Assessment of the Northern anchovy (*Engraulis mordax*) central subpopulation in 2021 for U.S. management in 2021-2022

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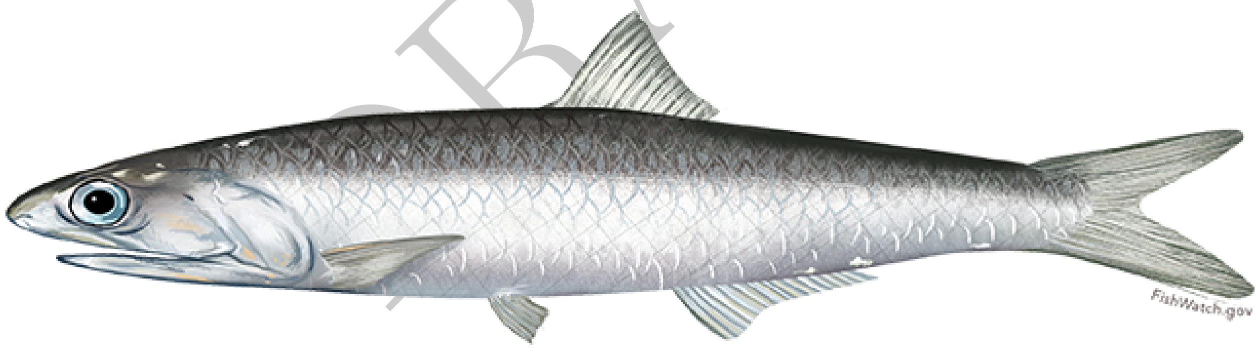

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Contents

1 Introduction

introduction

1.1 Distribution, Migration, Stock Structure, Management Units

distribution-migration-stock-structure-management-units

Northern anchovy (*Engraulis mordax* Girard) are distributed from northern British Columbia, Canada to the Gulf of California, Baja California Sur, Mexico. Past studies support a hypothesis for three subpopulations along the west coast of North America based on meristic and serological evidence (McHugh 1951, Vrooman et al. 1981): 1) a northern subpopulation ranging from the Queen Charlotte Islands, British Columbia, to Cape Mendocino, California; 2) a central subpopulation ranging from approximately Point Reyes, California, to Punta Baja, Baja California; and 3) a southern subpopulation, ranging from Sebastian Vizcaino Bay to the Gulf of California Fig. 1. The central subpopulation of northern anchovy is typically found in waters ranging from 12° to 22° C. The subpopulations do not seem to be genetically distinct (Lecomte et al. 2004). The following assessment is focused on fishery and survey information available for the central subpopulation of northern anchovy (CSNA).

1.2 Life History Features Affecting Management

life-history-features-affecting-management

Northern anchovy life history information is available in (Baxter 1967, Frey 1971, Council 1983, 1990) and references cited below. Northern anchovies are small, short-lived fish typically found in schools near the surface. They rarely exceed four years of age and 18 cm total length, although individuals as old as seven years and 23 cm have been recorded. Natural mortality is thought to be relatively high (e.g. M 0.8 yr-1; (Jacobson et al. 1994)), which means that about 55% of the total stock would die each year of natural causes in the absence of fishing. There is a great deal of regional variation in age composition (number of fish in each age group) and size at age with older fish and larger fish found at relatively offshore and northerly locations, probably due to northern and offshore migration of large fish, regional differences in growth rate, and water temperature (Parrish et al. 1985).

Northern anchovy are all sexually mature at age two. The fraction of one-year-olds that is sexually mature each year is theorized to depend on water temperature and has been observed to range from 47 to 100 percent (Methot 1989). They can spawn during every month of the year, but spawning increases during late winter and early spring and peaks during February to April. Spawning has been observed over a wide temperature range (12° to 22° C), but the preferred temperature is 14 °C and eggs are most abundant at temperatures of 12 °C to 16 °C. Individual females spawn batches of eggs throughout the spawning season at intervals as short as 7 to 10 days. Each large female spawns an estimated 20 to 30 thousand eggs annually. Spawned eggs are found near the surface, and require two to four days to hatch, depending on water temperature.

Information about long-term (ca 300 to 1970) changes in CSNA abundance is available from scales counted in sediment cores taken from the Southern California Bight (Soutar and Isaacs

1974, Baumgartner et al. 1992). These data indicate significant anchovy populations existed throughout the time period and that biomass levels during the late 1960s were modest relative to those during most of the previous two centuries. Sediment scale data indicate that CSNA tend to fluctuate less widely over time compared to Pacific sardine (Baumgartner et al. 1992).

Estimates of CSNA biomass (ages 1+) and recruitment were last provided by Jacobson et al. (1994, 1995). Biomass averaged 326,000 mt from 1963 through 1972, increased rapidly to over 1.54 million mt in 1974 and then declined to 326,000 mt in 1978. Since 1978, biomass levels have tended to decline slowly, falling to an average of 262,000 mt from 1986 through 1994. Anchovy biomass during 1995 was estimated to be 388,000 mt (Jacobson et al. 1995). Recruitment of CSNA is more variable than for most clupeoid fish (Beddington and Cooke 1983, Myers et al. 1990).

Northern anchovy have high fecundity and were recently estimated to have daily specific fecundity of 29 eggs per gram of popuulation weight per day (Dorval et al. 2018). In high density spawning areas, this value was 41 eggs per gram of population weight per day and 4 in low density areas (Dorval et al. 2018).

Anchovy distributions tend to vary based on life stage. Anchovy are filter feeders consuming various planktonic species. Young of year are typically found in nearshore waters, juveniles are both further offshore and nearshore, and adults are mostly offshore (Parrish et al. 1985). Geostrophic flow and depth at which maximum chlorphyll a occurred are two important predictors in habitat models of anchovy spawning habitat (Weber and McClatchie 2010).

1.3 Ecosystem Considerations

ecosystem-considerations

Juvenile anchovies, generally distributed inshore, are vulnerable to a variety of predators, including birds and some recreationally and commercially important species of fish. As adults offshore, anchovies are fed upon by numerous marine fishes (some of which have recreational and commercial value), marine mammals, and birds such as the California brown pelican (Koehn et al. 2017). Northern anchovy eat plankton either by filter feeding or biting, depending on size of the food. Adult anchovy are known to filter anchovy eggs and it is possible that this type of cannibalism is an important factor in regulating population size.

Ecosystem linkages to CSNA productivity are poorly understood. Until recently, it has generally assumed that anchovy increase productivity under cooler ocean conditions and sardine under warmer ocean conditions (Chavez et al. 2003), but the current CSNA boom began amid two marine heat waves seems to contradict this assumption (R. et al. 2019). Sardine and anchovy under warm and cold ocean regimes were thought to fluctuate asynchronously (Chavez et al. 2003), although analysis of sardine and anchovy time series across the world did not find evidence of widespread asynchrony (Siple et al. 2020). Environmental drivers may be density dependent as no physical or biological variable correlated to CSNA biomass for time series dating from 1951 to 2015 (Sydeman et al. 2020).

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

relevant-history-of-the-fishery-and-important-features-of-the-current-fishery

1.4.1 California's commercial fishery

californias-commercial-fishery

Official records of California landings of northern anchovy date from 1916. Anchovy landings were small until the scarcity of Pacific sardines caused processors to begin canning anchovies in quantity during 1947, when landings increased to 8,586 mt from 780 mt in 1946. A portion of the catch was reduced for fish meal and oil (Frey 1971). Anchovy landings declined with the temporary resurgence of sardine landings around 1951. Following the collapse of the sardine fishery in 1952, anchovy landings increased to nearly 39,000 mt in 1953, but subsequently declined due to low consumer demand for canned anchovy and to a temporary increase in sardine landings. During the early years (1916 through 1964), anchovy were harvested almost exclusively by California commercial roundhaul fishermen. Beginning in 1965, the California Fish and Game Commission managed anchovy using a reduction quota. Increases in abundance and in prices for fish meal and oil raised reduction landings to record highs by the mid-1970s. In 1965, only 155 mt of anchovy were landed for reduction, which increased to an average of over 58,000 mt per year between 1965 and 1982. After 1982, reduction landings decreased dramatically to an average of only 837 mt per year from 1983 to 1991. During the period 1995 to 1999, only four tons were reported as reduction landings. Decreased prices of fishmeal and the low prices offered to fishermen have deterred any significant reduction fishing in recent years.

California's commercial anchovy fishery today differs from the historical one. There is virtually no reduction capacity in California, which is one reason why landings have averaged less than 10,000 mt a year since the mid-1980s. The commercial fishery is currently focused in the Monterey area, with three large processors and 12 to 15 vessels that utilize anchovy when market squid are unavailable. Southern California's commercial CPS fishery has limited markets for anchovy due to their typically small size in that region. Anchovy currently landed by Monterey's directed commercial fishery are used as dead frozen bait, fresh fish for human consumption, exported for canning and human consumption, as animal food, and anchovy paste. The anchovy fishery operates in a very limited area, close to the ports of Monterey and Moss Landing, with short travel distances required for maintaining the product quality. From 2000-2019, California's commercial landings of anchovy have averaged 4,419 mt annually.

1.4.2 California's live bait fishery

californias-live-bait-fishery

California's live-bait fleet is distributed mostly along the southern California coast to serve the sport fishing markets in Los Angeles, Orange, and San Diego counties. Anchovy harvested by the live bait fishery are not landed but kept alive for sale to anglers as bait. Transactions between buyers and sellers of live bait take at bait wells tied up at docks. Live bait dealers generally supply bait to commercial passenger fishing vessels (CPFVs) on a contract basis and receive a percentage of the fees paid by passengers. Bait is also sold by the "scoop" to anglers in private vessels.

Modest amounts of anchovy were harvested for live bait before World War II. Live bait harvests fell to zero during the war years. Historically, the anchovy live bait catch ranged from 3,600 to 7,300 mt per year and averaged approximately 4,100 mt annually between 1974 and 1991. Anchovies comprised approximately 85 percent of the live bait catch prior to 1991. Pacific sardines became available to the live bait fishery again in 1992, so live bait catches shifted from anchovy to primarily sardine. California's live bait anchovy catch ranged from 91 to 1,519 mt between 2000 and 2019, averaging 700 mt per year, comprising about one quarter of all live bait catch.

1.4.3 Mexico's commercial fishery

`mexicos-commercial-fishery`

The CPS fishery based in Ensenada, Baja California, did not begin harvesting anchovy until 1962. Anchovy have historically been used primarily for reduction in Mexico. Mexico's harvesting and processing capacity increased significantly in the late 1970s when several large seiners were added to the fishing fleet and a large reduction plant was constructed by 'Pesquera Zapata' in Ensenada. Mexican anchovy landings averaged approximately 77,600 mt from 1962 to 1989, with a peak of over 260,000 mt in 1981. Northern anchovy catch decreased sharply in 1990, and despite landing 17,800 mt in 1995, average annual Mexican landings from 1990 to 1999 were only 3,300 mt per year. Landings remained at low levels from 2000-2009, averaging 1,600 mt year. Over the past decade (2010-2020), anchovy landings have increased by an order of magnitude to an average of ~15,900 mt per year, with a peak of 42,200 mt in 2018 (CONAPESCA 2020). Although fisheries in Mexico and the U.S. both harvest CSNA, there is no bilateral management agreement with Mexico. The Mexican fishery is managed independently and is not restricted by a quota at present.

1.5 Recent Management Performance

`recent-management-performance`

The U.S. northern anchovy central subpopulation fishery has been managed by the Pacific Fishery Management Council since 1978. Regulations currently described in the fishery management plan (FMP) designate the northern anchovy fishery as 'monitored', not 'actively managed', due to relatively low fishery demand (Council 1990). The FMP is currently being revised to remove the 'active' and 'monitored' management categories, and more regular assessments of the CSNA are anticipated. The default MSY control rule in the FMP gives an ABC for the entire stock equal to 25 percent of the MSY catch. An estimated 70 percent of the stock is assumed to be resident in U.S. waters. ABC in U.S. waters is approximately 25,000 mt. NMFS issued a new rule in response to a 2020 court decision (Oceana, Inc. v. Ross et al.), implementing an OFL of 119,153 mt, an ABC of 29,788 mt, and an ACL of 25,000 mt. The fishery has not caught this default amount since the onset of federal management. Harvests in major fishing regions from ENS to CCA are provided in Table 1 and Fig. 2.

2 Data

data

2.1 Fishery-Dependent Data

fishery-dependent-data

Available fishery data include commercial landings and biological samples from three regional fisheries: Ensenada (ENS), Southern California (SCA), and Central California (CCA) (Table 1). Standard biological samples include individual weight (kg), standard length (cm), sex, maturity, and otoliths for age determination. A complete list of available port sample data by fishing region, model year, and season is provided in (Table 2).

All fishery catches and compositions were compiled based on the anchovy's biological year ('model year') to match the June 1st birth-date assumption used in age assignments (Schwartzkopf et al. 2021). For example, model year 2005 spans June 1, 2005 to May 31, 2006. Semester 1 spans June to December (7 months) and semester 2 spans January to May (5 months). Major fishery regions were pooled to represent two "MexCal" fleets, each with semester-based selectivities (Table 3).

2.1.1 Landings

landings

Final Ensenada monthly landings from 2000-2018 were taken from CONAPESCA's web archive of Mexican fishery yearbook statistics (CONAPESCA 2017). Monthly landings for 2018 to 2021 were provided by INAPESCA (Concepción Enciso-Enciso, pers. comm.).

California (SCA and CCA) monthly commercial landings were obtained from the PacFIN database (2000-2021). Values for the aggregated semester-based fleets are in Table 3 and in Fig. 3. For forecasting beyond the model time frame for model year 2021-1 and 2021-2, landings were assumed to be the same as those from 2020-1 and 2020-2, respectively.

2.1.2 Age compositions

age-compositions

Age compositions for each fishing fleet and semester were the sums of catch-weighted age observations, with monthly landings (number of fish) within each port and season serving as the weighting unit. The following steps were used to develop the weighted age-composition time series:

1. 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).

2. Calculated total and average monthly catch weights, as well as average monthly weight-at-age estimates (in mt to match fishery catch units).

3. 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.

4. 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.

5. Calculated number of fish per age group by month by taking result of step 4 and dividing by the average monthly weight of each age group calculated in step 2.

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

7. Divided the result in step 6 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. Age compositions were input as proportions and presented in Figs. 5-7.

Northern anchovy are routinely aged by fishery biologists at CDFW and the SWFSC based on the number of annuli, defined to be the interface between an inner translucent growth increment and outer opaque growth increment (Fitch 1951, Collins 1969, Yaremko 1996). Note, the birth date is assumed to be June 1st. Ageing error vectors were calculated based on the methodology described in Punt (2008). Further details on the ageing methodology, increment analysis, and edge analysis are available in Schwartzkopf et al. (2021). The ageing error vectors are shown in Fig. 8.

2.1.3 Empirical weight-at-age

empirical-weight-at-age

Fishery mean weight-at-age estimates were calculated based on semester-specific fleets. There were no composition data for model year-semester 2016-2 (calendar year-semester 2017-1). Missing weight-at-age values were interpolated based on cohorts. There was no other smoothing or filling of other weight-at-age values.

2.2 Fishery-Independent Data: Acoustic-Trawl Survey

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 Index of abundance

index-of-abundance

The SWFSC acoustic-trawl survey is conducted in summer and sometimes in spring. Data from summer cruises in 2015-2019 and spring cruises in 2017 and 2021 are the primary fishery-independent data source used in this assessment (Stierhoff et al. 2019, 2020, 2021a, 2021b, Zwolinski et al. 2019).

The summer 2015 survey totaled 2,614 nmi from Cape Scott, BC to San Diego, CA with 62 daytime east-west transects, 158 nighttime surface trawls and 57 trawl clusters (Stierhoff et al. 2021a). CSNA biomass was estimated to be 10,528 mt (CI95%=3,210 to 19,787; CV=42%)

The summer 2016 survey totaled 4,590 nmi from Cape Scott, BC to San Diego, CA with 100 daytime east-west transects, 118 nighttime surface trawls and 50 trawl clusters (Stierhoff et al. 2021b). CSNA biomass was estimated to be 150,907 mt (CI95%=32,843 to 317,457; CV=51%).

The spring 2017 survey (model year-semester 2016-2) estimated CSNA biomass to be 173,973 mt with a CV of 0.33. The survey document is not available, but the values were calculated with the same methods as other cruises (Stierhoff pers. comm.).

The summer 2017 survey totaled 3,506 nmi from Cape Scott, BC to Morro Bay, CA with 103 daytime east-west transects, 84 nighttime surface trawls and 36 trawl clusters (Zwolinski et al. 2019). CSNA biomass was estimated to be 153,460 mt (CI95%=2,628 to 264,009; CV=45%).

The summer 2018 survey totaled 5,202 nmi from Cape Scott, BC to Morro Bay, CA with 136 daytime east-west transects, 170 nighttime surface trawls and 65 trawl clusters (Stierhoff et al. 2019). CSNA biomass was estimated to be 723,826 mt (CI95%=533,548 to 1,015,782; CV=17%).

The summer 2019 survey totaled 5,941 nmi from Cape Scott, BC to San Diego, CA with 118 daytime east-west transects, 163 nighttime surface trawls and 61 trawl clusters (Stierhoff et al. 2020). CSNA biomass was estimated to be 769,154 mt (CI95%=559,915 to 984,059; CV=14%). Nearshore biomass with coupled fishing vessel acoustic and trawl sampling had an estimated biomass value of 41,480 mt (CI95%=27,402 to 82,206; CV=34%).

The spring 2021 (model year-semester 2020-2) survey estimated CSNA biomass to be 1,358,587 mt with CV 0f 0.17. These values are preliminary as the spring 2021 cruise summary document has yet to be finalized (Stierhoff pers. comm.). The report is forthcoming and may be approved by the STAR panel in December.

2.2.2 Age compositions

age-compositions-1

Estimates of abundance-at-length were converted to abundance-at-age using survey-specific age-length keys for the summer (Fig. 14). Age-length keys were constructed using ordinal generalized additive regression models from the R package mgcv (Wood 2017). 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. The survey age compositions were weighted (i.e input sample sizes in Stock Synthesis) by the number of positive clusters in each cruise. This is in contrast to the calculation for the fishery age compositions, which considered a sample to be the number of total aged fish / 25. More details on processing of the survey age compositions are included in Appendix A.

2.2.3 Ageing error

ageing-error

Ageing error vectors were calculated based on the methodology described in Punt (2008). Further details on the ageing methodology, increment analysis, and edge analysis are available in Schwartzkopf et al. (2021). The ageing error vectors are shown in Fig. 8. There were three ageing error vectors calculated for calendar years 2015-2016, 2017-2018, and 2019-2021 (Table 5).

2.2.4 Empirical weight-at-age

empirical-weight-at-age-1

AT survey weight-at-age time series (Fig. 16) 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.

2.3 Nearshore sampling

nearshore-sampling

The AT survey collects information on nearshore areas with echosounder sampling from an unmanned surface vehicle and fishing vessels with coupled echosounder and purse-seine sampling (Stierhoff et al. 2020). These areas are too shallow to navigate NOAA ships safely. 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 unmanned surface vehicle; and the coasts of the Southern CA Bight (SCB), and Santa Cruz and Santa Catalina Islands were surveyed by F/V *Long Beach Carnage*. In 2019, the nearshore abundance was estimated to be 41,480 mt, about 5% of the core survey area abundance estimate of 754,396 mt [Stierhoff et al. (2020); Table 6]. The nearshore abundance estimates from 2015 and 2018 were calculated with model-based extrapolations from unmanned surface vehicles rather than fishing vessel sampling.

California Department of Fish and Wildlife has conducted an aerial survey off the coast of central and southern California. The challenge with standardizing these data is that the spatial coverage of the surveys has varied year to year. Additionally, there has been a temporal and spatial mismatch between the aerial surveys and associated biological sampling. The AT survey can in some case have acoustic observations and biological sampling separated by a day or two, whereas the aerial observations and associated biological samples have occurred weeks to months apart. There are age compositions associated with the aerial observations (see CCPSS report 2021), but technical challenges in incorporating these data to the assessment model.

The 2020 Pacific sardine benchmark assessment (Kuriyama et al. 2020) incorporated aerial survey data as an adjustment on the catchability (Q) associated with the AT survey. For sardine, the 2019 summer AT biomass observation was 33,138 mt, and the AT nearshore estiamte was 494 mt. The aerial survey from summer 2019 had an estimated biomass of 12,279. Because sardine biomass was so low, nearshore uncertainty posed a large challenge.

Biomass observations from the AT nearshore and aerial survey methods are in general agreement (Fig. 12), and anchovy biomass in the AT survey has increased from 2015-2021 (Fig. 11). Note that the surveys are not covering the same areas. The differences in mean biomass estimates between the AT methods is relatively small, particularly considering the AT survey estimates from 2018, 2019 and spring 2021 (Fig. 13). Additionally, adjusting Q values based on nearshore estimates resulted in comparable values for either AT nearshore or aerial survey methods (Table 7). For example in summer 2019 (calendar year-semester 2019-2; model year-semester 2019-1), Q adjusted based on AT nearshore biomass was 0.95, and Q adjusted based on the aerial survey was 0.93 (Table 7). In summer 2017 (calendar year-semester 2017-2; model year-semester 2017-1) the Q values were 0.77 for AT nearshore and 0.67 for the aerial survey (Table 7). Note, that the summer 2017 survey did not go south of Point Conception.

Nearshore sampling, particularly with consistent spatial coverage, sampling protocols, and closely-timed biological sampling (and ageing) is an important data source, and nearshore data collection efforts should continue. Uncertainty regarding nearshore and offshore anchovy distribution is likely to a more problematic when population biomass is low as it was for Pacific sardine. Currently, anchovy biomass seems to be high and distribution seems to be concentrated within the AT survey area.

2.4 Biological Parameters

biological-parameters

2.4.1 Stock structure

stock-structure

Fishery and survey observations from central California, southern California, and Ensenada, Mexico were assumed to be from the central subpopulation. There is currently no habitat modeling nor analysis of size-at-age to distinguish central from northern and southern subpopulation anchovy. The distributions of northern and central subpopulations do not seem to overlap; northern spans Westport, WA to Coos Bay, OR, and central spans Fort Bragg, CA to San Diego, CA (Stierhoff et al. 2020). Preliminary analysis of the summer 2021 acoustic-trawl cruise found that presumed central subpopulation anchovy distribution ended in northern Baja California, Mexico, and nearly all the central subpopulation anchovy were observed in US waters (forthcoming 2021 cruise report).

2.4.2 Growth

growth

Size-at-age from fishery samples and survey samples provided no indication of sexual dimorphism related to growth (Fig. 15), so combined sexes were included in the present assessment with a sex ratio of 50:50.

The assessment model used empirical weight-at-age values to account for anchovy growth. This approach is similar to that used in assessments of Pacific sardine (Kuriyama et al. 2020). Growth estimation for anchovy may be difficult due to growth variation in time and space and potential confounding of length-based selectivity and growth estimates. Growth estimation internal to SS was evaluated in the development of the base model, however anchovy growth was relatively quick;

2.4.3 Maturity

maturity

Maturity was modeled with a fixed vector of fecundity multiplied by maturity at age. To estimate maturity at age, the equation:

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

was fit to age and maturity for female anchovy collected in the spring 2017 and 2021 acoustic-trawl surveys. Reproductive state was established through histological examination (n=701, (Schwartzkopf et al. 2021)).

Parameters for the logistic maturity function were slope = -1.62 and $age_{inflection} = -0.6$. Note that these values are not used in SS model as growth was not internally estimated. Based on the model estimates, 73% of age-0, 93% of age-1, 99% of age-2 and 100% of age-3 and age-4 fish are mature. These values were input as fixed as part of the weight-at-age file in Stock Synthesis. Fecundity was assumed to be fixed at 1 g egg per gram body weight.

2.4.4 Natural mortality

`natural-mortality`

Natural mortality (M) is likely high for northern anchovy, similar to other small pelagic species which rarely become more than seven years old (Hoenig 1983). MacCall (1973) estimated instantaneous natural mortality to be 1.06, resulting in 65% mortality in the population each year. Methot (1989) assumed M to be 0.6, but estimates of biomass were not greatly affected by changing the values of M. Jacobson (1994) assumed M to be 0.8. In nature, M may be age- (or size-) specific and dependent on the population size. Estimates of M from catch curves are likely confounded by spatiotemporal variability in sampling and anchovy availability to fishing gear.

2.5 Available Data Sets Not Used in Assessment

`available-data-sets-not-used-in-assessment`

The STAT considered assessment models that spanned 2000 to 2020 and contained alternative fishery-independent indices of relative abundance. The current base model spans 2015 to 2021 (calendar years) to align with the time series of available AT survey observations. Catch records for both fishing fleets are avilable back to 2000, but fishery age compositions only date back to calendar year 2013. Anchovy have relatively short life spans (maximum modeled age of 4 in the base model), there may not be many benefits to an extended model. A longer model may better estimate scaling parameters such as R0 and M. Additionally, there may be better estimates of reference points (e.g. MSY values) as the model incorporates data from low and high periods of abundance.

John Field, Tanya Rogers, Rebecca Miller, and Keith Sakuma (SWFSC) provided indices of abundance from the Rockfish Recruitment and Ecosystem Assessment Survey (RREAS). The survey dates back to 1983 off central California, but beginning in 2004 coverage expanded into the Southern California Bight (see RREAS appendix). Length composition (assumed to be age 0) are available but were not evaluated in alternative models. The alternative model considered by the STAT used the anchovy young-of-year index as a recruitment index (survey units of 33 in Stock Synthesis), and fixed steepness, estimated M, and estimated R0 (sigmaR fixed at 1).

Data from the California Cooperative Oceangraphic Fishery Investigations (CalCOFI) survey began in 1951, although only data from 2000 to 2020 were considered in alternative model configurations. CalCOFI collects larval and egg data, and both indices were standardized with a delta-GLM. Egg data were also standardized with a vector autoregressive spatio-temporal (VAST) model (Thorson 2019). The standardized data sets showed similar trends from 2000 to 2020. More details on the data and modeling are available in Appendix C.

Alex Curtis (SWFSC) provided sea lion scat data collected on the Channel Islands in the Southern California Bight (see appendix). The STAT standardized the data with a delta-GLM but ultimately the data were not evaluated in alternative models. There were concerns regarding the ability of a delta-GLM to capture the sea lion sampling process and sea lion preferences for anchovy over other prey species.

The STAT focused on the RREAS young-of-year data in alternative model configurations. These data seemed to have potential as a recruitment index and be the most straightforward to incorporate into the assessment. CalCOFI eggs were also considered, as eggs would be an assumed proxy for spawning stock biomass. CalCOFI larvae were not evaluated thoroughly, as they would also be correlated to spawning stock biomass. However, there is likely stage-specific mortality as eggs transition to larvae, juveniles, and adults. It was not possible to explore these mortality rates further in development of this assessment. Results of alternative models are discussed at the end of the results section.

Aerial survey data were also considered as described in the Nearshore biomass section above.

3 Assessment

assessment

3.1 History of Modeling Approaches

history-of-modeling-approaches

The earliest attempts at estimating CSNA abundance used survey-based collections of eggs, larvae, and adults to back-calculate spawning stock biomass (SSB) based on the daily egg production method (DEPM) (Lasker 1985). Estimates of long-term biomass were first made available when the Stock Synthesis model was developed and implemented for this purpose (Methot 1989). The Stock Synthesis model was one of the earliest examples of fully integrated catch-at-age analyses incorporating auxiliary data on abundance (e.g., Fournier and Archibald (1982); Deriso et al. (1985)). The PFMC based anchovy management on Stock Synthesis estimates until 1992, after which fishery composition data became greatly limited as the fishery declined. In addition to the loss of fishery composition data, areas of retrospective bias were identified in Stock Synthesis models, caused by using an over-parameterized model with limited data. This prompted the development of a simpler and more parsimonious model, SMPAR (Jacobson et al. 1994, 1995). SMPAR is a hybrid between simple surplus production and more complicated age-structured approaches, modeling catch and a variety of fishery-independent abundance indices but ignoring age composition data from the fishery. SMPAR modeled the age 1+ population and age-0 recruits over time (Jacobson et al. 1994, 1995). SMPAR estimates were used for CSNA management until 1997, after which CSNA were moved to 'monitored' status (i.e., no regular assessments) due to low catch levels and prioritization of Pacific Sardine and Pacific Mackerel management by the PFMC (PFMC 1998). More recent attempts to update CSNA population status have been based on ichthyoplankton density collected during CalCOFI surveys, using the assumption that egg and larval abundance is proportional to SSB in any given year (Fissel et al. 2011, MacCall et al. 2016, Thayer et al. 2017). The following benchmark assessment is the first fully integrated catch-at-age model for CSNA to be formally reviewed through the PFMC's STAR Panel process.

3.2 Model Description

`model-description`

3.2.1 Time period and time step

`time-period-and-time-step`

The modeled timeframe begins in 2015 and extends through 2020, to match the time periods of available data from the AT survey. Time steps are based on two semester blocks for each fishing year. Semester 1 spans June-December (7 months) and semester 2 spans January to May (5 months). The decision to begin semester 1 in June is informed by the assumed birthdate of June 1 for anchovy, which has earlier recruitment than Pacific sardine (Schwartzkopf et al. 2021).

The goal of this assessment is to estimate terminal year stock biomass, and for a short-lived species like CSNA, a model with a longer time frame would likely not enhance achievement of this goal. Extending the timeframe of the model may facilitate estimation of scaling parameters but does not appear to result in significantly different biomass estimates in recent years. See results section below.

3.2.2 Surveys

`surveys`

The AT survey is the only fishery-independent data source included. The index of abundance, associated age compositions, and weight-at-age values are included in this base model.

3.2.3 Fisheries

`fisheries`

Two fisheries are included in the model, including two Mexico-California fleets separated into semesters (MexCal_S1 and MexCal_S2). Data are aggregated from three major fishing areas representing the range of CSNA distribution. The regions are northern Baja California (Ensenada, Mexico), southern California (Los Angeles to Santa Barbara), and central California (Monterey Bay). Age-based selectivity for the MexCal fleets was modeled separately for semesters 1 and 2.

3.2.4 Longevity and natural mortality

longevity-and-natural-mortality

There are 5 modeled age bins representing ages 0 to 4+. Anchovy age 5 and older are infrequently observed in the fishery and survey samples (Table 2), and as a result the plus group begins at age 4. Natural mortality is likely to be high, as it is in other coastal pelagic species. Methot (1989) fixed M at 0.6, although it had been estimated to be 0.9 by MacCall (1973). Jacobson (1994) assumed M to be 0.8, and this value has been used in subsequent PFMC analyses (e.g. Punt 2019 analysis of frequency of control rules and management guidelines).

