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DISTRIBUTION, BIOMASS, AND DEMOGRAPHICS OF COASTAL PELAGIC FISHES IN THE CALIFORNIA CURRENT ECOSYSTEM DURING SPRING 2021 BASED ON ACOUSTIC-TRAWL SAMPLING

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Contents

List of Tables

List of Figures

Executive Summary

This report provides: 1) a detailed description of the acoustic-trawl method used by NOAA's Southwest Fisheries Science Center (SWFSC) for direct assessments of the dominant coastal pelagic fish species (CPS), i.e.: Pacific Sardine *Sardinops sagax*, Northern Anchovy *Engraulis mordax*, Pacific Mackerel *Scomber japonicus*, and Jack Mackerel *Trachurus symmetricus* in the California Current Ecosystem (CCE) off the west coast of North America; and 2) estimates of the biomasses, distributions, and demographics of those CPS encountered in the survey area between 20 March and 13 April 2021. The core survey region, which was sampled by NOAA Ship *Reuben Lasker* (hereafter, *Lasker*), spanned most of the continental shelf between San Diego and San Francisco, California (CA). Throughout the core region, *Lasker* sampled along transects oriented approximately perpendicular to the coast, from the shallowest navigable depth (~30 m) to offshore distances of ~75 nmi in the Southern CA Bight (SCB) and ~35 nmi between Point Conception and San Francisco. To estimate the CPS biomasses in the nearshore region, where sampling by *Lasker* was deemed inefficient, unsafe, or both, fishing vessel (F/V) *Long Beach Carnage* sampled to ~10 m depth along 5-nmi-long transects spaced 5 nmi apart between Point Conception and San Diego, and around Santa Cruz and Santa Catalina Islands in the SCB.

The biomasses, distributions, and demographics for each species and stock are for the survey area and period, and therefore may not represent the entire populations.

The estimated biomass of the central stock of Northern Anchovy was 1,370,303 t ($CI_{95\%}$ = 1,076,749 - 1,959,163 t, CV = 16%). In the core region, sampled by *Lasker*, biomass was 1,358,587 t ($CI_{95\%}$ = 1,070,094 - 1,940,986 t, CV = 17%). In the nearshore region, sampled by *Long Beach Carnage*, biomass was 11,716 t ($CI_{95\%}$ = 6,655 - 18,176 t, CV = 26%), which was 0.86% of the total biomass. The central stock ranged from approximately Monterey Bay to San Diego, and its distribution of standard length (L_S) ranged from 8 to 16 cm with a mode between 10 and 12 cm.

The estimated biomass of the southern stock of Pacific Sardine in U.S. waters, distributed from approximately Point Conception to San Diego, was 24,547 t ($CI_{95\%}$ = 7,697 - 38,339 t, CV = 29%). Only 6% of the total biomass, 1,504 t ($CI_{95\%}$ = 556 - 2,959 t, CV = 40%), was in the core region. The remaining 94% (23,043 t, $CI_{95\%}$ = 7,140 - 35,380 t, CV = 31%), was in the nearshore region. Its L_S distribution was predominately between 12 to 15 cm with a mode at 10 cm.

The core survey area included some "good" and "optimal" habitat for the northern stock of Pacific Sardine, particularly north of Point Conception. However, the Pacific Sardine sampled in the SCB were exclusively in the nearshore region and around the northern Channel Islands, which had unsuitable habitat due to excessive chlorophyll-a concentration. Therefore, the Pacific Sardine observed in the spring 2021 survey were attributed to the southern stock.

The estimated biomass of Pacific Mackerel was 92.3 t ($CI_{95\%}$ = 7.43 - 221 t, CV = 64%), all observed in the nearshore region. Pacific Mackerel ranged from approximately Oceanside to San Diego and fork length (L_F) ranged from 14 to 25 cm with a mode at 18 cm.

The estimated biomass of Jack Mackerel was 16,882 t ($CI_{95\%}$ = 3,783 - 41,209 t, CV = 57%), all in the core region. Jack Mackerel ranged from approximately Point Conception to San Diego and L_F ranged from 9 to 23 cm with a mode at 13 cm.

The total estimated biomass of four stocks (four species) within the survey area was 1,411,825 t. Of this, 97% (1,370,303 t) was attributed to the central stock of Northern Anchovy. Contributions by other stocks were southern stock of Pacific Sardine (1.7%), Jack Mackerel (1.2%), and Pacific Mackerel (0.01%).

1 Introduction

In the California Current Ecosystem (CCE), five coastal pelagic fish species (CPS; i.e.: Pacific Sardine *Sardinops sagax*, Northern Anchovy *Engraulis mordax*, Jack Mackerel *Trachurus symmetricus*, Pacific Mackerel *Scomber japonicus*, and Pacific Herring *Clupea pallasii*) comprise the bulk of the forage fish assemblage. The biomasses of these populations can change by an order of magnitude within a few years and represent important prey for marine mammals, birds, and larger migratory fishes (Field *et al.*, 2001), and are targets of commercial fisheries.

During summer and fall, the northern stock of Pacific Sardine typically migrates north to feed in the productive coastal upwelling areas off Oregon (OR), Washington (WA), and Vancouver Island (Zwolinski *et al.*, 2012, and references therein). The predominantly piscivorous adult Pacific and Jack Mackerels also migrate north in summer, but go farther offshore to feed (Zwolinski *et al.*, 2014, and references therein). In the winter and spring, the northern stock of Pacific Sardine stock typically migrates south to its spawning grounds, generally off central and southern CA (Demer *et al.*, 2012) and occasionally off OR and WA (Lo *et al.*, 2011). These migrations vary in extent with population size; fish age and length; and oceanographic conditions. For example, the transition zone chlorophyll front (TZCF, Polovina *et al.*, 2001) may delineate the offshore and southern limits of Pacific Sardine and Pacific Mackerel habitats (e.g., Demer *et al.*, 2012; Zwolinski *et al.*, 2012), and juveniles may have nursery areas in and offshore of the SCB, downstream of upwelling regions. In contrast, Northern Anchovy spawn predominantly during winter, mostly within the SCB where seasonal down-welling increases retention of their eggs and larvae (Bakun and Parrish, 1982). Pacific Herring spawn in intertidal beach areas (Love, 1996). The northern stock of Northern Anchovy is located off WA and OR and the central stock is located off Central and Southern CA. Whether a species migrates or remains in an area depends on its stock size, reproductive and feeding behaviors, and affinity to certain oceanographic or seabed habitats.

Acoustic-trawl method (ATM) surveys, which combine information collected with echosounders and nets, were introduced to the CCE more than 48 years ago to survey CPS off the west coast of the U.S. (Mais, 1974, 1977; Smith, 1978). Following a two-decade hiatus, the ATM was reintroduced in the CCE in spring 2006 to sample the then abundant Pacific Sardine population (Cutter and Demer, 2008). Since then, this sampling effort has continued and expanded through annual or semi-annual surveys (Zwolinski *et al.*, 2014). Beginning in 2011, the ATM estimates of Pacific Sardine abundance, age structure, and distribution have been incorporated in the annual assessments of the northern stock (Hill *et al.*, 2017). Additionally, ATM survey results are applied to estimate the abundances, demographics, and distributions of epipelagic and semi-demersal fishes (e.g., Swartzman, 1997; Williams *et al.*, 2013; Zwolinski *et al.*, 2014) and plankton (Hewitt and Demer, 2000).

