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ESTIMATION OF NEARSHORE AERIAL SURVEY BIOMASS FOR THE 2021 STOCK ASSESSMENT OF THE CENTRAL SUBPOPULATION OF NORTHERN ANCHOVY (ENGRAULIS MORDAX)

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Estimation of Nearshore Aerial Survey Biomass for the 2021 Stock Assessment of the Central Subpopulation of Northern Anchovy (*Engraulis mordax*)

NOAA Technical Memorandum

By

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EXECUTIVE SUMMARY

The fishery for the central subpopulation of Northern Anchovy (*Engraulis mordax*) along the U.S. Pacific Coast has 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. Prior to 2019, relative abundance indices derived from research surveys did not fully reflect the distribution of CPS in nearshore waters of < 40 m, an area where the fishing industry takes most of its catches. In 2012, the California Department of Fish and Wildlife (CDFW) and the California Wetfish Producers Association (CWPA) began collaborating on an aerial survey known as the California Coastal Pelagic Species Survey (CCPSS) covering Northern and Southern California nearshore waters. Since August 2018, CCPSS also included new research components to estimate bias and precision and validate species identifications of aerial observer biomass. These research efforts, known as the Nearshore Cooperative Survey (NCS), also provided biological data for developing age and length compositions of CCPSS biomass. This document describes CCPSS design and methods used for estimating Northern Anchovy biomass from aerial surveys conducted since 2015 and highlights the changes implemented for 2020-2021 surveys.

Nearshore total biomass of Northern Anchovy estimated from spring and summer aerial surveys was consistently higher in Northern California than in Southern California. Southern California seasonal surveys since summer 2020 detected relatively high biomass between Santa Barbara and Ventura (3,483-11,383 mt). In Northern California, heavy concentrations of Northern Anchovy were observed in Monterey Bay since summer 2020 (11,800-38,565 mt) and off the Big Sur coast in 2018 (69,967 mt). In spring and summer off Southern California, Northern Anchovy sampled for aerial biomass ranged from 57 to 134 mm standard length (SL) and from 0 to 4 years in age. In summer off Northern California, lengths ranged from 62 to 142 mm SL, and ages ranged from 0 to 6 years. Compared to the total biomass of the central subpopulation of Northern Anchovy, estimated at 2.09 million mt in the 2021 stock assessment, CCPSS nearshore biomass estimates were comparatively low. Consequently, in the current period of high abundance, the inclusion of nearshore biomass estimates had little influence on stock assessment outcomes. However, the effect of nearshore biomass estimates is likely to increase as stock abundance declines and a greater proportion of the biomass resides in nearshore waters.

1. INTRODUCTION

Off the Pacific coast of North America, Northern Anchovy (*Engraulis mordax*) is divided into three populations: a northern subpopulation ranging from San Francisco to British Columbia; a central subpopulation (CSNA) occupying waters between San Francisco and Punta Baja, Mexico; and a southern subpopulation ranging from Punta Baja to the Gulf of California, Mexico (MacCall and Methot 1983, Fielder et al. 1986, PFMC 2019a). The CSNA has supported a major fishery in California since the 1940s, with historic peak landings dating from the late 1960s to the early 1980s (CDFW 2001). Northern Anchovy reside in nearshore waters at both low and high population levels (Mais 1974, MacCall 1990). Prior to 2021, the last stock assessment completed for the CSNA was in 1995 (Jacobson et al. 1995). Since then, the allowable biological catch has been set at 25,000 mt (PFMC 2019a), although annual landings have remained far below this catch limit (CDFW 2022). Recent surveys by the National Oceanic and Atmospheric Administration's (NOAA) Southwest Fisheries Science Center (SWFSC) documented a rebound in the CSNA spawning stock biomass (Dorval et al. 2018) and total biomass (Stierhoff et al. 2020).

The CSNA fishery has been federally managed since 2000 under the Pacific Fishery Management Council's (PFMC) Coastal Pelagic Species (CPS) Fishery Management Plan (PFMC 2019a), which modified the original Northern Anchovy Fishery Management Plan adopted in 1978. U.S. management of the CSNA assumes that most of the population migrates in winter and spring to spawn in Southern California, and then returns to Northern California (up to San Francisco) in summer. Tagging experiments have documented that Northern Anchovy move from Southern California to Monterey Bay in summer and from Northern to Southern California in the spring (Haugen et al. 1969). Previous studies consistently show much higher spawning stock biomass in Southern California than in Northern California during the spring season (e.g., Picquelle and Hewitt 1983, Hewitt 1985, Dorval et al. 2018), whereas total biomass is typically higher off Northern California during summer and fall (Mais 1974, Stierhoff et al. 2020, Kuriyama et al. 2022b). These population dynamics also control the distribution of the fishery, which is more productive in July to November and January to March off Monterey Bay, where catches comprise larger and older fish. Accordingly, since 2017 CCPSS has been conducted as two distinct seasonal surveys: a) a spring aerial survey off Southern California from Point Conception to San Diego; and b) a summer aerial survey off Northern California from Point Arena to Port San Luis (Figures 1 and 2).

Prior to 2019, CPS stock assessments did not directly account for the portion of stock abundance in nearshore waters of < 40m due to constraints on the ability of large research vessels to access these shallower waters. Fishery-independent surveys conducted during this period, covered mostly offshore waters greater than about 3.7 km (2 nm) from shore (Dorval et al. 2022). Information on the most productive fishing areas provided by industry and past research indicate that a substantial portion of juvenile abundance and non-negligible portions of adult biomass of Northern Anchovy and Pacific Sardine can reside in shallow nearshore waters within 4 km from the shoreline (Mais 1974, MacCall 1990), potentially resulting in underestimation of abundance and under-projection of future abundance. It has been recognized that additional sampling efforts are needed to supplement current research surveys to improve the estimation of 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 (Lynn et al. 2014), adapting aerial survey methods from California and the Pacific Northwest that were previously used in stock assessments (Lo 1992, Jagielo et al. 2012). This survey is now known as the California Coastal Pelagic Species Survey (CCPSS), and is intended to provide data on nearshore CPS biomass. These efforts focus on investigating abundance of two commercially important species off the U.S. Pacific Coast, starting with Pacific Sardine in 2012, and Northern Anchovy beginning in 2013. Both species occupy nearshore areas and their schools mix at different rates within these habitats depending on their abundance. Based on these dynamics, CCPSS surveys are conducted on both species concurrently.

A 2017 PFMC methodology review recommended research to develop methods for estimating aerial CCPSS biomass variance and quantifying observer bias (PFMC 2017). An ongoing Nearshore Cooperative Survey (NCS) research component of CCPSS began in August 2018 to address these recommendations. Preliminary results from the NCS research component were reviewed at a meeting for Northern Anchovy management in October 2019 hosted by PFMC (PFMC 2019b).

The CCPSS was only conducted within the Southern California Bight during the first five years (2012-2017). Surveys extended north of Point Conception to cover nearshore waters off Northern California beginning in August 2017 (Lynn et al. 2017). The 2017 summer survey sampled nearshore coastal areas corresponding to offshore transects with the southern 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 again successfully coordinated with the AT survey beginning in summer 2019.

CCPSS biomass data were used in recent CPS stock assessments to adjust acoustic survey catchability (e.g., Kuriyama et al. 2020, PFMC 2020a). The CCPSS design was further modified to address concerns raised over the lack of transect replication to compute variance of survey biomass (PFMC 2020a). The new design was used for surveys beginning in summer 2020 and continuing through summer 2021 and beyond. Research on validation of observer data also continued with the NCS, employing the same methods as used in previous work. This document describes CCPSS design, methods, and Northern Anchovy biomass estimates for aerial surveys conducted since 2015 and highlights the changes implemented for 2020-2021 surveys. Future surveys will be implemented based on the 2020-2021 design in both Southern and Northern California, and synoptically with the AT seasonal surveys.

2. METHODS

2.1 Aerial Survey

CCPSS flights were conducted in summer 2020 and 2021 off the Northern California coast, from approximately Point Arena to Morro Bay, and in summer 2020, spring 2021, and summer 2021 within the Southern California Bight from south of Point Conception to San Diego (Figures 1 and 2). These surveys were flown over areas inshore of the acoustic trawl (AT) survey and saildrone (unmanned surface vehicle, USV) track lines (Stierhoff et al. 2020). In the interest of providing aerial biomass estimates that can be expanded to unsampled nearshore waters, aerial transect flights were replicated beginning in 2020. Past CCPSS designs (2015-2019) did not include true replicated transects, but instead used nearshore and offshore transects, which were analyzed as replicates (PFMC 2020a). 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 selection of which strata were flown was based on local weather conditions, coordination with acoustic survey vessels (if any), and random selection within those constraints. Acceptable conditions for conducting a survey flight were 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 m altitude. No acoustic surveys were conducted in 2020 due to COVID-19 restrictions, so surveyable strata closest in proximity to nearshore sampling by F/V *Long Beach Carnage* were prioritized. For each stratum, the starting transect line (inner or outer) was randomly selected and maintained for the subsequent replicate flight for that stratum.

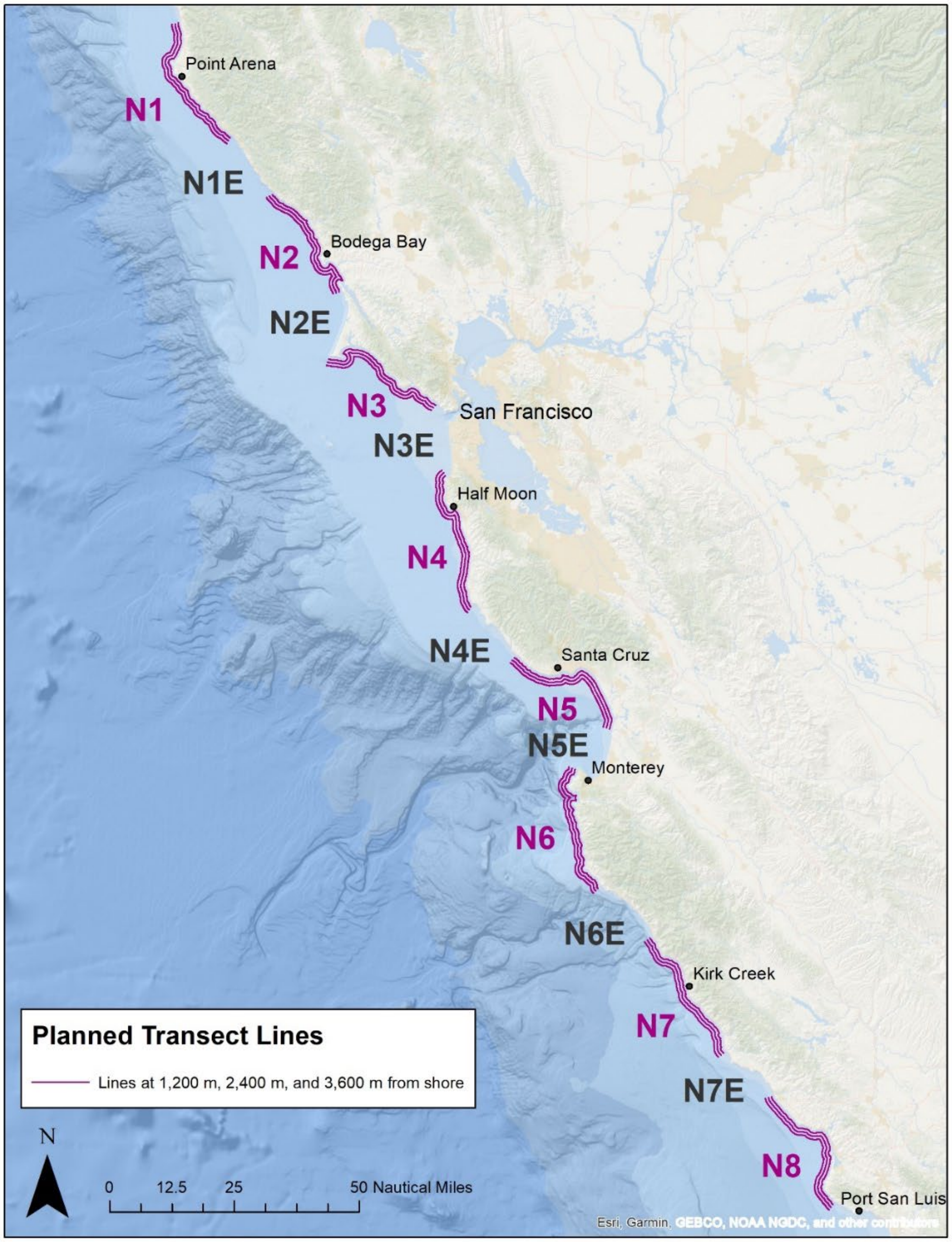


Figure 1. CCPSS strata in Northern California. Predesignated survey strata are in purple; strata for expansion of biomass are in black and denoted with "E" label.

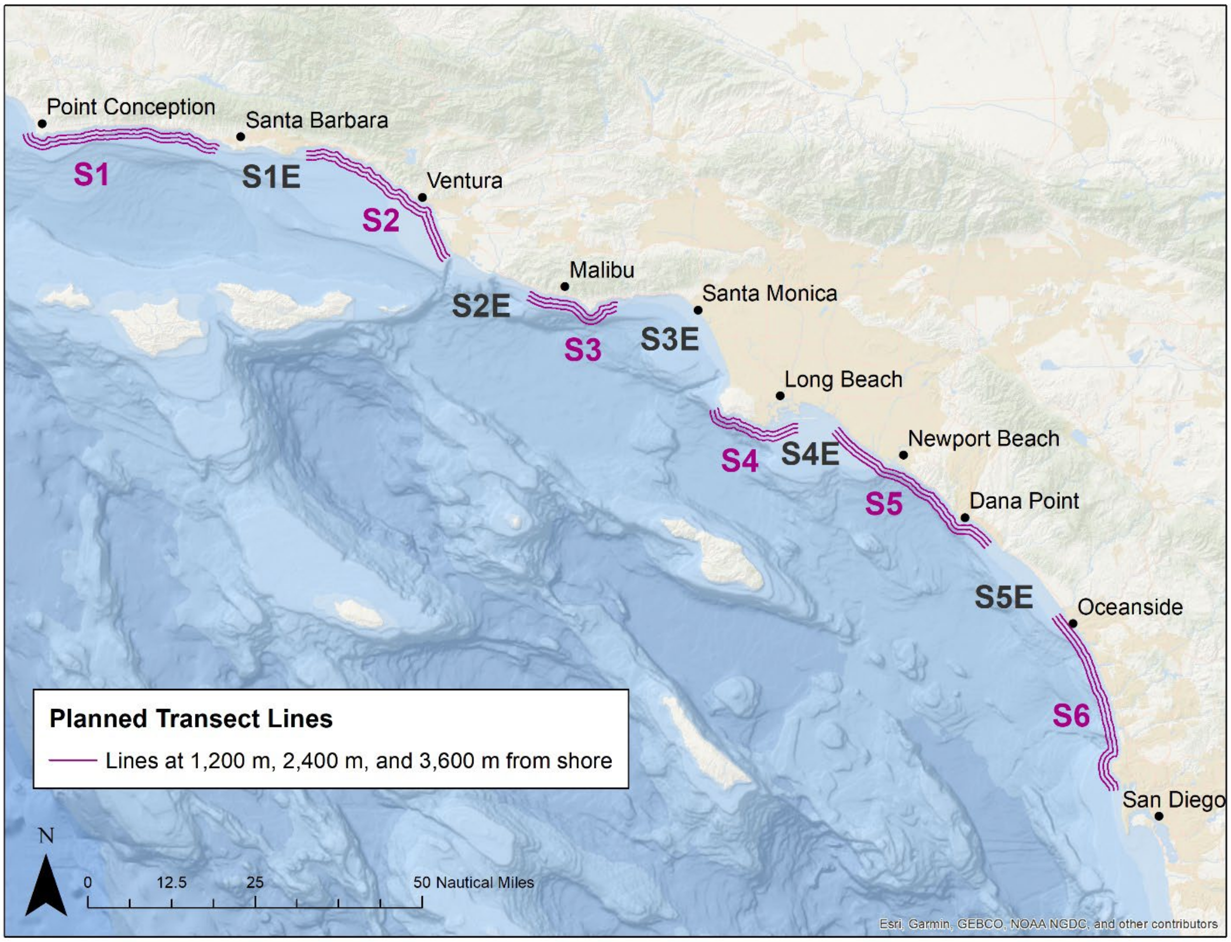


Figure 2. CCPSS strata in Southern California. Predesignated survey strata are in purple; strata for expansion of biomass are in black and denoted with "E". Note strata S3 and S4 are smaller to circumvent airspace restrictions.