The current base model estimates M and fixes steepness (h), and typically in assessments these values are negatively correlated. In development models, M was fixed at 0.8 with steepness estimated. These models estimated R0 at its upper limit (near 29) and steepness to be about 0.5. The resulting estimated biomass levels were unreasonably high at the end of the modeling period. As a result, the current base model fixes steepness and estimates M.

3.2.5 Growth

growth-1

Empirical weight-at-age estimates by fleet/year/semester were used in the base model. Input of weight-at-age simplifies the assessment run time as an age-length growth curve (or curves) does not need to be estimated. Weight-at-age values, with relatively high numbers of sampled fish, tracks time-varying growth patterns. In development models, growth estimates had a Lmin value of about 8, Lmax of 12 and high von Bertlanffy k of 1.

3.2.6 Stock-recruitment relationship

stock-recruitment-relationship

Equilibrium recruitment (R_0) and initial equilibrium offset (SR_{regime}) were estimated in the base model, and steepness (h) was fixed at 0.6. There was not much information in the data to estimate steepness, and the parameter was fixed as a result.

The value of average recruitment variability (σ_R) assumed in the stock-recruitment relationship was set to 1. This value was decided based on comparing likelihood values for models with different fixed values of steepness and σ_R. 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 2010-2014 (four 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 2015-2020 (S2 of each model year).

3.2.7 Selectivity

selectivity

The base model estimated age-based selectivity from the fishery and AT survey age compositions. Time-varying selectivity was implemented for both the fishery and the survey compositions. Estimation of time-varying selectivity was estimated to better capture seasonal and interannual variability in anchovy availability to gear (a proxy for movement) and to provide better fits to the age composition data.

Selectivities for the MexCal fisheries were modeled as non-parametric functions with estimated age-specific values using a random walk (Option 17; Methot et al. 2021). Selectivity patterns from 2015-2020 were freely estimated because age compositions showed year-to-year variability across some years. Technically, the replacement block function was used instead of alternative options that require specifying a base selectivity pattern and estimation of subsequent deviations from this base pattern. Ages 1-2 for MexCal S1 were estimated using time-varying annual blocks. Time-varying estimation increased the number of estiamted parameters in the model and also improved fits to the fishery age compositions.

Following recommendations from the recent Pacific sardine benchmark 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 anchovy 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 anchovy 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.

3.2.8 Catchability

catchability

Catchability (Q) was assumed to be 1 in the assessment. Throughout the model development, Q was not estimable (see likelihood profile section below). The summer 2021 AT survey extended to northern Baja California, Mexico for the first time in many years. Preliminary analysis of these data indicate that a large proportion of the central subpopulation anchovy are observed in US waters. While there is likely year to year variability in the distributions north and south of the US-Mexico border, these data suggest that Q is approximately 1 in summers.

Nearshore uncertainty is magnified when anchovy biomass is low. But in recent years, anchovy biomass has been high, and nearshore estimates (both from the AT survey and aerial methods) represent a small proportion of the total biomass. There are a number of technical challenges to incorporating estimates of both forms of nearshore estimates. The early nearshore estimates from the AT survey are from unmanned surface vehicles, with no associated biological sampling, and the summer 2019 nearshore estimates had coupled acoustic and biological sampling on fishing vessels. Inclusion of the AT nearshore estimates would likely require assuming that these sampling processes (and associated uncertainties) are constant. Inclusion of the nearshore aerial survey estimates would require an assumption about the selectivity pattern of aerial survey, and the data have spatiotemporally mismatched aerial observations and biological sampling.

3.2.9 Likelihood components and model parameters

`likelihood-components-and-model-parameters`

A complete list of model parameters for the base model is presented in Table 11. The total objective function was based on the likelihood components from fits to the AT survey abundance index and fits to age compositions from the three fleets and AT survey, and catch time series. Fits to equilibrium stock-recruitment relationship, and soft-bound penalties for specific parameters were not included in the total likelihood calculation.

3.2.10 Initial population and fishing conditions

`initial-population-and-fishing-conditions`

Given the northern anchovy central 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 northern anchovy (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.

The initial population was defined by estimating 'early' recruitment deviations from 2010-2014, i.e., five years prior to the start year in the model. Initial fishing mortality (F) was estimated for the MexCal S1 fishery and MexCal S2. 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 and Wetzel 2013, Methot et al. 2021). 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.

3.2.11 Assessment program with last revision date and bridging analysis

`assessment-program-with-last-revision-date-and-bridging-analysis`

This section is not applicable to this assessment, as this is the first assessment of northern anchovy as part of the PFMC process.

3.2.12 Convergence criteria and status

`convergence-criteria-and-status`

The iterative process for determining numerical solutions in the models was continued until the difference between successive likelihood estimates was <0.00001. The total likelihood and final gradient estimates for the base model were 17.49 and 2.10e-06, respectively.

3.3 Base Model Results

`base-model-results`

3.3.1 Likelihoods and derived quantities of interest

`likelihoods-and-derived-quantities-of-interest`

The base model total likelihod was 17.49. Likelihood values from the age compositions made of the majority of the total likelihood. The forecasted total biomass for June 2021 was 2,268,330 mt.

3.3.2 Parameter estimates and errors

parameter-estimates-and-errors

Parameter estimates and standard errors for the base model are presented in Table 11

3.3.3 Growth

growth-2

Growth parameters were not estimated in the 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 (Fig. 16).

3.3.4 Selectivity estimates and fits to fishery and survey age compositions

selectivity-estimates-and-fits-to-fishery-and-survey-age-compositions

Time-varying age-based selectivities were estimated for MexCal S1, MexCal S2 and the age0 AT survey (Fig. 17). The population age distributions (by numbers of fish) are greater than 50% age-0 fish in each year (Fig. 18). The fishery selectivity curves may explain the high estimated F values in recent years (Fig. 34), despite the low exploitation rates (Fig. 35).

3.3.5 Fit to survey index of abundance

fit-to-survey-index-of-abundance

Model fits to the AT survey index of abundance in arithmetic and log space are presented in Figs. 25 and 26. The predicted index values were generally good (near mean estimates and within error bounds) for all values in the time series.

3.3.6 Stock-recruitment relationship

stock-recruitment-relationship-1

Recruitment was modeled using a Beverton-Hold stock-recruitment relationship (Fig. 27). The assumed level of underlying recruitment deviation error was fixed (σ_R=1), equilibrium recruitment was estimated ($log(R_0)$=19.17) and steepness (h) was fixed at 0.6. Recruitment deviations for the early (2011-2014), main (2015-2020), and forecast (2021) periods in the model are presented in Fig. 28. Asymptotic standard errors for recruitment deviations are shown in Fig. 29, and the recruitment bias adjustment plot for the three periods are shown in Fig. 30.

3.3.7 Population number- and biomass-at-age estimates

population-number--and-biomass-at-age-estimates

Population number-at-age estimates for the base model are presented in Table 12. Corresponding estimates of population biomass-at-age, total biomass (age-0+, mt) and stock biomass (age-1+ fish, mt) are shown in Table 13. On average, age 0 fish comprise 75% of the total population biomass from 2015-2020.

3.3.8 Spawning stock biomass

spawning-stock-biomass

Time series of estimated spawning stock biomass (SSB; mt) and associated 95% confidence intervals are presented in Table 14 and Fig. 31. The initial level of SSB was estimated to be 129,335 mt. The SSB has increased continuously from 2015-2020. The SSB was projected to be 1,403,030 mt in June 2021.

3.3.9 Recruitment

recruitment

Time series of estimated recruitment abundance are presented in Tables 12 and 14 and Fig. 32. The equilibrium level of recruitment R_0 was estimated to be 211,555,937 thousand age-0 fish.

3.3.10 Fishing mortality

fishing-mortality

Estimated fishing mortality (apical F) time series by fishery are presented in Fig. 34. In early years of the modeling period, fishing mortality estimates are high due to harvest on anchovy in Ensenada and a low estimated population size. Exploitation rate has been less than 5% since 2016 (Table 15) and Fig. 35. Calendar year 2015 had an exploitation rate of 73% because the population was at low levels and US landings were about 16,000 mt and Mexico landings were about 26,000 mt.

3.4 Modeling Diagnostics

modeling-diagnostics

3.4.1 Convergence

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. There was a lower minimum likelihood, although the solution was not stable. The difference in likelihood values was 0.0093 units (17.4896 in base model; 17.4803 in lower jitter solution). For comparison the model year-semester 2020-1 age 0+ biomass was 1,554,480 mt in the base model and 1,555,900 mt in the jitter model with the lower likelihood by 0.004 units. 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.

3.4.2 Retrospective analysis

retrospective-analysis

A retrospective analysis was not conducted due to the short timeframe of the assessment model. Typically, retrospective analyses sequentially remove up to five years of data. In this assessment only five years of AT survey data were available.

3.4.3 Historical analysis

historical-analysis

A historical analysis was not conducted as the most recent PFMC-approved assessment was conducted in 1995 (Jacobson et al. 1995), which was before the beginning of the base model time period.

3.4.4 Likelihood profiles

likelihood-profiles

There was not much information in the age compositions nor AT index of abundance to estimate steepness. Steepness was fixed at 0.6 in the base model, although a steepness of 0.5 had a lower likelihood and "better" fit to the data (Table 16). This model (h=0.5) had a higher R0 of 29.826 (compared to 19.171 with h=0.6), resulting in biomass estimates that didn't seem to match the scale of the AT survey data assuming the survey sees nearly all of the anchovy biomass. The index of abundance was best fit with h=0.8, while the best fits to the survey age compositions were at h=0.4 (Fig. 36).

None of the data sets contained information on catchability (Fig. 37). Models with a lnQ of 0.3 had the lowest total likelihood (Table 17). Both the AT index and age compositions support a high lnQ of 0.3, which results in an estimate of M=0.6 (Table 17).

The AT survey age compositions seemed to contain the most information to estimate M. With fixed h=0.6, a M=0.6 had the best fit to the data (NLL=17.5093; Table 18). The AT survey index had the best fit with M=0.4, and the AT survey age compositions had the best fit with M=0.8 (Fig. 38).

A profile of M that estimated steepness (different model configuration than the base model), had a similar result, that M=0.6 had the lowest total likelihood (Table 19). When M=0.6, h was estimated at 0.5 but R0 was near the upper bound at 29.705 (Table 19). The overall profiles look similar to that with fixed steepness (Fig. 39).

3.4.5 Sensitivity to alternative data weighting

sensitivity-to-alternative-data-weighting

The base model was run with age compositions reweighted according to the Francis method (Francis 2011) to evaluate model sensitivity to data weighting. The variance adjustment values were 2.924 for MexCal S1, 2.979 for MexCal S2, and 0.623 for AT Survey. Parameter estimates, biomass estimates, and likelihood values are shown in Table 20 and Fig. 40. The model y-s 2020-1 biomass estimates ranged from 1,187,680 mt to 1,679,130 mt (Fig. 40).

The base model was also run with downweighted age compositions (lambda = 0.5 rather than 1 in the base model) to evaluate model sensitivity to data weighting. Parameter estimates, biomass estimates, and likelihood values are shown in Table 21 and Fig. 41. The model y-s 2020-1 biomass estimates ranged from 1,230,640 mt to 1,727,960 mt (Fig. 41).

3.4.6 Evaluation of models with longer timeframe

`evaluation-of-models-with-longer-timeframe`

The longer model considered and compared to the base model incorporated the RREAS young of year data as an index of recruitment, with a time period from 2000-2020 (model years). Main period recruitment deviations estimation started in 2000 (although the RREAS data began in 2005). The longer model estimated one InitF for MexCal S1, and assumed a fixed steepness of 0.6, as in the base model.

The results were similar to the base model results. M was estimated to be 0.82 (0.57 in base), R0=16.748 (19.11 in base). These values are also shown in Table 22. Estimated age 0+ biomass was low from model years 2000 to 2015, and 2020 age0+ biomass was 1,946,000 mt (compared to 1,554,480 in base; Fig. 42).

Models that included CalCOFI eggs and larval data faced a number of convergence issues. Additionally, estimates of M were around 0.4; lower than expected given the biology of anchovy.

4 Harvest Control Rules

`harvest-control-rules`

The CPS FMP includes a default harvest control for stocks without a stock-specific harvest control rule (HCR). The default HCR, which is currently used for CSNA, includes an OFL based on species-specific MSY proxy. The default ABC control rule consists of a 75 percent reduction from OFL to ABC. The ACL is determined by the PFMC and may be be equal or lower than the ABC.

5 Research and Data Needs

`research-and-data-needs`

Nearshore biomass, particularly the area inshore of the past AT survey footprint, will likely be an uncertainty when the anchovy population declines to low levels. There have been methodological improvements to the AT nearshore survey and aerial survey, and such refinements should continue.

The distribution of anchovy across the US-Mexico border will be a research need, particularly when the population drops to low levels. The summer 2021 AT survey was able to survey in Mexican waters, and hopefully such efforts will be able to continue.

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

Habitat separation may be one research need, although northern and central subpopulation anchovy seem to be well separated given recent survey cruise reports.

6 Acknowledgements

acknowledgements

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7 Tables

tables

Table 1: Northern anchovy landings (mt) for the three major fishing regions: central California (CCA), southern California (SCA), and Ensenada (ENS).

tab:landings_regional

Calendar Y-S	Model Y-S	CCA	SCA	ENS
2000-1	1999-2	1,939	2,976	235
2000-2	2000-1	4,999	2,674	1,337
2001-1	2000-2	11,398	5,292	47
2001-2	2001-1	324	3,610	29
2002-1	2001-2	1,833	1,117	0
2002-2	2002-1	874	1,838	0
2003-1	2002-2	515	390	0
2003-2	2003-1	191	1,558	244
2004-1	2003-2	2,871	1,554	160
2004-2	2004-1	1,020	1,540	60
2005-1	2004-2	3,362	2,174	2,476
2005-2	2005-1	2,830	4,335	2,396
2006-1	2005-2	5,877	1,341	0
2006-2	2006-1	1,828	4,266	1,567
2007-1	2006-2	6,595	1,748	1,452
2007-2	2007-1	1,121	1,634	2,606
2008-1	2007-2	6,865	1,429	753
2008-2	2008-1	5,367	1,346	238
2009-1	2008-2	978	1,429	1,076
2009-2	2009-1	9	1,085	1,367
2010-1	2009-2	0	90	119
2010-2	2010-1	765	874	3,020
2011-1	2010-2	1,225	740	1,330
2011-2	2011-1	818	864	431
2012-1	2011-2	2,272	119	321
2012-2	2012-1	6	440	1,488
2013-1	2012-2	0	341	320
2013-2	2013-1	5,551	786	2,107
2014-1	2013-2	10,121	385	242
2014-2	2014-1	256	891	296
2015-1	2014-2	7,861	183	392
2015-2	2015-1	9,325	645	25,751
2016-1	2015-2	384	4,633	1,389
2016-2	2016-1	3,446	170	3,619
2017-1	2016-2	119	236	6,845
2017-2	2017-1	5,098	138	8,881
2018-1	2017-2	6,112	34	18,152
2018-2	2018-1	11,277	91	24,020
2019-1	2018-2	3,680	21	17,090
2019-2	2019-1	6,323	146	18,048
2020-1	2019-2	3,612	14	19,803
2020-2	2020-1	1,895	114	20,934
2021-1	2020-2	1,601	78	19,803
2021-2	2021-1	206	59	7,782

Table 2: Northern anchovy samples available for the fishing regions central California (CCA), southern California (SCA), and the AT survey. The numbers of fish age 5+, numbers of total fish (with length, weights, and age measurements), and the number of fishery samples (one sample corresponds to 25 fish).

`tab:sample_sizes`

Region	Calendar Y-S	Model Y-S	N age 5+	N fish	N samples
CCA	2014-1	2013-2	1	1066	42.64
	2014-2	2014-1	0	75	3.00
	2015-1	2014-2	2	982	39.28
	2015-2	2015-1	3	868	34.72
	2016-2	2016-1	0	345	13.80
	2017-2	2017-1	2	393	15.72
	2018-1	2017-2	2	583	23.32
	2018-2	2018-1	8	1291	51.64
	2019-1	2018-2	3	646	25.84
	2019-2	2019-1	10	961	38.44
	2020-1	2019-2	2	574	22.96
	2020-2	2020-1	3	374	14.96
	2021-1	2020-2	0	50	2.00
SCA	2014-1	2013-2	0	24	0.96
	2014-2	2014-1	0	22	0.88
	2016-1	2015-2	0	593	23.72
Survey	2015-2	2015-1	1	490	19.60
	2016-2	2016-1	11	732	29.28
	2017-2	2017-1	1	129	5.16
	2018-2	2018-1	14	666	26.64
	2019-2	2019-1	52	1072	42.88
	2017-1	2016-2	0	548	21.92
	2021-1	2020-2	18	879	35.16

Table 3: Northern anchovy landings (mt) for the MexCal Semester 1 and MexCal Semester 2 fleet input to the stock assessment. The base model begins in model y-s 2015-1 (calendar y-s 2015-2) although landings from before this period are shown.

tab:landings_fleet

Calendar Y-S	Model Y-S	MexCal_S1	MexCal_S2
2000-1	1999-2	0	5,150
2000-2	2000-1	9,010	0
2001-1	2000-2	0	16,737
2001-2	2001-1	3,963	0
2002-1	2001-2	0	2,950
2002-2	2002-1	2,712	0
2003-1	2002-2	0	905
2003-2	2003-1	1,993	0
2004-1	2003-2	0	4,585
2004-2	2004-1	2,620	0
2005-1	2004-2	0	8,012
2005-2	2005-1	9,561	0
2006-1	2005-2	0	7,218
2006-2	2006-1	7,661	0
2007-1	2006-2	0	9,795
2007-2	2007-1	5,361	0
2008-1	2007-2	0	9,047
2008-2	2008-1	6,951	0
2009-1	2008-2	0	3,483
2009-2	2009-1	2,461	0
2010-1	2009-2	0	209
2010-2	2010-1	4,659	0
2011-1	2010-2	0	3,295
2011-2	2011-1	2,113	0
2012-1	2011-2	0	2,712
2012-2	2012-1	1,934	0
2013-1	2012-2	0	661
2013-2	2013-1	8,444	0
2014-1	2013-2	0	10,748
2014-2	2014-1	1,443	0
2015-1	2014-2	0	8,436
2015-2	2015-1	35,721	0
2016-1	2015-2	0	6,406
2016-2	2016-1	7,235	0
2017-1	2016-2	0	7,200
2017-2	2017-1	14,117	0
2018-1	2017-2	0	24,298
2018-2	2018-1	35,388	0
2019-1	2018-2	0	20,791
2019-2	2019-1	24,517	0
2020-1	2019-2	0	23,429
2020-2	2020-1	22,943	0
2021-1	2020-2	0	21,482
2021-2	2021-1	8,047	0

Table 4: US CSNA landings (mt) by model year (beginning June 1). CSNA has been considered a monitored species with an OFL of 100,000 mt and ABC and ACL equal to 25,000 mt.

tab:hg_table

Model year	US Landings	OFL	ABC/ACL	Percentage ACL
1999	4,915	100,000	25,000	20
2000	24,363	100,000	25,000	97
2001	6,884	100,000	25,000	28
2002	3,617	100,000	25,000	14
2003	6,174	100,000	25,000	25
2004	8,096	100,000	25,000	32
2005	14,383	100,000	25,000	58
2006	14,437	100,000	25,000	58
2007	11,049	100,000	25,000	44
2008	9,120	100,000	25,000	36
2009	1,184	100,000	25,000	5
2010	3,604	100,000	25,000	14
2011	4,073	100,000	25,000	16
2012	787	100,000	25,000	3
2013	16,843	100,000	25,000	67
2014	9,191	100,000	25,000	37
2015	14,987	100,000	25,000	60
2016	3,971	100,000	25,000	16
2017	11,382	100,000	25,000	46
2018	15,069	100,000	25,000	60
2019	10,095	100,000	25,000	40
2020	3,688	100,000	25,000	15
2021	265	100,000	25,000	1

Table 5: Coefficient of variation (CV) and standard deviation (SD) at age estimated for CSNA from the AT survey (2015-2021) and fishery samples (2015-2021). Note, the assessment assumed a maximum age of 4, so ageing error values greater than 4 were not included in the assessment.

`tab:ageing_error`

	Years	N	N readers	Age	CV	SD
AT_Survey	2015-2016	397	3	0	0.56	0.56
				1	0.56	0.56
				2	0.70	1.40
				3	0.57	1.72
				4	0.46	1.83
				5	0.38	1.87
				6	0.32	1.89
AT_Survey	2017-2018	424	3	0	0.66	0.66
				1	0.66	0.66
				2	0.62	1.25
				3	0.49	1.46
				4	0.38	1.54
				5	0.31	1.57
				6	0.26	1.58
				7	0.23	1.58
				8	0.20	1.58
AT_Survey	2019-2021	450	2	0	0.65	0.65
				1	0.65	0.65
				2	0.65	1.30
				3	0.65	1.95
				4	0.65	2.60
				5	0.65	3.25
				6	0.65	3.90
				7	0.58	4.05
				8	0.51	4.10
				9	0.51	4.58
MexCal	2014-2016	763	3	0	0.45	0.45
				1	0.45	0.45
				2	0.24	0.48
				3	0.22	0.66
				4	0.44	1.75
				5***	1.66	8.28
				6***	7.88	47.25
MexCal	2017-2018	552	3	0	0.38	0.38
				1	0.38	0.38
				2	0.19	0.38
				3	0.13	0.38
				4	0.12	0.50
				5***	0.77	3.87
				6***	16.67	100.00
MexCal	2019-2021	617	3	0	0.39	0.39
				1	0.39	0.39
				2	0.19	0.39
				3	0.13	0.39
				4	0.10	0.42
				5***	1.53	7.64

Table 6: Fishery-independent indices of Northern anchovy abundance and associated uncertainties (CVs). From model year 2015 to 2018, AT nearshore values were calculated from model extrapolations. From 2019 on, AT nearshore values were from fishing vessel acoustic-trawl sampling. From model years 2015-2019, aerial methods had only one replicate per band. From 2019 on, aerial methods had two replicates per band. Note, that the model year-semester 2020-2 AT nearshore value is preliminary and has no calculated CV yet.

tab:atvals

Calendar Y-S	Model Y-S	Index	CV	AT Nearshore	ATN CV	Aerial	Aerial CV
2015-2	2015-1	10,528	0.42	7,180	0.28	0	-
2016-1	2015-2	-	-	-	-	-	-
2016-2	2016-1	150,907	0.51	274	0.53	1,077	0.51
2017-1	2016-2	173,973	0.33	-	-	4,263	0.51
2017-2	2017-1	153,460	0.45	45,446	0.3	75,338	0.35
2018-1	2017-2	-	-	-	-	293	0.28
2018-2	2018-1	723,826	0.17	4,110	0.56	69,998	0.71
2019-1	2018-2	-	-	-	-	653	0.49
2019-2	2019-1	769,154	0.14	41,480	0.34	61,607	0.54
2020-1	2019-2	-	-	-	-	0	-
2020-2	2020-1	-	-	-	-	42,824	1.53
2021-1	2020-2	1,358,587	0.17	70,000	-	-	-
2021-2	2021-1	-	-	-	-	1,839	0.08

Table 7: Comparison of Q ratios (AT index / (AT index + nearshore value)) from the AT nearshore and aerial survey.

tab:qratio

Calendar Y-S	Model Y-S	AT Index	AT Nearshore	AT Q ratio	Aerial	Aerial Q ratio
2016-2	2016-1	150,907	274	1.00	1,077	0.99
2017-2	2017-1	153,460	45,446	0.77	75,338	0.67
2018-2	2018-1	723,826	4,110	0.99	69,998	0.91
2019-2	2019-1	769,154	41,480	0.95	61,607	0.93

Table 8: Abundance by standard length (cm) for AT summer surveys 2015-2019 (column names indicate model year-semester).

tab:abund_at_length

SL (cm)	2015-1	2016-1	2017-1	2018-1	2019-1
2	250,619,407	0	0	0	0
3	1,292,317,502	0	0	0	0
4	1,475,141,089	201,057	1,491,102	0	0
5	657,205,955	1,809,517	5,258,743	0	0
6	1,873,943,383	10,171,636	14,313,025	0	1,327,146,647
7	321,597,788	10,213,614	5,807,935	41,096,412	17,037,319,882
8	269,580,402	119,689,413	329,109,882	965,545,771	23,764,446,374
9	213,665,089	830,060,821	1,818,405,723	7,001,913,071	14,505,847,274
10	69,196,363	3,087,640,798	872,893,159	10,175,229,266	5,558,883,914
11	21,648,640	6,446,239,518	234,063,154	7,951,612,854	7,235,447,927
12	3,988,222	1,170,748,671	2,631,008,139	10,226,207,789	7,346,805,051
13	44,299	151,476,699	2,905,452,584	7,288,001,624	5,349,671,276
14	0	2,535,570	106,004,589	2,956,678,550	2,587,963,418
15	0	136,428	105,824,824	22,580,864	272,519,042
16	0	0	0	0	9,350,727
17	0	0	0	0	0
18	0	0	0	0	0
19	0	0	0	0	0
20	0	0	0	0	0

Table 9: Abundance by age for AT summer surveys 2015-2019 (column names indicate model year-semester).

tab:abund_at_age

Age	2015-1	2016-1	2017-1	2018-1	2019-1
0.00	6,382,846,725	3,747,020,227	2,691,781,345	15,592,332,064	55,363,648,561
1.00	35,971,945	5,244,311,678	3,864,460,391	17,133,921,069	13,356,511,132
2.00	23,218,653	1,832,204,375	361,449,845	7,489,967,728	11,265,252,029
3.00	5,212,058	703,471,103	1,717,587,093	4,749,526,624	2,289,677,487
4.00	869,555	190,315,556	394,352,262	1,126,676,589	1,905,120,589
5.00	829,173	72,456,282	976	470,723,406	653,680,483
6.00	30	41,144,521	947	65,718,720	161,511,252

Table 10: Likelihood components, parameters, and biomass estimates.

tab:like_table

	Description	Value
Likelihood	TOTAL	17.49
	Catch	0.008
	Equil_catch	0
	Survey	-6.596
	Length_comp	0
	Age_comp	22.095
	Recruitment	1.953
	InitEQ_Regime	0
	Forecast_Recruitment	0
	Parm_priors	0
	Parm_softbounds	0.029
	Parm_devs	0
	Crash_Pen	0
Parameter	NatM_uniform_Fem_GP_1	0.567
	SR_LN(R0)	19.17
	SR_BH_steep	0.6
	SR_sigmaR	1
	SR_regime_BLK1repl_2014	-2.367
	InitF_seas_1_flt_1MexCal_S1	8.88
	LnQ_base_AT(3)	0
Biomass (mt)	2019 Age0+	922,905
	2019 Age1+	541,968
	2020 Age0+	1,554,480
	2020 Age1+	924,421

tab:par_table

Table 11: Parameter estimates in the 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
NatM_uniform_Fem_GP_1	0.5670	2	(0.2, 1)	OK	0.1654
SR_LN(R0)	19.1703	1	(3, 30)	OK	1.1002
SR_regime_BLK1repl_2014	-2.3674	4	(-15, 15)	OK	1.2529
Early_InitAge_4	0.0013	2	(-5, 5)	act	1.0006
Early_InitAge_3	0.3318	2	(-5, 5)	act	0.8920
Early_InitAge_2	-0.1950	2	(-5, 5)	act	0.8196
Early_InitAge_1	-1.8811	2	(-5, 5)	act	0.5200
Main_RecrDev_2015	-0.2205	1	(-5, 5)	act	0.4960
Main_RecrDev_2016	0.1166	1	(-5, 5)	act	0.3357
Main_RecrDev_2017	-0.2983	1	(-5, 5)	act	0.3918
Main_RecrDev_2018	0.1509	1	(-5, 5)	act	0.4257
Main_RecrDev_2019	0.2073	1	(-5, 5)	act	0.6938
Main_RecrDev_2020	0.0440	1	(-5, 5)	act	0.9075
ForeRecr_2021	0.0000	5	(-5, 5)	act	1.0000
InitF_seas_1_flt_1MexCal_S1	8.8802	1	(0, 100)	OK	4.5346
AgeSel_P2_MexCal_S1(1)	1.8449	2	(-5, 9)	OK	0.5814
AgeSel_P3_MexCal_S1(1)	-0.9110	2	(-5, 9)	OK	1.1986
AgeSel_P4_MexCal_S1(1)	1.8819	2	(-5, 9)	OK	1.0537
AgeSel_P5_MexCal_S1(1)	-0.6996	2	(-5, 9)	OK	1.4509
AgeSel_P2_MexCal_S2(2)	1.4574	2	(-5, 9)	OK	0.4211
AgeSel_P3_MexCal_S2(2)	0.6261	2	(-5, 9)	OK	1.1883
AgeSel_P4_MexCal_S2(2)	-0.9149	2	(-5, 9)	OK	5.4832
AgeSel_P5_MexCal_S2(2)	-0.6433	2	(-5, 9)	OK	2.2788
AgeSel_P2_AT(3)	0.0006	4	(0, 9)	LO	0.0232
AgeSel_P3_MexCal_S1(1)_BLK4repl_2016	-1.2029	2	(-5, 9)	OK	21.9039
AgeSel_P3_MexCal_S1(1)_BLK4repl_2017	1.4674	2	(-5, 9)	OK	0.9765
AgeSel_P3_MexCal_S1(1)_BLK4repl_2018	1.3215	2	(-5, 9)	OK	0.6549
AgeSel_P3_MexCal_S1(1)_BLK4repl_2019	1.5444	2	(-5, 9)	OK	0.6303
AgeSel_P3_MexCal_S1(1)_BLK4repl_2020	2.0052	2	(-5, 9)	OK	0.9052
AgeSel_P4_MexCal_S1(1)_BLK4repl_2016	1.0566	2	(-5, 9)	OK	24.1951
AgeSel_P4_MexCal_S1(1)_BLK4repl_2017	1.4702	2	(-5, 9)	OK	1.8958
AgeSel_P4_MexCal_S1(1)_BLK4repl_2018	-0.3675	2	(-5, 9)	OK	0.9676
AgeSel_P4_MexCal_S1(1)_BLK4repl_2019	0.7300	2	(-5, 9)	OK	0.9599
AgeSel_P4_MexCal_S1(1)_BLK4repl_2020	-0.7074	2	(-5, 9)	OK	1.1925
AgeSel_P3_MexCal_S2(2)_BLK5repl_2017	-1.4774	2	(-5, 9)	OK	1.6217
AgeSel_P3_MexCal_S2(2)_BLK5repl_2018	0.5092	2	(-5, 9)	OK	0.9711
AgeSel_P3_MexCal_S2(2)_BLK5repl_2019	0.5669	2	(-5, 9)	OK	0.7866
AgeSel_P3_MexCal_S2(2)_BLK5repl_2020	-4.2726	2	(-5, 9)	OK	17.3283
AgeSel_P4_MexCal_S2(2)_BLK5repl_2017	3.7228	2	(-5, 9)	OK	1.4819
AgeSel_P4_MexCal_S2(2)_BLK5repl_2018	-0.4736	2	(-5, 9)	OK	1.6110
AgeSel_P4_MexCal_S2(2)_BLK5repl_2019	0.0969	2	(-5, 9)	OK	1.7847
AgeSel_P4_MexCal_S2(2)_BLK5repl_2020	2.9944	2	(-5, 9)	OK	18.2989
AgeSel_P2_AT(3)_BLK3repl_2016	1.6735	4	(0, 9)	OK	1.2616
AgeSel_P2_AT(3)_BLK3repl_2017	1.8177	4	(0, 9)	OK	2.8800
AgeSel_P2_AT(3)_BLK3repl_2018	0.0020	4	(0, 9)	LO	0.0664
AgeSel_P2_AT(3)_BLK3repl_2019	0.0002	4	(0, 9)	LO	0.0104
AgeSel_P2_AT(3)_BLK3repl_2020	0.9051	4	(0, 9)	OK	1.1957

tab:numbers_table
Table 12: Northern anchovy numbers-at-age (thousands of fish) estimated in base model year-semesters.

