0	0	6,382,960	858,061
2011-1	2010-2	346,715	20,725	0	0
2011-2	2011-1	0	0	400,378	275,621
2012-1	2011-2	265,112	16,697	0	0
2012-2	2012-1	0	0	320,608	160,608
2013-1	2012-2	148,558	13,115	0	0
2013-2	2013-1	0	0	230,611	98,577
2014-1	2013-2	69,620	9,106	0	0
2014-2	2014-1	0	0	267,296	131,230
2015-1	2014-2	37,557	6,214	0	0
2015-2	2015-1	0	0	874,285	171,644
2016-1	2015-2	30,991	4,662	0	0
2016-2	2016-1	0	0	198,698	82,566
2017-1	2016-2	33,300	4,377	0	0
2017-2	2017-1	0	0	533,748	135,803
2018-1	2017-2	27,435	4,083	0	0
2018-2	2018-1	0	0	644,242	147,018
2019-1	2018-2	24,561	3,595	0	0
2019-2	2019-1	0	0	580,925	683,231
2020-1	2019-2	20,623	3,924	0	0
2020-2	2020-1	0	0	0	0
2021-1	2020-2	16,768	11,190	0	0

Table 17: Annual exploitation rate (calendar year landings / July total biomass) by country and calendar year.

Calendar Year	Mexico	USA	Canada	Total
2005	0.00	0.04	0.00	0.05
2006	0.01	0.05	0.00	0.06
2007	0.02	0.08	0.00	0.10
2008	0.02	0.06	0.01	0.09
2009	0.03	0.09	0.02	0.13
2010	0.03	0.10	0.04	0.17
2011	0.05	0.08	0.04	0.17
2012	0.03	0.27	0.06	0.35
2013	0.07	0.33	0.00	0.40
2014	0.00	0.22	0.00	0.23
2015	0.00	0.05	0.00	0.05
2016	0.00	0.01	0.00	0.01
2017	0.16	0.01	0.00	0.17
2018	0.13	0.01	0.00	0.14
2019	0.22	0.01	0.00	0.23

Table 18: Parameter estimates and stock biomass (age 1+ mt) associated with fixed values of terminal-year biomass.

		Terminal-year biomass									
		10,000	20,000	30,000	40,000	50,000	60,000	70,000	80,000	90,000	100,000
Parameter	NatM_p_1_Fem_GP_1	0.608	0.599	0.591	0.587	0.583	0.581	0.579	0.578	0.577	0.576
	SR_LN(R0)	14.566	14.612	14.662	14.713	14.76	14.802	14.838	14.87	14.898	14.922
	SR_regime_BLK1repl_2004	2.507	2.421	2.338	2.265	2.202	2.148	2.105	2.068	2.036	2.008
	InitF_seas_1_flt_1MexCal_S1	1.261	1.304	1.336	1.357	1.371	1.382	1.389	1.394	1.397	1.4
Stock Biomass (age1+ mt)	2019	9,671	18,593	26,050	32,807	39,233	45,427	51,287	56,941	62,470	67,901
	2020	6,630	11,846	18,983	25,876	32,314	38,370	43,768	48,789	53,594	58,234

Table 19: Parameter estimates and stock biomass (age 1+; mt) associated with fixed values of natural mortality (M). The MLE estimate of M was 0.585 in the 2020 base model. Likelihood components associated with the natural mortality profile are in Figure 50.

		Natural mortality							
		0.3	0.4	0.5	MLE; 0.585	0.6	0.7	0.8	0.9
Parameter	SR_LN(R0)	24.996	14.715	14.613	14.731	14.762	14.984	15.218	15.485
	SR_regime_BLK1repl_2004	-9.366	1.358	1.937	2.241	2.281	2.532	2.769	2.971
	InitF_seas_1_flt_1MexCal_S1	2.192	1.985	1.677	1.362	1.304	0.875	0.41	0
Stock Biomass (age1+ mt)	2019	52,846	45,838	39,450	35,186	34,542	30,961	28,305	26,209
	2020	39,262	34,925	30,520	28,276	28,006	26,794	26,158	26,017

Table 20: Parameter estimates and stock biomass (age 1+ mt) associated percentage changes in catchability (Q).

		Percent change Q										
		-50	-40	-30	-20	-10	0	10	20	30	40	50
Parameter	NatM_p_1_Fem_GP_1	0.713	0.686	0.66	0.633	0.61	0.585	0.561	0.54	0.519	0.497	0.477
	SR_LN(R0)	15.108	14.974	14.876	14.801	14.757	14.731	14.729	14.642	14.703	14.793	14.906
	SR_regime_BLK1repl_2004	2.824	2.718	2.61	2.488	2.375	2.241	2.094	2.062	1.882	1.672	1.456
	InitF_seas_1_flt_1MexCal_S1	0.772	0.901	1.022	1.146	1.251	1.362	1.47	1.559	1.649	1.741	1.823
Stock Biomass (age1+; mt)	2019	67,559	56,856	49,258	43,140	38,920	35,152	32,382	29,317	27,413	25,557	24,181
	2020	71,557	57,614	47,528	39,264	33,476	28,238	24,258	15,176	14,221	13,185	12,314

Table 21: Parameter estimates and stock biomass (age 1+ mt) associated with fixed values of steepness (h). Likelihood components associated with the steepness profile are in Figure 52. Steepness was fixed at 0.3 in the 2020 base model

		Steepness							
		0.25	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Parameter	NatM_p_1_Fem_GP_1	0.586	0.585	0.584	0.584	0.583	0.583	0.582	0.582
	SR_LN(R0)	14.578	14.731	14.738	14.689	14.639	14.595	14.558	14.526
	SR_regime_BLK1repl_2004	2.396	2.241	2.231	2.278	2.327	2.369	2.406	2.437
	InitF_seas_1_flt_1MexCal_S1	1.358	1.362	1.369	1.375	1.38	1.384	1.387	1.39
Stock Biomass (age1+ mt)	2019	35,005	35,186	35,465	35,686	35,877	36,046	36,198	36,334
	2020	24,134	28,276	36,478	44,325	51,574	58,120	63,967	69,177

Table 22: Harvest control rules for the 2020-2021 management cycle. Base model SSB was projected to be 16,769 mt (SD=11,190 mt; CV=0.607) in January 2021, so the corresponding Sigma for calculating P-star buffers is 0.607, rather than the newly adopted default value (0.50) for Tier 1 assessments. ABC calculations based on sigma values (SigmaTier 1=0.607, SigmaTier 2=1.0) are provided below.

Harvest Control Rule Formulas									
OFL = BIOMASS * E_{MSY} * DISTRIBUTION; where E_{MSY} is bounded 0.00 to 0.25									
$ABC_{P\text{-}star}$ = BIOMASS * $BUFFER_{P\text{-}star}$ * E_{MSY} * DISTRIBUTION; where E_{MSY} is bounded 0.00 to 0.25									
HG = (BIOMASS - CUTOFF) * FRACTION * DISTRIBUTION; where FRACTION is E_{MSY} bounded 0.05 to 0.20									
Harvest Formula Parameters									
BIOMASS (ages 1+, mt)	**28,276**								
P-star	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05
ABC $Buffer_{(Sigma\ 0.607)}$	0.92657	0.85748	0.79148	0.72742	0.66408	0.60003	0.53312	0.45943	0.36852
ABC $Buffer_{Tier\ 2}$	0.88191	0.77620	0.68023	0.59191	0.50942	0.43101	0.35472	0.27761	0.19304
CalCOFI SST (2016-2018)	15.9965								
E_{MSY}	0.224584								
FRACTION	0.200000								
CUTOFF (mt)	150,000								
DISTRIBUTION (U.S.)	0.87								
Harvest Control Rule Values (MT)									
OFL =	**5,525**								
$ABC_{(Sigma\ 0.607)}$ =	5,119	4,737	4,373	4,019	3,669	3,315	2,945	2,538	2,036
$ABC_{Tier\ 2}$ =	4,872	4,288	3,758	3,270	2,814	2,381	1,960	1,534	1,067
HG =	**0**								

Table 23: CalCOFI annual and three-year (calendar) average sea surface temperature (SST, °C) since 1984. Three-year average SST is used to calculate E_{msy} in the harvest control rules.

Cal. year	Annual SST	3yr average SST
1984	16.35	—
1985	15.76	—
1986	15.98	16.032
1987	16.30	16.0134
1988	15.79	16.0216
1989	15.46	15.8485
1990	15.99	15.7476
1991	15.80	15.7525
1992	16.70	16.1657
1993	16.42	16.3069
1994	16.48	16.5324
1995	15.92	16.2729
1996	16.33	16.2419
1997	16.70	16.3148
1998	16.77	16.5973
1999	15.28	16.2504
2000	15.79	15.949
2001	15.55	15.5429
2002	14.94	15.4285
2003	16.03	15.5092
2004	15.88	15.6197
2005	15.46	15.792
2006	15.92	15.753
2007	15.15	15.5095
2008	15.27	15.4475
2009	15.36	15.2617
2010	15.55	15.3942
2011	15.56	15.4907
2012	15.29	15.4688
2013	14.91	15.2532
2014	16.77	15.6564
2015	17.47	16.3828
2016	16.33	16.8562
2017	16.12	16.6391
2018	15.89	16.1123
2019	15.98	15.9965

10 Figures

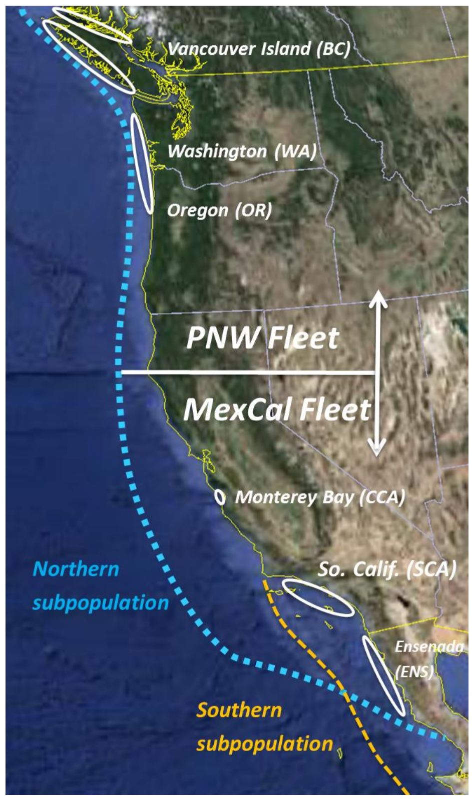

Figure 1: Distribution of the northern subpopulation (NSP) of Pacific sardine, primary commercial fishing areas, and modeled fishing fleets.

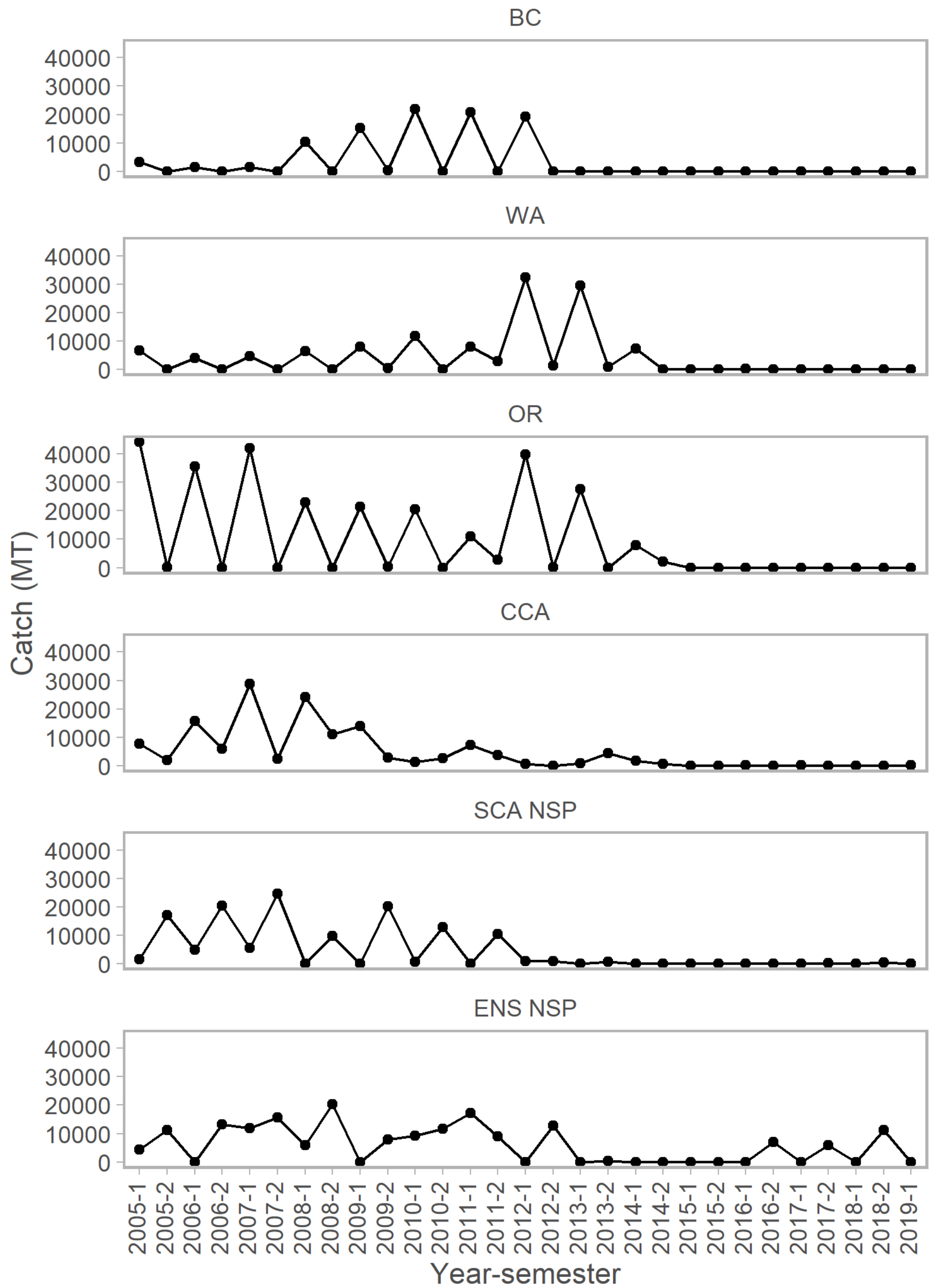

Figure 2: Pacific sardine landings (mt) by major fishing region (British Columbia, Washington, Oregon, Central California, Southern California, and Ensenada).

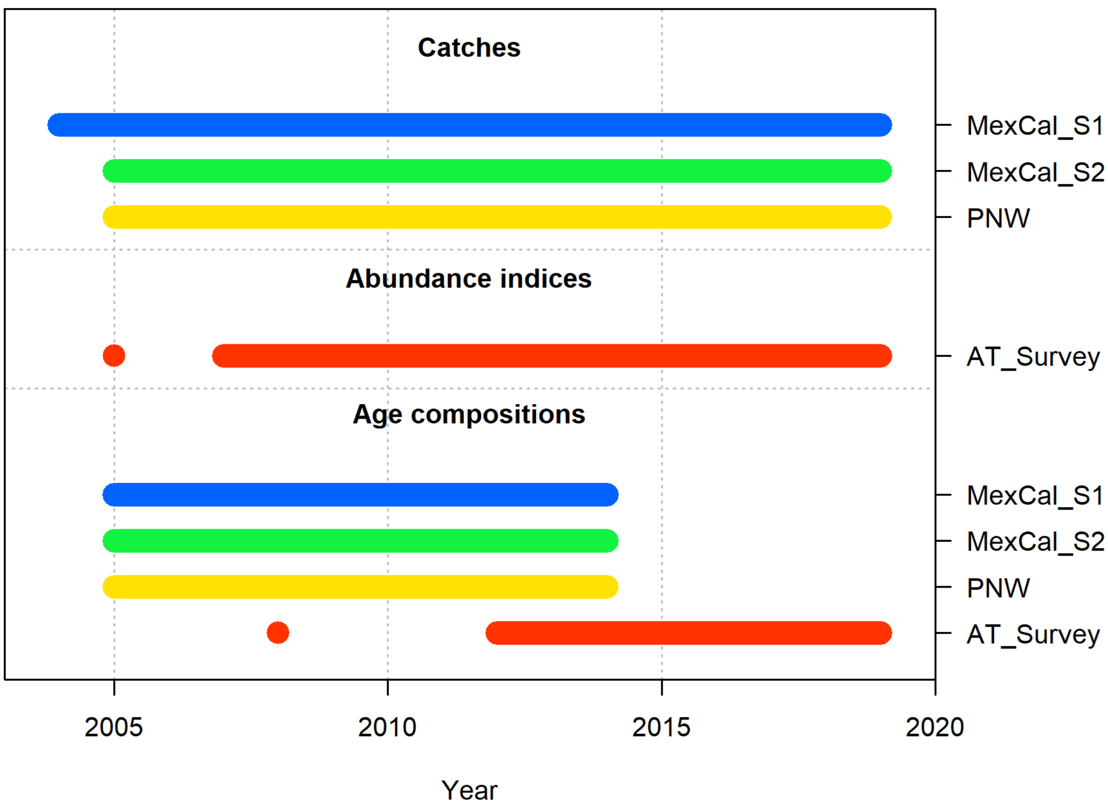

Figure 3: Summary of data sources used in the 2020 base model.

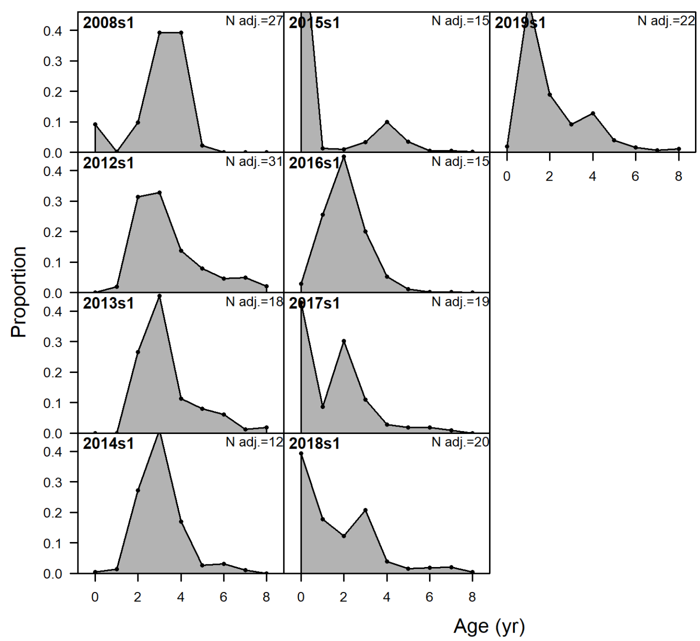

Figure 4: Age-composition time series for the AT Survey. N represents input sample sizes.

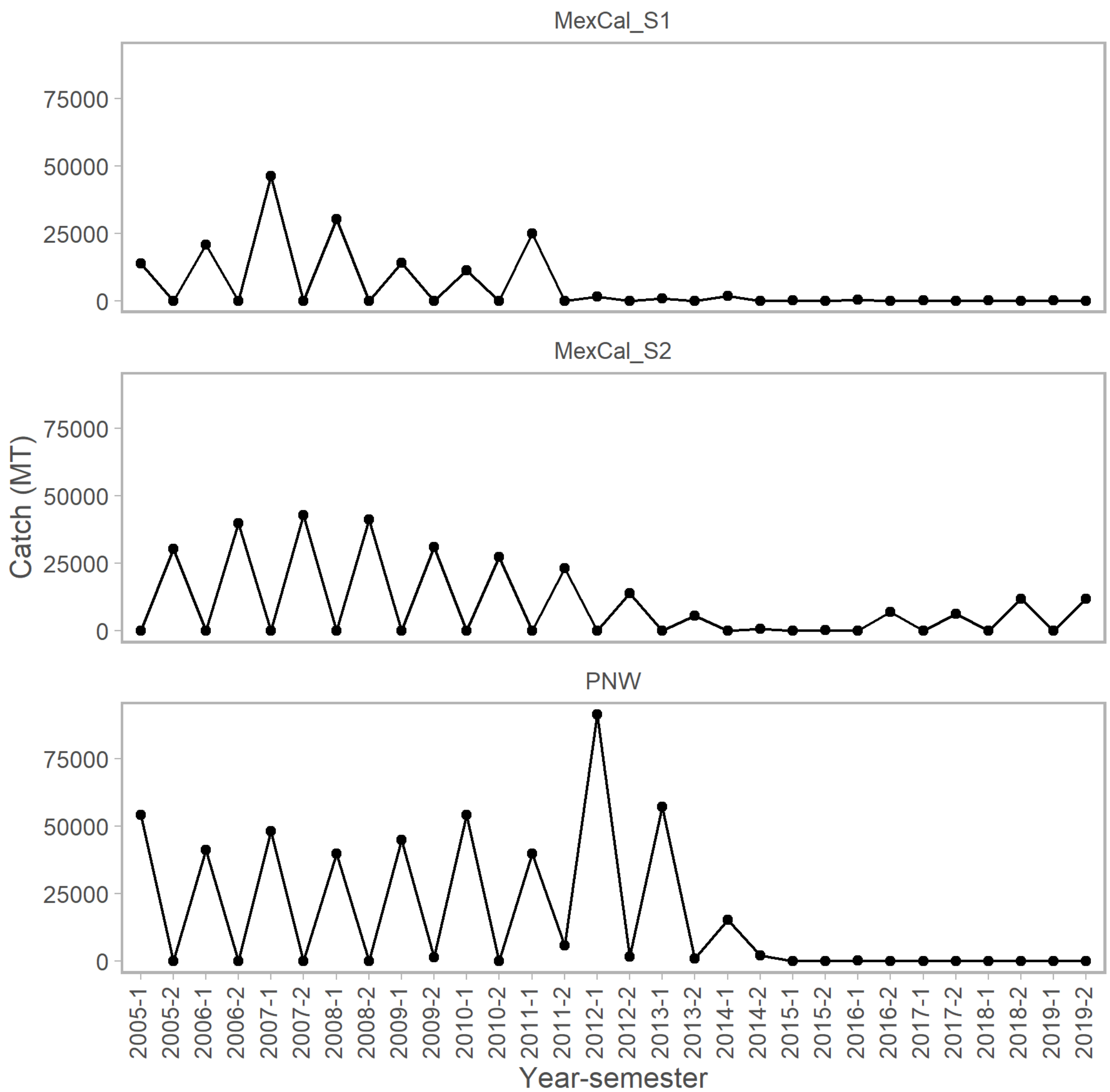

Figure 5: Pacific sardine landings (mt) by fleet, model year-semester as used in 2020 base model.

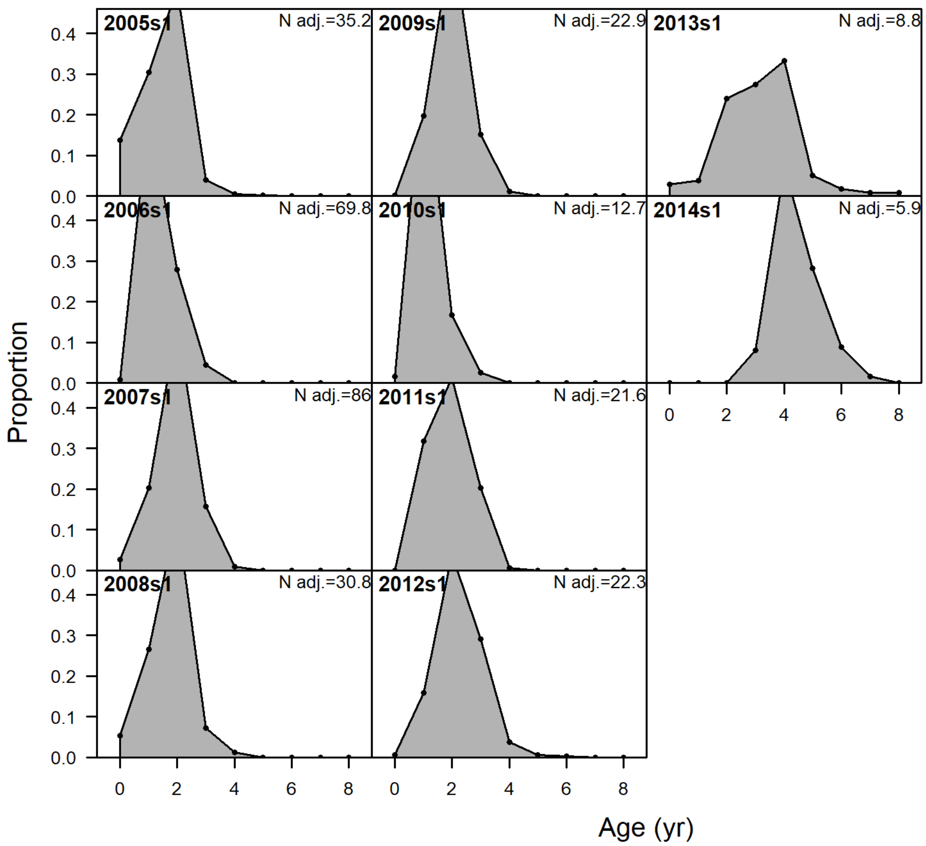

Figure 6: Age-composition time series for the MexCal fleet in semester 1 (S1). N represents input sample sizes.

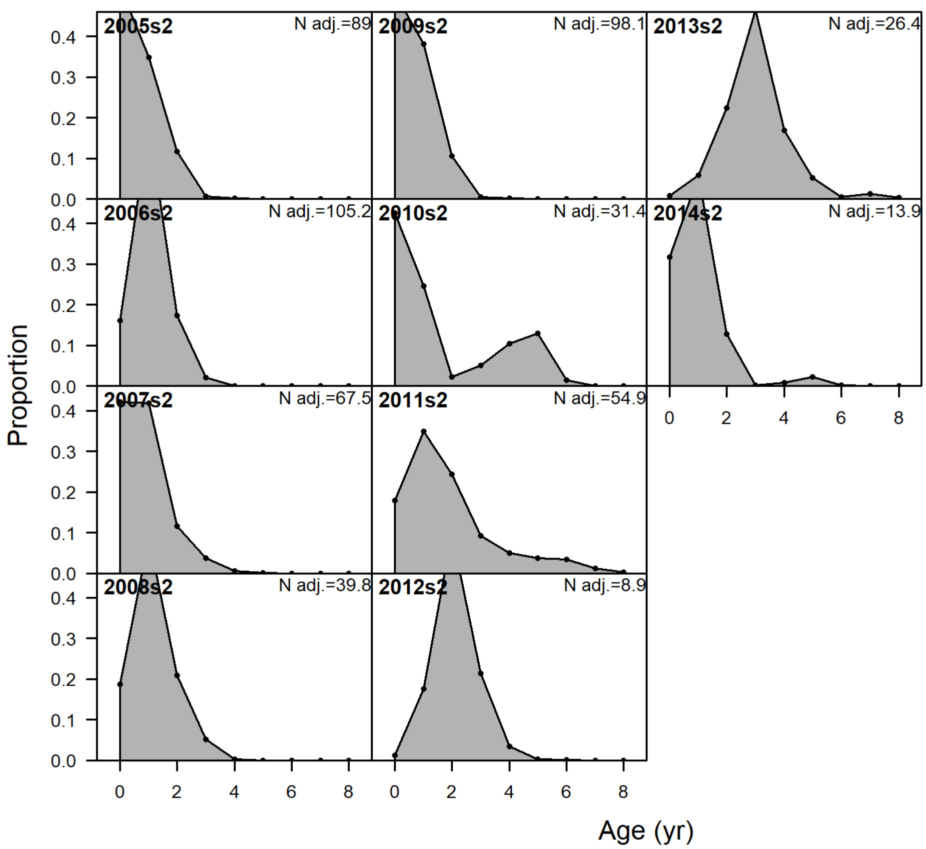

Figure 7: Age-composition time series for the MexCal fleet in semester 2 (S2). N represents input sample sizes.

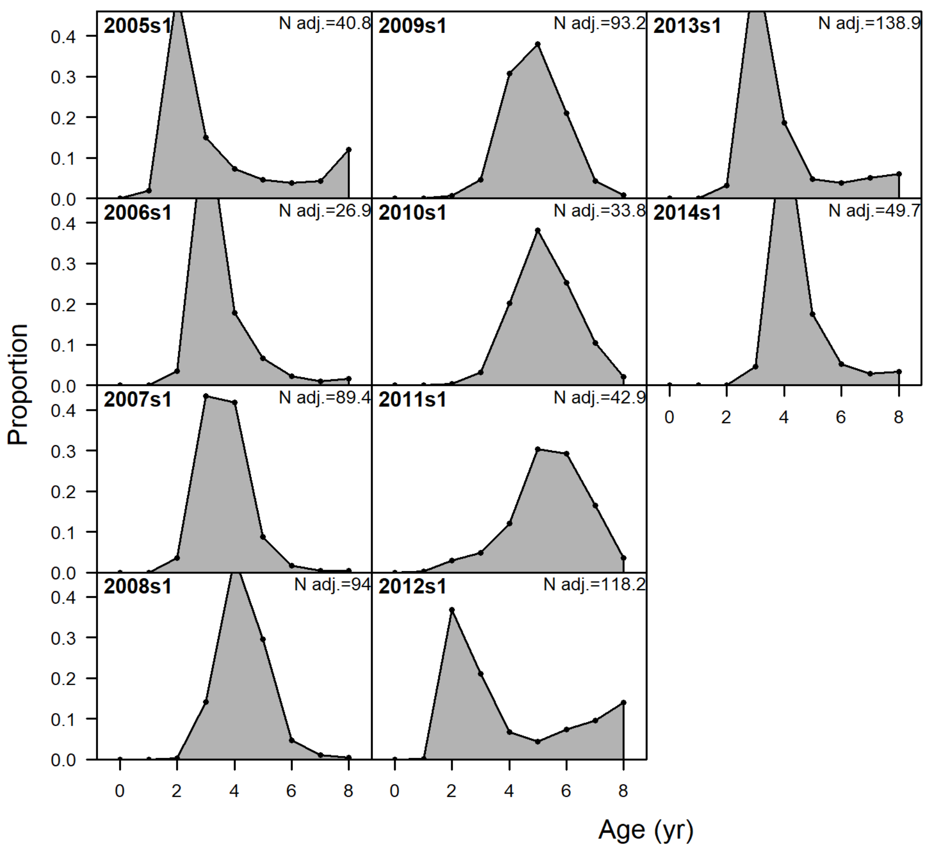

Figure 8: Age-composition time series for the PNW fleet. N represents input sample sizes.

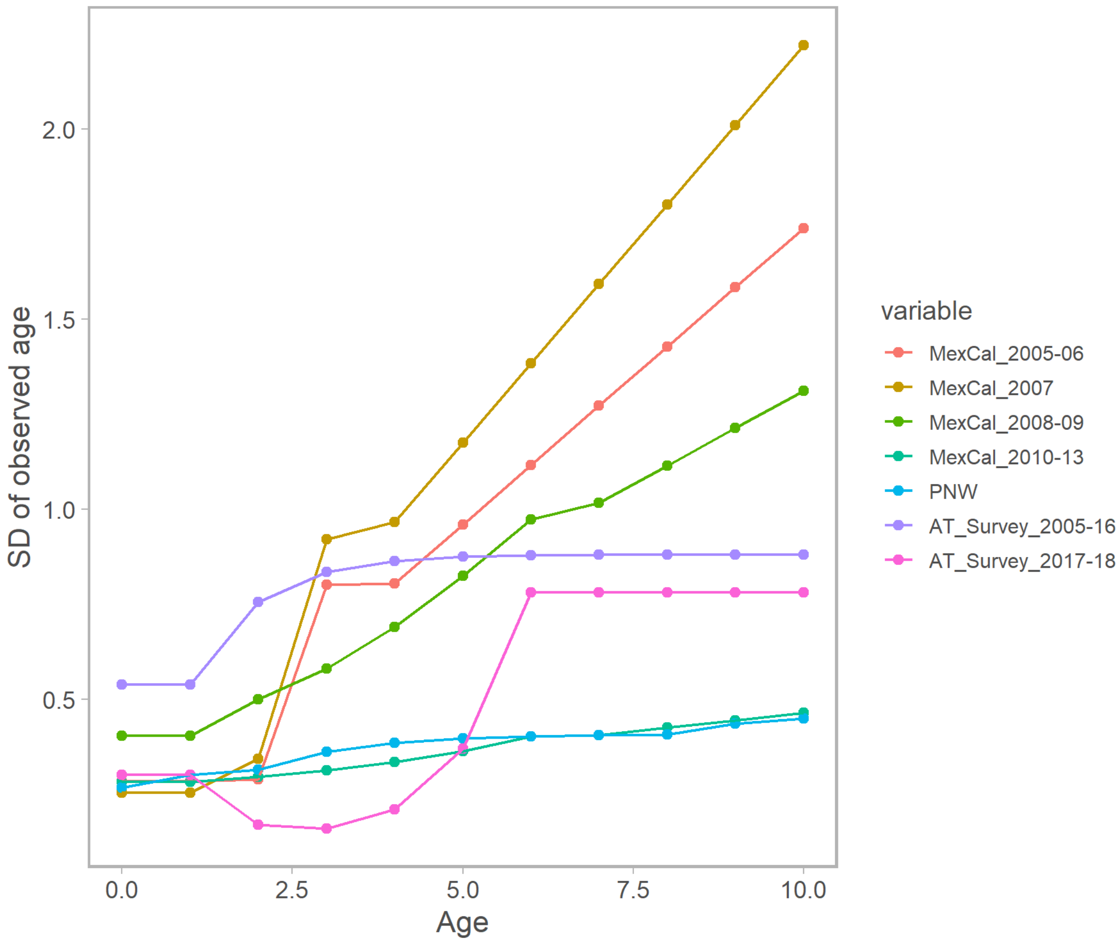

Figure 9: Laboratory- and year-specific ageing errors in the 2020 base model.