Table 1. Survey dates, locations, and difference in timing (days) between CCPSS aerial (A) and acoustic surveys conducted by FSV *Reuben Lasker* (RL) and F/V *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 Biomass (mt)**
Year	Season	Region	Aerial	RL	LBC	A-RL	A-LBC	-
2017	Summer	NCA	8/3	8/6, 8/7, 8/8	-	3−5	-	35,651
2017	Summer	NCA	8/4	8/3-8/6	-	1−2	-	32,039
2017	Summer	NCA	8/10	8/8, 8/9, 8/10	-	0−2	-	7,648
2019	Summer	NCA	8/6	7/21-7/25, 7/31, 8/1, 8/2, 8/7	-	1−16[1]	-	0
2019	Summer	NCA	8/7	8/3-8/10	-	3−4	-	47,102
2019	Summer	NCA	8/8	8/9-8/12	-	1−4	-	1,520
2019	Summer	SCA	8/27	8/25-8/29	8/27	0−2	0	9,744
2019	Summer	SCA	8/28	8/30-9/2	8/29, 9/3	2−5	1−6	33
2019	Summer	SCA	8/29	8/29, 8/30	26-Aug	0−1	3	6
2021	Spring	SCA	3/22	3/21, 3/22	3/21, 3/22	0−1	0−1	577
2021	Spring	SCA	3/24	3/23, 3/24	23-Mar	0−1	1	45
2021	Spring	SCA	4/1	3/29, 3/30, 3/31	3/29, 3/30	1−3	1−2	5,043
2021	Spring	SCA	4/2	3/23, 3/30	3/28, 3/31	3−10[2]	2−5	2,499
2021	Summer	NCA	8/6	8/8, 8/9	Not Surveyed	2−3	NA	16
2021	Summer	NCA	8/6	8/10, 8/11	8/12, 8/14	0−1	2−4	50
2021	Summer	NCA	8/6	11-Aug	8/14, 8/15	0	3−4	11,800
2021	Summer	SCA	9/12	9/10, 9/11	12-Sep	1−2	0	80
2021	Summer	SCA	9/12	9/11, 9/12, 9/13	9/14, 9/15	1−3	0−1	11,399
2021	Summer	SCA	9/12	9/14, 9/15, 9/16, 9/18, 9/19	9/17, 9/18	2−3	1−2	2
2021	Summer	SCA	9/12	9/17-9/21	9/18, 9/19	0−4	1−2	130

Notes: *No Northern Anchovy were observed. This survey flight date covered a large area from Cape Mendocino to ~ 50 miles S of Pt. Arena.
**The 10-day difference occurred in stratum S4 where no Northern Anchovy were observed. Northern Anchovy were observed in strata S1 and S1E, which the FSV *Reuben Lasker* surveyed on 3/30 and the F/V *Long Beach Carnage* surveyed on 3/28.

When CPS schools 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. Photos and coordinates were captured for observer data post-processing and geographic visualization.

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 wide. Survey coverage thus included nearshore waters from the shoreline out to 2,400 m. 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 detecting CPS schools in the upper water column (within about 10 m depth). For survey years 2015, 2016, and 2018, there was an 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, beginning in 2020, included 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 and 2). Airspace restrictions surrounding Los Angeles International Airport greatly limit surveyable areas in the vicinity. For this reason, there were two smaller selected strata, S3 and S4, to represent the surveyable area. The expansion stratum S3E, which contained the restricted flight zone, was not surveyable. Survey strata measured 56 km long, except for S3 and S4, which were 28 km long. Expansion strata were 28 km long, except S2E (26 km), S3E (56 km) and S4E (13 km). Locations and sizes of strata were selected to maximize coastline coverage while avoiding restricted flight zones, and to allow sufficient time for completing each stratum in a single day. Within each stratum, three transect lines that follow the shore contours were located at 1,200 m, 2,400 m, and 3,600 m off the coastline. Each line was the offshore boundary of the transect and delineated surveyed areas 1,200 m inshore of the line. Sampling of the additional survey area covered between 2,400 m, and 3,600 m offshore of the coastline was new to the survey design based on fish school spatial distributions observed in 2018-2020 from NCS research (Lynn et al. unpublished data). Two daily replicates were conducted for each transect line. Here, a flight referred to a survey of the area associated with a transect line, irrespective of which replicate it represented. Modifying the survey design using surveyed and expansion strata was deemed appropriate given the limited availability of personnel and equipment, the addition of transect replication, and the increase in survey coverage further offshore. After a hiatus in 2020 due to the COVID-19 pandemic, 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.

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 because of limited time and uncertain survey conditions due to weather and coastal areas inaccessible because of firefighting efforts. Data analyses for these surveys 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 area that can be surveyed while allowing for flexibility in tracking the acoustic survey vessels and for possible bad weather. In spring 2021, the Southern California survey was successful in surveying most of the Southern California region (i.e., including all expansion strata, except for S3E); therefore, only S3E biomass and variance were derived from expansion analysis. All strata were surveyed again in the summer 2021 Southern California survey, except for S3E and S5E (see Figure 3).

2.2 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 was determined 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 schools moving and intermixing on the transect. In 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 the transect line surveyed by the spotter during a flight in a given day and stratum. 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, total biomass, and their 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 hold were recorded separately for each point set, facilitating the determination of total weight and species composition of each captured school. All CCPSS field biomass estimates were corrected using an updated calibration curve with Pacific Sardine and Northern Anchovy data for Spotter 1 from NCS point sets conducted through October 2020 (Figure 4). Spotter 1 continued to be the sole observer providing school estimates for all CCPSS flights in 2021.

Assuming the observer detected all schools present at the surface on a transect line during a given flight, biomass and variance were estimated as described below (see also Table 2). Section 2.2.1 provides within-transect biomass and variance estimation methods for Northern Anchovy as was done for Pacific Sardine from NCS data in 2019, and per review panel recommendations to examine these parameters by species. Section 2.2.2 calculates total biomass in each stratum. Section 2.2.3 provides calculations on density and variance by stratum. Section 2.2.4 calculates regional biomass and proposes a method to calculate variance for the expanded biomass density in the strata that were not surveyed.

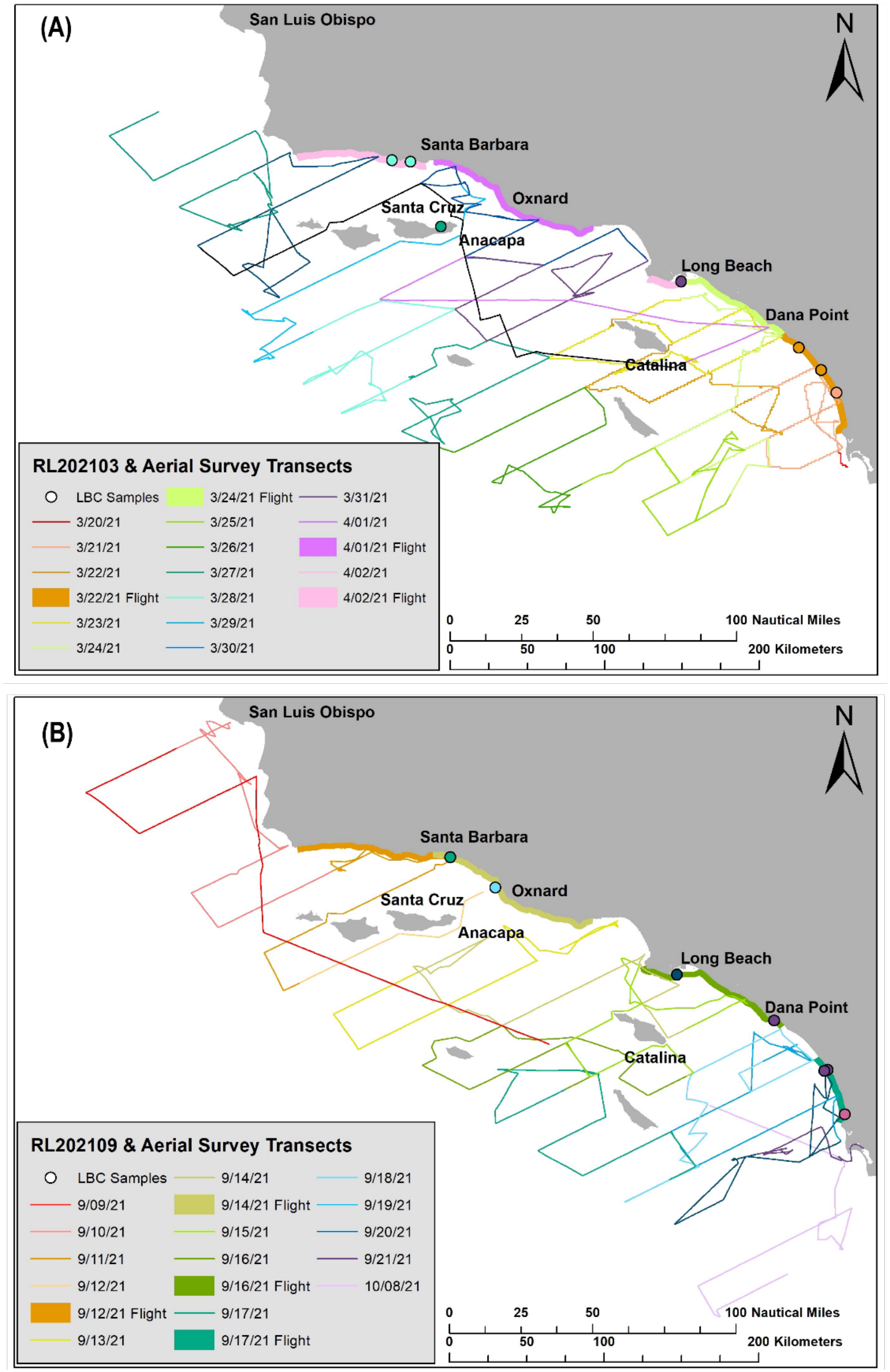


Figure 3. Maps displaying spatial and temporal patterns of aerial surveys conducted synoptically with the FSV *Reuben Lasker* (RL) and the F/V *Long Beach Carnage* (LBC) in spring (Panel A) and summer (Panel B) of 2021. Legend and colors indicate dates and locations of aerial, RL, and LBC transect surveys. Colored circles indicate locations of biological samples taken by LBC.

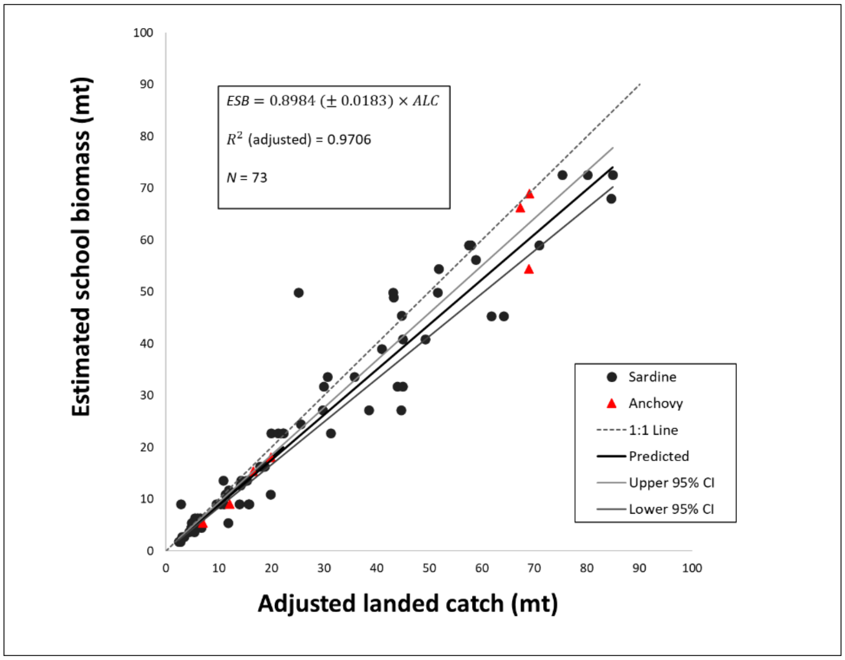


Figure 4. Calibration curve for Spotter 1 from 2010, 2018, 2019, and 2020 combined Pacific Sardine and Northern Anchovy point set data. Estimated school biomass (ESB) is the aerial estimate of school biomass and adjusted landed catch (ALC) is the corresponding landed biomass tonnage for those observations, corrected for estimated percent capture by the fishing vessel.

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

2.2.1 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:

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

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:

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

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

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

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

2.2.2 Computation of total biomass in each stratum

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:

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

2.2.3 Computation of density and 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

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

2.2.4 Computation of regional density, biomass, and variance

a) If n strata were sampled in region R, then the mean daily density over these strata was 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 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 the geographic location of these strata was adequate to compute variance from the bootstrap method. A minimum of two strata are needed to expand biomass into a non-surveyed stratum that is bracketed by them; but two strata located at the extreme ends of a region cannot be used to expand biomass into other non-surveyed strata of that region (i.e. between those two strata).

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.

2.3 Sampling for Length and Age Compositions

Age and length compositions are important information for integrating survey biomass in age-structured stock assessment models. For example, these data allow the computation of selectivity-at-age or -at-length of the survey index. These data can also help to determine the range of ages and lengths that are suitable to adjust catchability of the AT survey based on aerial biomass. As recommended by previous CPS stock assessment review panels, understanding the ontogenetic distribution (i.e., distribution of juveniles and adults) of CPS in nearshore and offshore waters is critical to accurately determine the AT survey catchability. To achieve this objective, fish samples for CCPSS were collected from three main sources: 1) purse seine catches from NCS point sets; 2) F/V *Long Beach Carnage* biological sampling during nearshore acoustic survey off California; and 3) port-landing samples collected monthly by CDFW. We describe below the rationale and methods of sample collection for each data source.

First, biological samples of Northern Anchovy were collected from NCS point sets conducted through an exempted fishing permit (EFP) for Pacific Sardine using purse seine gear deployed from chartered CPS fishing vessels. An EFP to collect Pacific Sardine for this purpose has been used since August 2018 and has been renewed since then, most recently through the 2022-2023 fishing year (PFMC 2022). The main objectives of collecting these biological data were to determine the accuracy of species identification by spotters and the length and age composition of each school collected during the aerial biomass validation process.

Second, in coordination with CCPSS, the F/V *Long Beach Carnage* collected biological data for Northern Anchovy beginning in summer 2020. In 2020, a new sampling protocol was developed to allow better coordination between CCPSS and nearshore acoustic surveys. As no AT survey was conducted in 2020, full coordination of synoptic surveys between CCPSS, nearshore and offshore AT surveys restarted in 2021. The F/V *Long Beach Carnage* collected fish samples using dip nets to subsample purse seine catches, within the same nearshore area as CCPSS. The captured schools were released after subsampling. Additional sampling information and protocols are presented in Appendix A. The protocol for processing the catch from each captured school has closely followed that used by the F/V *Lisa Marie* for acoustic survey research in the Pacific Northwest (PFMC 2020b).

Third, CDFW ceased sample collections from the commercial Northern Anchovy fishery during the 1982-2013 period, when the reduction fishery was closed in the US and the CSNA was designated a monitored species (PFMC 2019a, Dorval et al. 2022). In 2014, CDFW restarted collecting and processing biological samples to gather data for CSNA stock assessments. The fishery operates off California, within ~ 3 miles from the shoreline, using round-haul gears (including purse and drum seines; and lampara nets). All fishing grounds overlap with the spatial frame of CPSSS. Therefore, port landing samples can be also used to determine length and age composition for aerial biomass. Port-landing samples were filtered to include only those within one month of CCPSS observations of Northern Anchovy.