Calendar Y-S	Model Y-S	Age 0	Age 1	Age 2	Age 3	Age 4+
–	VIRG	211,625,000	120,043,000	68,093,400	38,625,500	50,628,800
–	VIRG	152,031,000	86,238,600	48,918,200	27,748,500	36,371,700
–	INIT	19,833,700	8,251,120	658,007	169,575	566
–	INIT	10,449,800	833,350	214,763	686	31
2015-2	2015-1	19,833,700	932,323	445,047	215,347	566
2016-1	2015-2	12,391,200	276,777	224,095	15,002	128
2016-2	2016-1	15,372,700	9,387,750	182,988	126,946	10,464
2017-1	2016-2	10,957,000	6,415,820	129,503	87,349	7,358
2017-2	2017-1	36,175,400	8,520,450	4,744,340	90,452	71,326
2018-1	2017-2	25,897,700	5,987,320	3,096,820	42,827	41,654
2018-2	2018-1	39,164,500	19,691,600	4,020,400	2,356,460	22,037
2019-1	2018-2	27,891,000	13,385,900	2,347,800	1,466,640	14,743
2019-2	2019-1	75,170,400	21,663,200	9,848,280	1,648,170	1,087,490
2020-1	2019-2	53,866,900	15,317,600	6,567,680	1,014,640	723,570
2020-2	2020-1	124,329,000	42,108,400	11,584,600	4,806,500	1,283,590
2021-1	2020-2	89,189,500	29,976,400	7,778,250	3,339,790	906,986

tab:biomass_table
Table 13: Northern anchovy biomass at age for base model year-semesters.

Calendar Y-S	Model Y-S	0	1	2	3	4	Total Age0+	Total Age1+
–	VIRG	328,960	1,241,210	842,946	550,542	755,681	3,719,339	3,390,379
–	VIRG	2,227,070	1,530,540	1,019,080	629,603	880,890	6,287,183	4,060,113
–	INIT	30,830	85,314	8,146	2,417	8	126,716	95,885
–	INIT	153,077	14,790	4,474	16	1	172,357	19,280
2015-2	2015-1	30,830	9,640	5,509	3,069	8	49,057	18,227
2016-1	2015-2	181,515	4,912	4,668	340	3	191,439	9,924
2016-2	2016-1	165,565	125,160	2,725	2,012	170	295,632	130,067
2017-1	2016-2	204,901	125,422	2,622	1,796	152	334,894	129,993
2017-2	2017-1	291,517	169,767	102,786	1,992	1,594	567,655	276,138
2018-1	2017-2	484,300	117,046	62,709	881	861	665,797	181,497
2018-2	2018-1	364,293	313,248	83,257	55,760	558	817,116	452,823
2019-1	2018-2	521,576	261,679	47,542	30,163	305	861,264	339,688
2019-2	2019-1	380,937	287,064	190,078	38,208	26,617	922,904	541,967
2020-1	2019-2	1,007,340	299,442	132,992	20,867	14,952	1,475,593	468,253
2020-2	2020-1	630,058	557,989	223,591	111,425	31,417	1,554,480	924,422
2021-1	2020-2	945,145	478,021	166,572	82,872	25,191	1,697,800	752,655

Table 14: 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 (June).

tab:ssb_table

Calendar Y-S	Model Y-S	SSB	SSB sd	Recruits	Recruits sd
–	VIRG-1	0	0	0	0
–	VIRG-2	5,553,680	7,247,540	211,625,000	232,827,000
–	INIT-1	0	0	0	0
–	INIT-2	129,335	45,166	0	0
2015-2	2015-1	0	0	19,833,700	5,951,270
2016-1	2015-2	141,309	39,410	0	0
2016-2	2016-1	0	0	15,372,700	8,139,350
2017-1	2016-2	270,014	70,078	0	0
2017-2	2017-1	0	0	36,175,400	11,449,800
2018-1	2017-2	524,094	97,461	0	0
2018-2	2018-1	0	0	39,164,500	10,782,700
2019-1	2018-2	699,442	82,838	0	0
2019-2	2019-1	0	0	75,170,400	27,986,500
2020-1	2019-2	1,176,860	242,035	0	0
2020-2	2020-1	0	0	124,329,000	127,334,000
2021-1	2020-2	1,403,030	791,611	0	0
2021-2	2021-1	0	0	0	0
2022-1	2021-2	1,979,160	1,750,030	0	0

Table 15: Annual exploitation rate (calendar year landings / June total biomass) by country and calendar year.

tab:hrate_table

Calendar Year	Mexico	USA	Total
2015	0.52	0.20	0.73
2016	0.01	0.02	0.03
2017	0.02	0.01	0.02
2018	0.03	0.01	0.04
2019	0.02	0.01	0.03
2020	0.01	0.00	0.02
2021	0.01	0.00	0.01

tab:steeptable

Table 16: Parameter estimates and total biomass (age 0+; mt) associated with fixed values of steepness (h). The model with h=0.5 had a lower likelihood than the base (h=0.6), but the R0 value is higher and results in large biomass estimates.

	Steepness							
Label	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
InitF_seas_1_flt_1MexCal_S1	4.016	9.666	8.055	8.025	8.048	8.971	9.085	9.192
LnQ_base_AT(3)	0	0	0	0	0	0	0	0
NatM_uniform_Fem_GP_1	0.856	0.694	0.585	0.567	0.569	0.576	0.586	0.598
SR_LN(R0)	29.994	29.997	29.826	19.171	18.558	18.258	18.077	17.957
2019 Age0+ biomass	961,861	923,897	932,172	922,979	914,226	907,029	901,177	896,746
2020 Age0+ biomass	1,140,070	1,289,700	1,701,850	1,555,350	1,423,390	1,332,120	1,264,090	1,212,370
Total NLL	22.176	18.21	17.465	17.532	17.662	17.794	17.989	18.172

tab:Qtable

Table 17: Parameter estimates and total biomass (age 0+; mt) associated with fixed values of log catchability (Q).

	Catchability						
Label	-0.3	-0.2	-0.1	0	0.1	0.2	0.3
InitF_seas_1_flt_1MexCal_S1	10.296	10.464	9.617	8.025	8.174	6.772	6.903
NatM_uniform_Fem_GP_1	0.603	0.591	0.579	0.567	0.555	0.542	0.529
SR_BH_steep	0.6	0.6	0.6	0.6	0.6	0.6	0.6
SR_LN(R0)	19.395	19.315	19.24	19.171	19.107	19.054	19.009
2019 Age0+ biomass	1,262,070	1,137,160	1,024,730	922,979	831,233	748,670	673,909
2020 Age0+ biomass	2,115,040	1,907,690	1,723,530	1,555,350	1,403,910	1,270,240	1,146,690
Total NLL	16.722	16.928	17.188	17.532	17.809	18.189	18.522

tab:Mtable_Fixedh

Table 18: Parameter estimates and total biomass (age 0+; mt) associated with fixed values of natural mortality (M) and fixed steepness (h=0.6).

	Natural Mortality						
Label	0.3	0.4	0.5	0.6	0.7	0.8	0.9
InitF_seas_1_flt_1MexCal_S1	8.663	8.988	8.94	8.82	8.561	8.204	7.169
LnQ_base_AT(3)	0	0	0	0	0	0	0
SR_BH_steep	0.6	0.6	0.6	0.6	0.6	0.6	0.6
SR_LN(R0)	29.996	20.829	19.423	19.097	18.982	18.955	18.955
2019 Age0+ biomass	843,398	886,351	908,187	930,349	956,658	986,618	1,016,470
2020 Age0+ biomass	1,389,060	1,655,680	1,586,500	1,542,890	1,517,390	1,499,300	1,493,920
Total NLL	19.292	18.043	17.565	17.509	17.776	18.303	19.088

tab:Mtable_esth

Table 19: Parameter estimates and total biomass (age 0+; mt) associated with fixed values of natural mortality (M) and estimated steepness. Note, that the base model estimates M and fixed steepness at 0.6

	Natural Mortality						
Label	0.3	0.4	0.5	0.6	0.7	0.8	0.9
InitF_seas_1_flt_1MexCal_S1	8.061	8.128	8.094	8.807	7.724	7.397	7.104
LnQ_base_AT(3)	0	0	0	0	0	0	0
SR_BH_steep	0.649	0.586	0.538	0.5	0.475	0.473	0.466
SR_LN(R0)	29.805	29.885	29.64	29.747	21.682	20.28	19.954
2019 Age0+ biomass	862,414	886,595	912,351	939,073	967,476	998,531	1,029,080
2020 Age0+ biomass	1,646,370	1,679,960	1,714,760	1,747,750	1,755,550	1,706,400	1,683,600
Total NLL	19.03	18.072	17.568	17.43	17.75	18.272	19.024

tab:francistable

Table 20: Parameter estimates and total biomass (age 0+; mt) associated Francis reweighting of the age compositions.

Label	Base	MexCal S1	MexCal S2	AT Survey
Variance adjustment	none	2.92	2.98	0.48
InitF_seas_1_flt_1MexCal_S1	8.88	5.952	9.365	12.028
LnQ_base_AT(3)	0	0	0	0
NatM_uniform_Fem_GP_1	0.567	0.611	0.535	0.495
SR_BH_steep	0.6	0.6	0.6	0.6
SR_LN(R0)	19.17	18.805	19.4	19.159
2019 Age0+ biomass	922,905	888,470	861,177	852,371
2020 Age0+ biomass	1,554,480	1,187,680	1,679,130	1,318,250
Total NLL	17.490	26.873	21.240	12.989

tab:lamtable

Table 21: Parameter estimates and total biomass (age 0+; mt) associated with downweighting age compositions in the likelihood calculation. Lambda values were 1 in the base model, and 0.5 in each of the fleet sensitivities shown here.

Label	Base	MexCal S1	MexCal S2	AT Survey
Agecomp lambda	1	0.5	0.5	0.5
InitF_seas_1_flt_1MexCal_S1	8.88	10.466	7.166	8.15
LnQ_base_AT(3)	0	0	0	0
NatM_uniform_Fem_GP_1	0.567	0.554	0.591	0.521
SR_BH_steep	0.6	0.6	0.6	0.6
SR_LN(R0)	19.17	19.373	19.062	19.056
2019 Age0+ biomass	922,905	932,612	962,046	831,120
2020 Age0+ biomass	1,554,480	1,727,960	1,517,500	1,230,640
Total NLL	17.490	14.545	15.847	9.970

Table 22: Parameter estimates from the base model (2015-2020) and longer model with RREAS index of abundance. Both models had a fixed lnQ of 0 and fixed steepness of 0.6.

tab:lpars

Label	Base	RREAS
NatM_uniform_Fem_GP_1	0.57	0.82
SR_LN(R0)	19.17	16.75
SR_BH_steep	0.60	0.60
InitF_seas_1_flt_1MexCal_S1	8.88	2.06

812 # 8 Figures

figures

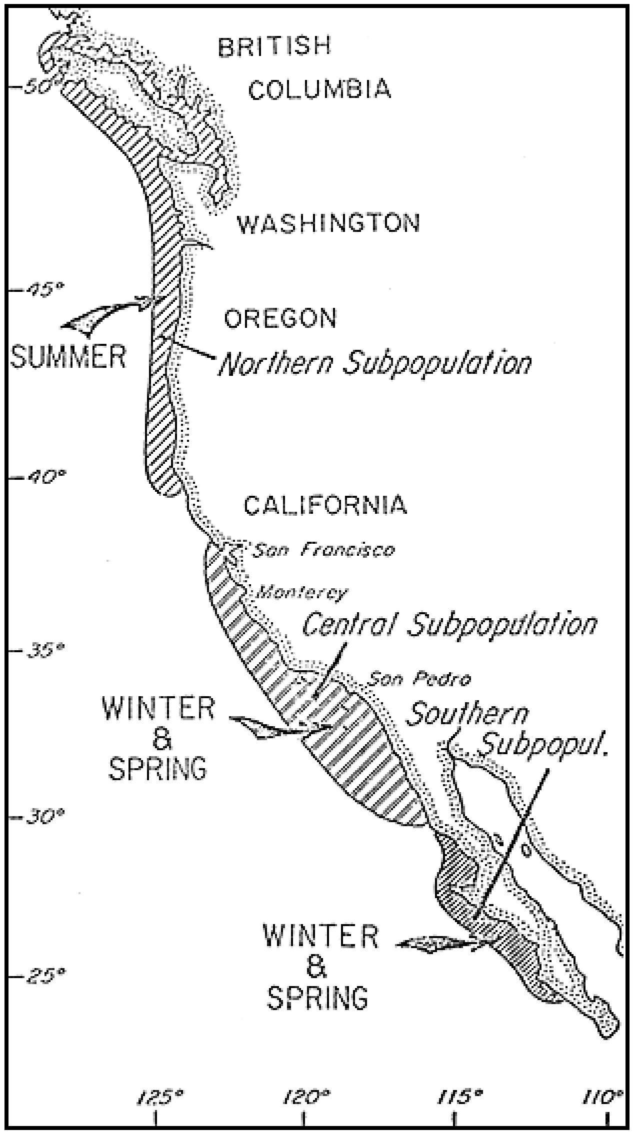

Figure 1: Map showing distribution of the three purported northern anchovy subpopulations.
fig:anchovy_map

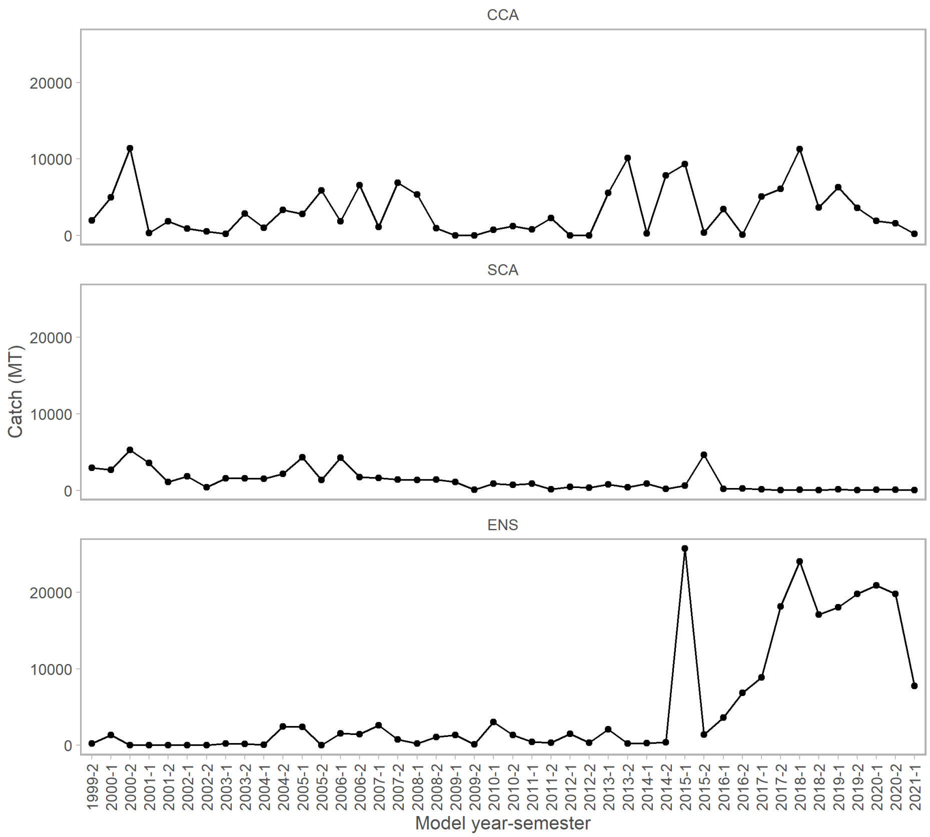

Figure 2: Northern anchovy landings (mt) by major fishing region (Central California, Southern California, and Ensenada, Mexico). fig:regional_landings

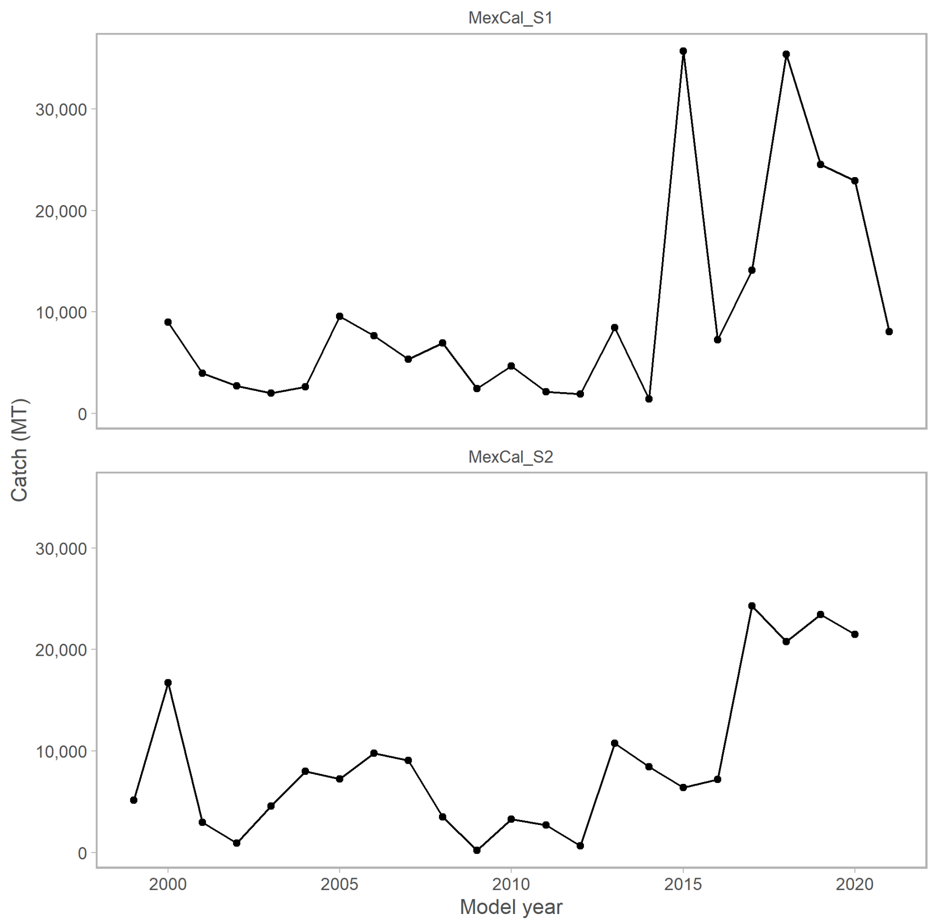

Figure 3: Northern anchovy landings (mt) by fleet (MexCal_S1 and MexCal_S2) used as input in the stock assessment model . fig:fleet_landings

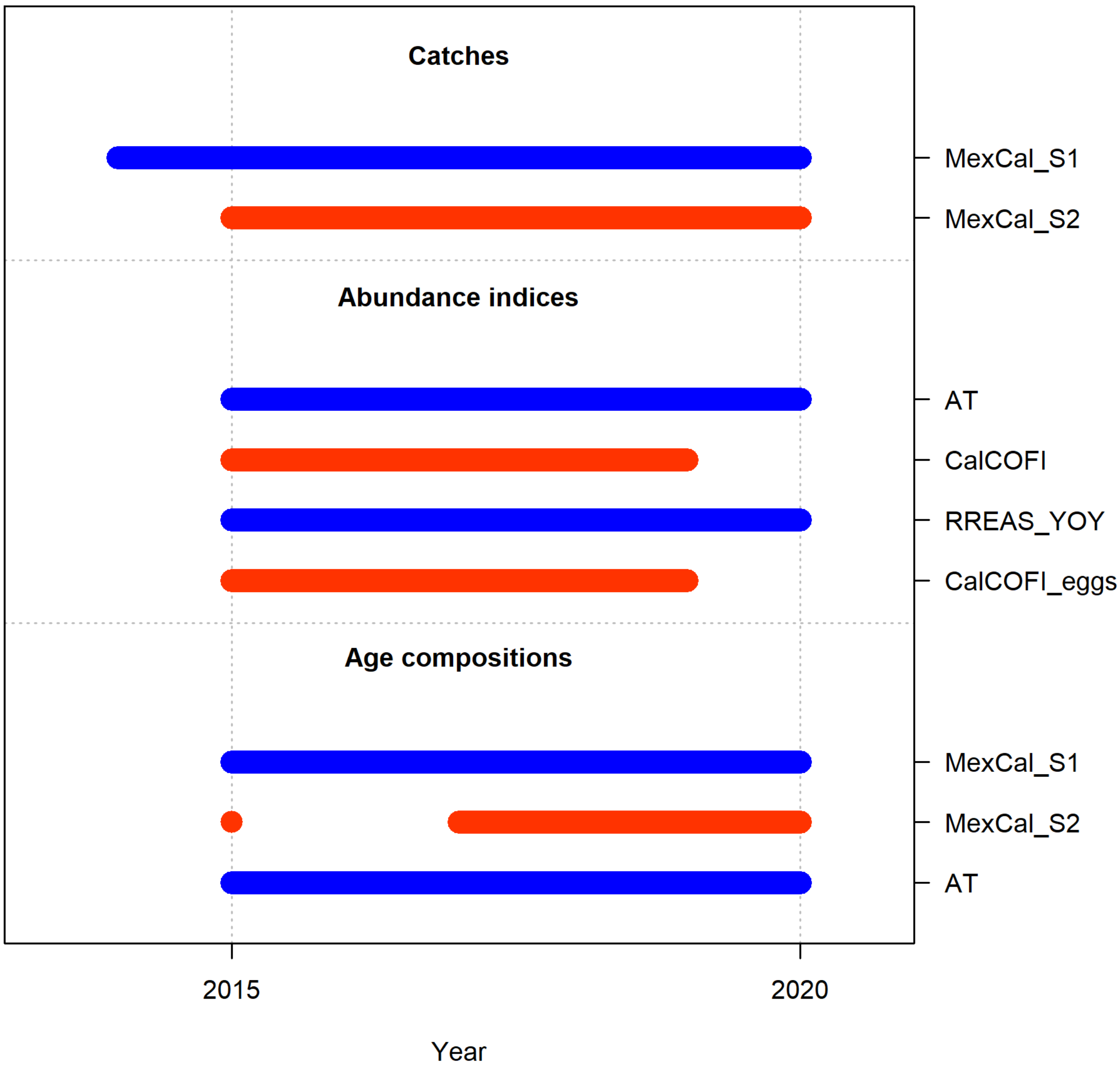

Figure 4: Summary of data sources used in the base model. fig:assessment_data

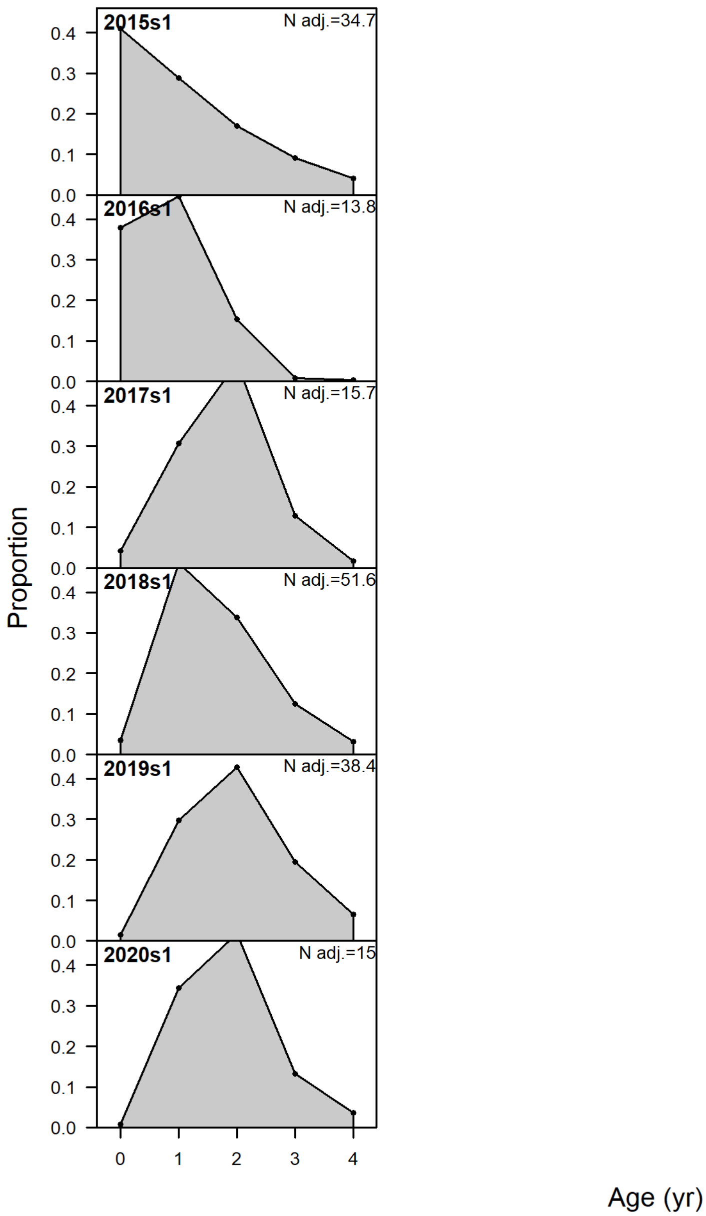

Figure 5: Age composition data for the fishing fleet MexCal_S1. The input sample sizes (number of fish/25) are shown in the top right of each panel. fig:acomp1

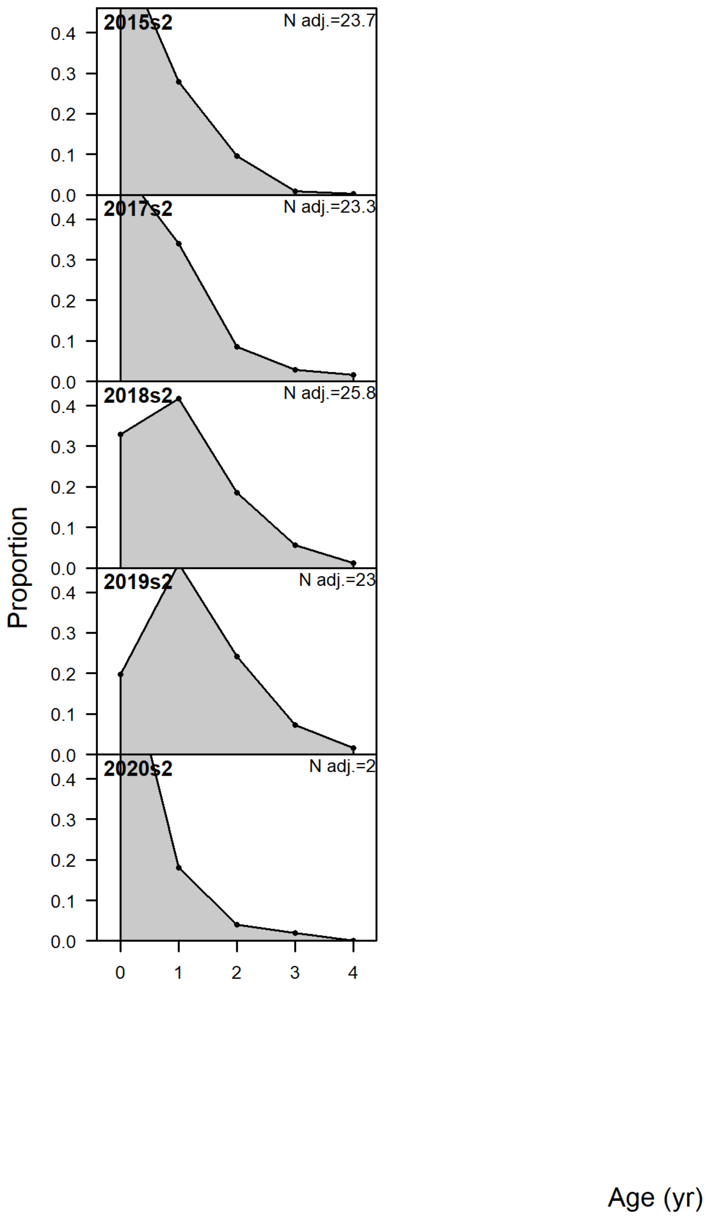

Figure 6: Age composition data for the fishing fleet MexCal S2. The input sample sizes (number of fish/25) are shown in the top right of each panel. fig:acomp2

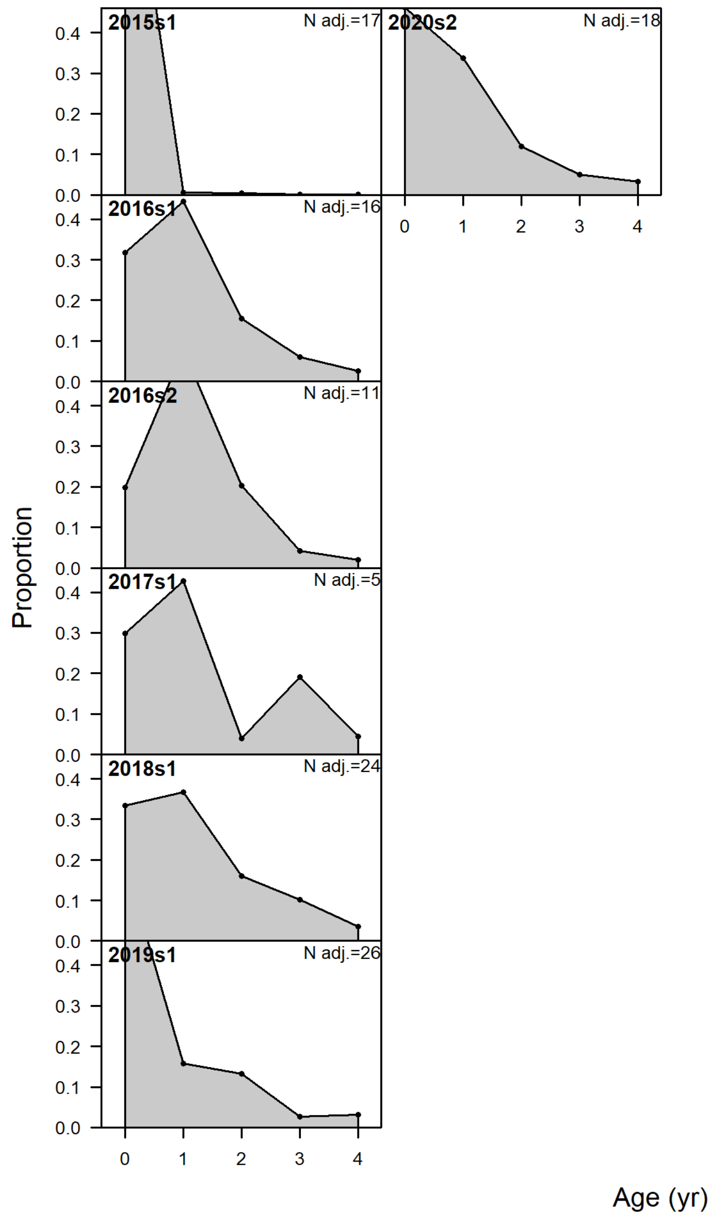

Figure 7: Age composition data for the AT survey. The input sample sizes (number of positive clusters) are shown in the top right of each panel. fig:acomp3

