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Nearshore Aerial Survey Biomass for the 2021 Northern Anchovy Stock Assessment

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Executive Summary

The Pacific Sardine (*Sardinops sagax*, sardine) and Northern Anchovy (*Engraulis mordax*, anchovy) fisheries along the U.S. Pacific Coast have been federally managed under the Coastal Pelagic Species (CPS) Fishery Management Plan since 2000 by the Pacific Fishery Management Council and the National Marine Fisheries Service. CPS finfish stock assessments do not account for the portion of stock abundance in nearshore waters due to constraints on the ability of National Oceanic and Atmospheric Administration research vessels to access these shallow waters while conducting acoustic trawl (AT) surveys. In 2012, the California Department of Fish and Wildlife and the California Wetfish Producers Association began collaborating on an aerial survey known as the California Coastal Pelagic Species Survey (CCPSS) covering Northern and Southern California nearshore waters. A Nearshore Cooperative Survey, which began in August 2018, was also developed to validate aerial observer biomass estimates and species identification. Nearshore biological sampling has been coordinated with these and the AT surveys. The CCPSS biomass estimate data were used in the 2020 sardine stock assessment to adjust AT survey catchability. This document describes CCPSS design, methods, and anchovy biomass estimates for aerial surveys conducted since 2015 and highlights the changes implemented for 2020-2021 surveys.

Nearshore regional aerial density and biomass estimates for 2015-2021 surveys were consistent with migration patterns of anchovy in Northern and Southern California. Observed anchovy abundance was consistently higher in Northern California, in part due to their apparent seasonal migration patterns and more northerly distribution in the summer/fall months and southerly in the winter/spring during the primary spawning season. Southern California surveys since summer 2020 have seen relatively high biomass between Santa Barbara and Ventura (3,483-11,383 metric tons [mt]). In Northern California since summer 2020, anchovy have been observed in heavy concentrations within Monterey Bay (11,800-38,565 mt) and in 2018 off the Big Sur coast (69,967 mt). Available length and age data from all collected samples since 2016 by CCPSS season and region show little fluctuation in the size and age ranges through the seasons and areas. Mean anchovy length in Northern California for all surveys was 111.99 millimeters (mm, standard deviation [SD]=14.17), and mean age was 1.80 years (SD=0.95), while for Southern California the mean length was 97.64 mm (SD=13.32) and mean age was 1.42 years (SD=0.80).

1.0 Introduction

The central subpopulation of Northern Anchovy (*Engraulis mordax,* anchovy, CSNA) ranges from Punta Baja, Mexico to San Francisco, California (PFMC, 2019), and has been a major fishery in California since the 1940s, with historic peak landings dating from the late 1960s to the early 1980s (CDFW, 2001). Anchovy reside in nearshore waters under both low and high population levels (MacCall, 1990). The last stock assessment completed for anchovy was in 1995 (Jacobson et al., 1995), and since the early 1980s annual landings have not reached the allowable biological catch of 25,000 mt (CDFW, 2022). Recent National Oceanic and Atmospheric Administration (NOAA) Southwest Fisheries Science Center (SWFSC) surveys have documented a rebound in the anchovy spawning stock biomass (Dorval et al., 2018) and total biomass (Stierhoff et al., 2020). The lack of a full stock assessment, combined with an interest in ecosystem management, has resulted in renewed interest in anchovy research and management.

The Pacific Sardine (*Sardinops sagax*, sardine) and anchovy fisheries have been federally managed since 2000 under the Pacific Fishery Management Council's (PFMC) Coastal Pelagic Species (CPS) Fishery Management Plan (PFMC, 2019). The sardine stock assessment uses an integrated population model that incorporates data such as age and growth, age and length composition, weight-at-length, and maturity schedule from multiple NOAA research surveys. Surveys include: SWFSC daily/total egg production (DEPM/TEP) surveys conducted in the spring in offshore waters within and around the Southern California Bight and off the central coast of California (Lasker, 1985; Lo et al., 2011); SWFSC coastwide acoustic-trawl (AT) surveys (Zwolinski et al., 2016); and an aerial survey in the Pacific Northwest conducted from 2009-2012 by the northwest sardine fishing industry (Jagielo et al., 2012). The sardine stock assessment previously used aerial survey results from a spotter pilot logbook survey, which was flown from 1985-2005 and covered the area from central California to Baja California, Mexico; however, this survey was removed from the assessment in 2007 (Lo et al., 1992; Hill et al., 2008).

Recent stock assessment methods for CPS have not directly accounted for the abundance of the portion of the stocks in the nearshore due to constraints on the ability of research vessels to access these shallow waters. Information on the most productive fishing areas provided by industry and past research (MacCall, 1990) indicate that a substantial portion of juvenile abundance and non-negligible portions of adult biomass reside in these waters, resulting in biased low estimates of abundance and potential under-projection of future abundance.

Fishery-independent data for CPS assessments from the seasonal DEPM/TEP and AT surveys focus only on offshore waters greater than about 3.7 kilometers (km), or two nautical miles (nm) from shore. Survey information from nearshore waters has been lacking, yet these areas are known habitat for CPS. As there is now PFMC interest in a current assessment of the abundance of anchovy, nearshore information may serve as a valuable data stream. It has been recognized that additional sampling efforts are needed to supplement current surveys to provide more data on the abundance of both species in nearshore waters (PFMC 2016).

In 2012, the California Department of Fish and Wildlife (CDFW) and the California Wetfish Producers Association (CWPA) began collaborating on a daytime visual aerial survey, adapting previous aerial survey methods from the Pacific Northwest for use over southern California waters (Jagielo et al., 2012). This survey is now known as the California Coastal Pelagic Species Survey (CCPSS). These surveys were intended to provide data necessary to account for the biomass of CPS inshore of the existing AT survey transects. These efforts were focused on investigating abundance of two commercially important species off the U.S. Pacific Coast, the northern subpopulation of sardine and beginning in 2013, anchovy.

A 2017 PFMC methodology review recommended research to develop methods for estimating CCPSS aerial survey biomass variance and quantifying observer bias (PFMC, 2017). An ongoing Nearshore Cooperative Survey (NCS) project, which began in August 2018 (Dorval and Lynn, 2019), was developed to address these recommendations. Preliminary results from the NCS project were reviewed at a meeting for anchovy management in October 2019 (October 2019 meeting) hosted by PFMC (PFMC, 2019).

The CCPSS was only conducted within the Southern California Bight during the first five years (2012- 2017), and then extended north of Point Conception to cover nearshore waters off Northern California beginning in August 2017 (Lynn et al., 2017; Lynn et al., 2019). The 2017 summer survey was intended to sample nearshore coastal areas corresponding to offshore transects with the southernmost extent of the AT survey conducted at the same time. Efforts to conduct the CCPSS off Northern California in summer 2018 were not successful due to logistical constraints. However, the CCPSS successfully coordinated with the AT survey in summer 2019.

The CCPSS biomass estimate data were used in the 2020 sardine stock assessment to adjust acoustic survey catchability (PFMC, 2020a). The methods were modified to address concerns raised during the 2020 sardine stock assessment review meeting over the lack of transect replication to compute variance of survey biomass estimates (PFMC, 2020a), and were used for surveys beginning in summer 2020 and continuing through summer 2021. Research on validation of observer data also continued with the NCS (Dorval and Lynn, 2019) employing the same methods as used in previous work. This document describes CCPSS design, methods, and anchovy biomass estimates for aerial surveys conducted since 2015 and highlights the changes implemented for 2020-2021 surveys.

2.0 Methods

2.1 Aerial Survey

CCPSS flights were conducted in summer 2020 off the Northern California coast, from approximately Point Arena to Morro Bay, and in both summer 2020 and spring 2021 within the Southern California Bight from just south of Point Conception to San Diego (Figures 1-2). These surveys flew over areas inshore of AT survey tracklines (Stierhoff et al., 2020), covering shallower waters that are not sampled by NOAA research vessels. In the interest of providing aerial biomass estimates that can be expanded to unsampled nearshore waters, aerial transect lines were replicated beginning in 2020. Past CCPSS designs (2015-2019) did not include true replicated transects, but simply inshore and offshore transects, which were analyzed as replicates (Lynn et al., 2019; PFMC, 2020a). Locations and sizes of strata were selected to cover the coastline while avoiding restricted flight zones, and to allocate sufficient time for completing each stratum in a single day. Coordination with both the Fisheries Survey Vessel (FSV) *Reuben Lasker* and the nearshore acoustic survey fishing vessel (F/V) *Long Beach Carnage* began in 2017 and 2019 respectively, with very close synchronization, generally within a few days (Table 1).

For a given flight day, the determination of which strata are flown is contingent on local weather conditions, coordination with acoustic survey vessels (if any), and random selection within those constraints. For any specific area, acceptable conditions for conducting a survey flight are wind speed no more than approximately 10-12 knots, and at least 90% clear of cloud cover. Transects were completed using a CDFW Cessna 185 aircraft flown by a CDFW Warden-Pilot with an experienced industry spotter from the CWPA serving as observer and a CDFW biologist as data recorder. Surveys were flown at 457 meters (m, 1,500 feet (ft)) altitude. Normally, strata were selected based on nearest proximity to the acoustic survey area that day in terms of location and time. No acoustic surveys were conducted in 2020 because of COVID-19 restrictions, so strata that met acceptable conditions were selected based on coordination with nearshore sampling by F/V *Long Beach Carnage*. For each stratum selected on a given day, the starting line (inner or outer) was randomly selected and maintained for the subsequent replicated flights for that stratum.

When sardine or anchovy were identified along a given transect, the aircraft diverted from the transect to confirm identification and obtain species composition and tonnage estimates. These observations were recorded on field datasheets. For additional details on survey methods and data recorded, refer to Lynn et al. (2019).

For 2015-2019 surveys, the CCPSS design used two parallel coastal transects following the contours of the shoreline. These consisted of an inner and outer transect line, each 1,200 m (0.65 nm) wide. Survey coverage thus included nearshore waters from the shoreline out to 2,400 m (1.3 nm). The observer was positioned on the right side of the aircraft and looked to the right. Direction of travel and plane flight path were chosen based on minimizing glare due to sun position at the time of the survey. Surveys were flown only when cloud cover and winds allowed for observing CPS schools based on detectability and fish presence in the upper water column (within about 10 m (32.8 ft) depth). Additional details are available in Lynn et al. 2019. For survey years 2015, 2016, and 2018 there was opportunity to survey the Southern California area twice in the same season; these surveys are referred to as Survey 1 and Survey 2.

The revised survey design implemented beginning in 2020 includes two types of strata: a) those selected to be surveyed (north: N1-N8 and south: S1-S6), and b) those for which post-survey expansion of aerial biomass estimates are applied ("expansion strata"; north: N1E-N7E and south: S1E-S5E) (Figures 1-2). Data that are opportunistically collected from expansion strata can be analyzed to examine variability when extrapolating into areas not surveyed. Airspace restrictions surrounding Los Angeles International Airport greatly limit surveyable areas in the vicinity. For this reason, there are two smaller selected strata, S3 and S4, to represent the surveyable area. The expansion stratum S3E, which contains the restricted flight zone, is not surveyable. Survey strata measure 56 km (30 nm) long, except for S3 and S4 at 28 km (15 nm) long. Expansion strata are 28 km (15 nm) long, except S2E (26 km (14 nm)), S3E (56 km (30 nm)) and S4E (13 km (7 nm)). Within each stratum, three transect lines that follow the shore contours are located at 1,200 m (0.65 nm), 2,400 m (1.3 nm), and 3,600 m (1.9 nm) off the coastline. Each line is the offshore boundary of the transect and delineates surveyed water areas 1,200 m inshore of the line. Sampling of the additional water area covered between 2,400 m and 3,600 m off the coastline is new to the survey design, based on fish school spatial distributions observed in 2018-2020 from NCS research (Dorval and Lynn, 2019; Lynn et al., unpublished data). Two daily replicates were conducted for each transect line. Here, a flight refers to a survey of the area associated with a transect line, irrespective of which replicate it represents. Modifying the survey design using surveyed and expansion strata was deemed appropriate given the limited availability of personnel and equipment and the addition of transect replication and the increase in survey coverage further offshore and is similar to the approach used by the AT survey of running a single transect of the coast without sampling all areas of the offshore. The resumption of NOAA offshore and nearshore acoustic surveys in 2021 again required coordination of acoustic survey vessels and CCPSS, with concurrent nearshore biological sampling representing an additional element to the survey design (Stierhoff et al., 2020).

During summer 2020, in Northern California, eight strata (N1-N8) were surveyed from September 5-16. In Southern California, six strata (S1-S6) were surveyed from September 18-20. These surveys were coordinated with nearshore biological sampling conducted by F/V *Long Beach Carnage*. In spring 2021, a Southern California survey was completed in tandem with the acoustic survey from San Diego to Point Conception. Ten strata (S1-S6, S1E-S2E, S4E-S5E) were surveyed from March 22-24 and April 1-2. During summer 2021, a Northern California survey was again completed with both acoustic survey vessels, surveying four strata (N1, N2, N4, N5) between August 8-11. After a brief pause due to a port call for AT survey vessel maintenance, the survey covered Southern California waters from Point Conception to San Diego between September 12-17, completing nine strata (S1-S6, S1E-S2E, S4E).

The summer 2020 surveys in both Northern and Southern California did not include expansion strata due to the limited time and uncertain survey conditions due to weather and coastal areas inaccessible because of firefighting efforts. Data analyses for these surveys will follow the methods described below. Surveys beginning in 2021 included expansion strata when time was available on a given survey day following a completed survey of a planned stratum. This helped maximize the coastal water area that can be surveyed while allowing for flexibility in tracking the acoustic survey vessels and accounting for possible bad weather. In spring 2021, the Southern California survey was successful in surveying all strata including expansion strata, except for S3E; therefore, only S3E biomass and variance will be derived from expansion analysis. In summer 2021 for Southern California, all strata were surveyed again, except for S3E and S5E.

2.2 Biological Sampling

Biological data were collected from the F/V *Long Beach Carnage*, which sampled strata in coordination with the aerial survey beginning summer 2020. These samples were taken using dip nets from fish captured by purse seine gear; the remainder of the fish was released. Total fish school biomass (not just fish wrapped) were estimated by vessel captains using SONAR. Nearshore acoustic surveys are designed to be in concert with the offshore AT survey, and these nearshore sample data are closest in time and space to CCPSS observations. Additional sampling information and protocols are presented in Appendix A. Since 2019, the nearshore catch processing protocol for each set has closely followed that used by the F/V *Lisa Marie* for acoustic survey research in the Pacific Northwest (PFMC, 2020b). Other sources of biological data, which include NCS point sets and commercial fishery samples, are described in Appendix B. All NCS point set sampled fish were aged at the CDFW lab. Samples from F/V *Long Beach Carnage* are not yet aged, and those from fishery landings are aged only through spring 2021. Samples for which less than 10 fish were collected are not included in the analysis.

2.3 Aerial Survey Biomass and Density Estimation

For the 2015-2019 surveys, biomass estimates from the two transects were summed to obtain total biomass, and variance obtained from data across the transects (PFMC, 2020a). In 2020-2021, for daily aerial surveys within each stratum, biomass was estimated for each school observed on a given transect whenever possible. However, in many instances, the observer was not able to estimate individual school biomass, particularly with numerous moving and intermixing schools on the transect. For these cases, the biomass was "aggregated" for all fish schools observed on this portion of the transect line. Therefore, the sampling unit of the survey was considered to be the transect line surveyed by the spotter during a flight in a given stratum (Dorval and Lynn, 2019). The main objectives were to: a) estimate the daily total biomass measured on a given stratum; b) estimate the mean biomass density and its variance on a given stratum on a given day; and c) estimate the mean density and variance for each region (Northern or Southern California) during the survey period.

During NCS point set sampling, the pilot ("Spotter 1") and an additional observer ("Spotter 2") communicated the location of observed schools and directed the purse seine fishing vessels to wrap selected individual schools. The spotters independently determined school species compositions and estimated the biomass and the proportion of each school that was effectively wrapped and caught by each purse seine set. The weight of the catch by species in each vessel well were recorded separately for each point set, facilitating the determination of total weight and species composition of each captured school (Dorval and Lynn, 2019). All CCPSS field biomass estimates were corrected using an updated calibration curve with sardine and anchovy data for Spotter 1 from NCS point sets conducted through October 2020 (Figure 3). Spotter 1 has continued to be the sole observer providing school estimates for all CCPSS flights.

Assuming the observer detects all schools present at the surface on a transect line during a given flight, biomass and variance can be estimated as described below (see also Table 2). Section 2.3.1 provides within-transect biomass and variance for anchovy as was done for sardine from NCS data in 2019, and per panel recommendations to examine these parameters by species. Section 2.3.2 calculates total biomass in each stratum. Section 2.3.3 provides calculations on density and variance by stratum. Section 2.3.4 calculates regional biomass and proposes a method to calculate variance for the expanded biomass density in the strata that were not surveyed.