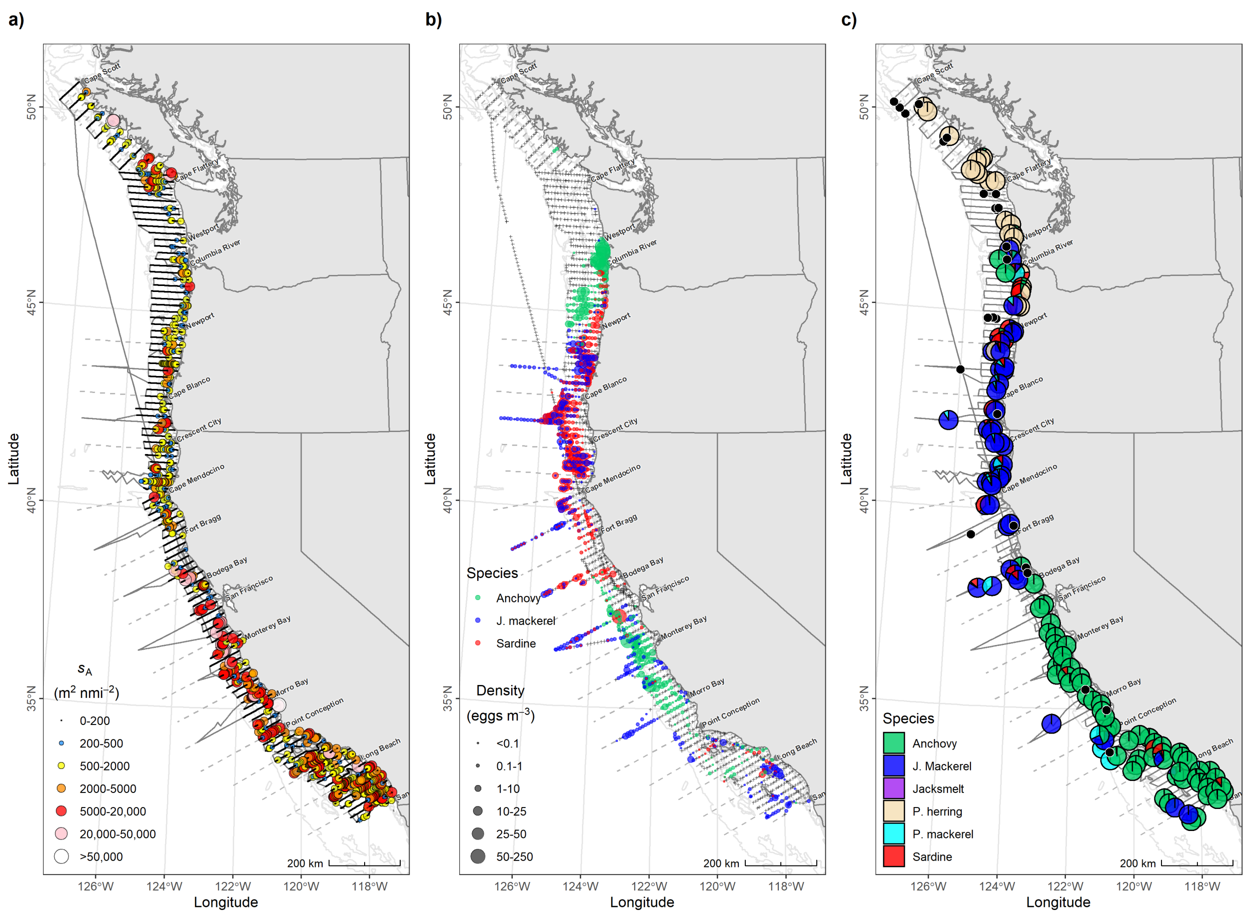

Figure 10: Results from the 2019 AT summer survey (Stierhoff et al. 2020). A map of the: a) distribution of 38-kHz integrated backscattering coefficients ($s_a, m^2 nmi^-2$; averaged over 2000m distance intervals) ascribed to CPS; b) CUFES egg density (eggs m^-3) for anchovy, sardine and jack mackerel; and c) proportions of CPS species in trawls (black points indicate trawls with no CPS).

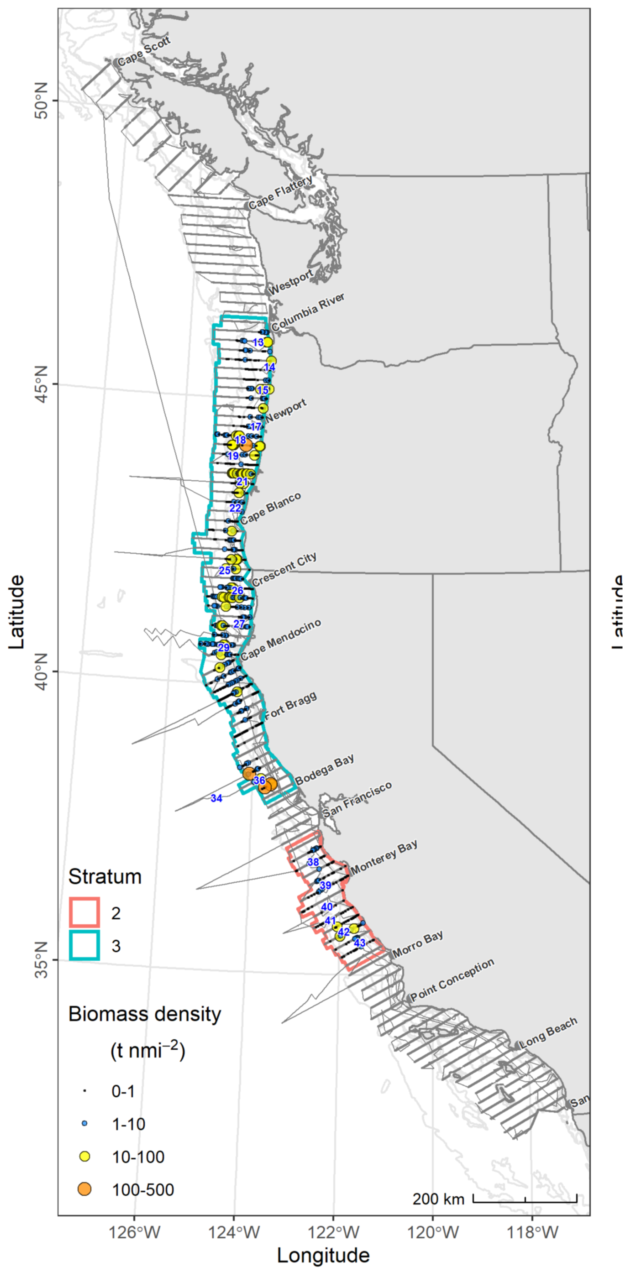

Figure 11: Biomass densities of Pacific sardine, northern stock, per stratum throughout the summer 2019 AT survey region. Blue numbers represent locations of positive sardine trawl clusters. Gray lines represent the vessel track. Stratum numbers for Pacific sardine begin at 2 (stratum 1 was south of Pt. Conception and assigned to the southern stock of Pacific sardine based on sea surface temperature).

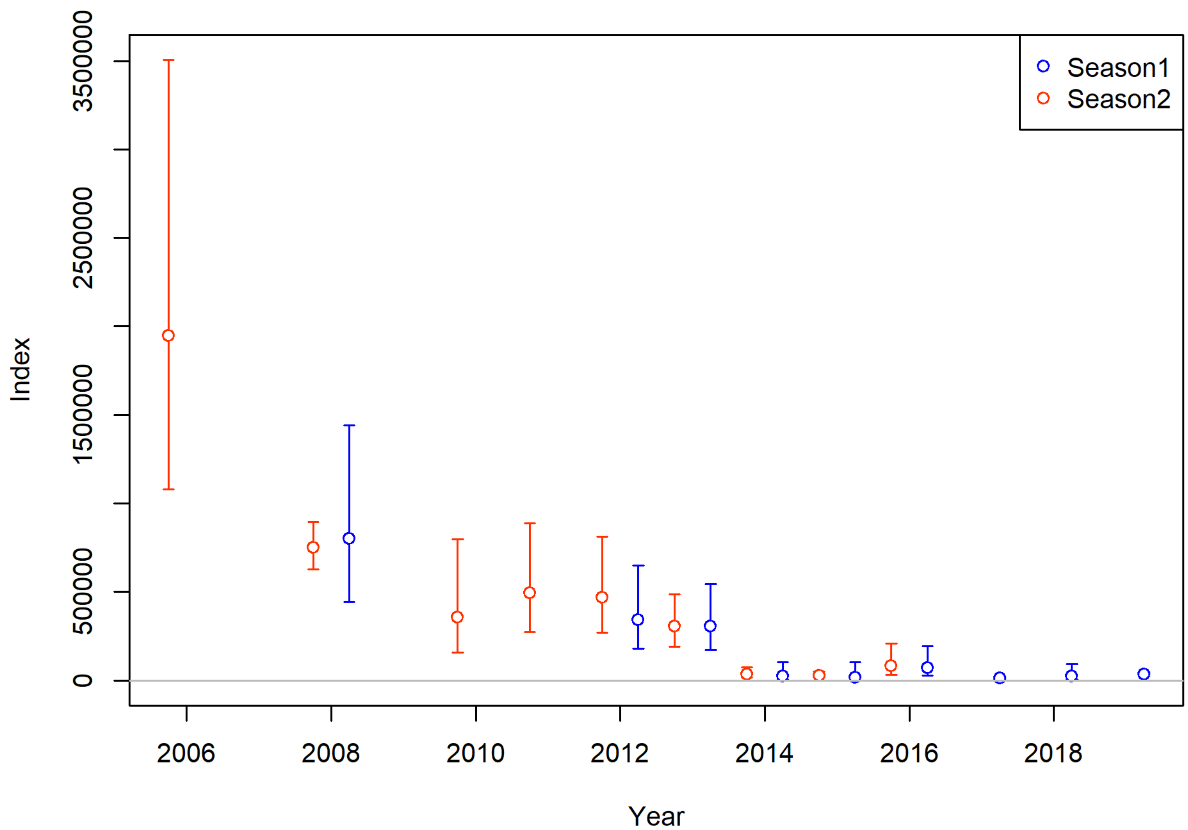

Figure 12: Time series of Pacific sardine biomass (age 0+, mt) from summer (semester 1) and spring (semester 2) AT surveys, 2006-2019 (bars are 95% CI).

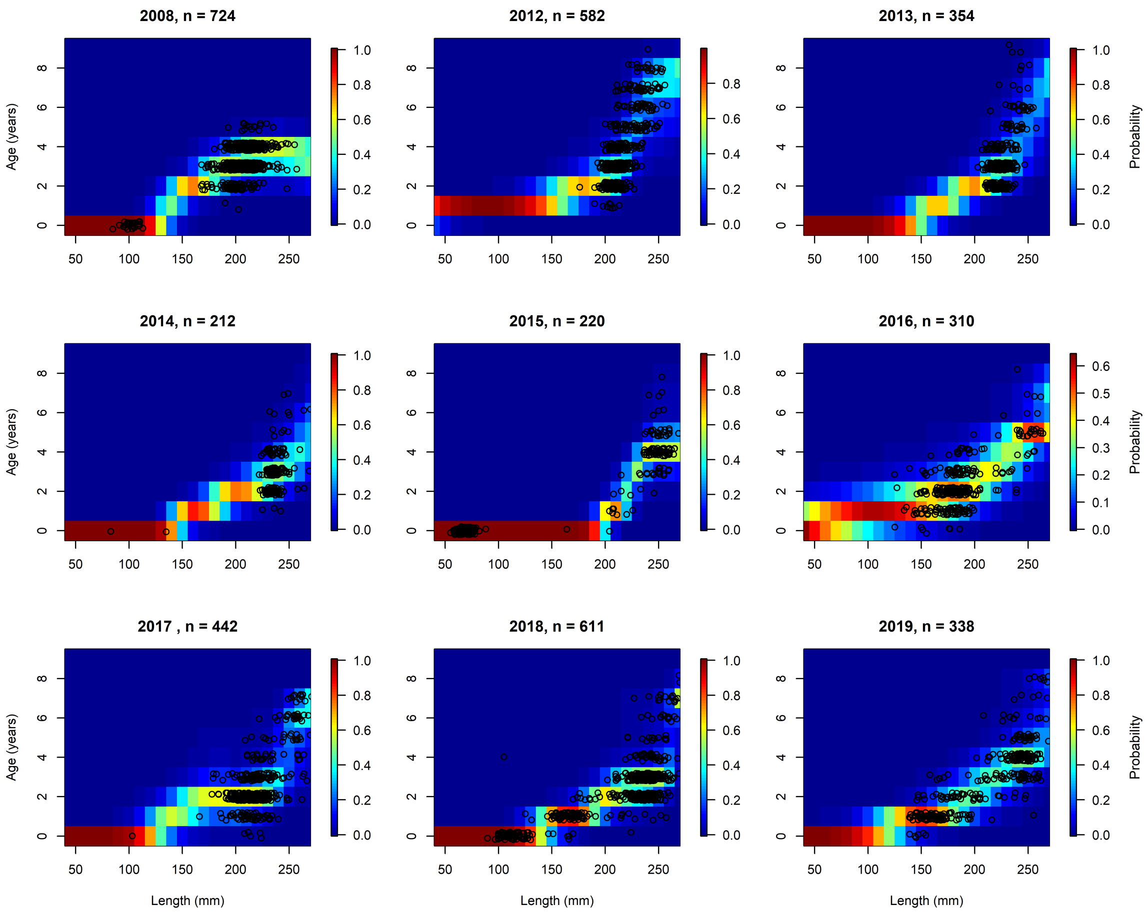

Figure 13: Annual age-length keys derived from summer AT survey samples collected from 2008-2019.

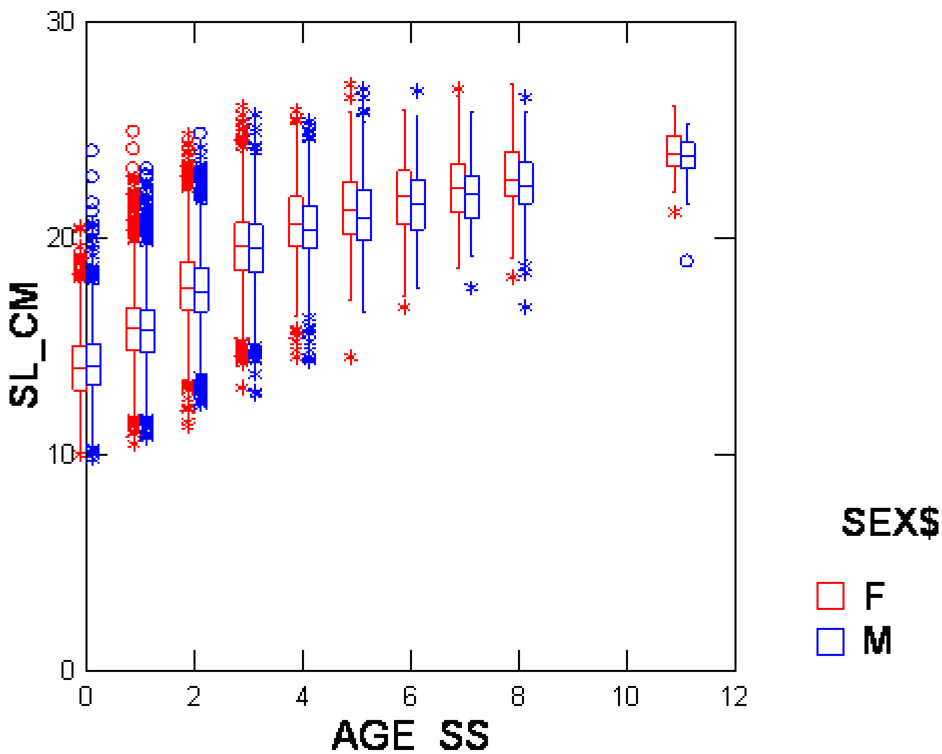

Figure 14: Length-at-age by sex from fishery samples (1993-2013), indicating lack of sexually dimorphic growth. Box symbols indicate median and quartile range for the raw data.

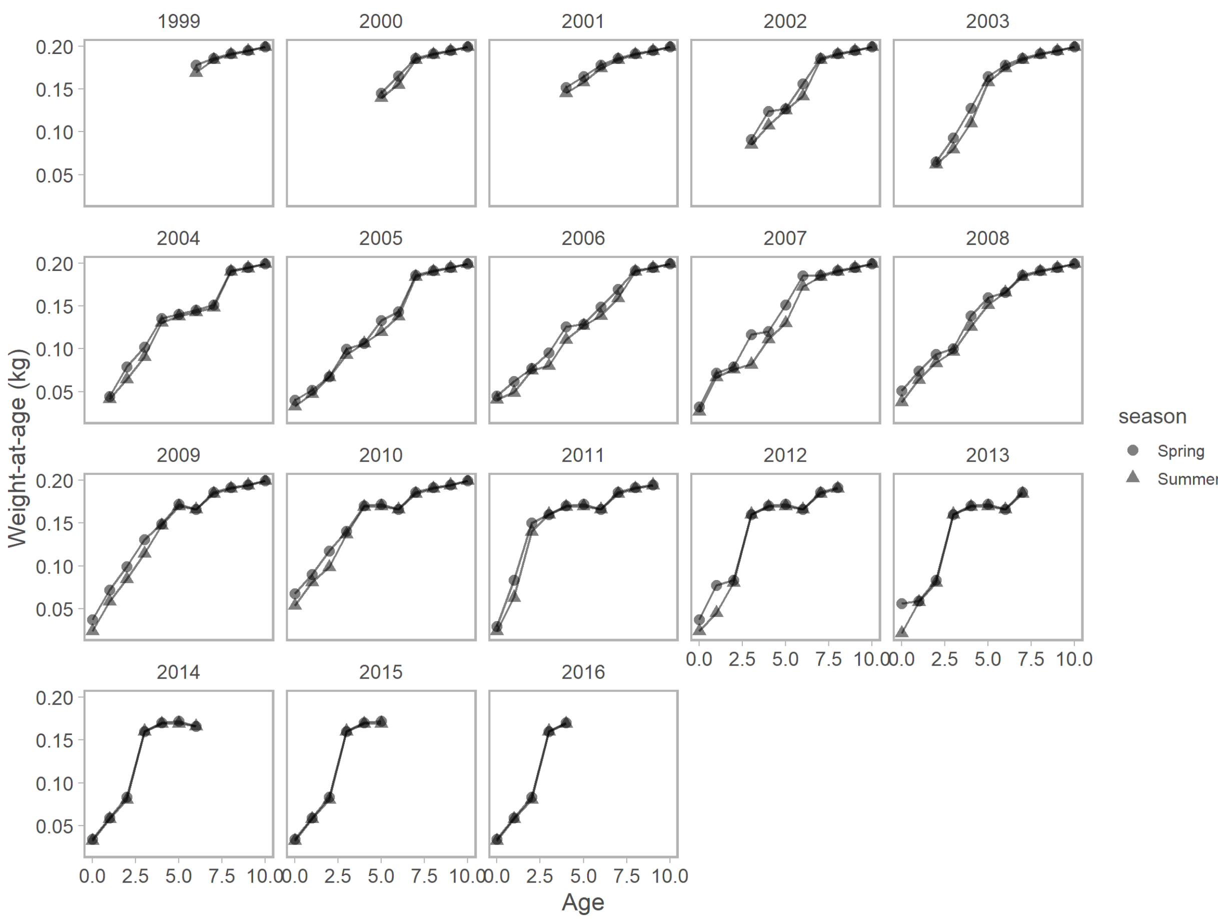

Figure 15: MexCal fleet weight-at-age values plotted by cohort for spring (S2; circles) and summer (S1; triangles).

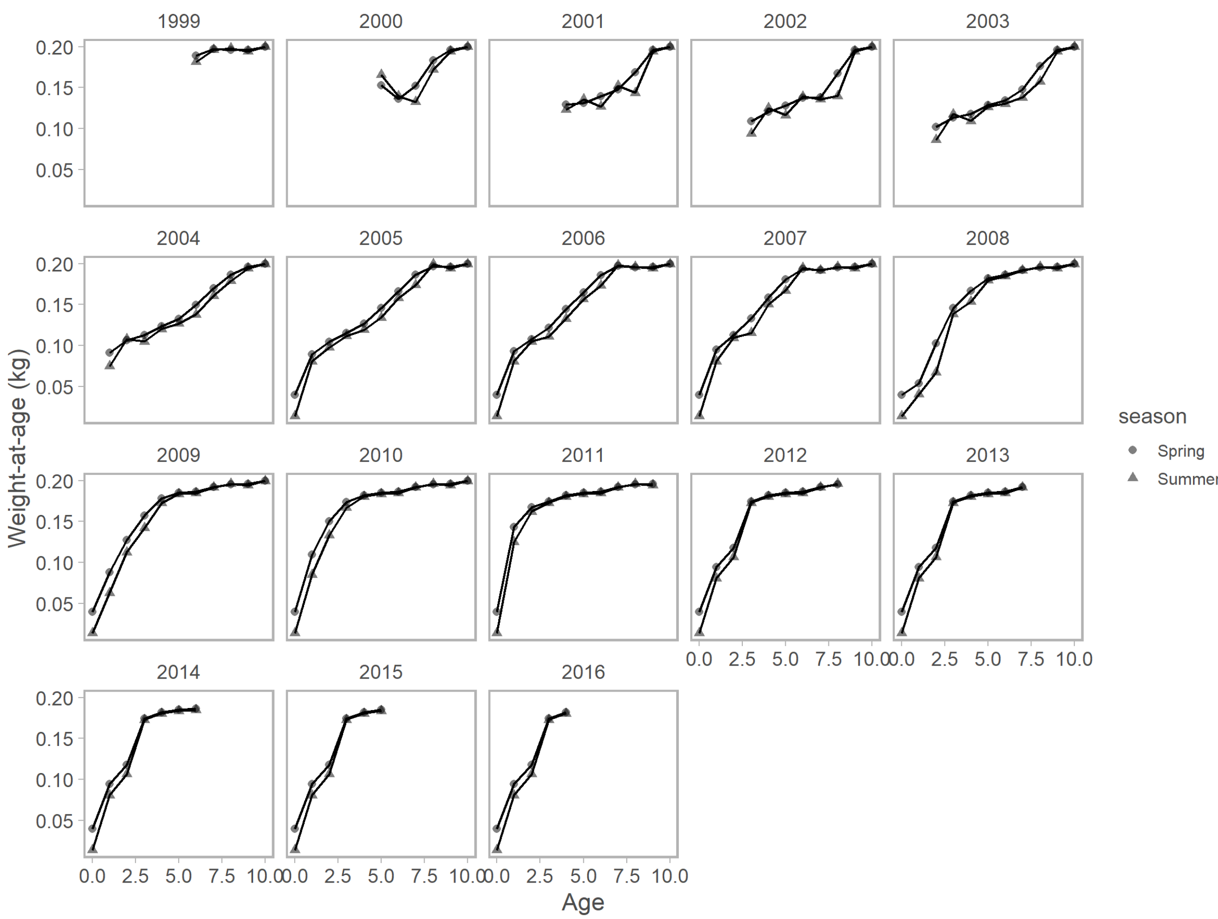

Figure 16: PNW fleet weight-at-age values plotted by cohort for spring (S2; circles) and summer (S1; triangles).

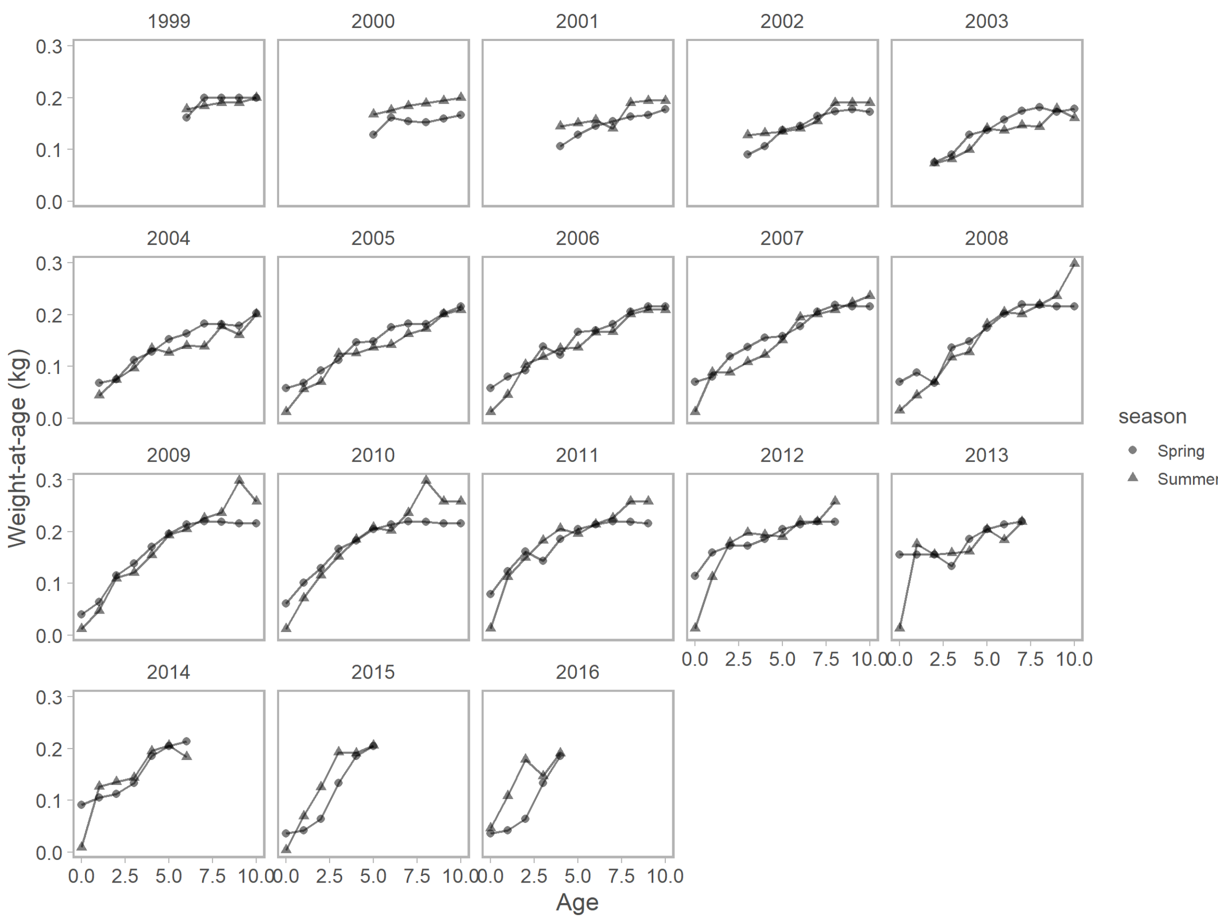

Figure 17: AT Survey weight-at-age values plotted by cohort for spring (S2; circles) and summer (S1; triangles).

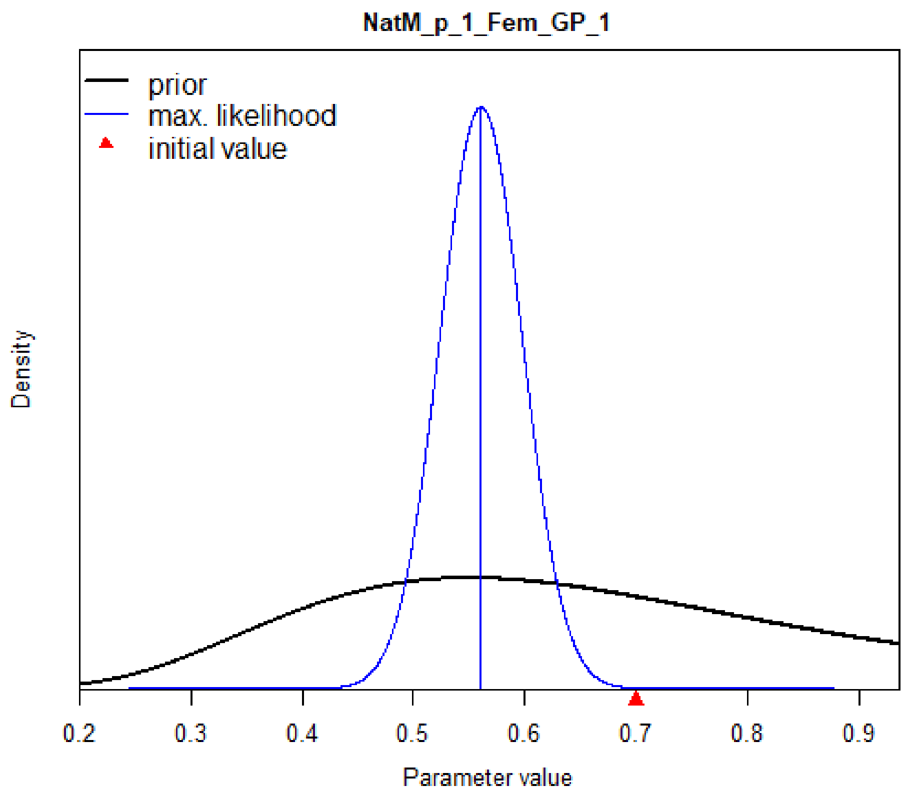

Figure 18: Natural mortality (M) prior and estimate. The prior was estimated based on a maximum age of 10 and six von Bertalanffy growth rate (k) estimates from previous assessments (See section 2.4.4 for more details).

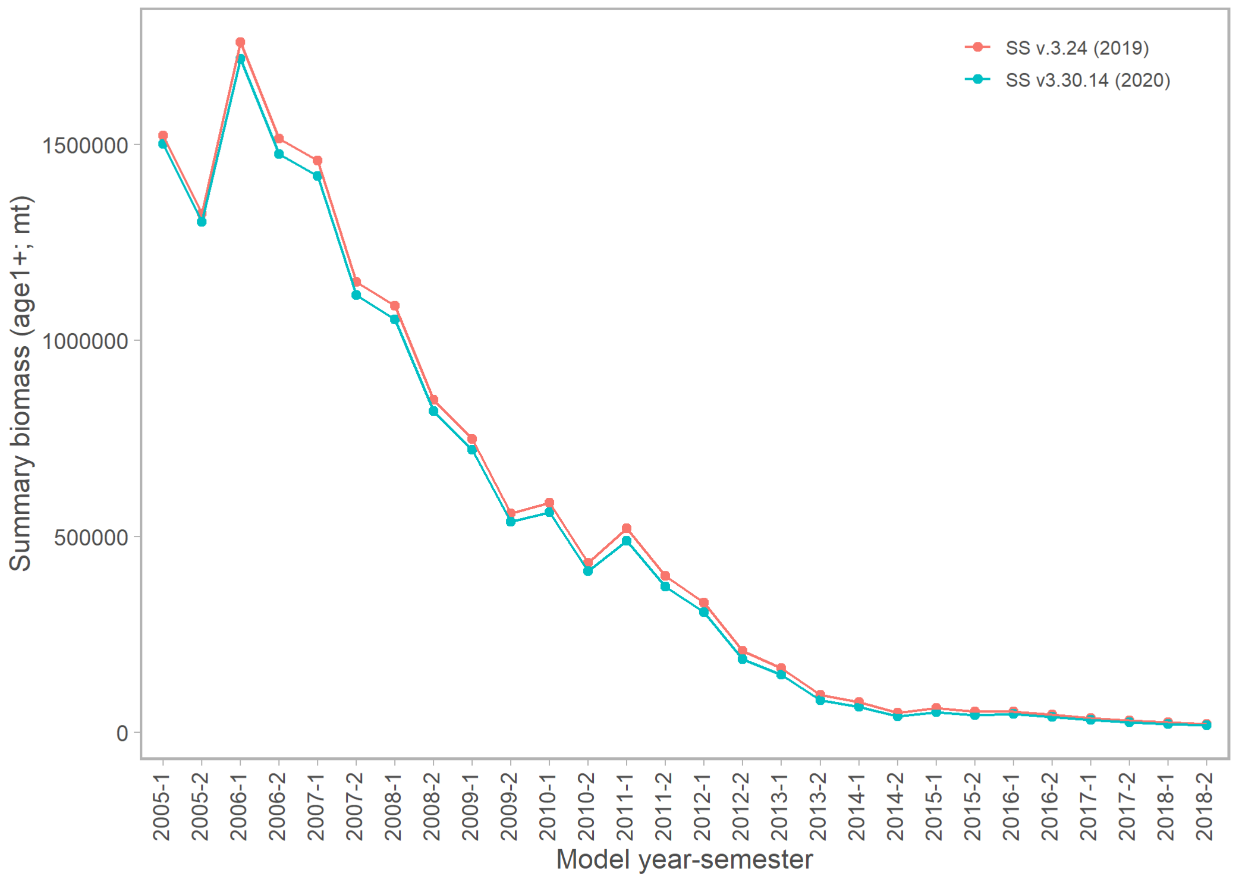

Figure 19: Comparison of model bridging estimates from Stock Synthesis version 3.24 to 3.30.14.