This document describes, in detail, the ATM as presently used by NOAA's Southwest Fisheries Science Center (SWFSC) to survey the distributions and abundances of CPS and their oceanographic environments (e.g., Cutter and Demer, 2008; Demer *et al.*, 2012; Zwolinski *et al.*, 2014). In general terms, the contemporary ATM combines information from satellite-sensed oceanographic conditions, calibrated multi-frequency echosounders, probe-sampled oceanographic conditions, pump-sampled fish eggs, and trawl-net catches of juvenile and adult CPS. The survey area is initially planned with consideration to the expected distribution of a priority stock or stock assemblage, in this case, the central stock of Northern Anchovy (**Fig. 1**). As time permits, the survey area is further expanded to encompass as much of the potential distribution as possible for other CPS present off the U.S. West Coast.

Along transects in the survey area, multi-frequency split-beam echosounders transmit sound pulses downward beneath the ship and receive echoes from animals and the seabed in the path of the sound waves. Measurements of sound speed and absorption from conductivity-temperature-depth (CTD) probes allow accurate compensation of these echoes for propagation losses. The calibrated echo intensities, normalized to the range-dependent observational volume, provide indications of the target type and behavior (e.g., Demer *et al.*, 2009).

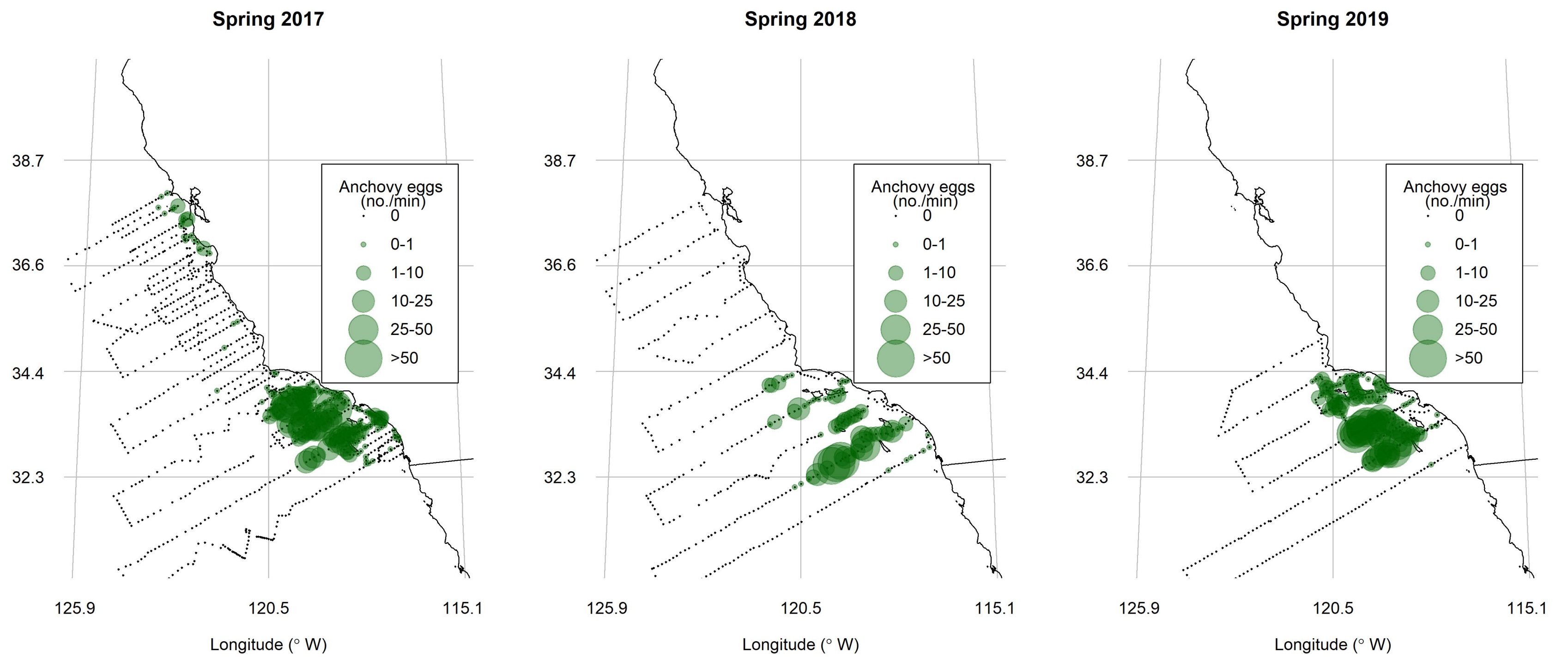

Figure 1: Distribution of eggs of Northern Anchovy sampled by the CUFES during spring surveys from 2017 through 2019. Eggs, indicating the presence of spawning Northern Anchovy, were used to delineate the spring 2021 survey area.

Echoes from marine organisms are a function of their body composition, shape, and size relative to the sensing-sound wavelength, and their orientation relative to the incident sound waves (Cutter *et al.*, 2009; Demer *et al.*, 2009; Renfree *et al.*, 2009). Variations in echo intensity across frequencies, known as echo spectra, indicate the taxonomic groups contributing to the echoes. The CPS, with highly reflective swim bladders, create high intensity echoes of sound pulses at all echosounder frequencies (e.g., Conti and Demer, 2003). In contrast, krill, with acoustic properties closer to those of the surrounding sea-water, produce lower intensity echoes, particularly at lower frequencies (e.g., Demer *et al.*, 2003). The echo energy attributed to CPS, based on empirical echo spectra (Demer *et al.*, 2012), are apportioned to species using trawl-catch proportions (Zwolinski *et al.*, 2014).

Animal densities are estimated by dividing the summed intensities attributed to a species by the length-weighted average echo intensity (the mean backscattering cross-section) from animals of that species (e.g., Demer *et al.*, 2012). Transects with similar densities are grouped into post-sampling strata that mimic the natural patchiness of the target species (e.g., Zwolinski *et al.*, 2014). An estimate of abundance is obtained by multiplying the average estimated density in the stratum by the stratum area (Demer *et al.*, 2012). The associated sampling variance is calculated using non-parametric bootstrap of the mean transect densities. The total abundance estimate in the survey area is the sum of abundances in all strata. Similarly, the total variance estimate is the sum of the variance in each stratum.

In spring 2021, the ATM survey performed aboard NOAA Ship *Reuben Lasker* (hereafter, *Lasker*) was augmented with coordinated sampling by a fishing vessel (F/V *Long Beach Carnage*) to estimate the biomasses of CPS in nearshore regions where sampling by *Lasker* was not possible or safe.

Presented here are: 1) a detailed description of the ATM used to survey CPS in the CCE off the west coast of North America; and 2) estimates of the abundance, biomass, size structure, and distribution of CPS, specifically the central stock of Northern Anchovy, southern stock of Pacific Sardine, Pacific Mackerel, and Jack Mackerel for the core and nearshore survey regions. Additional details about the survey may be found in the survey report (Zwolinski *et al.*, 2023).

2 Methods

2.1 Sampling

2.1.1 Design

The spring 2021 survey was conducted principally using *Lasker*. The sampling domain, or core region, between San Francisco and San Diego, was defined by the expected distribution of the central stock of Northern Anchovy (**Fig. 1**), which also includes a portion of the potential habitat of the northern stock of Pacific Sardine (**Fig. 2a**), predominantly north of Point Conception. Habitat unsuitable for the northern stock may be suitable for the southern stock of Pacific Sardine (Demer and Zwolinski, 2014). East to west, the sampling domain extends from the coast to at least the 1,000 ftm (~1830 m) isobath (**Fig. 3**). Considering the expected distribution of the target species, the acceptable uncertainty in biomass estimates, and the available ship time (25 days at sea, DAS), the principal survey objective was the estimations of biomass for the central stock of Northern Anchovy in the survey region. Additionally, biomass estimates were sought for the other CPS in the survey domain, including: Pacific Sardine, Pacific Mackerel, and Jack Mackerel.