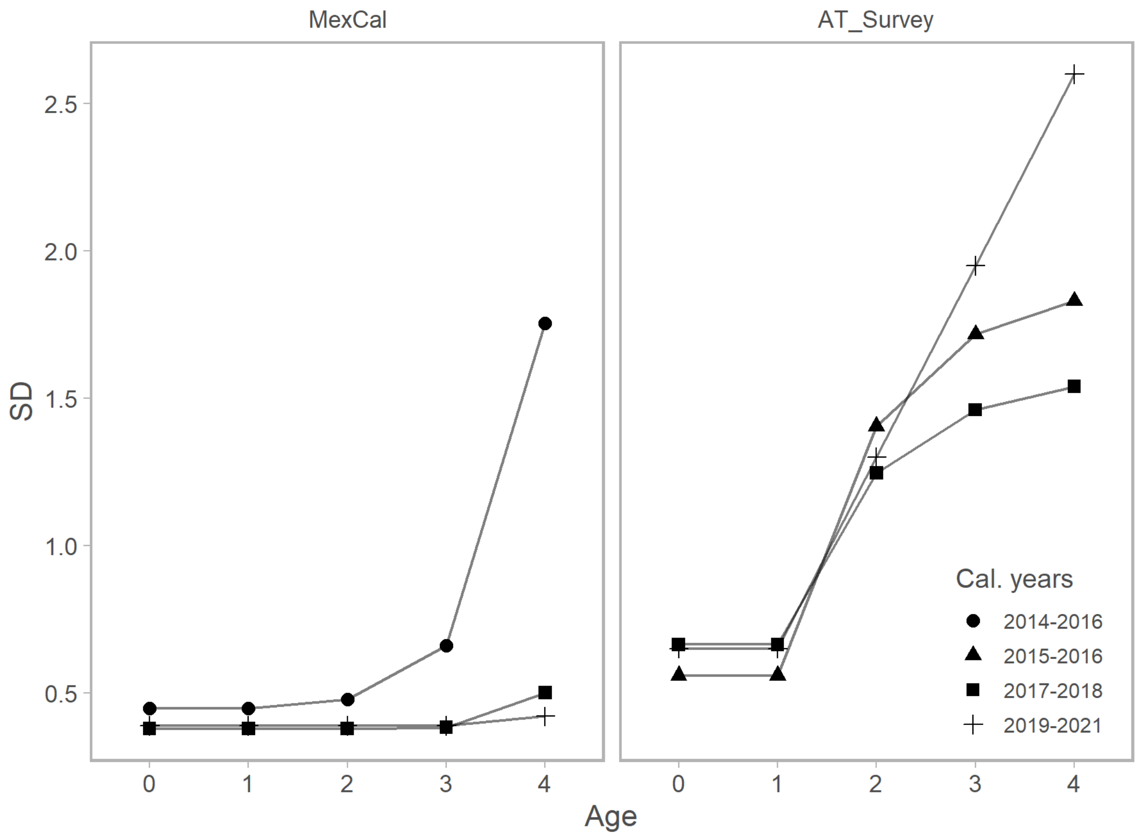

Figure 8: Ageing errors estimated for the MexCal fleets (aged by CDFW) and AT_Survey fleet (aged by CDFW and SWFSC). fig:ageing_error

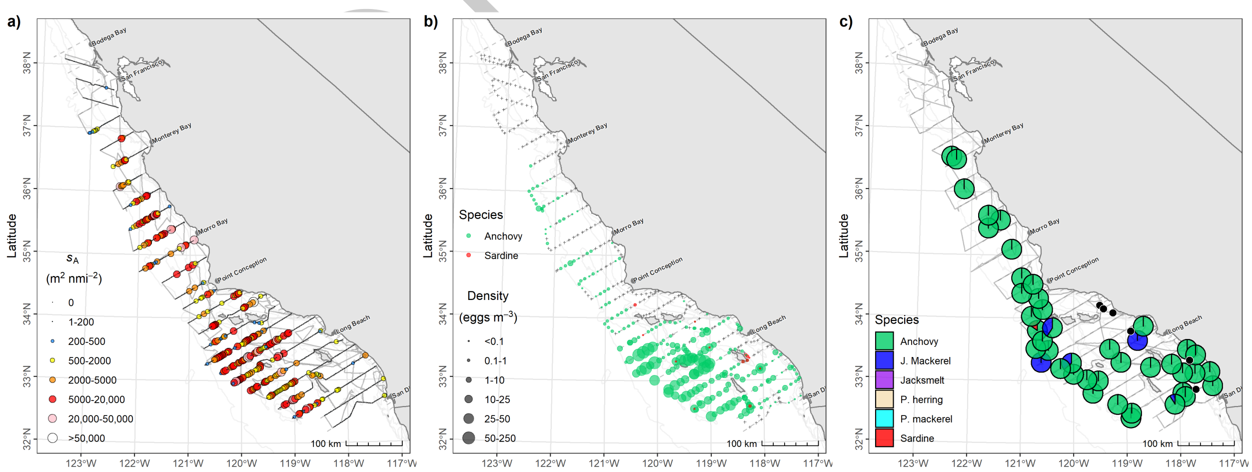

Figure 9: Results from the 2019 AT summer survey (Stierhoff et al. 2020). A map of the: a) distribution of 38-kHz integrated backscattering coefficients (s_a, m^2nmi^-2; averaged over 2000m distance intervals) ascribed to CPS; b) CUFES egg density (eggs m^-3) for anchovy and sardine; and c) proportions of CPS species in trawls (black points indicate trawls with no CPS). fig:at2019

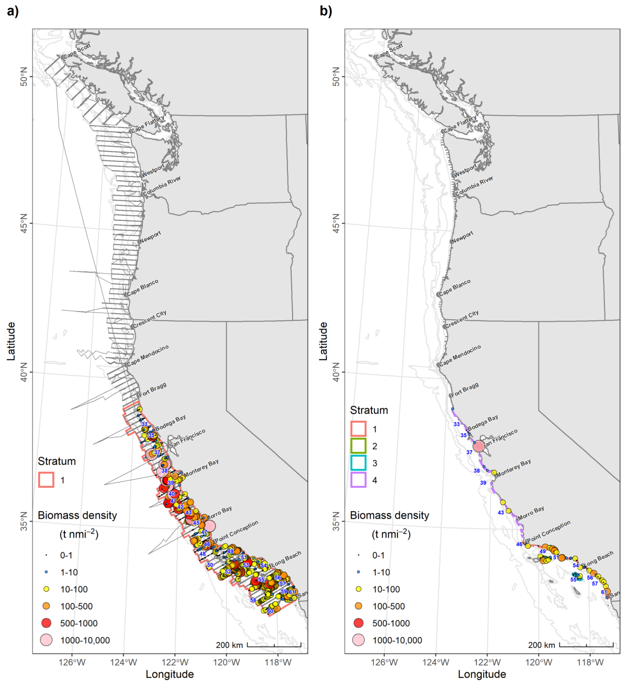

Figure 10: Biomass densities of northern anchovy, central stock, per stratum throughout the summer 2019 AT survey region from the Lasker and Long Beach Carnage. Blue numbers represent locations of positive sardine trawl clusters. Gray lines represent the vessel track. Stratum numbers for Pacific sardine begin at 2 (stratum 1 was south of Pt. Conception and assigned to the southern stock of Pacific sardine based on sea surface temperature). fig:anchovy_biomass

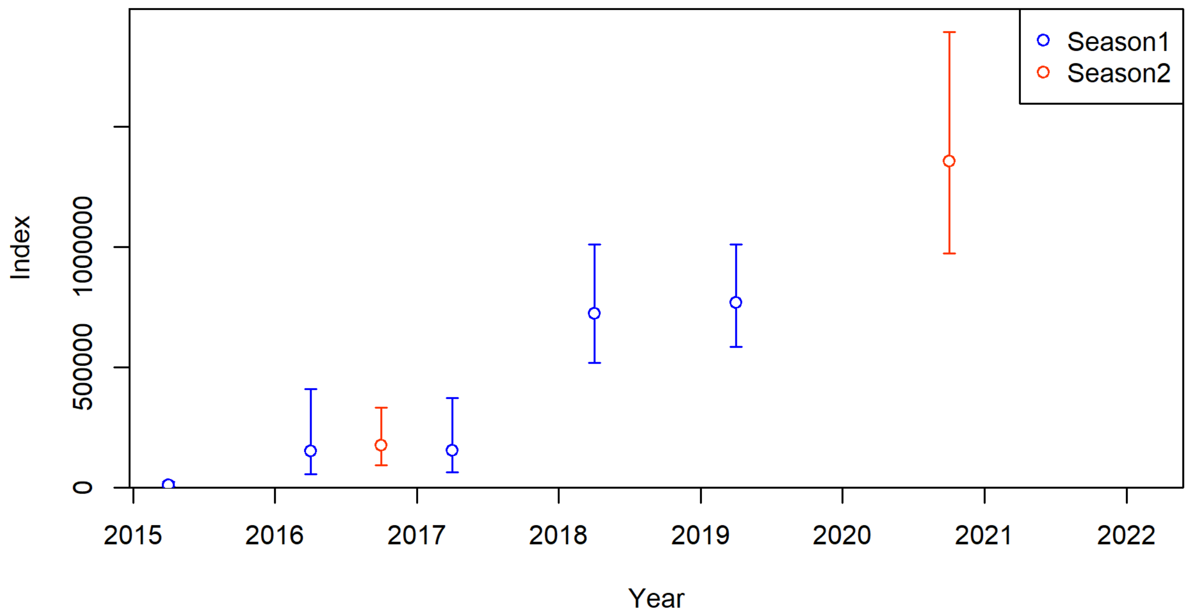

Figure 11: Observations of northern anchovy biomass (age 0+, mt) from summer (semester 1) and spring (semester 2) AT surveys from 2015-2020 (with 95% CI assuming lognormal error). Note that years shown are model years. Semester 1 model years are the same as calendar year. Semester 2 model years are calendar year - 1. fig:atindex

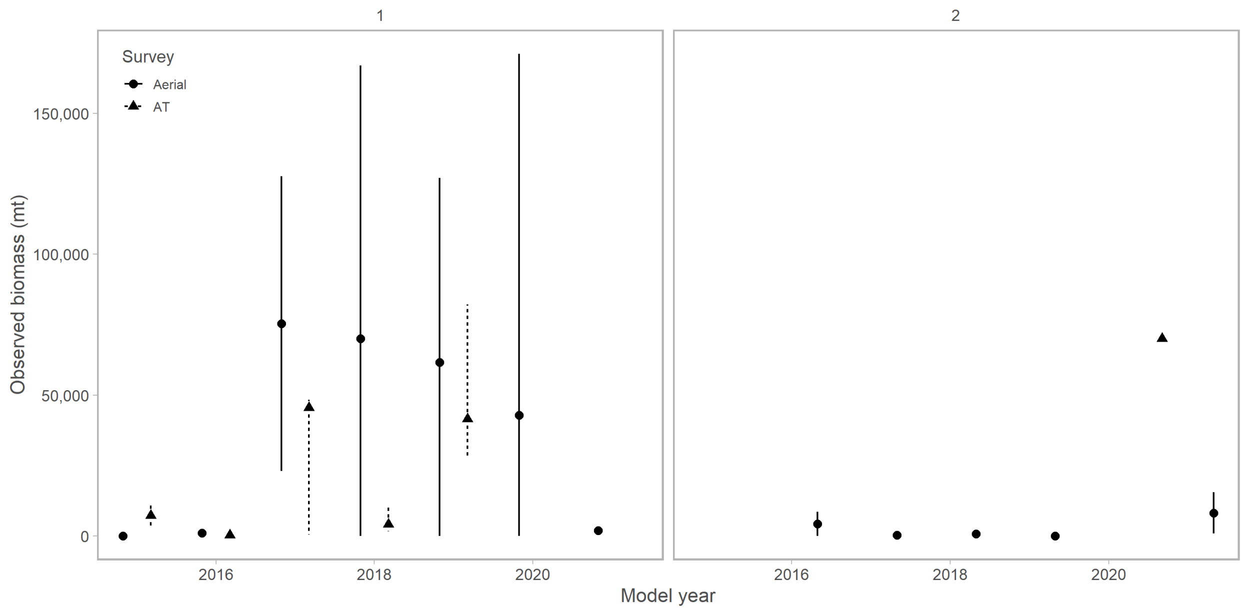

Figure 12: Nearshore biomass estimates from CDFW aerial surveys (circles) and AT methods (triangles) arranged by semester (1-June to December; 2-January to May). Aerial methods from 2015 to 2019 had one replicate the inner and one replicate for the outer band. From 2020 on, the aerial survey conducted two replicates per band. AT nearshore values were calculated from model extrapolation for 2015-2018, and later surveys observed nearshore biomass with AT methods on fishing vessels. Note, that the 2020-2 (model year-semester) value is preliminary and has no calculated CV yet. [fig:nearshore_nocore

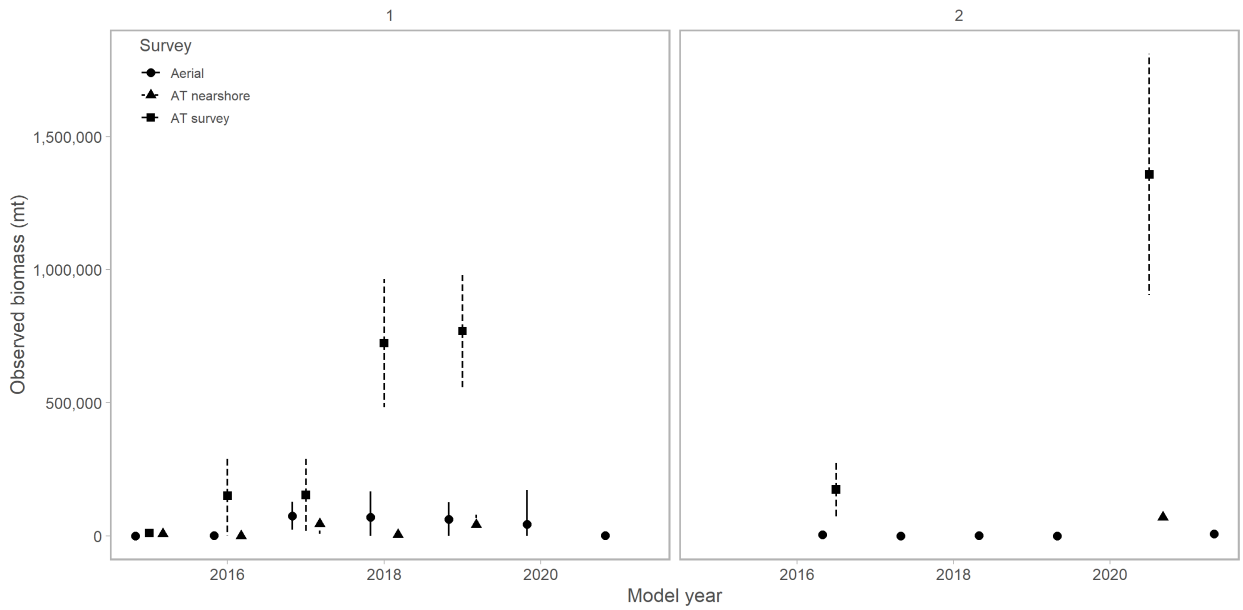

Figure 13: Nearshore biomass estimates from CDFW aerial surveys (circles) and AT methods (nearshore - triangles and core survey - squares) arranged by semester (1-June to December; 2-January to May). This plot contains the AT survey values from the core survey area resulting in a different scale on the y-axis. Aerial methods from 2015 to 2019 had one replicate the inner and one replicate for the outer band. From 2020 on, the aerial survey conducted two replicates per band. AT nearshore values were calculated from model extrapolation for 2015-2018, and later surveys observed nearshore biomass with AT methods on fishing vessels. Note, that the 2020-2 (model year-semester) value is preliminary and has no calculated CV yet. fig:nearshore_core

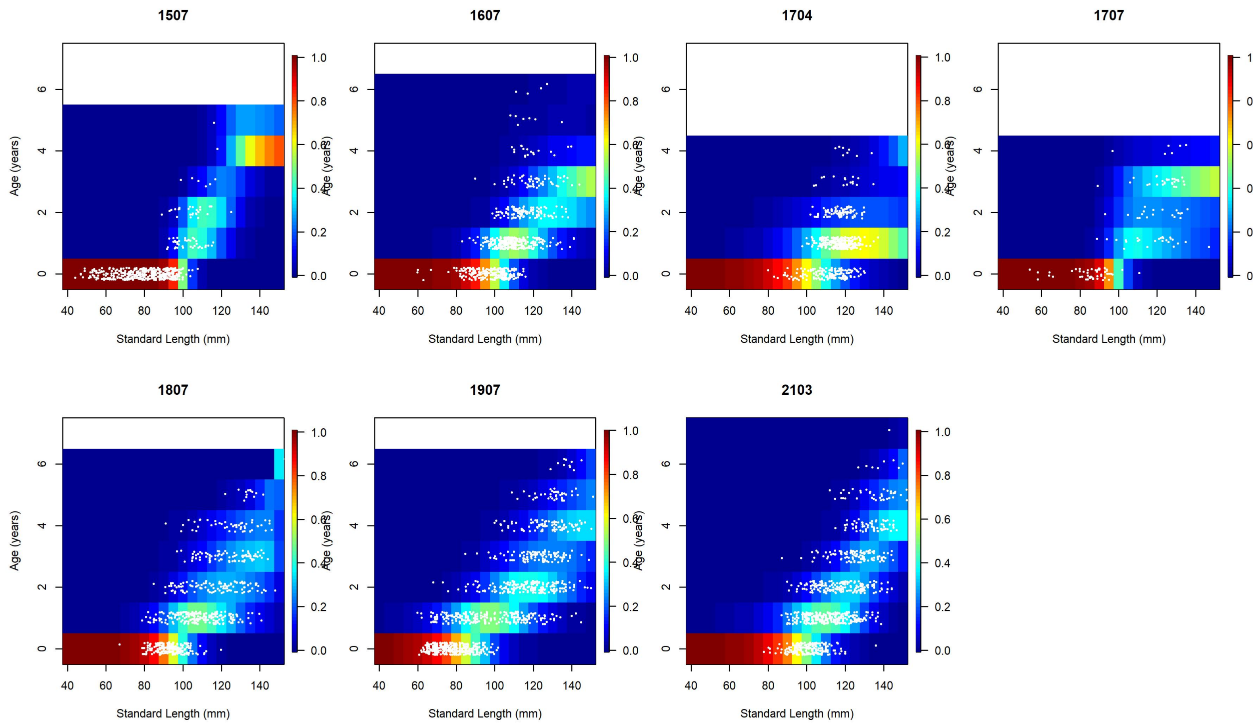

Figure 14: Cruise-specific age-length keys derived from acoustic-trawl survey trawl samples from summer 2015 to spring 2021. fig:al_key

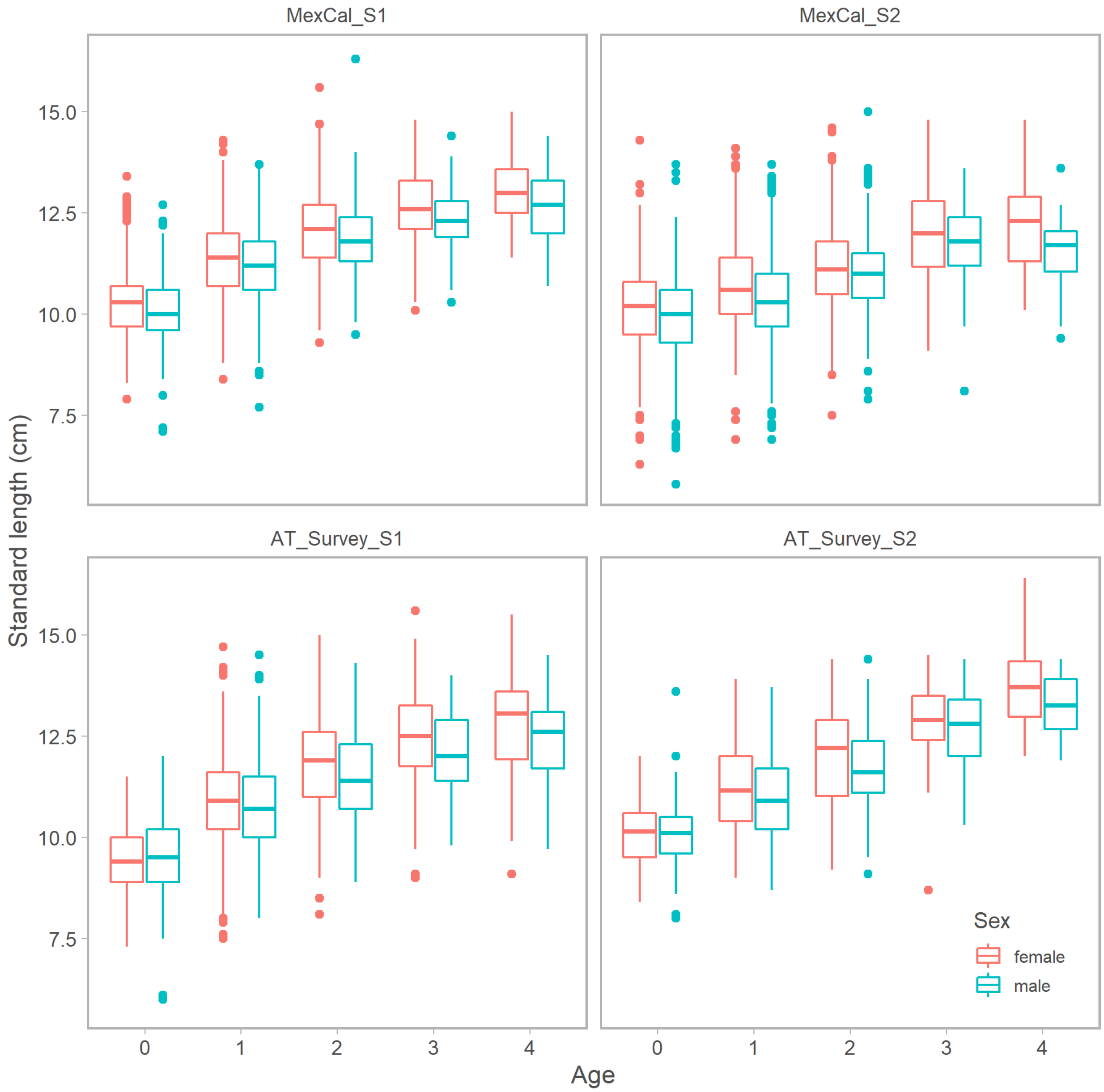

Figure 15: Length-at-age by sex, grouped by fleet, showing lack of sexually dimorphic growth. Boxes indicate the median and 25-75 percentiles of the data. fig:sex_growth

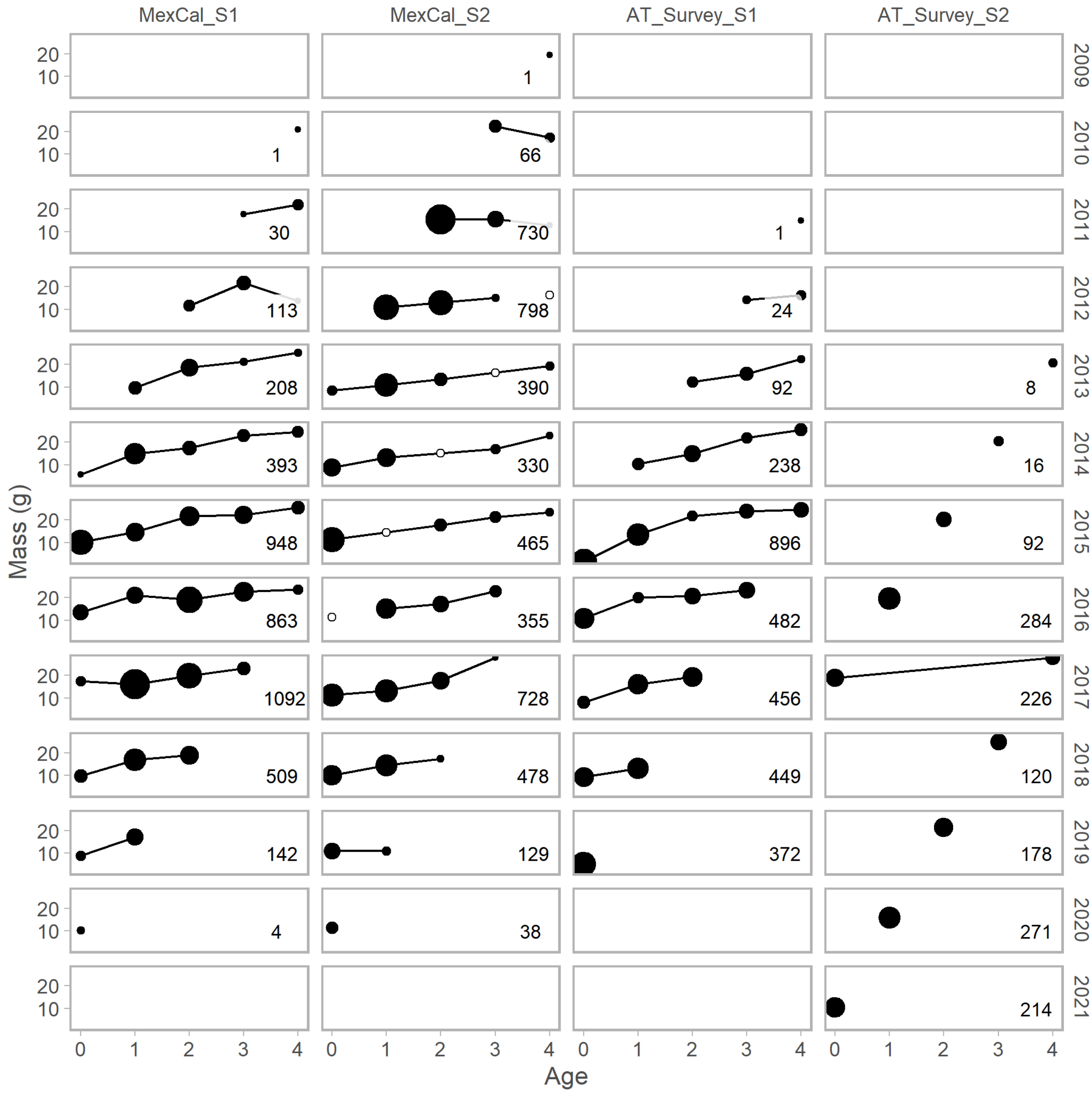

Figure 16: Weight-at-age values for anchovy arranged by fleet (columns) and cohort model year (rows). Numbers of fish are shown in the bottom right of each panel. The AT_Survey values are plotted as separate columns, but are part of the same fleet in the model. In the MexCal_S2 column, open points show the values interpolated for each cohort. fig:ewaa_samplesizes

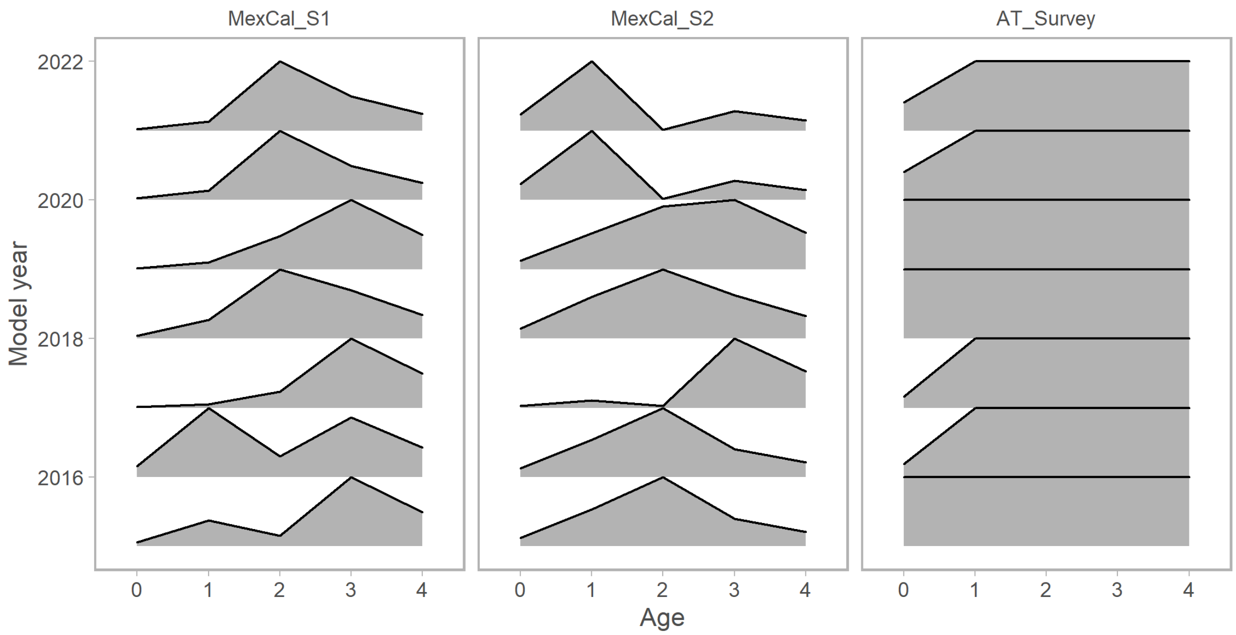

Figure 17: Time-varying age-based selectivity patterns for the MexCal_S1 and MexCal_S2 fishing fleets and AT survey. fig:aselex