All fish collected from NCS point sets were aged at the CDFW lab. Samples collected in 2020-2021 from F/V *Long Beach Carnage* are not yet aged by CDFW, and those from fishery landings were aged by CDFW only through spring 2021. Samples for which less than 10 fish were collected were not included in the analysis.

3. RESULTS

3.1 Point Set Survey and Calibration

Seventy-three NCS point sets, including 66 for Pacific Sardine and 7 for Northern Anchovy, were conducted in 2010 (Jagielo et al. 2012) and from 2018-2020 (Table 3, and see Table C1 in Appendix C) and were used to build a mixed calibration curve for these two species (Figure 4). A comparison of aerial estimated catch and adjusted landed catch (ALC, landed tonnage corrected for estimated percent school capture) showed Spotter 1 estimated less than landed tons by about 10% (slope = 0.8984, R^2 = 0.97). This correction factor was applied to all field estimates of Northern Anchovy tonnage.

Table 3. NCS point set date and weight of fish landed from which Northern 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 D for additional data from point sets.

NCS Point Set Date	NCS Point Set Landed Weight (mt)	CCPSS Season	CCPSS Region	CCPSS 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	69.1	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

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, Figures D1-D11 in Appendix D). No Northern Anchovy were observed in the 2015 Southern California surveys (see Figure D1 in Appendix D). Seasonal area biomass and variance were calculated (Table 4, see Appendix B) based on recommendations from the 2020 Pacific Sardine stock assessment review panel (PFMC 2020a). Northern 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, Northern 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 24% for spring survey 1 in 2016 to 141% for surveys in summer 2016, spring 2018 (survey 2), and spring 2019 (Table 4).

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, Figures D12–D16 in Appendix D). As with 2015-2019 surveys, observed Northern Anchovy aerial biomass in nearshore waters has been consistently higher in Northern California. As described in Section 2.2.4, regional seasonal biomass was computed from density estimates, and its variance was derived from resampling of survey data based on 1,000 iterations (Figure 5). 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 was 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 5 for each region and season. Northern Anchovy biomass computed based on density estimates for each of the five seasons and by region is reported in Table 5.

Table 4. Northern Anchovy biomass and density estimated per season from CCPSS flights in 2015-2019, including coastal water area coverage.

Year	Dates	Season	Region	Area (km^2)	Density (mt/km^2)	Biomass (mt)	CV
2015	8/7 - 8/26	Summer - Survey 1	SCA	1,046.88	0	0	-
2015	10/2 - 10/3	Summer - Survey 2	SCA	1,058.67	0	0	-
2016	4/16 - 5/1	Spring - Survey 1	SCA	984.35	1.07	1,050	0.24
2016	5/23 - 6/23	Spring - Survey 2	SCA	1,043.50	4.08	4,262	1.04
2016	8/11 - 8/29	Summer	SCA	1,037.10	0.03	29	1.41
2017	3/28 - 3/30	Spring	SCA	327.56	0.9	294	0.56
2017	8/3 - 8/10	Summer	NCA	1,352.58	55.7	75,338	0.71
2018	4/24 - 4/27	Spring - Survey 1	SCA	1,053.52	0.3	315	1.35
2018	5/4	Spring - Survey 2	SCA	1,055.14	0.32	338	1.41
2018	9/10 - 9/13	Summer	SCA	995.79	0.03	32	1.01
2018	10/13	Summer	NCA	239.22	292.48	69,967	1.41
2019	5/29 - 6/28	Spring	SCA	926.5	3.46	3,201	1.41
2019	8/6 - 8/8	Summer	NCA	1,388.02	35.03	48,623	1.37
2019	8/27 - 8/30	Summer	SCA	1,044.32	9.37	9,783	0.18

Southern California surveys in summer 2020 and summer 2021 comprised 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 in 2017 and 2019-2021, high concentrations of Northern Anchovy were observed within Monterey Bay (11,800-38,565 mt) (see Figures D5, D10, D12, D15 in Appendix D). An extremely high concentration was observed in 2018 off the Big Sur coast (69,967 mt) (see Figure D8 in Appendix D).

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	25.34	57,257	0.02
2020	9/18 - 9/20	Summer	SCA	1,515	3.07	4,649	0.27
2021	3/22 - 4/2	Spring	SCA	1,515	5.34	8,092	0.03
2021	8/6 - 8/11	Summer	NCA	1,373	15.33	21,049	0.13
2021	9/12 - 9/17	Summer	SCA	1,515	6.68	10,124	0.06

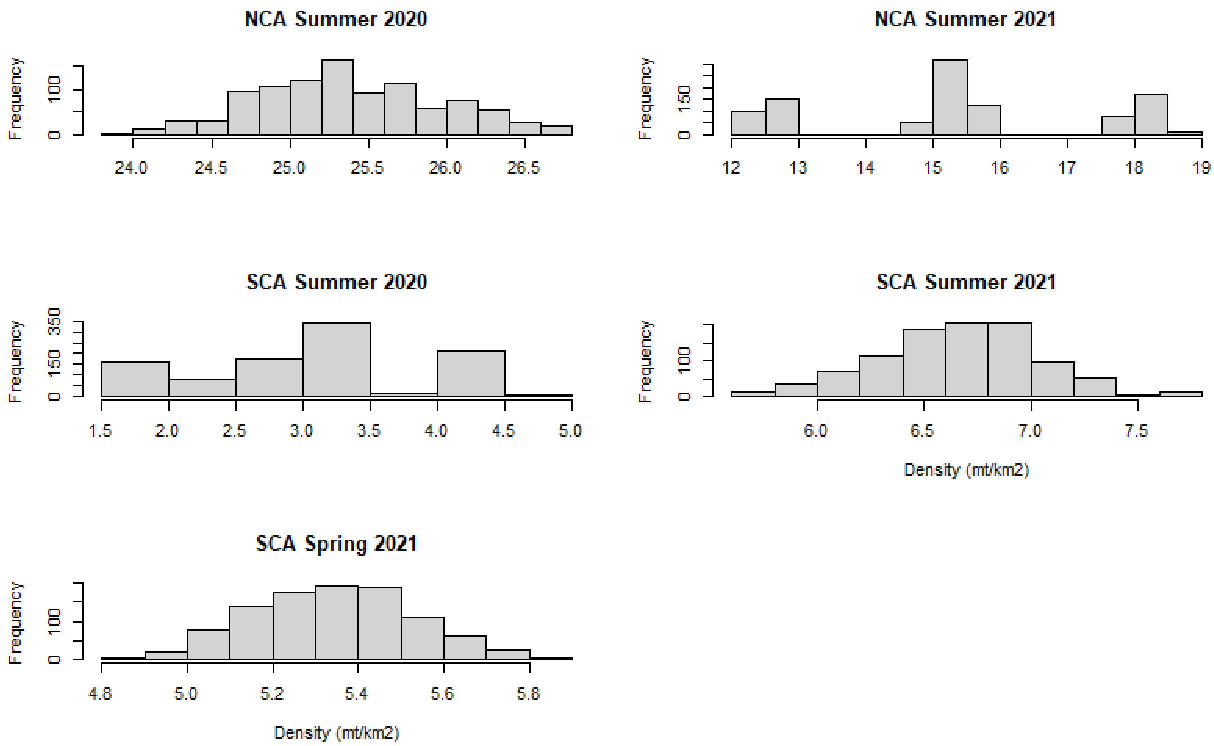


Figure 5. Distributions of mean densities (mt/km^2) of Northern Anchovy by region and season from bootstrap resampling analysis (n=1,000) for 2020-2021 CCPSS.

3.3 Length and Age Compositions

Seven NCS point sets for Northern Anchovy were conducted in 2019 and 2020 (Figure 5, Table 3, Table C1 in Appendix C). All but one point set was from the Monterey Bay area. Four point sets were within a few weeks of a CCPSS flight. Logistically, it was not possible to conduct point sets as close in time with CCPSS compared to other methods, as point set surveys used the same Spotter 1 as used in CCPSS, and these two surveys used different aircraft.

The F/V *Long Beach Carnage* sampled from 33 Northern Anchovy purse seine sets from nearshore waters between September 2020 and September 2021 (Table 6, Figures 7 and 8). 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 commercial fishery for Northern Anchovy in California 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 Northern Anchovy close to port, as fish quality rapidly deteriorates the longer they are transported after capture. Fishery samples collected within one month of CCPSS observations were conservatively considered as useful for analysis. Thus, the fishery samples used for comparison were clustered near Long Beach (see Figure D2 in Appendix D) and

Monterey (see Figures D5, D8, D10, D12, D15 in Appendix D). Available biological samples from all sources are summarized and compared with aerial Northern Anchovy observations in Table 8.

Table 6. Estimated school biomass of Northern Anchovy schools captured by F/V *Long Beach Carnage* (LBC) using purse seine gear. Northern Anchovy schools were either mixed with other CPS or pure schools. All LBC 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 Northern 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 Year	CCPSS Dates	CCPSS Season	Region	# Fishery Samples within the Week	# Fishery Samples within the 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, date, region, source, and corresponding survey observation dates for Northern Anchovy.

Year	Dates	Season	Region	Source	# of Samples	Sample Collection Dates	Aerial Obs Dates (#Anchovy 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)
2019	8/6-8/8	Summer	NCA	NCS Point Set	3	8/14, 8/15, 9/12	8/6 (1), 8/7 (30), 8/8 (5)
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)
2020	9/5-9/16	Summer	NCA	LBC	6	9/9 (2), 9/10 (3), 9/12	9/5, (7), 9/6 (2), 9/7 (3), 9/14 (2), 9/15 (43), 9/16 (2)
2020	9/5-9/16	Summer	NCA	NCS Point Set	2	4/14, 10/12	9/5, (7), 9/6 (2), 9/7 (3), 9/14 (2), 9/15 (43), 9/16 (2)
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)
2021	8/6-8/11	Summer	NCA	LBC	7	8/12, 8/13, 8/14, 8/15, 8/19, 8/20 (2)	8/6 (11), 8/10 (29), 8/11 (32)
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)

For spring samples of Northern Anchovy collected from all sources in Southern California (2016, 2021), fish ranged from 71-134 mm in standard length (SL) and from 0 to 4 years in age. Summer Southern California samples (2020-2021) ranged from 57 to 120 mm SL (age data are not available). For Northern California samples collected during summer (2017-2021), fish were 62-142 mm SL and 0-6 years old (Figures 6-8). Mean length for Northern Anchovy in Northern California for all surveys across all years was 111.99 mm (SD = 14.17; n = 1,774), and mean age was 1.80 years (SD = 0.95; n = 1,118), while for Southern California the mean length was 97.64 mm (SD = 13.32; n = 1,250) and mean age was 1.42 years (SD = 0.80; n = 419).

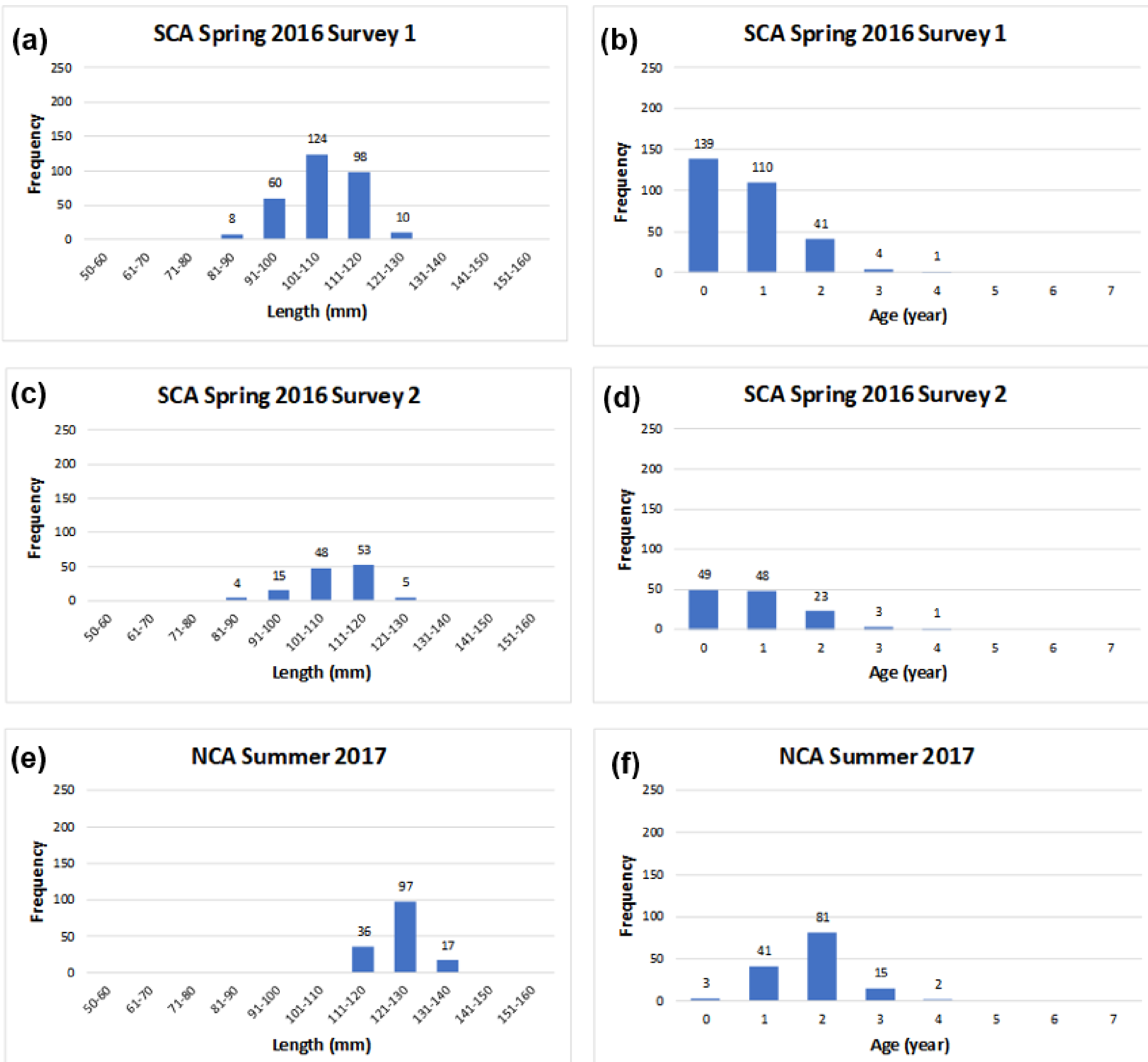


Figure 6. Length and age compositions of Northern Anchovy collected in Southern (SCA) and Northern (NCA) California from NCS point sets and fishery landings during spring and summer CCPSS surveys 2016-2017. The number on top of each bar indicates the sample size of each length bin and age.