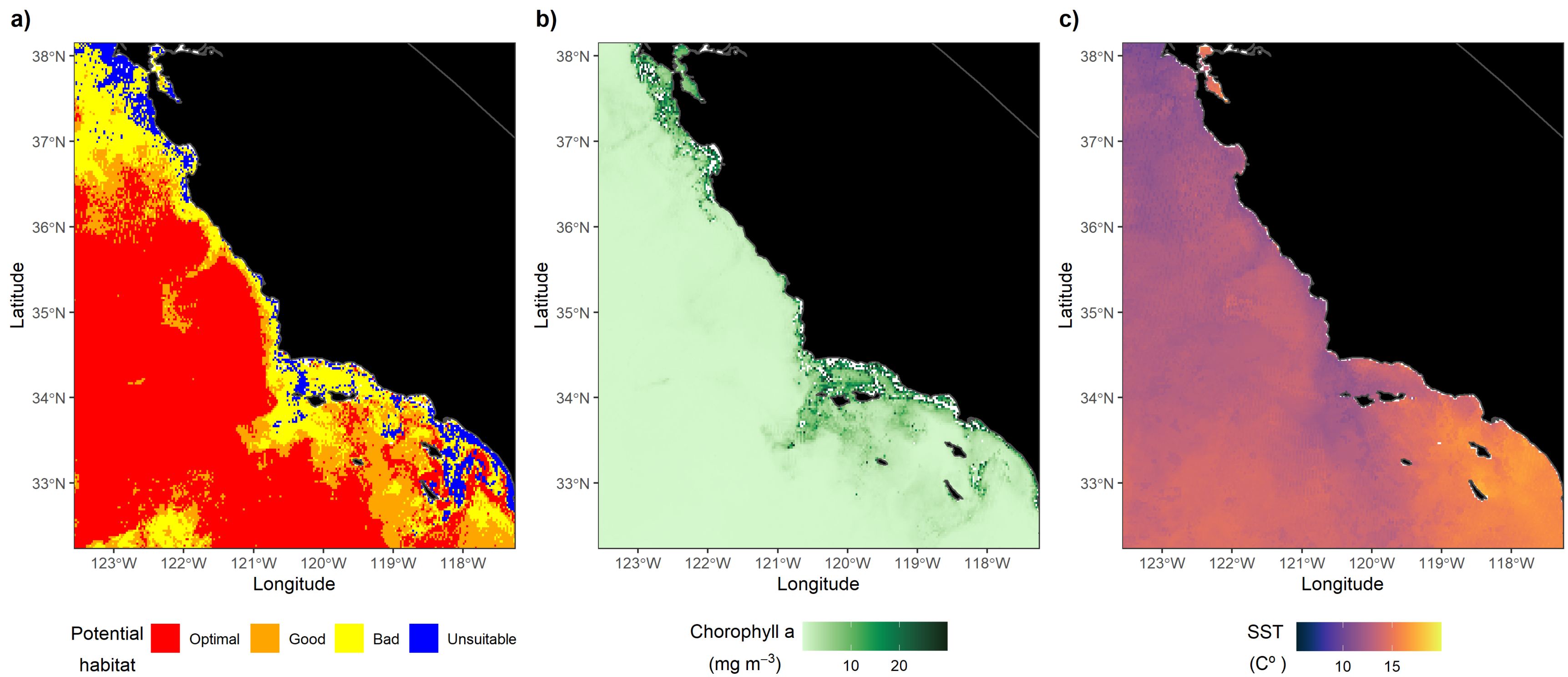

Figure 2: Distribution of a) potential habitat for the northern stock of Pacific Sardine (Zwolinski *et al.*, 2011), which is a function of b) chlorophyll-a concentration and c) sea surface temperature (SST). The images are 8-day composites including data from 23 March to 1 April, 2021. The potential habitat categories are based on data from spring CalCOFI surveys conducted between 1998 and 2009 and reflect the probability of finding at least one Pacific Sardine egg on a standard CUFES sample. The good and optimal habitat areas collectively include 90% of the Pacific Sardine biomass, and the bad and unsuitable areas contain the remaining 10%.

In the core region north of Point Conception, the transects were spaced 20 nmi apart, and extend from the shallowest navigable depth (~30 m) to either a distance of ~35 nmi offshore or to the 1,000-fathom isobath, whichever is farthest (**Fig. 3**). South of Point Conception, the transects were spaced 15 nmi apart, and were as long as 70 nmi. Throughout the core region, where CPS were observed within the westernmost 3 nmi of the transect, that transect and the next one to the north were extended in 5-nmi increments until no CPS were observed in the echograms in the last 3 nmi of the extension. The aim was to reach the end of the transects with a practically zero biomass density.

Additional sampling was conducted in the nearshore region along 5-nmi-long transects spaced 5 nmi apart between Point Conception and San Diego using *Long Beach Carnage* equipped with multi-frequency echosounders (magenta lines, **Fig. 3**). The goal of the nearshore sampling was to estimate the abundance and biomass of CPS close to shore, in shallow water, or both, where *Lasker* could not safely navigate or trawl.

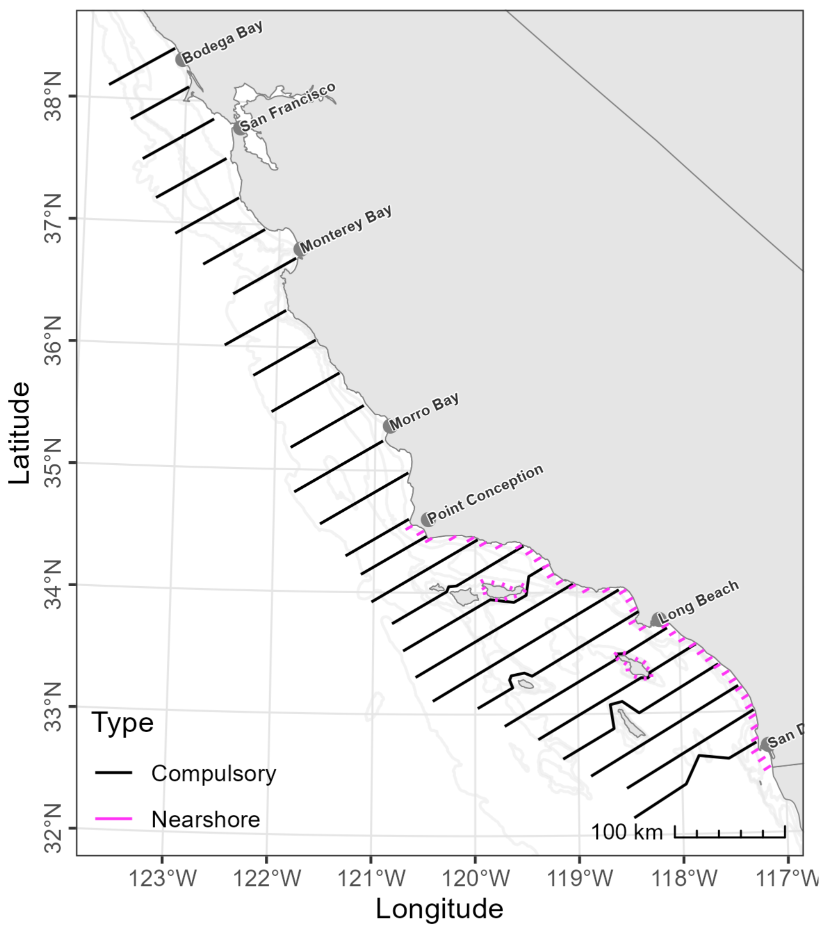

Figure 3: Planned compulsory (black lines) transect lines sampled by *Lasker*; nearshore transect lines sampled by *Long Beach Carnage* (magenta lines); and 50-, 200-, 500-, and 2,000-m isobaths (gray lines).