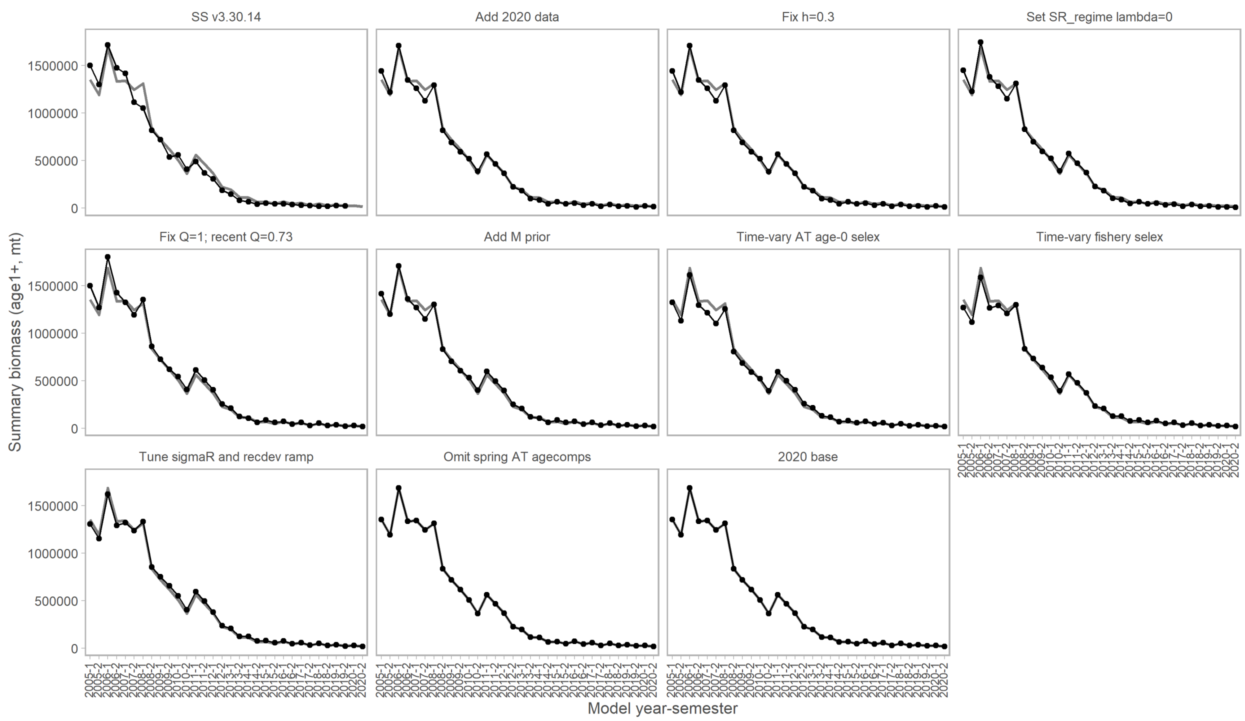

Figure 20: Stock biomass time series from bridging models with addition of individual configurations resulting in the 2020 base model. The addition of features was cumulative, and the 2020 base model stock biomass time series is shown in each panel (grey line). Note, the "Omit spring AT agecomps" and "2020 base" panels are identical.

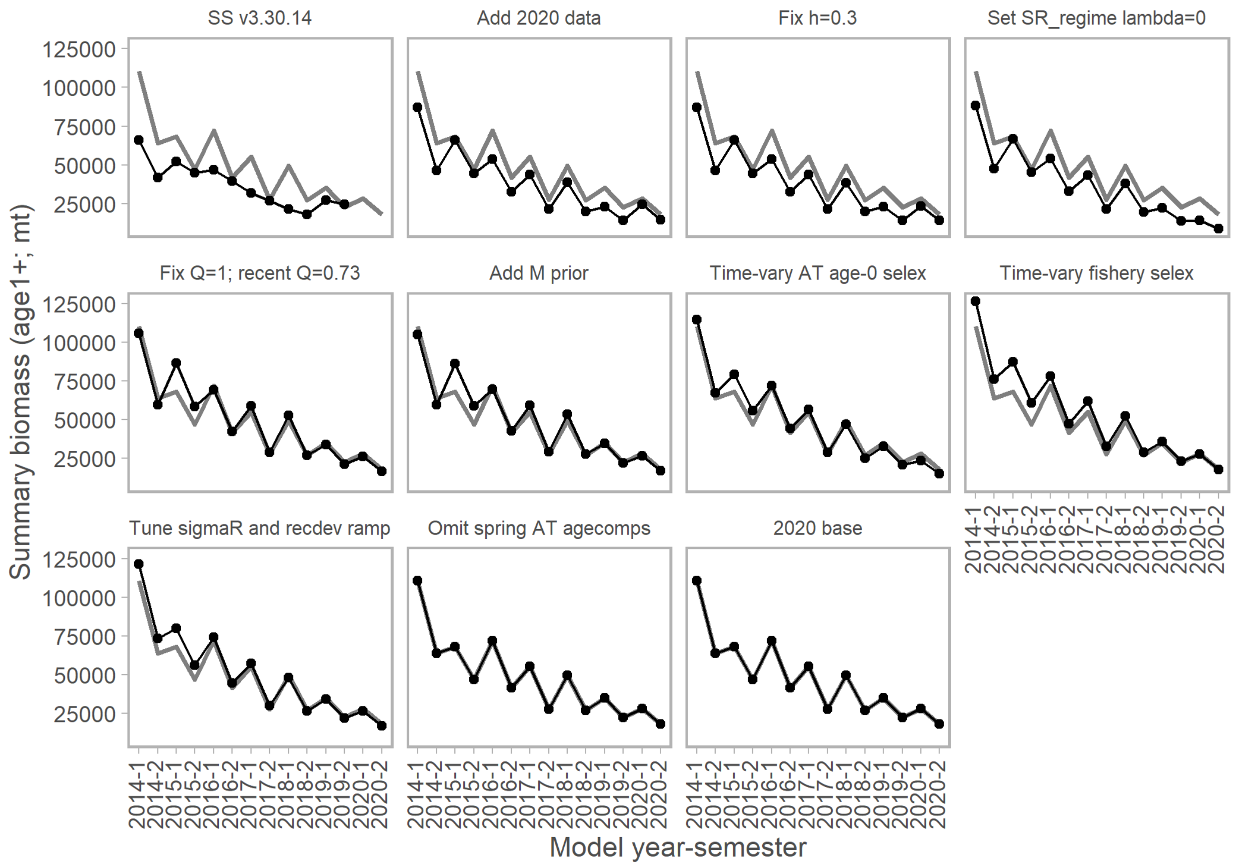

Figure 21: Stock biomass time series, focused on 2014-2020, from bridging models with addition of individual configurations resulting in the 2020 base model. The addition of features was cumulative, and the 2020 base model stock biomass time series is shown in each panel (grey line). Note, the "Omit spring AT agecomps" and "2020 base" panels are identical.

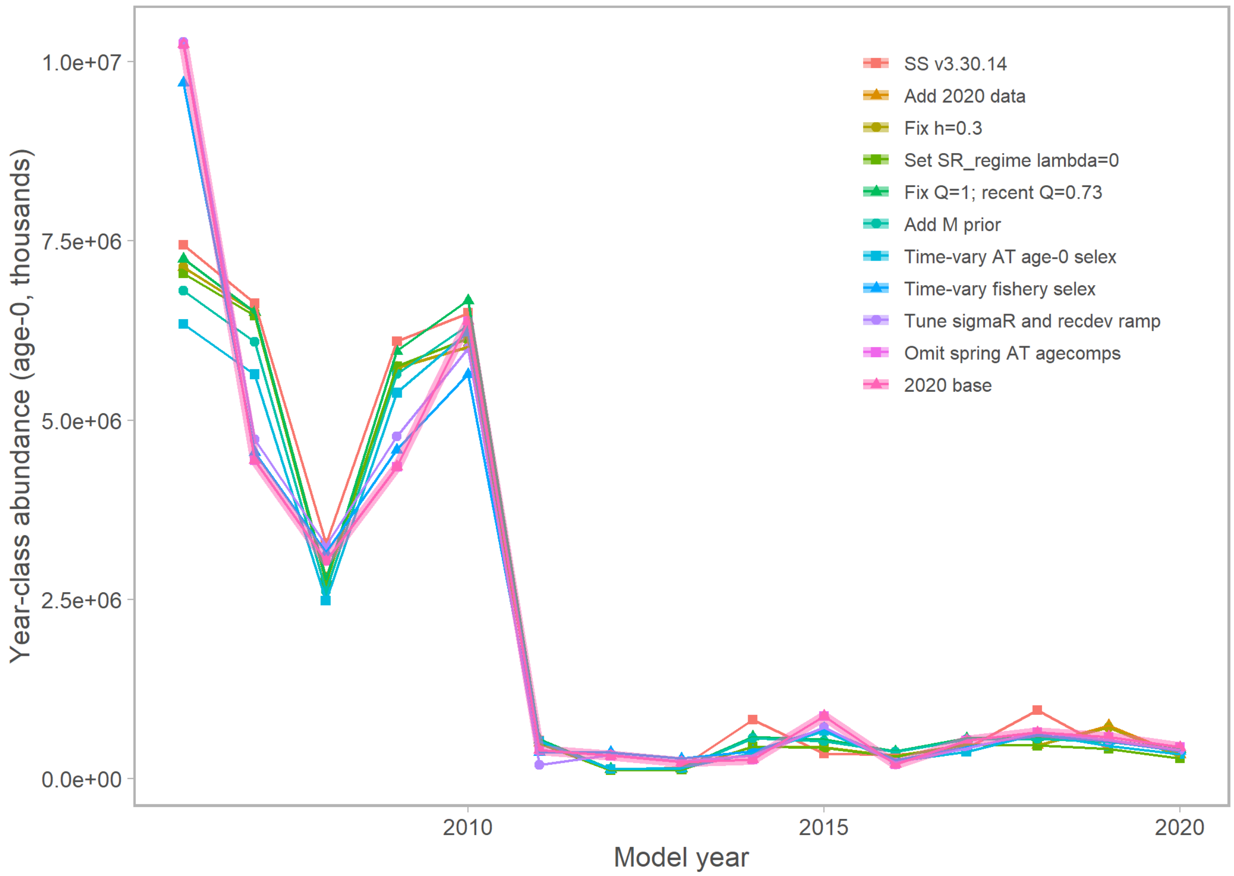

Figure 22: Recruitment time series with each change to model configuration. Time series for the 2020 base model is displayed as well (thick line).

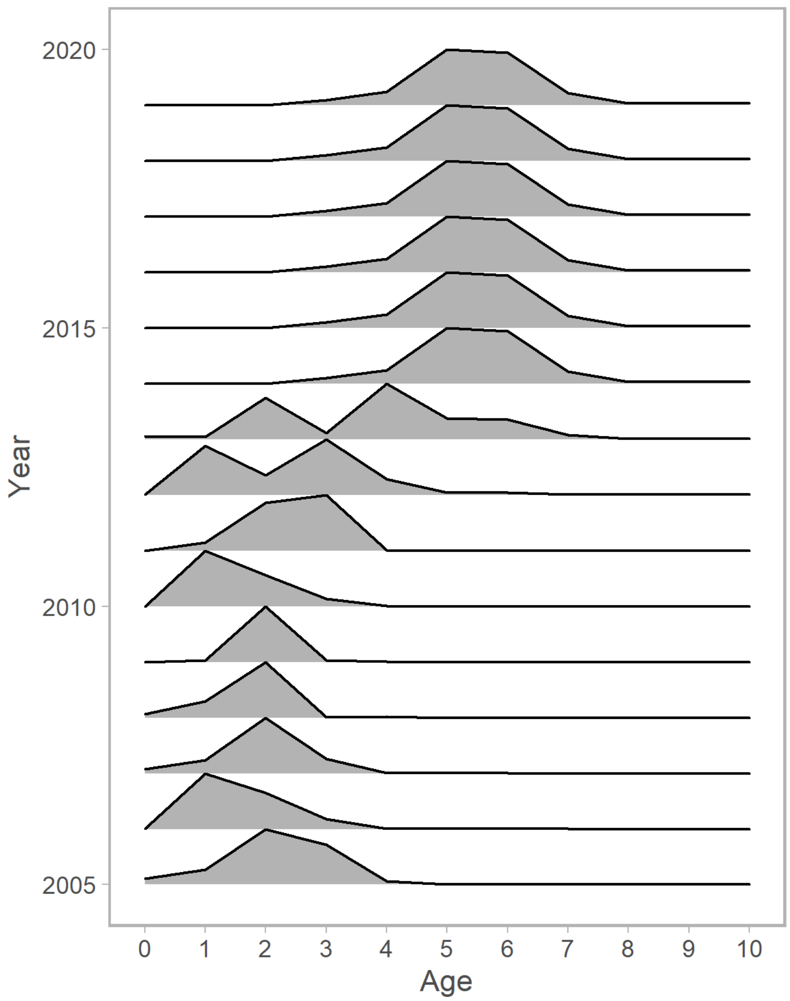

Figure 23: Time-varying age-based selectivity patterns for MexCal S1 fishing fleet in the 2020 base model.

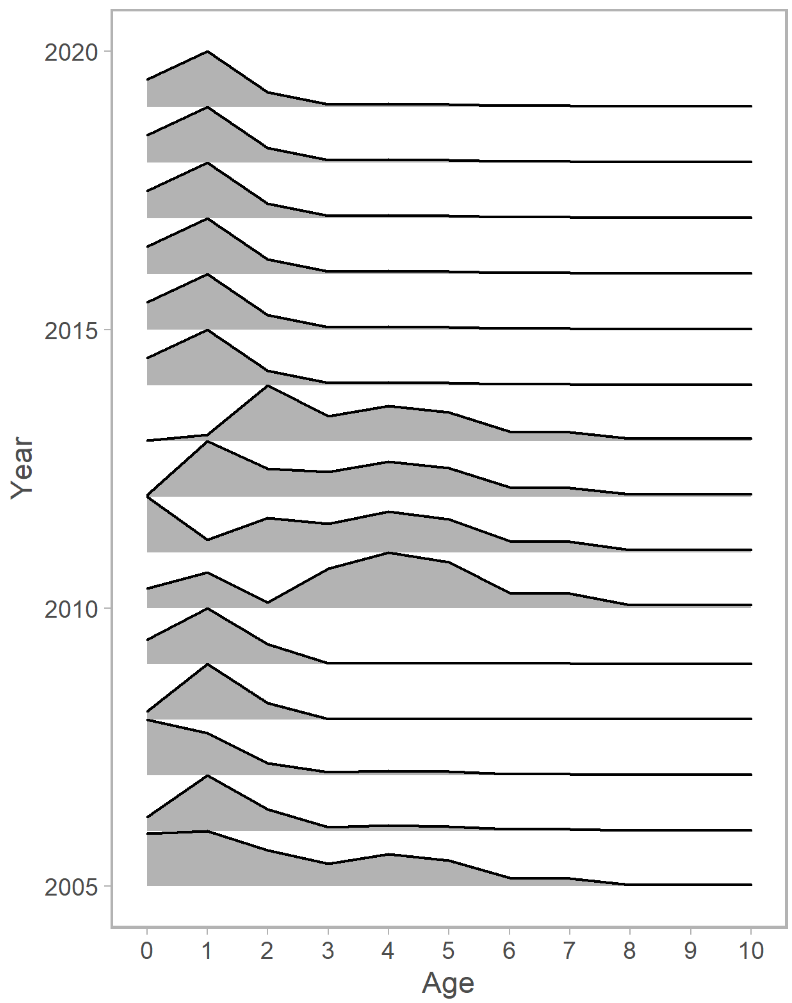

Figure 24: Time-varying age-based selectivity patterns for MexCal S2 fishing fleet in the 2020 base model.

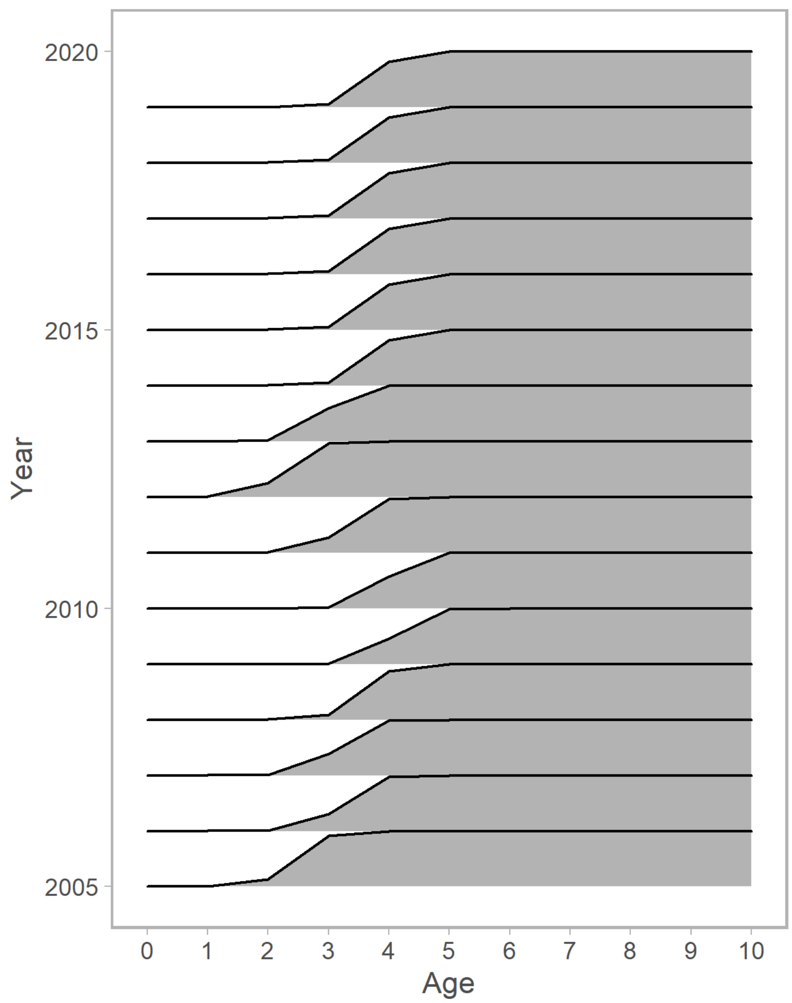

Figure 25: Time-varying age-based selectivity patterns for PNW fishing fleet in the 2020 base model.

Figure 26: Time-varying age-based selectivity patterns for AT survey in the 2020 base model.

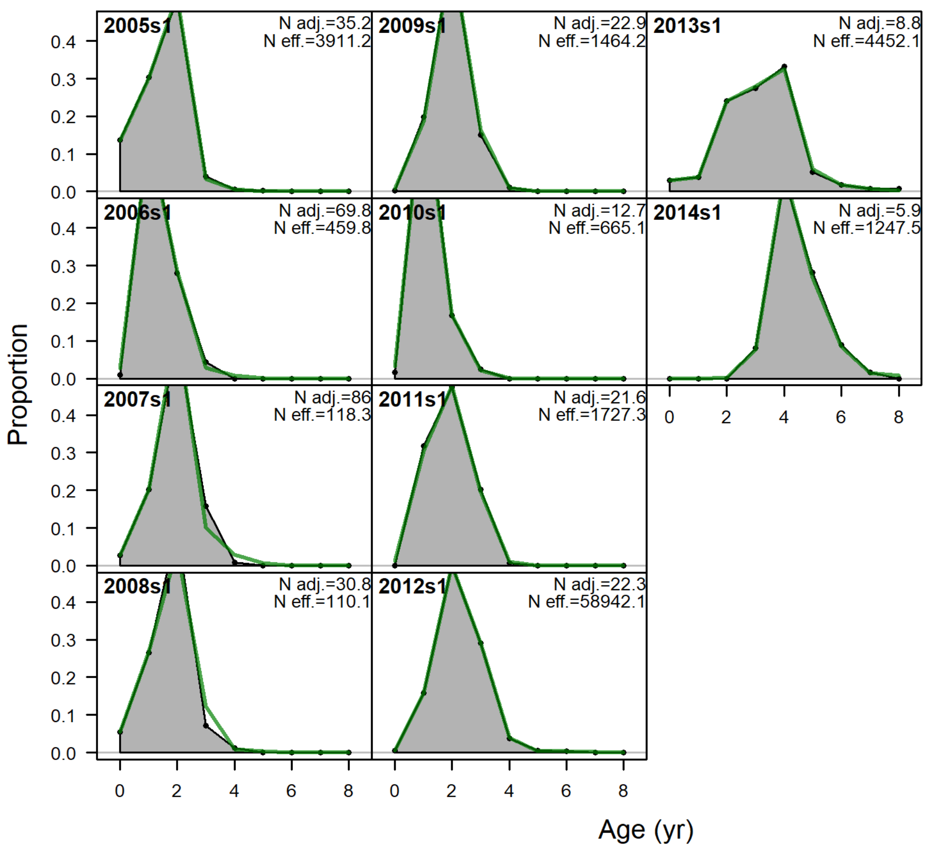

Figure 27: Fit to age-composition time series for the MexCal S1 fleet in 2020 base model. Values in the top right are input sample sizes (N adj) and effective sample size given statistical fit in the model (N eff.).

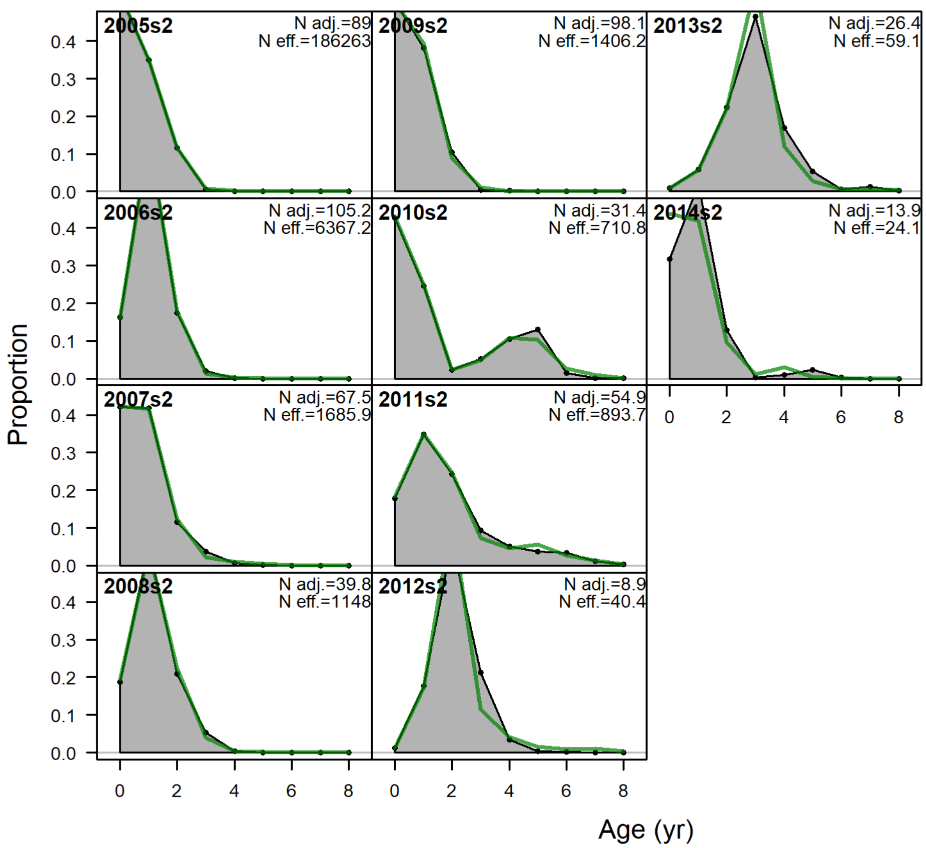

Figure 28: Fit to age-composition time series for the MexCal S2 fleet in 2020 base model. Values in the top right are input sample sizes (N adj) and effective sample size given statistical fit in the model (N eff.).

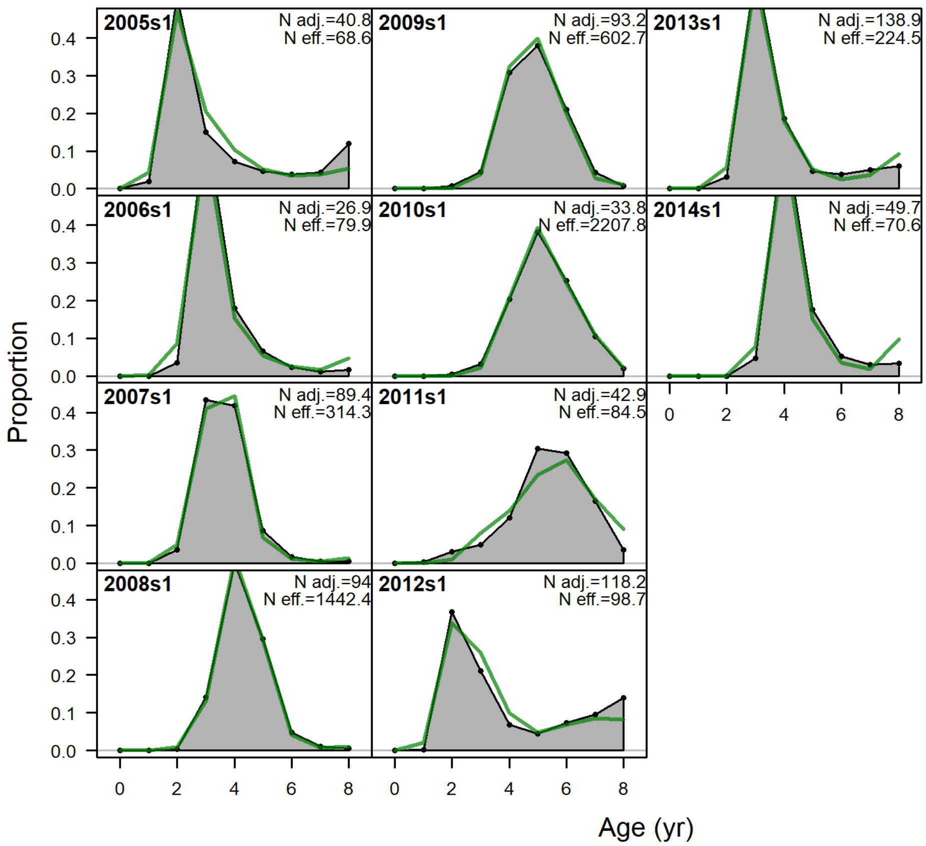

Figure 29: Fit to age-composition time series for the PNW fleet in 2020 base model. Values in the top right are input sample sizes (N adj) and effective sample size given statistical fit in the model (N eff.).

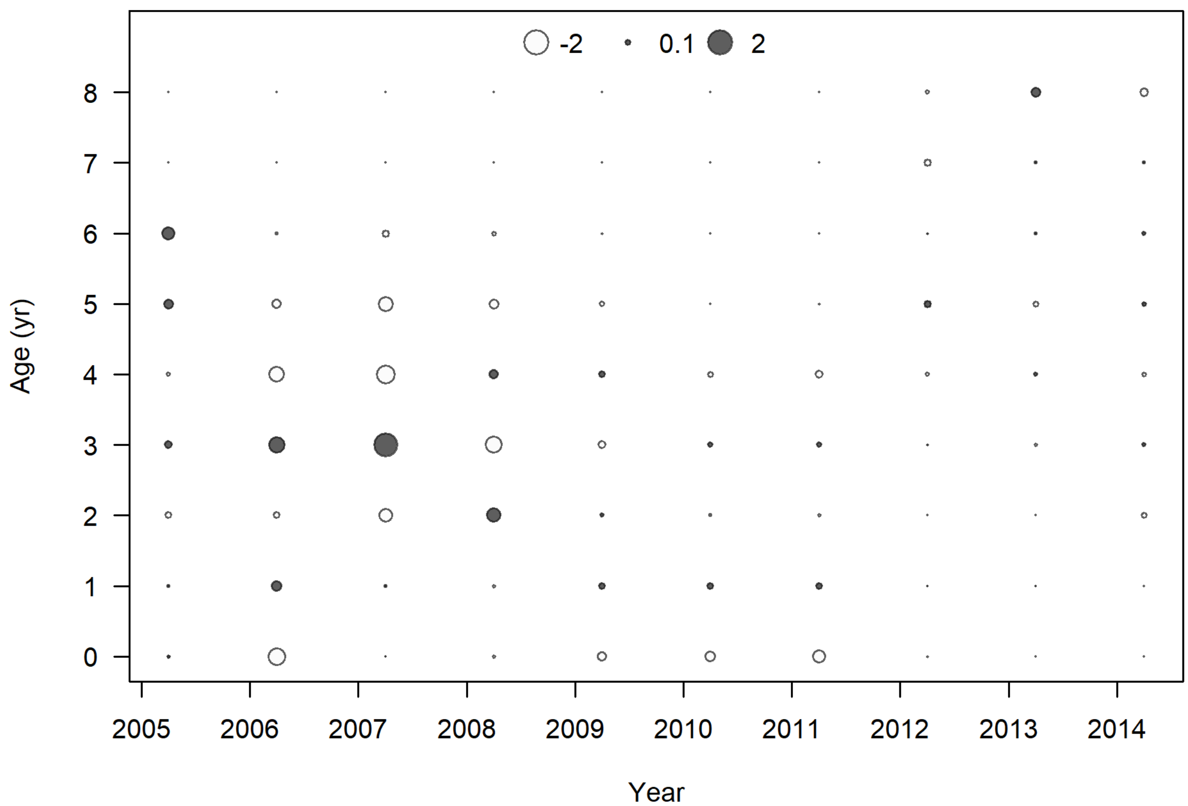

Figure 30: Residuals of fit to age-composition time series for the MexCal S1 fleet in 2020 base model.

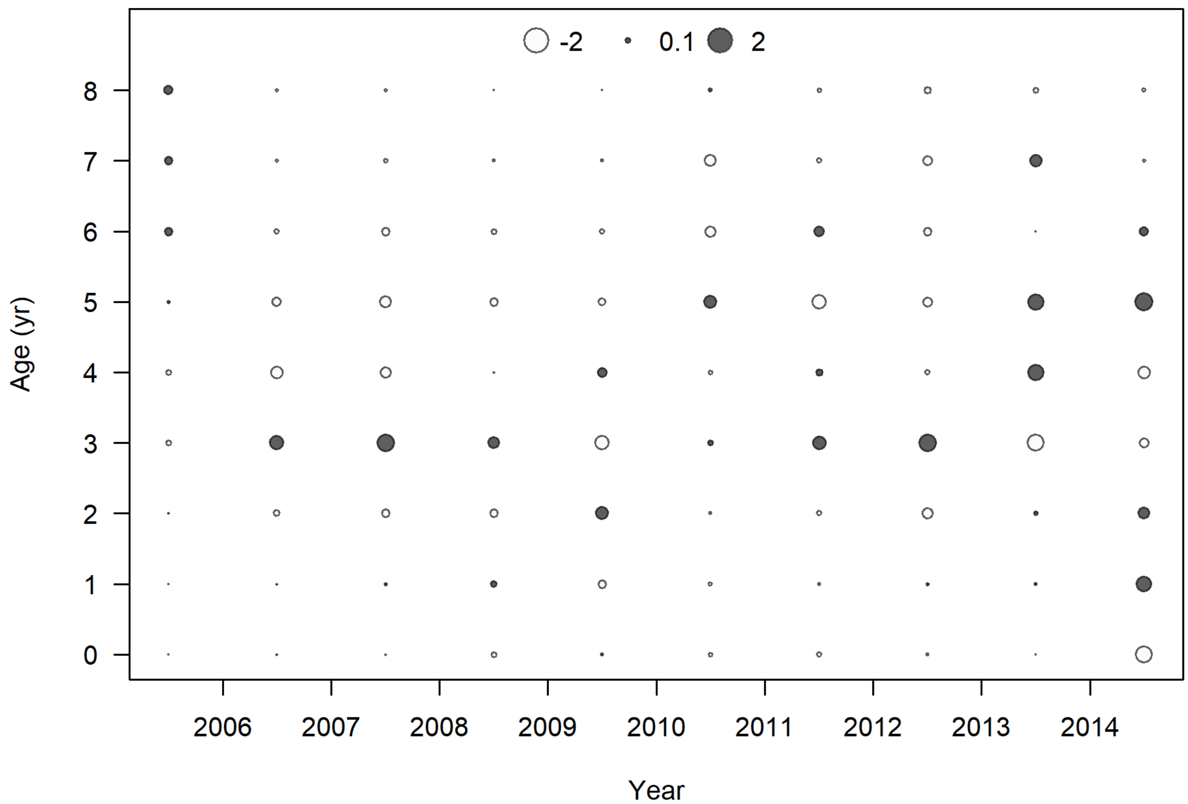

Figure 31: Residuals of fit to age-composition time series for the MexCal S2 fleet in 2020 base model.

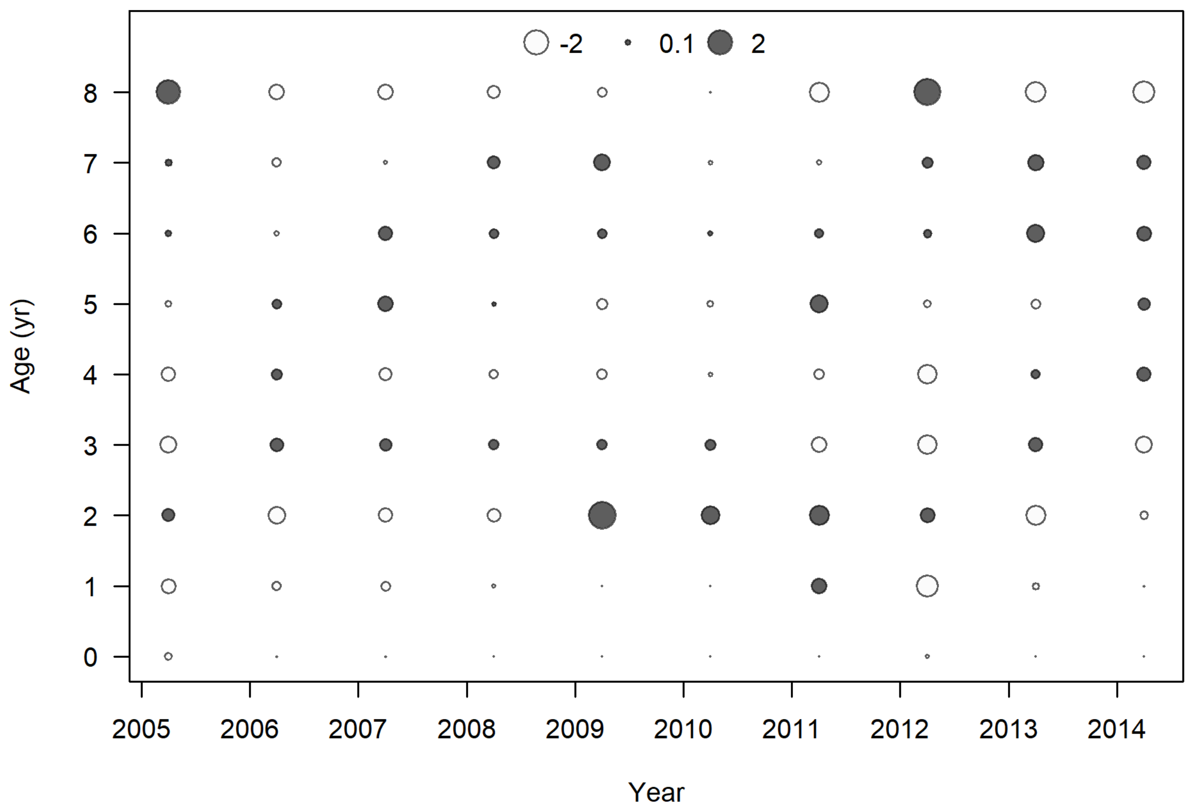

Figure 32: Residuals of fit to age-composition time series for the PNW fleet in 2020 base model.