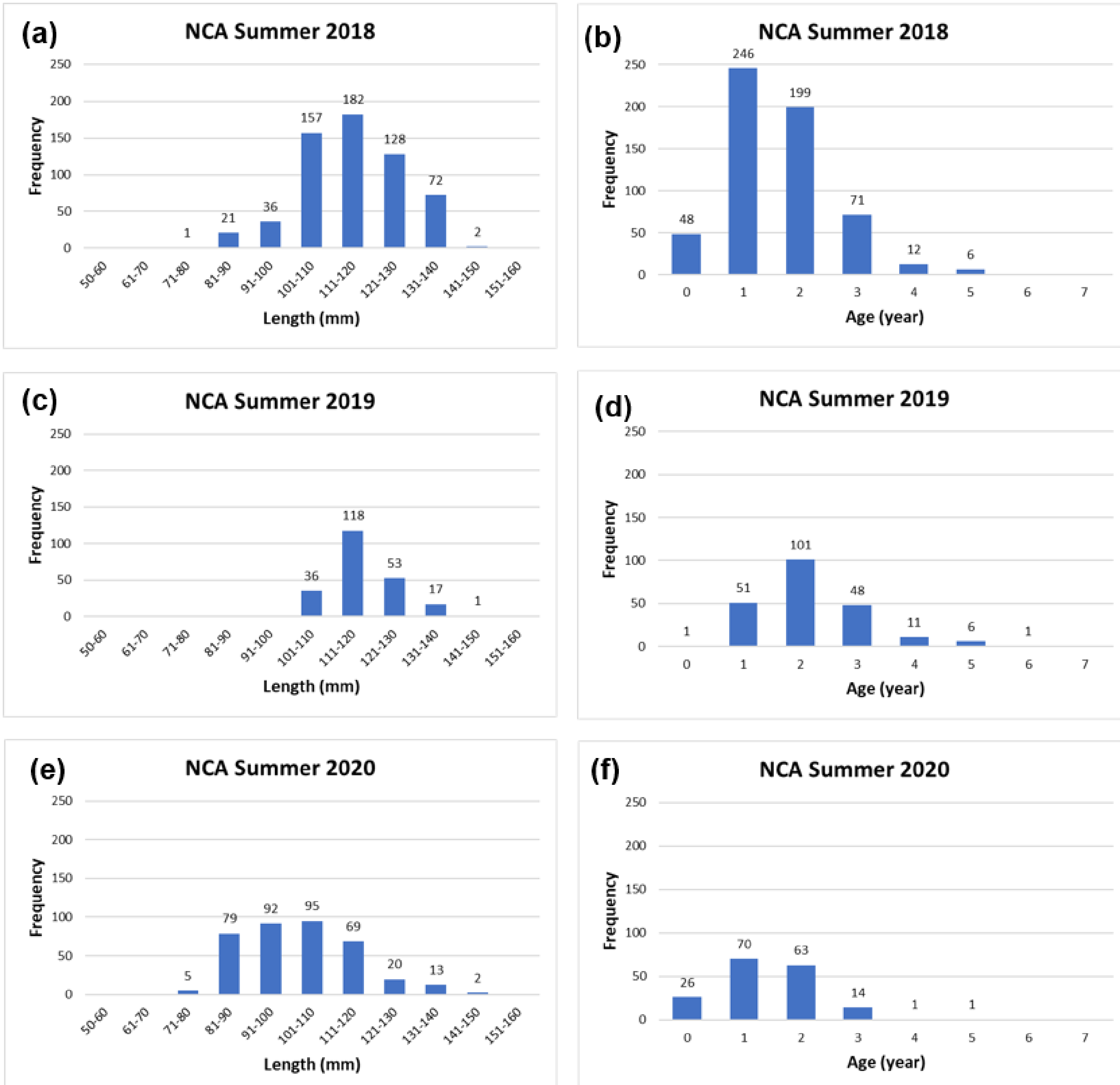


Figure 7. Length and age compositions of Northern Anchovy collected in Southern (SCA) and Northern (NCA) California from NCS point sets, F/V *Long Beach Carnage* (summer 2020, length data only), and fishery landings during spring and summer CCPSS surveys in 2018-2020. The number on top of each bar indicates the sample size of each length bin and age.

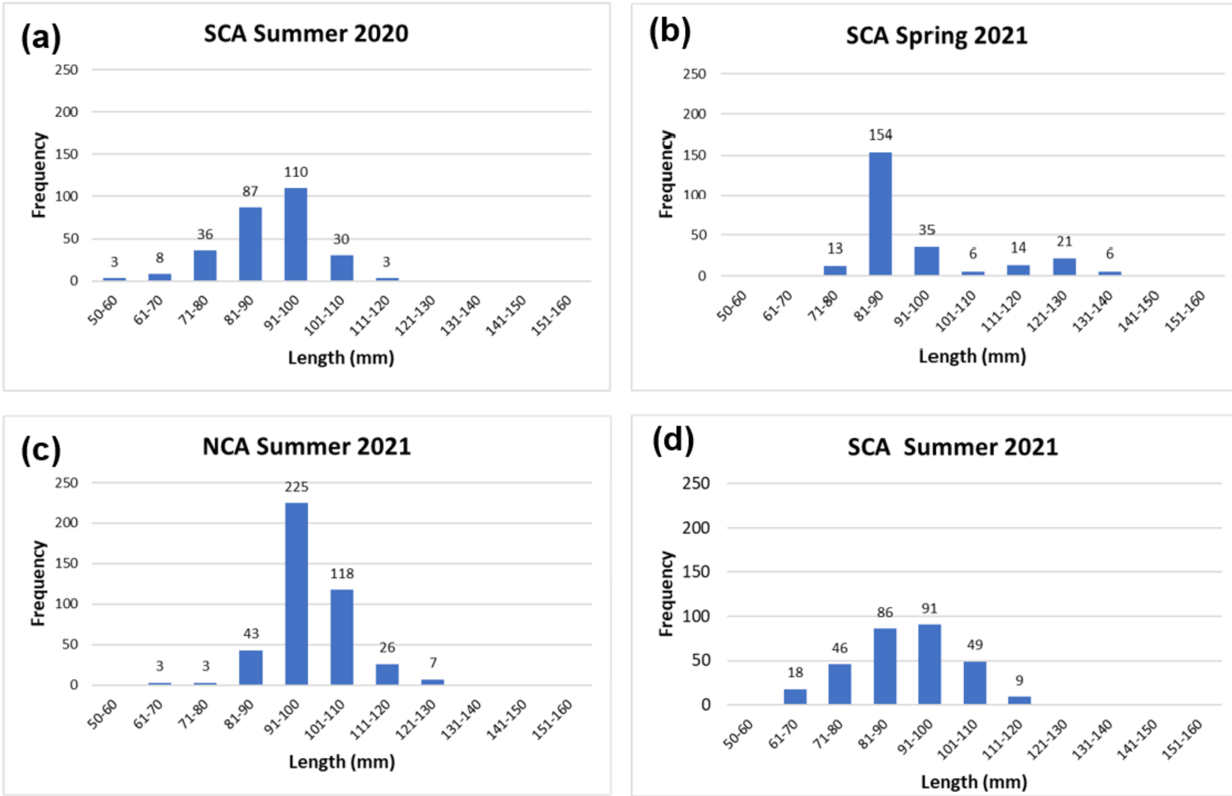


Figure 8. Length compositions of Northern Anchovy collected in Southern (SCA) and Northern (NCA) California from NCS point sets, F/V *Long Beach Carnage*, and fishery landings during spring and summer CCPSS surveys in 2020-2021. Age data are not available for seasons starting with summer 2020 SCA surveys. The number on top of each bar indicates the sample size of each length bin.

4. DISCUSSION

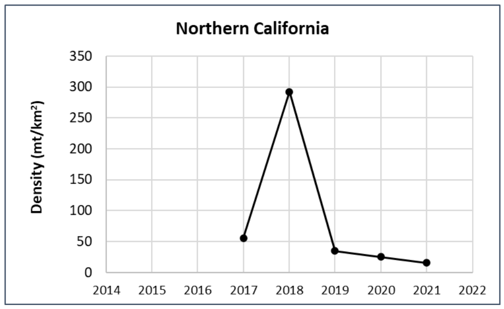
Past studies show that professional aerial spotter pilots are accurate at estimating school tonnage (Williams 1981, Squire 1993) and identifying species (Taylor 2015). The results of this study corroborate those findings by using spotter pilot data in conjunction with landed tonnage and biological sampling. Due to the limited number of synoptic surveys, it is not yet possible to estimate correlation between CCPSS and AT survey biomass estimates; however, past studies have found that aerial survey indices were strongly correlated with egg production (Lo et al., 1985) and larval production (Squire 1993) indices for Northern Anchovy.

Nearshore regional aerial density and biomass estimates for 2015-2021 surveys (Table 4 and Table 5) were consistent with migration patterns of CSNA in Northern and Southern California (Haugen et al. 1969). Consistently higher summer abundance and density of Northern Anchovy in Northern California aligns with summer Northern Anchovy migrations to northern waters, while in spring Northern Anchovy are concentrated in the Southern California Bight for spawning (Picquelle and Hewitt 1983, Hewitt 1985, Dorval et al. 2018).

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 difference may reflect the spatial distributions (patchiness) of Northern Anchovy in nearshore waters. For example, the discrete patterns observed in Northern California in summer 2021 were likely due to known feeding dynamics of Northern Anchovy as related to the patchy food distribution in their preferred habitat (Nonacs et al. 1994). These differences might also be related to fish movements and the interplay with the timing of survey flights conducted during a given season. In some seasons, the strata within a region were surveyed in 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). Surveying relatively few strata within the available time window may have affected the resampling patterns that emerged from the bootstrap analysis. These results might also indicate the need for more daily replicated flights in each stratum per region. Due to logistical constraints, only two replicated flights were conducted on each transect. Thus, future CCPSS should consider increasing the number of replicated flights so that most of the temporal variability of biomass within strata is captured.

CCPSS aerial biomass estimated in spring 2017 was used in adjusting AT survey catchability in the 2021 CSNA stock assessment (Kuriyama et al. 2022b). As in previous Pacific Sardine stock assessments (Kuriyama et al., 2020; Kuriyama et al., 2022a), aerial biomass was evaluated for adjusting catchability based on how closely CCPSS was coordinated with AT survey efforts temporally and spatially as well as the proportion of observed schools whose sizes fall within those validated by NCS point set data. One caveat to consider is 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 9). These indices can document regional shifts in abundance possibly tied to seasonal spawning and feeding migrations (Mais 1974). Use of CCPSS data in this way would, however, require the collection of more length and age composition data. In addition, the CCPSS temporal frame (within each season) would need to be more consistent across years to increase the applicability of this index, given the variable proportion of the total biomass nearshore vs. offshore over time.



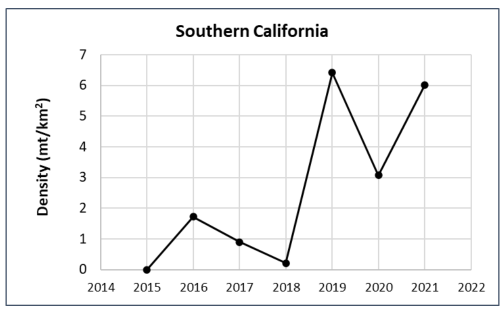


Figure 9. Northern Anchovy density estimates grouped by year for (a) Northern California (2017-2021) and (b) Southern California (2015-2021).

In the 2021 stock assessment, the CSNA total stock was estimated at 2.09 million mt (Kuriyama et al. 2022b). Compared to this total population biomass, adjustments to the catchability of the AT survey based on CCPSS biomass had no significant impacts on the stock biomass estimate. However, CPS stock abundance can fluctuate unexpectedly (Baumgartner et al. 1992, McClatchie et al. 2011), and continued aerial surveys will likely be useful in the long-term to estimate nearshore abundance to inform CPS stock assessments especially when stock biomass declines, noting that starting in 2021 the AT survey also samples nearshore biomass through partnerships with industry vessels that use acoustics and purse seine data. At lower stock biomass (as recently with Pacific Sardine), there may be a greater proportion of biomass inshore of the AT survey (MacCall 1990, MacCall et al. 2016), and in such cases the CCPSS surveys can help account for the underestimation of nearshore biomass. Further analysis of the proportional volume of the nearshore waters inshore of the AT survey sampled by acoustic vs. aerial methods may provide insight into how to use these data, given the differing spatial sampling coverage and the patchy/variable nature of the distribution of CPS.

Future survey efforts to use an aerial platform to collect data on CPS stock abundance include a preliminary effort by CDFW 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 Pacific Sardine stock assessment review. Data collected from 2018-2020 NCS point sets provided information on Pacific Sardine and Northern Anchovy school depth distributions as related to ocean depth and school size (Figures 10 and 11). During the daytime, at depths shallower than 50 m, from the plotted schools covering the entire range of depths, it appears that both Pacific Sardine and Northern Anchovy schools extend to near the seafloor bottom. This phenomenon may be useful in estimating school biomass from photogrammetric techniques in making assumptions on school density based on depth, although more information is needed at deeper depths and for Northern Anchovy. This work can potentially lead to survey methods that will be more flexible, cost-effective, comprehensive, repeatable, and accurate. Using vessels to survey the extent of CPS abundance in the shallowest nearshore habitats remains a challenging task given constraints and limitations posed by the ship's draft, which aerial platforms do not face. Fish avoidance of vessels, primarily due to noise and turbulence, can bias acoustics survey abundance estimates (De Robertis and Handegard 2013, DuFour et al. 2018). In addition, off California the distribution of lobster and crab pots in nearshore waters may limit access to sail drones, while the LBC cannot operate in shallow waters of less than 5 m depth.

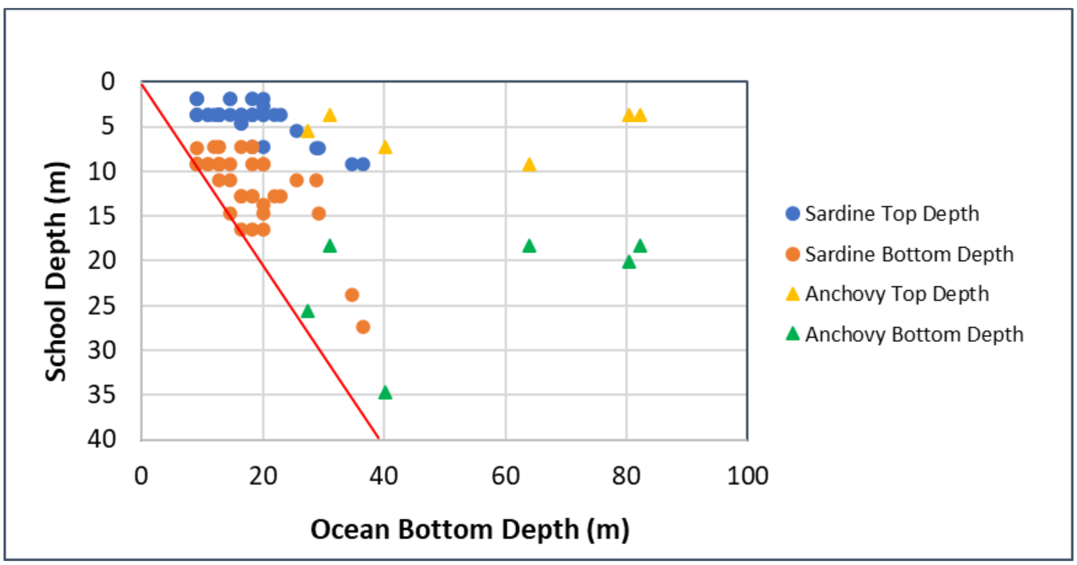


Figure 10. Pacific Sardine and Northern Anchovy school depth distributions (top and bottom depths) from 2018-2020 NCS point set SONAR data. Red line denotes ocean bottom.

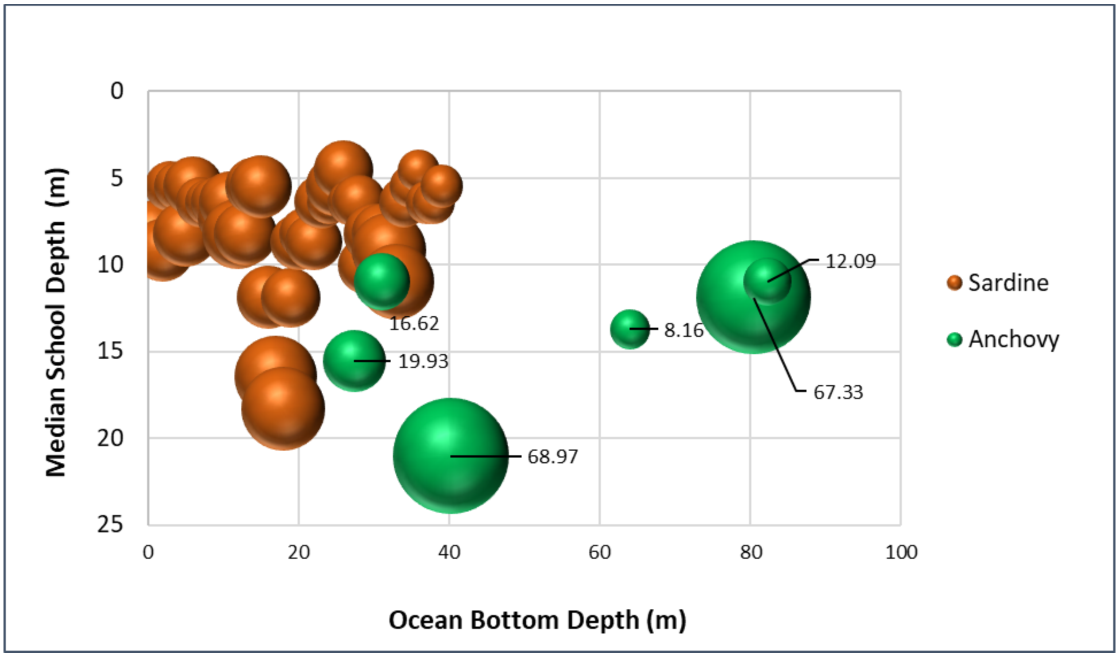


Figure 11. Median school depth distribution, biomass (ALC), and ocean bottom depth from 2018-2020 NCS point sets. Biomass (mt) indicated for Northern Anchovy schools to show scale**.**

A current research question concerns the proportion of adult and sub-adult ("pinhead") individuals within observed Northern Anchovy schools. This unknown has important ramifications on assessments and management, as only adult biomass is applicable as spawning stock biomass, which is the biomass metric of interest for the stock assessment and management. 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.
In addition, future point set surveys will focus on obtaining more data on Northern Anchovy schools, especially the larger schools closer to the capture limit of about 100 mt due to fishing vessel hold size. This will allow a greater number of biomass estimates of these larger schools to be validated by point sets.