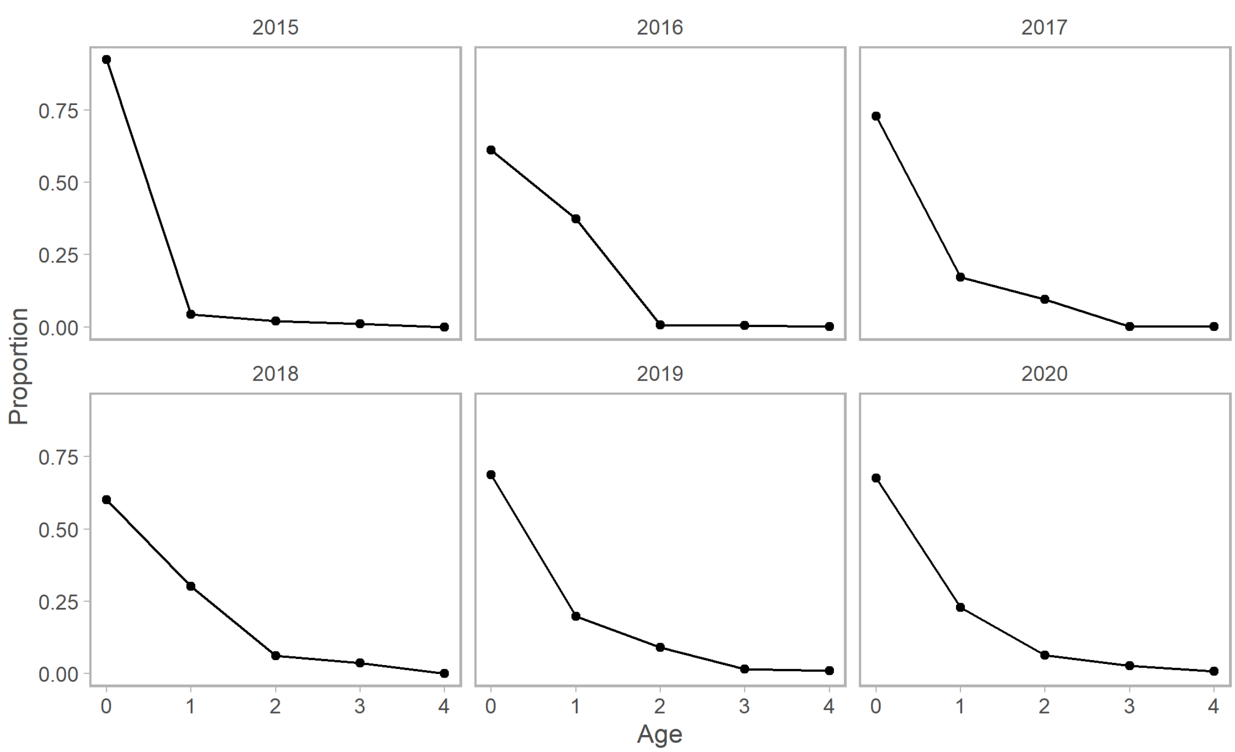

Figure 18: Population numbers at age from the base model. More than 50% of the population is age0 fish in each year. fig:natage

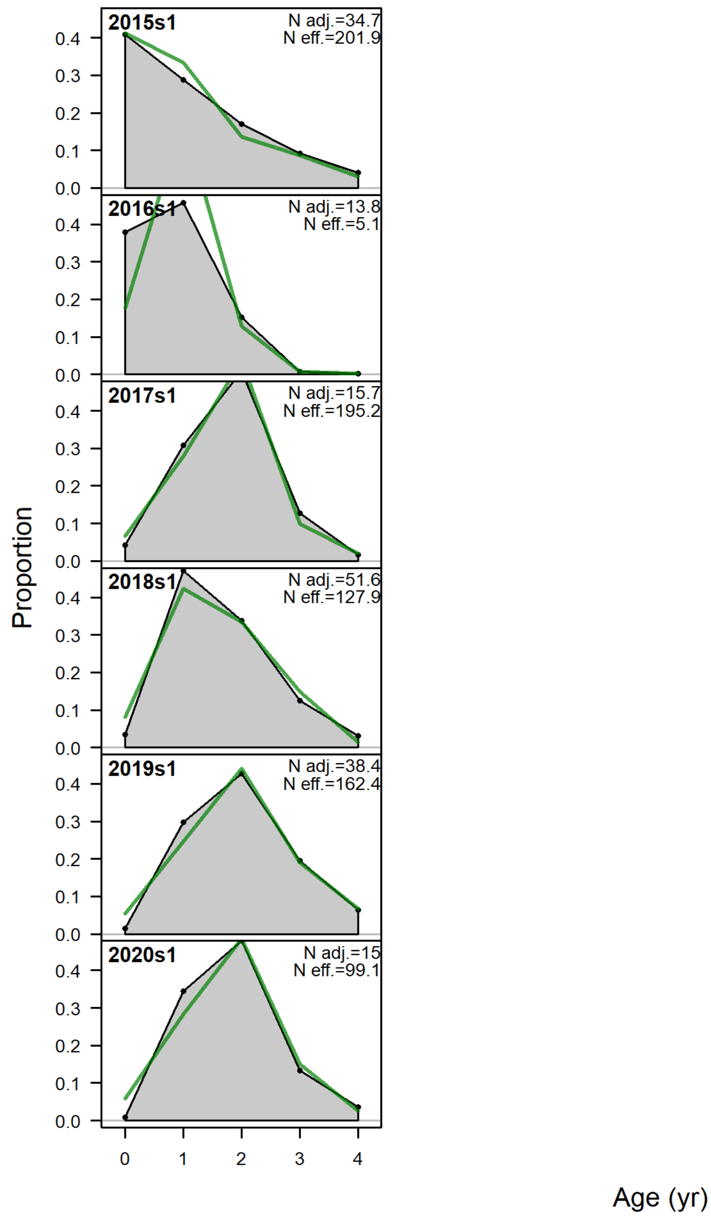

Figure 19: Fit to age-composition time series for the MexCal_S1 fleet in the base model. Values in the top right are input sample sizes (N adj) and effective sample size given statstical fit in the model (N eff). fig:acomp_fit1

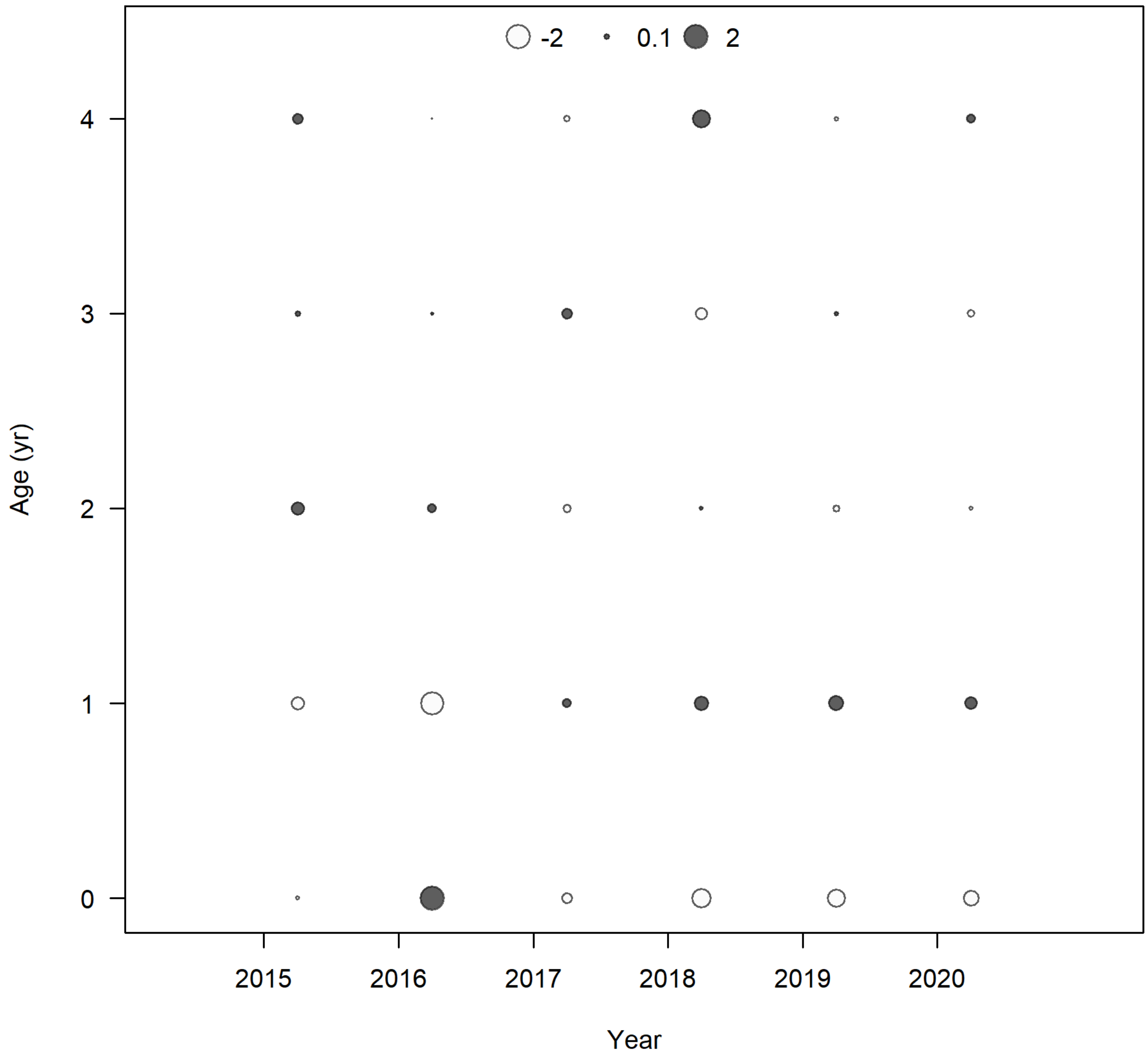

Figure 20: Residuals of fit to age-composition time series for the MexCal_S1 fleet in base model. fig:acomp_resid1

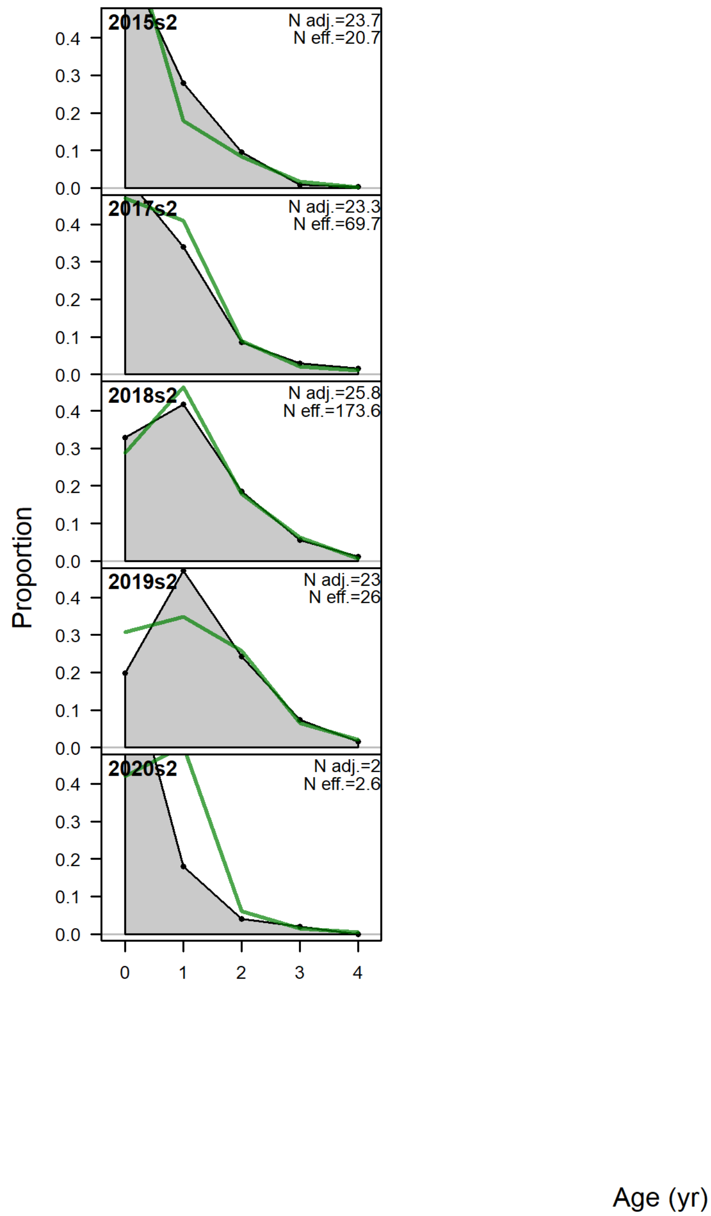

Figure 21: Fit to age-composition time series for the MexCal_S2 fleet in the base model. Values in the top right are input sample sizes (N adj) and effective sample size given statstical fit in the model (N eff). fig:acomp_fit2

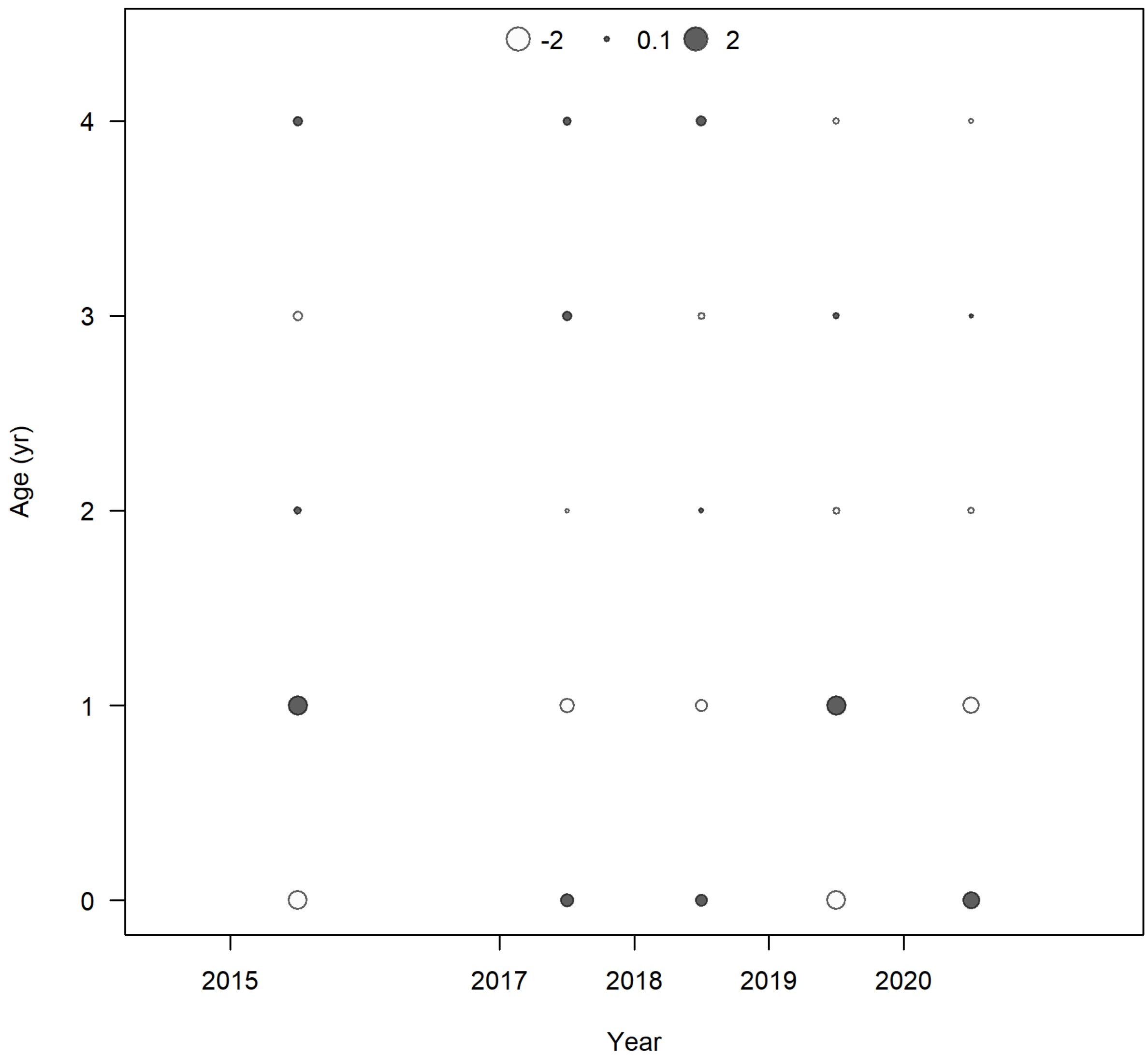

Figure 22: Residuals of fit to age-composition time series for the MexCal_S2 fleet in base model. fig:acomp_resid2

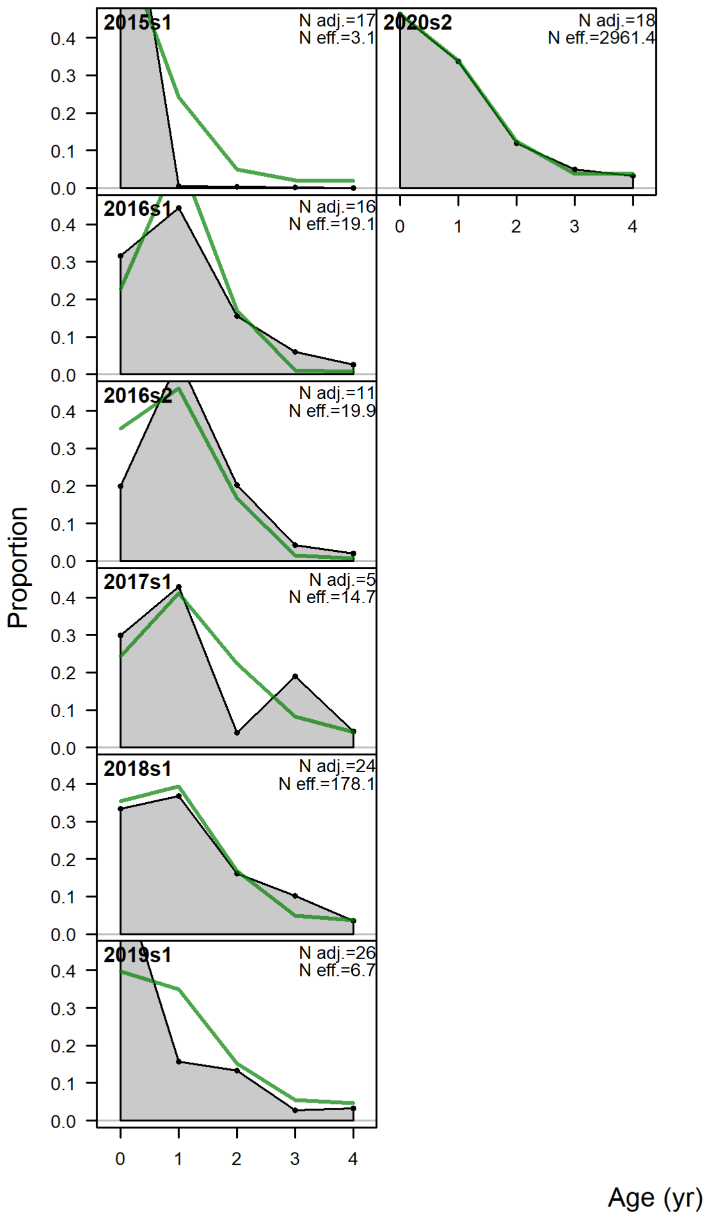

Figure 23: Fit to age-composition time series for the AT survey in the base model. Values in the top right are input sample sizes (N adj) and effective sample size given statstical fit in the model (N eff). fig:acomp_fit3

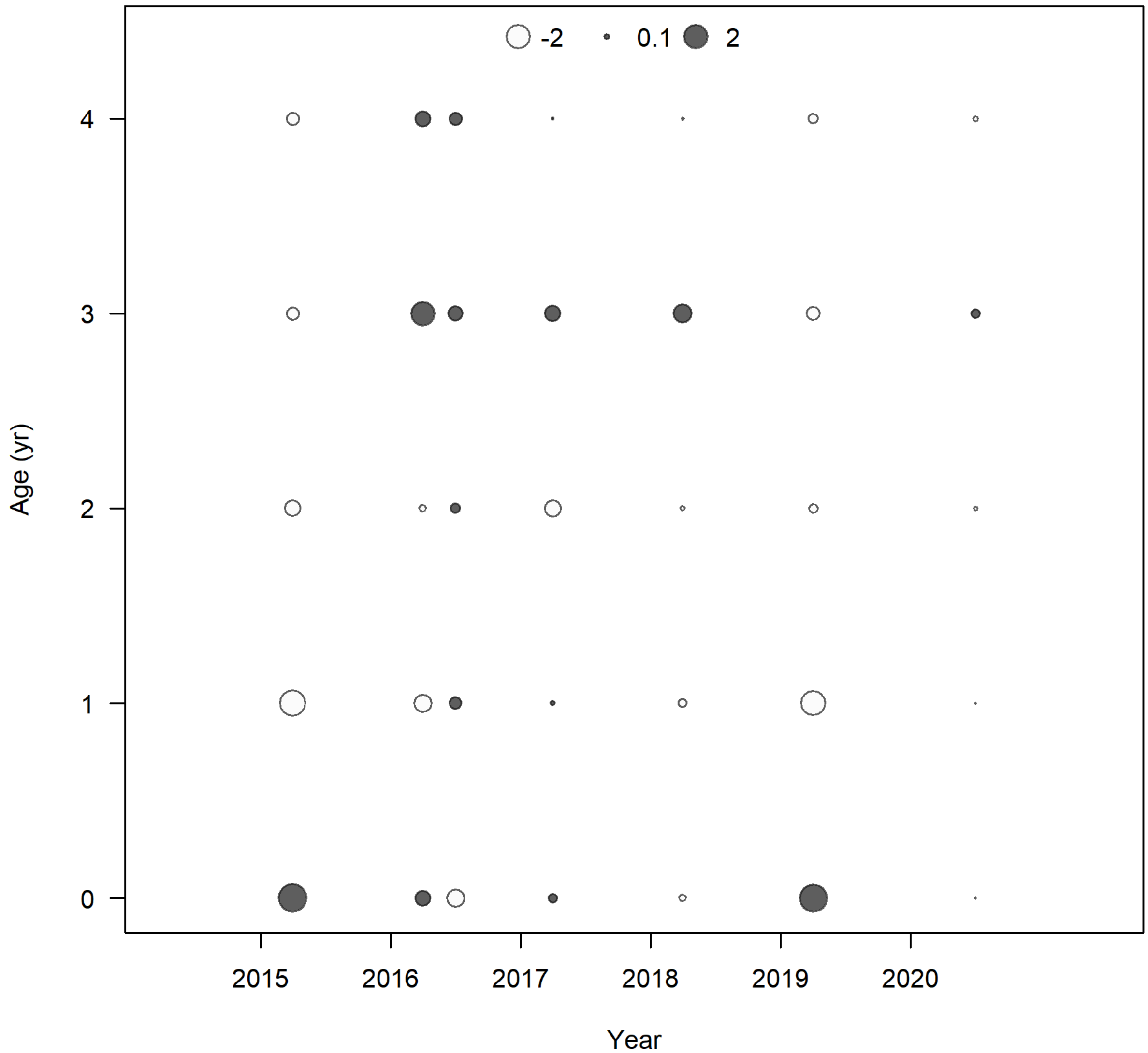

Figure 24: Residuals of fit to age-composition time series for the AT survey fleet in base model. fig:acomp_resid3

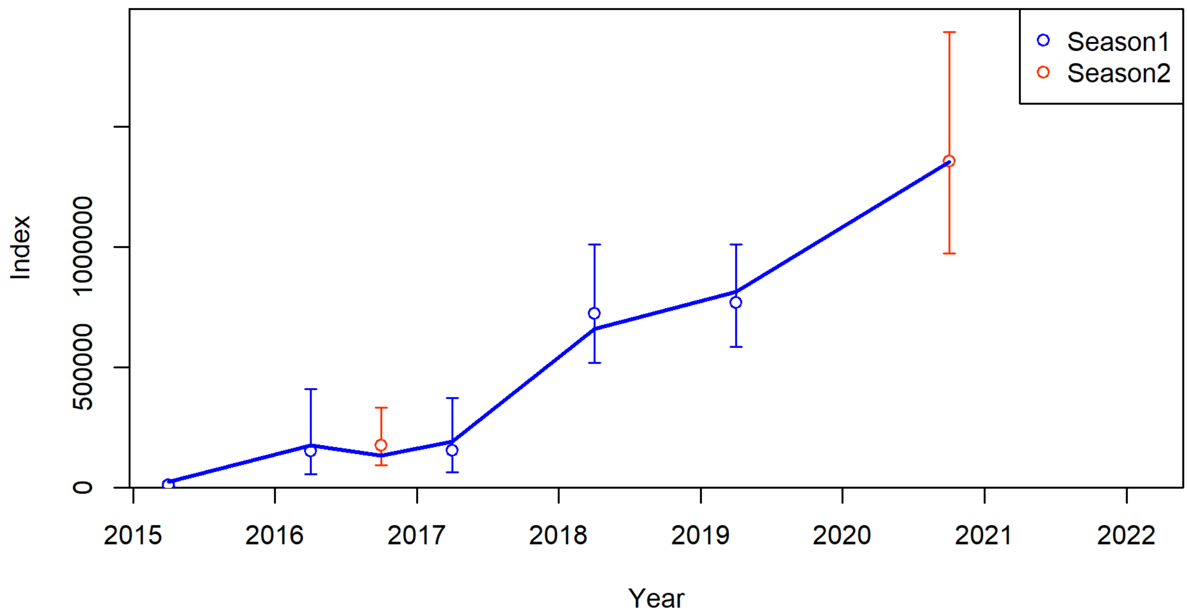

Figure 25: Fit to index data for AT survey in linear space. Vertical lines indicated 95% uncertainty interval around index values based on model assumption of lognormal error. fig:index_fit

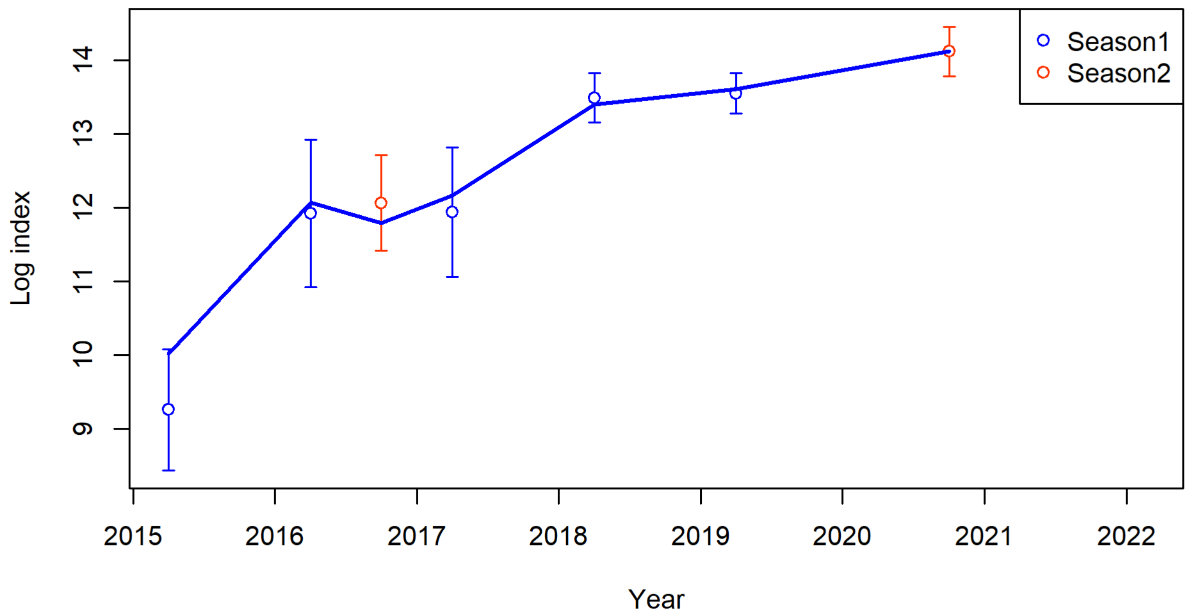

Figure 26: Fit to index data for AT survey in log space. Vertical lines indicated 95% uncertainty interval around index values based on model assumption of lognormal error. fig:logindex_fi

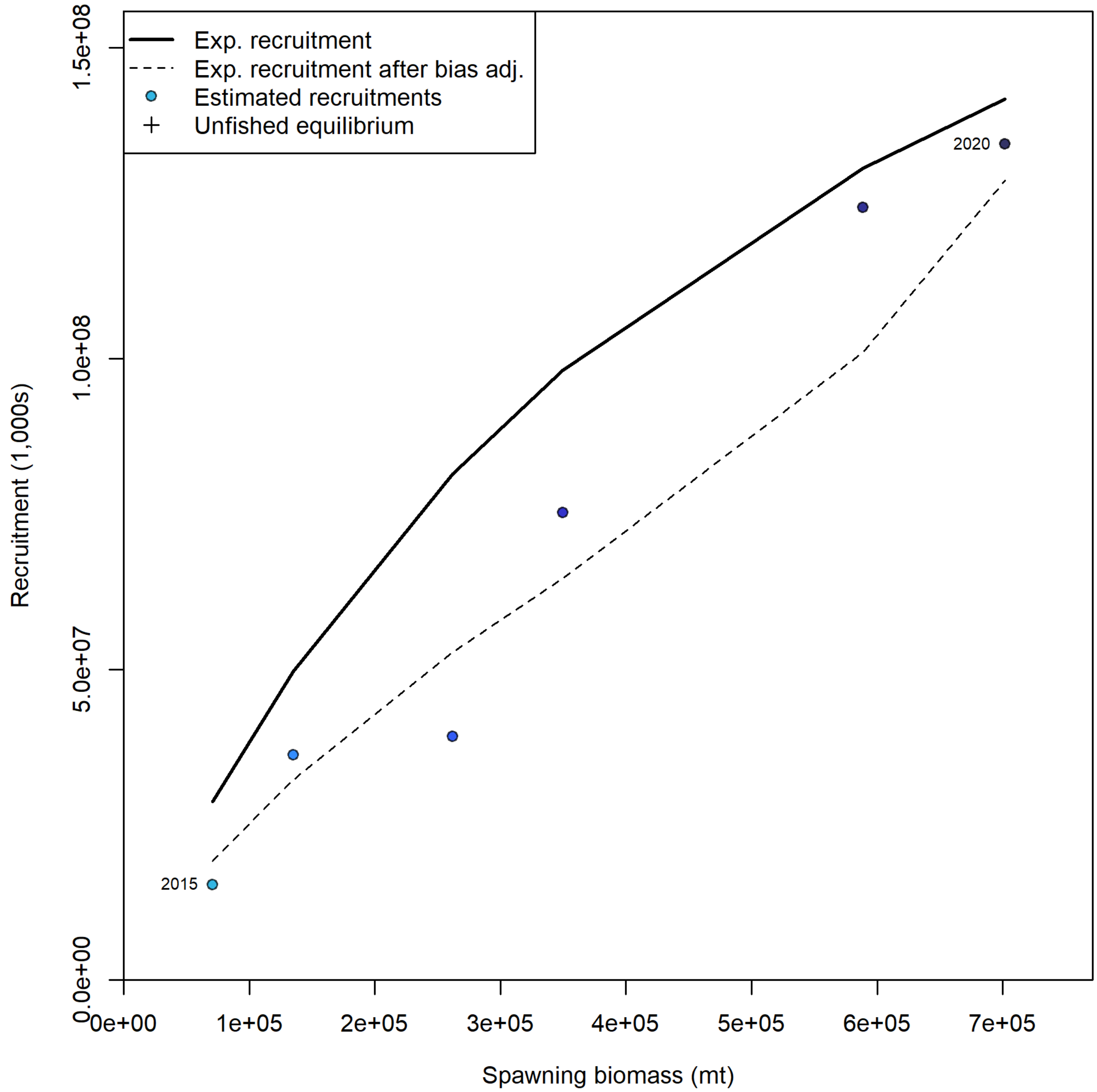

Figure 27: Estimated stock-recruitment (Beverton-Holt) curve with steepness fixed at 1. Year numbers indicate the first, last, and years with (log) deviations > 0.5. fig:srcurve