2.1.2 Acoustic

2.1.2.1 Acoustic equipment

On *Lasker*, multi-frequency Wide-Bandwidth Transceivers (Simrad 18-, 38-, 70-, 120-, 200-, and 333-kHz EK80 WBTs; Kongsberg) were configured with split-beam transducers (Simrad ES18-11, ES38B, ES70-7C, ES120-7C, ES200-7C, and ES333-7C, respectively; Kongsberg). The transducers were mounted on the bottom of a retractable keel or "centerboard" (**Fig. 4**). The keel was retracted (transducers ~5-m depth) during calibration, and extended to the intermediate position (transducers ~7-m depth) during the survey. Exceptions were made during shallow water operations, when the keel was retracted; or during times of heavy weather, when the keel was extended (transducers ~9-m depth) to provide extra stability and reduce the effect of weather-generated noise. In addition, acoustic data were also collected using a multibeam echosounder (Simrad ME70; Kongsberg), multibeam sonar (Simrad MS70, Kongsberg), and scanning sonar (Simrad SX90; Kongsberg). Transducer position and motion were measured at 5 Hz using an inertial motion unit (Applanix POS-MV; Trimble).

On *Long Beach Carnage*, the SWFSC's multi-frequency echosounders (Simrad 38-, 70-, 120-, and 200-kHz EK60 GPTs; Kongsberg) were configured with the SWFSC's multi-frequency transducer array (MTA4) with split-beam transducers (Simrad ES38-12, ES70-7C, ES120-7C and ES200-7C; Kongsberg) mounted on the bottom of a pole(**Fig. 5**).

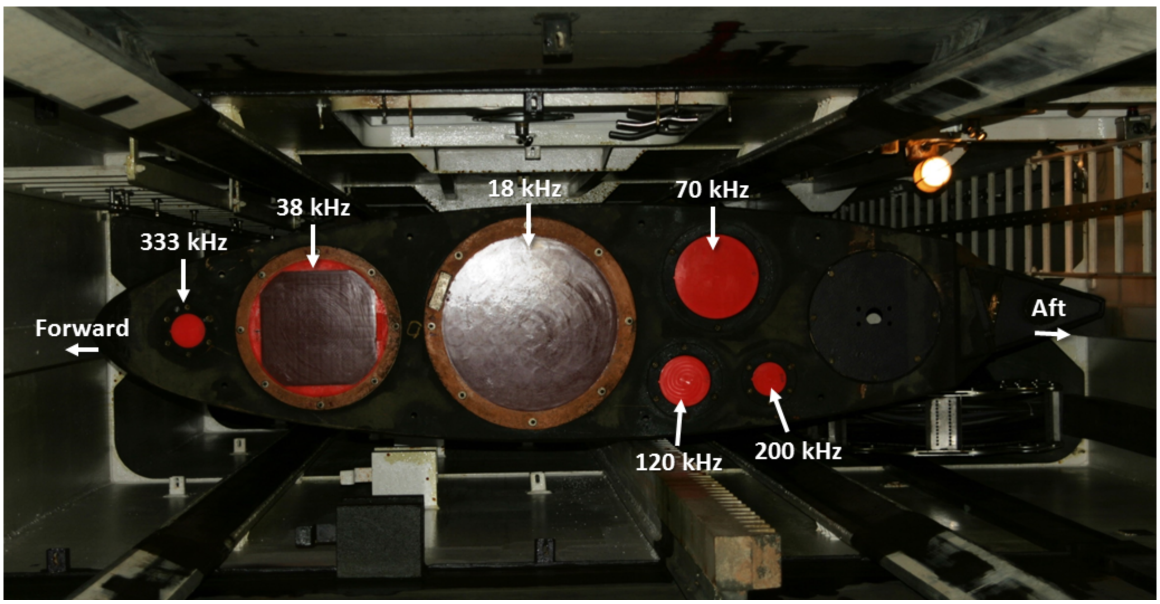

Figure 4: Echosounder transducers mounted on the bottom of the retractable centerboard on *Lasker*. During the survey, the centerboard was extended, typically positioning the transducers ~2 m below the keel at a water depth of ~7 m.

Figure 5: Transducers (Top-bottom: Simrad ES200-7C, ES120-7C, ES38-12, and ES70-7C, Kongsberg) in a pole-mounted multi-transducer array (MTA4) installed on the *Long Beach Carnage*.

2.1.2.2 Echosounder calibrations

2.1.2.2.1 *Lasker*

The echosounder systems aboard *Lasker* were calibrated on 1 March while the vessel was docked at 10th Avenue Marine Terminal (32.6956 °N, -117.15278 °W) using the standard sphere technique (Demer *et al.*, 2015; Foote *et al.*, 1987). Each WBT was calibrated in both CW (continuous wave or narrowband mode) and FM mode (i.e., frequency modulation or broadband mode). The principle reference target was a 38.1-mm diameter sphere made from tungsten carbide (WC) with 6% cobalt binder material (WC38.1; *Lasker* sphere #1). Calibrations of WBTs in FM mode used both the WC38.1 and a 25-mm diameter WC sphere. A CTD was cast to measure temperature and salinity versus depth, to estimate sound speeds at the transducer and sphere depths, and the time-averaged sound speed and absorption coefficients for the range between them. The theoretical target strength (TS; dB re 1 m^2) of the sphere was calculated using the Standard Sphere Target Strength Calculator[1] and values for the sphere, sound-pulse, and seawater properties. The sphere was positioned throughout the main lobe of each of the transducer beams using three motorized downriggers, two on one side of the vessel and one on the other. The GPTs and WBTs were configured using the calibration results via the control software (Simrad EK80 v1.12.2; Kongsberg; **Table 1**). Calibration results for WBTs in FM mode are presented in the survey report (Stierhoff *et al.*, 2020a).

[1] https://swfscdata.nmfs.noaa.gov/AST/SphereTS/

Table 1: Wide-Bandwidth Transceiver (Simrad EK80 WBT; Kongsberg) information, pre-calibration settings, and beam model results following calibration (below the horizontal line). Prior to the survey, on-axis gain (G_0), beam angles and angle offsets, and S_A Correction (S_{A}corr) values from calibration results were entered into the WBT control software (Simrad EK80 v1.12.2; Kongsberg).

		Frequency (kHz)					
	Units	18	38	70	120	200	333
Model		ES18	ES38-7	ES70-7C	ES120-7C	ES200-7C	ES333-7C
Serial Number		2106	337	233	783	513	124
Transmit Power (p_{et})	W	1000	1000	600	200	90	35
Pulse Duration (τ)	ms	1.024	1.024	1.024	1.024	1.024	1.024
Eq. Two-way Beam Angle (Ψ)	dB re 1 sr	-17	-20.7	-20.7	-20.7	-20.7	-20.7
On-axis Gain (G_0)	dB re 1	23.1	26.27	27.63	26.79	27.14	26.59
S_{a} Correction (S_{a}corr)	dB re 1	-0.0267	0.0471	-0.0081	-0.037	-0.0755	-0.1435
RMS	dB	0.039	0.047	0.04	0.032	0.079	0.11
3-dB Beamwidth Along. ($\alpha_{-3\mathrm{dB}}$)	deg	10.37	6.41	6.73	6.6	6.57	6.55
3-dB Beamwidth Athw. ($\beta_{-3\mathrm{dB}}$)	deg	10.42	6.42	6.71	6.6	6.57	6.62
Angle Offset Along. (α_0)	deg	-0.06	0	-0.03	-0.02	-0.03	0.06
Angle Offset Athw. (β_0)	deg	-0.02	-0.04	-0.03	0.01	0	0.03

2.1.2.2.2 *Long Beach Carnage*

The echosounders were calibrated using a WC38.1 sphere in a tank at the SWFSC. Beam model results were entered into the GPT-control software and are presented in **Table 2**.