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7. 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 poor 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 Northern Anchovy stock assessment. 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.

8. APPENDIX B

Steps in calculating CCPSS biomass and variance for 2015-2019 surveys (reproduced from PFMC 2020a, Appendix 4).

- Two bands, each 1200m width, were flown on the same day one time;
- Biomass estimated on each band was assumed independent;
- When few schools were observed, spotter was able to estimate the biomass of each schools;
- When too many schools were observed on a given transect for the spotter to be able to estimate single school biomass, he instead provided an aggregated biomass estimate;
- Hence, it was not possible to develop a method to consistently estimate a variance for all individual bands;
- Therefore, only total biomass was estimated for each band in the analysis as follows:

$$B_{j,A} = \sum_{i=1}^{n\,(j)} b_{i,j,A}$$

where $b_{i,j,A}$ is the biomass estimated for each single (or aggregated) school *i* (total number of schools = *n*(*j*)) on band *j* in area *A*;

- An estimated of number of schools was provided for each band;
- The estimate in inshore biomass in area *A* is then

$$B_A^{tot} = \sum_{j=1}^{2} B_{j,A}$$

- For daily biomass observed in a given area, the mean of total biomass across the two bands, can be estimated as follows:

$$\bar{B}_A = \frac{1}{2}\sum_{j=1}^{2} B_{j,A}$$

- And the variance of each daily biomass $\bar{B}_A$ is estimated as

follows:

$$v(\bar{B}_A) = \frac{1}{(2-1)}\sum_{j=1}^{2}\left(B_{j,A} - \bar{B}_A\right)^2$$

Variance of a given season where x areas were surveyed is computed as:

$$\sum_{A=1}^{x} 4 \times V(\bar{B}_A)$$

9. APPENDIX C

Table C1. Estimated school biomass (ESB) and percent school wrapped by Spotter 1, landed catch (mt), and adjusted landed catch (ALC) for Pacific Sardine and Northern Anchovy.

Date	Region	Species	Aerial observed Est. School Biomass (mt)	Aerial observed Est. % School Wrapped	Purse seine sampling Landed Catch (mt)	Purse seine sampling 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 Northern Anchovy survey data for CCPSS flights from 2015-2019, including coastal water area coverage. The survey design consisted of two unreplicated transects covering waters from 0 to 2,400 m offshore.

Date	Region	Season	Area	Start Location - Latitude	Start Location - Longitude	End Location - Latitude	End Location - Longitude	Area (km²)	Biomass (mt)	CV
8/7/2015	SCA	Summer	Carlsbad-Mexico	32.885	-117.253	32.533	-117.125	124	0	-
8/11/2015	SCA	Summer	Point Vicente-Dana Point	33.737	-118.4	33.471	-117.719	184	0	-
8/13/2015	SCA	Summer	Dana Point-La Jolla	33.459	-117.699	32.886	-117.254	187	0	-
8/26/2015	SCA	Summer	Point Conception-Point Vicente	34.451	-120.435	33.739	-118.41	552	0	-
10/2/2015	SCA	Summer	Point Conception-Point Fermin	34.45	-120.425	33.705	-118.291	581	0	-
10/3/2015	SCA	Summer	Long Beach-Mexico	33.705	-118.29	32.533	-117.125	477	0	-
4/16/2016	SCA	Spring	Long Beach-Mexico	33.721	-118.078	32.533	-117.125	429	137	0.71
4/17/2016	SCA	Spring	Point Mugu-Long Beach	34.079	-119.029	33.703	-118.288	103	142	-
4/26/2016	SCA	Spring	Point Conception-Point Mugu	34.455	-120.403	34.079	-119.029	359	771	0.11
5/1/2016	SCA	Spring	Long Beach-Dana Point	33.881	-118.425	33.351	-117.877	93	0	-
5/23/2016	SCA	Spring	Point Conception-Santa Monica	34.456	-120.385	34.007	-118.498	490	3,213	0.67
6/22/2016	SCA	Spring	Manhattan Beach-Carlsbad	33.88	-118.411	33.287	-117.462	312	1,048	0.52
6/23/2016	SCA	Spring	Carlsbad-Mexico	33.287	-117.462	32.533	-117.125	242	0	-
8/11/2016	SCA	Summer	Point Conception-Santa Monica	34.455	-120.4	34.018	-118.507	489	0	-
8/29/2016	SCA	Summer	Manhattan Beach-Mexico	33.865	-118.404	32.533	-117.125	548	29	0.71
3/28/2017	SCA	Spring	Point Fermin-Dana Point	33.741	-118.413	33.461	-117.715	190	255	0.31
3/30/2017	SCA	Spring	Point Mugu-Santa Monica	34.086	-119.066	34.009	-118.5	138	39	0.71
8/3/2017	NCA	Summer	Half Moon Bay-Carmel	37.499	-122.492	36.524	-121.952	402	35,651	0.69
8/4/2017	NCA	Summer	Point Arena-Half Moon Bay	38.802	-123.595	37.499	-122.492	539	32,039	0.29
8/10/2017	NCA	Summer	Carmel-Morro Bay	36.525	-121.957	35.448	-120.921	412	7,648	0.63
4/24/2018	SCA	Spring	Point Fermin-Mexico	33.725	-118.186	32.533	-117.125	452	14	0.71
4/26/2018	SCA	Spring	Point Conception-Ventura	34.455	-120.408	34.273	-119.301	274	301	0.71
4/27/2018	SCA	Spring	Ventura-Point Fermin	34.274	-119.301	33.725	-118.186	327	0	-
5/4/2018	SCA	Spring	Point Conception-Mexico	34.449	-120.423	32.533	-117.125	1,055	338	0.71
9/10/2018	SCA	Summer	Manhattan Beach-Mexico	33.886	-118.413	32.533	-117.125	554	18	0.71
9/13/2018	SCA	Summer	Point Conception-Santa Monica	34.452	-120.418	34.006	-118.494	442	14	0.71
10/13/2018	NCA	Summer	Garrapata SP-Ragged Point	36.418	-121.917	35.775	121.328	239	69,967	0.71
5/29/2019	SCA	Spring	Los Alamitos-Newport Beach	33.729	-118.089	33.594	-117.884	60	0	-
6/8/2019	SCA	Spring	Point Conception-Point Dume	34.453	-120.413	34.041	-118.913	391	3,201	0.71
6/14/2019	SCA	Spring	Newport Beach-Mexico	33.594	-117.884	32.533	-117.125	357	0	-
6/28/2019	SCA	Spring	Manhattan Beach-Los Alamitos	33.872	-118.407	33.729	-118.089	119	0	-
8/6/2019	NCA	Summer	S. of Cape Mendocino-Stewarts Point	40.343	-124.363	38.627	-123.386	571	0	-

8/7/2019	NCA	Summer	Drakes Bay-Manresa Beach	37.989	-122.964	36.622	-121.906	572	47,102	0.71
8/8/2019	NCA	Summer	Davenport-Limekiln SP (Kirk Creek)	36.622	-121.906	36.013	-121.528	245	1,520	0.71
8/27/2019	SCA	Summer	Point Conception-Oxnard	34.45	-120.421	34.156	-119.228	312	9,744	0.09
8/28/2019	SCA	Summer	Point Dume-Mexico	34.039	-118.886	32.533	-117.125	645	33	0.71
8/29/2019	SCA	Summer	Ventura-Point Dume	34.156	-119.228	34.038	-118.886	87	6	0.71

Note: For 4/17/16, Transect 2 not flown, so no variance provided.

Table C3. Daily Northern 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 - Latitude	Start Location - Longitude	End Location - Latitude	End Location - Longitude	Area (km^2)	Biomass (mt)	CV
9/5/2020	NCA	Summer	N8	35.555	-121.104	35.206	-120.857	200	619	1.73
9/6/2020	NCA	Summer	N2	38.535	-123.282	38.214	-122.981	187	21	1.73
9/6/2020	NCA	Summer	N3	37.996	-123.026	37.854	-122.57	196	0	-
9/7/2020	NCA	Summer	N1	39.09	-123.707	38.721	-123.473	200	27	1.73
9/14/2020	NCA	Summer	N4	37.498	-122.501	37.182	-122.393	148	39	1.73
9/15/2020	NCA	Summer	N6	37.014	-122.207	36.774	-121.798	165	0	-
9/15/2020	NCA	Summer	N5	36.637	-121.938	36.302	-121.896	194	38,565	1.7
9/16/2020	NCA	Summer	N7	35.815	-121.376	35.702	-121.305	51	0	-
9/18/2020	SCA	Summer	S1	34.45	-120.472	34.428	-119.913	200	0	-
9/18/2020	SCA	Summer	S2	34.417	-119.657	34.15	-119.219	195	3,483	0.72
9/19/2020	SCA	Summer	S3	34.061	-118.987	34.032	-118.725	100	40	1.35
9/19/2020	SCA	Summer	S4	33.758	-118.418	33.723	-118.193	95	0	-
9/19/2020	SCA	Summer	S5	33.706	-118.06	33.413	-117.614	199	30	1.73
9/20/2020	SCA	Summer	S6	33.226	-117.412	32.781	-117.255	197	0	-
3/22/2021	SCA	Spring	S5E	33.411	-117.614	33.226	-117.412	101	0	-
3/22/2021	SCA	Spring	S6	33.226	-117.412	32.828	-117.28	175	577	0.94
3/24/2021	SCA	Spring	S4E	33.722	-118.192	33.706	-118.06	44	0	-
3/24/2021	SCA	Spring	S5	33.706	-118.06	33.411	-117.614	199	45	1.73
4/1/2021	SCA	Spring	S2	34.417	-119.656	34.15	-119.219	195	4,100	0.48
4/1/2021	SCA	Spring	S2E	34.15	-119.219	34.061	-118.988	93	784	1.03
4/1/2021	SCA	Spring	S3	34.061	-118.988	34.032	-118.725	100	160	1.14
4/2/2021	SCA	Spring	S1	34.442	-120.453	34.428	-119.913	180	1,763	1.57
4/2/2021	SCA	Spring	S1E	34.428	-119.913	34.397	-119.707	81	736	1.55
4/2/2021	SCA	Spring	S4	33.736	-118.4	33.722	-118.192	78	0	-
8/6/2021	NCA	Summer	N1	38.921	-123.729	38.721	-123.473	122	16	0.88
8/10/2021	NCA	Summer	N2	38.535	-123.282	38.214	-122.981	187	50	1.73
8/10/2021	NCA	Summer	N4	37.6	-122.514	37.252	-122.418	164	0	-
8/11/2021	NCA	Summer	N5	37.014	-122.208	36.774	-121.798	194	11,800	1.56
9/12/2021	SCA	Summer	S1	34.442	-120.453	34.428	-119.913	179	0	-
9/12/2021	SCA	Summer	S1E	34.428	-119.913	34.417	-119.656	100	80	1.73
9/14/2021	SCA	Summer	S2	34.417	-119.656	34.15	-119.219	195	11,383	0.63
9/14/2021	SCA	Summer	S2E	34.15	-119.219	34.061	-118.987	93	16	1.73
9/14/2021	SCA	Summer	S3	34.061	-118.987	34.032	-118.725	100	0	-
9/16/2021	SCA	Summer	S4	33.758	-118.418	33.722	-118.192	95	2	1.73
9/16/2021	SCA	Summer	S4E	33.722	-118.192	33.706	-118.06	44	0	-
9/16/2021	SCA	Summer	S5	33.706	-118.06	33.411	-117.614	199	0	-
9/17/2021	SCA	Summer	S6	33.226	-117.412	32.838	-117.283	167	130	0.98

10. APPENDIX D

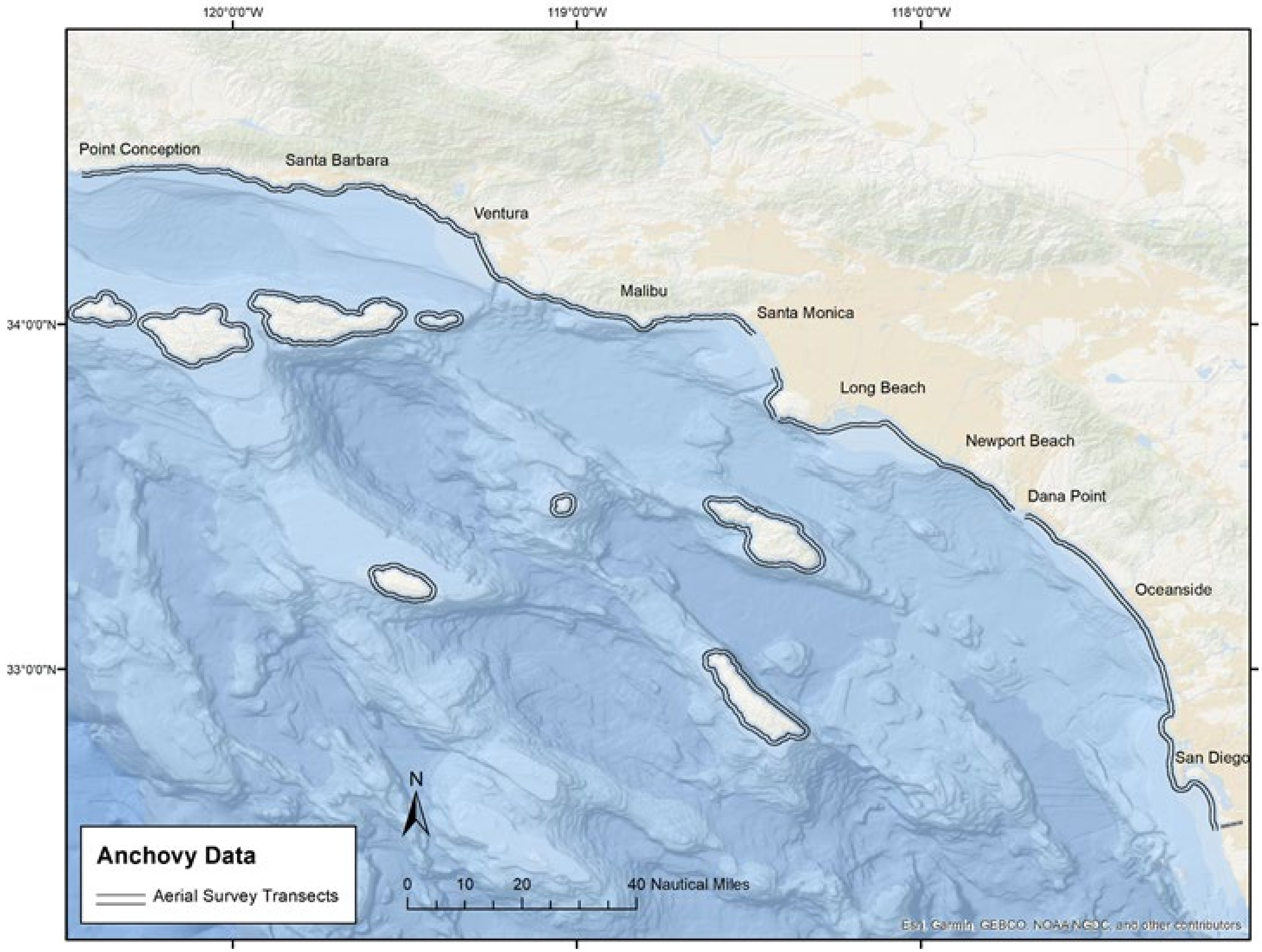

Figure D1. Survey area in Southern California for Survey 1 and Survey 2 during summer 2015. Two unreplicated transects were flown and no anchovy were observed.