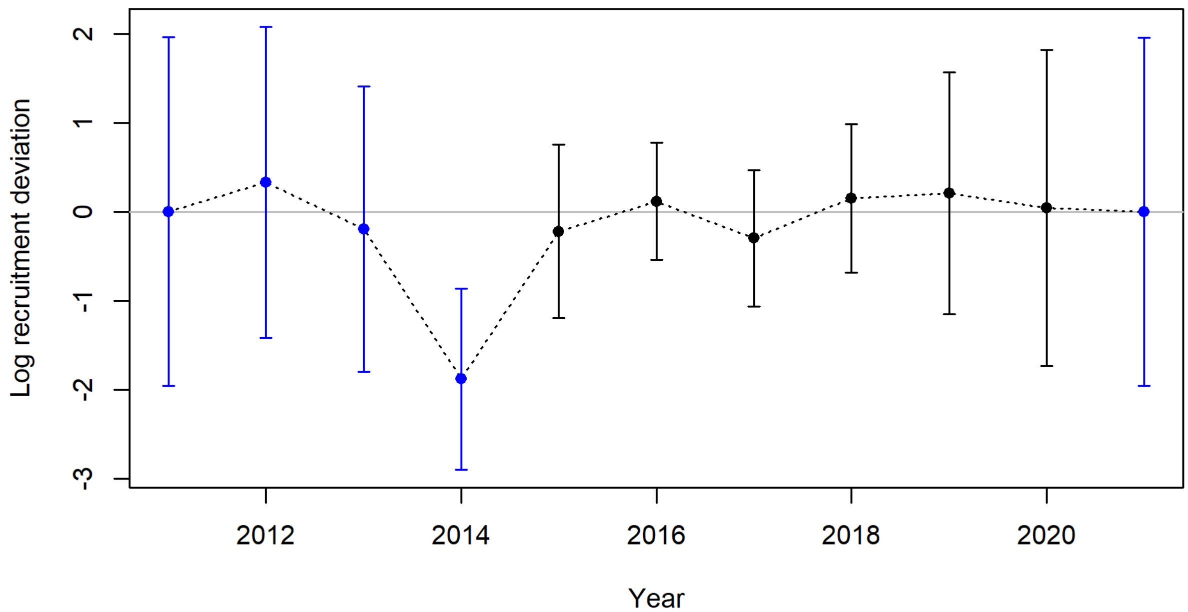

Figure 28: Recruitment deviations with 95% intervals for the base model ($\Sigma_R = 1$). fig:recdevs

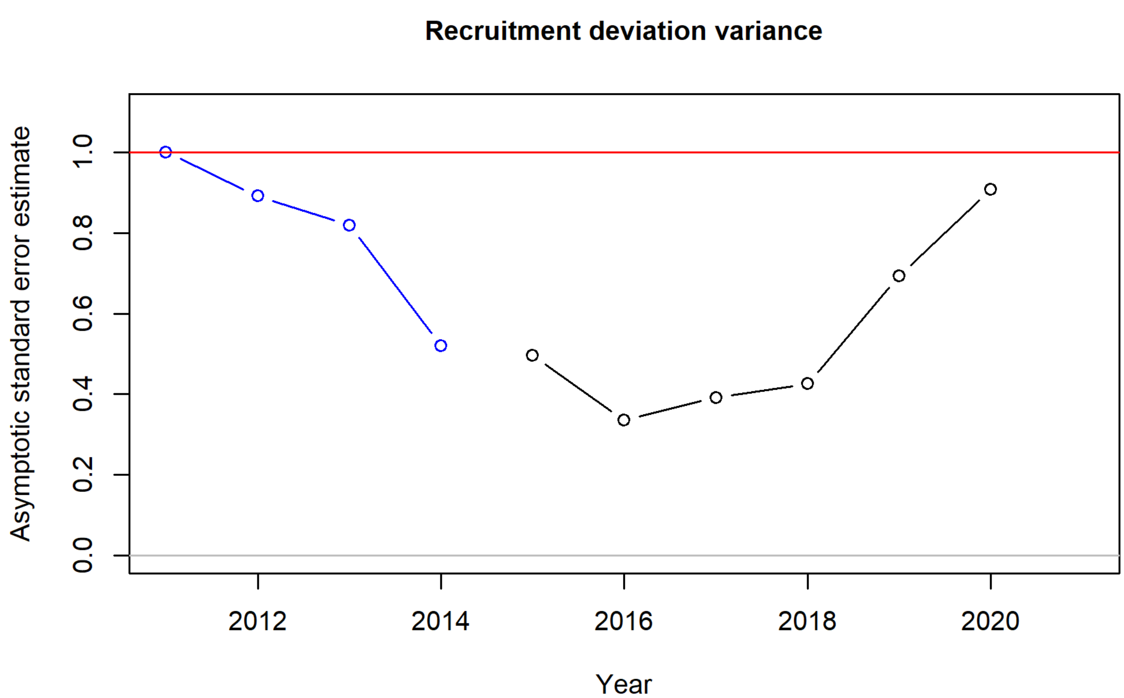

Figure 29: Asymptotic standard errors for estimated recruitment deviations. fig:recdevs_var

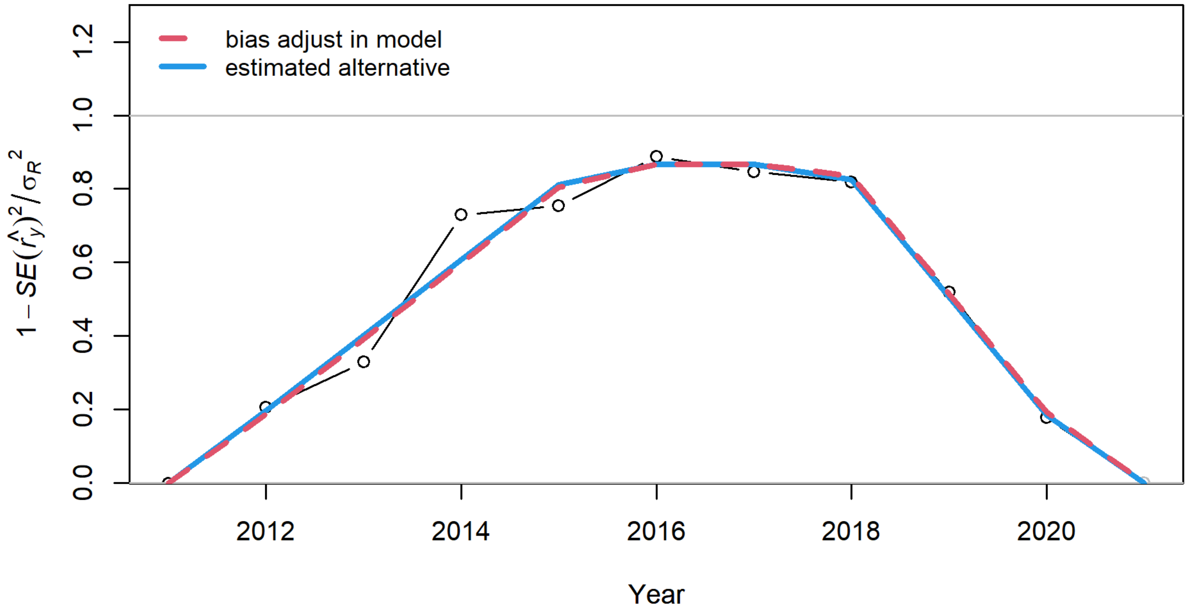

Figure 30: Recruitment bias adjustment plot for early, main, and forecast periods. fig:recdevs_adj

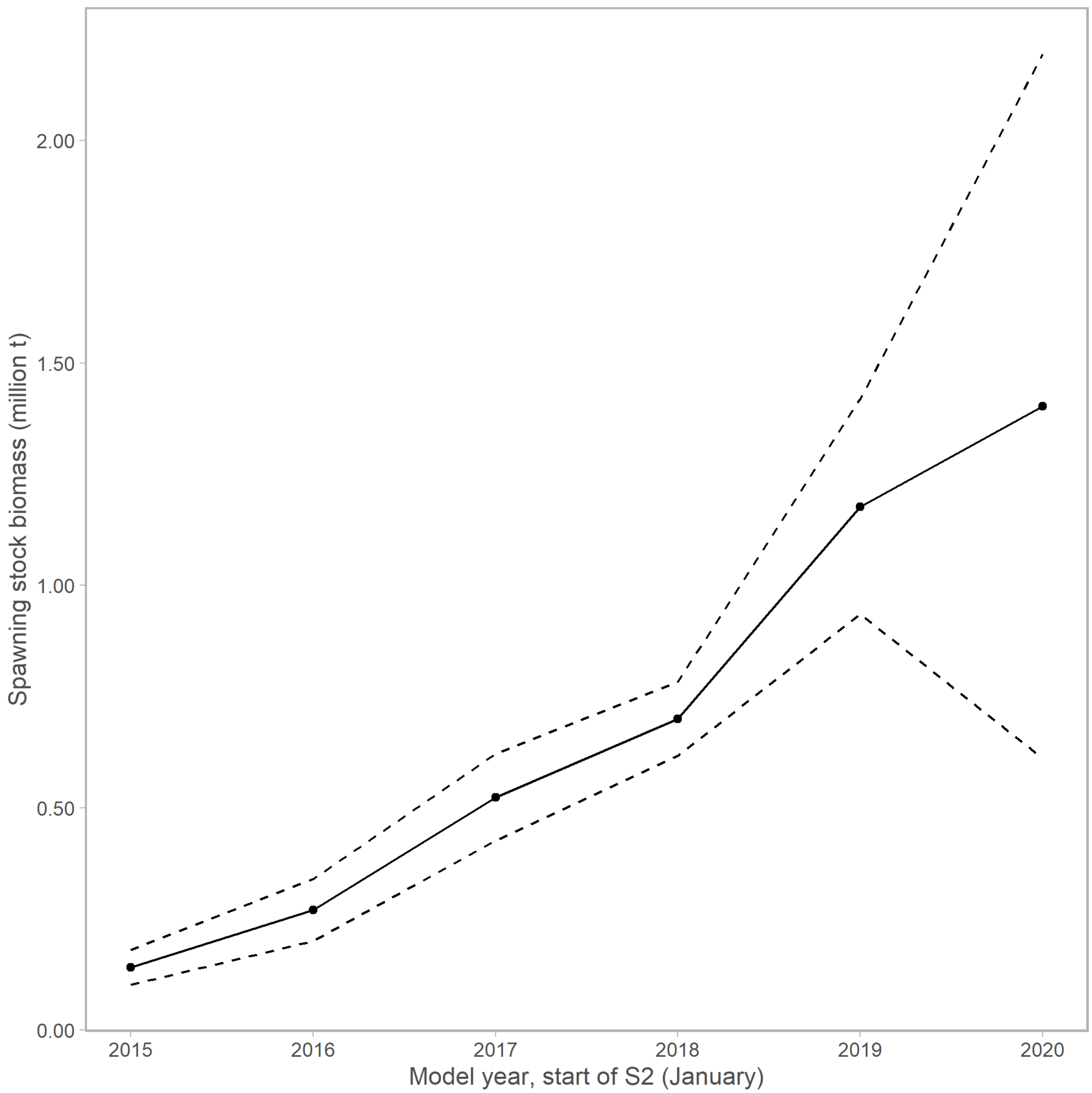

Figure 31: Estimated spawning stock biomass time series (million mt; 95% CI dashed lines). fig:ssb

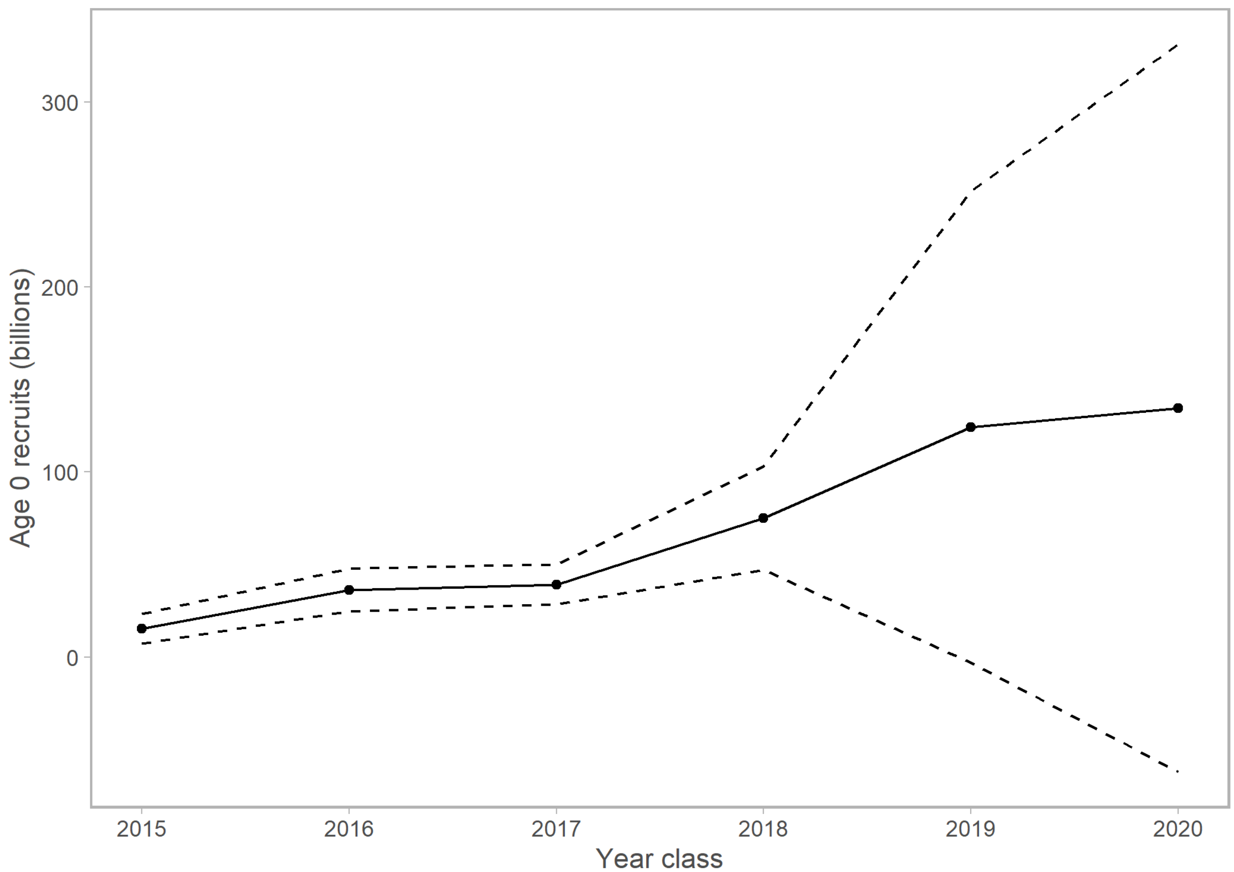

Figure 32: Estimated recruitment time series (billions fish; 95% CI dashed lines). fig:recs

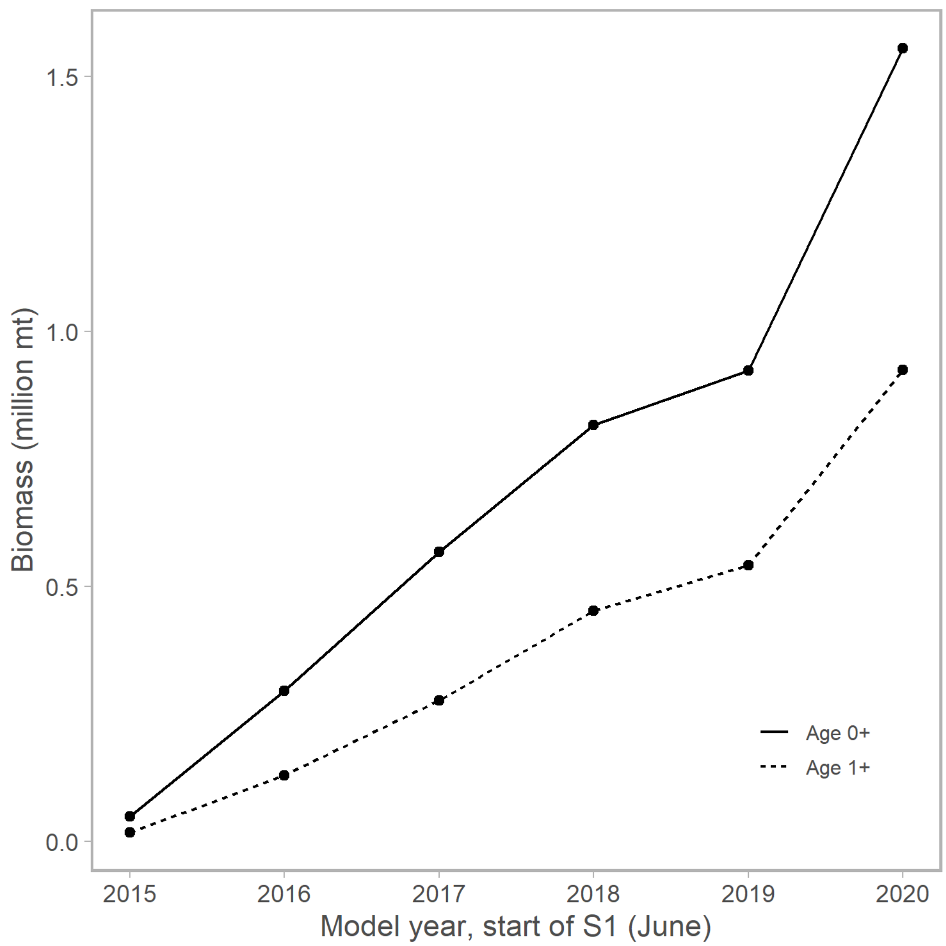

Figure 33: Estimated age 0+ (solid) and age 1+ (dashed) biomass. fig:biomass

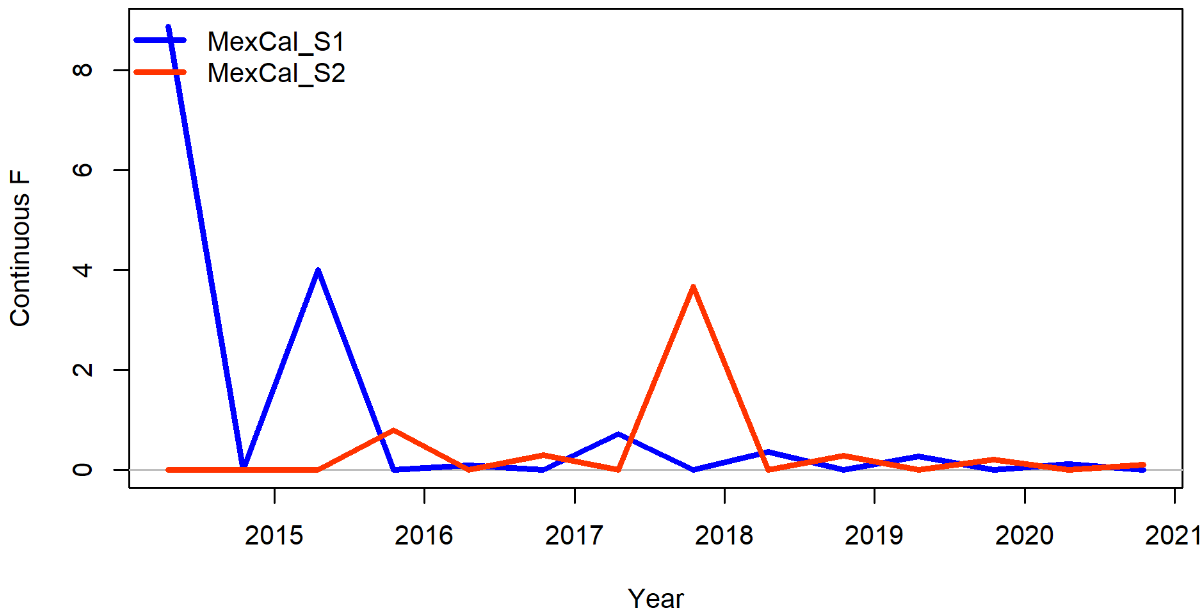

Figure 34: Continuous fishing mortality (F) estimates. fig:contF

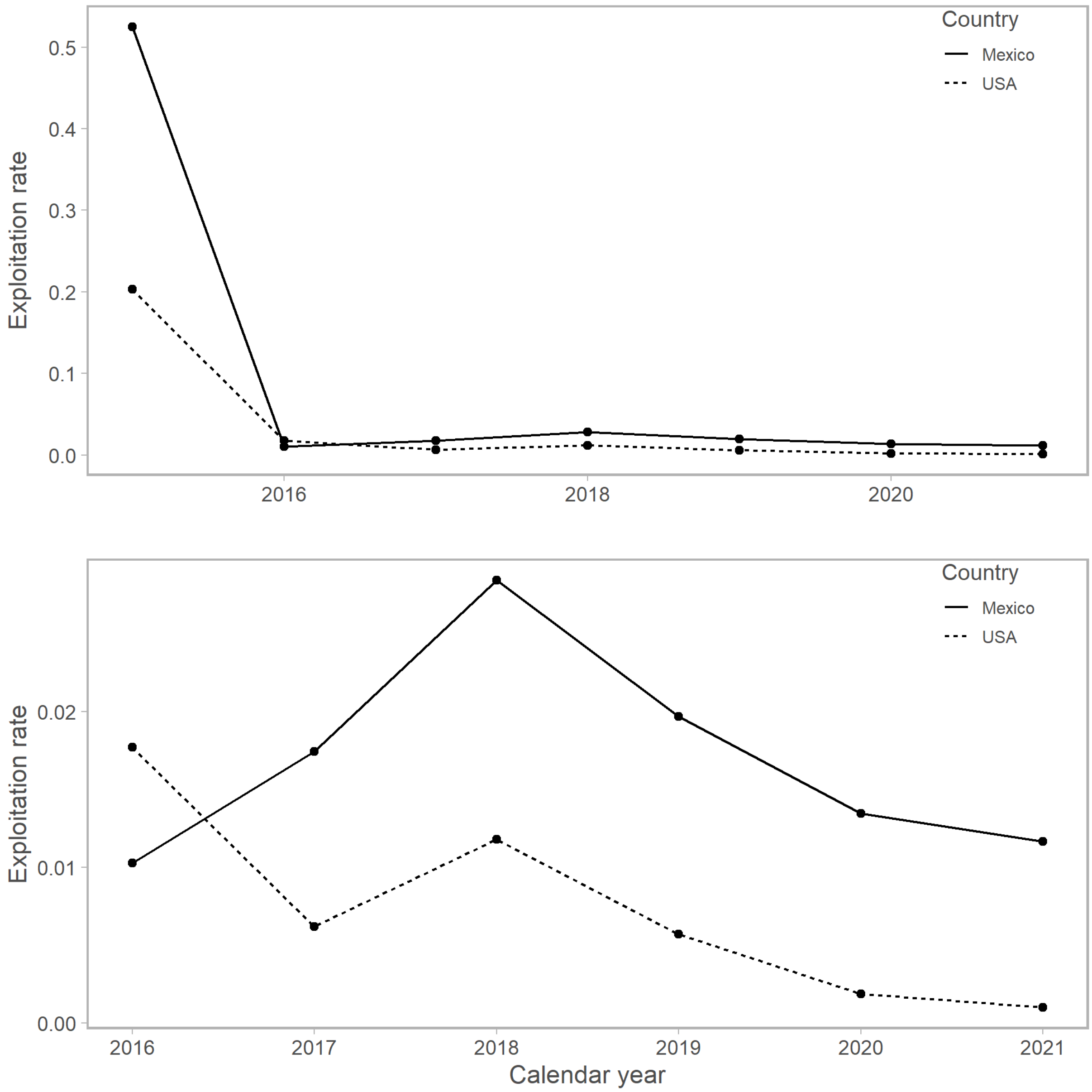

Figure 35: Annual exploitation rates (calendyear landings / June total biomass) including the 2015 estimate (top panel) and excluding (bottom panel). fig:exp_rate

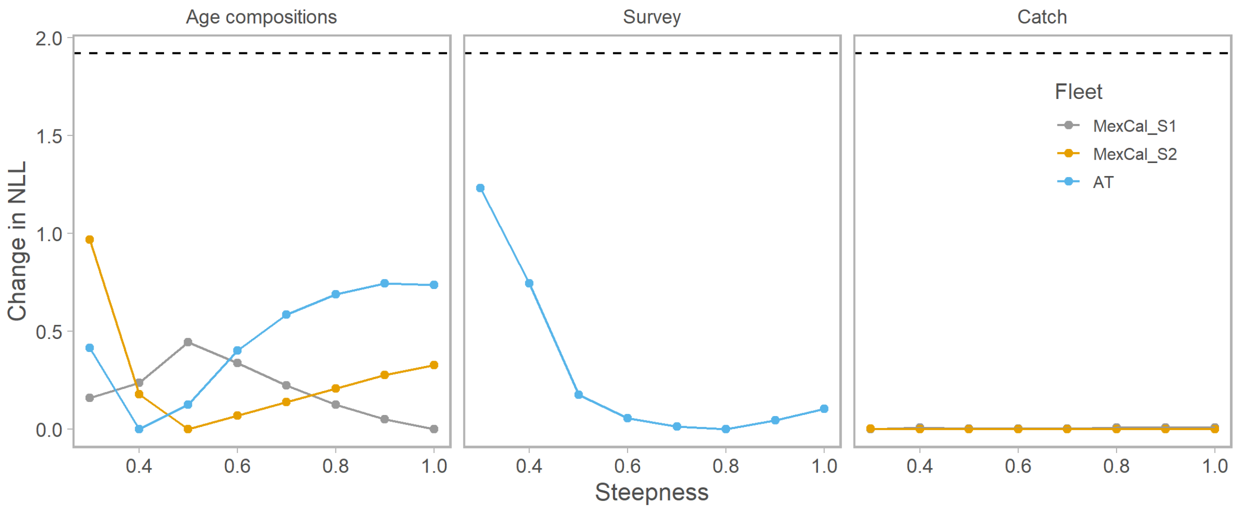

Figure 36: Likelihood profile for values of steepness (h) ranging from 0.3 to 0.9. Values within 1.92 units of the MLE (dashed horizontal line) are within the 95% confidence interval. fig:hprofile

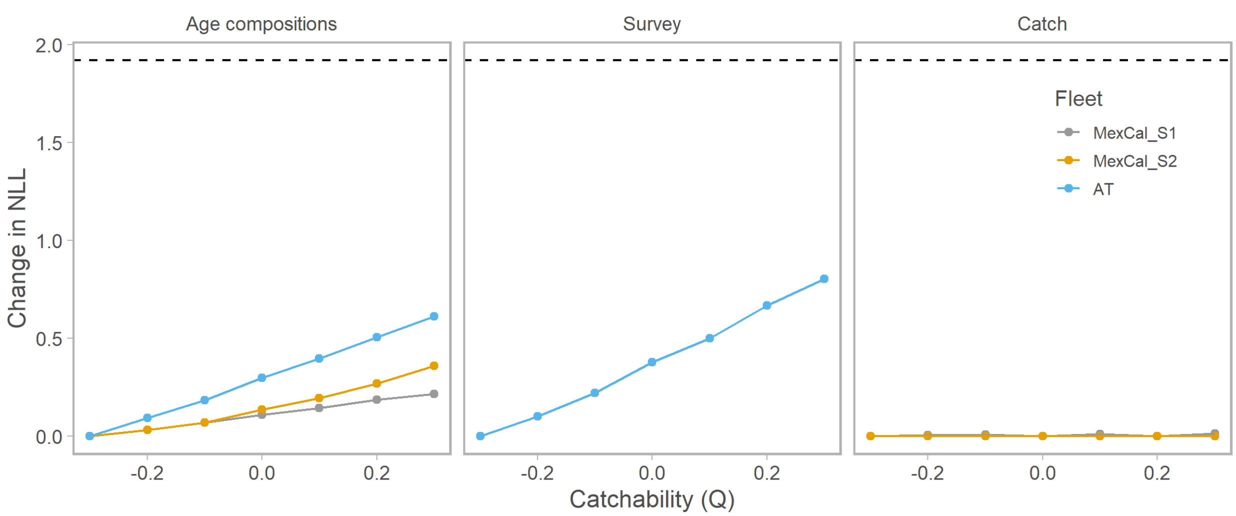

Figure 37: Likelihood profile for values of catchability (log Q) ranging from -0.3 to 0.3. Values within 1.92 units of the MLE (dashed horizontal line) are within the 95% confidence interval. fig:Qprofile