Table 2: General Purpose Transceiver (Simrad EK60 GPT; Kongsberg) beam model results estimated from a tank calibration of echosounders aboard *Long Beach Carnage* using a WC38.1. Prior to the survey, calibrated on-axis gain (G_0), beam angles and angle offsets, and S_a Correction (S_{a}corr) values were entered into the GPT-control software (Simrad EK80 v1.12.2; Kongsberg).

		Frequency (kHz)			
	Units	38	70	120	200
Model		ES38-12	ES70-7C	ES120-7C	ES200-7C
Serial Number		28075	234	813	616
Transmit Power (p_{et})	W	1000	600	200	90
Pulse Duration (τ)	ms	1.024	1.024	1.024	1.024
Eq. Two-way Beam Angle (Ψ)	dB re 1 sr	-15.5	-20.7	-20.7	-20.7
On-axis Gain (G_0)	dB re 1	21.75	26.35	26.35	26.64
S_{a} Correction (S_{a}corr)	dB re 1	-0.6298	-0.3434	-0.4141	-0.2052
RMS	dB	0.051	0.03	0.068	0.11
3-dB Beamwidth Along. ($\alpha_{-3\mathrm{dB}}$)	deg	12.66	6.76	6.82	6.83
3-dB Beamwidth Athw. ($\beta_{-3\mathrm{dB}}$)	deg	12.71	6.73	6.74	6.82
Angle Offset Along. (α_0)	deg	-0.03	0.06	0.15	-0.02
Angle Offset Athw. (β_0)	deg	0.07	0.02	0.06	0.1

2.1.2.3 Data collection

Computer clocks were synchronized with the GPS clock (UTC) using synchronization software (NetTime[2]). The 18-kHz GPT, operated by a separate PC from the other echosounders, was programmed to track the seabed and output the detected depth to the ship's Scientific Computing System (SCS). The echosounders were controlled by the ER60 Adaptive Logger (EAL[3], Renfree and Demer, 2016). The EAL optimizes the pulse interval based on the seabed depth, while avoiding aliased seabed echoes, and was programmed such that once an hour the echosounders would operate in passive mode and record three pings, for obtaining estimates of the background noise level. The echosounders collected data continuously throughout the survey, but transect sampling was conducted only during daylight hours, approximately between sunrise and sunset.

Measurements of volume backscattering strength (S_V; dB re 1 m^2 m^{-3}) and TS (dB re 1 m^2), indexed by time and geographic positions provided by GPS receivers, were logged to 60 m beyond the detected seabed range or to a maximum of 350 m, and stored in Simrad .raw format with a 50-MB maximum file size. During daytime, the echosounders were set to operate in CW mode to remain consistent with echo integration methods used during prior surveys and to reduce data volume; at nighttime, echosounders were set to FM mode to improve TS estimation and species differentiation for CPS near the surface. For each acoustic instrument, the prefix for the file names is a concatenation of the survey name (e.g., 2103RL), the operational mode (CW or FM), and the logging commencement date and time from the EK80 software. For example, file generated by the Simrad EK80 software for a WBT operated in CW mode is named `2103RL-CW-D20210401-T125901.raw`.

To minimize acoustic interference, transmit pulses from the EK80, ME70, MS70, SX90, and acoustic Doppler current profiler (ADCP; Ocean Surveyor Model OS75, Teledyne RD Instruments) were triggered using a synchronization system (K-Sync, Simrad). The K-Sync trigger rate, and thus echosounder ping interval, was modulated by the EAL using the 18-kHz seabed depth provided by the SCS. During daytime, the ME70, SX90, and ADCP were operated continuously, while the MS70 was only operated at times when CPS were present. At nighttime, only the EK80 and ADCP were operated. All other instruments that produce sound within the echosounder bandwidths were secured during daytime survey operations. Exceptions were made during stations (e.g., plankton sampling and fish trawling) or in shallow water when the vessel's command occasionally operated the bridge's 50- and 200-kHz echosounders (Furuno), the Doppler velocity log (Sperry Marine Model SRD-500A), or both. Data from the ME70, MS70, and SX90 are not presented in this report.

2.1.3 Oceanographic

2.1.3.1 Conductivity and temperature versus depth (CTD) sampling

Conductivity and temperature were measured versus depth to 350 m (or to within ~10 m of the seabed when less than 350 m) with calibrated sensors on a CTD rosette (Model SBE911+; Seabird) or underway probe [UnderwayCTD (UCTD); Oceanscience] cast from the vessel. At least one cast was planned along each acoustic transect. These data were used to calculate the harmonic mean sound speed (Demer *et al.*, 2015) for estimating ranges to the sound scatterers, and frequency-specific sound absorption coefficients for compensating signal attenuation of the sound pulse between the transducer and scatters (Simmonds and MacLennan, 2005) (see **Section 2.2.2**). These data also indicated the depth of the surface mixed layer, above which most epipelagic CPS reside during the day, which aids in the determination of the integration-stop depth and removal of non-CPS backscatter during acoustic data processing (see **Section 2.2.4**).

2.1.3.2 Scientific Computer System sampling

While underway, information about the position and direction (e.g., latitude, longitude, speed, course over ground, and heading), weather (air temperature, humidity, wind speed and direction, and barometric pressure), and sea-surface oceanography (e.g., temperature, salinity, and fluorescence) were measured continuously and logged using *Lasker*'s Scientific Computer System (SCS). Data from a subset of these sensors, logged with a standardized form at 1-min resolution, are available on NOAA's ERDDAP data server[4].

[2] http://timesynctool.com
[3] https://www.fisheries.noaa.gov/west-coast/science-data/ek80-adaptive-logger
[4] https://coastwatch.pfeg.noaa.gov/erddap/tabledap/fsuNoaaShipWTEG.html

2.1.4 Fish-eggs

During the day, fish eggs were sampled using a continuous underway fish egg sampler (CUFES, Checkley *et al.*, 1997), which collects particles at a rate of ~640 l min^{-1} from an intake at ~3-m depth on the hull of the ship. Fish eggs in the sampled water were sieved by a 505-μm mesh. Pacific Sardine, Northern Anchovy, Jack Mackerel, and Pacific Hake (*Merluccius productus*) eggs were identified to species, counted, and logged. Eggs from other species (e.g., Pacific Mackerel and flatfishes) were also counted and logged as "other fish eggs." Typically, the duration of each CUFES sample was 30 min, corresponding to a distance of 5 nmi at a speed of 10 kn. Because the duration of the egg phase is less than three days for most CPS, the egg distributions inferred from CUFES indicated the presence of actively spawning fish within roughly 10 nmi, depending on advection and dispersal, and were used in combination with CPS echoes to select trawl locations.