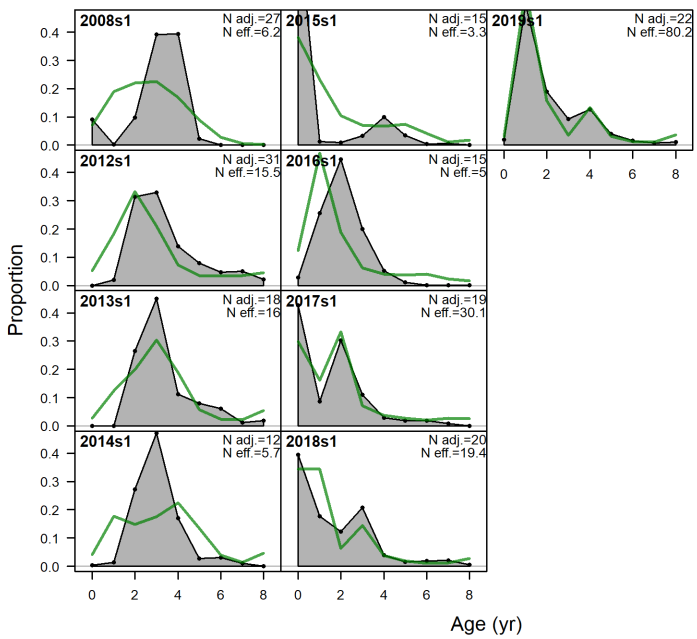

Figure 33: Fit to age-composition time series for the AT survey in 2020 base model. Values in the top right are input sample sizes (N adj) and effective sample size given statistical fit in the model (Neff).

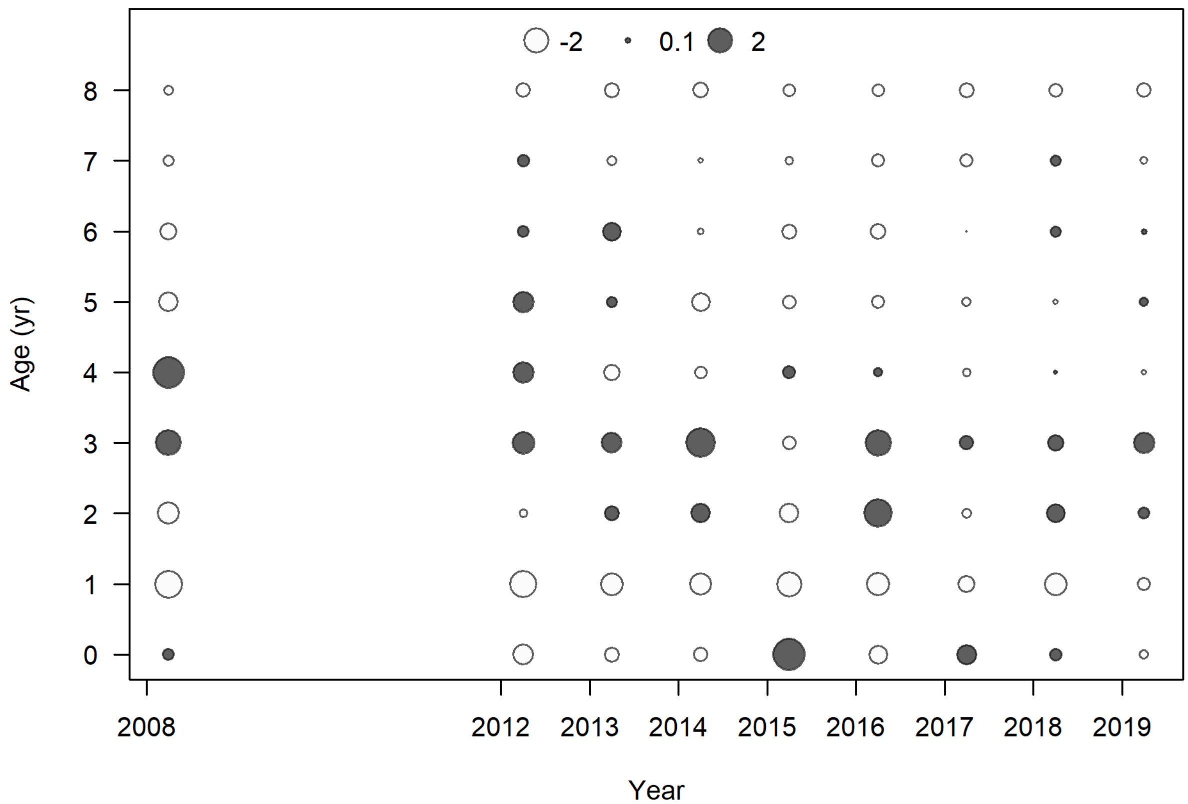

Figure 34: Residuals of fit to age-composition time series for the AT survey in 2020 base model.

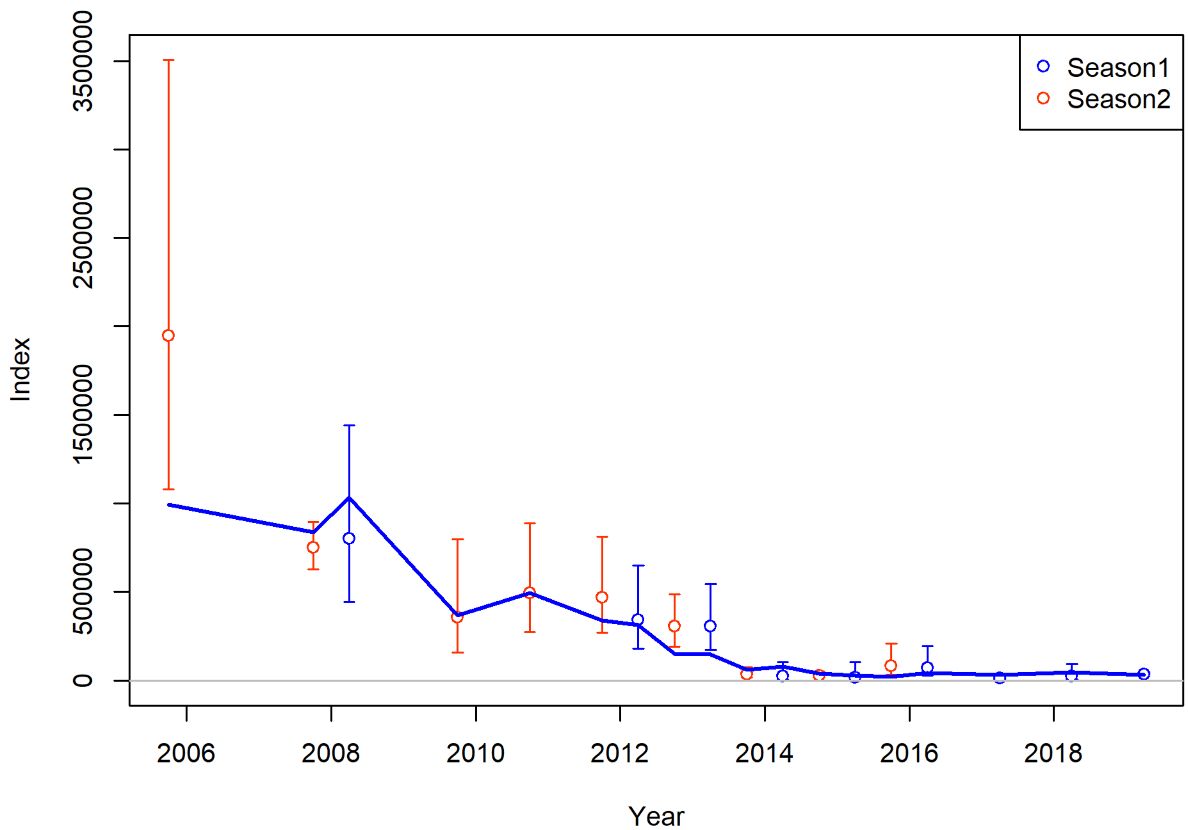

Figure 35: Fit to index data for AT survey. Lines indicate 95% uncertainty interval around index values.

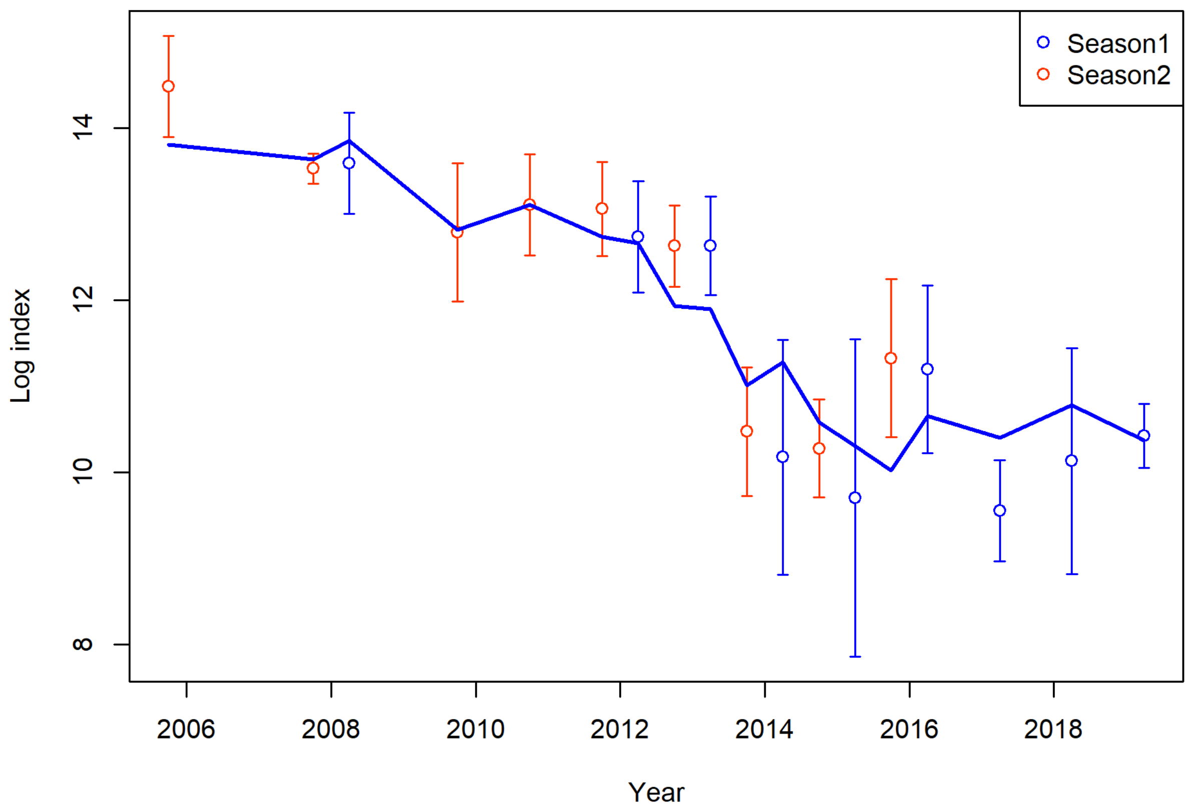

Figure 36: Fit to log-transformed index data for AT survey. Lines indicate 95% uncertainty interval around index values.

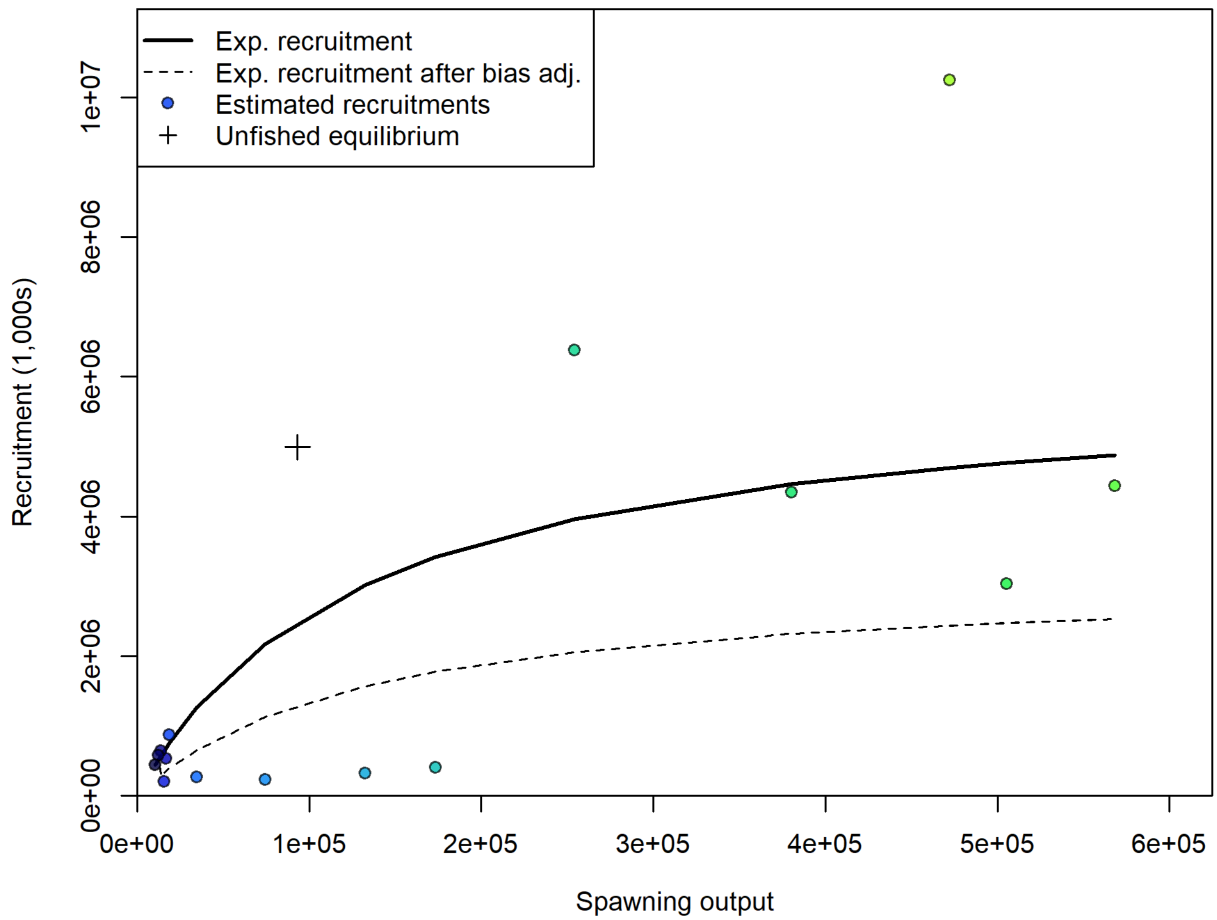

Figure 37: Estimated stock-recruitment (Beverton-Holt) relationship for 2020 base model. Steepness is fixed (h = 0.3). Year labels represent year of SSB producing the subsequent recruitment year class.

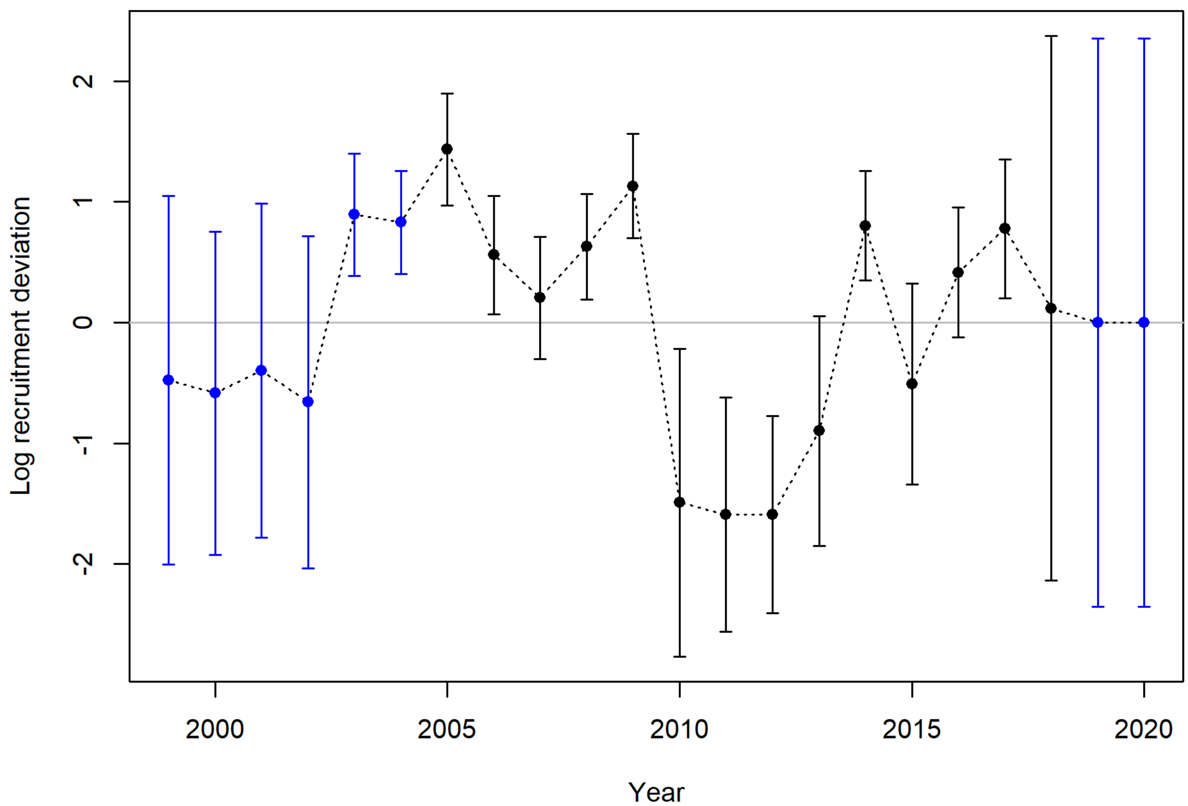

Figure 38: Recruitment deviations and standard errors (σ_R=1.2) for 2020 base model.

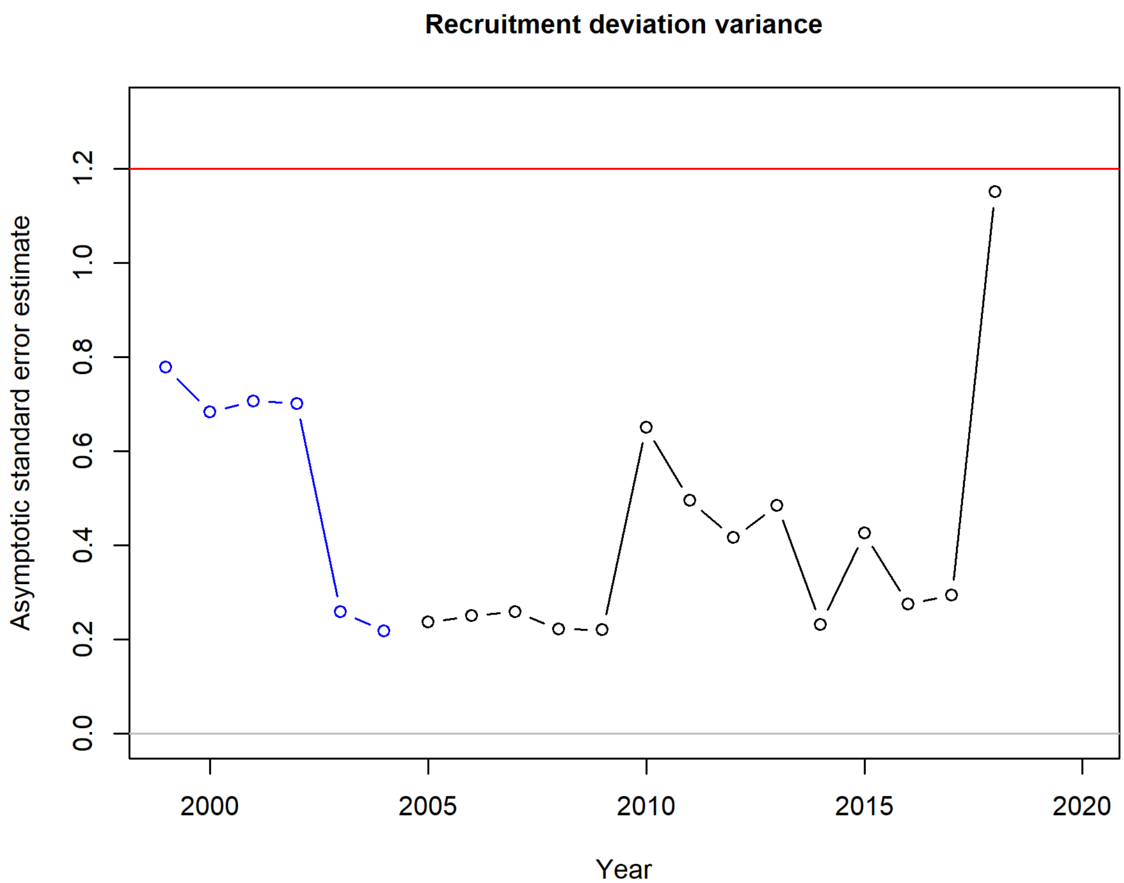

Figure 39: Asymptotic standard errors for estimated recruitment deviations for 2020 base model.

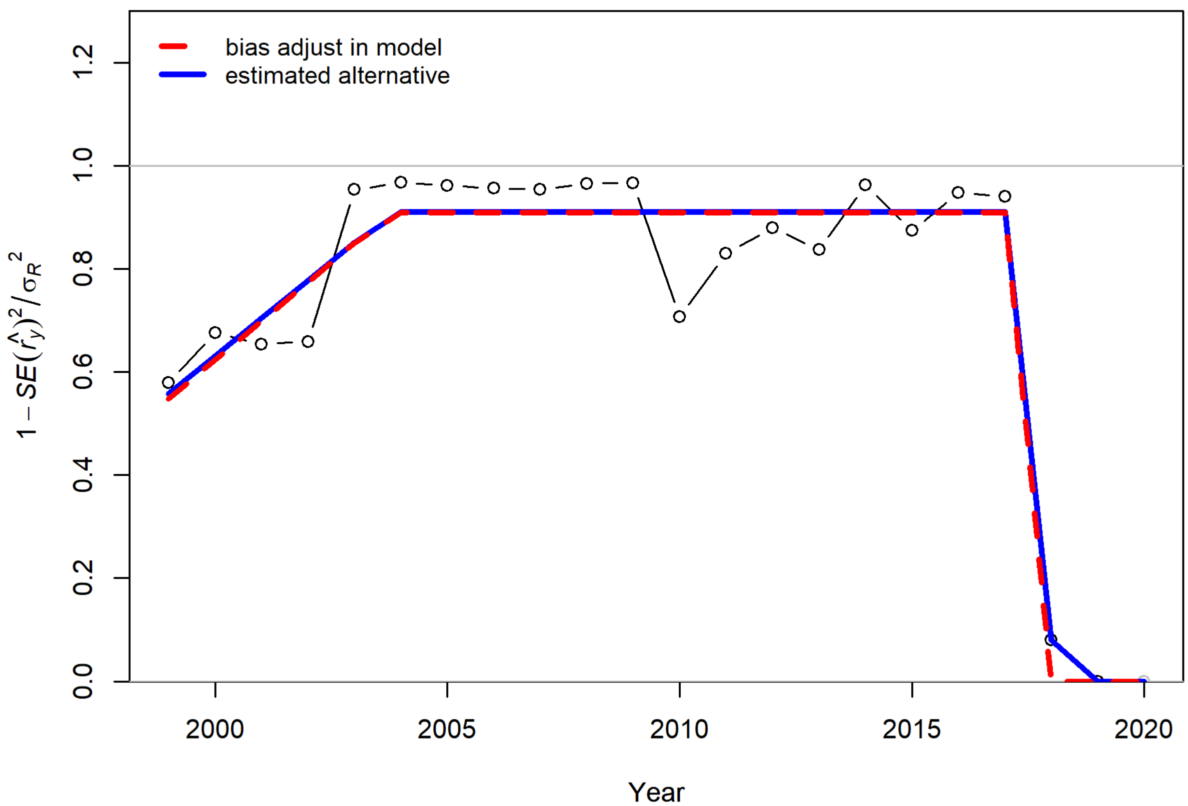

Figure 40: Recruitment bias adjustment plot for early, main, and forecast periods in 2020 base model.

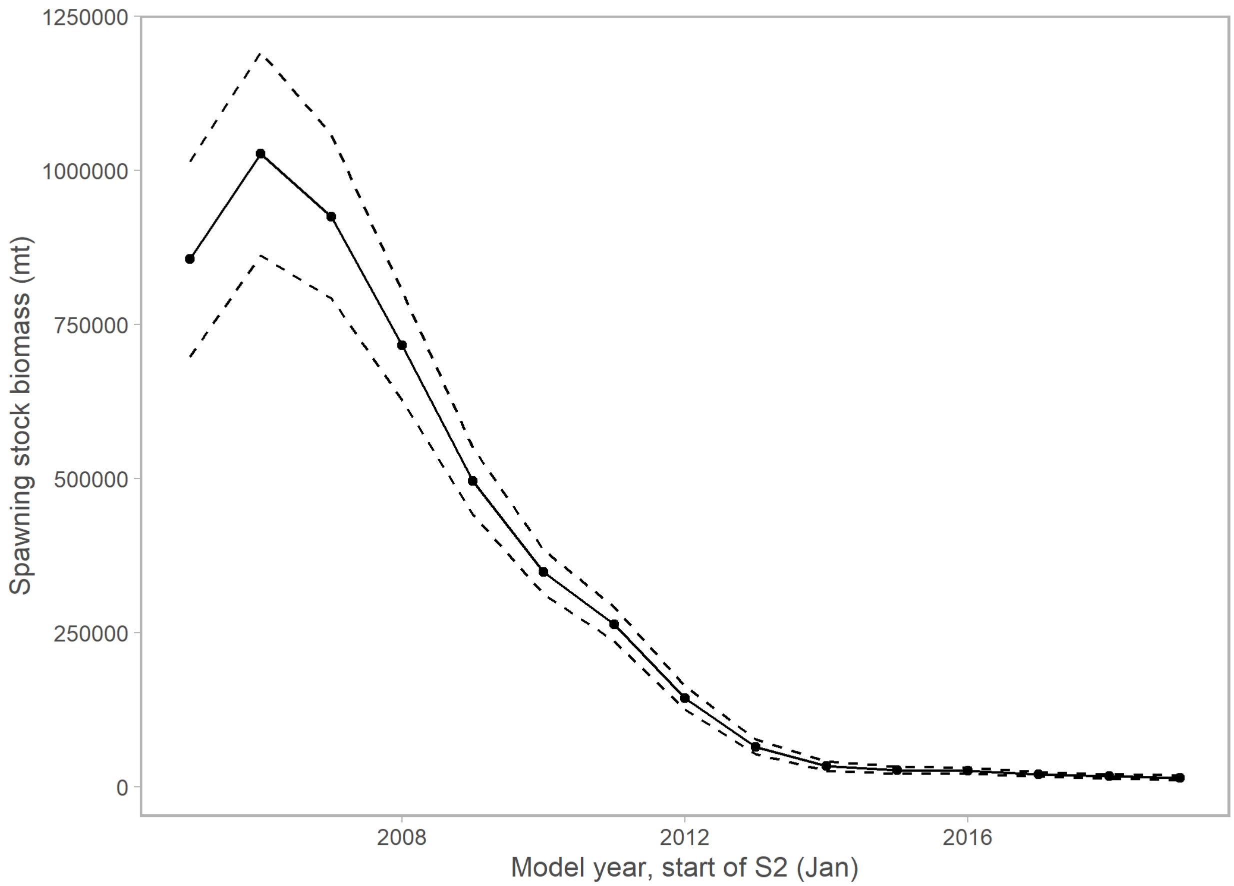

Figure 41: Spawning stock biomass time series (95% CI dashed lines) for 2020 base model.

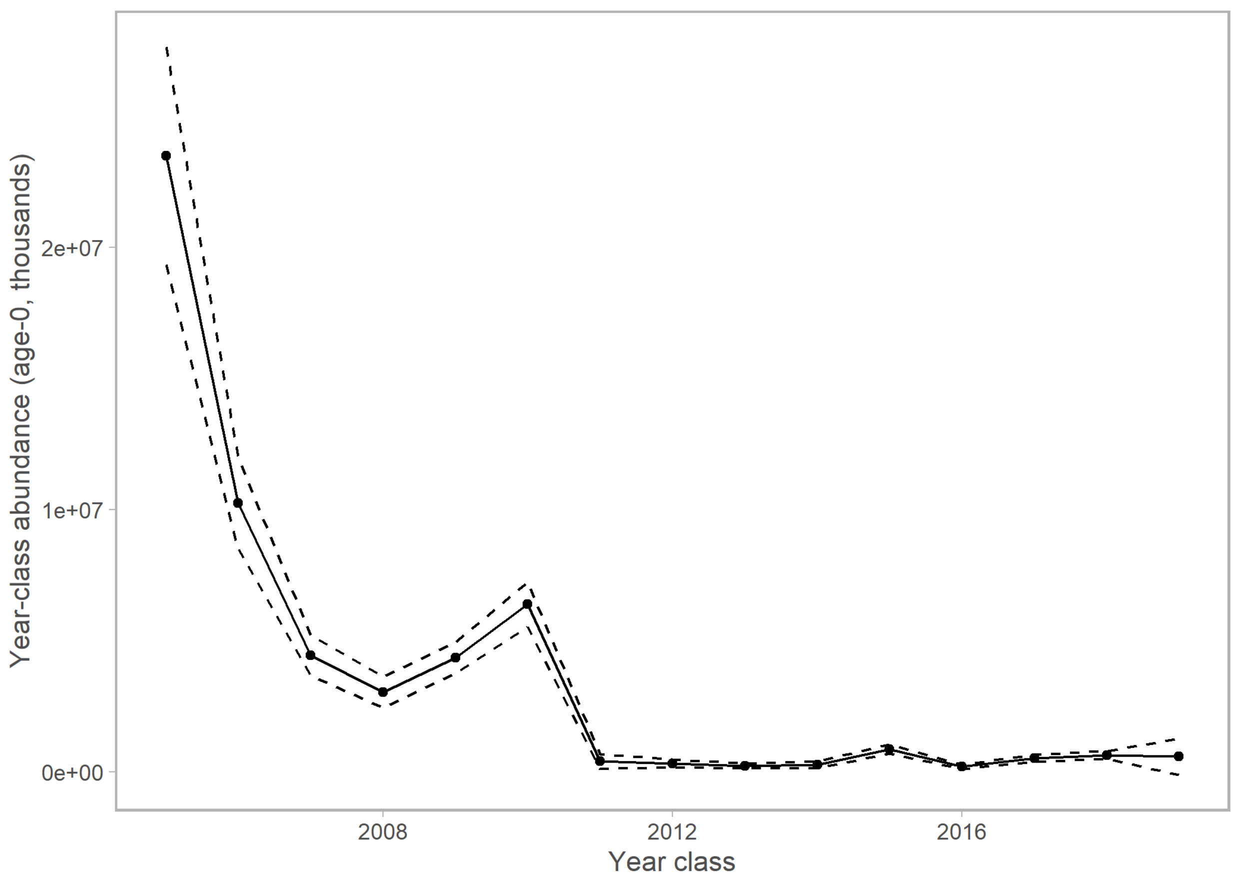

Figure 42: Estimated recruitment (age 0 fish, thousands) time series for 2020 base model.