2.3.1 Computation of sampling error within each stratum (within-flight variance estimator)

a) For any given species, the total biomass estimated on *j^th^* transect during the *k^th^* flight in the *s^th^* stratum is:

$$b_{j,k,s} = \sum_{i=1}^{n(i)} b_{i,j,k,s} \qquad (1)$$

where b_i is the biomass estimated for each individual (or aggregated) school, and *n(i)* the total number of schools observed on transect *j,* during flight *k,* in stratum *s*.

b) The simple mean of biomass estimated from all flights in each stratum $\bar{B}_s$ is then estimated as:

$$\bar{B}_s = \frac{\sum_{k=1}^{n(j,k)} b_{j,k,s}}{n(j,k)} \qquad (2)$$

where *n(j,k)* is number of flights in the stratum.

c) Hence, the sampling error (within-flight variance) estimated for each stratum is:

$$Var(\bar{B}_s) = \sum_{k=1}^{n(j,k)} \frac{(b_{j,k,s}-\bar{B}_s)^2}{n(j,k)-1} \qquad (3)$$

2.3.2 Computation of total biomass in each stratum *s*

a) The mean of daily total biomass estimated on the j^{th} transect in the s^{th} stratum is:

$$\bar{B}_{j,s} = \frac{\sum_{k=1}^{2} b_{j,k,s}}{2} \tag{4}$$

b) The grand mean of daily total biomass across the transects $\bar{\boldsymbol{B}}_s$ is estimated as:

$$\bar{\boldsymbol{B}}_s = \frac{1}{N(j,s)} \sum_{j=1}^{N(j,s)} \bar{B}_{j,s} \tag{5}$$

where *N(j,s)* is the number of transects surveyed.

c) The variance of the grand mean of daily mean biomass is:

$$Var(\bar{\boldsymbol{B}}_s) = \frac{1}{N(j,s)-1} \sum_{j=1}^{N(j,s)} (\bar{B}_{j,s} - \bar{\boldsymbol{B}}_s)^2 \tag{6}$$

d) Therefore, the estimator of the total biomass of stratum *s* during the daily survey is:

$$B_s^{tot} = N(j,s) \times \bar{\boldsymbol{B}}_s \tag{7}$$

e) The variance of the estimator of the total biomass of stratum *s* is:

$$Var(B_s^{tot}) = (N(j,s))^2 \times Var(\bar{\boldsymbol{B}}_{\boldsymbol{s}}) \tag{8}$$

2.3.3 Computation of the density and its variance in each stratum

a) The biomass density in stratum *s* was estimated as follows:

$$D_s = \frac{B_s^{tot}}{A_s} \tag{9}$$

where A_s is the area (km^2) effectively flown by the pilot during the aerial survey of stratum *s*.

b) Thus, the variance of the density estimated in each stratum is computed as

$$Var(D_s) = \frac{1}{(A_s)^2} \times Var(B_s^{tot}) \tag{10}$$

2.3.4 Computation of regional density, biomass, and variance

a) If *n* strata were sampled in region *R*, then the mean daily density over these strata will be computed as:

$$\overline{D}_{s,R} = \frac{1}{n(s)} \sum_{s=1}^{n(s)} D_s \tag{11}$$

with *n(s)* being the total number of strata in region *R*.

b) Regional biomass is then the sum of mean daily density multiplied by each stratum area*:*

$$B_R^{tot} = \sum_{s=1}^{n(s)} \overline{D}_{s,R}\, A_s \tag{12}$$

As mentioned above, due to logistical constraints of the aerial survey, some strata were not surveyed. A new approach to expand aerial biomass to those areas was applied using aerial survey data collected in 2020 and in 2021 from surveyed strata. Although prior to the start of each season a pre-determined number of areas was selected to be surveyed, not all selected strata could be effectively surveyed because of weather conditions, delays in acoustic survey legs, availability of spotter or pilot, etc. Consequently, not all possible nearshore strata and transects were sampled, and final estimates of variance for the mean daily density in equation 11 could not reflect a full stratified random sample including all potential strata. However, unbiased estimates of regional density variance can be approximated by: a) assuming that the number of transects measured (*N*) in a given region is a random sample of the total transect population of that region; b) assuming each replicated flight is an independent measurement of biomass within a given stratum for a given day; and c) using bootstrap methods to resample with replacement the replicated (*k*) flights that have been surveyed within each stratum of a given region. Accordingly, for each season the collected aerial biomass data computed for each replicated flight by region, stratum, and transect were resampled. One thousand iterations were conducted and for each iteration (*i*) mean biomass density for the region was computed as:

$$\overline{D}_{s,R,i} = \frac{1}{N} \sum_{s=1}^{s} D_{s,R,i} \tag{13}$$

These resampled means were then used to compute the variance, standard deviation, and coefficient of variation (CV) for mean density estimated in equation 11 for each of the two regions (Northern and Southern California) per season (spring and summer). Finally, equation 11 and its variance (as computed from equation 13) was applied to expand aerial biomass to all areas within the region (bounded by surveyed strata) that were not surveyed either by design (i.e., expansion strata) or due to inclement weather or restricted areas.

Total area of all strata was estimated using geographic information system software (ArcMap Version 10.5.1), which was then multiplied by mean density (equation 11) of a region to calculate an estimate of biomass for the region, including non-surveyed areas. The viability of the proposed approach will depend on the effective number of surveyed strata, and if that number is adequate to compute variance from the bootstrap method.

For days with highly favorable weather conditions, and due to the need to conduct concurrent surveys with the FSV *Reuben Lasker*, aerial surveys were conducted on some expansion strata in Southern California in 2021, for the spring (SE1, SE2, SE4, SE5) and summer (SE1, SE2, SE4) seasons. In these seasons, the survey was post-stratified, with any expansion strata treated as surveyed area with biomass estimates.

3.0 Results

3.1 Point Set Survey and Calibration

Seventy-three NCS point sets for sardine (66) and anchovy (7) were successfully conducted from 2010 and 2018-2020 (Table 3, and see Appendix C, Table C1) and were used to build a mixed calibration curve for these two species (Figure 3). Comparison of aerial estimated catch and adjusted landed catch (ALC, landed tonnage corrected for estimated percent school capture) showed Spotter 1 estimates less than landed tons by about 10% (slope = 0.8984, R^2 = 0.97). This correction factor was applied to all field estimates of anchovy tonnage. Future NCS point set surveys will focus on obtaining more data on anchovy schools, especially the larger schools closer to the capture limit of about 100 mt due to fishing vessel hold size.

3.2 CCPSS Aerial Biomass Estimates

Surveys between 2015-2019 were conducted solely over Southern California waters in 2015 and 2016 and did not begin in Northern California until summer of 2017 (see Table C2 in Appendix C, and Figures D1-D11 in Appendix D). No anchovy were observed in the 2015 Southern California surveys (see Appendix D, Figure D1). Seasonal area biomass and variance (Table 4) were calculated (for details on biomass and variance calculations, see Appendix 4 in PFMC, 2020a). Anchovy biomass and density were much higher in Northern California summer surveys, with area density estimated at 55.70 mt/km^2 (CV=71%) in 2017, 292.48 mt/km^2 (CV=141%) in 2018, and 35.03 mt/km^2 (CV=137%) in 2019. For Southern California surveys between 2015 and 2019, anchovy density ranged between 0 mt/km^2 in the 2015 surveys and 9.37 mt/km^2 (CV=18%) in summer 2019. CV values for Southern California surveys ranged from 18% for summer 2019 to 141% for summer 2016, spring 2018 survey 2, and spring 2019.

Since 2020, summer surveys have been conducted in both Northern and Southern California and spring surveys only in Southern California (see Table C3 in Appendix C, and Figures D12–D16 in Appendix D). As with 2015-2019 surveys, observed anchovy abundance has been consistently higher in Northern California, in part due to their apparent seasonal migration patterns and more northerly distribution in the summer/fall months and southerly in the winter/spring during the primary spawning season (Table 5). As described in section 2.3.4, regional seasonal biomass was computed from density estimates, and its variance was derived from resampling of survey data based on 1,000 iterations (Figure 4). Regional density for Northern California surveys were estimated to be 25.35 mt/km^2 (CV= 2%) and 15.33 mt/km^2 (CV=13%) respectively in summer 2020 and 2021 (Table 5). Regional density for Southern California surveys were estimated to be 5.34 mt/km^2 (CV= 3 %) in spring 2021, whereas summer 2020 and 2021 densities were 3.07 mt/km^2 (CV=27 %) and 6.68 mt/km^2 (CV= 5 %). The distribution of mean density estimated from each iteration is shown in Figure 4 for each of the two regions per season. Anchovy biomass computed based on density estimates for each of the five seasons and by region is reported in Table 5.

Southern California surveys in summer 2020 and summer 2021 have seen relatively high biomass between Santa Barbara and Ventura (3,483-11,383 mt), while the spring 2021 survey also observed notable biomass between Ventura and Malibu (944 mt) and off San Diego County (577 mt) (see Figures D13, D14, D16 in Appendix D). In Northern California, anchovy have been observed in heavy concentrations within Monterey Bay (11,800-38,565 mt) and in 2018 off the Big Sur coast (69,967 mt) (see Figures D5, D8, D11, D12, D15 in Appendix D).

3.3 Biological Samples

Seven anchovy NCS point sets were successfully conducted in 2019 and 2020 (Table 3, see Table C1 in Appendix C, and Figure E1, panels i-m in Appendix E). All but one was from the Monterey Bay area. Four were within a few weeks of a CCPSS flight. Logistically, it is not possible to conduct point sets as close in time with CCPSS compared to other methods, as point set surveys use the same Spotter 1 as used in CCPSS and use different aircraft.

The F/V *Long Beach Carnage* collected 33 anchovy samples from nearshore waters between September 2020 and September 2021 (Table 6, see Figure E1, panels k-p in Appendix E). Summer 2020 samples were collected in close coordination with CCPSS, without the need to coordinate with the offshore AT survey, which was not conducted due to COVID-19.

The California anchovy commercial fishery is currently focused in Northern California, due to market demand. For that reason, the majority of commercial fishery samples that might be useful for CCPSS data were limited to Northern California (Table 7). In addition, the fishery tends to catch anchovy close to port, as the quality rapidly deteriorates the longer they are transported after capture. Samples collected within a month of CCPSS observations were conservatively considered as useful for analysis.

Thus, the fishery samples that were collected within at most a month from CCPSS observations were clustered near Long Beach (see Figure D2 in Appendix D) and Monterey (see Figures D5, D8, D11, D12, D16 in Appendix D). Available biological samples from all sources are summarized and compared with aerial anchovy observations in Table 8.

Available length and age data from all collected samples by CCPSS season and region show little fluctuation in the size and age ranges through the seasons and areas (see Appendix E). Mean anchovy length in Northern California for all surveys was 111.99 mm (SD=14.17), and mean age was 1.80 years (SD=0.95), while for Southern California the mean length was 97.64 mm (SD=13.32) and mean age was 1.42 years (SD=0.80). Mean length-at-age for Northern California fish significantly increased from ages 0-6 (Figure 5). In contrast, Southern California fish showed similar mean length at age across all ages. There was a slight increase in sizes of larger fish in Southern California during spring 2021 (see Figure E1, panel n in Appendix E) compared to those in summer 2020 (see Figure E1, panel g in Appendix E) and spring 2016 (see Figure E1, panels a-d in Appendix E).

4.0 Discussion

Past studies have shown professional commercial fishery aerial spotter pilots to be extremely accurate in tonnage estimates (Williams, 1981; Squire, 1993) and species identification (Taylor, 2015). This has been corroborated by spotter pilot data used in this study compared with both landed tonnage and biological sampling. Squire (1993) found slightly more correlation between aerial index and anchovy biomass estimates than with acoustic survey estimates.

Nearshore regional aerial density and biomass estimates for 2015-2021 surveys were consistent with migration patterns of the anchovy in Northern and Southern California. Consistently higher summer abundance and density of anchovy in Northern California aligns with summer anchovy migrations to northern waters, while in spring anchovy are concentrated in the Southern California Bight for spawning (Dorval et al. 2018). The northern areas may provide a preferred habitat for growth and/or decreased predation. The fact that CCPSS has not observed high abundance in southern waters in the spring may be due to a greater offshore concentration of anchovy, as evidenced by the distribution of anchovy eggs and larvae at that time (MacCall 2016). This suggests that a summer aerial survey index for anchovy in Northern California could be highly valuable, as this may reflect a more complete accounting of stock biomass.

Estimated regional CVs were very low (2%-6%) in Northern California for summer 2020 and in Southern California for spring and summer 2021, compared to regional estimates in Southern California for summer 2020 and in Northern California for summer 2021. This level of differences may reflect the spatial distributions (patchiness) of anchovy in nearshore waters. For example, the discrete patterns observed in Northern California in summer 2021 were likely due to strong geographical pockets of biomass in the preferred habitat of this species during this time period. These differences might be possibly related to fish movements and the interplay with the timing of survey flights conducted in a given season. In some seasons, the strata within a region were surveyed within as few as three days (e.g., summer 2020 in Southern California, 9/18 – 9/20), compared to other seasons where it took many more days to complete flights for a region (spring 2021 in Southern California, 3/22 – 4/2). If relatively few strata can be surveyed within the available time window, this also affects the resampling in the bootstrap analysis. These results might also indicate the need for more daily replicated flights in each stratum per region. Due to logistic constraints, only two replicated flights were conducted on each transect. Thus, future CCPSS should consider increasing the number of replicated flights, so most of the temporal variability of biomass within strata can be captured.

As used in the 2020 sardine stock assessment, CCPSS biomass estimate data synoptic with offshore AT surveys can be useful in adjusting AT survey catchability to account for CPS biomass unaccounted for in nearshore waters. These data could be evaluated for suitability for this purpose based on how closely CCPSS was coordinated with AT survey efforts in time and space, as well as the proportion of observed schools whose sizes fall within those validated by NCS point set data. One caveat to be accounted for would be the relatively smaller latitudinal coverage of the CCPSS compared to the AT survey.

Another potential use of CCPSS data would be as a stand-alone index, using a standardized measure of biomass, such as density. CCPSS data could be segmented by region and season (spring vs. summer), possibly for comparison to other surveys and data, as needed. For example, CCPSS data could be examined as an annual or seasonal regional index (Figure 6). These indices can document regional shifts in abundance possibly tied to life history characteristics described above. Use of CCPSS data in this way would, however, require more biological samples for these surveys than have been able to be collected to date. In addition, the CCPSS aerial coverage has varied over much of the current time series, potentially limiting its applicability, given the variable proportion of the total biomass inshore vs. offshore over time.

The fact that the anchovy stock in recent years has been estimated by the offshore AT survey at more than 1.3 million metric tons (mt) (P. Kuriyama, pers. comm., May 16, 2022) compared with the lower recent CCPSS nearshore estimates has meant that nearshore catchability attributed to CCPSS has been relatively less and reduces the utility of nearshore data as an index or the effect of catchability as a significant factor in overall stock abundance when in high abundance. However, CPS stock abundance can fluctuate unexpectedly, and continued aerial surveys will be useful in the long-term to estimate inshore abundance to inform catchability of the AT survey when stock biomass declines, and a greater proportion of the biomass will likely be inshore. At lower stock biomass (as recently with sardine), there is a greater proportion of biomass inshore of the AT survey, and the CCPSS will account for the underestimation of biomass omitted in the nearshore. While efforts have recently been made to estimate inshore abundance with acoustic methods, further analysis of the proportional volume of the nearshore waters inshore of the AT survey sampled by each method may provide insight into which is preferable given spatial sampling coverage and the patchy/variable nature of the distribution of CPS.

Future surveys using an aerial platform to efficiently collect data on CPS stock abundance can continue to provide valuable information for management. CDFW is currently engaged in preliminary efforts to use alternative means of data acquisition and analysis to improve nearshore CPS surveys by evaluating the use of remote sensing techniques such as multi-spectral sensors to estimate biomass from aerial images as suggested from the 2020 sardine stock assessment review. Data collected from 2018-2020 NCS point sets have provided some information on sardine and anchovy school depth distributions as related to ocean depth and school size (Figures 7-8). During the daytime, at depths shallower than 50 m, it appears that both sardine and anchovy schools extend to near the seafloor bottom. This phenomenon may be useful in estimating school biomass from photogrammetric techniques, although more information is needed for anchovy. This work can potentially lead to survey methods that will be more flexible, cost-effective, comprehensive, repeatable, and accurate. Surveying nearshore CPS abundance with surface vessels remains a challenging task in completely covering the shallowest of habitats given constraints and limitations posed by the ships draft, which aerial platforms do not face.

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6.0 Tables and Figures

Table 1. Survey dates, locations, and difference in timing (days) between CCPSS aerial (A) and acoustic surveys conducted by *Reuben Lasker* (RL) and *Long Beach Carnage* (LBC). Differences in timing are based on areas covered by the CCPSS on specific survey dates.

Aerial Season			Survey Dates			Difference in Days		Aerial B (mt)
Year	Season	Region	Aerial	RL	LBC	A-RL	A-LBC	
2017	Sum	NCA	8/3	8/6, 8/7, 8/8	-	3-5	-	35,651
2017	Sum	NCA	8/4	8/3-8/6	-	1-2	-	32,039
2017	Sum	NCA	8/10	8/8, 8/9, 8/10	-	0-2	-	7,648
2019	Sum	NCA	8/6	7/21-7/25, 7/31, 8/1, 8/2, 8/7	-	1-16[1]	-	0
2019	Sum	NCA	8/7	8/3-8/10	-	3-4	-	47,102
2019	Sum	NCA	8/8	8/9-8/12	-	1-4	-	1,520
2019	Sum	SCA	8/27	8/25-8/29	8/27	0-2	0	9,744
2019	Sum	SCA	8/28	8/30-9/2	8/29, 9/3	2-5	1-6	33
2019	Sum	SCA	8/29	8/29, 8/30	8/26	0-1	3	6
2021	Spr	SCA	3/22	3/21, 3/22	3/21, 3/22	0-1	0-1	577
2021	Spr	SCA	3/24	3/23, 3/24	3/23	0-1	1	45
2021	Spr	SCA	4/1	3/29, 3/30, 3/31	3/29, 3/30	1-3	1-2	5,043
2021	Spr	SCA	4/2	3/23, 3/30	3/28, 3/31	3-10[2]	2-5	2,499
2021	Sum	NCA	8/6	8/8, 8/9	Not Surveyed	2-3	NA	16
2021	Sum	NCA	8/10	8/10, 8/11	8/12, 8/14	0-1	2-4	50
2021	Sum	NCA	8/11	8/11	8/14, 8/15	0	3-4	11,800
2021	Sum	SCA	9/12	9/10, 9/11	9/12	1-2	0	80
2021	Sum	SCA	9/14	9/11, 9/12, 9/13	9/14, 9/15	1-3	0-1	11,399
2021	Sum	SCA	9/16	9/14, 9/15, 9/16, 9/18, 9/19	9/17, 9/18	2-3	1-2	2
2021	Sum	SCA	9/17	9/17-9/21	9/18, 9/19	0-4	1-2	130

[1]No anchovy observed. Survey flight date covered large area from Cape Mendocino to ~ 50 miles S of Pt. Arena.

[2]The 10-day difference was stratum S4 where no anchovy were observed. Anchovy were observed in strata S1 and S1E, which the RL surveyed 3/30 and LBC surveyed 3/28.

Table 2. Parameters, notation, and values included in computations, including additional notes.

Parameter	Notation	Possible Values	Notes
biomass	*b*	variable, mt	Observer estimated biomass
school	*i*	variable (count)	
transect	*j*	1,2,3	One of three survey "bands", each 1,200 m wide
flight	*k*	1,2	Equal to transect-replicate
stratum	*s*	[stratum name]	Either planned or expansion (ex. S1, S1E)
area	*A*	variable, km^2	Survey area
density	*D*	variable, mt/km^2	Biomass/Area, or b/A

Table 3. NCS point set date and weight of fish landed from which anchovy samples were collected, and CCPSS season, region, and dates closest in time to each point set are listed. Data from Spring 2020 in Northern California are not included in biological data analyses for CCPSS, as sample collection dates are considered too distant from closest CCPSS dates. See Appendix C for details on point sets.

NCS Point Set		CCPSS		
Date	**Landed Weight (mt)**	**Season**	**Region**	**Dates**
8/14/19	10.88	Summer	NCA	8/6/19 - 8/8/19
8/15/19	67.33	Summer	NCA	8/6/19 - 8/8/19
9/12/19	62.07	Summer	NCA	8/6/19 - 8/8/19
4/14/20	69.10	Spring	NCA	9/5/20 - 9/16/20
6/18/20	16.62	Summer	SCA	9/18/20 - 9/20/20
10/12/20	7.03	Summer	NCA	9/5/20 - 9/16/20

Table 4. Regional aerial survey density and biomass estimated by season, 2015-2019.