2.1.5 Trawl

After sunset, CPS schools tend to ascend and disperse and are less likely to avoid a net (Mais, 1977). Therefore, trawling was conducted during the night to better sample the fish aggregations dispersed near the surface to obtain information efficiently about species composition, lengths, and weights.

2.1.5.1 Sampling gear

The net, a Nordic 264 rope trawl (NET Systems, Bainbridge Island, WA; **Fig. 6a,b**), was towed at the surface for 45 min at a speed of 3.5-4.5 kn. The net has a rectangular opening with an area of approximately 300 m^2 (~15-m tall x 20-m wide), a throat with variable-sized mesh and a "marine mammal excluder device" to prevent the capture of large animals, such as dolphins, turtles, or sharks while retaining target species (Dotson *et al.*, 2010), and an 8-mm square-mesh cod-end liner (to retain a large range of animal sizes). The trawl doors were foam-filled and the trawl headrope was lined with floats so the trawl towed at the surface.

2.1.5.2 Sampling locations

Up to three nighttime (i.e., 30 min after sunset to 30 min before sunrise) surface trawls, typically spaced 10-nmi apart, were conducted in areas where echoes from CPS schools were observed earlier that day. Each evening, trawl locations were selected by an acoustician who monitored CPS echoes and a member of the trawl group who measured the densities of CPS eggs in the CUFES. The locations were provided to the watch officers who charted the proposed trawl sites.

Trawl locations were selected using the following criteria, in descending priority: CPS schools in echograms that day; CPS eggs in CUFES that day; and the trawl locations and catches during the previous night. If no CPS echoes or CPS eggs were observed along a transect that day, the trawls were alternatively placed nearshore one night and offshore the next night, with consideration given to the seabed depth and the modeled distribution of CPS habitat. Each morning, after the last trawl or 30 min prior to sunrise, *Lasker* resumed sampling at the location where the acoustic sampling stopped the previous day.

2.1.5.3 Sample processing

If the total volume of the trawl catch was five 35-l baskets (~175 l) or less, all target species were separated from the catch, sorted by species, weighed, and enumerated. If the volume of the entire catch was more than five baskets, a five-basket random subsample that included non-target species was collected, sorted by species, weighed, and enumerated; the remainder of the total catch was weighed. In these cases, the weight of the entire catch was calculated as the sum of the subsample and remainder weights. The weight of the e-th species in the total catch ($C_{T,e}$) was obtained by summing the catch weight of the respective species in the subsample ($C_{S,e}$) and the corresponding catch in the remainder ($C_{R,e}$), which was calculated as:

$$C_{R,e} = C_R * P_{w,e}, \tag{1}$$

where $P_{w,e} = C_{S,e} / \ {}_{1}^{s} C_{S,e}$, is the proportion in weight of the e-th species in the subsample. The number of specimens of the e-th species in the total catch ($N_{T,e}$) was estimated by:

$$N_{T,e} = \frac{C_{T,e}}{\overline{w}_e}, \tag{2}$$

where $\overline{w}_e$ is the mean weight of the e-th species in the subsample. If available, a random sample of 50 specimens of Jack and Pacific Mackerel, and 75 specimens of Pacific Sardine and Northern anchovy were removed randomly from the subsample. Individual measurements were made of standard length (L_S) for Pacific Sardine and Northern Anchovy, and fork length (L_F) for Pacific Herring and Jack and Pacific Mackerels, in cm, and total weight (w), in g. In addition, sex and maturity were recorded for all specimens following the methods described in Dorval et al. (2022). Otoliths were removed from all 50 Pacific Sardine in the subsample; for other CPS species, 25 otoliths were removed uniformly from the range of sizes present for aging (Schwartzkopf *et al.*, 2022). The combined catches in up to three trawls per night (i.e., trawl cluster) were used to estimate the proportions of species contributing to the nearest samples of acoustic backscatter.

2.1.5.4 Quality assurance and quality control

At sea, trawl data were entered into a database (Microsoft Access). During and following the survey, data were further scrutinized and verified, or corrected. Missing length (L_{miss}) and weight (W_{miss}) measurements were estimated as $W_{miss} = \beta_0 L^{\beta_1}$ and $L_{miss} = (W/\beta_0)^{(1/\beta_1)}$, respectively, where values for β_0 and β_1 are species- and season-specific parameters of the length-versus-weight relationships described in Palance et al. (Palance *et al.*, 2019). To identify measurement or data-entry errors, length and weight data were graphically compared (**Fig.** 7) to measurements from previous surveys and models of season-specific length-versus-weight from previous surveys (Palance *et al.*, 2019). Outliers were flagged, reviewed by the trawl team, and mitigated. Catch data were removed from aborted trawl hauls, or hauls otherwise deemed unacceptable.

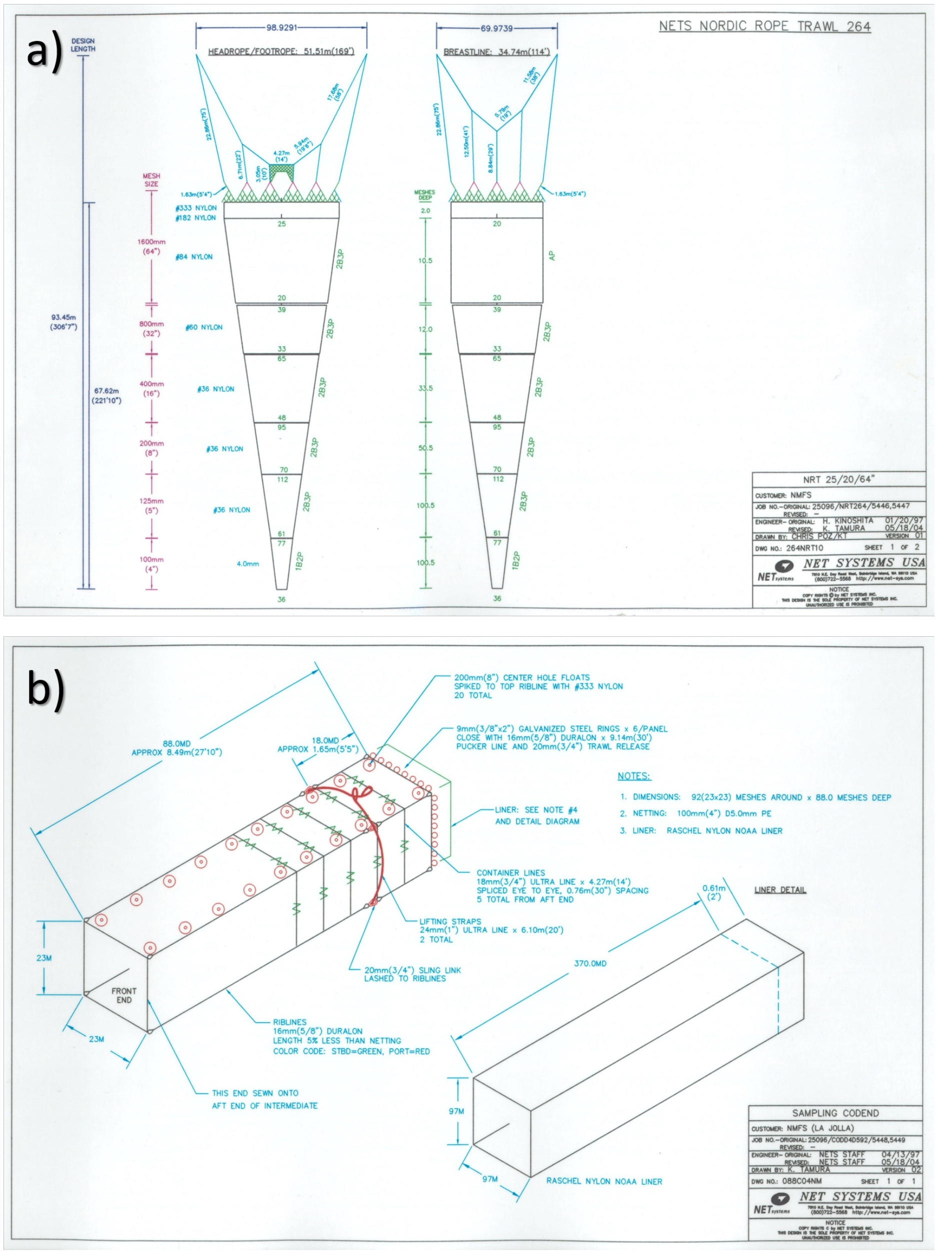

Figure 6: Schematic drawings of the Nordic 264 rope trawl a) net and b) cod-end.