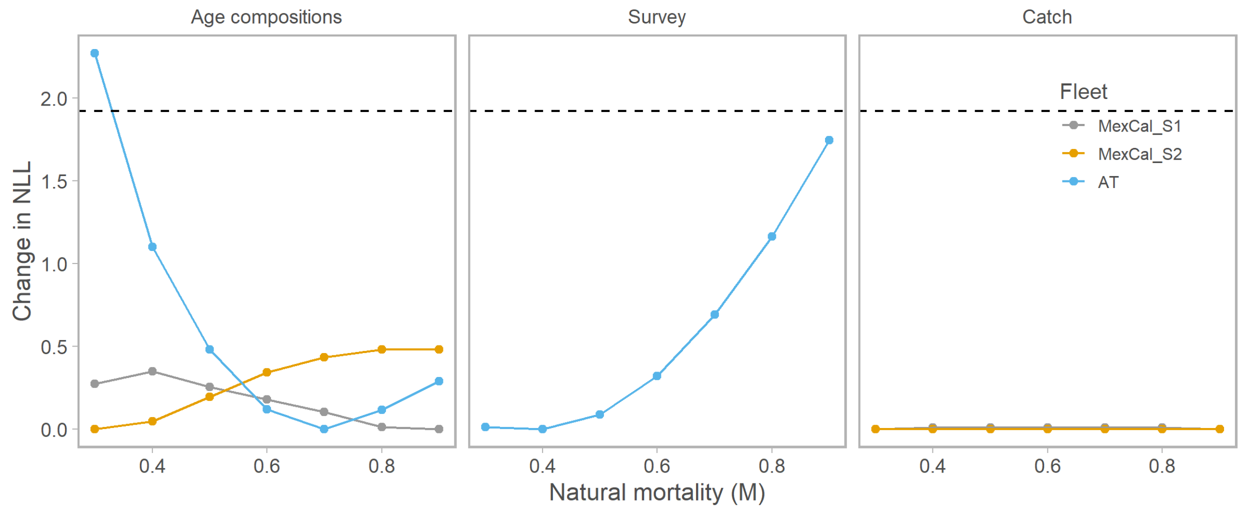

Figure 38: Likelihood profile for values of natural mortality (M) ranging from 0.3 to 0.9 and steepness fixed at 0.6 (as in the base model). Values within 1.92 units of the MLE (dashed horizontal line) are within the 95% confidence interval. fig:Mprofile

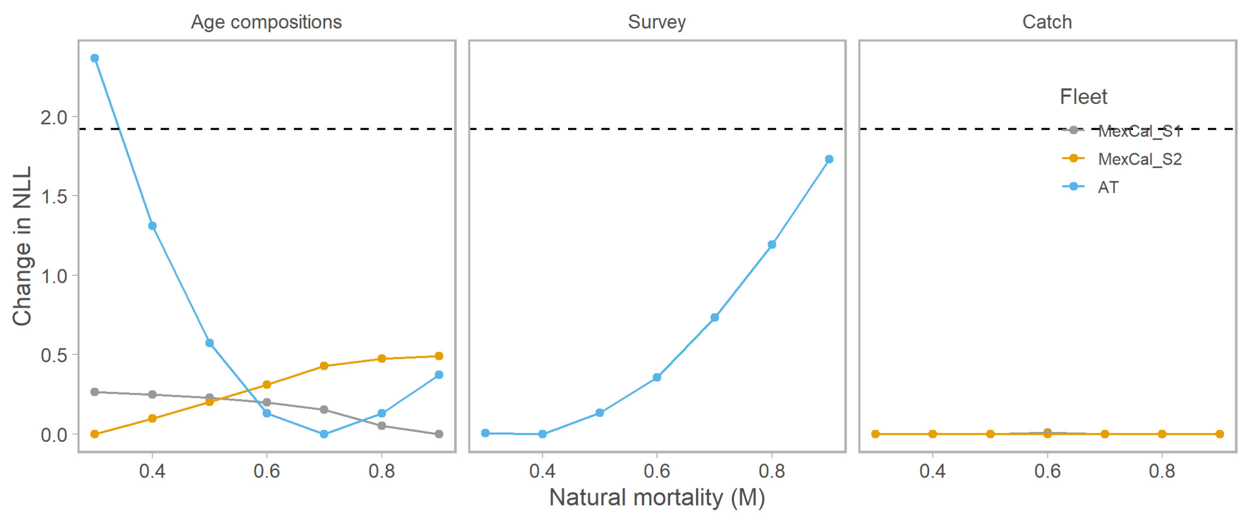

Figure 39: Likelihood profile for values of natural mortality (M) ranging from 0.3 to 0.9 and steepness estimated. This model configuration differs from the base model which fixed steepness. Values within 1.92 units of the MLE (dashed horizontal line) are within the 95% confidence interval. fig:Mprofile_esth

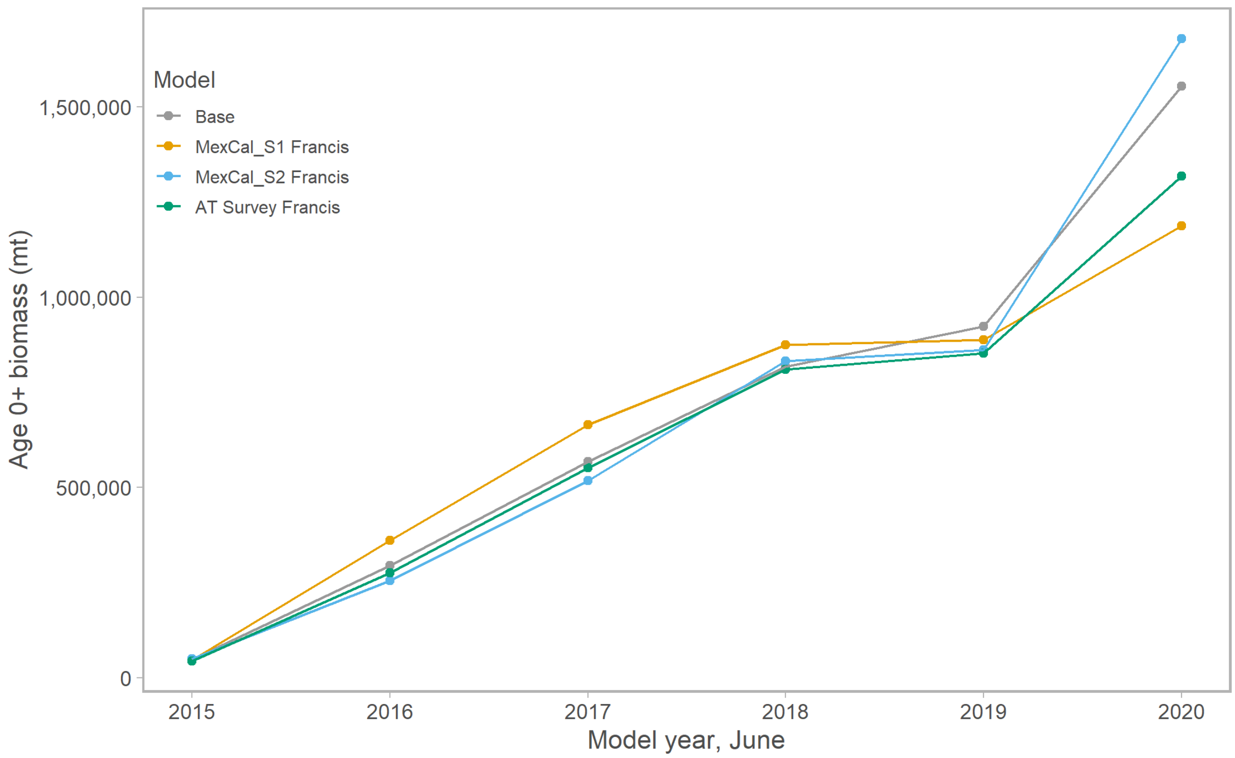

Figure 40: Age 0+ biomass (mt) values estimated from the base model (solid line) and models with Francis reweighting for the age compositions for each of the MexCal S1, MexCal S2, and AT survey fleets. The variance adjustment values were 2.924 for MexCal S1, 2.979 for MexCal S2, and 0.623 for AT Survey. [fig:francis_bio

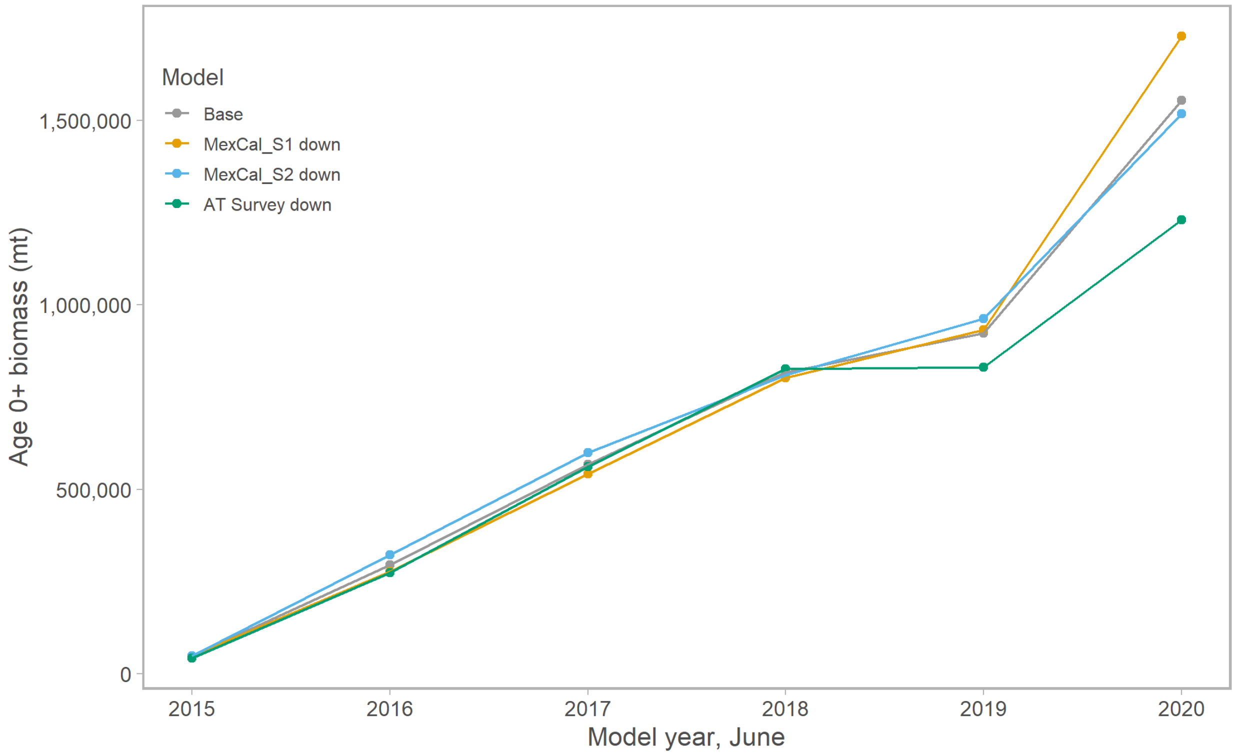

Figure 41: Age 0+ biomass (mt) values estimated from the base model (solid line) and models with downweighted age compositions for each of the MexCal S1, MexCal S2, and AT survey fleets. fig:lambda_bio

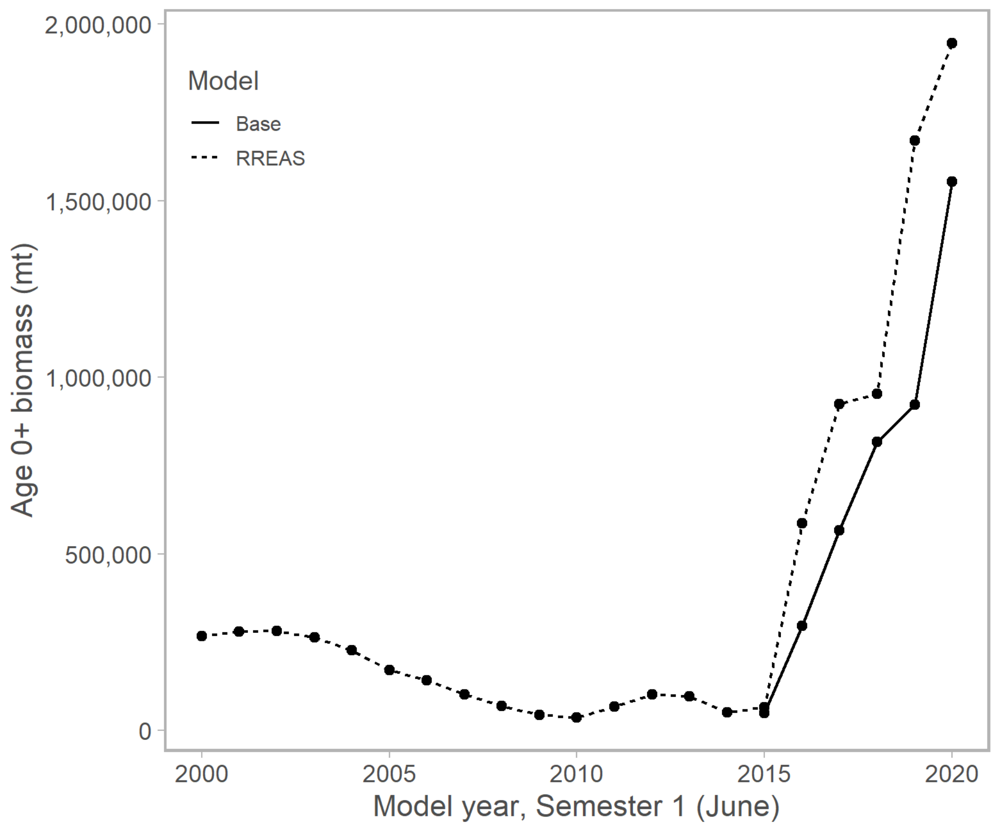

Figure 42: Age 0+ biomass (mt) values estimated from the base model (solid line) and longer model (dashed line) with RREAS young-of-year data. fig:longmod_comparison

9 Appendix A: Calculation of abundance-at-age and weight-at-age from acoustic trawl-method surveys

ppendix-a-calculation-of-abundance-at-age-and-weight-at-age-from-acoustic-trawl-method-surveys

Two of the outputs of the acoustic-trawl method (ATM) surveys 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 anchovy assessment rely on the constructions of age-length keys. 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 necessary requires a sufficient number of individuals to estimate the conditional age-distribution over a set of fixed length intervals. For Northern Anchovy, 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 $a \in \{0,1,\ldots,6+\}$, the probability distribution conditioned on length l, $P_a(l) = \{p_0(l), p_1(l), \ldots, p_{6+}(l)\}$, follows an ordered categorical distribution. $P_a(l)$ was 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 7, corresponding to ages 0, 1, 2, … 6+ years, and *standard.length* – coded as a continuous variable in mm, the *gam* model can be fitted by

```
R = 7 # 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(20,200, by =10)), type =
    "response")
```

which results in a 19 by 7 matrix in which each row is the estimated vector of probabilities $P_a(l)$ of a fish of length l (in cm) with $l \in \{2,3,\ldots,20\}$ belonging to an age group a, with $a \in \{0,1,\ldots,6+\}$. Considering a vector of abundances at length $N_l = n_2, n_3, \ldots, n_{20}$, the elements of vector of abundances at age N_a are calculated by $n_a = \sum_{l=2}^{20} P_a(l) n_l$. Similarly, the elements of biomass at age B_a are given by $b_a = \sum_{l=2}^{20} P_a(l) n_l w_l$, where $w_l$is the average weight of anchovy in the l-th length class derived from a length-to-weight relationship. Finally, mean weight-at-age is obtained by dividing B_a by N_a.

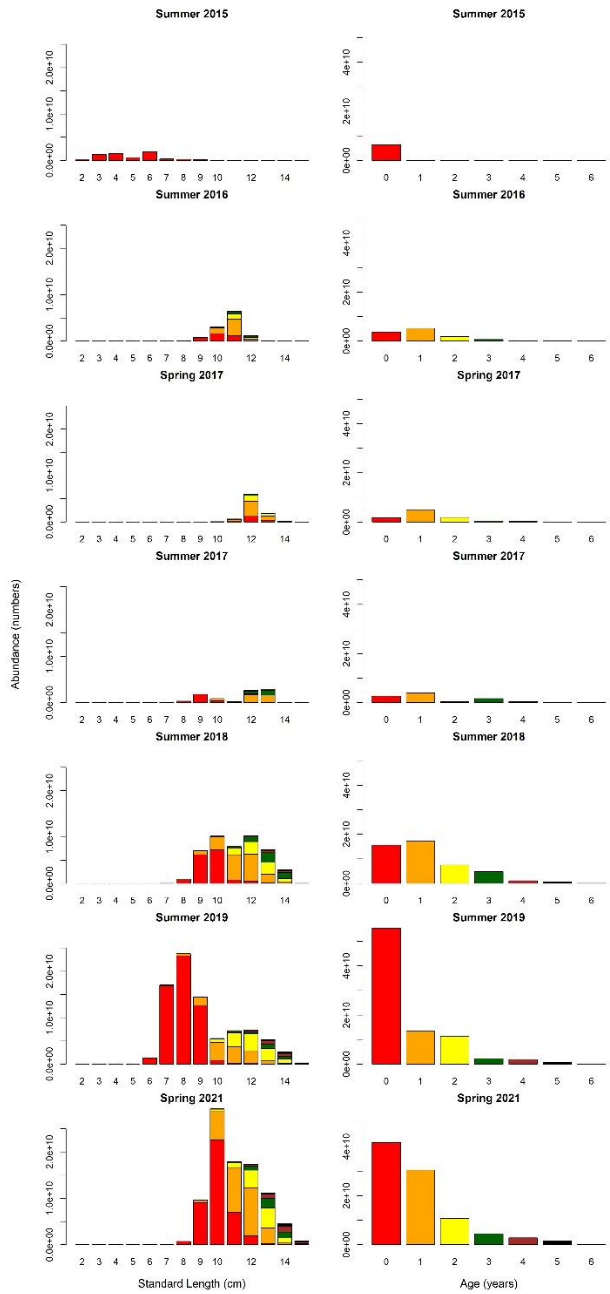

Figure 1 – Left column: abundance-at-length derived from the ATM surveys; Right column: abundance-at-age derived using survey-specific age length keys. The age color code on the right column graphs matches that of the age-disaggregated abundance-at-length on the left column.

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10 Appendix B: Rockfish Recruitment and Ecosystem Assessment Survey (RREAS) CSNA abundance indices

appendix-b-rockfish-recruitment-and-ecosystem-assessment-survey-rreas-csna-abundance-indices

821 Prepared by John Field, Tanya Rogers, Rebecca Miller and Keith Sakuma

Catch data from the Rockfish Recruitment and Ecosystem Assessment Survey (RREAS) were used to develop relative abundance indices of all anchovy biomass, adult (age 1+) anchovy biomass and young-of-the-year (age 0) abundance from 2004 through 2021. The RREAS began in 1983 in central California waters to assess ocean conditions and the abundance and distribution of young-of-the-year (YOY) rockfish, other young-of-the-year groundfish (such as Pacific hake and sanddabs), and other forage taxa in late spring of each year. Data have been used to inform stock assessment models of rockfish and other groundfish with recruitment indices that improve forecasts of the abundance and availability of strong year classes to commercial and recreational fisheries (Ralston et al. 2013, Field et al. 2021). Since 1990 the survey has also quantified other epipelagic micronekton, with an emphasis on ecologically important forage species, to support a growing array of ecosystem studies and to provide ecosystem indicators to marine resource managers (e.g., Harvey et al. 2021).

From 1983 through 2003 the survey operated solely off of Central California (between approximately 36° N and 38° N latitude), however since 2004 the survey has covered most of the California coastline, from the U.S./Mexico maritime border to the California/Oregon border (Sakuma et al. 2016). Comparable collections have been conducted by the NWFSC since 2001 for YOY groundfish and since 2011 for all taxa (see Field et al. 2021). Mid-water trawls are collected at fixed sampling stations during night using a modified Cobb mid-water with a 9.5 mm cod-end liner, the net design and methods are highly comparable to historical CDFW acoustic trawl surveys (Mais et al. 1974). Standardized fifteen minute tows are made at each station with a headrope depth of 30 m, although for some nearshore stations the shallow bottom depth precludes fishing at that depth, and haul target headrope depths are 10 meters. Trawls are standardized by adjusting the amount of trawl warp deployed and using a Simrad ITI sensor system to adjust the vessel speed in real time to maintain a headrope depth of 30 meters, and thus a constant speed through the water. After each haul, all taxa are identified, enumerated and a subset of key taxa are measured (standard length). Details on methods, routinely encountered taxa, and other data collected during surveys are available at Sakuma et al. (2016) and Santora et al. (2021). For the indices developed here, we focus only on RREAS data from 2004 through 2021, as the limited spatial extent of the pre-2004 data may reduce the information content of the indices (see figures 4 and 5 on relative distribution of both YOY and adult anchovy over time). Table 1 lists the number of trawls conducted, the number of positive trawls by life history stage and year, and the number of length observations collected during the RREAS between 1990 and 2021.

For biomass estimates, length data were expanded from the subset (generally 20-30) of individuals measured in each trawl, and converted to biomass based on published length/weight relationships informed by ontogenetic stage (e.g., YOY, adult). YOY and adults typically distinguished morphologically, and by assuming a 90 mm cutoff between age 0 and age 1 fish at larger sizes. Length data are available for adult life history stages from 1990 through 2021, length data for YOY are only available from 2013 through 2021. While there is some potential for incorrect assignment of some individuals near this size cutoff, the vast majority (>92%) of YOY are between sizes of 15 and 60mm, and clearly recognizable as YOY. Relative abundance indices were estimated using a delta-generalized linear model (GLM) approach (also referred to as a hurdle model), an approach routinely used for developing indices of relative abundance from fisheries survey and catch rate data (Maunder and Punt 2004). The year effects are the parameter of primary interest, with spatial and temporal covariates explored within the model structure, and either included or excluded based on Akaike's Information Criteria (AIC) are also estimated. Covariates explored include station effect, area effects (where station line is a proxy for area), depth effects (inshore and offshore of 200m), Julian day bin effects (typically very important for strongly seasonal YOY groundfish index development, but not significant for CSNA). Uncertainty in the year effects was quantified by running the model in a Bayesian framework using the R package ‘rstanarm’ to estimate standard error and confidence limits (R project, 2020). Relative abundance indices were developed for total biomass (age 0 and age 1+), and age 0 and age 1+ biomass independently (Figures 1-3).

The trends in relative abundance seen in this dataset are consistent with observations from other data sources such as the acoustic trawl survey, CalCOFI egg and larval abundance data, and predator food habits data. All of these datasets tend to show an increase in relative abundance early in the time series (2004-2006), very low abundance and availability between 2007 and 2014, with a sharp increase in YOY abundance starting around 2014-2015, and an increase in adult abundance trailing the increase in YOY abundance. Spatial patterns indicate considerable spatial autocorrelation in relative catch rates, with the greatest catches of adults typically found around Point Conception and up to Monterey Bay in high abundance years, while YOY are more frequently encountered throughout the Southern California Bight (SCB) at the timing of the survey (Figure 4). The distribution of YOY in 2015 (during the large marine heatwave) was unusual in that YOY were found widespread throughout the survey area, but were not unusually abundant in their (typical) high abundance region (the SCB) during that year (Figure 5). This was consistent with the observation of unusual spatial distributions and abundance patterns of many different taxa during the year of the large marine heatwave (Sakuma et al. 2015, Santora et al. 2017). Note that survey effort was limited in 2020 to a small number of trawls (15) conducted onboard a chartered fishing vessel solely within the core area, thus data are quite thin with respect to this year for the relative abundance indices. However, 2020 and other recent years have seen extremely high abundance of CSNA in both this and other surveys. Data from 1990-2003 in the core area only were not included here as they do not include the core range of the stock, but could be useful in evaluating regional abundance for other investigations.

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Table 1: Number of trawls, number of trawls positive for either YOY or adult northern anchovy, the percentage of positive trawls, and the number of length observations recorded for the RREAS survey, 1990-2021.

year	trawls (south of 40 10)	positive YOY	% positive YOY	YOY length data	positive adult	% positive adults	adult length data
1990	80	2	0.025		24	0.300	
1991	93	10	0.108		0	0.000	
1992	73	27	0.370		21	0.288	
1993	75	50	0.667		9	0.120	
1994	75	47	0.627		8	0.107	
1995	74	14	0.189		23	0.311	
1996	76	35	0.461		13	0.171	
1997	74	36	0.486		15	0.203	
1998	78	6	0.077		23	0.295	
1999	77	3	0.039		19	0.247	322
2000	87	0	0.000		7	0.080	515
2001	80	4	0.050		11	0.138	136
2002	67	1	0.015		4	0.060	106
2003	88	0	0.000		12	0.136	2
2004	119	12	0.101		49	0.412	63
2005	130	26	0.200		71	0.546	905
2006	142	13	0.092		72	0.507	1130
2007	154	15	0.097		33	0.214	1355
2008	95	9	0.095		19	0.200	648
2009	123	11	0.089		6	0.049	298
2010	123	9	0.073		2	0.016	42
2011	58	0	0.000		1	0.017	2
2012	83	2	0.024		0	0.000	1
2013	135	4	0.030	32	6	0.044	38
2014	141	34	0.241	185	3	0.021	16
2015	161	129	0.801	1308	5	0.031	21
2016	131	72	0.550	791	9	0.069	108
2017	91	33	0.363	334	9	0.099	105
2018	126	71	0.563	905	45	0.357	725
2019	102	54	0.529	416	68	0.667	1162
2020	15	5	0.333	28	12	0.800	224
2021	100	27	0.270	310	65	0.650	897

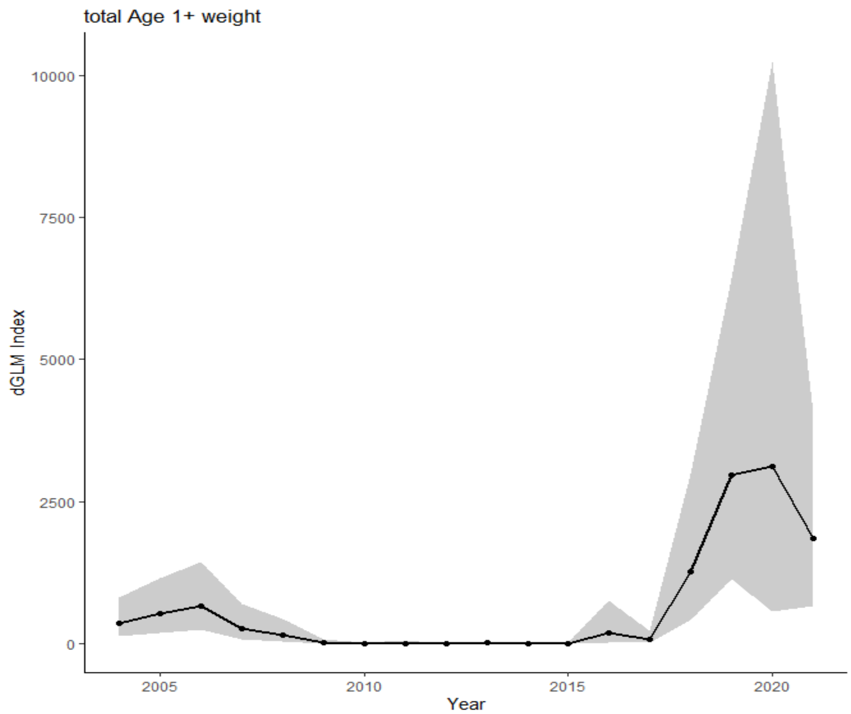

Figure 1: Relative abundance of adult (age 1+) anchovy biomass from the Rockfish Recruitment and Ecosystem Assessment Survey (south of Cape Mendocino to the U.S./Mexico border).

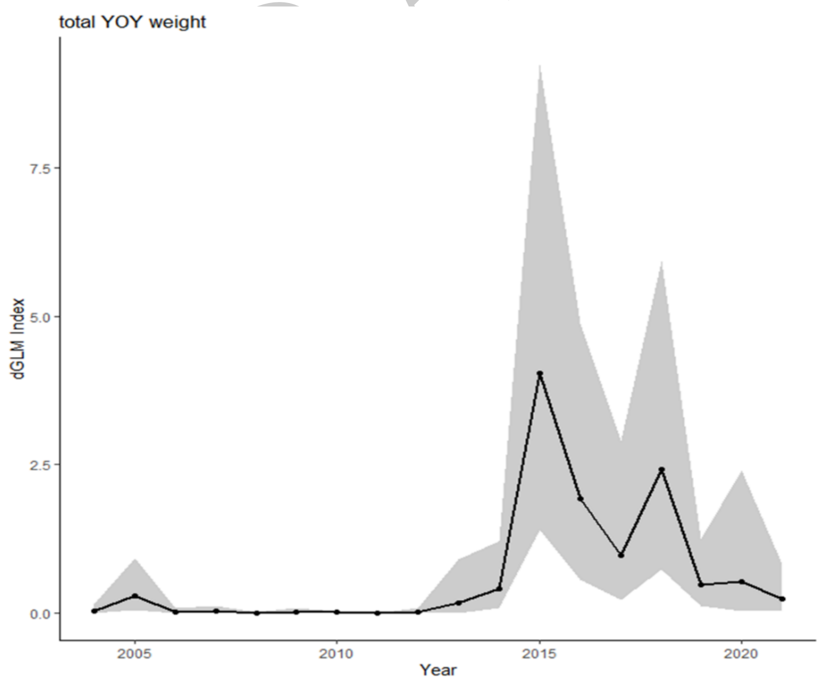

Figure 2: Relative abundance of young-of-the-year (YOY) anchovy from the Rockfish Recruitment and Ecosystem Assessment Survey (south of Cape Mendocino to the U.S./Mexico border).

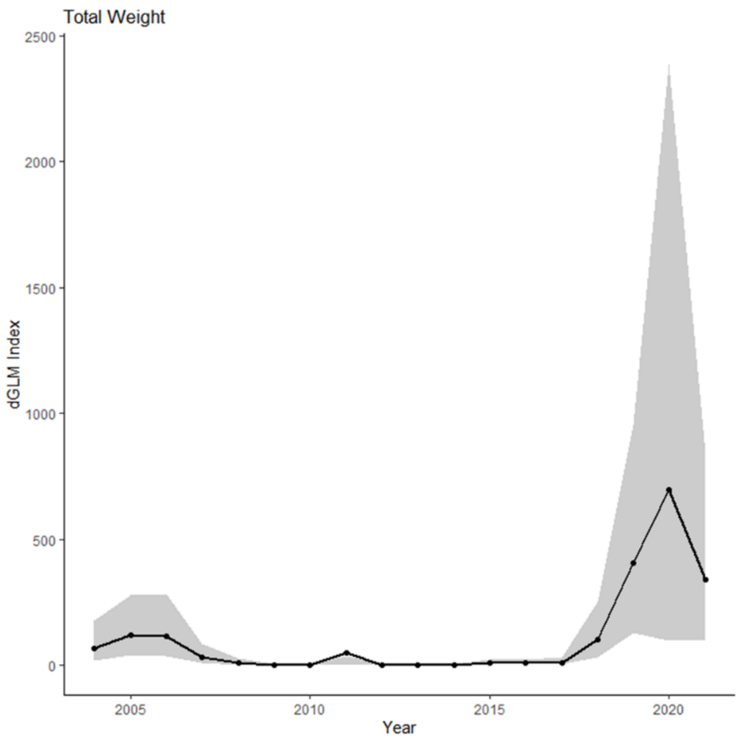

Figure 3: Relative abundance of all anchovy biomass from the Rockfish Recruitment and Ecosystem Assessment Survey (south of Cape Mendocino to the U.S./Mexico border).