Year	Dates	Season	Region	Area (km^2)	Density (mt/km^2)	Biomass (mt)	CV
2015	8/7 - 8/26	Summer - Survey 1	SCA	1046.88	0.00	0	-
	10/2 - 10/3	Summer - Survey 2	SCA	1058.67	0.00	0	-
2016	4/16 - 5/1	Spring - Survey 1	SCA	984.35	1.07	1,050	0.24
	5/23 - 6/23	Spring - Survey 2	SCA	1043.50	4.08	4,262	1.04
	8/11 - 8/29	Summer	SCA	1037.10	0.03	29	1.41
2017	3/28 - 3/30	Spring	SCA	327.56	0.90	294	0.56
	8/3 - 8/10	Summer	NCA	1352.58	55.70	75,338	0.71
2018	4/24 - 4/27	Spring - Survey 1	SCA	1053.52	0.30	315	1.35
	5/4	Spring - Survey 2	SCA	1055.14	0.32	338	1.41
	9/10 - 9/13	Summer	SCA	995.79	0.03	32	1.01
	10/13	Summer	NCA	239.22	292.48	69,967	1.41
2019	5/29 - 6/28	Spring	SCA	926.50	3.46	3,201	1.41
	8/6 - 8/8	Summer	NCA	1388.02	35.03	48,623	1.37
	8/27 - 8/30	Summer	SCA	1044.32	9.37	9,783	0.18

Table 5. Regional aerial survey density and biomass estimated by season, 2020-2021. Biomass variance was obtained from resampling analysis.

Year	Dates	Season	Region	Area (km^2)	Density (mt/km^2)	Biomass (mt)	CV
2020	9/5 - 9/16	Summer	NCA	2,259.18	25.34	57,257	0.02
2020	9/18 - 9/20	Summer	SCA	1,514.70	3.07	4,649	0.27
2021	3/22 - 4/2	Spring	SCA	1,514.70	5.34	8,092	0.03
2021	8/6 - 8/11	Summer	NCA	1,372.76	15.33	21,049	0.13
2021	9/12 - 9/17	Summer	SCA	1,514.70	6.68	10,124	0.06

Table 6. Estimated school biomass of anchovy schools captured by F/V *Long Beach Carnage* using purse seine gear. Anchovy schools were either mixed with other CPS or pure schools. Note all surveys were coordinated with CCPSS and offshore acoustic surveys, except for fall 2020 when only with CCPSS.

Date	Season	Region	Biomass (mt)	Latitude	Longitude	School Type
9/9/20	Summer	NCA	8.07	37.964	-122.821	Pure
9/9/20	Summer	NCA	28.25	37.931	-122.806	Pure
9/10/20	Summer	NCA	4.04	36.942	-122.077	Mixed
9/10/20	Summer	NCA	3.63	36.947	-122.013	Mixed
9/10/20	Summer	NCA	3.23	36.946	-121.933	Pure
9/12/20	Summer	NCA	16.14	35.417	-120.944	Mixed
9/17/20	Summer	SCA	8.07	34.388	-119.556	Mixed
9/18/20	Summer	SCA	16.14	34.212	-119.294	Mixed
9/20/20	Summer	SCA	6.46	33.705	-118.239	Mixed
9/21/20	Summer	SCA	NA	33.438	-117.674	Mixed
9/21/20	Summer	SCA	NA	33.151	-117.362	Mixed
9/21/20	Summer	SCA	NA	33.144	-117.382	Mixed
9/22/20	Summer	SCA	NA	32.891	-117.264	Mixed
3/21/21	Spring	SCA	8.07	33.063	117.315	Mixed
3/22/21	Spring	SCA	605.39	33.195	117.404	Pure
3/22/21	Spring	SCA	16.14	33.325	117.534	Mixed
3/27/21	Spring	SCA	80.72	34.029	119.613	Mixed
3/28/21	Spring	SCA	32.29	34.415	119.898	Mixed
3/28/21	Spring	SCA	8.07	34.405	119.790	Pure
3/31/21	Spring	SCA	0.81	33.709	118.218	Mixed
8/12/21	Summer	NCA	16.14	38.292	-123.024	Pure
8/13/21	Summer	NCA	1.61	37.884	-122.622	Pure
8/14/21	Summer	NCA	NA	36.949	-122.005	Pure
8/15/21	Summer	NCA	16.14	36.908	-121.867	Pure
8/19/21	Summer	NCA	NA	36.602	-121.156	Mixed
8/20/21	Summer	NCA	40.36	35.136	-120.684	Pure
8/20/21	Summer	NCA	40.36	34.844	-120.651	Mixed
9/13/21	Summer	SCA	40.36	34.371	-119.498	Pure
9/13/21	Summer	SCA	24.22	34.259	-119.286	Pure
9/15/21	Summer	SCA	1.61	34	-118.507	Pure
9/15/21	Summer	SCA	2.42	33.73	-118.367	Mixed
9/17/21	Summer	SCA	12.11	33.708	-118.213	Mixed
9/18/21	Summer	SCA	24.22	33.182	-117.386	Mixed

Table 7. Number of anchovy samples collected by CDFW from standard commercial fishery sampling efforts within one week and one month of CCPSS observations and within the same region (NCA= Northern California, SCA= Southern California). Survey season start and end dates are shown.

CCPSS				# Fishery Samples	
Year	Dates	Season	Region	Week	Month
2016	4/16 - 5/2	Spring	SCA	4	12
2016	5/23 - 6/23	Spring	SCA	0	5
2017	8/3 - 8/10	Summer	NCA	0	6
2018	10/13	Summer	NCA	5	24
2019	8/6 - 8/8	Summer	NCA	1	5
2020	9/5 - 9/16	Summer	NCA	2	5
2021	8/6 - 8/11	Summer	NCA	0	3

Table 8. Biological sample collection dates by season, region, and corresponding survey observation dates for anchovy (NA). The source indicates whether data came from the commercial fishery (purple), NCS point sets (green), or from the F/V *Long Beach Carnage* (blue).

Year	Dates	Season	Region	Source	# of Samples	Sample Collection Dates	Aerial Obs Dates (#NA Obs)
2016	4/16-4/26	Spring	SCA	Fishery	12	3/16 (3), 3/29, 4/6, 4/13 (2), 4/27, 5/3, 5/4, 5/5 (2)	4/16 (9), 4/17 (22), 4/26 (19)
2016	5/23-6/23	Spring	SCA	Fishery	5	4/27, 5/3, 5/4, 5/5 (2)	5/23 (15), 6/22 (27), 6/23 (2)
2016	8/11-8/29	Summer	SCA	None	0	NA	8/11 (9), 8/29 (6)
2017	3/28-3/30	Spring	SCA	None	0	NA	3/28 (6), 3/30 (4)
2017	8/3-8/10	Summer	NCA	Fishery	6	8/18 (2), 8/24, 8/25, 9/5 (2)	8/3 (18), 8/4 (17), 8/10 (11)
2018	4/24-4/27	Spring	SCA	None	0	NA	4/24 (3), 4/26 (8), 4/27 (3)
2018	5/4	Spring	SCA	None	0	NA	5/4 (20)
2018	9/10-9/13	Summer	SCA	None	0	NA	9/10 (8), 9/13 (32)
2018	10/13	Summer	NCA	Fishery	24	9/13, 9/18, 9/19, 9/20, 9/21, 9/24, 9/26, 9/27, 9/28, 10/2, 10/5, 10/9, 10/12, 10/15, 10/16, 10/18, 10/22, 10/24, 10/25, 10/26, 11/2, 11/5, 11/7, 11/9	10/13 (18)
2019	5/29-6/28	Spring	SCA	None	0	NA	5/29 (3), 6/8 (13), 6/14 (2), 6/28 (5)
2019	8/6-8/8	Summer	NCA	Fishery	5	8/5, 8/21, 8/22, 8/28, 8/30	8/6 (1), 8/7 (30), 8/8 (5)
				NCS Point Set	3	8/14, 8/15, 9/12	
2019	8/27-8/29	Summer	SCA	NCS Point Set	1	6/19	8/27 (26), 8/28 (9), 8/29 (1)
2020	9/5-9/16	Summer	NCA	Fishery	5	8/27, 9/16, 9/17, 10/7, 10/8	9/5, (7), 9/6 (2), 9/7 (3), 9/14 (2), 9/15 (43), 9/16 (2)
				LBC	6	9/9 (2), 9/10 (3), 9/12	
				NCS Point Set	2	4/14, 10/12	
2020	9/18-9/20	Summer	SCA	LBC	7	9/17, 9/18, 9/20, 9/21 (3), 9/22	9/18 (27), 9/19 (69), 9/20 (10)
2021	3/22-4/2	Spring	SCA	LBC	7	3/21, 3/22 (2), 3/27, 3/28 (2), 3/31	3/22 (70), 3/24 (46), 4/1 (67), 4/2 (71)
2021	8/6-8/11	Summer	NCA	Fishery	3	9/7, 9/9, 9/10	8/6 (11), 8/10 (29), 8/11 (32)
				LBC	7	8/12, 8/13, 8/14, 8/15, 8/19, 8/20 (2)	
2021	9/12-9/17	Summer	SCA	LBC	6	9/13 (2), 9/15 (2), 9/17, 9/18	9/12 (68), 9/14 (57), 9/16 (61), 9/17 (67)

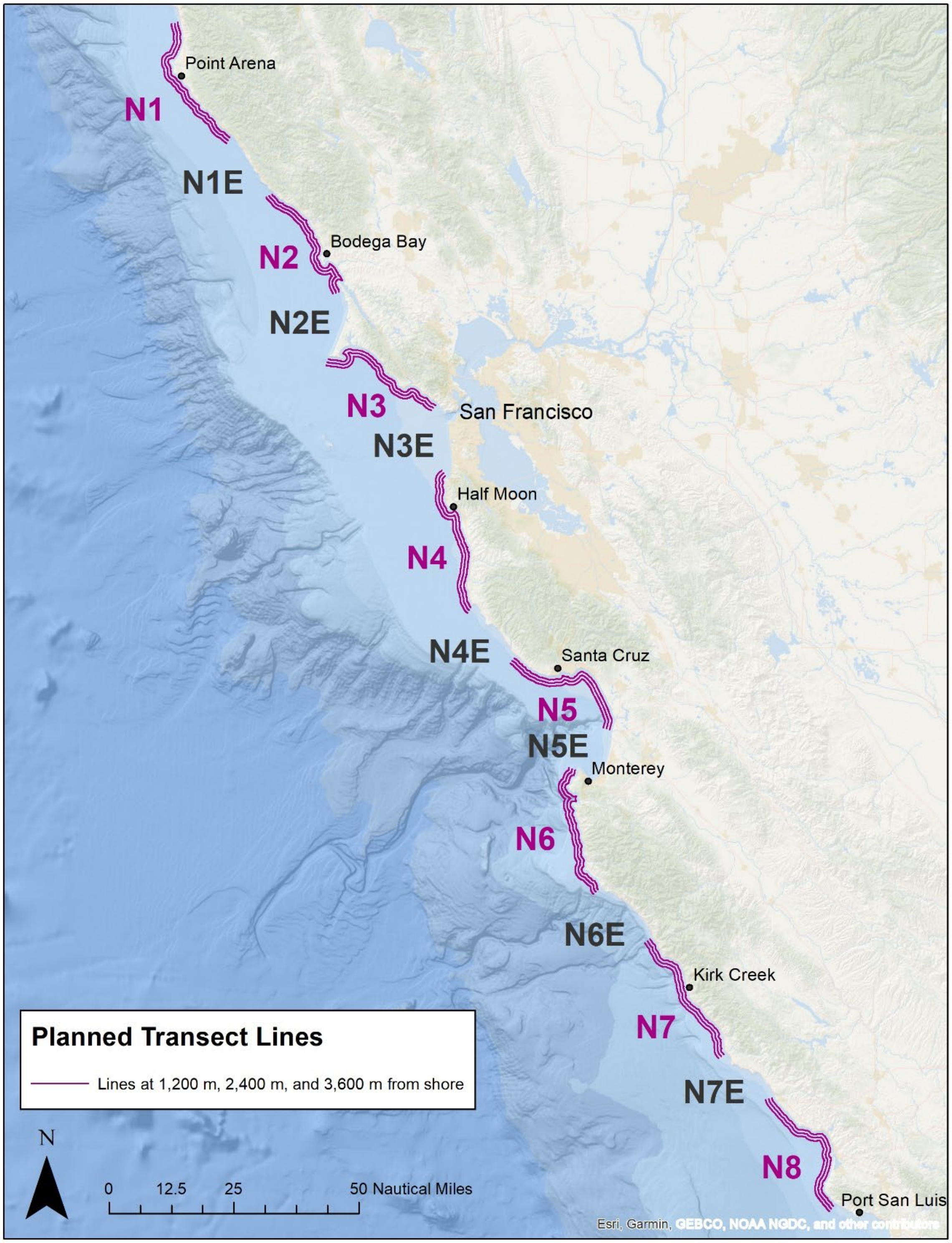


Figure 1. CCPSS strata in Northern California. Predesignated survey strata are in purple; strata for expansion of biomass are in black and denoted with “E” label.

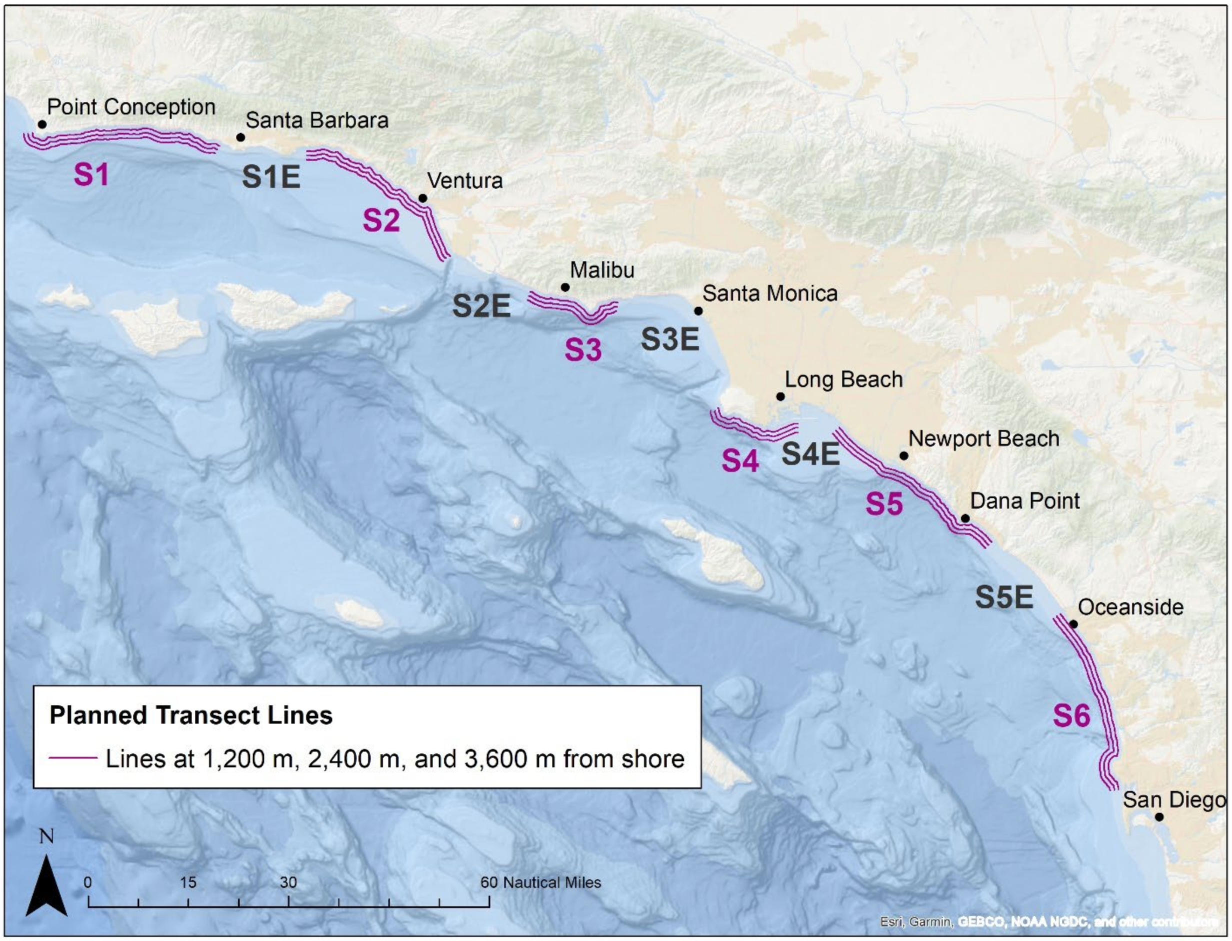


Figure 2. CCPSS strata in Southern California. Predesignated survey strata are in purple; strata for expansion of data are in black and denoted with “E”. Note strata S3 and S4 are smaller to circumvent airspace restrictions.

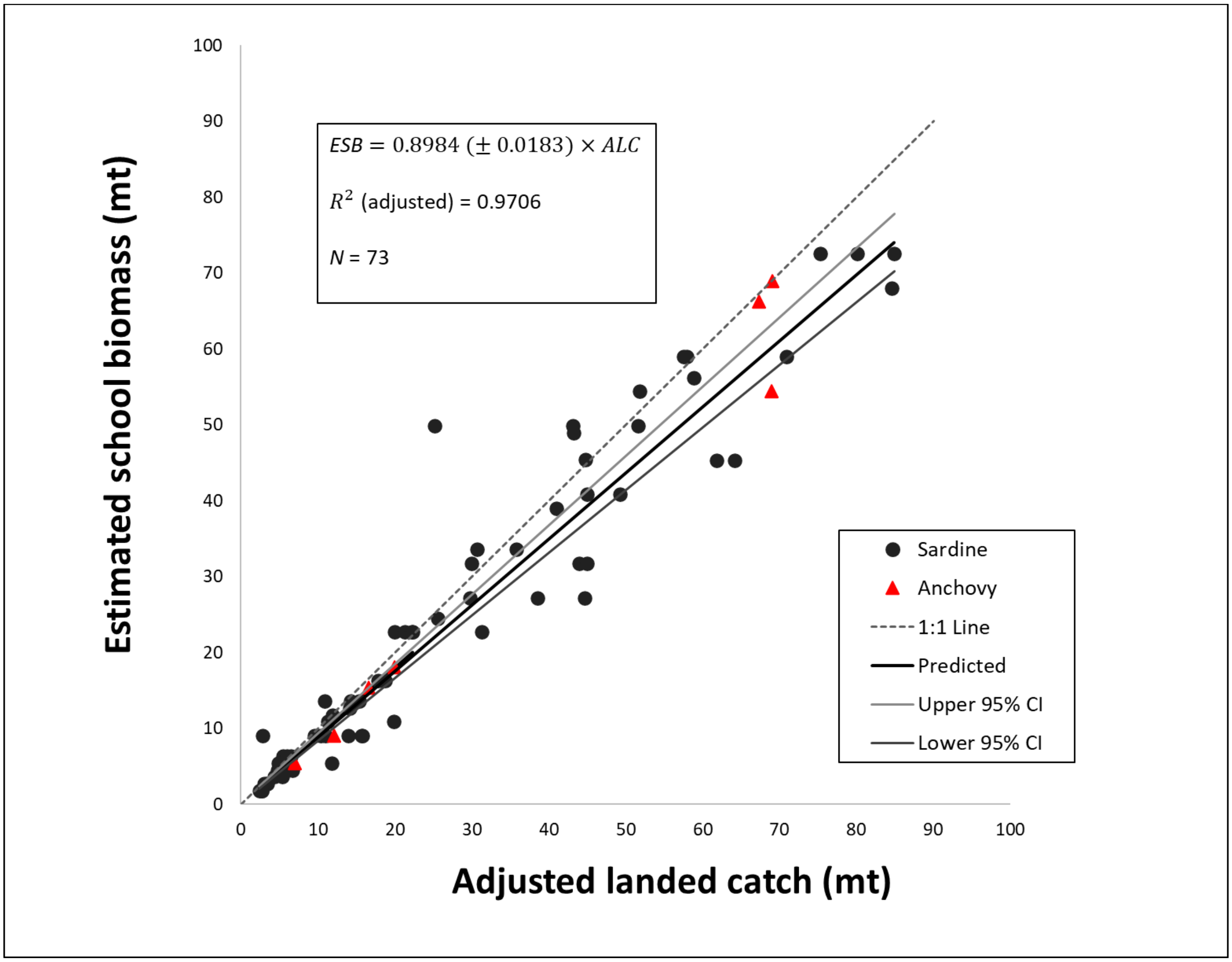


Figure 3. Calibration curve for Spotter 1 from 2010, 2018, 2019, 2020 combined sardine and anchovy point set data. Estimated school biomass (ESB) are aerial estimates of school biomass and Adjusted landed catch (ALC) are the corresponding landed biomass tonnage for those observations, corrected for estimated percent capture by the fishing vessel.