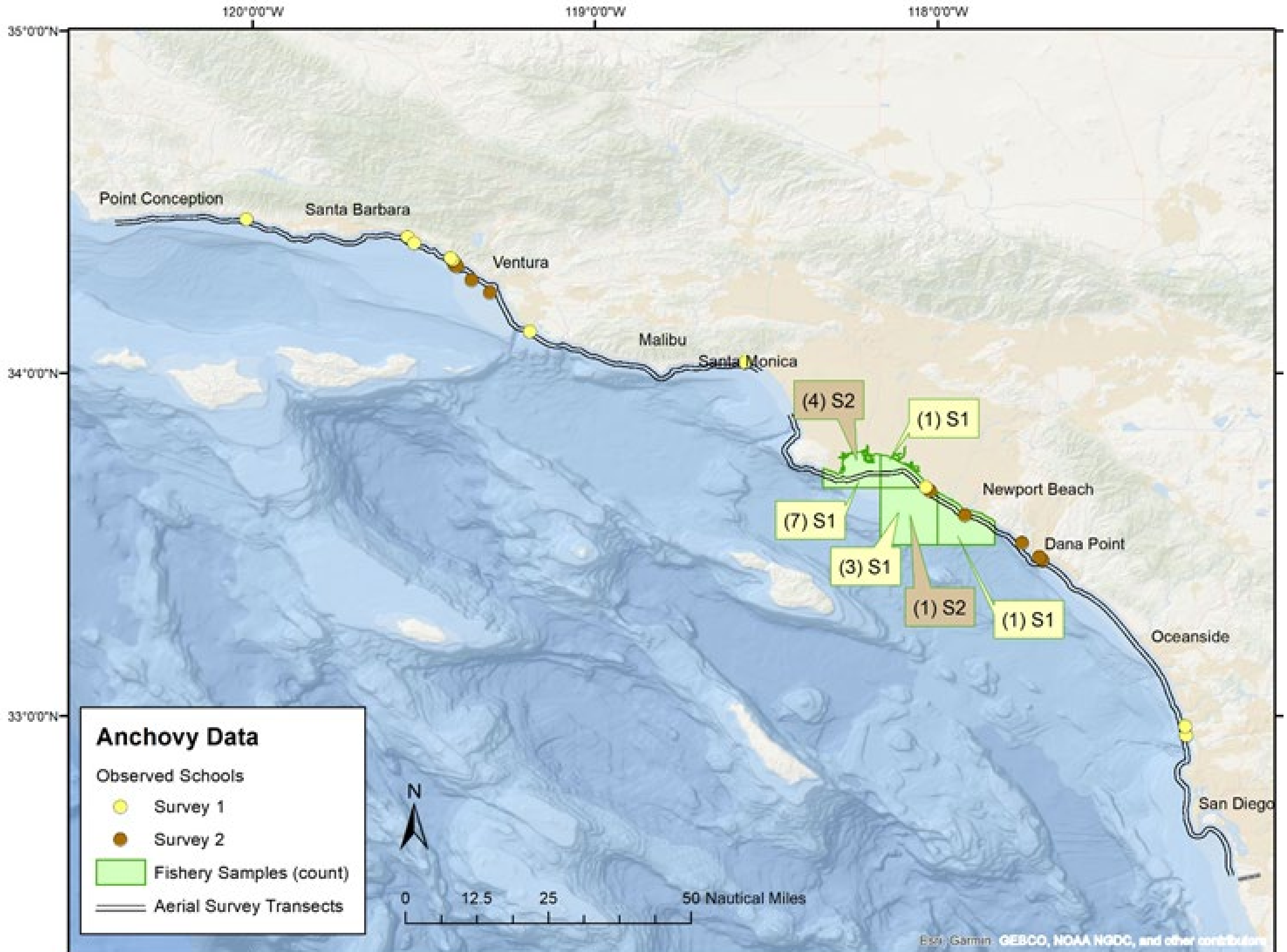

Figure D2. Survey area, school distributions from CCPSS, and fishing block locations of commercial fishery samples collected within one month of CCPSS Survey 1 and Survey 2 in Southern California during spring 2016.

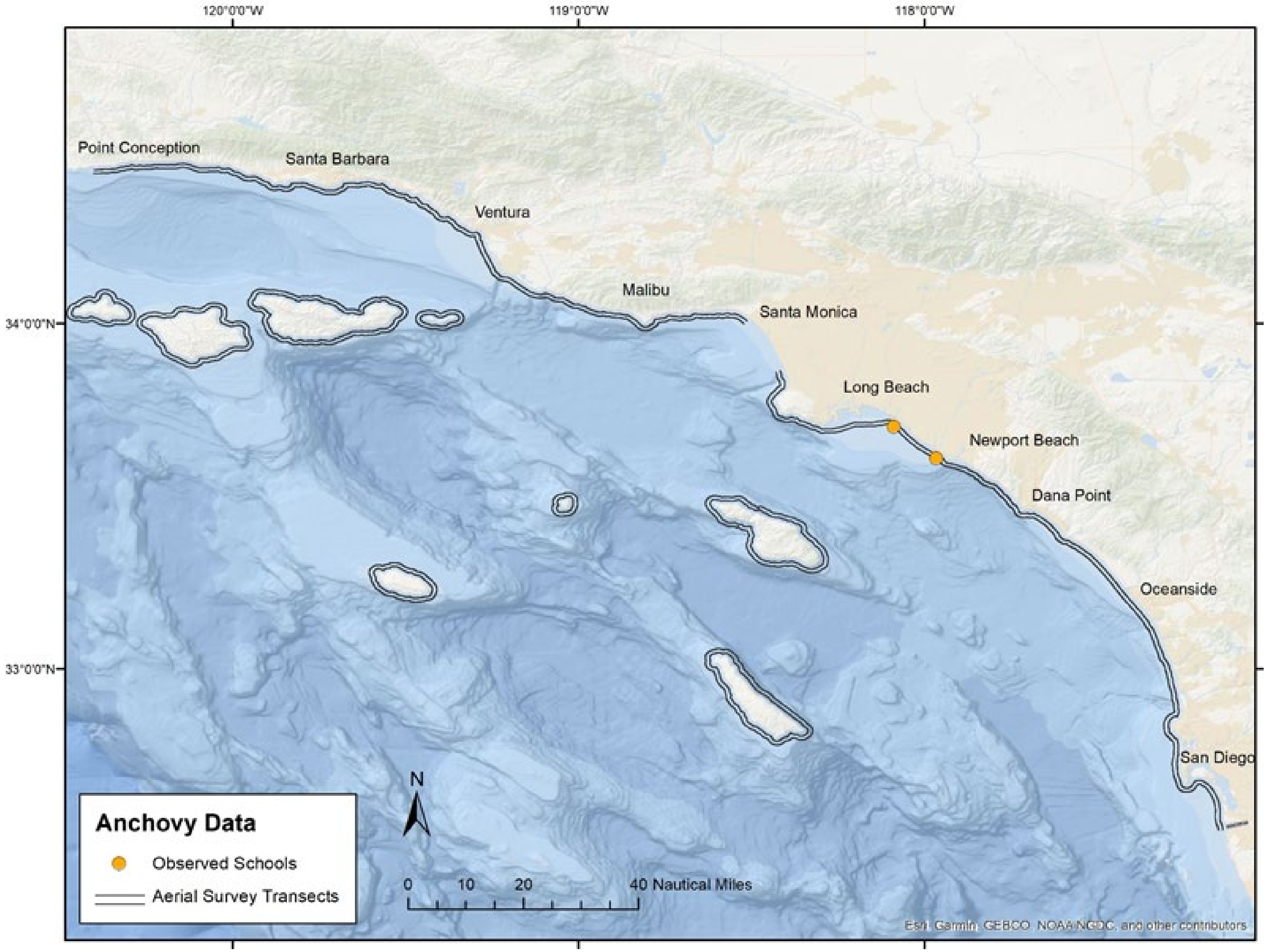

Figure D3. Survey area and school distributions from CCPSS in Southern California during spring 2016.

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

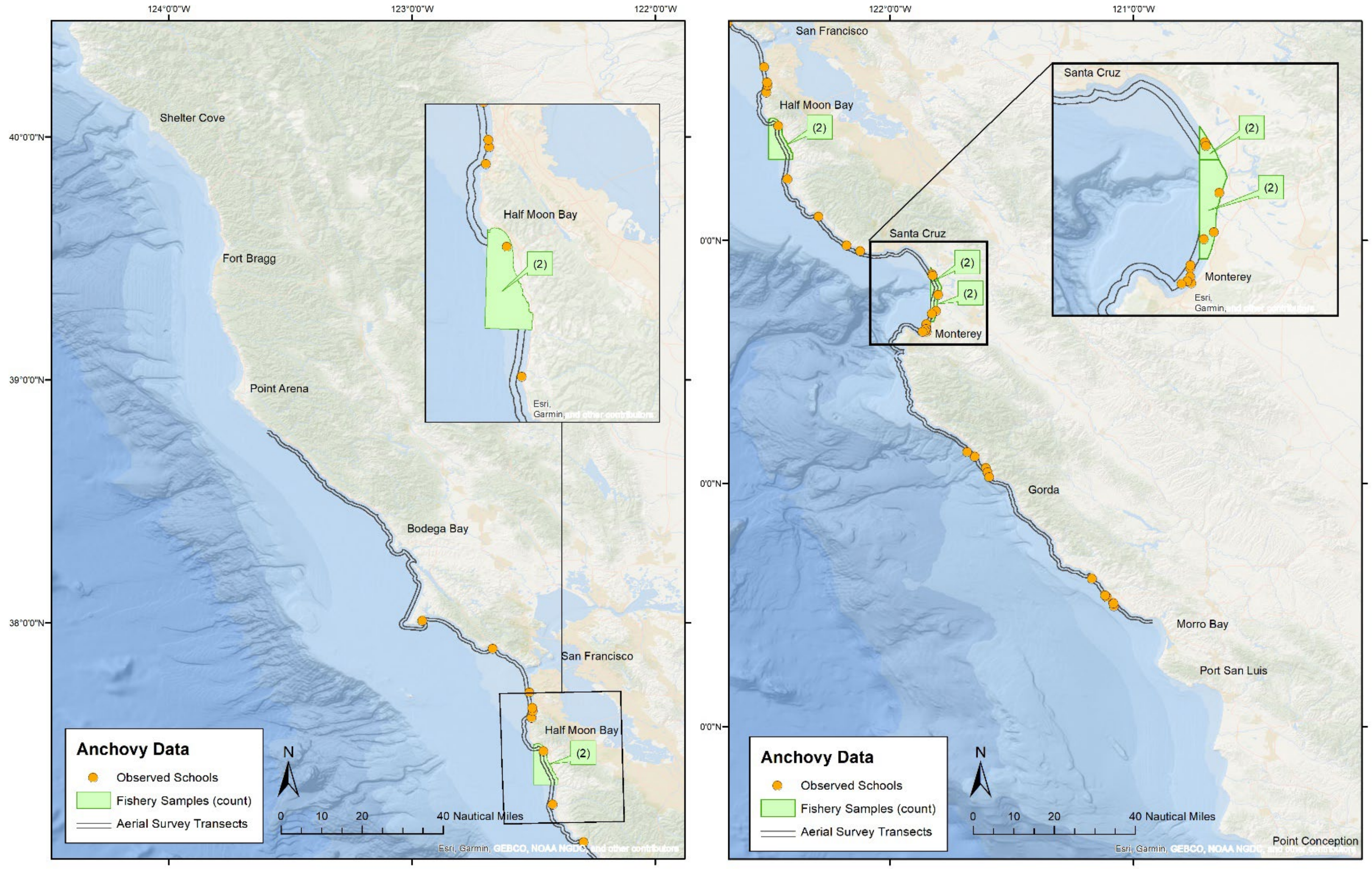

Figure D5. Survey area, school distributions from CCPSS, and fishing block locations of commercial fishery samples collected within one month of CCPSS in Northern California during summer 2017.

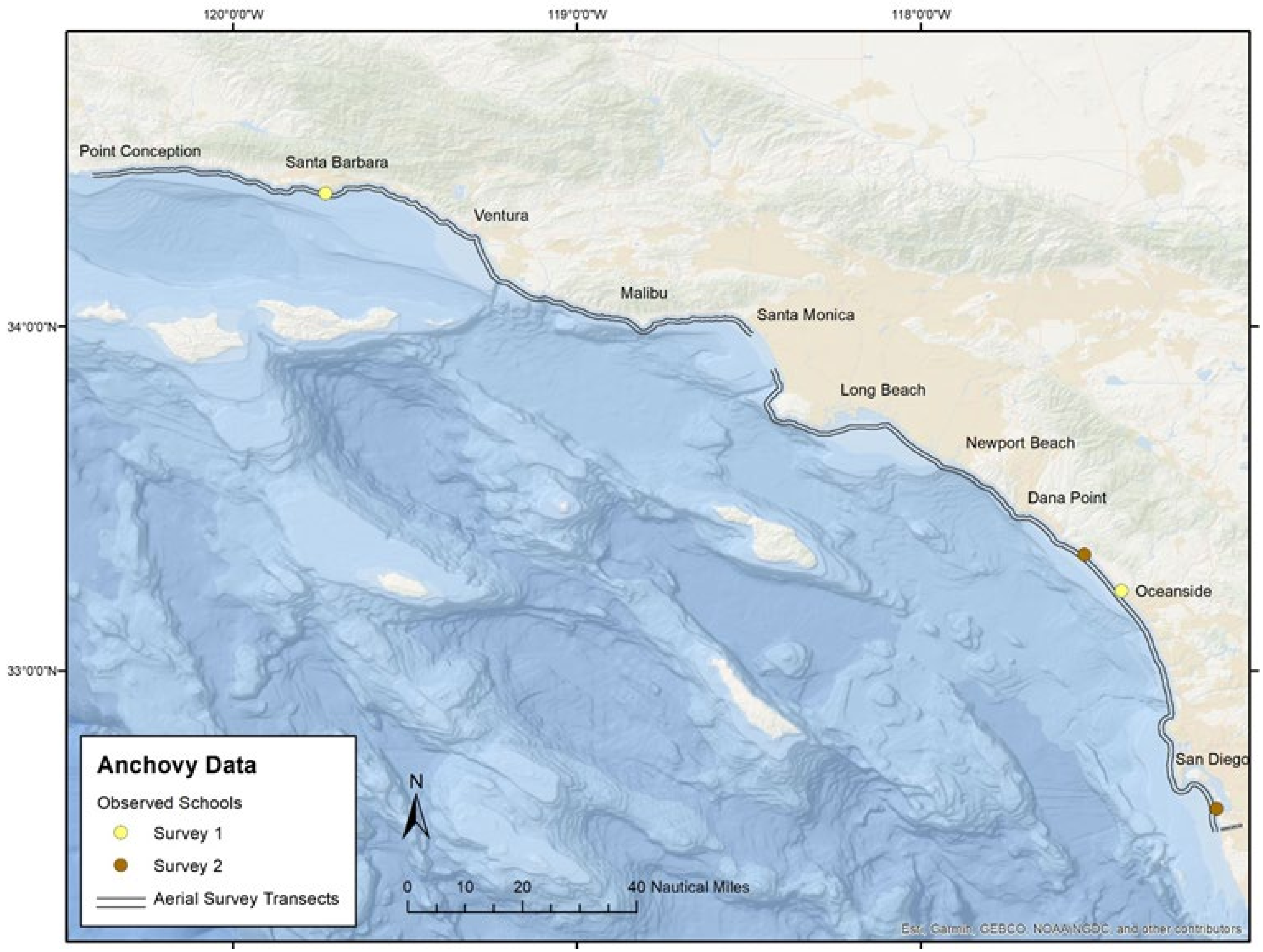

Figure D6. Survey area and school distributions from CCPSS Survey 1 and Survey 2 in Southern California during spring 2018.