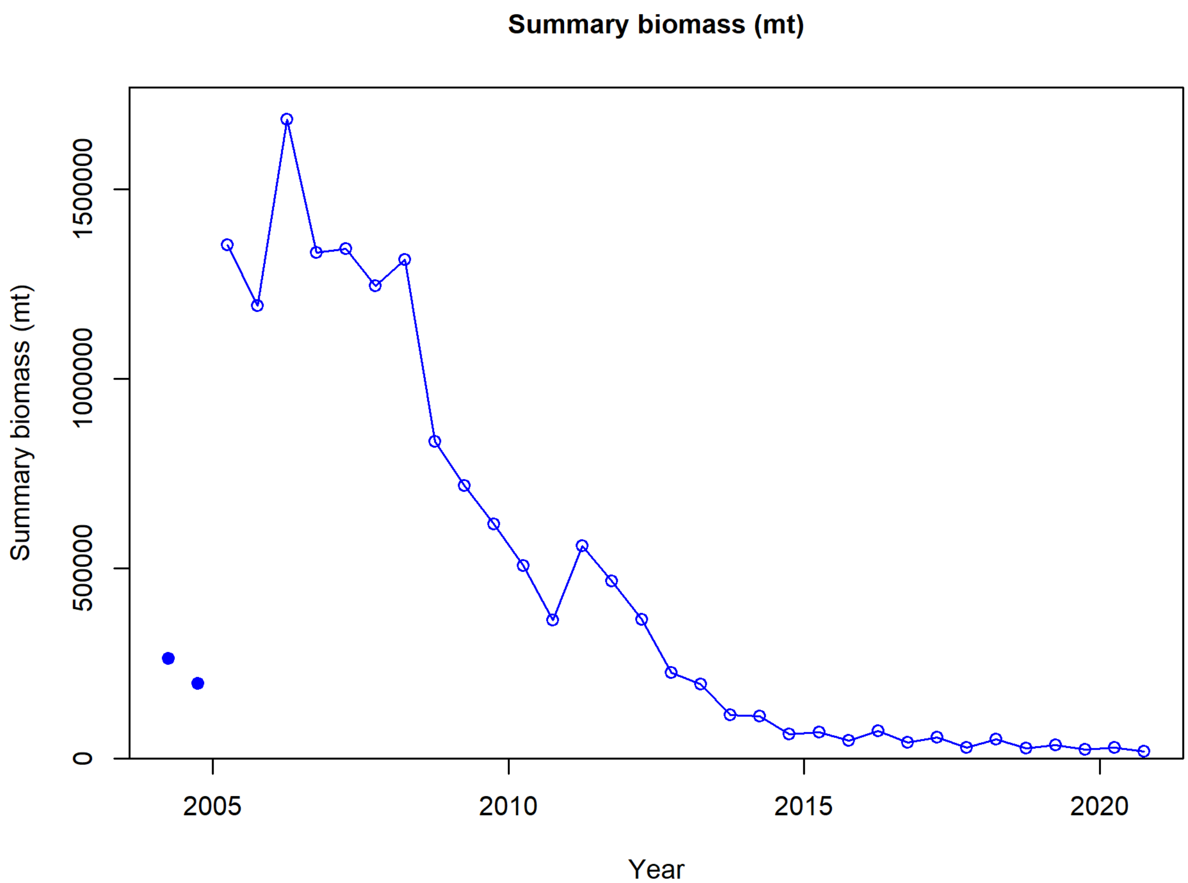

Figure 43: Estimated stock biomass (age 1+ fish, mt) time series for 2020 base model.

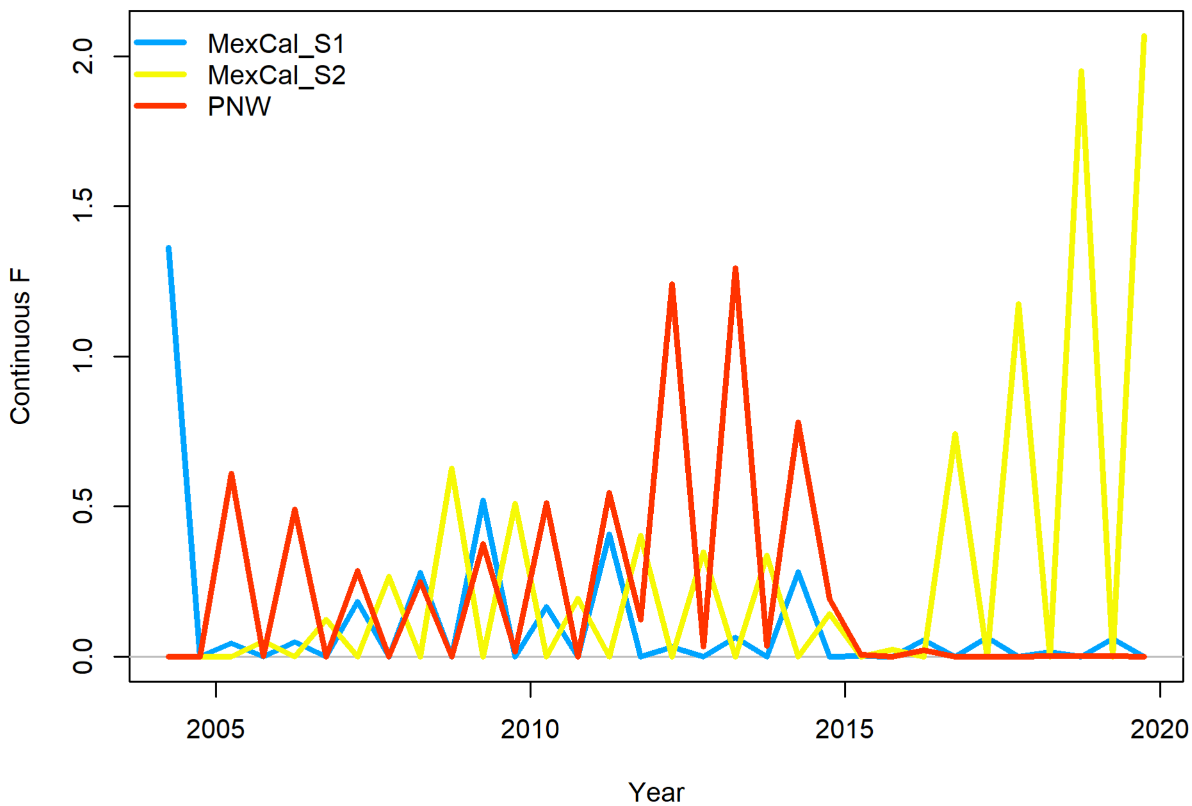

Figure 44: Instantaneous fishing mortality (apical F) time series for 2020 base model.

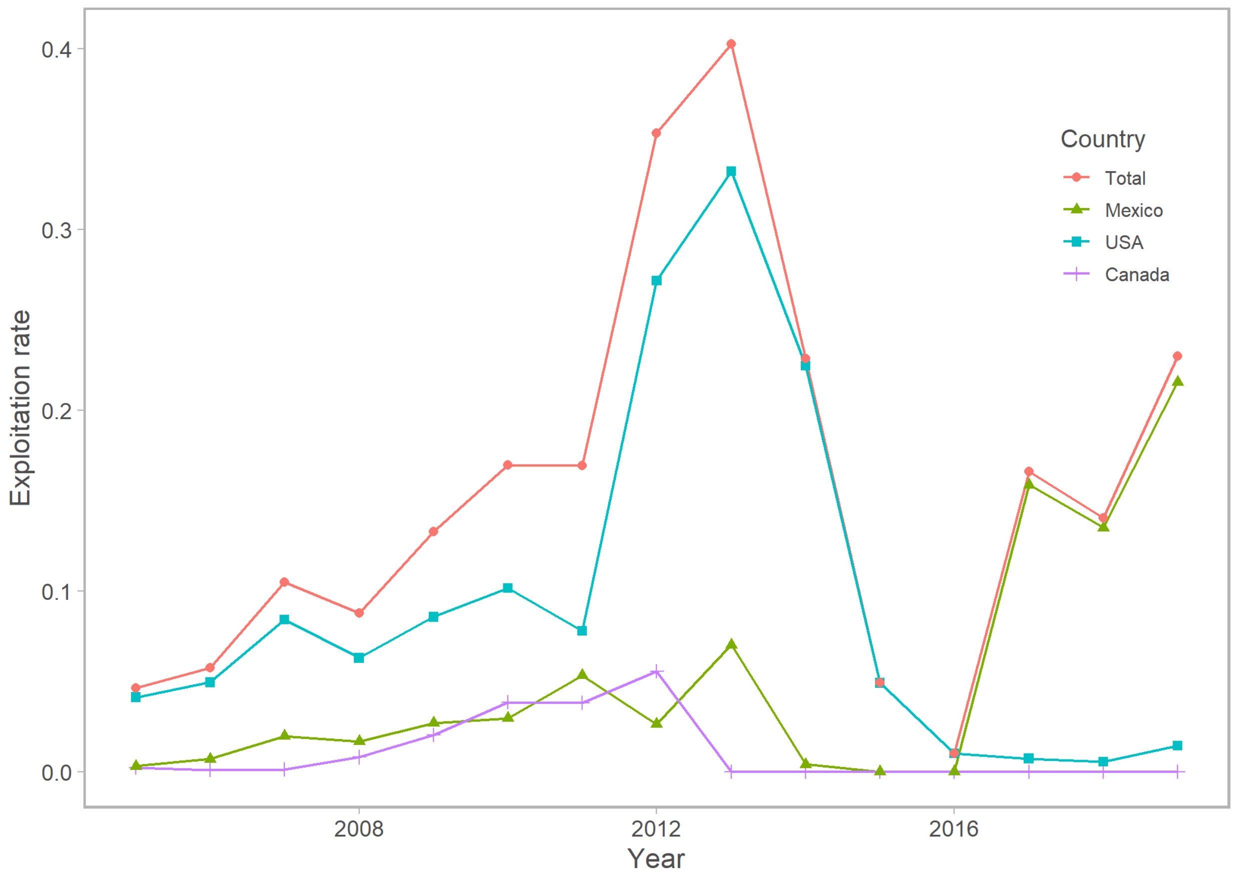

Figure 45: Annual exploitation rates (calendar year landings / July total biomass) for 2020 base model.

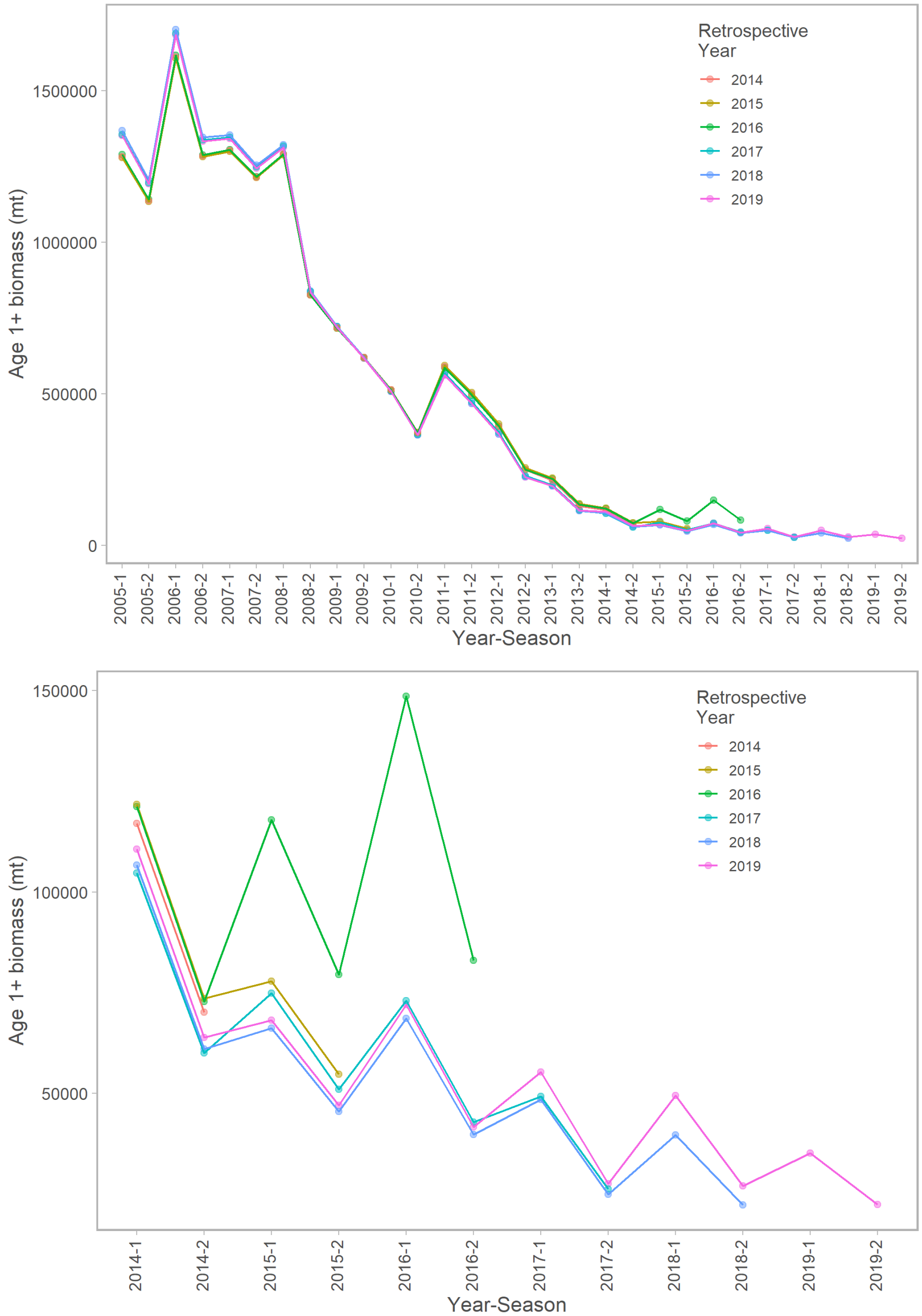

Figure 46: Retrospective analyses of stock biomass (age 1+) for 2020 base model. The full time series (2005-2020; top panel) and zoomed in time series (2014-2020; bottom panel) are shown.

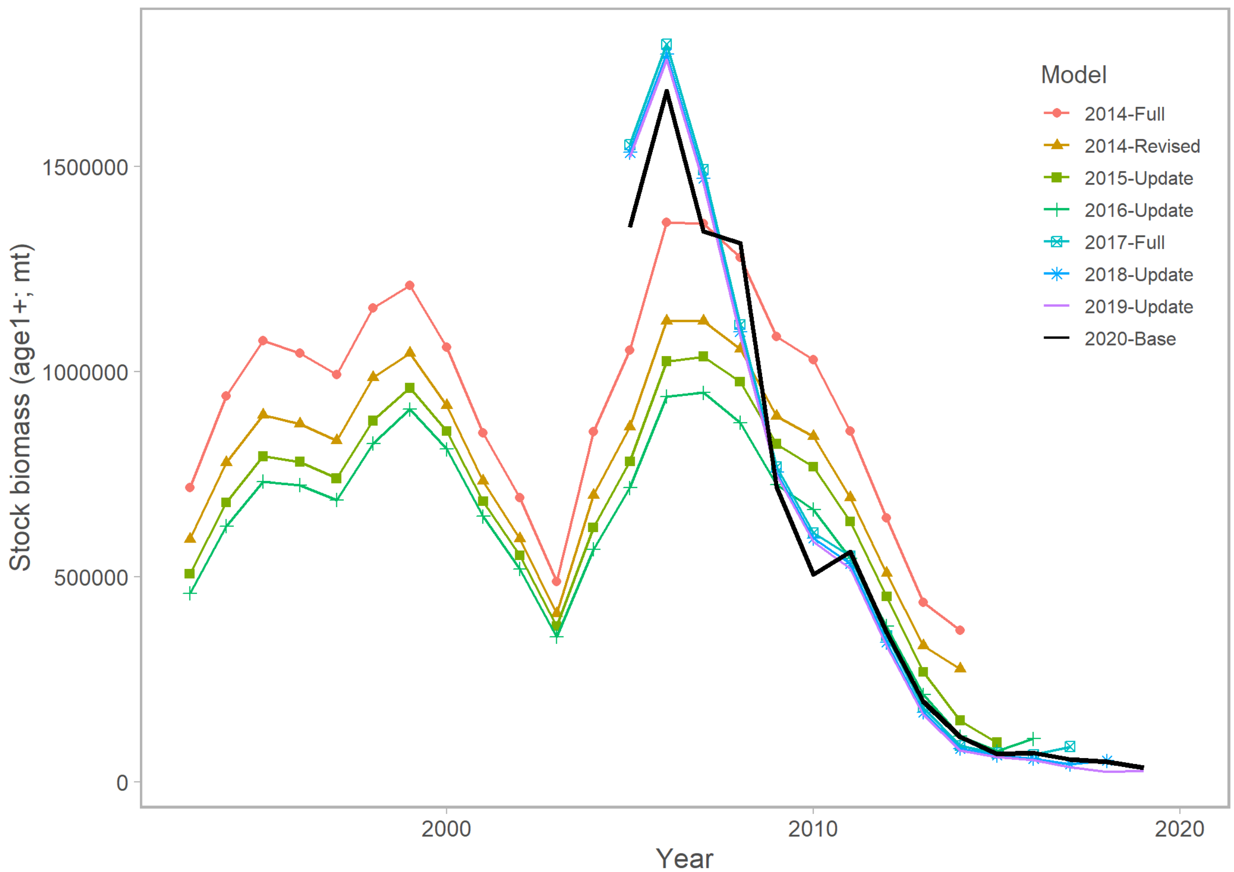

Figure 47: Estimated stock biomass (age 1+, mt) time series for 2020 base model and past assessment models used for management.

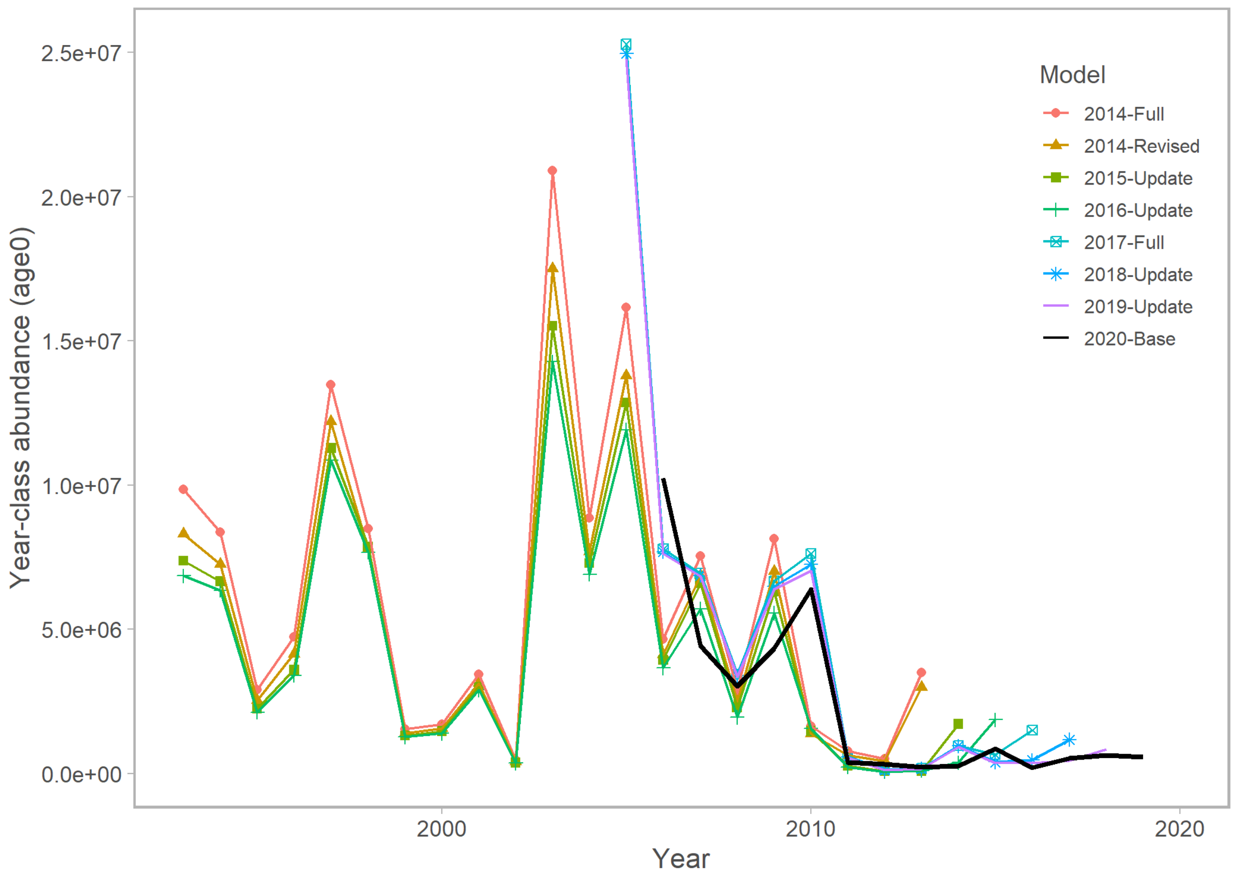

Figure 48: Estimated recruits (age-0) time series for 2020 base model and past assessment models used for management.

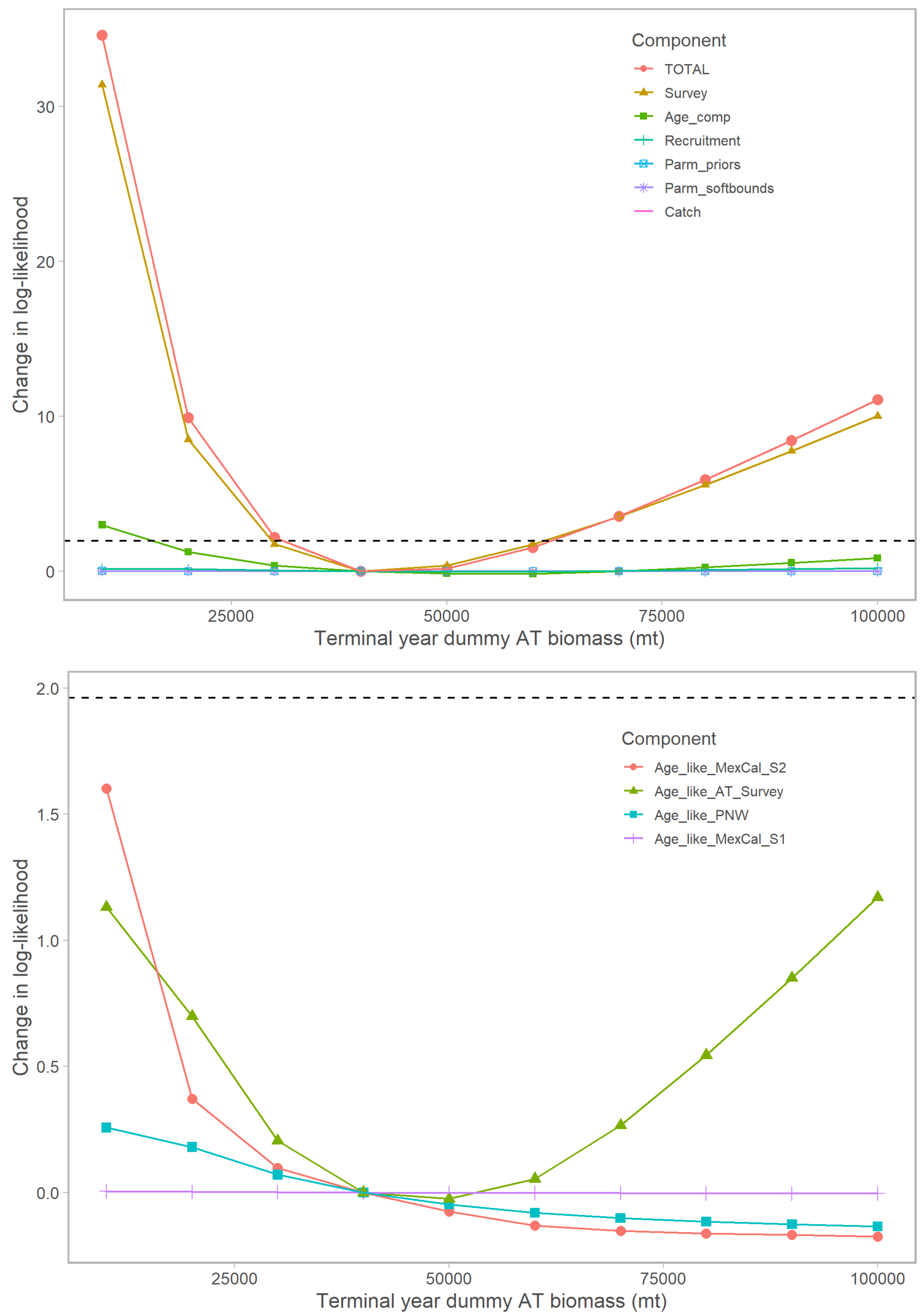

Figure 49: Likelihood profile across fixed values of terminal-year biomass. Values within 1.92 units of the MLE (dashed horizontal line) are within the 95% confidence interval.

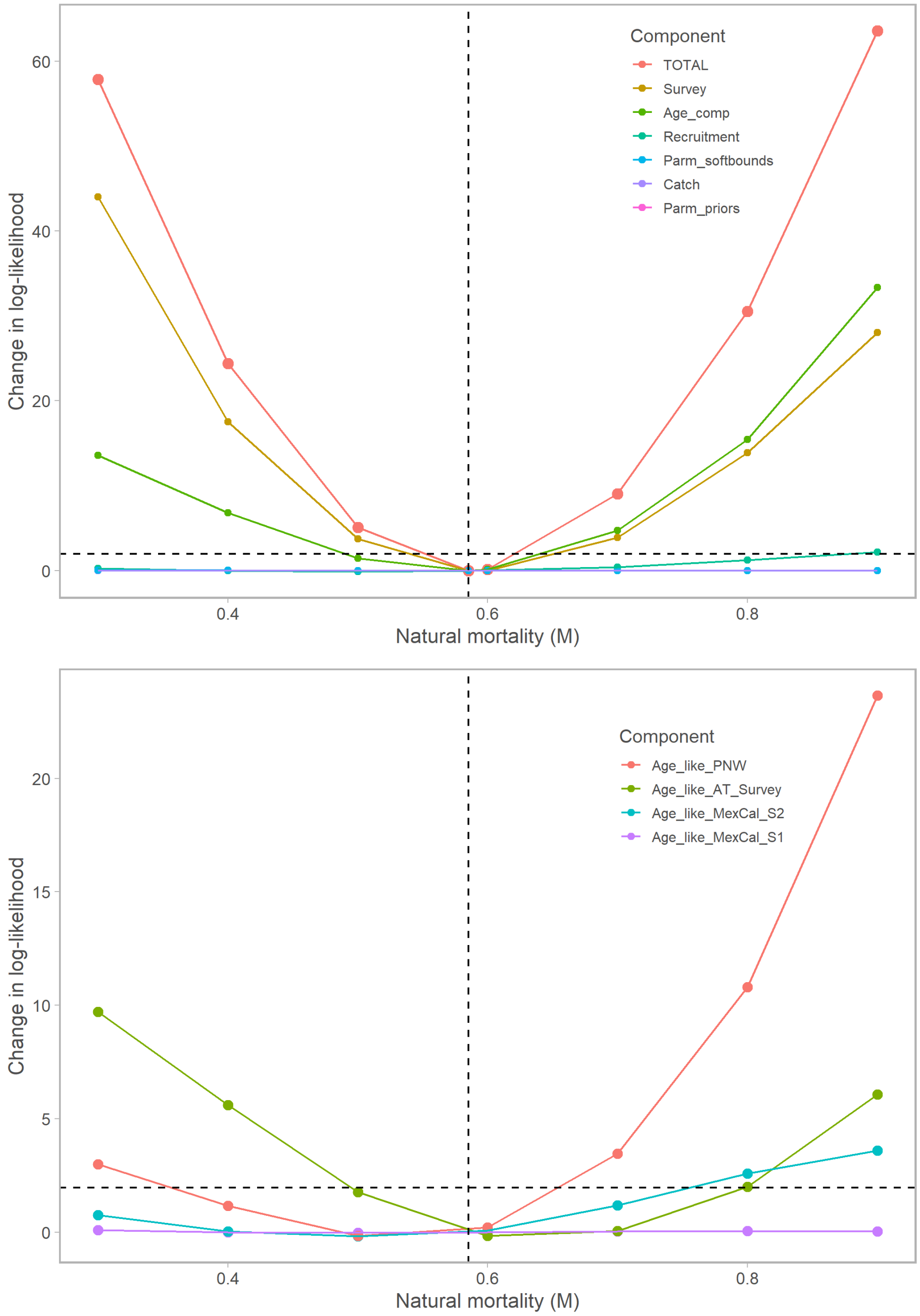

Figure 50: Likelihood profile across fixed values of natural mortality (M). Vertical line indicates the value of the MLE (0.56). Values within 1.92 units of the MLE (dashed horizontal line) are within the 95% confidence interval.

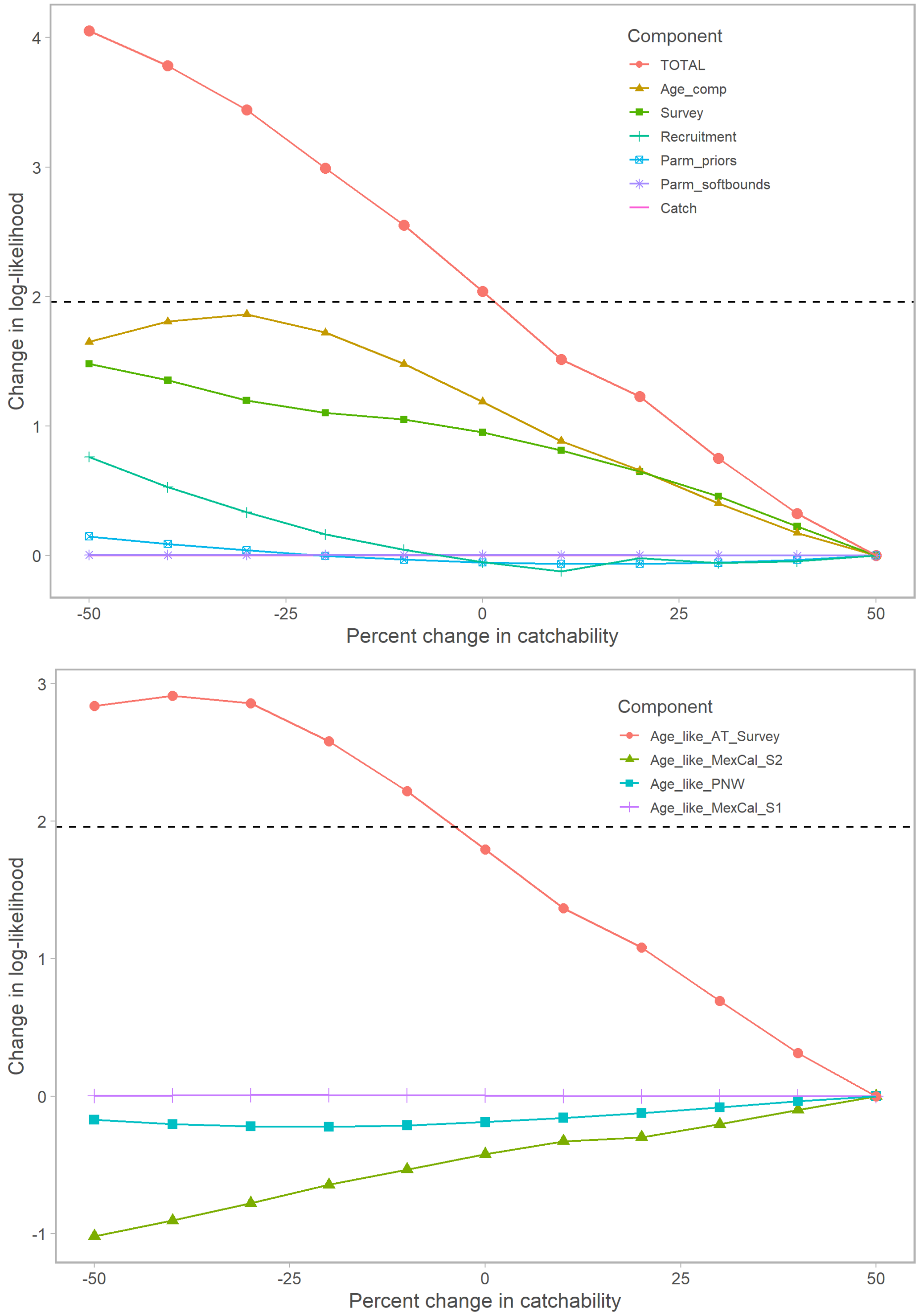

Figure 51: Likelihood profile across percent changes in fixed catchability (Q) values. In the 2020 base model a fixed Q=1 was used for 2005-2014 and a fixed Q=0.73 for 2015-2019. Values within 1.92 units of the MLE (dashed horizontal line) are within the 95% confidence interval.

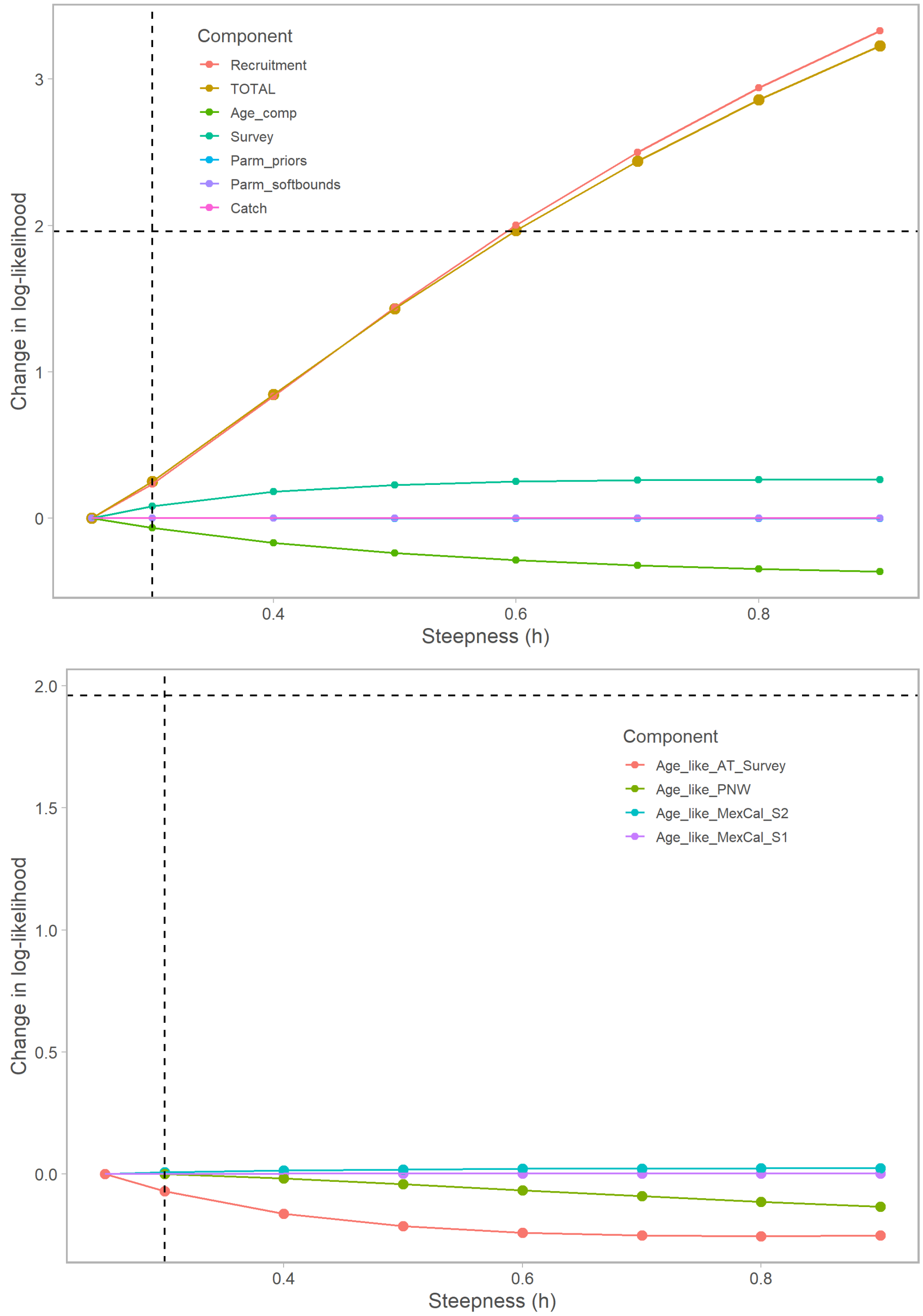

Figure 52: Likelihood profile across fixed values of steepness (h). Steepness was fixed at 0.3 in the 2020 base model. Values within 1.92 units of the MLE (dashed horizontal line) are within the 95% confidence interval.