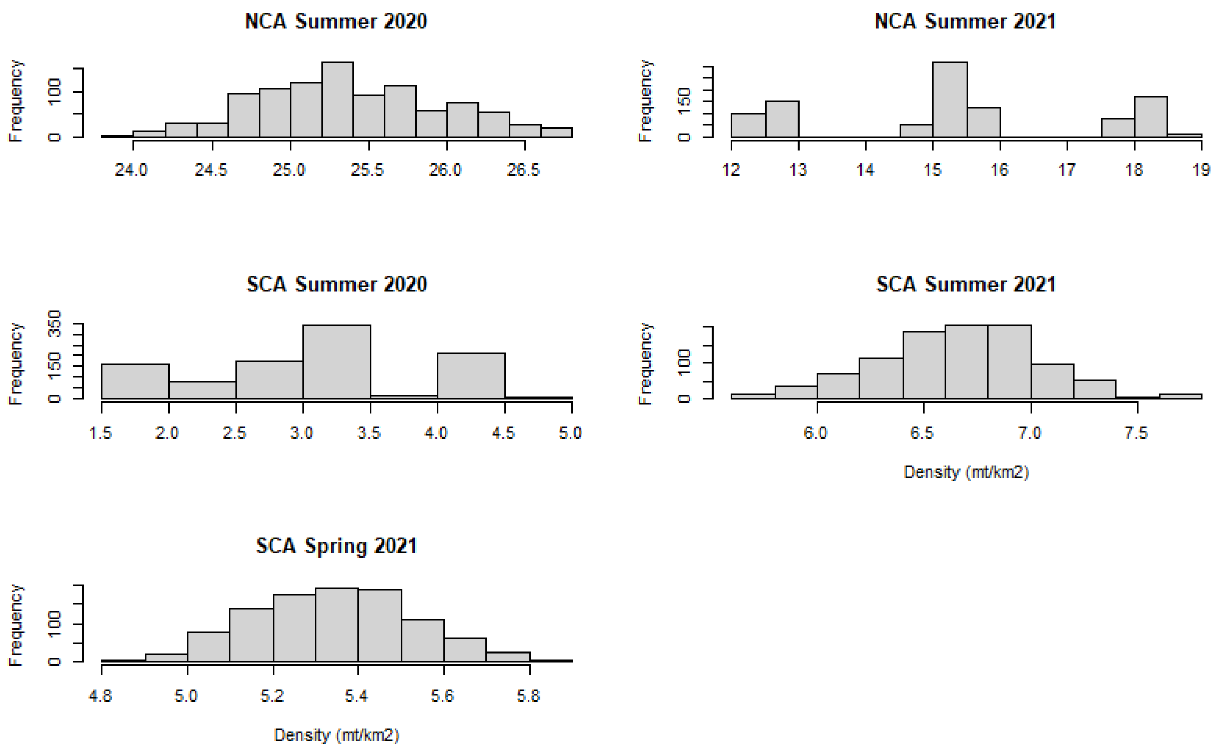


Figure 4. Distributions of mean densities (mt/km^2) of anchovy by region and season from bootstrap resampling analysis (n=1,000) for 2020-2021 CCPSS.

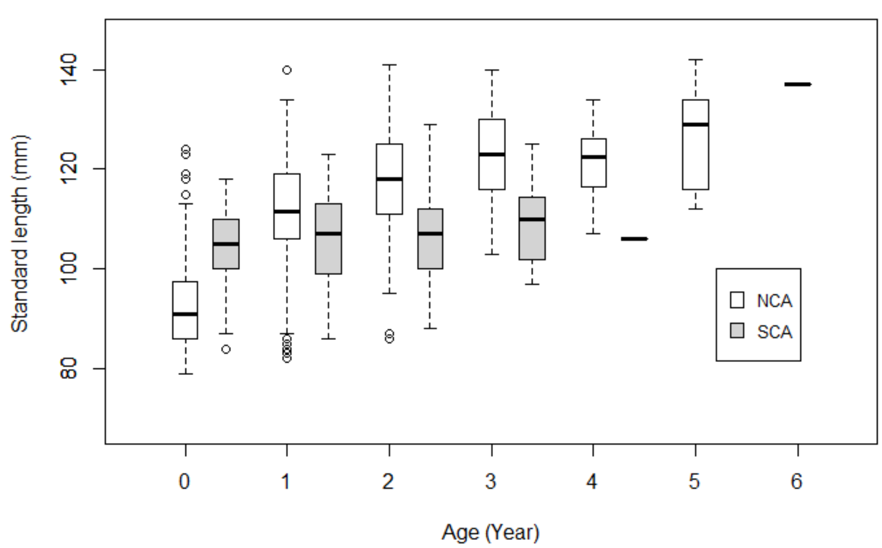


Figure 5. Mean length-at-age of fish collected in nearshore waters off Northern California (NCA, white box plot) and Southern California (SCA, light gray box plot) from 2016-2021. Each box represents the interquartile range of values, with the bold horizontal line indicating the median. Vertical dashed lines indicate values that are within a distance of 1.5 times the interquartile range from the upper and lower quartiles.

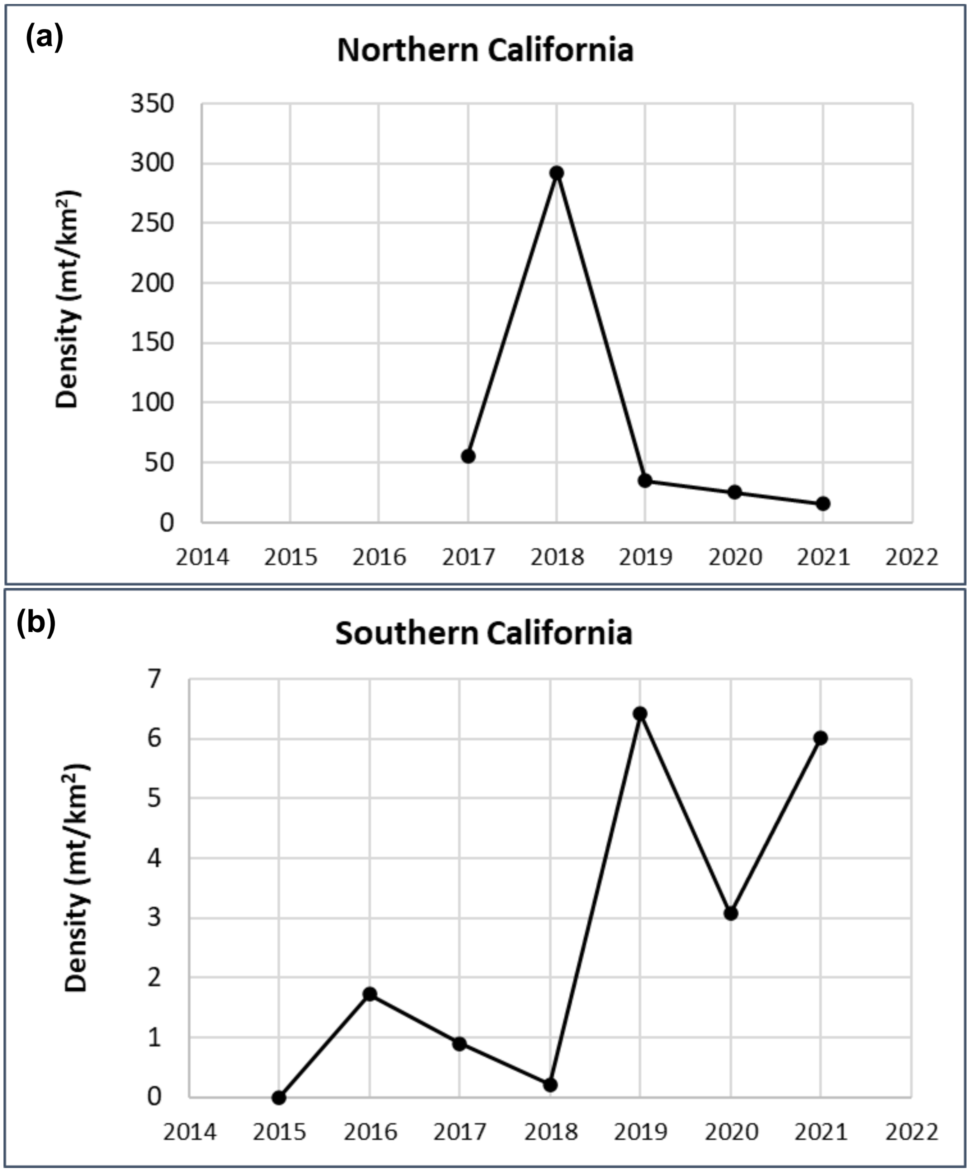


Figure 6. Anchovy density estimates grouped by year for (a) Northern California (2017-2021) and (b) Southern California (2015-2021).

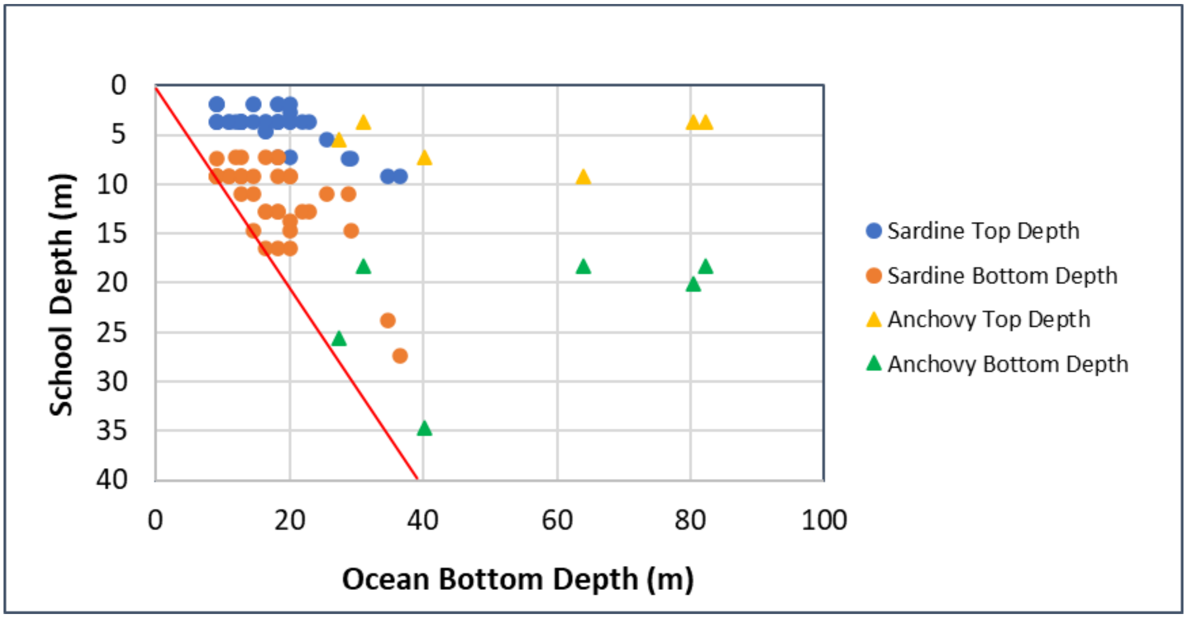


Figure 7. Sardine and anchovy school depth distributions (top and bottom depths) from 2018-2020 NCS point set SONAR data. Red line denotes ocean bottom.

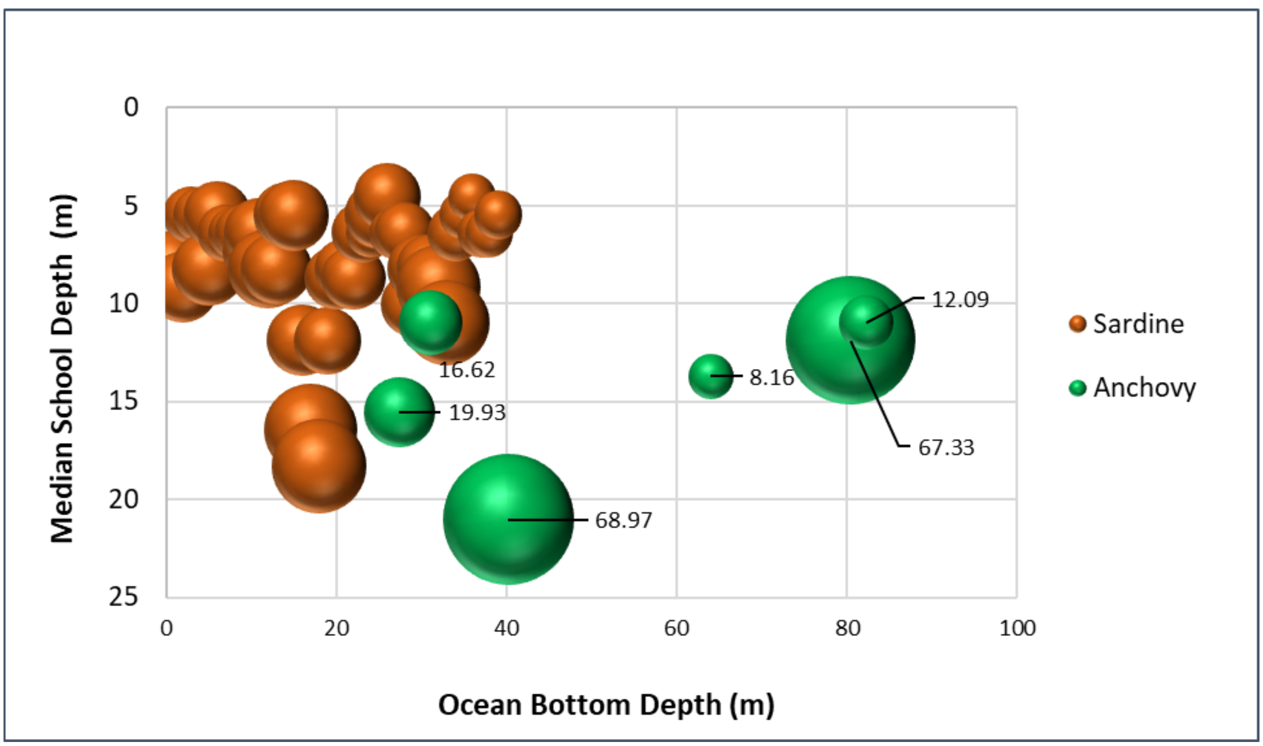


Figure 8. Median school depth distribution, biomass (ALC), and ocean bottom depth from 2018-2020 NCS point sets. Biomass (mt) indicated for anchovy schools to show scale.

Appendix A.

CCPSS Biological Sampling during 2020/2021– F/V *Long Beach Carnage*

In September 2020, the F/V *Long Beach Carnage* was available to support the CCPSS by collecting biological samples off the California coast from the Bodega Bay area south to San Diego. Sampling took place using the same survey strata area as the CCPSS aerial flight path, but occurred independently of aerial surveys, as close in time as possible (no more than three days apart from aerial survey of those strata). The F/V *Long Beach Carnage* began in the north with stratum N2 and proceeded southward, ending at stratum S6 (Figures 1-2). In March 2021, the F/V *Long Beach Carnage* again sampled along with the CCPSS from San Diego to Point Conception, this time in concert with the offshore NOAA AT survey conducted by FSV *Reuben Lasker*. Due to weather and safety issues, the F/V *Long Beach Carnage* began the survey from San Diego and after reaching Orange County proceeded to Santa Catalina and Santa Cruz islands, and then to Point Conception and nearshore areas back to Orange County.The goal was at least three samples taken per sample day. Beginning in August 2021, F/V *Long Beach Carnage* again surveyed nearshore waters off California, beginning at Bodega Bay (Figure 1) and continuing southward through September to the Southern California Bight, in concert with the CCPSS (Figure 2).

The key objective of this sampling is to provide nearshore biological data for acoustic surveys with the added benefit of providing samples for aerial spotter observations, particularly for the 2021 anchovy stock assessment, and possibly the 2022 Pacific Sardine stock assessment update. Fall 2020 and spring and summer/fall 2021 length/age data can potentially be used for the anchovy assessment in late 2021. Data collected with this protocol can also be used to analyze length and age compositions of schools vs. distance from shore, to inform the structuring of future aerial survey design.

Appendix B.

Biological data from point sets and commercial fishery

Additional biological samples may come from NCS point sets for sardine and anchovy conducted through an exempted fishing permit (EFP) for sardine using purse seine gear deployed from chartered CPS fishing vessels. An EFP to collect sardine for this purpose has been used since August 2018, and has been renewed since then, most recently through the 2021-2022 fishing year (PFMC, 2021). Six vessels were approved to provide additional samples coordinated with aerial surveys under the EFP, including increased sampling frequency during spring and summer in Northern and Southern California to complement CCPSS data. These point sets will continue validating aerial estimates on anchovy schools as have been done for sardine, allowing proxy estimates of catchability for the upcoming anchovy assessment.