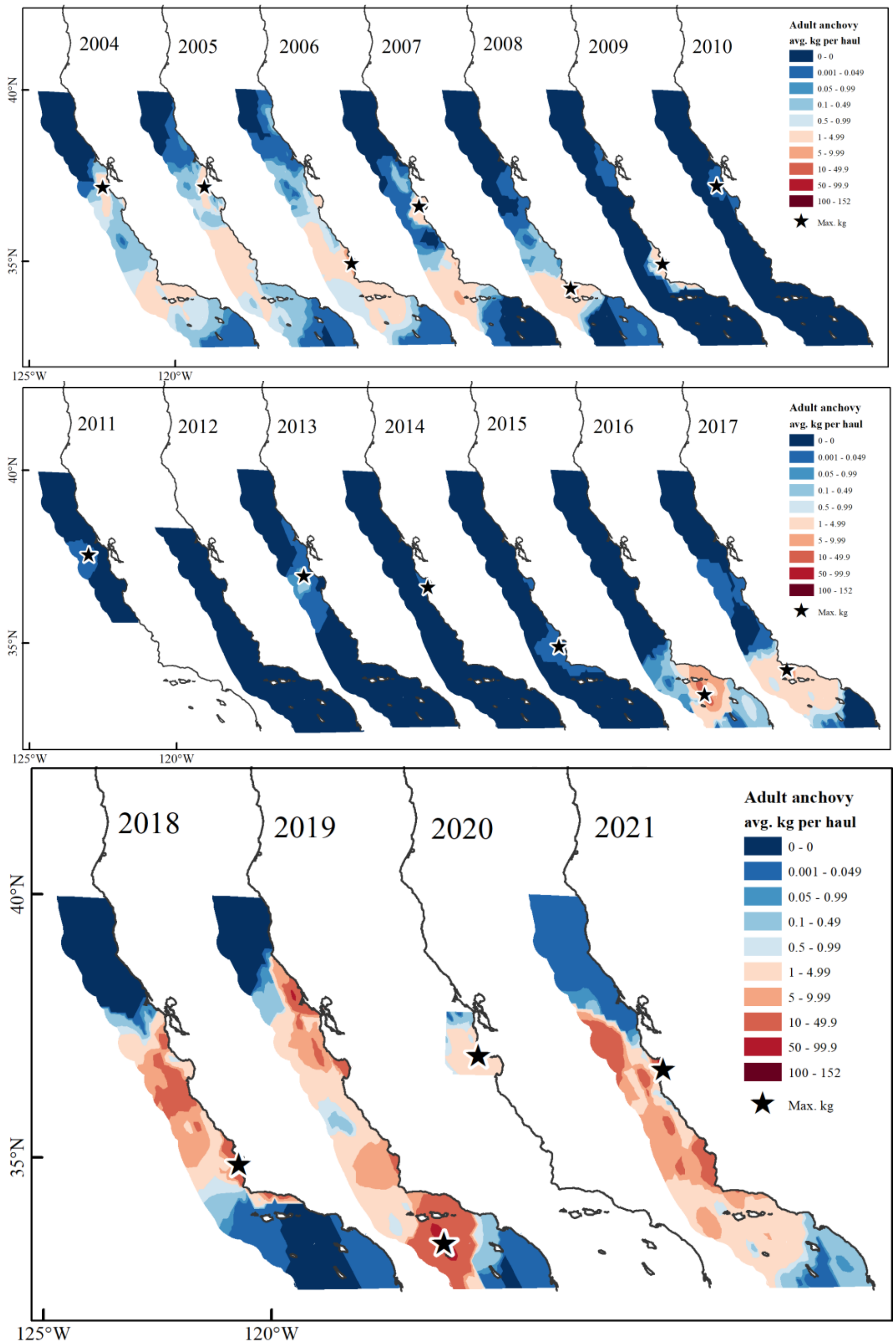

Figure 4: Spatial distribution of adult (age 1+) anchovy catches, 2004-2021

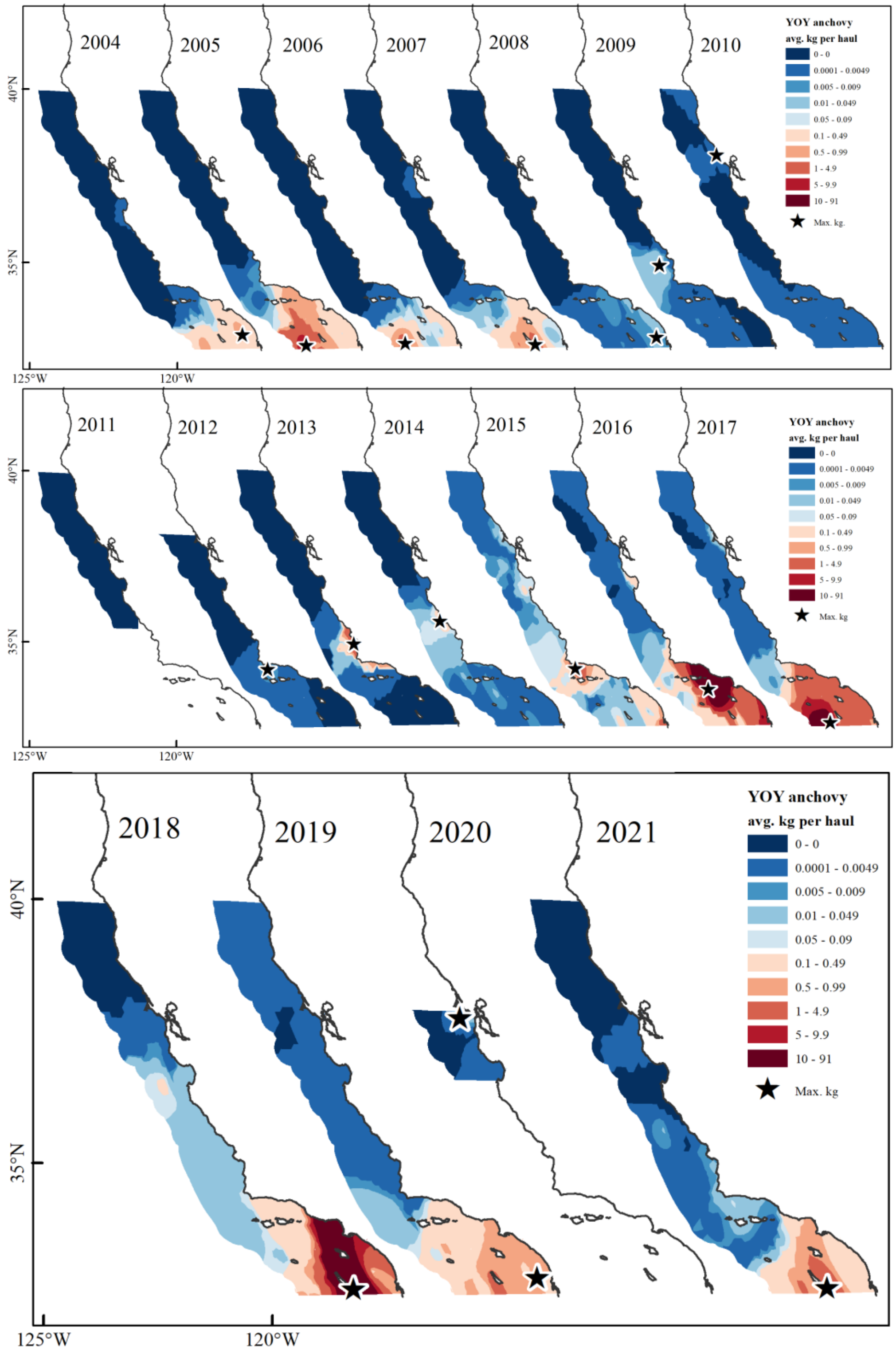

Figure 5: Spatial distribution of young-of-the-year (YOY) anchovy catches, 2004-2021

11 Appendix C: CalCOFI larval and egg indices of abundance

appendix-c-calcofi-larval-and-egg-indices-of-abundance

Historical egg or larval abundance data from the California Cooperative Oceanic and Fisheries Investigations (CalCOFI) surveys have been used in previous stock assessments of northern anchovy (Jacobson et al. 1994), as well as several West Coast species including, Boccacio (He and Field 2017), shortbelly rockfish (Field et al. 2007), Cowcod (Dick and MacCall 2014), and California sheephead (Alonzo et al. 2004). The CalCOFI surveys of ichthyoplankton in the California Current began in 1951, with the primary objective of understanding and evaluating the causes of the collapse of Pacific sardine (Sardinops sagax) fishery in the late 1940s. Although sardine was the original focus of the surveys, the eggs and larvae of northern anchovy and other species were also identified and quantified. The sampling area and frequency of the surveys have changed over time due to budget constraints. For example, the surveys switched to a triennial cycle after 1969 to maintain spatial coverage at reduced costs. However, this resulted in a lack of sampling during the 1982 El Nino event, and the CalCOFI surveys subsequently switched to an annual, quarterly cycle after 1983, albeit with a smaller spatial coverage limited to central and southern California (McClatchie 2014). Currently, each annual cycle consists of four seasonal surveys although surveys were conducted near-monthly in the early years. The CalCOFI data for this assessment were from oblique larval tows, which sample from approximately 15 m off the bottom to the surface, up to a maximum depth of approximately 210 m. The sampling gear for oblique tows have changed over time, from silk to nylon nets in 1969, and from ring to bongo nets in 1978 (McClatchie 2014).

The spatial extent of the CalCOFI data used to develop this larval index was constrained to the core CalCOFI area, which have been relatively consistently sampled over time and covers the main anchovy larval habitat. This core CalCOFI area consisted of the stations between line 76.7, which abuts the shoreline near Pismo Beach, just north of Point Conception, to line 93.3 to line 93.3, which runs just off of San Diego. Each line were further separated into multiple stations, with a total of 66 line-stations in the core CalCOFI area. The initial and final years for the CalCOFI data in this assessment were 2000 and 2019, respectively, which correspond to the start of the assessment period and the final year of CalCOFI data available. Data from the winter, spring, and summer surveys were used to develop the indices because anchovy spawning peaks in spring. Figure C-1 shows the overall proportions of positive egg and larval samples for the 66 core line-stations during the 2000-2019 period. Figure C-2 shows the overall CPUE of positive egg and larval samples for the 66 core line-stations during the 2000-2019 period.

The CalCOFI larval fish index in this assessment was developed using a similar approach to the CalCOFI index used in the Boccacio assessment (He and Field 2017). The larval fish index used tow-specific information and a delta-GLM approach to derive an index of spawning output. Fixed effects of the model included year, season, line-station. Based on AIC criteria, we used a lognormal distribution for the positive model and a logit link function for the binomial model. The CalCOFI egg and larval fish index and associated standard errors estimated from a jackknife routine were used as an alternative relative index of spawning output in this assessment (Fig. C-3). The trends suggest that anchovy spawning output have been relatively low over most of the assessment period but increased substantially since summer 2016.

Egg data were also standardized with a vector autoregressive spatio-temporal (VAST) model (Thorson 2019). The models considered full spatiotemporal, spatial, and temporal correlations for both year-season and season-season (code based on the seasonal model code available on the VAST github). The model takes two days to converge with number of knots = 300, using a premade grid. The VAST output showed a similar trend to that from the deltaGLM, particularly in recent years (Figs. C-4 and C-5).

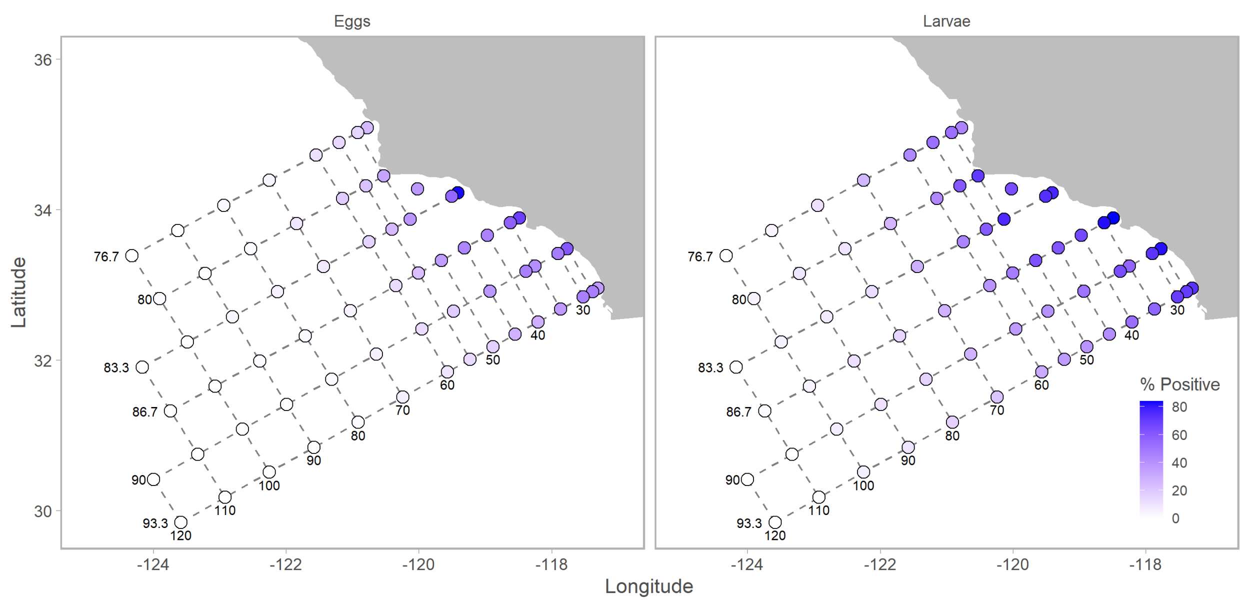

Figure C-1: Percentage positive observations in the core CalCOFI grid averaged from 2000-2019. Percentages for eggs (left) and larvae (right) are displayed. CalCOFI lines are latitudinal and stations are longitudinal, with corresponding lines and stations displayed.Both eggs and larvae tended to be most concentrated nearshore. fig:calcofi_percpos

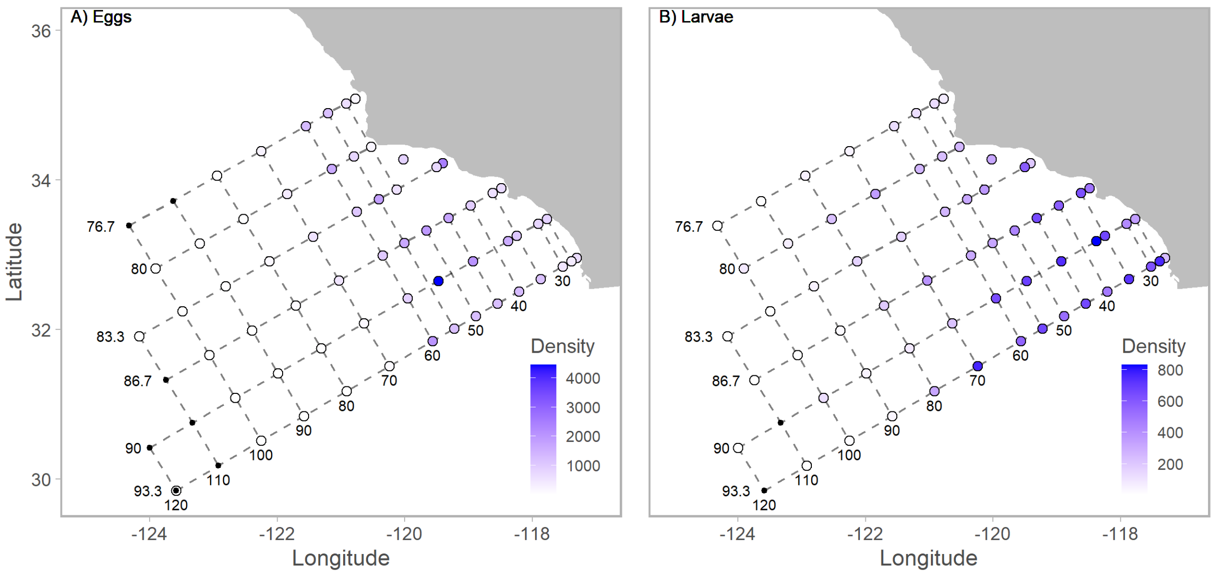

Figure C-2: Average egg (A) and larval (B) densities at CalCOFI stations averaged from 2000-2019. Both eggs and larvae tended to be most concentrated nearshore. fig:calcofi_averages

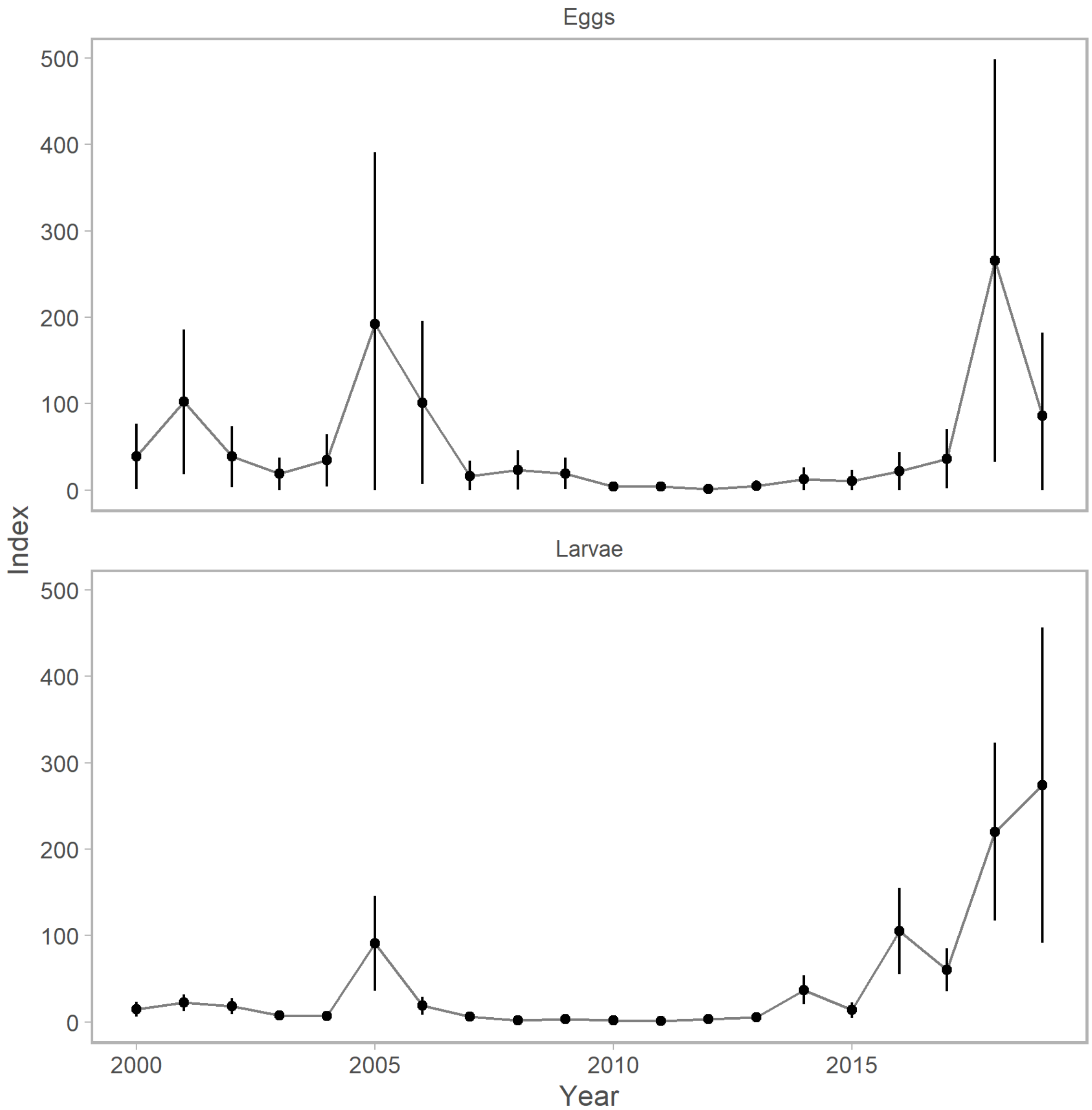

Figure C-3: Standardized CalCOFI indices of abundance for egg (top) and larvae (bottom) data from a delta GLM for 2000-2019.The deltaGLM had effects for year, season, and station.
fig:calcofi_index

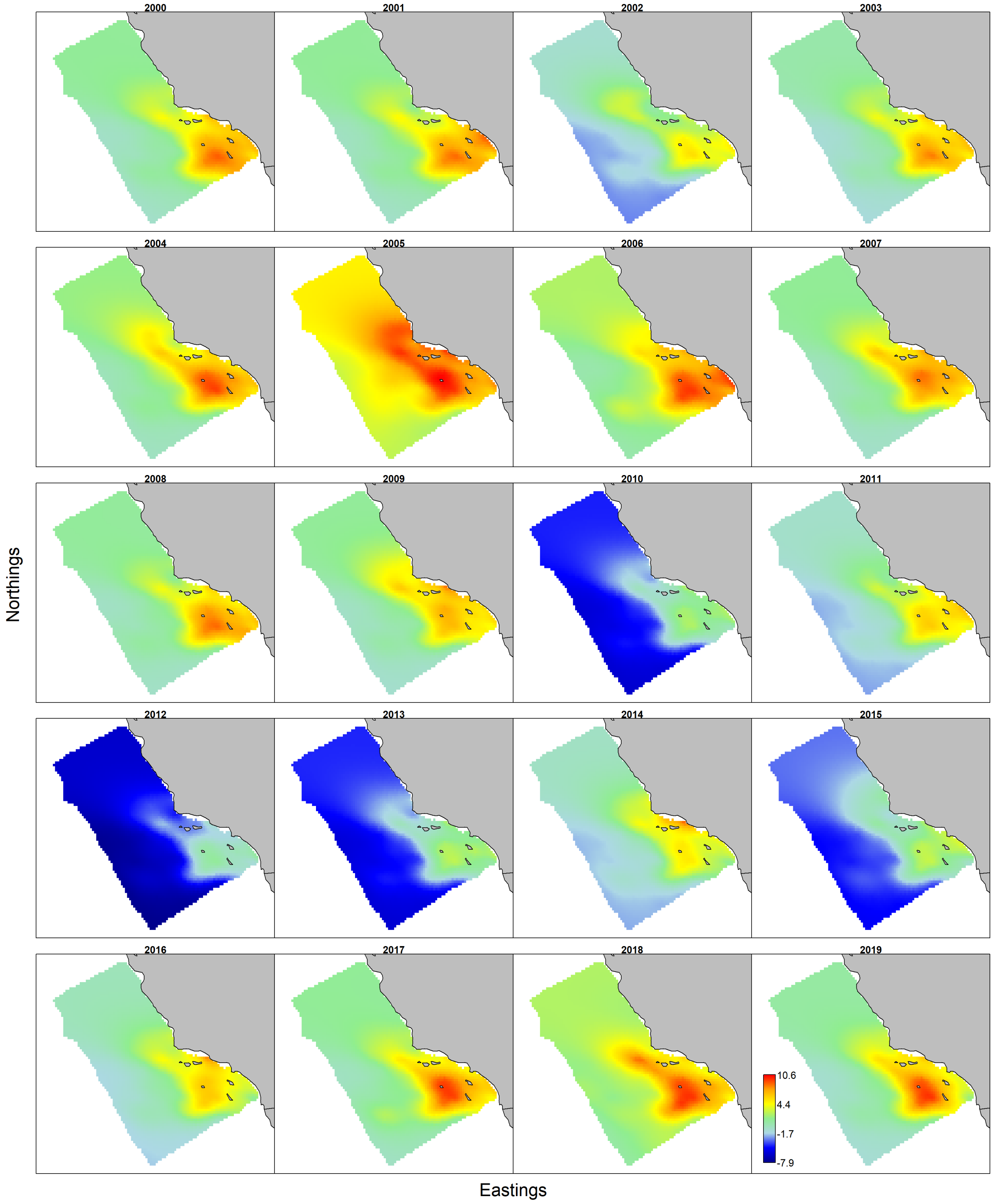

Figure C-4: Spatiotemporal density estimates for CalCOFI eggs. fig:vast_egg_map

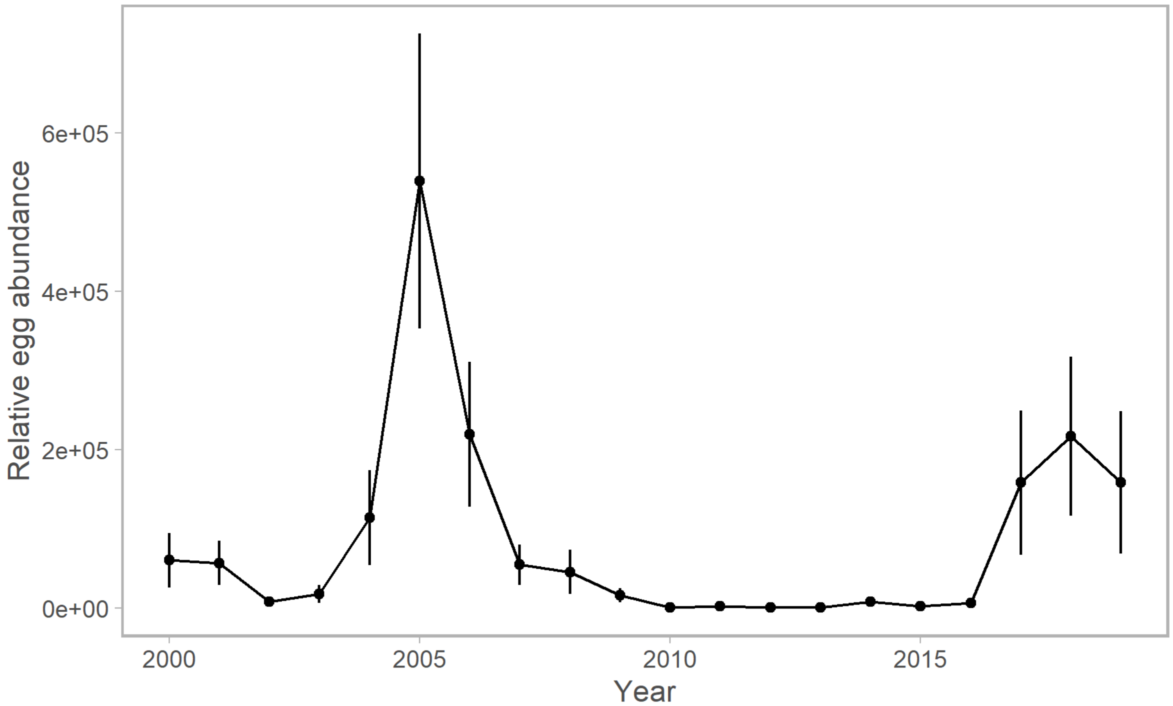

Figure C-5: Relative index of abundance VAST estimates for CalCOFI eggs. fig:vast_eggs

12 Appendix D: California Sea Lion diet time series of anchovy availability

appendix-d-california-sea-lion-diet-time-series-of-anchovy-availability

Prepared by Alex Curtis (SWFSC)

California sea lion diet data have been collected at two key southern Channel Islands rookeries on a quarterly basis since 1981 (Fig. 1; Lowry and Carretta 1999). As important predators of small pelagic forage fishes, sea lions provide an index of anchovy relative abundance as well as insight into their relative mortality rates from predation. The time series includes data on frequency of occurrence, numeric abundance, and size of prey (95% of measured anchovy are between 49-153 mm), allowing reconstruction of consumption of specific age classes and relative biomass over time. This data set greatly extends our knowledge of abundance of all anchovy age classes– including non-reproductive – in past decades in the Southern California Bight, an important nursery area that only has been covered by annual trawl surveys in recent years.

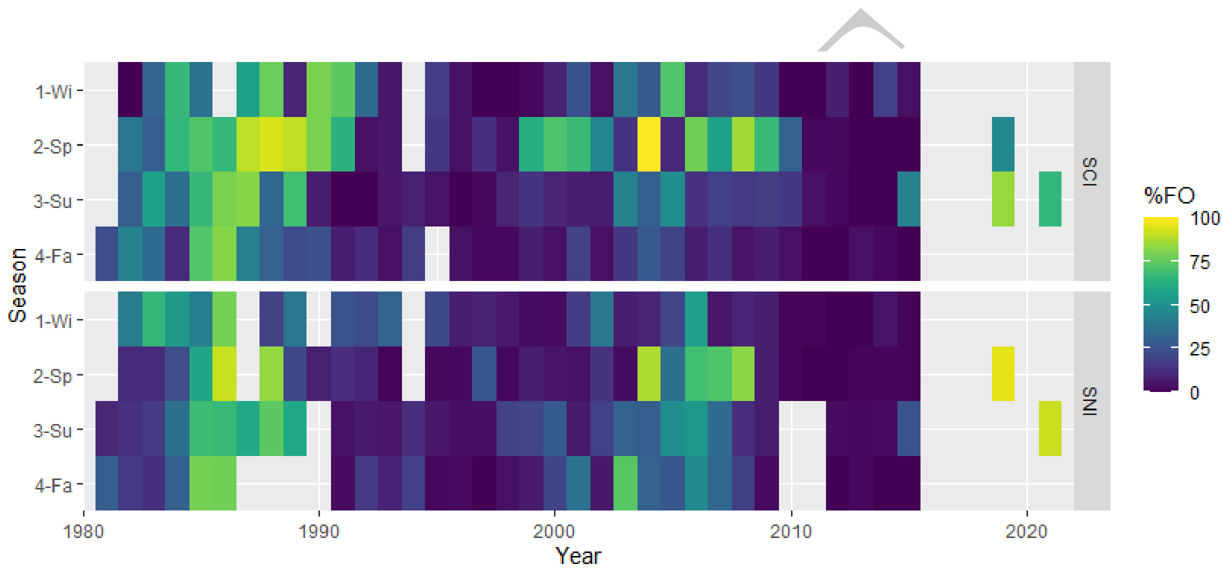

Figure 1. Heat map of percent frequency of occurrence (%FO) of anchovy in California sea lion scats collected quarterly at San Clemente Island (SCI) and San Nicolas Island (SNI). Season abbreviations are 1-Wi = Winter, 2-Sp = Spring, 3-Su = Summer, and 4-Fa = Fall. Apparent gaps in 2010 and recent years are largely an artefact due to a backlog in sample processing, with the exception of spring 2020 through winter 2021, a true gap attributable to COVID-19 sampling restrictions.

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