11 Appendix A: Calculation of abundance-at-age and weight-at-age from ATM surveys

Juan P. Zwolinski

Two of the outputs of the ATM survey are abundance-at-length and biomass-at-length (Zwolinski et al., 2019). The calculations of abundance-at-age, biomass-at-age, and weight-at-age required for the current sardine assessment rely on the constructions of age-length keys (Hill et al., 2017). An age-length key (ALK) is a model that describes the probability of a fish of a known length belonging to an age-class (Stari et al., 2010). ALKs are used often to calculate abundance and catch-at-age from fisheries-dependent and -independent sources (e.g., Kimura, 1977; Clark, 1981; Hoenig and Heisey, 1987; Robotham et al., 2008). Their use is common when only a subsample of all the fish sampled for lengths are aged, a practice that reduces the time and costs of sampling and analysis. The use of an ALK relies on the assumption that the conditional distribution of ages given length in the subsample is representative of that in the population (Kimura, 1977; Westrheim and Ricker, 1978).

The sampling scheme to build an ALK requires a sufficient number of individuals to estimate the conditional age-distribution over a set of fixed length intervals. For Pacific sardine, ALKs were based on individuals from a two-stage sampling procedure. The first level sampling was used to obtain a length-frequency distribution for the population, and a subsample of those individuals was used to derive the distribution of ages-at length (Clark, 1981).

When the number of individuals sampled for age is large, an empirical age-length key can be built by computing the proportion of individuals of all ages across all discrete length classes (Ailloud and Hoenig, 2019). However, when sample size is small and there is ageing error, empirical age-length keys might be dominated by error (Stari et al., 2010). In these cases creating a smooth ALK relying on some sound underlying process is preferable (e.g., Martin and Cook, 1990; Berg and Kristensen, 2012).

There are numerous analytical approaches to build smooth or model-based ALK (e.g., references above; Stari et al., 2010; and references therein). Here, we postulated that for ages a (in years) such that $a \in \{0, 1, ..., 9+\}$, the probability distribution conditioned on length l, $P_a(l) = \{p_0 l, p_1 l, ..., p_{9+}(l)\}$, follows an ordered categorical distribution. $P_a(l)$ modeled using the *gam* function in the *mgcv* package (Wood et al., 2016) for R, with distribution ocat. Detailed information about the ordered categorical regression used can be found in the supplementary information of Wood et al. (2016). Below is brief explanation of the model fitting in R. For a data set with a variable *age.ordinal* – coded by natural numbers from 1 to 10, corresponding to ages 0, 1, 2, . . . 9+ years, and *standard.length* – coded as a continuous variable in mm, the gam model can be fitted by

R = 10 # number of age categories

model <- gam(age.ordinal ~ s(standard.length) , data = data , family= ocat(R= R)) # the ordinal model as smooth function of length and the resulting ALK can be created by

prob.matrix <- predict(model , newdata = data.frame(standard.length = seq(40,300, by =10)), type = "response")

which results in a 27x10 matrix in which each row is the estimated vector of probabilities $P_a(l)$ of a fish of length l (in cm) with $l \in \{4, 5, ..., 30\}$ belonging to an age group a, with $a \in \{0, 1, ..., 9+\}$. Considering a vector of abundances at length $N_l = n_4, n_5, ..., n_{30}$, the elements of vector of abundances at age N_a are calculated by $n_a = \sum_{l=4}^{30} P_a(l)n_l$. Similarly, the elements of biomass at age B_a are given by $b_a = \sum_{l=4}^{30} P_a(l)n_l * w_l$, where w_l is the average weight of sardine in the l-th length class. Finally, mean weight-at-age is obtained by dividing B_a by N_a.

A diagnostic of the model for age-length keys involves visually comparing the empirical distribution of numbers-at-age in the subsample (Fig. A-1), to those of the reconstructed distribution (Fig. A-1) using the smooth ALK (Fig. A-1) as described above. Additionally, the residuals of the ALK are calculated as:

$$r_{la} = \frac{n_{la} - P_a(l)n_l}{\sqrt{n_l P_a(l)(1 - p_a(l))}}$$

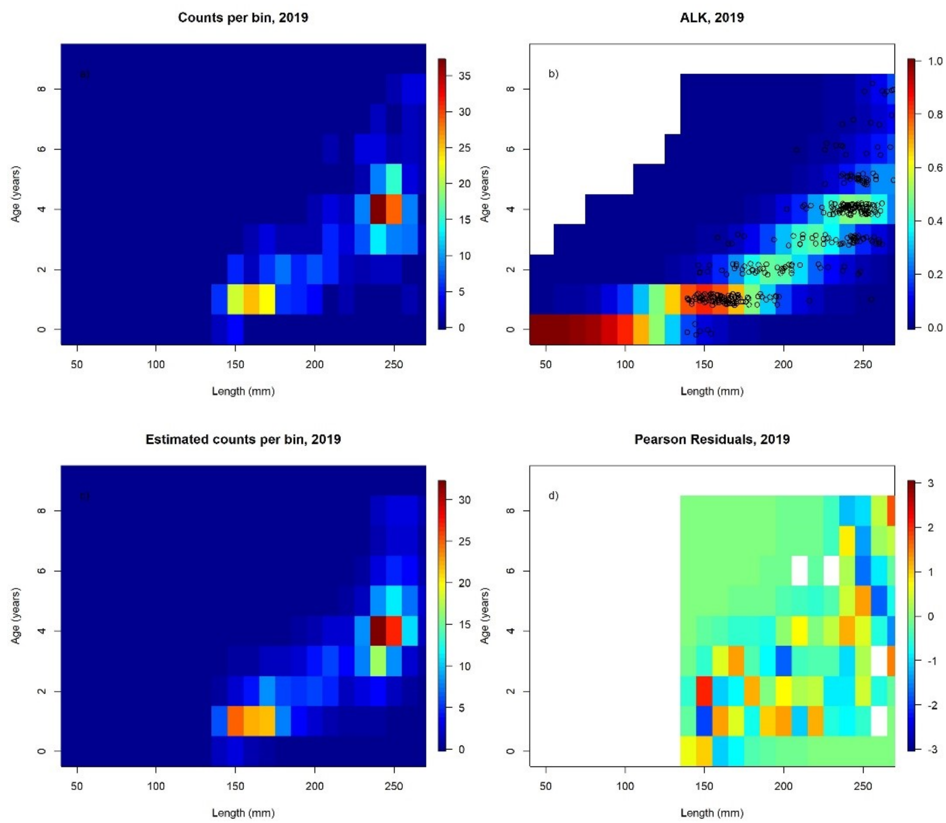

Figure A-1: Example of the fit of an age-length key to the 2019 survey data. a) Empirical distribution of numbers-at-age and length; b) ALK generated by the *gam* model with ordered categorical distribution and with the pairs of observations overlaid (jittered black circles); c) reconstructed distribution of numbers-at-age and length; d) residuals-at-age and length.

References:

- Ailloud, L. E., and Hoenig, J. M. 2019. A general theory of age-length keys: combining the forward and inverse keys to estimate age composition from incomplete data. ICES Journal of Marine Science, 76: 1515-1523.
- Berg, C. W., and Kristensen, K. 2012. Spatial age-length key modelling using continuation ratio logits. Fisheries Research, 129: 119-126.
- Clark, W. G. 1981. Restricted Least-Squares Estimates of Age Composition from Length Composition. Canadian Journal of Fisheries and Aquatic Sciences, 38: 297-307.
- Hill, K., Crone, P., and Zwolinski, J. P. 2017. Assessment of the Pacific Sardine resource in 2017 for U.S. management in 2017-18. US Department of Commerce. NOAA Technical Memorandum NMFS-SWFSC-576. 262 pp.
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- Kimura, D. K. 1977. Statistical Assessment of Age-Length Key. Journal of the Fisheries Research Board of Canada, 34: 317-324.
- Martin, I., and Cook, R. M. 1990. Combined Analysis of Length and Age-at-Length Data. Journal Du Conseil, 46: 178-186.
- Robotham, H., Young, Z. I., and Saavedra-Nievas, J. C. 2008. Jackknife method for estimating the variance of the age composition using two-phase sampling with an application to commercial catches of swordfish (Xiphias gladius). Fisheries Research, 93: 135-139.
- Stari, T., Preedy, K. F., McKenzie, E., Gurney, W. S. C., Heath, M. R., Kunzlik, P. A., and Speirs, D. C. 2010. Smooth age length keys: Observations and implications for data collection on North Sea haddock. Fisheries Research, 105: 2-12.
- Westrheim, S. J., and Ricker, W. E. 1978. Bias in Using an Age-Length Key to Estimate Age-Frequency Distributions. Journal of the Fisheries Research Board of Canada, 35: 184-189.
- Wood, S. N., Pya, N., and Safken, B. 2016. Smoothing Parameter and Model Selection for General Smooth Models. Journal of the American Statistical Association, 111: 1548-1563.
- Zwolinski, J. P., Stierhoff, K. L., and Demer, D. A. 2019. Distribution, biomass, and demography of coastal pelagic fishes in the California Current Ecosystem during summer 2017 based on acoustic-trawl sampling. NOAA Technical Memorandum NMFS, NOAA-TM-NMFS-SWFSC-610: 74.

12 Appendix B: SS input files for 2020 base model

Starter.ss

```
#V3.30.13.00-trans;_2019_03_09;_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.ss
control.ss
0 # 0=use init values in control file; 1=use ss.par
0 # 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
0.00 # jitter initial parm value by this fraction
2003 # min yr for sdreport outputs (-1 for styr)
-2 # max yr for sdreport outputs (-1 for endyr; -2 for endyr+Nforecastyrs
0 # N individual STD years
#vector of year values

1e-05 # 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
1 # 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
0 8 #_min and max age over which average F will be calculated
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)
0.0001 # ALK tolerance (example 0.0001)
3.30 # check value for end of file and for version control

Forecast.ss

#V3.30.13.00-trans;_2019_03_09;_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.
for all year entries except rebuilder; enter either: actual year, -999 for styr, 0 for endyr, neg number for rel. endyr
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)
0.4 # SPR target (e.g. 0.40)
0.4 # 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)
2019 2019 2019 2019 2019 2019 2005 2019 2005 2019
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
1 # 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 -999 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), negative value invokes list of [year, scalar]
with filling from year to YrMax
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 (need to set phase to -1 in control to get constant recruitment in MCMC)
1 # value is ignored
0 #_Forecast loop control #5 (reserved for future bells&whistles)
2021 #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 0.0490493
# 1 3 0.0312885
# 2 2 0.908688
# 2 3 0.0109746
# -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
99 # 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)
2020 1 1 0.01475
2020 2 1 0.00

2020 1 2 0.00
2020 2 2 1.95

2020 1 3 0.0015
2020 2 3 0.00

#2020 1 1 130.86
#2020 2 1 0.00
#2020 1 2 0.00
#2020 2 2 11819.39
#2020 1 3 7.73
#2020 2 3 2.51
-9999 1 1 0

#
999 # verify end of input
```

sardine.ctl

```
#V3.30.13.00-trans;_2019_03_09;_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_19.dat // ALT_19.ctl
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, Settle timing, Area; 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
#
4 #_Nblock_Patterns
1 13 9 1 #_blocks_per_pattern
# begin and end years of blocks
```

2004 2004

#Survey blocks; No survey in 2006 and 2005 is the base selex pattern
2007 2007
2008 2008
2009 2009
2010 2010
2011 2011
2012 2012
2013 2013
2014 2014
2015 2015
2016 2016
2017 2017
2018 2018
2019 2019

#Fishery blocks; 2005 is base selex pattern
2006 2006
2007 2007
2008 2008
2009 2009
2010 2010
2011 2011
2012 2012
2013 2013
2014 2019
#
#Q prior block
2015 2019

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
1 1 1 1 1 # 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: P_block=P_base*exp(TVP); 1: P_block=P_base+TVP; 2: P_block=TVP; 3: P_block=P_block(-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)=P_base*exp(TVP*env(y)); 2: P(y)=P_base+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)+=dev(y)*dev_se; 3: random walk; 4: zero-reverting random walk with rho; 21-24 keep last dev for rest of years
#
#
#
# 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=NA; 7=NA; 8=growth cessation
0.5 #_Age(post-settlement)_for_L1;linear growth below this
999 #_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
0 #_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
0.199 0.936 0.7 -0.5975586 0.394758 3 2 0 0 0 0 0 0 0 # NatM_p_1_Fem_GP_1
# 0.3 0.8 0.6 0 99 0 3 0 0 0 0 0 0 0 # NatM_p_1_Fem_GP_1
# Sex: 1 BioPattern: 1 Growth
3 15 10 0 99 0 -3 0 0 0 0 0 0 0 # L_at_Amin_Fem_GP_1
20 30 25 0 99 0 -3 0 0 0 0 0 0 0 # L_at_Amax_Fem_GP_1
0.05 0.99 0.4 0 99 0 -3 0 0 0 0 0 0 0 # VonBert_K_Fem_GP_1
0.05 0.5 0.14 0 99 0 -3 0 0 0 0 0 0 0 # CV_young_Fem_GP_1
0.01 0.1 0.05 0 99 0 -3 0 0 0 0 0 0 0 # CV_old_Fem_GP_1
# Sex: 1 BioPattern: 1 WtLen
-3 3 7.5242e-006 0 99 0 -3 0 0 0 0 0 0 0 # Wtlen_1_Fem
-3 5 3.2332 0 99 0 -3 0 0 0 0 0 0 0 # Wtlen_2_Fem
# Sex: 1 BioPattern: 1 Maturity&Fecundity
9 19 15.44 0 99 0 -3 0 0 0 0 0 0 0 # Mat50%_Fem
-20 3 -0.89252 0 99 0 -3 0 0 0 0 0 0 0 # Mat_slope_Fem
```

```
0 10 1 0 99 0 -3 0 0 0 0 0 0 0 # Eggs/kg_inter_Fem
-1 5 0 0 99 0 -3 0 0 0 0 0 0 0 # Eggs/kg_slope_wt_Fem
# Hermaphroditism
# Recruitment Distribution
#-4 4 0 0 99 0 -3 0 0 0 0 0 0 0 # RecrDist_GP_1
#-4 4 1 0 99 0 -3 0 0 0 0 0 0 0 # RecrDist_Area_1
#-4 4 1 0 99 0 -3 0 0 0 0 0 0 0 # RecrDist_timing_1
# Cohort growth dev base
0.1 10 1 1 1 6 -1 0 0 0 0 0 0 0 # CohortGrowDev
# Movement
# Age Error from parameters
# catch multiplier
# fraction female, by GP
0.000001 0.999999 0.5 0.5 0.5 0 -99 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
3 25 14.2 0 99 0 1 0 0 0 0 0 0 0 # SR_LN(R0)
0.2 1 0.3 0 99 0 -5 0 0 0 0 0 0 0 # SR_BH_steep
0 2 1.2 0 99 0 -3 0 0 0 0 0 0 0 # SR_sigmaR
-15 15 0 0 99 0 -1 0 0 0 0 0 1 2 # SR_regime
```

```
0 0 0 0 99 0 -3 0 0 0 0 0 0 0 # SR_autocorr
#Next are short parm lines for timevary
#_LO HI INIT PRIOR PR_SD PR_type PHASE
-15 15 2.01545 0 0 0 4 # SR_regime_BLK1add_2004_2004
1 #do_recdev: 0=none; 1=devvector (R=F(SSB)+dev); 2=deviations (R=F(SSB)+dev); 3=deviations
(R=R0*dev; dev2=R-f(SSB)); 4=like 3 with sum(dev2) adding penalty
2005 # first year of main recr_devs; early devs can preceed this era
2018 # 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)
2 #_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
1991.7 #_last_yr_nobias_adj_in_MPD; begin of ramp
2003.8 #_first_yr_fullbias_adj_in_MPD; begin of plateau
2017.0 #_last_yr_fullbias_adj_in_MPD
2018.0 #_end_yr_for_ramp_in_MPD (can be in forecast to shape ramp, but SS sets bias_adj to 0.0 for
fcast yrs)
0.9093 #_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)
-5 #min rec_dev
5 #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
```

```
# 1999E 2000E 2001E 2002E 2003E 2004E 2005R 2006R 2007R 2008R 2009R 2010R 2011R 2012R
2013R 2014R 2015R 2016R 2017R 2018F 2019F
# -0.268996 -0.317947 -0.407416 0.0690791 0.892756 0.15518 -0.192824 -0.475354 -0.955199 -0.180308
0.206281 -1.63497 -2.4461 -1.71318 0.281394 0.547216 0.534335 1.04716 4.98155 0 0
# implementation error by year in forecast: 0
#
#Fishing Mortality info
0.1 # F ballpark
-2006 # 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
10 # N iterations for tuning F in hybrid method (recommend 3 to 7)
#
#_initial_F_parms; count = 1
#_ LO HI INIT PRIOR PR_SD PR_type PHASE
0 3 2.25258 0 99 0 1 # InitF_seas_1_flt_1MexCal_S1
#2019 2074
# F rates by fleet
# Yr: 2005 2005 2006 2006 2007 2007 2008 2008 2009 2009 2010 2010 2011 2011 2012 2012 2013 2013
2014 2014 2015 2015 2016 2016 2017 2017 2018 2018 2019 2019
# seas: 1 2 1 2 1 2 1 2 1 2 1 2 1 2 1 2 1 2 1 2 1 2 1 2 1 2 1 2 1 2
# MexCal_S1 0.0438255 0 0.0660767 0 0.176544 0 0.187782 0 0.135454 0 0.13695 0 0.216923 0 0.0187663
0 0.0356888 0 0.175152 0 0.00049481 0 0.0142116 0 0.00991665 0 0.000951018 0 5.05195e-05 0
# MexCal_S2 0 0.0821925 0 0.119609 0 0.224956 0 0.258034 0 0.275264 0 0.168161 0 0.199346 0 0.356185
0 0.335375 0 0.053009 0 0.00880949 0 0.488743 0 0.487494 0 0.0176186 0 0.00958493
# PNW 1.38581 0.00373427 0.44885 0 0.367948 0 0.256983 0 0.339426 0.0145672 0.582787 1.3703e-06
0.571456 0.12506 2.17521 0.070177 1.7188 0.0480624 0.59509 0.135034 0.00409881 0.000115873 0.0074476
1.15541e-05 0.000104843 0.000262809 0.000606653 0.000212787 0.000314888 0.000108745
#
```

```
#_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;
4=mirror with offset, 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
4 1 0 0 0 0 # AT_Survey
-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
-3 3 0 0 99 0 -2 0 0 0 0 0 4 2 # LnQ_base_ATM_Summer(4)
#-3 3 0 0 .1 6 -2 0 0 0 0 0 4 2 # LnQ_base_ATM_Summer(4)
#-3 3 0.157183 0 99 0 4 0 0 0 0 0 0 0 # LnQ_base_AT_Survey(4)
#_no timevary Q parameters
#
0 3 -0.311 0 99 0 -1 # Q block
#_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_dome-shaped_retention

#_Pattern Discard Male Special
0 0 0 0 # 1 MexCal_S1
0 0 0 0 # 2 MexCal_S2
0 0 0 0 # 3 PNW
0 0 0 0 # 4 AT_Survey
#
#_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+special+3; // cubic spline; with 2 additional param for scaling (average over bin range)
#_Pattern Discard Male Special
17 0 0 8 # 1 MexCal_S1
17 0 0 8 # 2 MexCal_S2
12 0 0 0 # 3 PNW
17 0 0 1 # 4 AT_Survey
#
#_ 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 MexCal_S1 LenSelex
2 MexCal_S2 LenSelex
3 PNW LenSelex
4 AT_Survey LenSelex
1 MexCal_S1 AgeSelex
-7 9 1.23 -1 99 0 3 0 0 0 0 0 0 0 # AgeSel_P1_MexCal_S1(1)
-7 9 3.7717 -1 99 0 3 0 0 0 0 0 3 2 # AgeSel_P2_MexCal_S1(1)
-7 9 0.809132 -1 99 0 3 0 0 0 0 0 3 2 # AgeSel_P3_MexCal_S1(1)
-7 9 -1.29578 -1 99 0 3 0 0 0 0 0 3 2 # AgeSel_P4_MexCal_S1(1)
-7 9 -0.223181 -1 99 0 3 0 0 0 0 0 3 2 # AgeSel_P5_MexCal_S1(1)
-7 9 -1.1357 -1 99 0 3 0 0 0 0 0 3 2 # AgeSel_P6_MexCal_S1(1)
-7 9 -0.16435 -1 99 0 3 0 0 0 0 0 0 0 # AgeSel_P7_MexCal_S1(1)
-7 9 -0.694264 -1 99 0 3 0 0 0 0 0 0 0 # AgeSel_P8_MexCal_S1(1)
-7 9 0.0568794 -1 99 0 3 0 0 0 0 0 0 0 # AgeSel_P9_MexCal_S1(1)

2 MexCal_S2 AgeSelex
-7 9 1.99999 -1 99 0 -3 0 0 0 0 0 0 0 # AgeSel_P1_MexCal_S2(2)
-7 9 0.670819 -1 99 0 3 0 0 0 0 0 3 2 # AgeSel_P2_MexCal_S2(2)
-7 9 -0.967526 -1 99 0 3 0 0 0 0 0 3 2 # AgeSel_P3_MexCal_S2(2)
-7 9 -0.42972 -1 99 0 3 0 0 0 0 0 3 2 # AgeSel_P4_MexCal_S2(2)
-7 9 -0.629359 -1 99 0 3 0 0 0 0 0 0 0 # AgeSel_P5_MexCal_S2(2)

```
-7 9 0.472316 -1 99 0 3 0 0 0 0 0 0 0 0 # AgeSel_P6_MexCal_S2(2)
-7 9 -0.224747 -1 99 0 3 0 0 0 0 0 0 0 0 # AgeSel_P7_MexCal_S2(2)
-7 9 0.299453 -1 99 0 3 0 0 0 0 0 0 0 0 # AgeSel_P8_MexCal_S2(2)
-7 9 -0.65828 -1 99 0 3 0 0 0 0 0 0 0 0 # AgeSel_P9_MexCal_S2(2)

# 3 PNW AgeSelex
0 10 3.40597 0 99 0 4 0 0 0 0 0 0 3 2 # AgeSel_P1_PNW(3)
-5 15 1.36441 0 99 0 4 0 0 0 0 0 0 0 0 # AgeSel_P2_PNW(3)
# 4 AT_Survey AgeSelex
0 9 0 -1 99 0 -3 0 0 0 0 0 0 0 0 #AgeSel_P1_AT_Survey(4)
0 9 .1 -1 99 0 4 0 0 0 0 0 0 2 2 #AgeSel_P2_AT_Survey(4)

# timevary selex parameters
#_ LO HI INIT PRIOR PR_SD PR_type PHASE # parm_name
-7 9 3.7717 -1 99 0 3 # AgeSel_P2_MexCal_S1(1)_BLK3repl_2006
-7 9 3.7717 -1 99 0 3 # AgeSel_P2_MexCal_S1(1)_BLK3repl_2007
-7 9 3.7717 -1 99 0 3 # AgeSel_P2_MexCal_S1(1)_BLK3repl_2008
-7 9 3.7717 -1 99 0 3 # AgeSel_P2_MexCal_S1(1)_BLK3repl_2009
-7 9 3.7717 -1 99 0 3 # AgeSel_P2_MexCal_S1(1)_BLK3repl_2010
-7 9 3.7717 -1 99 0 3 # AgeSel_P2_MexCal_S1(1)_BLK3repl_2011
-7 9 3.7717 -1 99 0 3 # AgeSel_P2_MexCal_S1(1)_BLK3repl_2012
-7 9 3.7717 -1 99 0 3 # AgeSel_P2_MexCal_S1(1)_BLK3repl_2013
-7 9 3.7717 -1 99 0 3 # AgeSel_P2_MexCal_S1(1)_BLK3repl_2014
-7 9 0.809132 -1 99 0 3 # AgeSel_P3_MexCal_S1(1)_BLK3repl_2006
-7 9 0.809132 -1 99 0 3 # AgeSel_P3_MexCal_S1(1)_BLK3repl_2007
-7 9 0.809132 -1 99 0 3 # AgeSel_P3_MexCal_S1(1)_BLK3repl_2008
-7 9 0.809132 -1 99 0 3 # AgeSel_P3_MexCal_S1(1)_BLK3repl_2009
-7 9 0.809132 -1 99 0 3 # AgeSel_P3_MexCal_S1(1)_BLK3repl_2010
-7 9 0.809132 -1 99 0 3 # AgeSel_P3_MexCal_S1(1)_BLK3repl_2011
-7 9 0.809132 -1 99 0 3 # AgeSel_P3_MexCal_S1(1)_BLK3repl_2012
-7 9 0.809132 -1 99 0 3 # AgeSel_P3_MexCal_S1(1)_BLK3repl_2013
-7 9 0.809132 -1 99 0 3 # AgeSel_P3_MexCal_S1(1)_BLK3repl_2014
```

-7 9 -1.29578 -1 99 0 3 # AgeSel_P4_MexCal_S1(1)_BLK3repl_2006
-7 9 -1.29578 -1 99 0 3 # AgeSel_P4_MexCal_S1(1)_BLK3repl_2007
-7 9 -1.29578 -1 99 0 3 # AgeSel_P4_MexCal_S1(1)_BLK3repl_2008
-7 9 -1.29578 -1 99 0 3 # AgeSel_P4_MexCal_S1(1)_BLK3repl_2009
-7 9 -1.29578 -1 99 0 3 # AgeSel_P4_MexCal_S1(1)_BLK3repl_2010
-7 9 -1.29578 -1 99 0 3 # AgeSel_P4_MexCal_S1(1)_BLK3repl_2011
-7 9 -1.29578 -1 99 0 3 # AgeSel_P4_MexCal_S1(1)_BLK3repl_2012
-7 9 -1.29578 -1 99 0 3 # AgeSel_P4_MexCal_S1(1)_BLK3repl_2013
-7 9 -1.29578 -1 99 0 3 # AgeSel_P4_MexCal_S1(1)_BLK3repl_2014
-7 9 -0.223181 -1 99 0 3 # AgeSel_P5_MexCal_S1(1)_BLK3repl_2006
-7 9 -0.223181 -1 99 0 3 # AgeSel_P5_MexCal_S1(1)_BLK3repl_2007
-7 9 -0.223181 -1 99 0 3 # AgeSel_P5_MexCal_S1(1)_BLK3repl_2008
-7 9 -0.223181 -1 99 0 3 # AgeSel_P5_MexCal_S1(1)_BLK3repl_2009
-7 9 -0.223181 -1 99 0 3 # AgeSel_P5_MexCal_S1(1)_BLK3repl_2010
-7 9 -0.223181 -1 99 0 3 # AgeSel_P5_MexCal_S1(1)_BLK3repl_2011
-7 9 -0.223181 -1 99 0 3 # AgeSel_P5_MexCal_S1(1)_BLK3repl_2012
-7 9 -0.223181 -1 99 0 3 # AgeSel_P5_MexCal_S1(1)_BLK3repl_2013
-7 9 -0.223181 -1 99 0 3 # AgeSel_P5_MexCal_S1(1)_BLK3repl_2014
-7 9 -1.1357 -1 99 0 3 # AgeSel_P6_MexCal_S1(1)_BLK3repl_2006
-7 9 -1.1357 -1 99 0 3 # AgeSel_P6_MexCal_S1(1)_BLK3repl_2007
-7 9 -1.1357 -1 99 0 3 # AgeSel_P6_MexCal_S1(1)_BLK3repl_2008
-7 9 -1.1357 -1 99 0 3 # AgeSel_P6_MexCal_S1(1)_BLK3repl_2009
-7 9 -1.1357 -1 99 0 3 # AgeSel_P6_MexCal_S1(1)_BLK3repl_2010
-7 9 -1.1357 -1 99 0 3 # AgeSel_P6_MexCal_S1(1)_BLK3repl_2011
-7 9 -1.1357 -1 99 0 3 # AgeSel_P6_MexCal_S1(1)_BLK3repl_2012
-7 9 -1.1357 -1 99 0 3 # AgeSel_P6_MexCal_S1(1)_BLK3repl_2013
-7 9 -1.1357 -1 99 0 3 # AgeSel_P6_MexCal_S1(1)_BLK3repl_2014
-7 9 0.670819 -1 99 0 3 # AgeSel_P2_MexCal_S2(2)_BLK3repl_2006
-7 9 0.670819 -1 99 0 3 # AgeSel_P2_MexCal_S2(2)_BLK3repl_2007
-7 9 0.670819 -1 99 0 3 # AgeSel_P2_MexCal_S2(2)_BLK3repl_2008
-7 9 0.670819 -1 99 0 3 # AgeSel_P2_MexCal_S2(2)_BLK3repl_2009
-7 9 0.670819 -1 99 0 3 # AgeSel_P2_MexCal_S2(2)_BLK3repl_2010