Before 2014, CDFW had not collected samples from the commercial anchovy fishery since 1982 when it was a reduction fishery (CDFW, 2020). Staff began collecting and processing biological samples to aid in monitoring the changes in the fishery in California and to gather data that could be used in the development of a stock assessment. And similar to using samples from the sardine fishery to correspond with the aerial survey, fishery samples from the anchovy fleet can be used in the same way.

A continuing research question concerns the proportion of adult and sub-adult (“pinhead”) individuals within observed anchovy schools. This has important ramifications on assessments and management, as only adult biomass is applicable as spawning stock biomass. Commercial fishery gear does not capture pinhead biomass, so collaborative efforts with alternative gear types may be able to provide more useful information. The authors have made efforts to procure the requisite gear and expertise to investigate this issue further.

Appendix C.

Table C1. Estimated school biomass (ESB) and percent school wrapped by Spotter 1, landed catch (mt), and adjusted landed catch (ALC) for sardine and anchovy.

			Aerial observation		Purse seine sampling	
Date	Region	Species	Est. School Biomass (mt)	Est. % School Wrapped	Landed Catch (mt)	Adj. Landed Catch (mt)
8/9/10	SCA	Sardine	4.54	100	4.80	4.80
8/12/10	SCA	Sardine	27.22	90	40.20	44.67
8/16/10	SCA	Sardine	27.22	100	38.50	38.50
8/17/10	SCA	Sardine	13.61	100	10.90	10.90
8/18/10	SCA	Sardine	13.61	100	15.40	15.40
8/18/10	SCA	Sardine	9.07	95	15.00	15.79
8/18/10	SCA	Sardine	4.54	100	6.70	6.70
8/18/10	SCA	Sardine	10.89	90	17.90	19.89
8/19/10	SCA	Sardine	9.07	100	2.80	2.80
8/19/10	SCA	Sardine	9.07	100	9.60	9.60
8/22/10	SCA	Sardine	9.07	95	14.90	15.68
8/23/10	SCA	Sardine	22.68	100	20.00	20.00
8/23/10	SCA	Sardine	10.89	95	10.70	11.26
8/31/10	SCA	Sardine	45.36	95	58.70	61.79
8/31/10	SCA	Sardine	22.68	100	31.30	31.30
8/31/10	SCA	Sardine	31.75	100	44.00	44.00
9/1/10	SCA	Sardine	58.97	95	67.40	70.95
9/1/10	SCA	Sardine	40.82	100	45.00	45.00
9/8/10	SCA	Sardine	49.90	90	38.80	43.11
9/8/10	SCA	Sardine	49.90	95	23.90	25.16
9/9/10	SCA	Sardine	40.82	95	46.80	49.26
9/10/10	SCA	Sardine	72.57	100	84.90	84.90
9/12/10	SCA	Sardine	68.04	100	84.60	84.60
9/13/10	SCA	Sardine	22.68	95	20.20	21.26
9/13/10	SCA	Sardine	45.36	100	64.20	64.20
9/13/10	SCA	Sardine	31.75	90	40.50	45.00
8/20/18	SCA	Sardine	2.72	100	3.38	3.38
8/20/18	SCA	Sardine	3.63	95	4.09	4.31
8/21/18	SCA	Sardine	4.54	95	5.70	6.00
8/21/18	SCA	Sardine	4.54	100	5.01	5.01
8/21/18	SCA	Sardine	1.81	100	2.74	2.74
8/22/18	SCA	Sardine	3.63	100	5.38	5.38
8/22/18	SCA	Sardine	16.33	100	18.79	18.79
8/22/18	SCA	Sardine	9.07	100	11.01	11.01
8/22/18	SCA	Sardine	12.70	100	14.20	14.20
8/22/18	SCA	Sardine	11.79	100	11.86	11.86
8/27/18	SCA	Sardine	2.72	100	3.36	3.36
8/27/18	SCA	Sardine	6.35	100	5.45	5.45
8/27/18	SCA	Sardine	1.81	90	2.14	2.38
8/28/18	SCA	Sardine	1.81	100	2.76	2.76
8/28/18	SCA	Sardine	2.72	90	2.76	3.06
8/28/18	SCA	Sardine	5.44	100	4.91	4.91
3/26/19	SCA	Sardine	27.22	100	29.78	29.78
3/26/19	SCA	Sardine	39.01	100	41.02	41.02
3/26/19	SCA	Sardine	13.61	100	15.15	15.15
4/1/19	SCA	Sardine	58.97	100	57.91	57.91
4/1/19	SCA	Sardine	31.75	100	29.97	29.97
4/1/19	SCA	Sardine	49.90	100	51.66	51.66
4/2/19	SCA	Sardine	24.49	100	25.64	25.64
6/28/19	SCA	Sardine	72.57	95	71.49	75.26
8/13/19	Monterey	Sardine	6.35	90	5.88	6.53
8/14/19	Monterey	Anchovy	9.07	90	10.88	12.09
8/15/19	Monterey	Anchovy	66.22	100	67.33	67.33
8/21/19	Monterey	Sardine	5.44	95	11.21	11.80
8/21/19	Monterey	Sardine	33.57	90	27.60	30.67
8/21/19	Monterey	Sardine	9.07	95	13.24	13.93
9/12/19	Monterey	Sardine	54.43	90	62.07	68.97
9/12/19	Monterey	Anchovy	58.97	90	51.82	57.58
4/14/20	Monterey	Anchovy	68.95	100	69.10	69.10
4/22/20	SCA	Sardine	33.57	90	32.21	35.79
6/18/20	SCA	Anchovy	15.42	100	16.62	16.62
6/18/20	SCA	Anchovy	18.14	100	19.93	19.93
10/12/20	Monterey	Anchovy	48.99	100	43.21	43.21
10/12/20	Monterey	Sardine	5.44	100	7.03	7.03
10/13/20	Monterey	Sardine	16.33	100	17.83	17.83
10/13/20	Monterey	Sardine	22.68	100	22.25	22.25
10/14/20	Monterey	Sardine	9.07	100	10.37	10.37
10/14/20	Monterey	Sardine	6.35	100	5.96	5.96
10/15/20	Monterey	Sardine	22.68	100	22.33	22.33
10/15/20	Monterey	Sardine	45.36	100	44.73	44.73
10/15/20	Monterey	Sardine	54.43	100	51.85	51.85
10/21/20	Monterey	Sardine	56.25	100	58.82	58.82
10/21/20	Monterey	Sardine	72.57	100	80.08	80.08

Table C2. Daily anchovy survey data for CCPSS flights from 2015-2019. The survey design consisted of two unreplicated transects covering waters from 0 to 2,400 m offshore.

Date	Region	Area	Start Location		End Location		Area (km^2)	Biomass (mt)	CV
			Latitude	Longitude	Latitude	Longitude			
8/7/15	SCA	Carlsbad-Mexico	32.885	-117.253	32.533	-117.125	124.25	0.00	-
8/11/15	SCA	Point Vicente-Dana Point	33.737	-118.400	33.471	-117.719	183.84	0.00	-
8/13/15	SCA	Dana Point-La Jolla	33.459	-117.699	32.886	-117.254	186.52	0.00	-
8/26/15	SCA	Point Conception-Point Vicente	34.451	-120.435	33.739	-118.410	552.27	0.00	-
10/2/15	SCA	Point Conception-Point Fermin	34.450	-120.425	33.705	-118.291	581.44	0.00	-
10/3/15	SCA	Long Beach-Mexico	33.705	-118.290	32.533	-117.125	477.23	0.00	-
4/16/16	SCA	Long Beach-Mexico	33.721	-118.078	32.533	-117.125	428.87	136.91	0.71
4/17/16	SCA	Point Mugu-Long Beach	34.079	-119.029	33.703	-118.288	102.95	141.92	-
4/26/16	SCA	Point Conception-Point Mugu	34.455	-120.403	34.079	-119.029	359.43	771.37	0.11
5/1/16	SCA	Long Beach-Dana Point	33.881	-118.425	33.351	-117.877	93.10	0.00	-
5/23/16	SCA	Point Conception-Santa Monica	34.456	-120.385	34.007	-118.498	489.93	3213.49	0.67
6/22/16	SCA	Manhattan Beach-Carlsbad	33.880	-118.411	33.287	-117.462	311.71	1048.25	0.52
6/23/16	SCA	Carlsbad-Mexico	33.287	-117.462	32.533	-117.125	241.86	0.00	-
8/11/16	SCA	Point Conception-Santa Monica	34.455	-120.400	34.018	-118.507	488.60	0.00	-
8/29/16	SCA	Manhattan Beach-Mexico	33.865	-118.404	32.533	-117.125	548.49	28.83	0.71
3/28/17	SCA	Point Fermin-Dana Point	33.741	-118.413	33.461	-117.715	189.52	254.90	0.31
3/30/17	SCA	Point Mugu-Santa Monica	34.086	-119.066	34.009	-118.500	138.04	38.96	0.71
8/3/17	NCA	Half Moon Bay-Carmel	37.499	-122.492	36.524	-121.952	402.35	35650.95	0.69
8/4/17	NCA	Point Arena-Half Moon Bay	38.802	-123.595	37.499	-122.492	538.61	32039.18	0.29
8/10/17	NCA	Carmel-Morro Bay	36.525	-121.957	35.448	-120.921	411.62	7648.04	0.63
4/24/18	SCA	Point Fermin-Mexico	33.725	-118.186	32.533	-117.125	451.92	14.47	0.71
4/26/18	SCA	Point Conception-Ventura	34.455	-120.408	34.273	-119.301	274.19	300.53	0.71
4/27/18	SCA	Ventura-Point Fermin	34.274	-119.301	33.725	-118.186	327.41	0.00	-
5/4/18	SCA	Point Conception-Mexico	34.449	-120.423	32.533	-117.125	1055.14	338.38	0.71
9/10/18	SCA	Manhattan Beach-Mexico	33.886	-118.413	32.533	-117.125	553.94	17.81	0.71
9/13/18	SCA	Point Conception-Santa Monica	34.452	-120.418	34.006	-118.494	441.86	13.91	0.71
10/13/18	NCA	Garrapata SP-Ragged Point	36.418	-121.917	35.775	121.328	239.22	69966.61	0.71
5/29/19	SCA	Los Alamitos-Newport Beach	33.729	-118.089	33.594	-117.884	59.82	0.00	-
6/8/19	SCA	Point Conception-Point Dume	34.453	-120.413	34.041	-118.913	390.98	3201.25	0.71
6/14/19	SCA	Newport Beach-Mexico	33.594	-117.884	32.533	-117.125	356.64	0.00	-
6/28/19	SCA	Manhattan Beach-Los Alamitos	33.872	-118.407	33.729	-118.089	119.06	0.00	-
8/6/19	NCA	S. of Cape Mendocino-Stewarts Point	40.343	-124.363	38.627	-123.386	570.77	0.00	-
8/7/19	NCA	Drakes Bay-Manresa Beach	37.989	-122.964	36.622	-121.906	572.12	47102.35	0.71
8/8/19	NCA	Davenport-Limekiln SP (Kirk Creek)	36.622	-121.906	36.013	-121.528	245.12	1520.48	0.71
8/27/19	SCA	Point Conception-Oxnard	34.45	-120.421	34.156	-119.228	311.57	9744.27	0.09
8/28/19	SCA	Point Dume-Mexico	34.039	-118.886	32.533	-117.125	645.25	33.39	0.71
8/29/19	SCA	Ventura-Point Dume	34.156	-119.228	34.038	-118.886	87.49	5.57	0.71

Table C3. Daily anchovy survey data for flown strata for 2020-2021 surveys. Survey design consisted of two replicate flights on three transects covering waters from 0 to 3,600 m offshore.

Date	Region	Season	Stratum	Start Location		End Location		Area (km^2)	Biomass (mt)	CV
				Latitude	Longitude	Latitude	Longitude			
9/5/20	NCA	Summer	N8	35.555	-121.104	35.206	-120.857	199.90	618.88	1.73
9/6/20	NCA		N2	38.535	-123.282	38.214	-122.981	187.38	21.15	1.73
9/6/20	NCA		N3	37.996	-123.026	37.854	-122.570	196.11	0.00	-
9/7/20	NCA		N1	39.090	-123.707	38.721	-123.473	200.11	27.27	1.73
9/14/20	NCA		N4	37.498	-122.501	37.182	-122.393	148.12	38.96	1.73
9/15/20	NCA		N6	37.014	-122.207	36.774	-121.798	164.52	0.00	-
9/15/20	NCA		N5	36.637	-121.938	36.302	-121.896	193.65	38,564.67	1.70
9/16/20	NCA		N7	35.815	-121.376	35.702	-121.305	51.16	0.00	-
9/18/20	SCA	Summer	S1	34.450	-120.472	34.428	-119.913	200.34	0.00	-
9/18/20	SCA		S2	34.417	-119.657	34.150	-119.219	194.99	3,483.24	0.72
9/19/20	SCA		S3	34.061	-118.987	34.032	-118.725	99.76	40.07	1.35
9/19/20	SCA		S4	33.758	-118.418	33.723	-118.193	95.09	0.00	-
9/19/20	SCA		S5	33.706	-118.060	33.413	-117.614	198.56	30.05	1.73
9/20/20	SCA		S6	33.226	-117.412	32.781	-117.255	196.84	0.00	-
3/22/21	SCA	Spring	S5E	33.411	-117.614	33.226	-117.412	100.75	0.00	-
3/22/21	SCA		S6	33.226	-117.412	32.828	-117.280	175.25	576.80	0.94
3/24/21	SCA		S4E	33.722	-118.192	33.706	-118.060	44.27	0.00	-
3/24/21	SCA		S5	33.706	-118.060	33.411	-117.614	198.56	45.41	1.73
4/1/21	SCA		S2	34.417	-119.656	34.15	-119.219	194.99	4,099.58	0.48
4/1/21	SCA		S2E	34.150	-119.219	34.061	-118.988	93.28	784.07	1.03
4/1/21	SCA		S3	34.061	-118.988	34.032	-118.725	99.76	159.62	1.14
4/2/21	SCA		S1	34.442	-120.453	34.428	-119.913	180.36	1,762.58	1.57
4/2/21	SCA		S1E	34.428	-119.913	34.397	-119.707	80.91	736.32	1.55
4/2/21	SCA		S4	33.736	-118.400	33.722	-118.192	78.01	0.00	-
8/6/21	NCA	Summer	N1	38.921	-123.729	38.721	-123.473	122.49	16.14	0.88
8/10/21	NCA		N2	38.535	-123.282	38.214	-122.981	187.38	50.09	1.73
8/10/21	NCA		N4	37.600	-122.514	37.252	-122.418	164.14	0.00	-
8/11/21	NCA		N5	37.014	-122.208	36.774	-121.798	193.65	11,799.70	1.56
9/12/21	SCA	Summer	S1	34.442	-120.453	34.428	-119.913	179.44	0.00	-
9/12/21	SCA		S1E	34.428	-119.913	34.417	-119.656	99.84	80.14	1.73
9/14/21	SCA		S2	34.417	-119.656	34.15	-119.219	194.99	11,383.01	0.63
9/14/21	SCA		S2E	34.150	-119.219	34.061	-118.987	93.28	16.14	1.73
9/14/21	SCA		S3	34.061	-118.987	34.032	-118.725	99.76	0.00	-
9/16/21	SCA		S4	33.758	-118.418	33.722	-118.192	95.09	2.23	1.73
9/16/21	SCA		S4E	33.722	-118.192	33.706	-118.060	44.27	0.00	-
9/16/21	SCA		S5	33.706	-118.060	33.411	-117.614	198.56	0.00	-
9/17/21	SCA		S6	33.226	-117.412	32.838	-117.283	166.68	129.67	0.98

Appendix D.

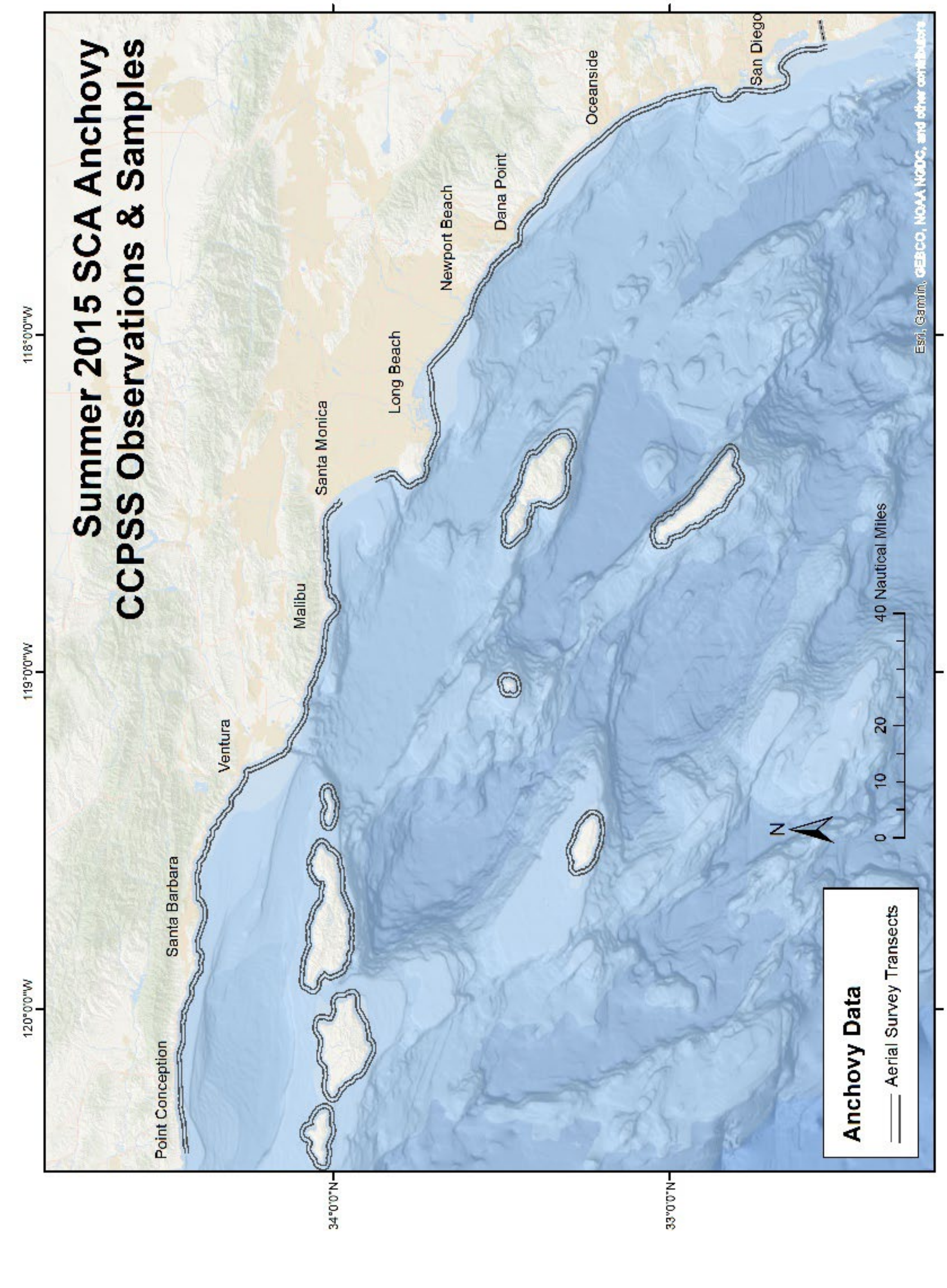


Figure D1. Survey area in Southern California for Survey 1 and Survey 2 during summer 2015. Two unreplicated transects were flown, and no anchovy were observed.