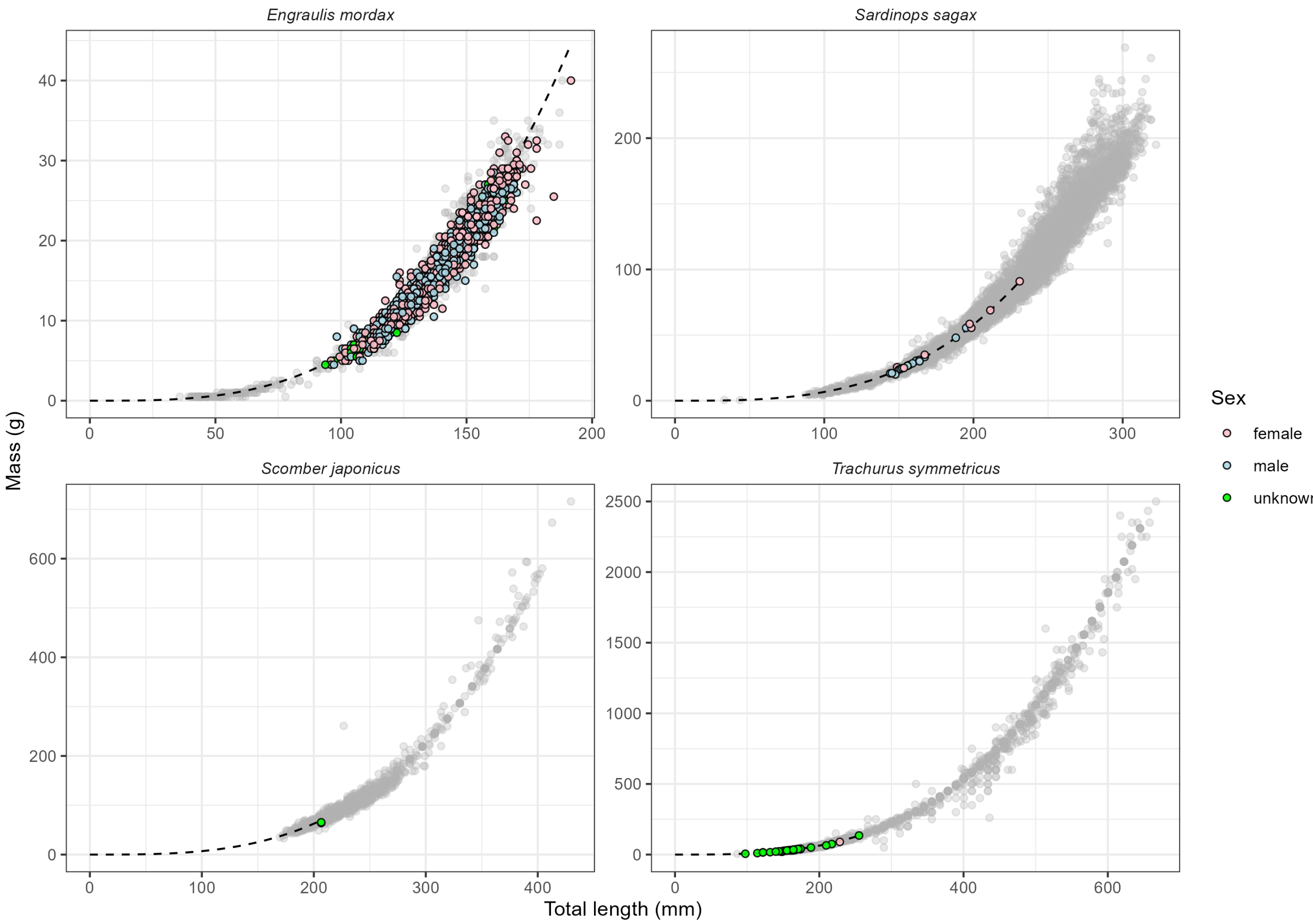

Figure 7: Specimen length-versus-weight from the current survey (colored points, by sex) compared to those from previous SWFSC surveys during the same season (gray points, all sexes) and models (dashed lines, Palance *et al.*, 2019).

2.1.6 Purse-seine

A purse seine net, ~290-m-long and ~22-m-deep net with ~17.5 mm mesh size, was set from *Long Beach Carnage* to provide information about size, age, and species composition of fishes observed in the echosounders in the nearshore region. All specimens collected were frozen and later processed by the CA Department of Fish and Wildlife (CDFW).

A minimum of one set per day was planned during daylight hours. In the event of abundant CPS or an unsuccessful daytime set, a set was made at night. For each set, three dip net samples, spatially separated as much as possible, were collected, and specimens were frozen for later analysis by CDFW biologists. The total weight (tons) of the school was estimated by the captain. After the survey, each dip net sample was sorted, weighed, and counted to provide a combined weight and count for each species. Next, all three dip net samples were combined and up to 50 specimens were randomly sampled to provide a combined weight for each set. Lengths (mm; L_S for Pacific Sardine and Northern Anchovy and L_F for all others) and weights (g) were measured for up to 50 randomly selected specimens of each species. Macroscopic maturity stages were determined visually, and otoliths were extracted for aging.

2.2 Data processing

2.2.1 Acoustic and oceanographic data

The calibrated echosounder data from each transect were processed using commercial software (Echoview v12.0, Echoview Software Pty Ltd.) and estimates of the sound speed and absorption coefficient were calculated with contemporaneous data from CTD probes cast while stationary or underway (UCTD, see **Section 2.1.3.1**). Data collected along the daytime transects at speeds $\geq$ 5 kn were used to estimate CPS densities. Nighttime acoustic data were assumed to be negatively biased due to diel-vertical migration (DVM) and disaggregation of the target species' schools (Cutter and Demer, 2008).

2.2.2 Sound speed and absorption calculation

Depth derived from pressure in CTD casts was used to bin samples into 1-m depth increments. Sound speed in each increment ($c_{w,i}$, m s^{-1}) was estimated from the average salinity, density, and pH [if measured, else pH = 8; Chen and Millero (1977); Seabird (2013)]. The harmonic sound speed in the water column ($\overline{c}_w$, m s^{-1}) was calculated over the upper 70 m as:

$$\overline{c}_w = \frac{\sum_{i=1}^{N} \mathit{\Delta} r_i}{\sum_{i=1}^{N} \mathit{\Delta} r_i / c_{w,i}}, \tag{3}$$

where $\mathit{\Delta} r$ is the depth of increment i (Seabird, 2013). Measurements of seawater temperature (t_w, °C), salinity (s_w, psu), depth, pH, and $\overline{c}_w$ are also used to calculate the mean frequency-specific absorption coefficients ($\overline{\alpha}_a$, dB m^{-1}) over the entire depth range using equations in Francois and Garrison (1982), Ainslie and McColm (1998), and Doonan et al. (2003). Both $\overline{c}_w$ and $\overline{\alpha}_a$ are later used to estimate ranges to the sound scatterers, to compensate the echo signal for spherical spreading and attenuation during propagation of the sound pulse from the transducer to the scatterer range and back (Simmonds and MacLennan, 2005). The CTD rosette, when cast, also provides measures of fluorescence and dissolved oxygen concentration versus depth, which may be used to estimate the vertical dimension of Pacific Sardine potential habitat (Zwolinski *et al.*, 2011), particularly the depth of the upper-mixed layer where most epipelagic CPS reside. The latter information is used to inform echo classification (see **Section 2.2.3**).