-7 9 0.670819 -1 99 0 3 # AgeSel_P2_MexCal_S2(2)_BLK3repl_2011
-7 9 0.670819 -1 99 0 3 # AgeSel_P2_MexCal_S2(2)_BLK3repl_2012
-7 9 0.670819 -1 99 0 3 # AgeSel_P2_MexCal_S2(2)_BLK3repl_2013
-7 9 0.670819 -1 99 0 3 # AgeSel_P2_MexCal_S2(2)_BLK3repl_2014
-7 9 -0.967526 -1 99 0 3 # AgeSel_P3_MexCal_S2(2)_BLK3repl_2006
-7 9 -0.967526 -1 99 0 3 # AgeSel_P3_MexCal_S2(2)_BLK3repl_2007
-7 9 -0.967526 -1 99 0 3 # AgeSel_P3_MexCal_S2(2)_BLK3repl_2008
-7 9 -0.967526 -1 99 0 3 # AgeSel_P3_MexCal_S2(2)_BLK3repl_2009
-7 9 -0.967526 -1 99 0 3 # AgeSel_P3_MexCal_S2(2)_BLK3repl_2010
-7 9 -0.967526 -1 99 0 3 # AgeSel_P3_MexCal_S2(2)_BLK3repl_2011
-7 9 -0.967526 -1 99 0 3 # AgeSel_P3_MexCal_S2(2)_BLK3repl_2012
-7 9 -0.967526 -1 99 0 3 # AgeSel_P3_MexCal_S2(2)_BLK3repl_2013
-7 9 -0.967526 -1 99 0 3 # AgeSel_P3_MexCal_S2(2)_BLK3repl_2014
-7 9 -0.42972 -1 99 0 3 # AgeSel_P4_MexCal_S2(2)_BLK3repl_2006
-7 9 -0.42972 -1 99 0 3 # AgeSel_P4_MexCal_S2(2)_BLK3repl_2007
-7 9 -0.42972 -1 99 0 3 # AgeSel_P4_MexCal_S2(2)_BLK3repl_2008
-7 9 -0.42972 -1 99 0 3 # AgeSel_P4_MexCal_S2(2)_BLK3repl_2009
-7 9 -0.42972 -1 99 0 3 # AgeSel_P4_MexCal_S2(2)_BLK3repl_2010
-7 9 -0.42972 -1 99 0 3 # AgeSel_P4_MexCal_S2(2)_BLK3repl_2011
-7 9 -0.42972 -1 99 0 3 # AgeSel_P4_MexCal_S2(2)_BLK3repl_2012
-7 9 -0.42972 -1 99 0 3 # AgeSel_P4_MexCal_S2(2)_BLK3repl_2013
-7 9 -0.42972 -1 99 0 3 # AgeSel_P4_MexCal_S2(2)_BLK3repl_2014
0 10 3.40597 0 99 0 4 # Age_inflection_PNW(3)_BLK3repl_2006
0 10 3.40597 0 99 0 4 # Age_inflection_PNW(3)_BLK3repl_2007
0 10 3.40597 0 99 0 4 # Age_inflection_PNW(3)_BLK3repl_2008
0 10 3.40597 0 99 0 4 # Age_inflection_PNW(3)_BLK3repl_2009
0 10 3.40597 0 99 0 4 # Age_inflection_PNW(3)_BLK3repl_2010
0 10 3.40597 0 99 0 4 # Age_inflection_PNW(3)_BLK3repl_2011
0 10 3.40597 0 99 0 4 # Age_inflection_PNW(3)_BLK3repl_2012
0 10 3.40597 0 99 0 4 # Age_inflection_PNW(3)_BLK3repl_2013
0 10 3.40597 0 99 0 4 # Age_inflection_PNW(3)_BLK3repl_2014
0 9 0.1 -1 99 0 4 # AgeSel_P2_AT_Survey(4)_BLK2repl_2007

```
0 9 0.1 -1 99 0 4 # AgeSel_P2_AT_Survey(4)_BLK2repl_2008
0 9 0.1 -1 99 0 4 # AgeSel_P2_AT_Survey(4)_BLK2repl_2009
0 9 0.1 -1 99 0 4 # AgeSel_P2_AT_Survey(4)_BLK2repl_2010
0 9 0.1 -1 99 0 4 # AgeSel_P2_AT_Survey(4)_BLK2repl_2011
0 9 0.1 -1 99 0 4 # AgeSel_P2_AT_Survey(4)_BLK2repl_2012
0 9 0.1 -1 99 0 4 # AgeSel_P2_AT_Survey(4)_BLK2repl_2013
0 9 0.1 -1 99 0 4 # AgeSel_P2_AT_Survey(4)_BLK2repl_2014
0 9 0.1 -1 99 0 4 # AgeSel_P2_AT_Survey(4)_BLK2repl_2015
0 9 0.1 -1 99 0 4 # AgeSel_P2_AT_Survey(4)_BLK2repl_2016
0 9 0.1 -1 99 0 4 # AgeSel_P2_AT_Survey(4)_BLK2repl_2017
0 9 0.1 -1 99 0 4 # AgeSel_P2_AT_Survey(4)_BLK2repl_2018
0 9 0.1 -1 99 0 4 # AgeSel_P2_AT_Survey(4)_BLK2repl_2019

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 9 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 4 1 1 1
4 4 1 0 1
5 1 1 1 1
5 2 1 1 1
5 3 1 1 1
5 4 1 1 1
9 1 1 0 1
9 2 1 0 1
9 3 1 0 1
18 1 1 0 1
18 2 1 0 1
18 3 1 0 1
18 4 1 0 1
-9999 1 1 1 1 # terminator
#
# lambdas (for info only; columns are phases)
# 0 #_CPUE/survey:_1
# 0 #_CPUE/survey:_2
# 0 #_CPUE/survey:_3
# 1 #_CPUE/survey:_4
# 0 #_lencomp:_1
# 0 #_lencomp:_2
```

```
# 0 #_lencomp:_3
# 0 #_lencomp:_4
# 1 #_agecomp:_1
# 1 #_agecomp:_2
# 1 #_agecomp:_3
# 1 #_agecomp:_4
# 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
```

sardine.dat

```
#V3.30.14.08-safe;_2019_12_02;_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: Thu Dec 12 15:17:28 2019
#_Number_of_datafiles: 1
#C data file created using the SS_writedat function in the R package r4ss
#C should work with SS version:
#C file write time: 2019-12-12 15:16:18
#_observed data:
#V3.30.14.08-safe;_2019_12_02;_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.
2005 #_StartYr
2019 #_EndYr
2 #_Nseas
6 6 #_months/season
2 #_Nsubseasons (even number, minimum is 2)
7 #_spawn_month
1 #_Ngenders: 1, 2, -1 (use -1 for 1 sex setup with SSB multiplied by female_frac parameter)
10 #_Nages=accumulator age, first age is always age 0
1 #_Nareas
4 #_Nfleets (including surveys)
#_fleet_type: 1=catch fleet; 2=bycatch only fleet; 3=survey; 4=ignore
#_sample_timing: -1 for fishing fleet to use season-long 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 MexCal_S1 # 1
1 -1 1 1 0 MexCal_S2 # 2
1 -1 1 1 0 PNW # 3
3 1 1 2 0 AT_Survey # 4
#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 1000.00 0.05
-999 2 1 0.00 0.05
2005 1 1 13802.99 0.05
2005 2 1 0.00 0.05
2006 1 1 20726.23 0.05
2006 2 1 0.00 0.05
2007 1 1 46228.11 0.05
2007 2 1 0.00 0.05
2008 1 1 30249.18 0.05
2008 2 1 0.00 0.05
2009 1 1 14044.87 0.05
```

2009 2 1 0.00 0.05
2010 1 1 11273.97 0.05
2010 2 1 0.00 0.05
2011 1 1 24871.40 0.05
2011 2 1 0.00 0.05
2012 1 1 1528.37 0.05
2012 2 1 0.00 0.05
2013 1 1 921.56 0.05
2013 2 1 0.00 0.05
2014 1 1 1830.92 0.05
2014 2 1 0.00 0.05
2015 1 1 6.13 0.05
2015 2 1 0.00 0.05
2016 1 1 283.54 0.05
2016 2 1 0.00 0.05
2017 1 1 170.41 0.05
2017 2 1 0.00 0.05
2018 1 1 35.31 0.05
2018 2 1 0.00 0.05
2019 1 1 130.86 0.05
2019 2 1 0.00 0.05 #Assume MexCal 2019-1 landings are same as MexCal 2018-1
-999 1 2 0.00 0.05
-999 2 2 0.00 0.05
2005 1 2 0.00 0.05
2005 2 2 30364.20 0.05
2006 1 2 0.00 0.05
2006 2 2 39900.28 0.05
2007 1 2 0.00 0.05
2007 2 2 42910.05 0.05
2008 1 2 0.00 0.05
2008 2 2 41198.49 0.05
2009 1 2 0.00 0.05

2009 2 2 31146.46 0.05
2010 1 2 0.00 0.05
2010 2 2 27267.62 0.05
2011 1 2 0.00 0.05
2011 2 2 23189.90 0.05
2012 1 2 0.00 0.05
2012 2 2 13884.90 0.05
2013 1 2 0.00 0.05
2013 2 2 5625.03 0.05
2014 1 2 0.00 0.05
2014 2 2 727.71 0.05
2015 1 2 0.00 0.05
2015 2 2 185.82 0.05
2016 1 2 0.00 0.05
2016 2 2 7080.53 0.05
2017 1 2 0.00 0.05
2017 2 2 6229.43 0.05
2018 1 2 0.00 0.05
2018 2 2 11819.39 0.05
2019 1 2 0.00 0.05
2019 2 2 11819.39 0.05 #Assume MexCal 2019-2 landings are same as MexCal 2018-2
-999 1 3 0.00 0.05
-999 2 3 0.00 0.05
2005 1 3 54152.62 0.05
2005 2 3 101.70 0.05
2006 1 3 41220.90 0.05
2006 2 3 0.00 0.05
2007 1 3 48237.10 0.05
2007 2 3 0.00 0.05
2008 1 3 39800.10 0.05
2008 2 3 0.00 0.05
2009 1 3 44841.15 0.05

2009 2 3 1369.73 0.05
2010 1 3 54085.91 0.05
2010 2 3 0.09 0.05
2011 1 3 39750.49 0.05
2011 2 3 5805.63 0.05
2012 1 3 91425.63 0.05
2012 2 3 1570.78 0.05
2013 1 3 57217.96 0.05
2013 2 3 908.01 0.05
2014 1 3 15216.82 0.05
2014 2 3 2193.87 0.05
2015 1 3 66.28 0.05
2015 2 3 1.29 0.05
2016 1 3 173.15 0.05
2016 2 3 0.05 0.05
2017 1 3 1.17 0.05
2017 2 3 2.22 0.05
2018 1 3 7.86 0.05
2018 2 3 2.51 0.05
2019 1 3 7.73 0.05
2019 2 3 2.51 0.05 #Assume PNW 2019-2 landings are same as PNW 2018-2
-9999 0 0 0.00 0

#
#_CPUE_and_surveyabundance_observations
#_Units: 0=numbers; 1=biomass; 2=F; 30=spawnbio; 31=recdev; 32=spawnbio*recdev; 33=recruitment; 34=depletion(&see Qsetup); 35=parm_dev(&see Qsetup)
#_Errtype: -1=normal; 0=lognormal; ¿0=T
#_SD_Report: 0=no sdreport; 1=enable sdreport
#_Fleet Units Errtype SD_Report
1 1 0 0 # MexCal_S1
2 1 0 0 # MexCal_S2

```
3 1 0 0 # PNW
4 1 0 0 # AT_Survey
#_yr month fleet obs stderr
2005 10 4 1.94706e+006 0.3 #_ AT_Survey_Spring
2007 10 4 751075 0.09 #_ AT_Survey_Spring
2009 10 4 357006 0.41 #_ AT_Survey_Spring
2010 10 4 493672 0.3 #_ AT_Survey_Spring
2011 10 4 469480 0.28 #_ AT_Survey_Spring
2012 10 4 305146 0.24 #_ AT_Survey_Spring
2013 10 4 35339 0.38 #_ AT_Survey_Spring
2014 10 4 29048 0.29 #_ AT_Survey_Spring
2015 10 4 83030 0.47 #_ AT_Survey_Spring
2008 1 4 801000 0.3 #_ AT_Survey_Summer
2012 1 4 340831 0.33 #_ AT_Survey_Summer
2013 1 4 306191 0.293 #_ AT_Survey_Summer
2014 1 4 26279 0.697 #_ AT_Survey_Summer
2015 1 4 16375 0.94 #_ AT_Survey_Summer
2016 1 4 72867 0.497 #_ AT_Survey_Summer
2017 1 4 14103 0.30 #_AT_Survey_summer_newDec19
2018 1 4 25148 0.67 #_AT_Survey_summer_newDec19
2019 1 4 33632 0.19 #_AT_Survey_summer_newDec19

#2019 1 4 33138 0.21 #_AT_Survey_summer_newDec19
#2017 1 4 24349 0.36 #_ AT_Survey_Summer
#2018 1 4 35501 0.65 #_ AT_Survey_Summer
#2019 1 4 35501 0.65 #_ Dummy values_Summer
-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
2 # length bin method: 1=use databins; 2=generate from binwidth,min,max below; 3=read vector
0.5 # binwidth for population size comp
8 # minimum size in the population (lower edge of first bin and size at age 0.00)
30 # maximum size in the population (lower edge of last bin)
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
-0.0001 0.0001 0 0 0 0 1 #_fleet:1_MexCal_S1
-0.0001 0.0001 0 0 0 0 1 #_fleet:2_MexCal_S2
-0.0001 0.0001 0 0 0 0 1 #_fleet:3_PNW
-0.0001 0.0001 0 0 0 0 1 #_fleet:4_AT_Survey
```

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
39 #_N_LengthBins; then enter lower edge of each length bin
9 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5 15 15.5 16 16.5 17 17.5 18 18.5 19 19.5 20 20.5 21 21.5 22 22.5 23 23.5 24 24.5 25 25.5 26 26.5 27 27.5 28
#_yr month fleet sex part Nsamp datavector(female-male)
#2008 1 -4 0 0 27 0.017005 0.017005 0.022107 0.022107 0.006802 0.006802 0 0 0 0 0 0 0 0 0.006802 0.006802 0.020097 0.020097 0.021648 0.021648 0.089515 0.089515 0.109393 0.109393 0.140293 0.140293 0.053859 0.053859 0.011184 0.011184 0.001294 0.001294 0 0 0 0 0 0 0
2008 1 -4 0 0 27 0.002550816 0.008502719 0.015304895 0.018705982 0.02210707 0.014454623 0.006802175 0.003401088 0 0 0 0 0 0 0 0.003401088 0.006802175 0.013449687 0.020097198 0.020872513 0.021647829 0.055581484 0.089515139 0.099454205 0.109393271 0.124842891 0.140292511 0.097075801 0.053859091 0.032521424 0.011183757 0.006239051 0.001294345 0.000647173 0 0 0 0 0
2012 1 -4 0 0 31 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0.000177406 0.000354812 0.001144885 0.001934958 0.069152124 0.136369291 0.176159798 0.215950306 0.142628664 0.069307022 0.057297458 0.045287894 0.036447961 0.027608028 0.015277719 0.00294741 0.001593845 0.00024028 0.00012014 0 0 0
2013 1 -4 0 0 18 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1.35E-05 2.71E-05 0.01455483 0.029082588 0.119209313 0.209336038 0.190275637 0.171215236 0.120855699 0.070496163 0.044441884 0.018387606 0.009921452 0.001455297 0.000727648 0 0 0
2014 1 -4 0 0 12 0.00409961 0 0 0 0 0 0 0 0 5.49E-07 1.10E-06 5.49E-07 0 0 0 0 0 0 0 0 0 0 0 0 0.004516027 0.009032054 0.082124708 0.155217362 0.208107635 0.260997907 0.161192697 0.061387486 0.036350886 0.011314287 0.005657143 0 0 0
2015 1 -4 0 0 15 0.79429195 8.57E-05 0 0 0 0 0 0 0 0 0 0 0 1.68E-05 3.35E-05 1.68E-05 0 0 0 0 0 0.001010557 0.002021115 0.004042788 0.006064461 0.004070661 0.002076861 0.003060104 0.004043347 0.016553714 0.029064081 0.040951613 0.052839145 0.029726398 0.006613651 0.003334303 5.50E-05 2.75E-05 0
2016 1 -4 0 0 15 0.009338466 0.000982996 0.000982996 0.000491498 0 0.000491498 0.000982996 0.000522176 6.14E-05 0.000170837 0.000280318 0.002418245 0.004556172 0.02063787 0.036719568 0.10164821 0.166576851 0.128591193 0.090605536 0.135250751 0.179895967 0.091514108 0.003132248 0.001768912 0.000405575 0.000895845 0.001386114 0.001295556 0.001204998 0.001741413 0.002277828 0.002801192 0.003324555 0.002834413 0.00234427 0.001345969 0.000347669 0.000173834 0

2017 1 -4 0 0 19 0.185486439 0.109083326 0.109083326 0.054541663 0 0 0 0 0 0 0 0 0 0 0 1.31E-07
2.62E-07 0.003853991 0.007707719 0.005535727 0.003363735 0.017557276 0.031750817 0.044534672
0.057318527 0.076383367 0.095448207 0.071588726 0.047729245 0.027426247 0.00712325 0.007344242
0.007565234 0.009804063 0.012042892 0.006447814 0.000852736 0.000426368 0
2018 1 -4 0 0 20 0.010352473 0.021493546 0.038724011 0.055529912 0.072335812 0.066973488
0.061611164 0.040155461 0.018699758 0.009349879 0 0.009316801 0.018633602 0.026652204 0.034670806
0.034396152 0.034121498 0.019596705 0.005071911 0.003017807 0.000963703 0.000736254 0.000508806
0.00090881 0.001308814 0.001789959 0.002271105 0.014482497 0.026693889 0.054691631 0.082689373
0.078777531 0.074865689 0.045916968 0.016968247 0.008727045 0.000485844 0.001809902 0.00470094
2019 1 -4 0 0 22 0 0 0 0 0 0 0 0 0 0.00345338 0.006906761 0.033719807 0.060532852 0.073676954
0.086821055 0.109406209 0.131991362 0.08952663 0.047061897 0.034012247 0.020962596 0.015231793
0.009500989 0.0096543 0.009807611 0.006712922 0.003618234 0.008567707 0.01351718 0.029133795
0.044750411 0.044819101 0.044887792 0.029866851 0.014845911 0.009152939 0.003459968 0.002390896
0.002009849
2005 10 -4 0 0 10 0 0 0 0 0 0 0 0 0 0.002709 0.002709 0 0 0.011009 0.011009 0.123534 0.123534 0.064539
0.064539 0.157732 0.157732 0.06427 0.06427 0.050097 0.050097 0.015162 0.015162 0.005054 0.005054 0 0
0.001685 0.001685 0.003369 0.003369 0.001685 0 0 0 0
2007 10 -4 0 0 12 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0.018711 0.018711 0.044561 0.044561 0.078855 0.078855
0.07721 0.07721 0.091963 0.091963 0.108039 0.108039 0.068818 0.068818 0.003212 0.003212 0.008259
0.008259 0.000373 0.000373 0 0 0 0 0
2009 10 -4 0 0 19 0 0 0 0 0.000719 0.000719 0.000362 0.000362 0 0 0.001215 0.001215 0.002653 0.002653
0.003321 0.003321 0.005555 0.005555 0.002244 0.002244 0.008334 0.008334 0.055063 0.055063 0.171078
0.171078 0.165809 0.165809 0.069541 0.069541 0.011538 0.011538 0.00243 0.00243 0.000273 0 0 0 0
2010 10 -4 0 0 18 0 0 0 0 0 0 4e-006 4e-006 0 0 0 0 0.000151 0.000151 0.080206 0.080206 0.22136 0.22136
0.089188 0.089188 0.045352 0.045352 0.009572 0.009572 0.002872 0.002872 0.017106 0.017106 0.022393
0.022393 0.009604 0.009604 0.001399 0.001399 0.001586 0 0 0 0
2011 10 -4 0 0 12 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0.009662 0.009662 0 0 0.008743 0.008743 0.091096
0.091096 0.113486 0.113486 0.055875 0.055875 0.105951 0.105951 0.087153 0.087153 0.027972 0.027972
6.2e-005 6.2e-005 0 0 0
2012 10 -4 0 0 18 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0.00087 0.00087 0.000435 0.000435 0.019339 0.019339
0.152651 0.152651 0.186422 0.186422 0.07408 0.07408 0.047499 0.047499 0.007583 0.007583 0.011121
0.011121 0 0 0

```
2013 10 -4 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 0 0 0 0 0 0.035539 0.035539 0.320503 0.320503
0.100577 0.100577 0.043381 0.043381 0 0 0 0 0
2014 10 -4 0 0 6 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0.001959 0.001959 0 0 0.04069 0.04069 0.123611 0.123611
0 0 0 0 0.011109 0.011109 0.181874 0.181874 0.120413 0.120413 0.020345 0.020345 0 0 0
2015 10 -4 0 0 8 0 0 0 0 3.1e-005 3.1e-005 0.000208 0.000208 0.025117 0.025117 0.118094 0.118094
0.089035 0.089035 0.020526 0.020526 0.002281 0.002281 0 0 0.027494 0.027494 0.038594 0.038594
0.024419 0.024419 0.007236 0.007236 0.003437 0.003437 0.042049 0.042049 0.063239 0.063239 0.038241
0.038241 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
#
9 #_N_age_bins
0 1 2 3 4 5 6 7 8
7 #_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 # 1_CA_1981-06
0.2832 0.2832 0.289 0.8009 0.8038 0.9597 1.1156 1.2715 1.4274 1.5833 1.7392 # 1_CA_1981-06
0.5 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5 9.5 10.5 # 2_CA_2007
0.2539 0.2539 0.3434 0.9205 0.9653 1.1743 1.3832 1.5922 1.8011 2.0101 2.219 # 2_CA_2007
0.5 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5 9.5 10.5 # 3_CA_2008-09
0.4032 0.4032 0.4995 0.58 0.6902 0.8246 0.9727 1.0165 1.1144 1.2123 1.3102 # 3_CA_2008-09
0.5 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5 9.5 10.5 # 4_CA_2010-13
0.2825 0.2825 0.2955 0.3125 0.3347 0.3637 0.4017 0.4046 0.4245 0.4445 0.4645 # 4_CA_2010-13
0.5 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5 9.5 10.5 # 5_ORWA_all
0.26655 0.30145 0.3149 0.3615 0.3847 0.3961 0.4018 0.4047 0.4061 0.4352 0.4487 # 5_ORWA_all
0.5 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5 9.5 10.5 # 6_CalCOFI_C
0.5386 0.5386 0.7547 0.8341 0.8634 0.8741 0.8781 0.8796 0.8801 0.8801 0.8801 # 6_CalCOFI_C
0.5 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5 9.5 10.5 # 7_CA_2017-2018
0.30 0.30 0.17 0.16 0.21 0.37 0.78 0.78 0.78 0.78 0.78 # 7_CA_2017-2018

#_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
-0.0001 0.0001 -1 0 0 0 1 #_fleet:1_MexCal_S1
-0.0001 0.0001 -1 0 0 0 1 #_fleet:2_MexCal_S2
-0.0001 0.0001 -1 0 0 0 1 #_fleet:3_PNW
-0.0001 0.0001 -1 0 0 0 1 #_fleet:4_AT_Survey
3 #_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)
2005 4 1 0 0 1 -1 -1 35.24 0.137477 0.303964 0.510811 0.03914 0.005113 0.00233 0.001165 0 0
2006 4 1 0 0 1 -1 -1 69.76 0.008804 0.667228 0.279683 0.044285 0 0 0 0 0
2007 4 1 0 0 2 -1 -1 86 0.026432 0.202585 0.605505 0.157132 0.008346 0 0 0 0
2008 4 1 0 0 3 -1 -1 30.84 0.053881 0.266218 0.595457 0.072169 0.012275 0 0 0 0
2009 4 1 0 0 3 -1 -1 22.88 0.002422 0.19769 0.63721 0.151247 0.011431 0 0 0 0
2010 4 1 0 0 4 -1 -1 12.68 0.015773 0.791798 0.167192 0.025237 0 0 0 0 0
2011 4 1 0 0 4 -1 -1 21.64 0 0.317241 0.474132 0.202402 0.006225 0 0 0 0
2012 4 1 0 0 4 -1 -1 22.32 0.005658 0.15868 0.498581 0.291705 0.036994 0.005588 0.002794 0 0
2013 4 1 0 0 4 -1 -1 8.84 0.029394 0.037768 0.239965 0.27489 0.332571 0.051027 0.018172 0.008106
0.008106
2014 4 1 0 0 4 -1 -1 5.92 0 0 0 0.080645 0.532258 0.282258 0.08871 0.016129 0
2005 10 2 0 0 1 -1 -1 89.04 0.524126 0.348819 0.116324 0.005929 0.001559 0.001162 0.000918 0.000581
0.000581
2006 10 2 0 0 1 -1 -1 105.16 0.162126 0.641856 0.174771 0.020491 0.000755 0 0 0 0
2007 10 2 0 0 2 -1 -1 67.52 0.422179 0.418221 0.116009 0.037188 0.005664 0.000739 0 0 0
2008 10 2 0 0 3 -1 -1 39.76 0.187575 0.547993 0.20955 0.052175 0.002707 0 0 0 0
2009 10 2 0 0 3 -1 -1 98.08 0.506321 0.382339 0.105307 0.004408 0.001625 0 0 0 0
```

2010 10 2 0 0 4 -1 -1 31.4 0.425845 0.245818 0.023273 0.051803 0.105411 0.130053 0.015059 0.001369 0.001369
2011 10 2 0 0 4 -1 -1 54.88 0.179076 0.348701 0.243588 0.092515 0.05004 0.037403 0.033995 0.012393 0.002289
2012 10 2 0 0 4 -1 -1 8.92 0.011949 0.176552 0.558778 0.213588 0.034503 0.003086 0.001543 0 0
2013 10 2 0 0 4 -1 -1 26.4 0.008626 0.05826 0.224121 0.465501 0.169079 0.053158 0.005662 0.012583 0.003009
2014 10 2 0 0 4 -1 -1 13.88 0.31814 0.517188 0.127883 0.002213 0.009274 0.023373 0.001929 0 0
2005 4 3 0 0 5 -1 -1 40.84 0 0.020037 0.509718 0.150097 0.072855 0.046552 0.037797 0.043245 0.119699
2006 4 3 0 0 5 -1 -1 26.92 0 0 0.034953 0.669603 0.178925 0.066269 0.022835 0.010686 0.016728
2007 4 3 0 0 5 -1 -1 89.4 0 0 0.03488 0.43386 0.417806 0.087018 0.017499 0.004772 0.004164
2008 4 3 0 0 5 -1 -1 94 0 0 0.003128 0.142014 0.496809 0.295466 0.047241 0.010413 0.004929
2009 4 3 0 0 5 -1 -1 93.24 0 0 0.007061 0.045293 0.308376 0.379603 0.209294 0.042683 0.00769
2010 4 3 0 0 5 -1 -1 33.76 0 0 0.004404 0.031777 0.203143 0.382668 0.252581 0.104811 0.020617
2011 4 3 0 0 5 -1 -1 42.88 0 0.003026 0.030078 0.048993 0.120887 0.30363 0.292121 0.16502 0.036245
2012 4 3 0 0 5 -1 -1 118.24 0 0.00103 0.368383 0.210661 0.067972 0.043743 0.073765 0.095138 0.139308
2013 4 3 0 0 5 -1 -1 138.92 0 0 0.031902 0.585661 0.186248 0.046977 0.038397 0.05047 0.060346
2014 4 3 0 0 5 -1 -1 49.68 0 0 0 0.047067 0.661293 0.175672 0.052809 0.029632 0.033526
#2008 1 4 0 0 6 -1 -1 27 0.087312 0.043801 0.265755 0.365386 0.194453 0.024188 0.008299 0.007736 0.003071 #AT_Survey_Summer
2008 1 4 0 0 6 -1 -1 27 0.090988 0.002693 0.097948 0.392634 0.393232 0.022505 0.000000 0.000000 0.000000 #AT_Survey_Summer_updated with jpz.4
2012 1 4 0 0 6 -1 -1 31 0 0.020066219 0.313555749 0.328842391 0.138517112 0.080076686 0.047044428 0.050241787 0.021655629 #AT_Survey_Summer_updated
2013 1 4 0 0 6 -1 -1 18 0 0 0.265436408 0.450251003 0.112339558 0.079124328 0.061521091 0.012423732 0.018903881 #AT_Survey_Summer_updated
2014 1 4 0 0 6 -1 -1 12 0.004195675 0.013239287 0.272298702 0.471303871 0.170663462 0.026854971 0.030696956 0.010747077 0 #AT_Survey_Summer_updated
2015 1 4 0 0 6 -1 -1 15 0.796639652 0.013269464 0.009868461 0.033672834 0.100257149 0.034615751 0.004927998 0.00532594 0.001422751 #AT_Survey_Summer_updated
2016 1 4 0 0 6 -1 -1 15 0.0285 0.2556 0.4467 0.2007 0.0525 0.0117 0.0016 0.0016 0.0011 #AT_Survey_Summer_newDec19

#2016 1 4 0 0 6 -1 -1 15 0.753167151 0.214173156 0.013912937 0.003599231 0.010262723 0.003691677 0.000496474 0.000536157 0.000160494 #AT_Survey_Summer_updated
2017 1 4 0 0 7 -1 -1 19 0.427483258 0.08679116 0.302280944 0.109741294 0.028489857 0.017943378 0.019069287 0.008200823 0 #AT_Survey_Summer_newDec19
2018 1 4 0 0 7 -1 -1 20 0.394309348 0.177747179 0.122363693 0.207402147 0.038572074 0.015552172 0.018334993 0.020649486 0.00506891 #AT_Survey_Summer_newDec19
2019 1 4 0 0 7 -1 -1 22 0.019502068 0.497805779 0.188868999 0.092476117 0.127227276 0.040112689 0.015937622 0.006882764 0.011186686 #AT_Survey_Summer_newDec19

#2005 10 4 0 0 6 -1 -1 10 0.040971 0.267197 0.401856 0.205029 0.062319 0.017772 0.003929 0.000721 0.000205 #AT_Survey_Spring
#2007 10 4 0 0 6 -1 -1 12 0.010962 0.12545 0.293866 0.321903 0.171457 0.060949 0.013077 0.001783 0.000553 #AT_Survey_Spring
#2009 10 4 0 0 6 -1 -1 19 0.00482 0.033878 0.139398 0.358673 0.29524 0.129363 0.032194 0.004941 0.001493 #AT_Survey_Spring
#2010 10 4 0 0 6 -1 -1 18 0.036941 0.281702 0.402681 0.174148 0.066897 0.02782 0.00789 0.001493 0.000428 #AT_Survey_Spring
#2011 10 4 0 0 6 -1 -1 12 0.001253 0.028717 0.124825 0.310893 0.302769 0.165121 0.052648 0.010742 0.003032 #AT_Survey_Spring
#2012 10 4 0 0 6 -1 -1 18 0.000215 0.014686 0.099732 0.337344 0.325543 0.162916 0.047695 0.009239 0.002629 #AT_Survey_Spring
#2013 10 4 0 0 6 -1 -1 4 1.1e-005 0.002305 0.030465 0.237621 0.379864 0.244214 0.083315 0.017323 0.004881 #AT_Survey_Spring
#2014 10 4 0 0 6 -1 -1 6 0.000965 0.029295 0.111987 0.224496 0.29106 0.219112 0.092273 0.024314 0.006499 #AT_Survey_Spring
#2015 10 4 0 0 6 -1 -1 8 0.151623 0.255532 0.173873 0.119932 0.135449 0.102719 0.045011 0.012549 0.003312 #AT_Survey_Spring
-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
```

wtatage.ss

```
10 # 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 comment
2005 2 1 1 1 -2 0.0046 0.0354000 0.0773 0.11000 0.1339 0.1515 0.1644 0.1739 0.18080 0.1858 0.1939
#fecundity
2005 1 1 1 1 -1 0.0125 0.0445000 0.0734 0.12780 0.1443 0.1676 0.1778 0.1920 0.20030 0.1942 0.1995
#popwt_mid
2005 2 1 1 1 -1 0.0584 0.0677000 0.0756 0.08990 0.1063 0.1281 0.1616 0.1998 0.19520 0.1709 0.1709
#popwt_mid
2005 1 1 1 1 0 0.0125 0.0445000 0.0734 0.12780 0.1443 0.1676 0.1778 0.1920 0.20030 0.1942 0.1995
#popwt_beg
2005 2 1 1 1 0 0.0584 0.0677000 0.0756 0.08990 0.1063 0.1281 0.1616 0.1998 0.19520 0.1709 0.1709
#popwt_beg
2005 1 1 1 1 1 0.0329 0.0416000 0.0623 0.08520 0.1450 0.1398 0.1692 0.1652 0.17280 0.1831 0.1906
#wt_flt_1
2005 2 1 1 1 1 0.0329 0.0416000 0.0623 0.08520 0.1450 0.1398 0.1692 0.1652 0.17280 0.1831 0.1906
#wt_flt_1
2005 1 1 1 1 2 0.0403 0.0445000 0.0653 0.09130 0.1516 0.1450 0.1782 0.1706 0.18030 0.1866 0.1959
#wt_flt_2
2005 2 1 1 1 2 0.0403 0.0445000 0.0653 0.09130 0.1516 0.1450 0.1782 0.1706 0.18030 0.1866 0.1959
#wt_flt_2
2005 1 1 1 1 3 0.0138 0.0747000 0.0864 0.09380 0.1229 0.1655 0.1816 0.2058 0.20670 0.1943 0.1996
#wt_flt_3
2005 2 1 1 1 3 0.0396 0.0913000 0.1020 0.10920 0.1292 0.1526 0.1887 0.1910 0.20050 0.1957 0.2000
#wt_flt_3
```

2005 1 1 1 1 4 0.0125 0.0445000 0.0734 0.12780 0.1443 0.1676 0.1778 0.1920 0.20030 0.1942 0.1995
#wt_flt_4
2005 2 1 1 1 4 0.0584 0.0677000 0.0756 0.08990 0.1063 0.1281 0.1616 0.1998 0.19520 0.1709 0.1709
#wt_flt_4
2006 2 1 1 1 -2 0.0046 0.0354000 0.0773 0.11000 0.1339 0.1515 0.1644 0.1739 0.18080 0.1858 0.1939
#fecundity
2006 1 1 1 1 -1 0.0125 0.0563000 0.0750 0.08170 0.1313 0.1506 0.1754 0.1843 0.19230 0.2003 0.1995
#popwt_mid
2006 2 1 1 1 -1 0.0584 0.0677000 0.0756 0.08990 0.1063 0.1281 0.1616 0.1998 0.19520 0.1709 0.1709
#popwt_mid
2006 1 1 1 1 0 0.0125 0.0563000 0.0750 0.08170 0.1313 0.1506 0.1754 0.1843 0.19230 0.2003 0.1995
#popwt_beg
2006 2 1 1 1 0 0.0584 0.0677000 0.0756 0.08990 0.1063 0.1281 0.1616 0.1998 0.19520 0.1709 0.1709
#popwt_beg
2006 1 1 1 1 1 0.0411 0.0477000 0.0645 0.07950 0.1077 0.1581 0.1552 0.1840 0.17280 0.1831 0.1906
#wt_flt_1
2006 2 1 1 1 1 0.0411 0.0477000 0.0645 0.07950 0.1077 0.1581 0.1552 0.1840 0.17280 0.1831 0.1906
#wt_flt_1
2006 1 1 1 1 2 0.0451 0.0518000 0.0793 0.09310 0.1240 0.1647 0.1655 0.1860 0.18030 0.1866 0.1959
#wt_flt_2
2006 2 1 1 1 2 0.0451 0.0518000 0.0793 0.09310 0.1240 0.1647 0.1655 0.1860 0.18030 0.1866 0.1959
#wt_flt_2
2006 1 1 1 1 3 0.0138 0.0809000 0.1080 0.11760 0.1247 0.1355 0.1397 0.1959 0.17620 0.1943 0.1996
#wt_flt_3
2006 2 1 1 1 3 0.0396 0.0893000 0.1065 0.11350 0.1205 0.1312 0.1361 0.1969 0.18530 0.1957 0.2000
#wt_flt_3
2006 1 1 1 1 4 0.0125 0.0563000 0.0750 0.08170 0.1313 0.1506 0.1754 0.1843 0.19230 0.2003 0.1995
#wt_flt_4
2006 2 1 1 1 4 0.0584 0.0677000 0.0756 0.08990 0.1063 0.1281 0.1616 0.1998 0.19520 0.1709 0.1709
#wt_flt_4
2007 2 1 1 1 -2 0.0046 0.0354000 0.0773 0.11000 0.1339 0.1515 0.1644 0.1739 0.18080 0.1858 0.1939
#fecundity