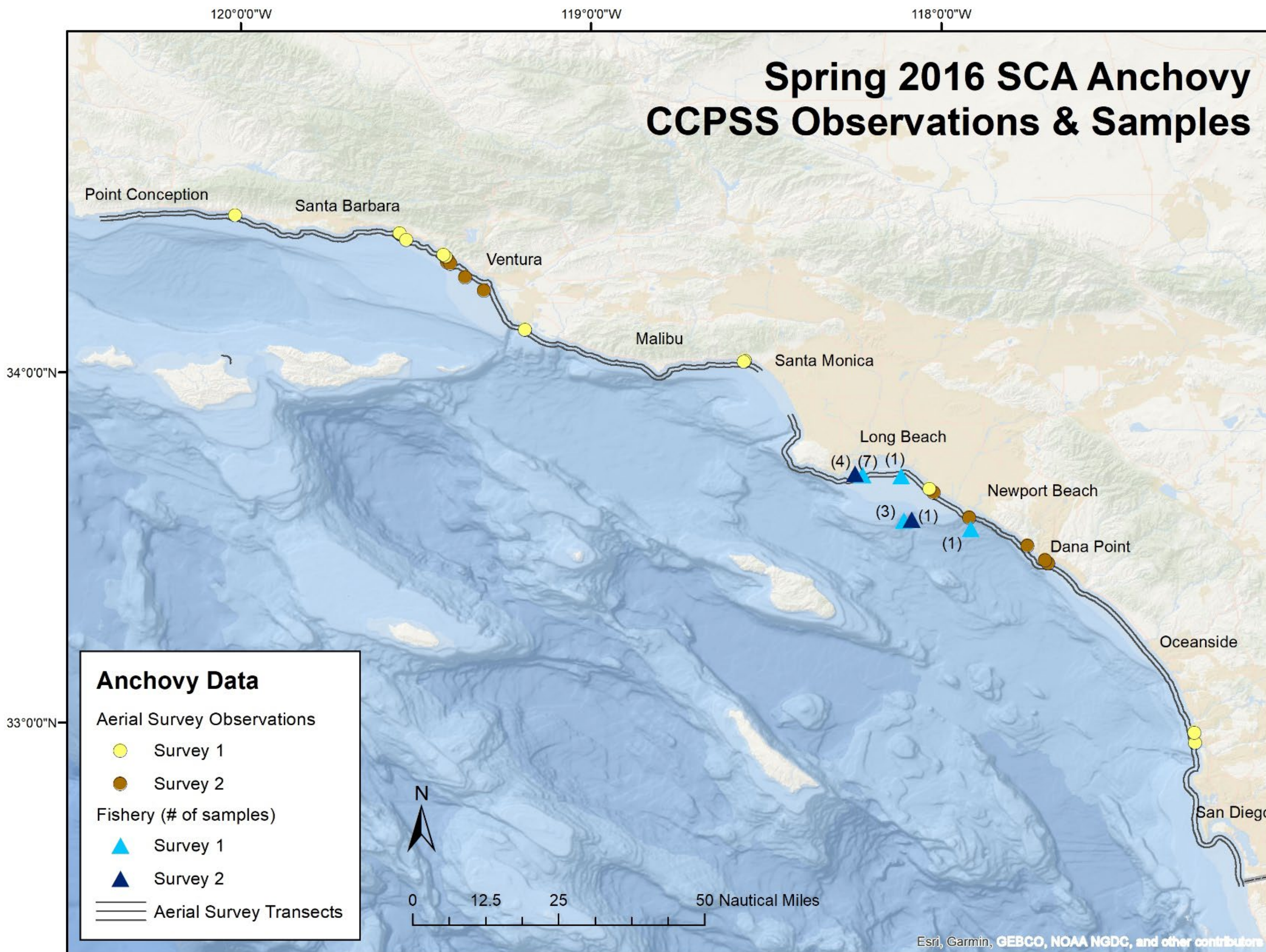


Figure D2. Survey area, school distributions from CCPSS, and location of commercial fishery samples closest in time to Survey 1 and Survey 2 in Southern California during spring 2016.

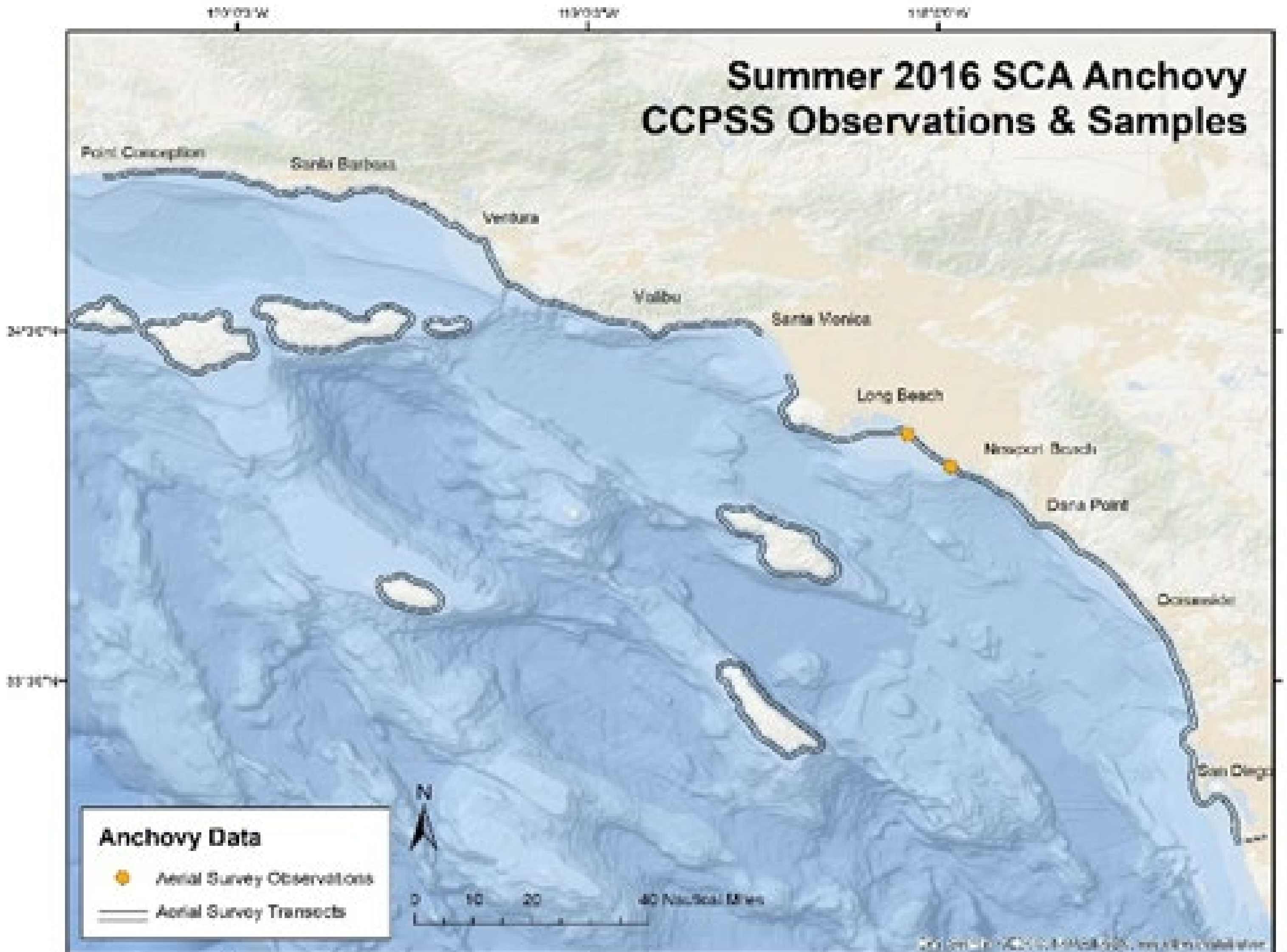


Figure D3. Survey area and school distributions from CCPSS in Southern California during summer 2016.

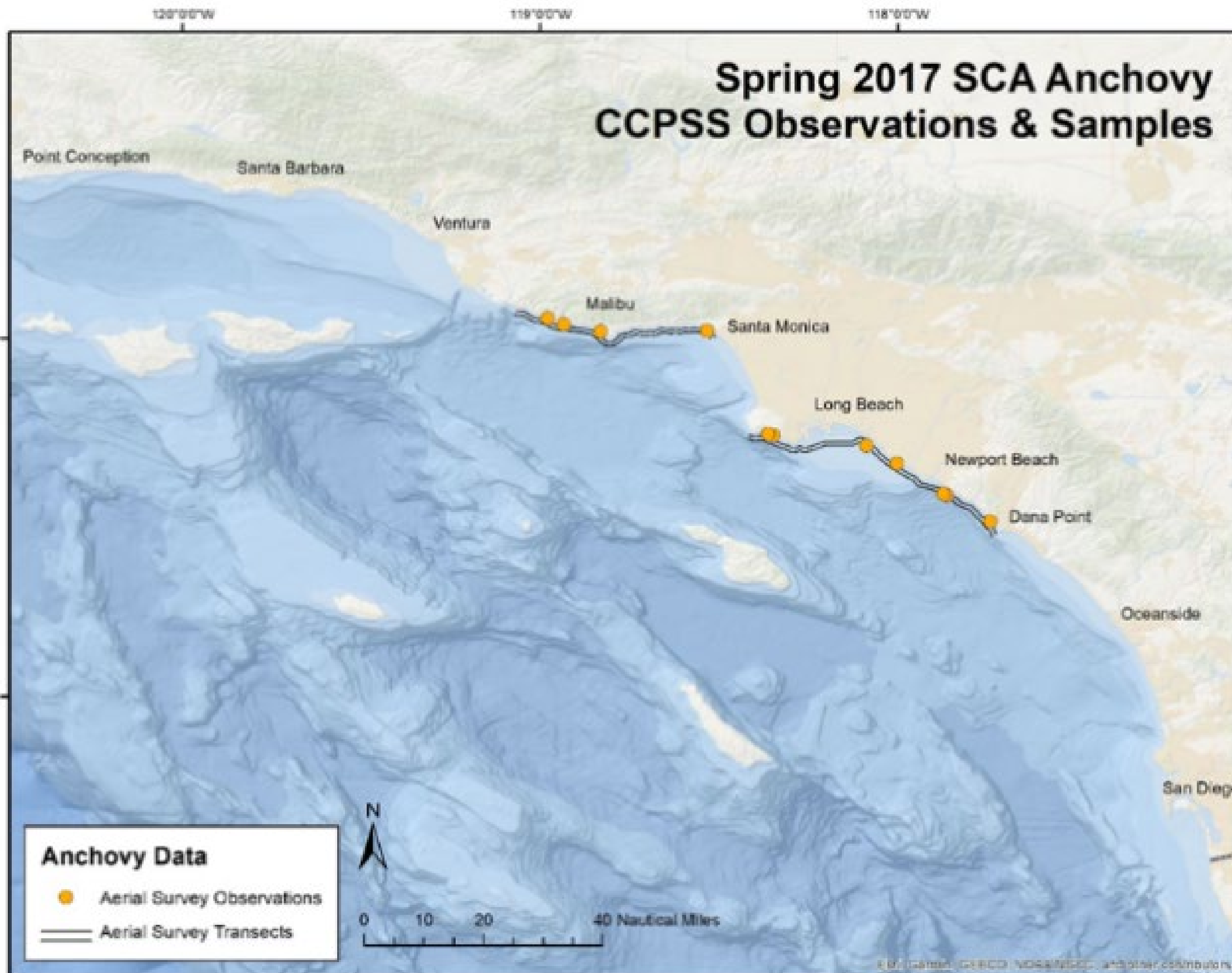


Figure D4. Survey area and school distributions from CCPSS in Southern California during spring 2017.

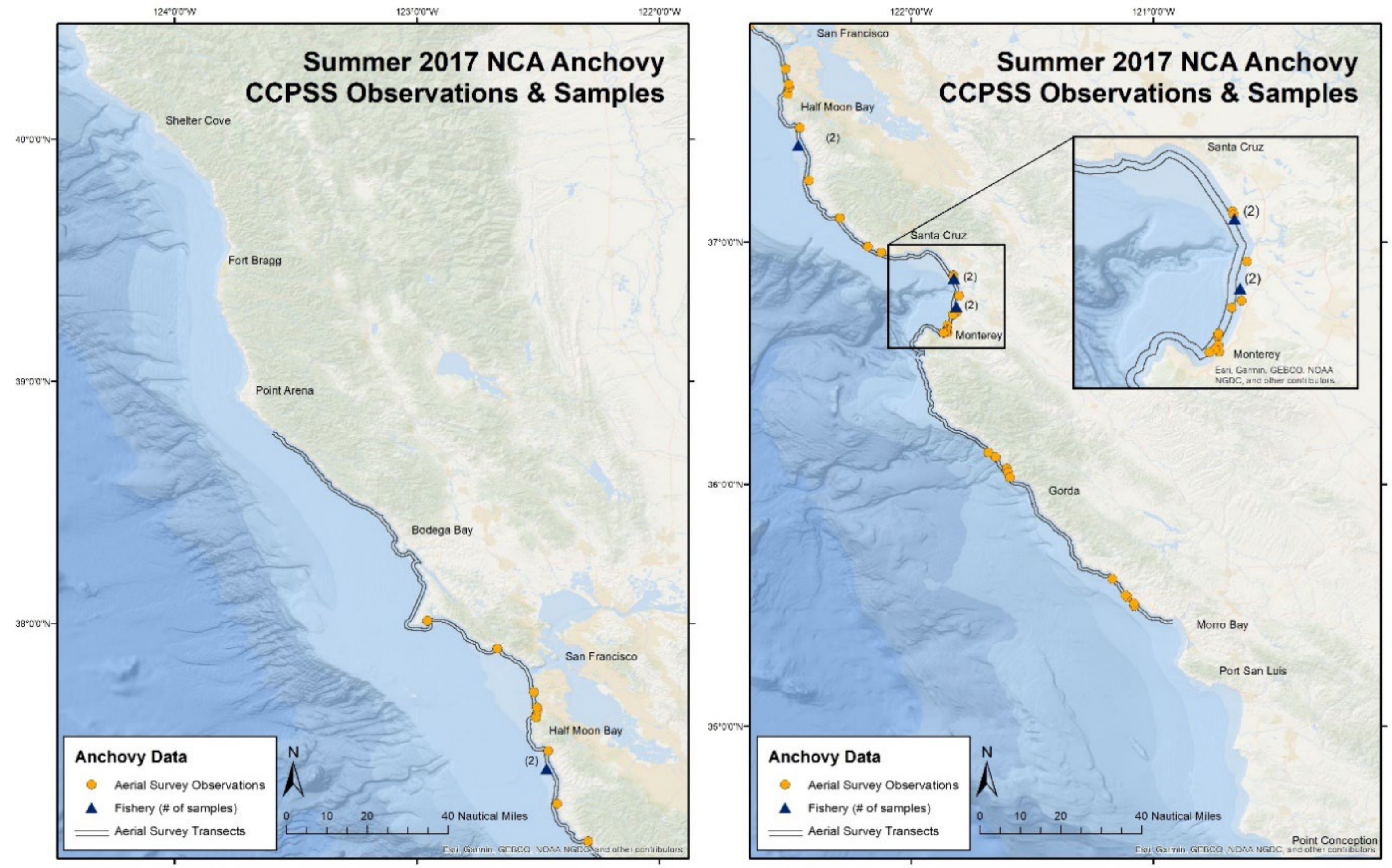


Figure D5. Survey area, school distributions from CCPSS, and location of commercial fishery samples closest in time to CCPSS in Northern California during summer 2017.

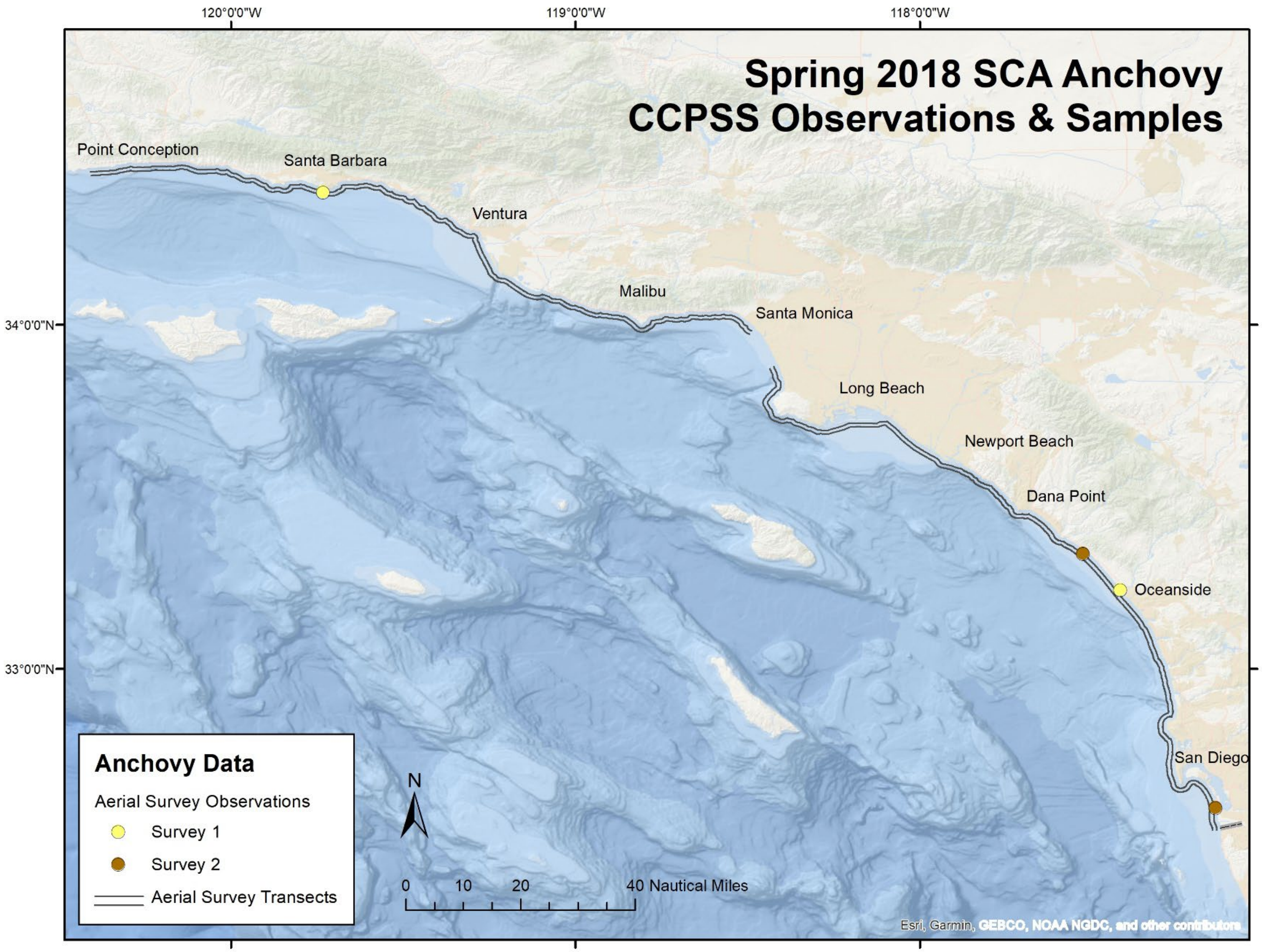


Figure D6. Survey area and school distributions from CCPSS Survey 1 and Survey 2 in Southern California during spring 2018.