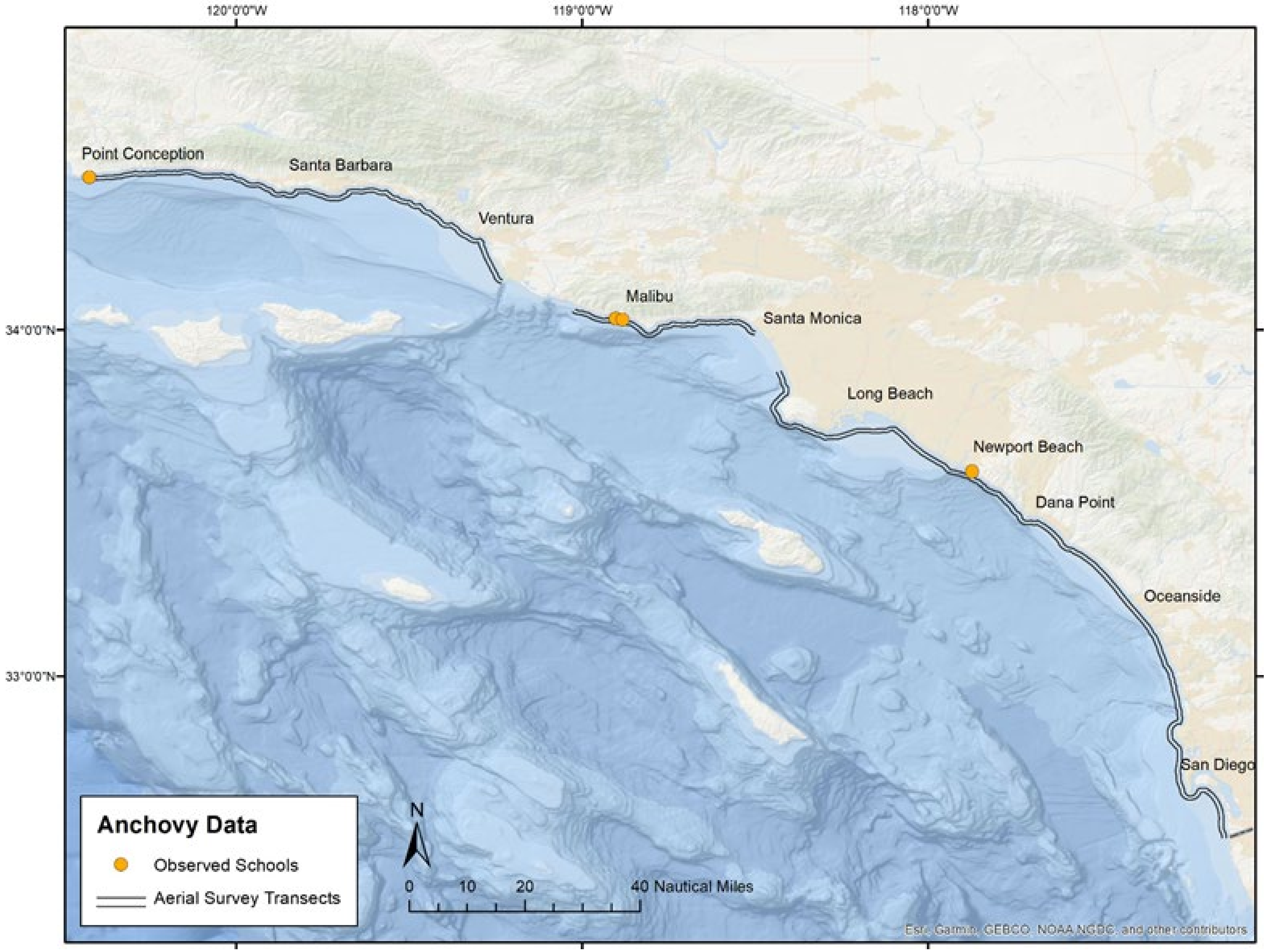

Figure D7. Survey area and school distributions from CCPSS in Southern California during summer 2018.

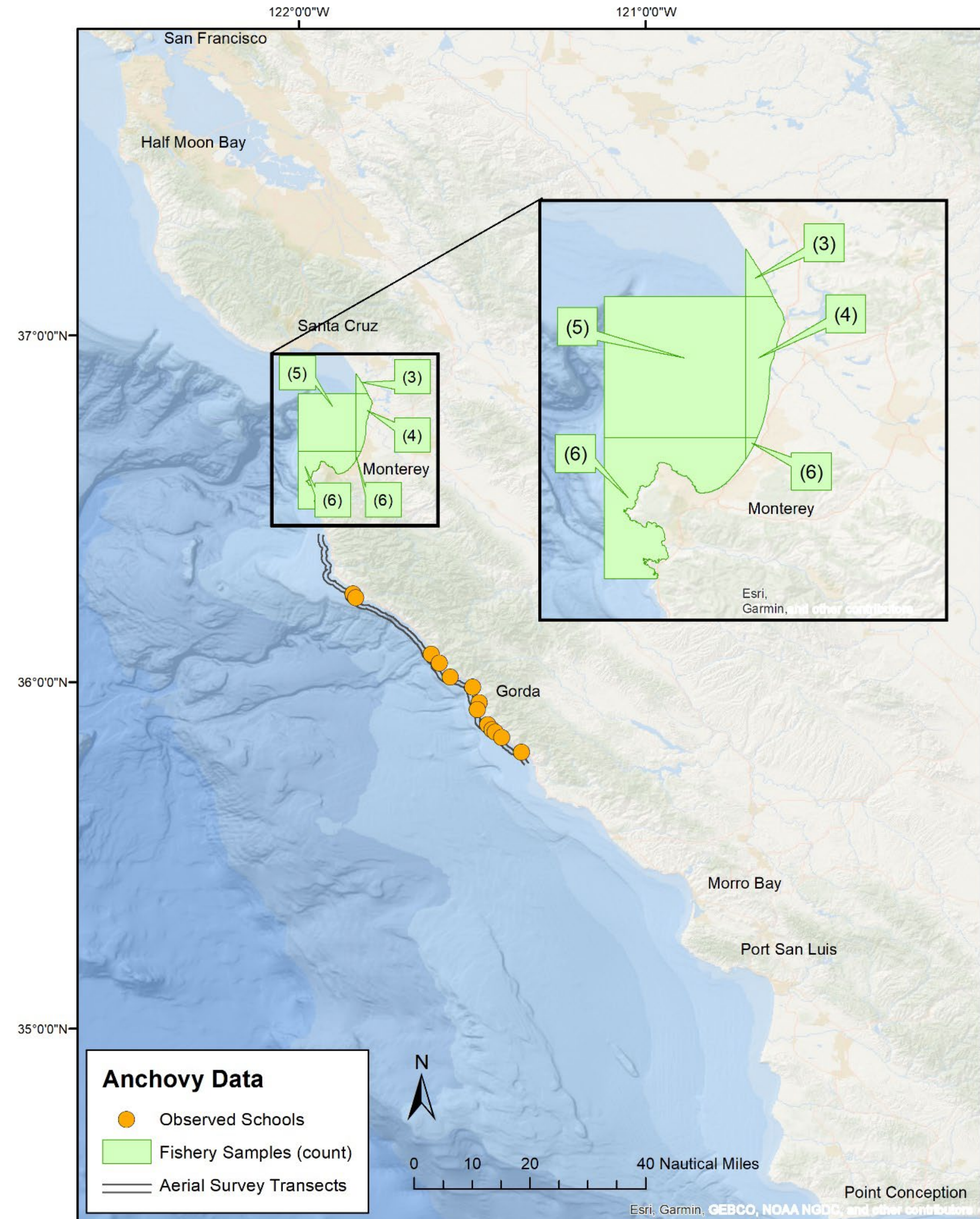

Figure D8. Survey area, school distributions from CCPSS, and fishing block locations of commercial fishery samples collected within one month of CCPSS in Northern California during summer 2018.

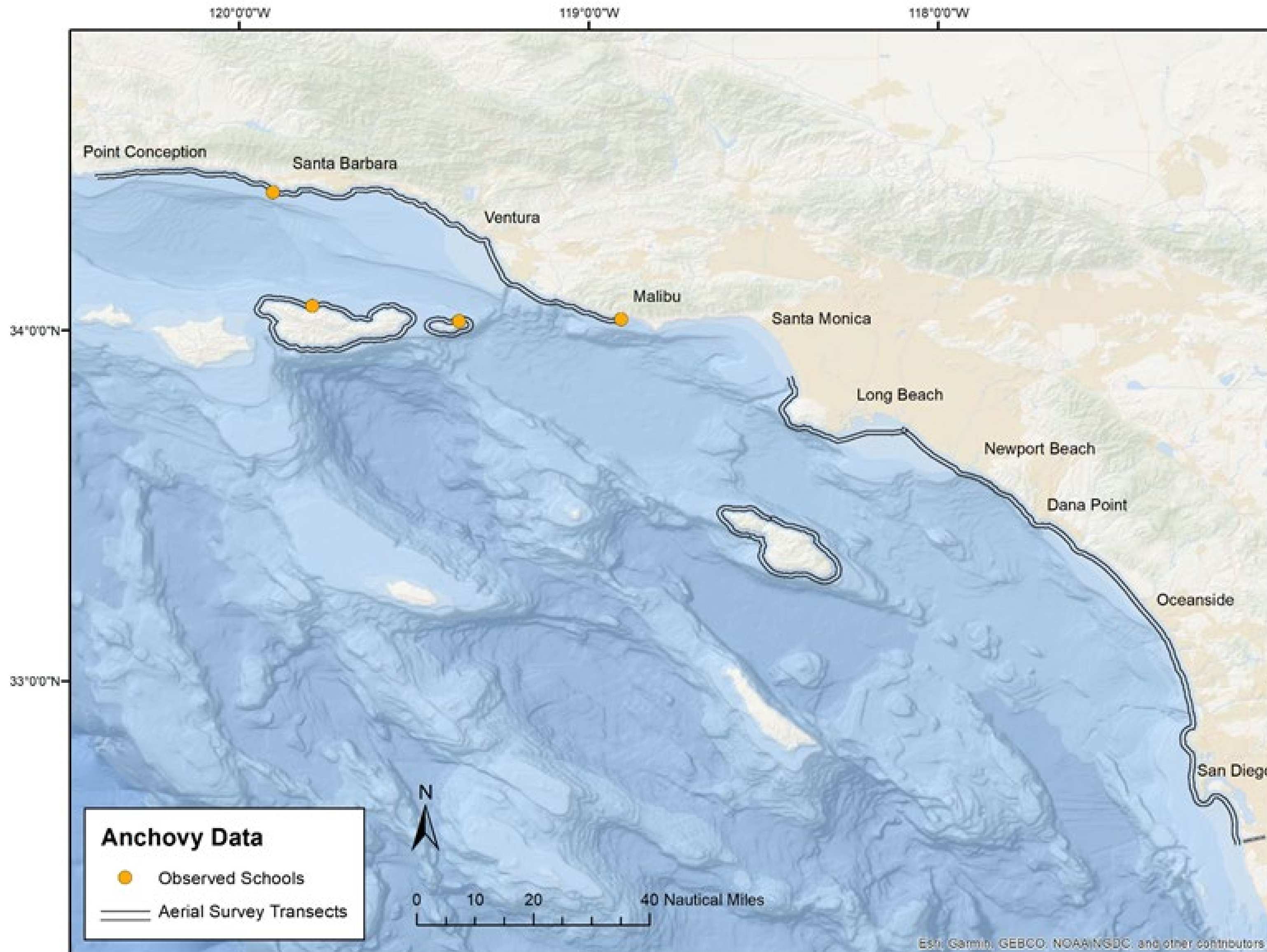

Figure D9. Survey area and school distributions from CCPSS in Southern California during spring 2019.

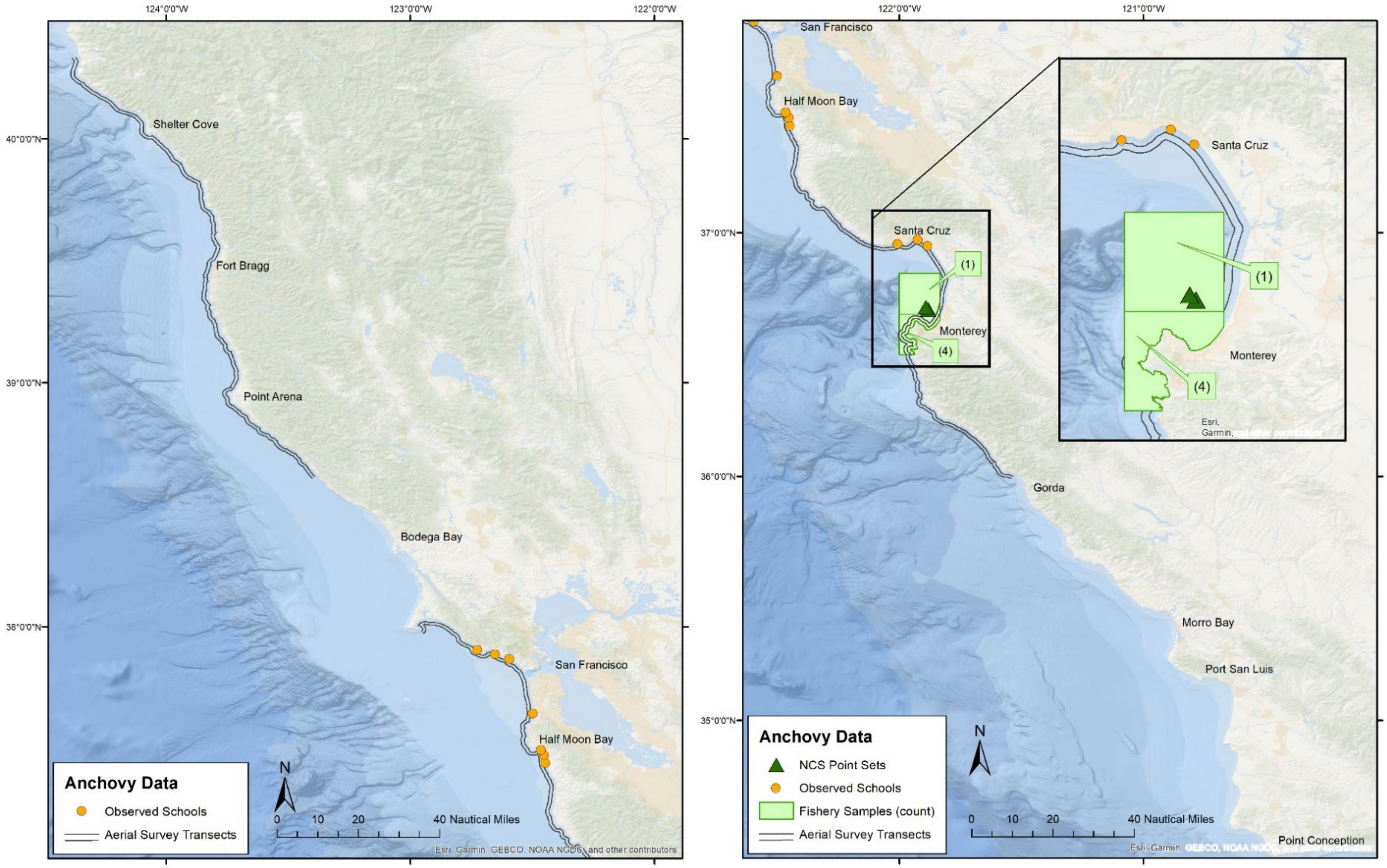

Figure D10. Survey area, school distributions from CCPSS, locations of NCS point sets, and fishing blocks of commercial fishery samples collected within one month of CCPSS in Northern California during summer 2019.