```
2007 1 1 1 1 -1 0.0125 0.0451000 0.0705 0.09690 0.0996 0.1348 0.1569 0.1843 0.19030 0.1942 0.2003
#popwt_mid
2007 2 1 1 1 -1 0.0702 0.0806000 0.0920 0.11280 0.1279 0.1369 0.1451 0.1542 0.19980 0.1952 0.1471
#popwt_mid
2007 1 1 1 1 0 0.0125 0.0451000 0.0705 0.09690 0.0996 0.1348 0.1569 0.1843 0.19030 0.1942 0.2003
#popwt_beg
2007 2 1 1 1 0 0.0702 0.0806000 0.0920 0.11280 0.1279 0.1369 0.1451 0.1542 0.19980 0.1952 0.1471
#popwt_beg
2007 1 1 1 1 1 0.0270 0.0490000 0.0670 0.09060 0.1103 0.1253 0.1743 0.1840 0.19010 0.1831 0.1906
#wt_flt_1
2007 2 1 1 1 1 0.0270 0.0490000 0.0670 0.09060 0.1103 0.1253 0.1743 0.1840 0.19010 0.1831 0.1906
#wt_flt_1
2007 1 1 1 1 2 0.0326 0.0619000 0.0678 0.10190 0.1274 0.1267 0.1777 0.1860 0.19130 0.1866 0.1959
#wt_flt_2
2007 2 1 1 1 2 0.0326 0.0619000 0.0678 0.10190 0.1274 0.1267 0.1777 0.1860 0.19130 0.1866 0.1959
#wt_flt_2
2007 1 1 1 1 3 0.0138 0.0809000 0.0977 0.10500 0.1093 0.1163 0.1269 0.1324 0.19800 0.1943 0.1996
#wt_flt_3
2007 2 1 1 1 3 0.0396 0.0930000 0.1046 0.11260 0.1178 0.1278 0.1395 0.1521 0.19610 0.1957 0.2000
#wt_flt_3
2007 1 1 1 1 4 0.0125 0.0451000 0.0705 0.09690 0.0996 0.1348 0.1569 0.1843 0.19030 0.1942 0.2003
#wt_flt_4
2007 2 1 1 1 4 0.0702 0.0806000 0.0920 0.11280 0.1279 0.1369 0.1451 0.1542 0.19980 0.1952 0.1471
#wt_flt_4
2008 2 1 1 1 -2 0.0046 0.0354000 0.0773 0.11000 0.1339 0.1515 0.1644 0.1739 0.18080 0.1858 0.1939
#fecundity
2008 1 1 1 1 -1 0.0153 0.0883000 0.1041 0.12440 0.1350 0.1406 0.1406 0.1406 0.18925 0.1903 0.1942
#popwt_mid
2008 2 1 1 1 -1 0.0702 0.0806000 0.0920 0.11280 0.1279 0.1369 0.1451 0.1542 0.15290 0.1998 0.1952
#popwt_mid
2008 1 1 1 1 0 0.0153 0.0883000 0.1041 0.12440 0.1350 0.1406 0.1406 0.1406 0.18925 0.1903 0.1942
#popwt_beg
```

```
2008 2 1 1 1 0 0.0702 0.0806000 0.0920 0.11280 0.1279 0.1369 0.1451 0.1542 0.15290 0.1998 0.1952
#popwt_beg
2008 1 1 1 1 1 0.0380 0.0671000 0.0747 0.09310 0.1307 0.1581 0.1415 0.1840 0.19010 0.1941 0.1906
#wt_flt_1
2008 2 1 1 1 1 0.0380 0.0671000 0.0747 0.09310 0.1307 0.1581 0.1415 0.1840 0.19010 0.1941 0.1906
#wt_flt_1
2008 1 1 1 1 2 0.0511 0.0716000 0.0773 0.09970 0.1356 0.1647 0.1563 0.1860 0.19130 0.1947 0.1959
#wt_flt_2
2008 2 1 1 1 2 0.0511 0.0716000 0.0773 0.09970 0.1356 0.1647 0.1563 0.1860 0.19130 0.1947 0.1959
#wt_flt_2
2008 1 1 1 1 3 0.0138 0.0809000 0.1050 0.11160 0.1202 0.1264 0.1392 0.1522 0.17180 0.1943 0.1996
#wt_flt_3
2008 2 1 1 1 3 0.0396 0.0952000 0.1079 0.11550 0.1234 0.1284 0.1376 0.1479 0.18300 0.1957 0.2000
#wt_flt_3
2008 1 1 1 1 4 0.0153 0.0883000 0.1041 0.12440 0.1350 0.1406 0.1406 0.1406 0.18925 0.1903 0.1942
#wt_flt_4
2008 2 1 1 1 4 0.0702 0.0806000 0.0920 0.11280 0.1279 0.1369 0.1451 0.1542 0.15290 0.1998 0.1952
#wt_flt_4
2009 2 1 1 1 -2 0.0046 0.0354000 0.0773 0.11000 0.1339 0.1515 0.1644 0.1739 0.18080 0.1858 0.1939
#fecundity
2009 1 1 1 1 -1 0.0125 0.0446000 0.0890 0.11820 0.1257 0.1264 0.1368 0.1547 0.19030 0.1942 0.1995
#popwt_mid
2009 2 1 1 1 -1 0.0399 0.0884000 0.1197 0.13810 0.1467 0.1524 0.1579 0.1642 0.16330 0.1593 0.1998
#popwt_mid
2009 1 1 1 1 0 0.0125 0.0446000 0.0890 0.11820 0.1257 0.1264 0.1368 0.1547 0.19030 0.1942 0.1995
#popwt_beg
2009 2 1 1 1 0 0.0399 0.0884000 0.1197 0.13810 0.1467 0.1524 0.1579 0.1642 0.16330 0.1593 0.1998
#popwt_beg
2009 1 1 1 1 1 0.0237 0.0642000 0.0762 0.08000 0.1064 0.1380 0.1743 0.1840 0.19010 0.1941 0.1992
#wt_flt_1
2009 2 1 1 1 1 0.0237 0.0642000 0.0762 0.08000 0.1064 0.1380 0.1743 0.1840 0.19010 0.1941 0.1992
#wt_flt_1
```

```
2009 1 1 1 1 2 0.0372 0.0739000 0.0790 0.09520 0.1065 0.1403 0.1777 0.1860 0.19130 0.1947 0.1995
#wt_flt_2
2009 2 1 1 1 2 0.0372 0.0739000 0.0790 0.09520 0.1065 0.1403 0.1777 0.1860 0.19130 0.1947 0.1995
#wt_flt_2
2009 1 1 1 1 3 0.0138 0.0405000 0.1095 0.11080 0.1194 0.1267 0.1304 0.1359 0.14360 0.1943 0.1996
#wt_flt_3
2009 2 1 1 1 3 0.0396 0.0539000 0.1126 0.12180 0.1268 0.1323 0.1341 0.1379 0.16890 0.1957 0.2000
#wt_flt_3
2009 1 1 1 1 4 0.0125 0.0446000 0.0890 0.11820 0.1257 0.1264 0.1368 0.1547 0.19030 0.1942 0.1995
#wt_flt_4
2009 2 1 1 1 4 0.0399 0.0884000 0.1197 0.13810 0.1467 0.1524 0.1579 0.1642 0.16330 0.1593 0.1998
#wt_flt_4
2010 2 1 1 1 -2 0.0046 0.0354000 0.0773 0.11000 0.1339 0.1515 0.1644 0.1739 0.18080 0.1858 0.1939
#fecundity
2010 1 1 1 1 -1 0.0125 0.0480000 0.0708 0.10880 0.1348 0.1368 0.1402 0.1463 0.19030 0.1942 0.1995
#popwt_mid
2010 2 1 1 1 -1 0.0609 0.0644000 0.0684 0.13755 0.1228 0.1485 0.1635 0.1745 0.17310 0.1663 0.1663
#popwt_mid
2010 1 1 1 1 0 0.0125 0.0480000 0.0708 0.10880 0.1348 0.1368 0.1402 0.1463 0.19030 0.1942 0.1995
#popwt_beg
2010 2 1 1 1 0 0.0609 0.0644000 0.0684 0.13755 0.1228 0.1485 0.1635 0.1745 0.17310 0.1663 0.1663
#popwt_beg
2010 1 1 1 1 1 0.0534 0.0585000 0.0836 0.08180 0.1105 0.1197 0.1427 0.1840 0.19010 0.1941 0.1992
#wt_flt_1
2010 2 1 1 1 1 0.0534 0.0585000 0.0836 0.08180 0.1105 0.1197 0.1427 0.1840 0.19010 0.1941 0.1992
#wt_flt_1
2010 1 1 1 1 2 0.0673 0.0715000 0.0934 0.11660 0.1258 0.1329 0.1451 0.1860 0.19130 0.1947 0.1995
#wt_flt_2
2010 2 1 1 1 2 0.0673 0.0715000 0.0934 0.11660 0.1258 0.1329 0.1451 0.1860 0.19130 0.1947 0.1995
#wt_flt_2
2010 1 1 1 1 3 0.0138 0.0632000 0.0673 0.11560 0.1328 0.1341 0.1380 0.1379 0.13990 0.1943 0.1996
#wt_flt_3
```

2010 2 1 1 1 3 0.0396 0.0879000 0.1029 0.13310 0.1447 0.1461 0.1495 0.1477 0.16710 0.1957 0.2000
#wt_flt_3
2010 1 1 1 1 4 0.0125 0.0480000 0.0708 0.10880 0.1348 0.1368 0.1402 0.1463 0.19030 0.1942 0.1995
#wt_flt_4
2010 2 1 1 1 4 0.0609 0.0644000 0.0684 0.13755 0.1228 0.1485 0.1635 0.1745 0.17310 0.1663 0.1663
#wt_flt_4
2011 2 1 1 1 -2 0.0046 0.0354000 0.0773 0.11000 0.1339 0.1515 0.1644 0.1739 0.18080 0.1858 0.1939
#fecundity
2011 1 1 1 1 -1 0.0131 0.0720000 0.1101 0.11790 0.1224 0.1369 0.1419 0.1389 0.14400 0.1903 0.1942
#popwt_mid
2011 2 1 1 1 -1 0.0792 0.1016000 0.1154 0.13640 0.1554 0.1669 0.1755 0.1827 0.18180 0.1773 0.1773
#popwt_mid
2011 1 1 1 1 0 0.0131 0.0720000 0.1101 0.11790 0.1224 0.1369 0.1419 0.1389 0.14400 0.1903 0.1942
#popwt_beg
2011 2 1 1 1 0 0.0792 0.1016000 0.1154 0.13640 0.1554 0.1669 0.1755 0.1827 0.18180 0.1773 0.1773
#popwt_beg
2011 1 1 1 1 1 0.0237 0.0812000 0.0845 0.09670 0.1113 0.1272 0.1381 0.1481 0.19010 0.1941 0.1992
#wt_flt_1
2011 2 1 1 1 1 0.0237 0.0812000 0.0845 0.09670 0.1113 0.1272 0.1381 0.1481 0.19010 0.1941 0.1992
#wt_flt_1
2011 1 1 1 1 2 0.0296 0.0898000 0.0993 0.10000 0.1205 0.1286 0.1433 0.1512 0.19130 0.1947 0.1995
#wt_flt_2
2011 2 1 1 1 2 0.0296 0.0898000 0.0993 0.10000 0.1205 0.1286 0.1433 0.1512 0.19130 0.1947 0.1995
#wt_flt_2
2011 1 1 1 1 3 0.0138 0.0853000 0.1127 0.13860 0.1505 0.1565 0.1580 0.1609 0.15750 0.1943 0.1996
#wt_flt_3
2011 2 1 1 1 3 0.0396 0.1094000 0.1274 0.14610 0.1588 0.1649 0.1659 0.1699 0.17590 0.1957 0.2000
#wt_flt_3
2011 1 1 1 1 4 0.0131 0.0720000 0.1101 0.11790 0.1224 0.1369 0.1419 0.1389 0.14400 0.1903 0.1942
#wt_flt_4
2011 2 1 1 1 4 0.0792 0.1016000 0.1154 0.13640 0.1554 0.1669 0.1755 0.1827 0.18180 0.1773 0.1773
#wt_flt_4

```
2012 2 1 1 1 -2 0.0046 0.0354000 0.0773 0.11000 0.1339 0.1515 0.1644 0.1739 0.18080 0.1858 0.1939
#fecundity
2012 1 1 1 1 -1 0.0131 0.1124500 0.1160 0.12120 0.1279 0.1512 0.1661 0.1628 0.17740 0.1787 0.1903
#popwt_mid
2012 2 1 1 1 -1 0.1141 0.1239000 0.1294 0.13860 0.1489 0.1585 0.1694 0.1830 0.18110 0.1724 0.1724
#popwt_mid
2012 1 1 1 1 0 0.0131 0.1124500 0.1160 0.12120 0.1279 0.1512 0.1661 0.1628 0.17740 0.1787 0.1903
#popwt_beg
2012 2 1 1 1 0 0.1141 0.1239000 0.1294 0.13860 0.1489 0.1585 0.1694 0.1830 0.18110 0.1724 0.1724
#popwt_beg
2012 1 1 1 1 1 0.0237 0.0630000 0.0984 0.11410 0.1257 0.1302 0.1387 0.1840 0.19010 0.1941 0.1992
#wt_flt_1
2012 2 1 1 1 1 0.0237 0.0630000 0.0984 0.11410 0.1257 0.1302 0.1387 0.1840 0.19010 0.1941 0.1992
#wt_flt_1
2012 1 1 1 1 2 0.0370 0.0833000 0.1175 0.13070 0.1385 0.1513 0.1490 0.1860 0.19130 0.1947 0.1995
#wt_flt_2
2012 2 1 1 1 2 0.0370 0.0833000 0.1175 0.13070 0.1385 0.1513 0.1490 0.1860 0.19130 0.1947 0.1995
#wt_flt_2
2012 1 1 1 1 3 0.0138 0.1250000 0.1334 0.14210 0.1536 0.1671 0.1733 0.1737 0.17900 0.1943 0.1996
#wt_flt_3
2012 2 1 1 1 3 0.0396 0.1435000 0.1502 0.15740 0.1666 0.1810 0.1857 0.1866 0.18660 0.1957 0.2000
#wt_flt_3
2012 1 1 1 1 4 0.0131 0.1124500 0.1160 0.12120 0.1279 0.1512 0.1661 0.1628 0.17740 0.1787 0.1903
#wt_flt_4
2012 2 1 1 1 4 0.1141 0.1239000 0.1294 0.13860 0.1489 0.1585 0.1694 0.1830 0.18110 0.1724 0.1724
#wt_flt_4
2013 2 1 1 1 -2 0.0046 0.0354000 0.0773 0.11000 0.1339 0.1515 0.1644 0.1739 0.18080 0.1858 0.1939
#fecundity
2013 1 1 1 1 -1 0.0131 0.1124500 0.1498 0.15220 0.1548 0.1818 0.1953 0.1667 0.17260 0.1612 0.1612
#popwt_mid
2013 2 1 1 1 -1 0.1556 0.1593000 0.1619 0.16640 0.1707 0.1742 0.1778 0.1819 0.18130 0.1787 0.1787
#popwt_mid
```

2013 1 1 1 1 0 0.0131 0.1124500 0.1498 0.15220 0.1548 0.1818 0.1953 0.1667 0.17260 0.1612 0.1612
#popwt_beg
2013 2 1 1 1 0 0.1556 0.1593000 0.1619 0.16640 0.1707 0.1742 0.1778 0.1819 0.18130 0.1787 0.1787
#popwt_beg
2013 1 1 1 1 1 0.0214 0.0452000 0.1398 0.13650 0.1473 0.1512 0.1723 0.1592 0.19010 0.1941 0.1992
#wt_flt_1
2013 2 1 1 1 1 0.0214 0.0452000 0.1398 0.13650 0.1473 0.1512 0.1723 0.1592 0.19010 0.1941 0.1992
#wt_flt_1
2013 1 1 1 1 2 0.0563 0.0773000 0.1499 0.14020 0.1489 0.1599 0.1850 0.1694 0.19130 0.1947 0.1995
#wt_flt_2
2013 2 1 1 1 2 0.0563 0.0773000 0.1499 0.14020 0.1489 0.1599 0.1850 0.1694 0.19130 0.1947 0.1995
#wt_flt_2
2013 1 1 1 1 3 0.0138 0.0809000 0.1621 0.16700 0.1728 0.1795 0.1949 0.1980 0.19940 0.1943 0.1996
#wt_flt_3
2013 2 1 1 1 3 0.0396 0.0947000 0.1675 0.17380 0.1783 0.1821 0.1932 0.1971 0.19680 0.1957 0.2000
#wt_flt_3
2013 1 1 1 1 4 0.0131 0.1124500 0.1498 0.15220 0.1548 0.1818 0.1953 0.1667 0.17260 0.1612 0.1612
#wt_flt_4
2013 2 1 1 1 4 0.1556 0.1593000 0.1619 0.16640 0.1707 0.1742 0.1778 0.1819 0.18130 0.1787 0.1787
#wt_flt_4
2014 2 1 1 1 -2 0.0046 0.0354000 0.0773 0.11000 0.1339 0.1515 0.1644 0.1739 0.18080 0.1858 0.1939
#fecundity
2014 1 1 1 1 -1 0.0097 0.1757000 0.1786 0.18280 0.1846 0.1933 0.2047 0.2009 0.20090 0.2009 0.2009
#popwt_mid
2014 2 1 1 1 -1 0.0914 0.1556000 0.1724 0.14380 0.1829 0.1955 0.2015 0.2058 0.20520 0.2026 0.2026
#popwt_mid
2014 1 1 1 1 0 0.0097 0.1757000 0.1786 0.18280 0.1846 0.1933 0.2047 0.2009 0.20090 0.2009 0.2009
#popwt_beg
2014 2 1 1 1 0 0.0914 0.1556000 0.1724 0.14380 0.1829 0.1955 0.2015 0.2058 0.20520 0.2026 0.2026
#popwt_beg
2014 1 1 1 1 1 0.0323 0.0577000 0.0803 0.16010 0.1690 0.1693 0.1659 0.1840 0.19010 0.1941 0.1992
#wt_flt_1

```
2014 2 1 1 1 1 0.0323 0.0577000 0.0803 0.16010 0.1690 0.1693 0.1659 0.1840 0.19010 0.1941 0.1992
#wt_flt_1
2014 1 1 1 1 2 0.0344 0.0591000 0.0833 0.16010 0.1700 0.1721 0.0830 0.1860 0.19130 0.1947 0.1995
#wt_flt_2
2014 2 1 1 1 2 0.0344 0.0591000 0.0833 0.16010 0.1700 0.1721 0.1659 0.1860 0.19130 0.1947 0.1995
#wt_flt_2
2014 1 1 1 1 3 0.0138 0.0809000 0.1067 0.17300 0.1805 0.1838 0.1846 0.1915 0.19610 0.1943 0.1996
#wt_flt_3
2014 2 1 1 1 3 0.0396 0.0947000 0.1178 0.17470 0.1819 0.1851 0.1862 0.1922 0.19520 0.1957 0.2000
#wt_flt_3
2014 1 1 1 1 4 0.0097 0.1757000 0.1786 0.18280 0.1846 0.1933 0.2047 0.2009 0.20090 0.2009 0.2009
#wt_flt_4
2014 2 1 1 1 4 0.0914 0.1556000 0.1724 0.14380 0.1829 0.1955 0.2015 0.2058 0.20520 0.2026 0.2026
#wt_flt_4
2015 2 1 1 1 -2 0.0046 0.0354000 0.0773 0.11000 0.1339 0.1515 0.1644 0.1739 0.18080 0.1858 0.1939
#fecundity
2015 1 1 1 1 -1 0.0040 0.1269000 0.1557 0.19770 0.2059 0.2077 0.2047 0.2012 0.20930 0.2093 0.2093
#popwt_mid
2015 2 1 1 1 -1 0.0359 0.1055333 0.1556 0.17240 0.1855 0.2045 0.2137 0.2196 0.21890 0.2153 0.2153
#popwt_mid
2015 1 1 1 1 0 0.0040 0.1269000 0.1557 0.19770 0.2059 0.2077 0.2047 0.2012 0.20930 0.2093 0.2093
#popwt_beg
2015 2 1 1 1 0 0.0359 0.1055333 0.1556 0.17240 0.1855 0.2045 0.2137 0.2196 0.21890 0.2153 0.2153
#popwt_beg
2015 1 1 1 1 1 0.0323 0.0577000 0.0803 0.16010 0.1690 0.1693 0.1659 0.1840 0.19010 0.1941 0.1992
#wt_flt_1
2015 2 1 1 1 1 0.0323 0.0577000 0.0803 0.16010 0.1690 0.1693 0.1659 0.1840 0.19010 0.1941 0.1992
#wt_flt_1
2015 1 1 1 1 2 0.0344 0.0591000 0.0833 0.16010 0.1700 0.1721 0.0830 0.1860 0.19130 0.1947 0.1995
#wt_flt_2
2015 2 1 1 1 2 0.0344 0.0591000 0.0833 0.16010 0.1700 0.1721 0.1659 0.1860 0.19130 0.1947 0.1995
#wt_flt_2
```

```
2015 1 1 1 1 3 0.0138 0.0809000 0.1067 0.17300 0.1805 0.1838 0.1846 0.1915 0.19610 0.1943 0.1996
#wt_flt_3
2015 2 1 1 1 3 0.0396 0.0947000 0.1178 0.17470 0.1819 0.1851 0.1862 0.1922 0.19520 0.1957 0.2000
#wt_flt_3
2015 1 1 1 1 4 0.0040 0.1269000 0.1557 0.19770 0.2059 0.2077 0.2047 0.2012 0.20930 0.2093 0.2093
#wt_flt_4
2015 2 1 1 1 4 0.0359 0.1055333 0.1556 0.17240 0.1855 0.2045 0.2137 0.2196 0.21890 0.2153 0.2153
#wt_flt_4
2016 2 1 1 1 -2 0.0046 0.0354000 0.0773 0.11000 0.1339 0.1515 0.1644 0.1739 0.18080 0.1858 0.1939
#fecundity
2016 1 1 1 1 -1 0.0464 0.0700000 0.1354 0.15870 0.1940 0.1959 0.2022 0.2260 0.21885 0.2229 0.2093
#popwt_mid
2016 2 1 1 1 -1 0.0359 0.0424000 0.1126 0.13380 0.1855 0.2045 0.2137 0.2196 0.21890 0.2153 0.2153
#popwt_mid
2016 1 1 1 1 0 0.0464 0.0700000 0.1354 0.15870 0.1940 0.1959 0.2022 0.2260 0.21885 0.2229 0.2093
#popwt_beg
2016 2 1 1 1 0 0.0359 0.0424000 0.1126 0.13380 0.1855 0.2045 0.2137 0.2196 0.21890 0.2153 0.2153
#popwt_beg
2016 1 1 1 1 1 0.0323 0.0577000 0.0803 0.16010 0.1690 0.1693 0.1659 0.1840 0.19010 0.1941 0.1992
#wt_flt_1
2016 2 1 1 1 1 0.0323 0.0577000 0.0803 0.16010 0.1690 0.1693 0.1659 0.1840 0.19010 0.1941 0.1992
#wt_flt_1
2016 1 1 1 1 2 0.0344 0.0591000 0.0833 0.16010 0.1700 0.1721 0.0830 0.1860 0.19130 0.1947 0.1995
#wt_flt_2
2016 2 1 1 1 2 0.0344 0.0591000 0.0833 0.16010 0.1700 0.1721 0.1659 0.1860 0.19130 0.1947 0.1995
#wt_flt_2
2016 1 1 1 1 3 0.0138 0.0809000 0.1067 0.17300 0.1805 0.1838 0.1846 0.1915 0.19610 0.1943 0.1996
#wt_flt_3
2016 2 1 1 1 3 0.0396 0.0947000 0.1178 0.17470 0.1819 0.1851 0.1862 0.1922 0.19520 0.1957 0.2000
#wt_flt_3
2016 1 1 1 1 4 0.0464 0.0700000 0.1354 0.15870 0.1940 0.1959 0.2022 0.2260 0.21885 0.2229 0.2093
#wt_flt_4
```

2016 2 1 1 1 4 0.0359 0.0424000 0.1126 0.13380 0.1855 0.2045 0.2137 0.2196 0.21890 0.2153 0.2153
#wt_flt_4
2017 2 1 1 1 -2 0.0046 0.0354000 0.0773 0.11000 0.1339 0.1515 0.1644 0.1739 0.18080 0.1858 0.1939
#fecundity
2017 1 1 1 1 -1 0.0107 0.1089000 0.1259 0.14390 0.1617 0.1903 0.2143 0.2365 0.23650 0.2365 0.2365
#popwt_mid
2017 2 1 1 1 -1 0.0359 0.0424000 0.0638 0.13380 0.1855 0.2045 0.2137 0.2196 0.21890 0.2153 0.2153
#popwt_mid
2017 1 1 1 1 0 0.0107 0.1089000 0.1259 0.14390 0.1617 0.1903 0.2143 0.2365 0.23650 0.2365 0.2365
#popwt_beg
2017 2 1 1 1 0 0.0359 0.0424000 0.0638 0.13380 0.1855 0.2045 0.2137 0.2196 0.21890 0.2153 0.2153
#popwt_beg
2017 1 1 1 1 1 0.0323 0.0577000 0.0803 0.16010 0.1690 0.1693 0.1659 0.1840 0.19010 0.1941 0.1992
#wt_flt_1
2017 2 1 1 1 1 0.0323 0.0577000 0.0803 0.16010 0.1690 0.1693 0.1659 0.1840 0.19010 0.1941 0.1992
#wt_flt_1
2017 1 1 1 1 2 0.0344 0.0591000 0.0833 0.16010 0.1700 0.1721 0.0830 0.1860 0.19130 0.1947 0.1995
#wt_flt_2
2017 2 1 1 1 2 0.0344 0.0591000 0.0833 0.16010 0.1700 0.1721 0.1659 0.1860 0.19130 0.1947 0.1995
#wt_flt_2
2017 1 1 1 1 3 0.0138 0.0809000 0.1067 0.17300 0.1805 0.1838 0.1846 0.1915 0.19610 0.1943 0.1996
#wt_flt_3
2017 2 1 1 1 3 0.0396 0.0947000 0.1178 0.17470 0.1819 0.1851 0.1862 0.1922 0.19520 0.1957 0.2000
#wt_flt_3
2017 1 1 1 1 4 0.0107 0.1089000 0.1259 0.14390 0.1617 0.1903 0.2143 0.2365 0.23650 0.2365 0.2365
#wt_flt_4
2017 2 1 1 1 4 0.0359 0.0424000 0.0638 0.13380 0.1855 0.2045 0.2137 0.2196 0.21890 0.2153 0.2153
#wt_flt_4
2018 2 1 1 1 -2 0.0046 0.0354000 0.0773 0.11000 0.1339 0.1515 0.1644 0.1739 0.18080 0.1858 0.1939
#fecundity
2018 1 1 1 1 -1 0.0195 0.0549000 0.1788 0.19290 0.1955 0.2045 0.2199 0.2263 0.29840 0.2984 0.2984
#popwt_mid

```
2018 2 1 1 1 -1 0.0359 0.0424000 0.0638 0.13380 0.1855 0.2045 0.2137 0.2196 0.21890 0.2153 0.2153
#popwt_mid
2018 1 1 1 1 0 0.0195 0.0549000 0.1788 0.19290 0.1955 0.2045 0.2199 0.2263 0.29840 0.2984 0.2984
#popwt_beg
2018 2 1 1 1 0 0.0359 0.0424000 0.0638 0.13380 0.1855 0.2045 0.2137 0.2196 0.21890 0.2153 0.2153
#popwt_beg
2018 1 1 1 1 1 0.0323 0.0577000 0.0803 0.16010 0.1690 0.1693 0.1659 0.1840 0.19010 0.1941 0.1992
#wt_flt_1
2018 2 1 1 1 1 0.0323 0.0577000 0.0803 0.16010 0.1690 0.1693 0.1659 0.1840 0.19010 0.1941 0.1992
#wt_flt_1
2018 1 1 1 1 2 0.0344 0.0591000 0.0833 0.16010 0.1700 0.1721 0.0830 0.1860 0.19130 0.1947 0.1995
#wt_flt_2
2018 2 1 1 1 2 0.0344 0.0591000 0.0833 0.16010 0.1700 0.1721 0.1659 0.1860 0.19130 0.1947 0.1995
#wt_flt_2
2018 1 1 1 1 3 0.0138 0.0809000 0.1067 0.17300 0.1805 0.1838 0.1846 0.1915 0.19610 0.1943 0.1996
#wt_flt_3
2018 2 1 1 1 3 0.0396 0.0947000 0.1178 0.17470 0.1819 0.1851 0.1862 0.1922 0.19520 0.1957 0.2000
#wt_flt_3
2018 1 1 1 1 4 0.0195 0.0549000 0.1788 0.19290 0.1955 0.2045 0.2199 0.2263 0.29840 0.2984 0.2984
#wt_flt_4
2018 2 1 1 1 4 0.0359 0.0424000 0.0638 0.13380 0.1855 0.2045 0.2137 0.2196 0.21890 0.2153 0.2153
#wt_flt_4
2019 2 1 1 1 -2 0.0046 0.0354000 0.0773 0.11000 0.1339 0.1515 0.1644 0.1739 0.18080 0.1858 0.1939
#fecundity
2019 1 1 1 1 -1 0.0439 0.0586000 0.0744 0.14740 0.1915 0.2057 0.1840 0.2189 0.25780 0.2578 0.2578
#popwt_mid
2019 2 1 1 1 -1 0.0359 0.0424000 0.0638 0.13380 0.1855 0.2045 0.2137 0.2196 0.21890 0.2153 0.2153
#popwt_mid
2019 1 1 1 1 0 0.0439 0.0586000 0.0744 0.14740 0.1915 0.2057 0.1840 0.2189 0.25780 0.2578 0.2578
#popwt_beg
2019 2 1 1 1 0 0.0359 0.0424000 0.0638 0.13380 0.1855 0.2045 0.2137 0.2196 0.21890 0.2153 0.2153
#popwt_beg
```

```
2019 1 1 1 1 1 0.0323 0.0577000 0.0803 0.16010 0.1690 0.1693 0.1659 0.1840 0.19010 0.1941 0.1992
#wt_flt_1
2019 2 1 1 1 1 0.0323 0.0577000 0.0803 0.16010 0.1690 0.1693 0.1659 0.1840 0.19010 0.1941 0.1992
#wt_flt_1
2019 1 1 1 1 2 0.0344 0.0591000 0.0833 0.16010 0.1700 0.1721 0.0830 0.1860 0.19130 0.1947 0.1995
#wt_flt_2
2019 2 1 1 1 2 0.0344 0.0591000 0.0833 0.16010 0.1700 0.1721 0.1659 0.1860 0.19130 0.1947 0.1995
#wt_flt_2
2019 1 1 1 1 3 0.0138 0.0809000 0.1067 0.17300 0.1805 0.1838 0.1846 0.1915 0.19610 0.1943 0.1996
#wt_flt_3
2019 2 1 1 1 3 0.0396 0.0947000 0.1178 0.17470 0.1819 0.1851 0.1862 0.1922 0.19520 0.1957 0.2000
#wt_flt_3
2019 1 1 1 1 4 0.0439 0.0586000 0.0744 0.14740 0.1915 0.2057 0.1840 0.2189 0.25780 0.2578 0.2578
#wt_flt_4
2019 2 1 1 1 4 0.0359 0.0424000 0.0638 0.13380 0.1855 0.2045 0.2137 0.2196 0.21890 0.2153 0.2153
#wt_flt_4
2020 2 1 1 1 -2 0.0046 0.0354000 0.0773 0.11000 0.1339 0.1515 0.1644 0.1739 0.18080 0.1858 0.1939
#fecundity
2020 1 1 1 1 -1 0.0439 0.0586000 0.0744 0.14740 0.1915 0.2057 0.1840 0.2189 0.25780 0.2578 0.2578
#popwt_mid
2020 2 1 1 1 -1 0.0359 0.0424000 0.0638 0.13380 0.1855 0.2045 0.2137 0.2196 0.21890 0.2153 0.2153
#popwt_mid
2020 1 1 1 1 0 0.0439 0.0586000 0.0744 0.14740 0.1915 0.2057 0.1840 0.2189 0.25780 0.2578 0.2578
#popwt_beg
2020 2 1 1 1 0 0.0359 0.0424000 0.0638 0.13380 0.1855 0.2045 0.2137 0.2196 0.21890 0.2153 0.2153
#popwt_beg
2020 1 1 1 1 1 0.0323 0.0577000 0.0803 0.16010 0.1690 0.1693 0.1659 0.1840 0.19010 0.1941 0.1992
#wt_flt_1
2020 2 1 1 1 1 0.0323 0.0577000 0.0803 0.16010 0.1690 0.1693 0.1659 0.1840 0.19010 0.1941 0.1992
#wt_flt_1
2020 1 1 1 1 2 0.0344 0.0591000 0.0833 0.16010 0.1700 0.1721 0.0830 0.1860 0.19130 0.1947 0.1995
#wt_flt_2
```

2020 2 1 1 1 2 0.0344 0.0591000 0.0833 0.16010 0.1700 0.1721 0.1659 0.1860 0.19130 0.1947 0.1995

#wt_flt_2

2020 1 1 1 1 3 0.0138 0.0809000 0.1067 0.17300 0.1805 0.1838 0.1846 0.1915 0.19610 0.1943 0.1996

#wt_flt_3

2020 2 1 1 1 3 0.0396 0.0947000 0.1178 0.17470 0.1819 0.1851 0.1862 0.1922 0.19520 0.1957 0.2000

#wt_flt_3

2020 1 1 1 1 4 0.0439 0.0586000 0.0744 0.14740 0.1915 0.2057 0.1840 0.2189 0.25780 0.2578 0.2578

#wt_flt_4

2020 2 1 1 1 4 0.0359 0.0424000 0.0638 0.13380 0.1855 0.2045 0.2137 0.2196 0.21890 0.2153 0.2153

#wt_flt_4

-9999 2 1 1 1 -2 0.0046 0.0354000 0.0773 0.11000 0.1339 0.1515 0.1644 0.1739 0.18080 0.1858 0.1939

#fecundity