Figure D7. Survey area and school distributions from CCPSS in Southern California during summer 2018.

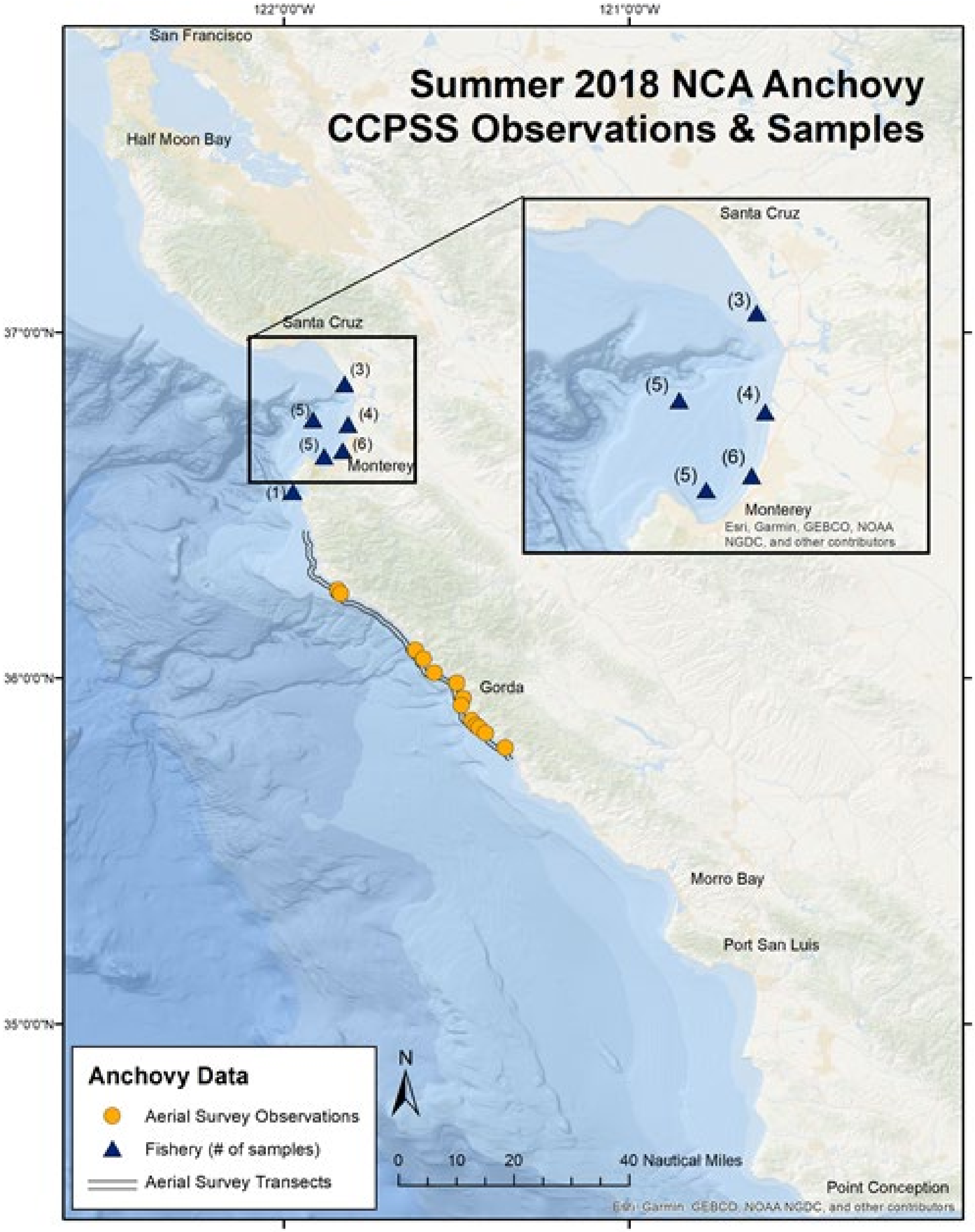


Figure D8. Survey area, school distributions from CCPSS, and location of commercial fishery samples closest in time to CCPSS in Northern California during summer 2018.

Figure D9. Survey area and school distributions from CCPSS in Southern California during spring 2019.

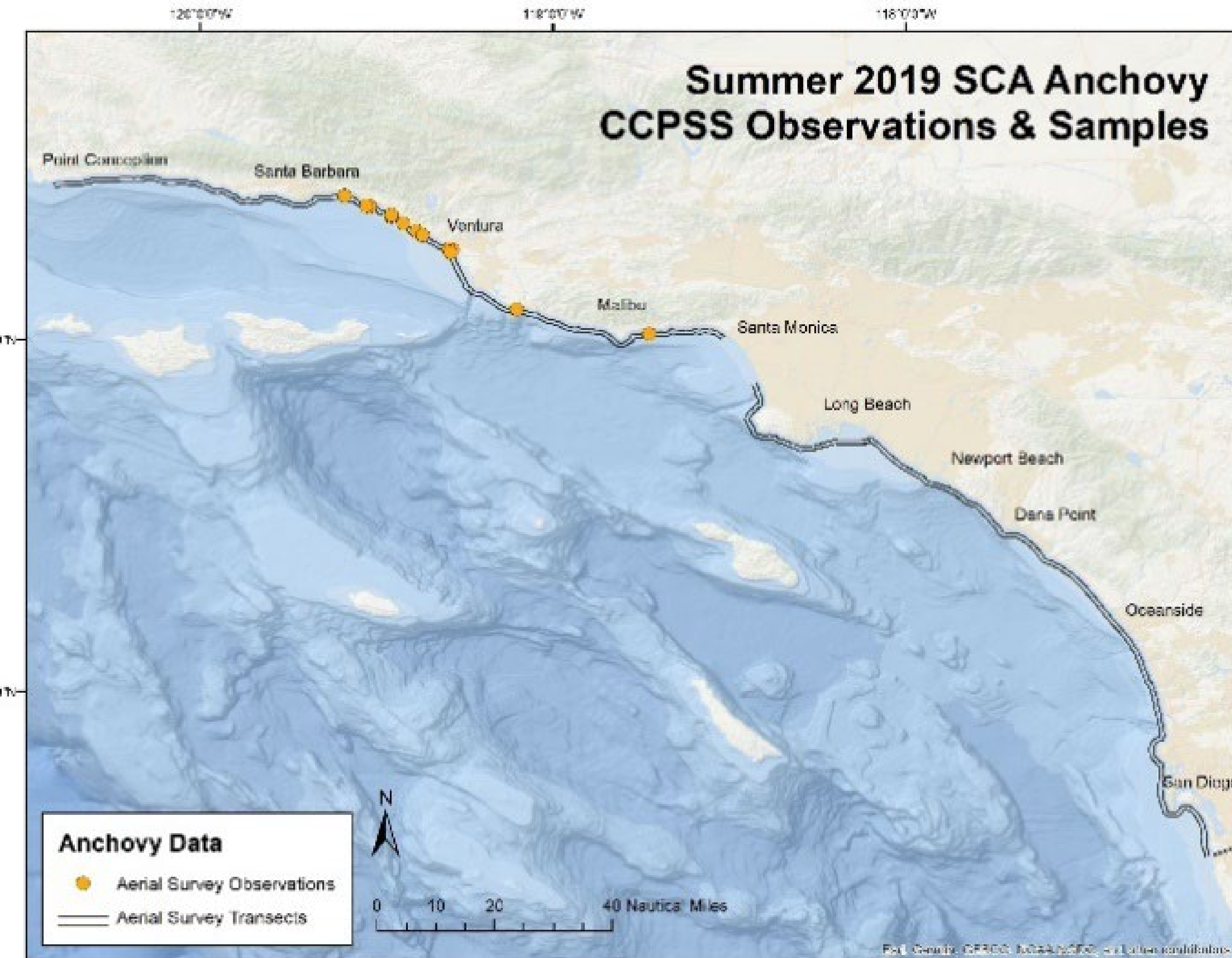


Figure D10. Survey area and school distributions from CCPSS in Southern California during summer 2019.

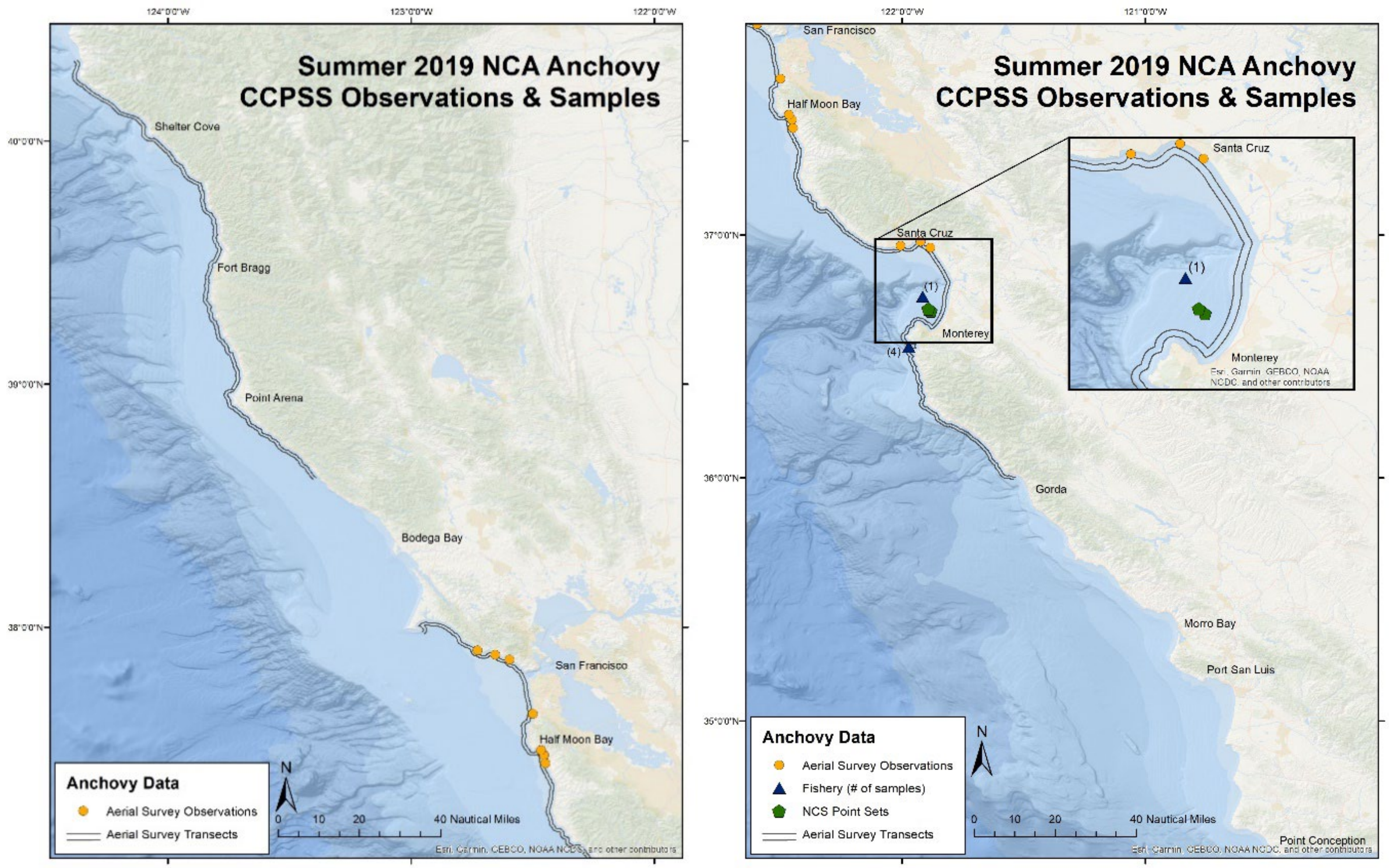
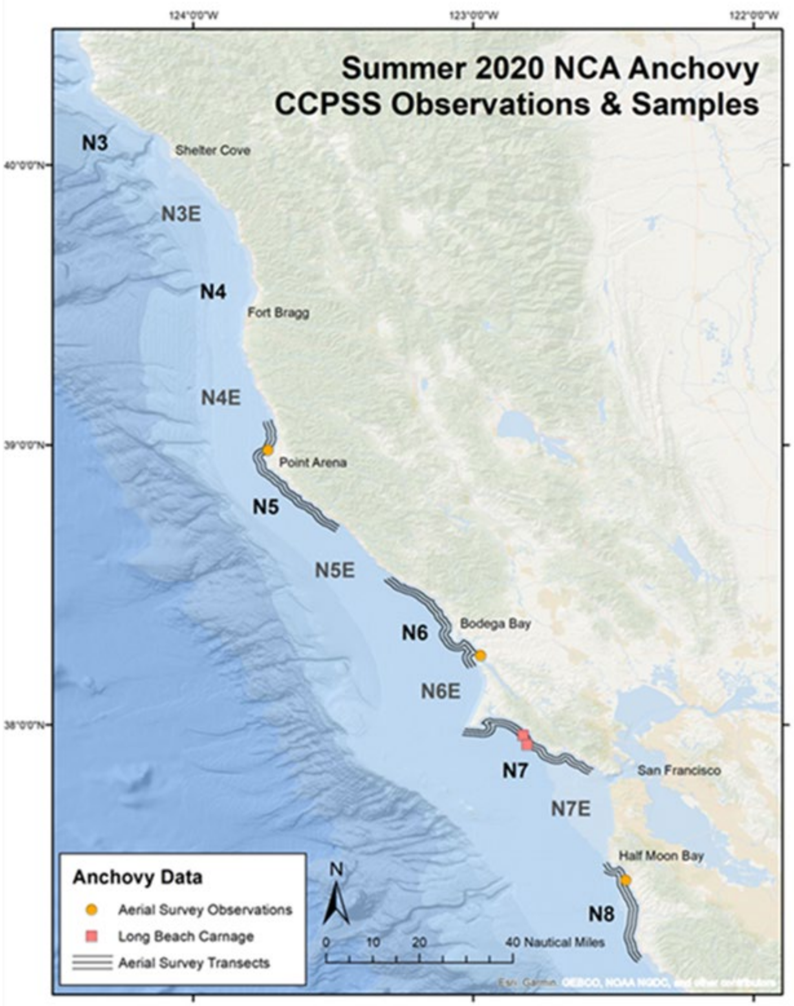


Figure D11. Survey area, school distributions from CCPSS, and locations of NCS point set and commercial fishery samples closest in time to CCPSS in Northern California during summer 2019.



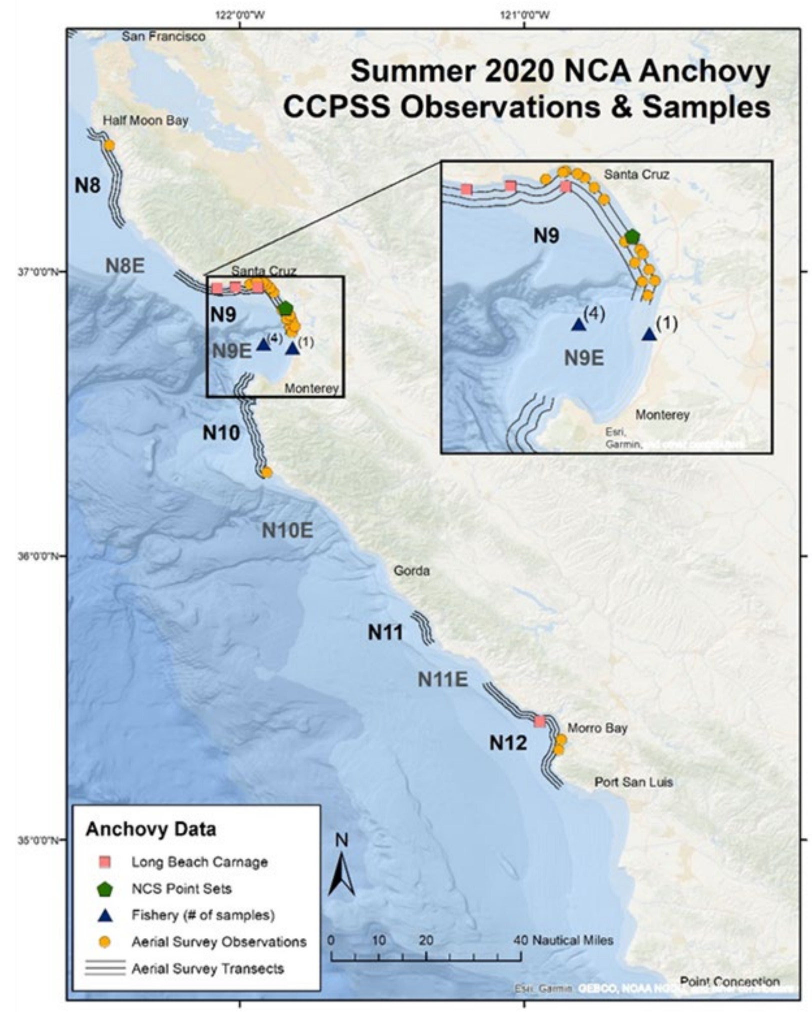


Figure D12. Survey area, school distributions from CCPSS, and locations of F/V Long Beach Carnage, NCS point set, and commercial fishery samples closest in time to CCPSS in Northern California during summer 2020.

Figure D13. Survey area, school distributions from CCPSS, and locations of F/V Long Beach Carnage samples in Southern California during summer 2020.