Figure D11. Survey area and school distributions from CCPSS in Southern California during summer 2019.

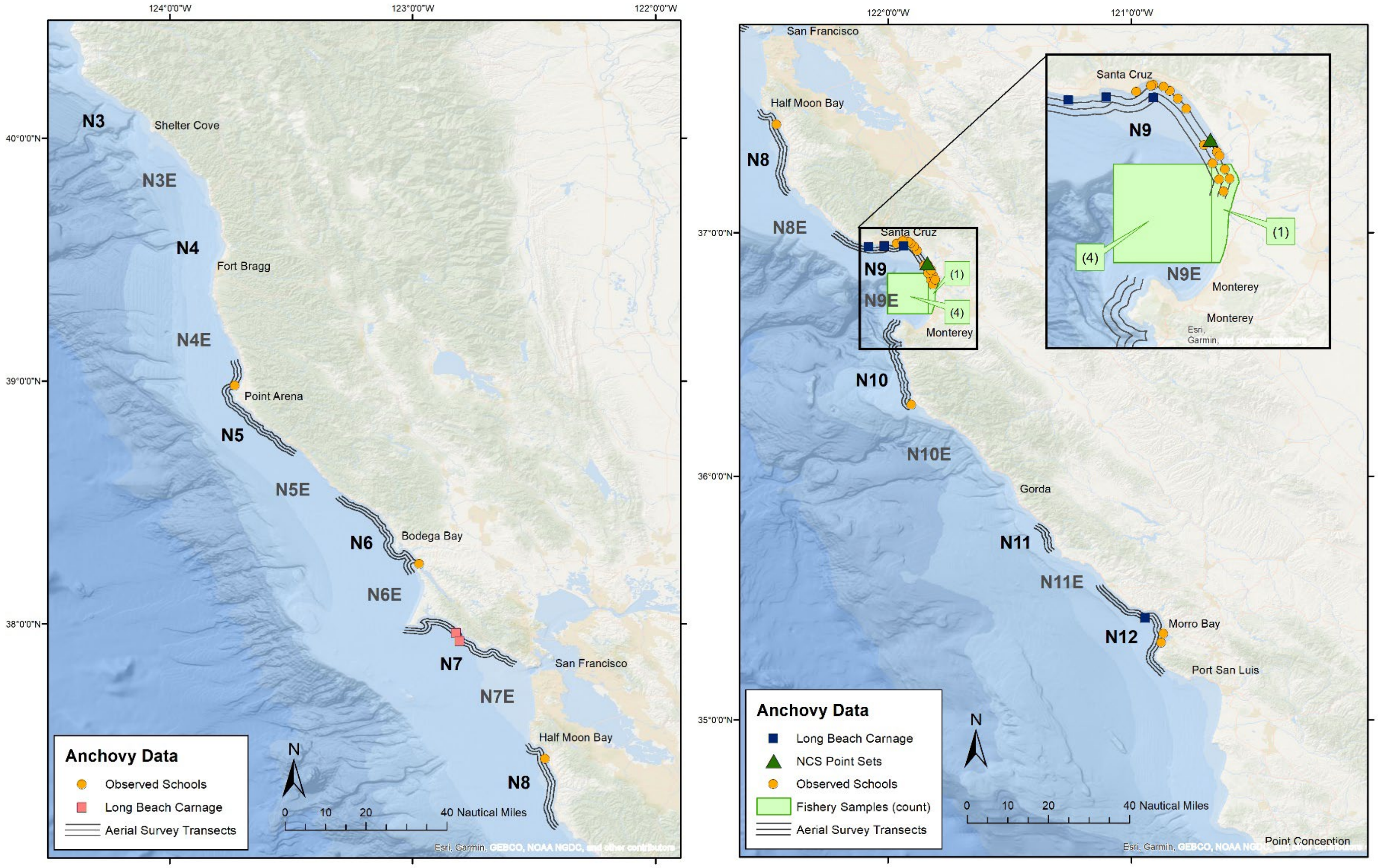

Figure D12. Survey area, school distributions from CCPSS, locations of *F/V Long Beach Carnage* samples and NCS point sets, and fishing blocks of commercial fishery samples collected within one month of CCPSS in Northern California during summer 2020.

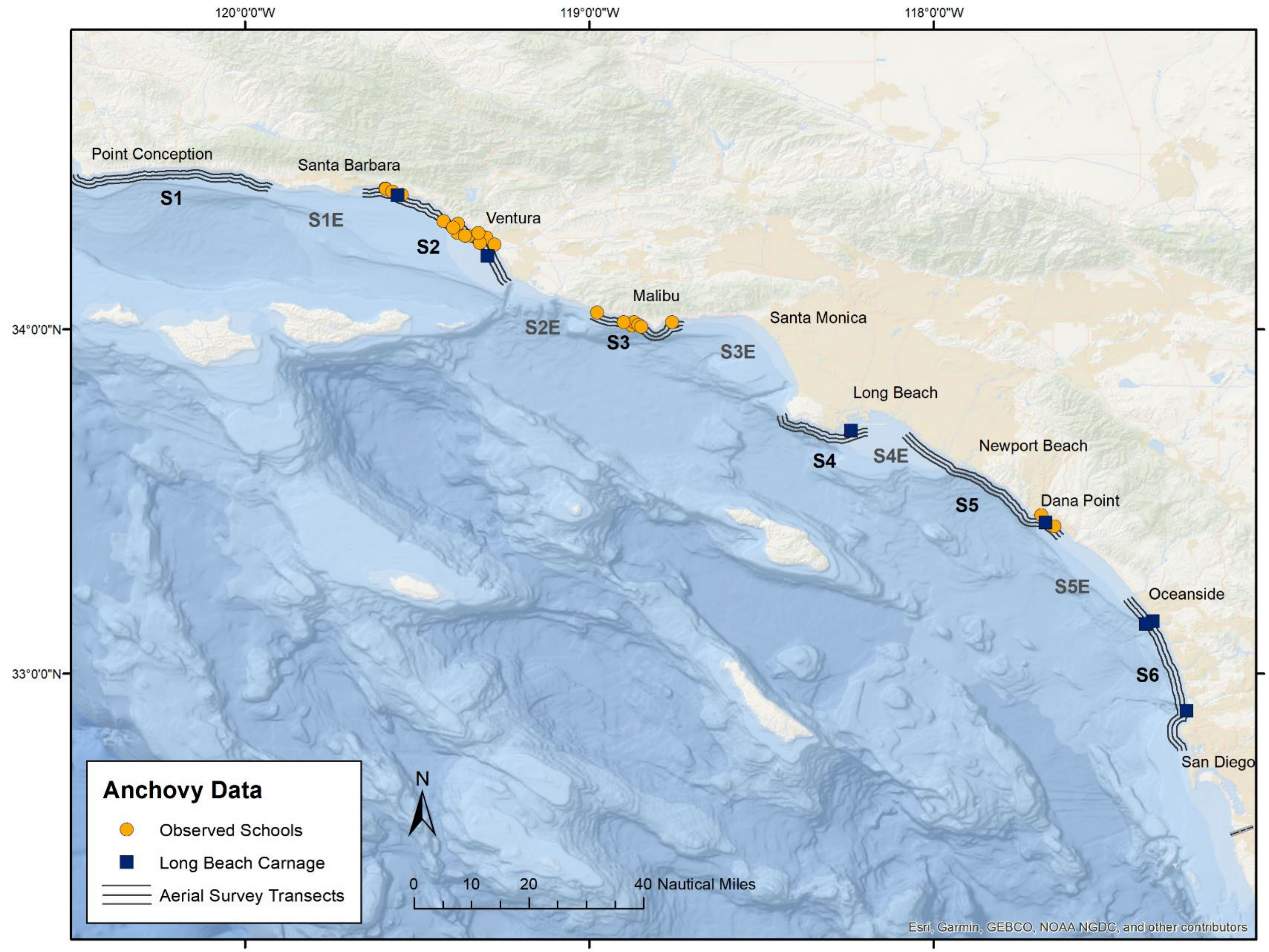

Figure D13. Survey area, school distributions from CCPSS, and locations of *F/V Long Beach Carnage* samples in Southern California during summer 2020.

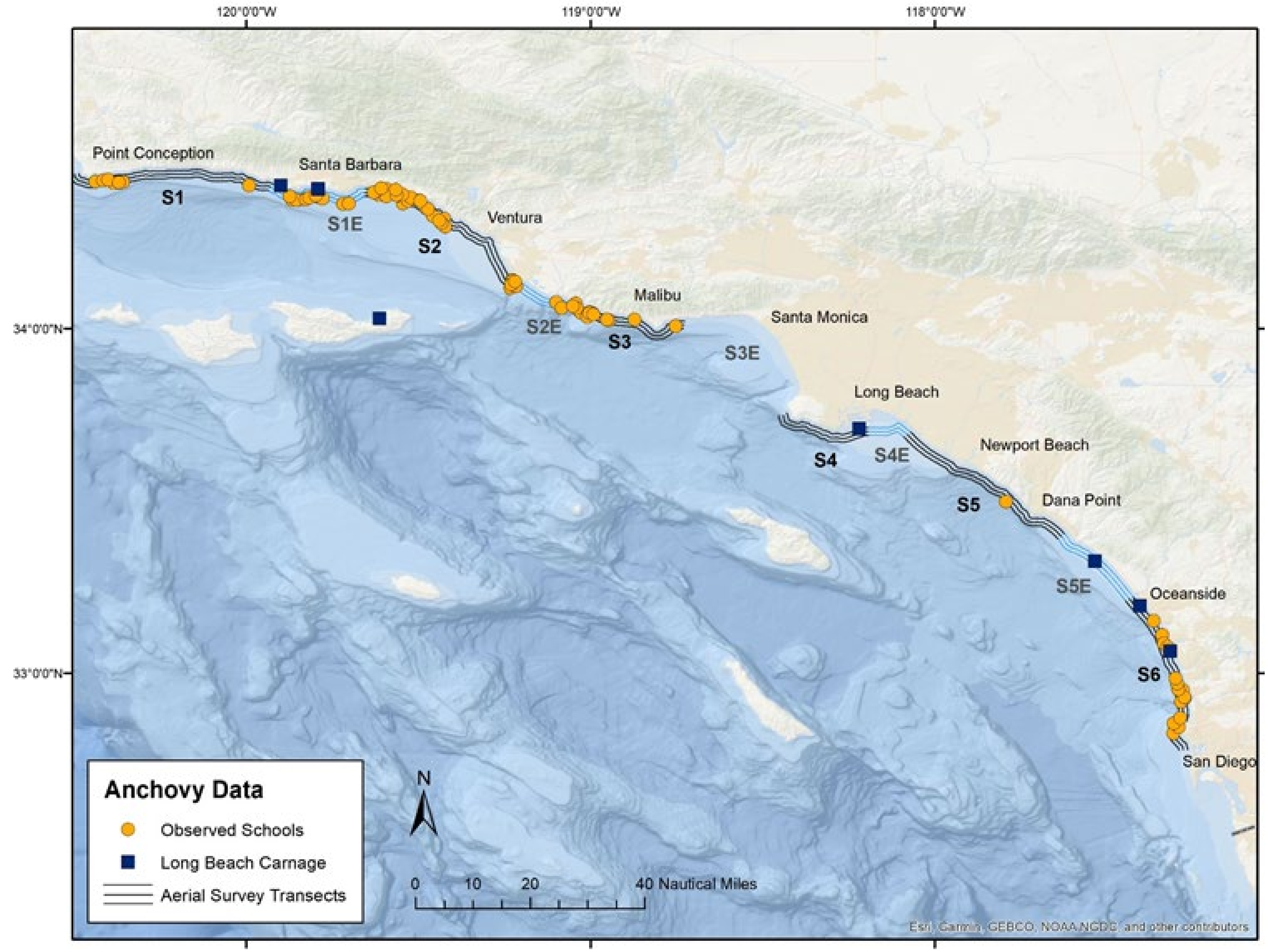

Figure D14. Survey area, school distributions from CCPSS, and locations *of F/V Long Beach Carnage* samples in Southern California during spring 2021.

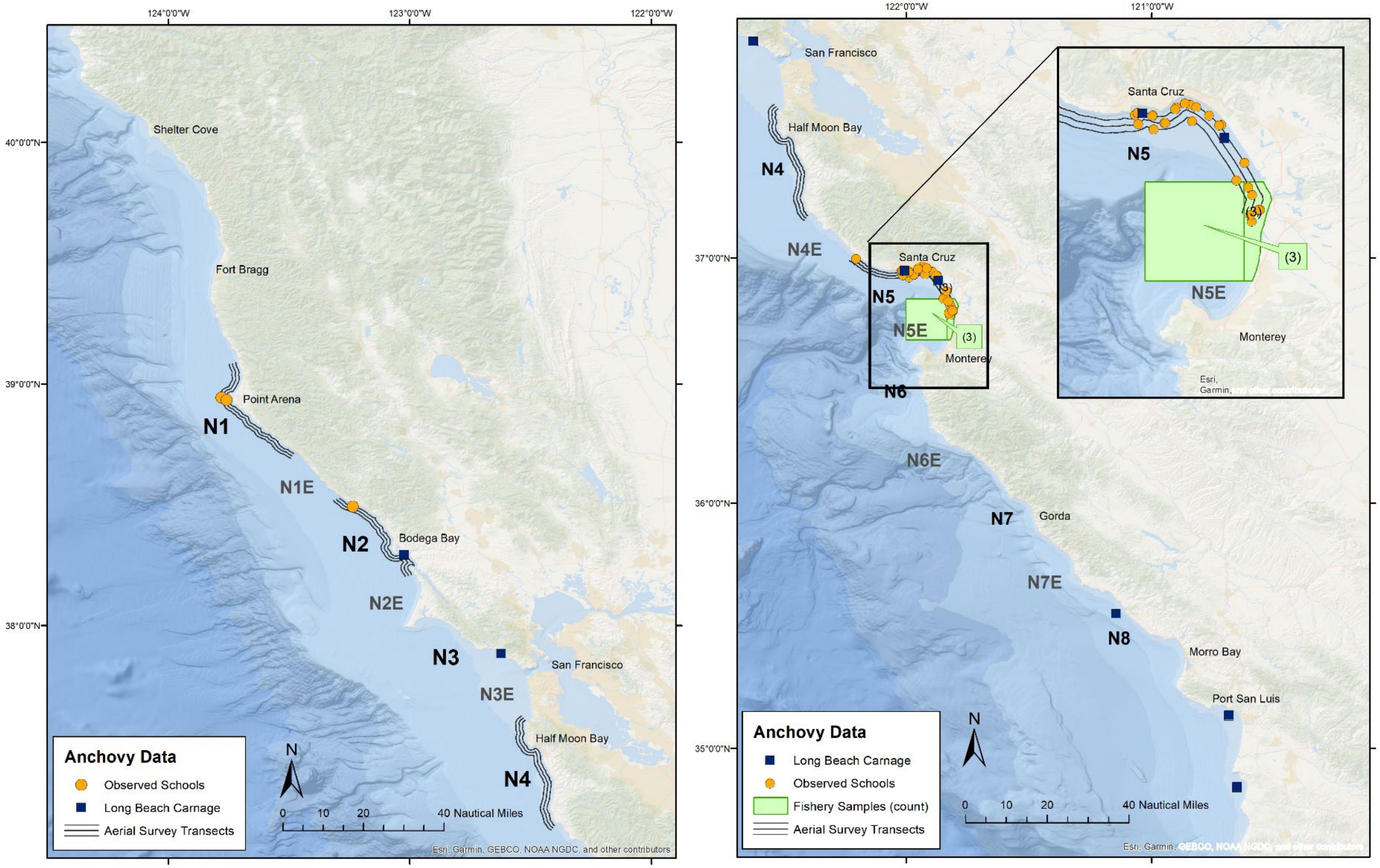

Figure D15. CCPSS surveyed area, school distributions, locations of F/V *Long Beach Carnage* samples, and fishing blocks of commercial fishery samples collected within one month of CCPSS in Northern California during summer 2021.

Figure D16. CCPSS surveyed area, school distributions, and locations of *F/V Long Beach Carnage* samples in Northern California during summer 2021. Expansion strata included in the survey area are colored blue.