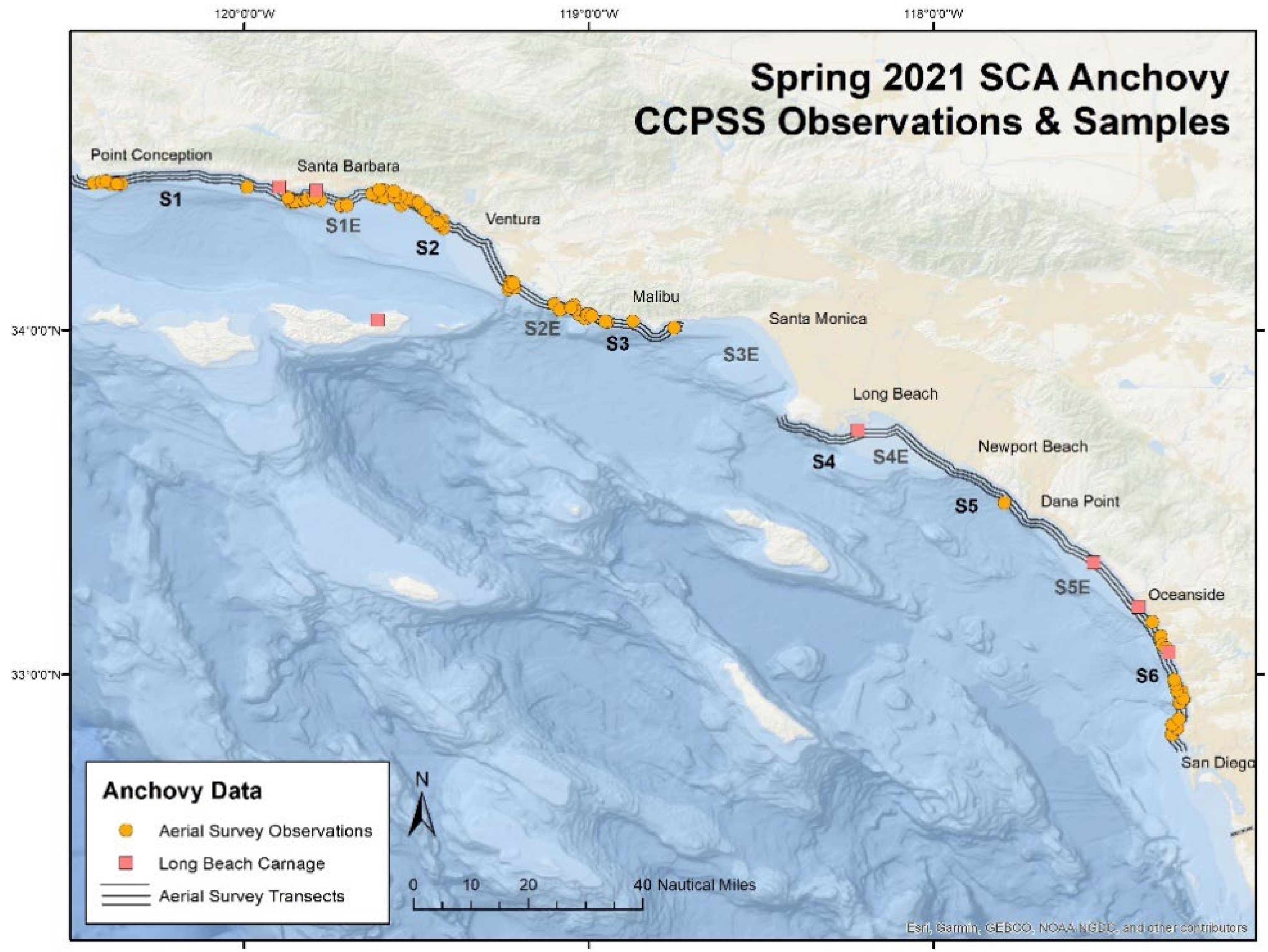


Figure D14. Survey area, school distributions from CCPSS, and locations of F/V Long Beach Carnage samples in Southern California during spring 2021.

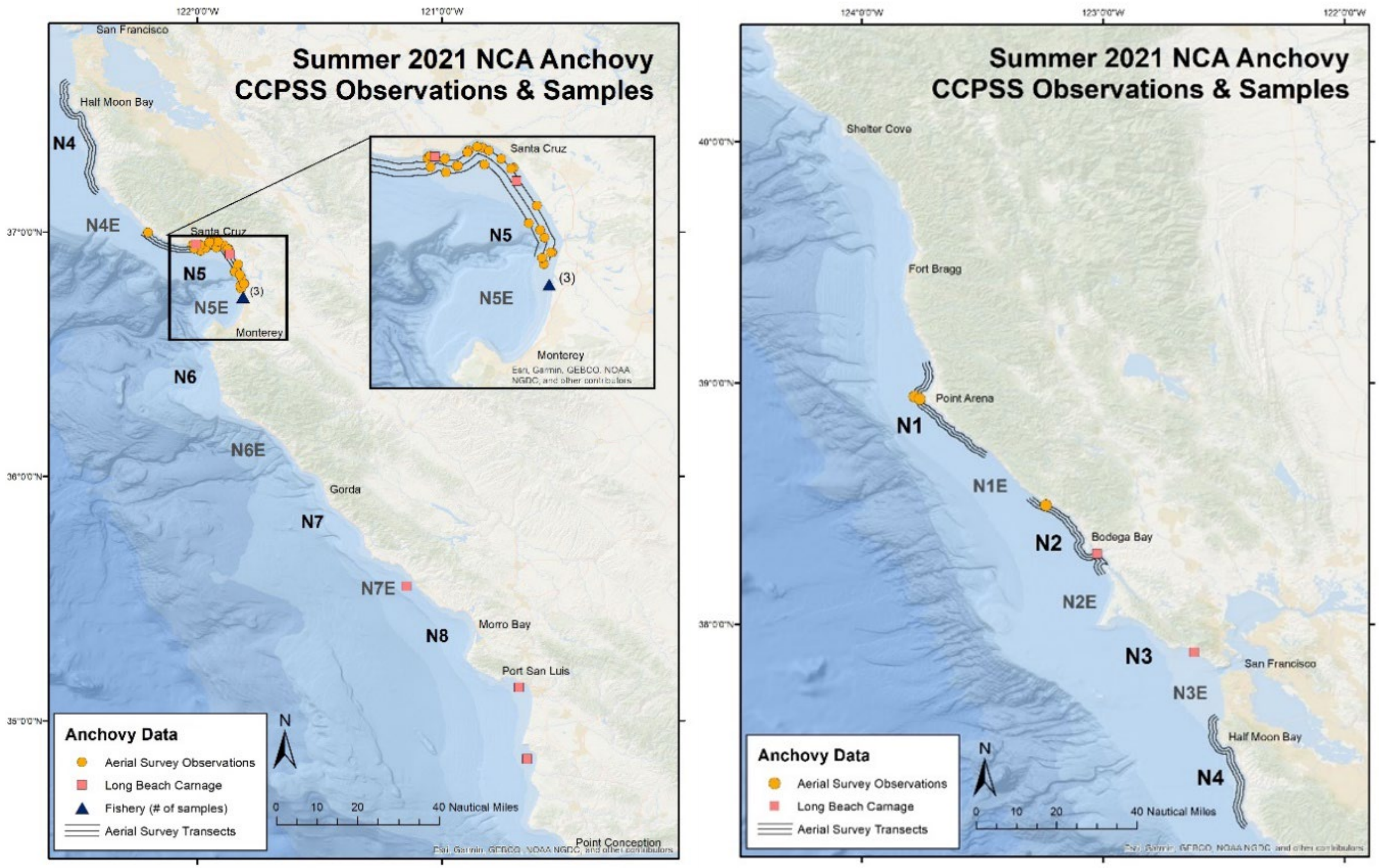


Figure D15. CCPSS surveyed area, school distributions, and locations of F/V Long Beach Carnage and commercial fishery samples closest in time to CCPSS in Northern California during summer 2021.

Figure D16. Survey area, school distributions from CCPSS, and locations of F/V Long Beach Carnage samples in Southern California during summer 2021.

Appendix E.

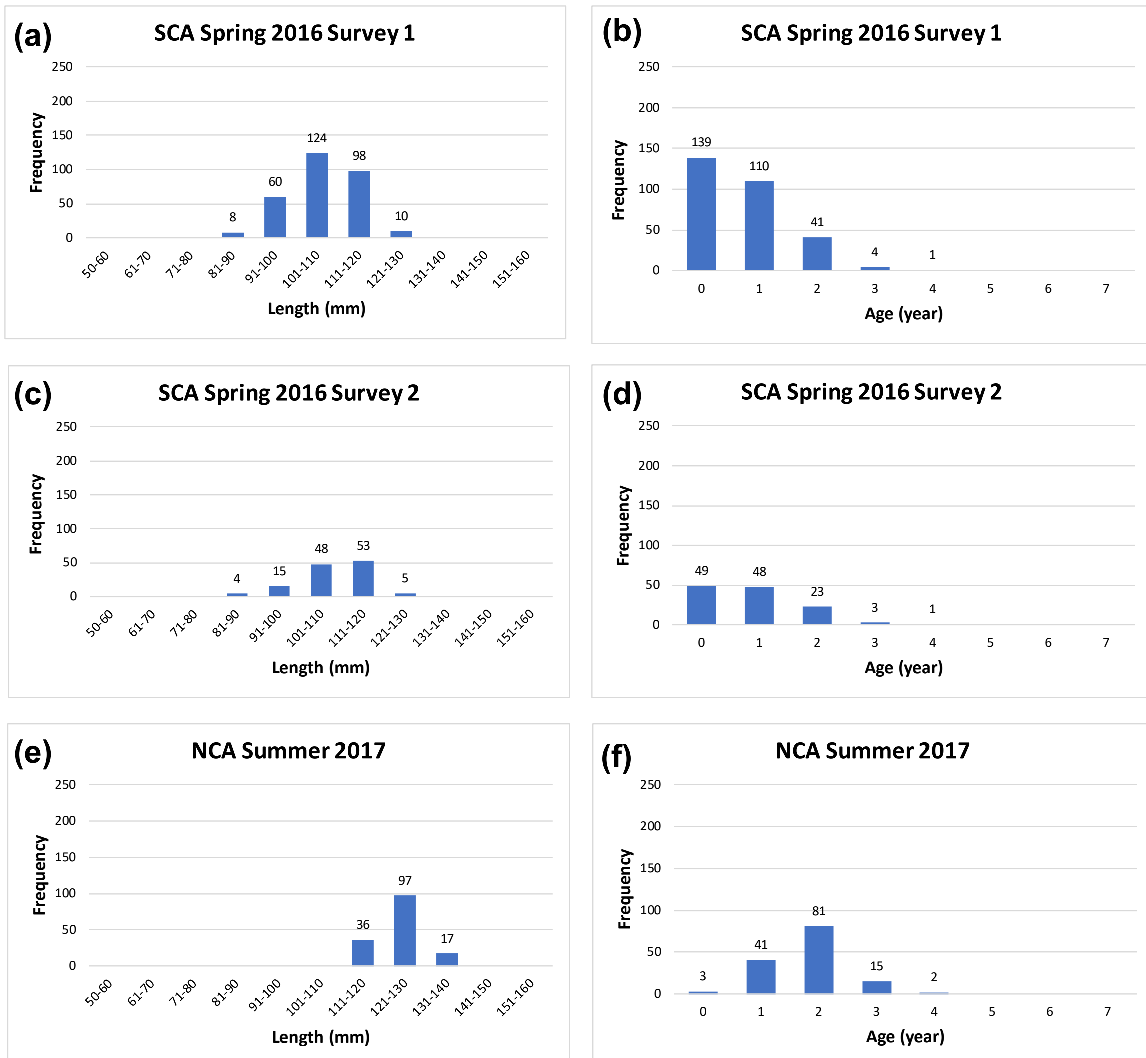


Figure E1. Anchovy length and age frequency plots collected in Southern (SCA) and Northern (NCA) California from NCS point sets, F/V *Long Beach Carnage*, and fishery landings during spring and summer CCPSS surveys 2016-2021.

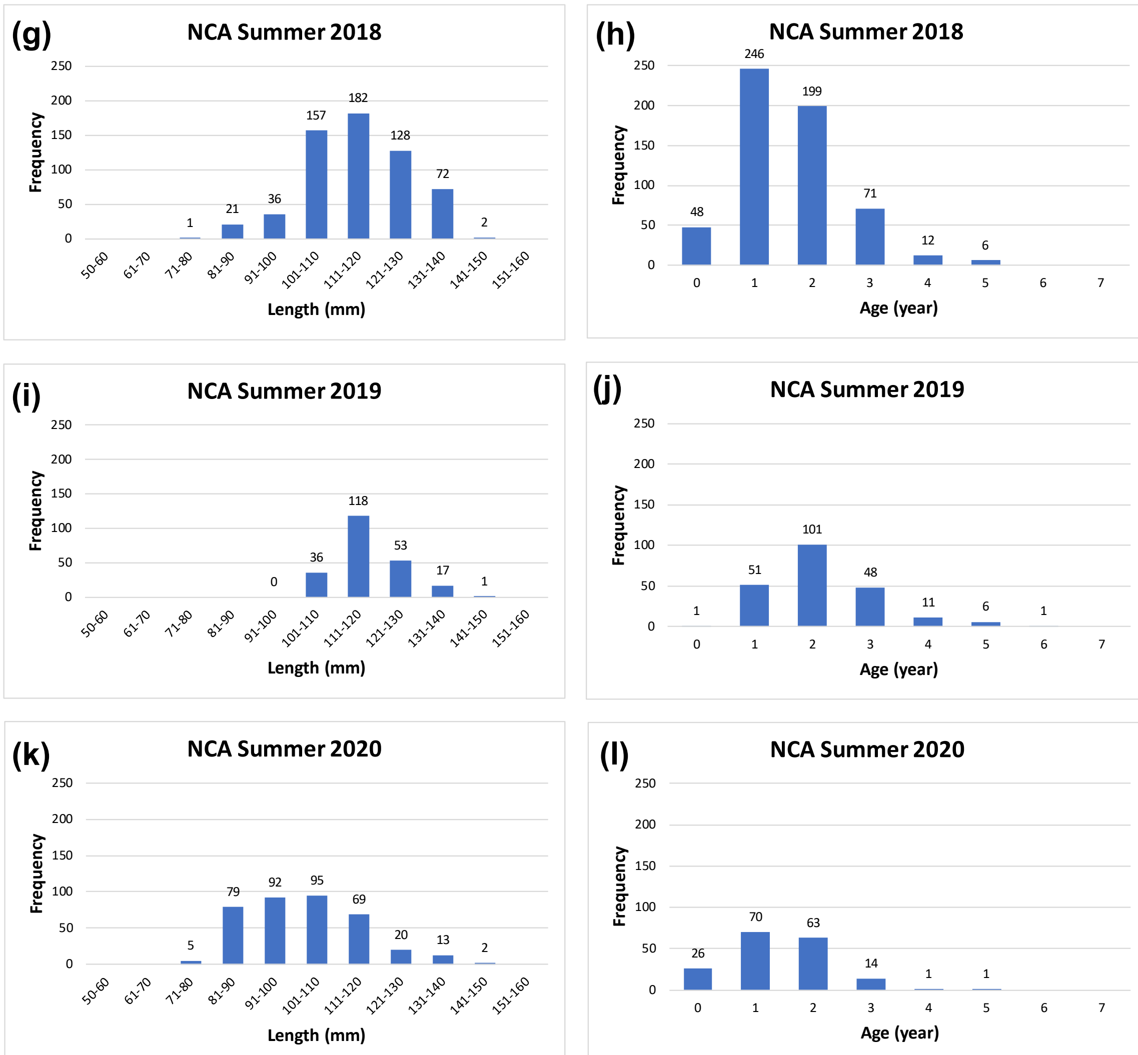


Figure E1 (continued). Anchovy length and age frequency plots collected in Southern (SCA) and Northern (NCA) California from NCS point sets, F/V *Long Beach Carnage*, and fishery landings during spring and summer CCPSS surveys in 2016-2021.

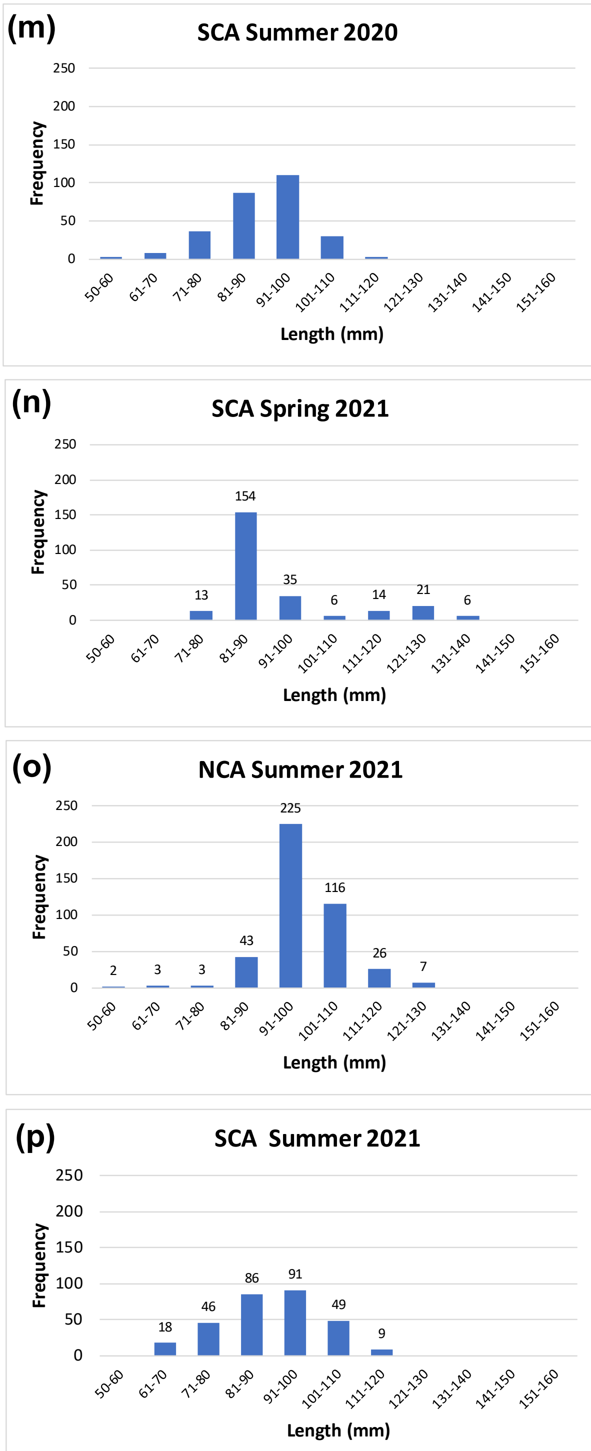


Figure E1 (continued). Anchovy length and age frequency plots collected in Southern (SCA) and Northern (NCA) California from NCS point sets, F/V *Long Beach Carnage*, and fishery landings during spring and summer CCPSS surveys in 2016-2021. Age data are not available for seasons starting with summer 2020 SCA surveys.