2.2.3 Echo-classification

Echoes from schooling CPS were identified using a semi-automated data processing algorithm implemented using Echoview software (v12.0). The filters and thresholds were based on a subsample of echoes from randomly selected CPS schools. The aim of the filter criteria is to retain at least 95% of the noise-free backscatter from CPS schools while rejecting at least 95% of the non-CPS backscatter (**Fig. 8**). Data from *Lasker* and *Long Beach Carnage* were processed using the following steps:

1. Match geometry of the 70-, 120-, 200-, and 333-kHz S_v to the 38-kHz S_v;
2. Remove passive-mode pings;
3. Estimate and subtract background noise using the background noise removal function (De Robertis and Higginbottom, 2007) in Echoview (**Figs. 8b, e**);
4. Average the noise-free S_v echograms using non-overlapping 11-sample by 3-ping bins;
5. Expand the averaged, noise-reduced S_v echograms with a 7 pixel x 7 pixel dilation;
6. For each pixel, compute: $S_{v,200\mathrm{kHz}} - S_{v,38\mathrm{kHz}}$, $S_{v,120\mathrm{kHz}} - S_{v,38\mathrm{kHz}}$, and $S_{v,70\mathrm{kHz}} - S_{v,38\mathrm{kHz}}$;
7. Create a Boolean echogram for S_v differences in the CPS range: $-13.85 < S_{v,70\mathrm{kHz}} - S_{v,38\mathrm{kHz}} < 9.89$ and $-13.5 < S_{v,120\mathrm{kHz}} - S_{v,38\mathrm{kHz}} < 9.37$ and $-13.51 < S_{v,200\mathrm{kHz}} - S_{v,38\mathrm{kHz}} < 12.53$;
8. Compute the 120- and 200-kHz Variance-to-Mean Ratios ($VMR_{120\mathrm{kHz}}$ and $VMR_{200\mathrm{kHz}}$, respectively, Demer *et al.*, 2009) using the difference between noise-filtered S_v (Step 3) and averaged S_v (Step 4);
9. Expand the $VMR_{120\mathrm{kHz}}$ and $VMR_{200\mathrm{kHz}}$ echograms with a 7 pixel x 7 pixel dilation;

10. Create a Boolean echogram based on the VMRs in the CPS range: $VMR_{120\text{kHz}}$ > -65 dB and $VMR_{200\text{kHz}}$ > -65 dB. Diffuse backscattering layers have low VMR (Zwolinski *et al.*, 2010) whereas fish schools have high VMR (Demer *et al.*, 2009);
11. Intersect the two Boolean echograms to create an echogram with “TRUE” samples for candidate CPS schools and “FALSE” elsewhere;
12. Mask the noise-reduced echograms using the CPS Boolean echogram (**Figs. 8c, f**);
13. Create an integration-start line 5 m below the transducer (~10 m depth);
14. Create an integration-stop line 3 m above the estimated seabed (Demer *et al.*, 2009), or to the maximum logging range (e.g., 1000 m), whichever is shallowest;
15. Set the minimum S_v threshold to -60 dB (corresponding to a density of approximately three 20-cm-long Pacific Sardine per 100 m^3);
16. Integrate the volume backscattering coefficients (s_V, m^2 m^{-3}) attributed to CPS over 5-m depths and averaged over 100-m distances;
17. Output the resulting nautical area scattering coefficients (s_A; m^2 nmi^{-2}) and associated information from each transect and frequency to comma-delimited text (.csv) files.

When necessary, the start and stop integration lines were manually edited to exclude reverberation due to bubbles, to include the entirety of shallow CPS aggregations, or to exclude seabed echoes.

2.2.4 Removal of non-CPS backscatter

In addition to echoes from target CPS, echoes may also be present from other pelagic fish species (e.g., Pacific Saury, *Cololabis saira*), or semi-demersal fish such as Pacific Hake and rockfishes (*Sebastes* spp.). When analyzing the acoustic-survey data, it was therefore necessary to manually filter “acoustic by-catch,” i.e., backscatter not from the target species. Fish echoes in proximity to rocky seabed, and diffuse backscatter were excluded from the CPS analysis using a custom interactive script for R (**Fig. 9**).

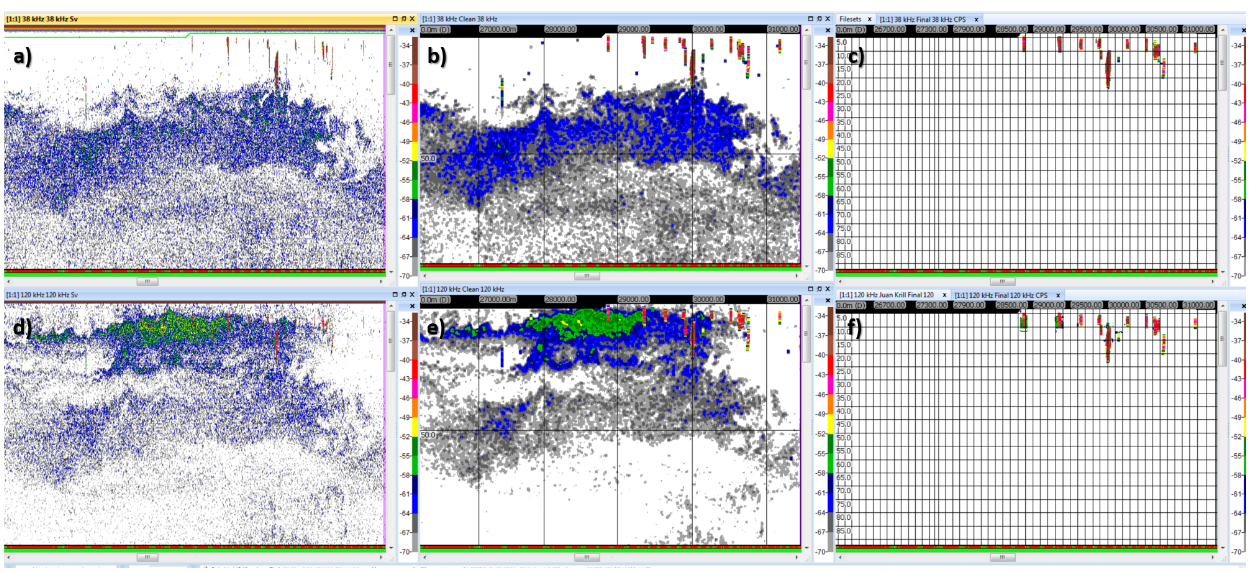

Figure 8: Two examples of echograms depicting CPS schools (red) and plankton aggregations (blue and green) at 38 kHz (top) and 120 kHz (bottom). Example data processing steps include the original echogram (a, d), after noise subtraction and bin-averaging (b, e), and after filtering to retain only putative CPS echoes (d, f).

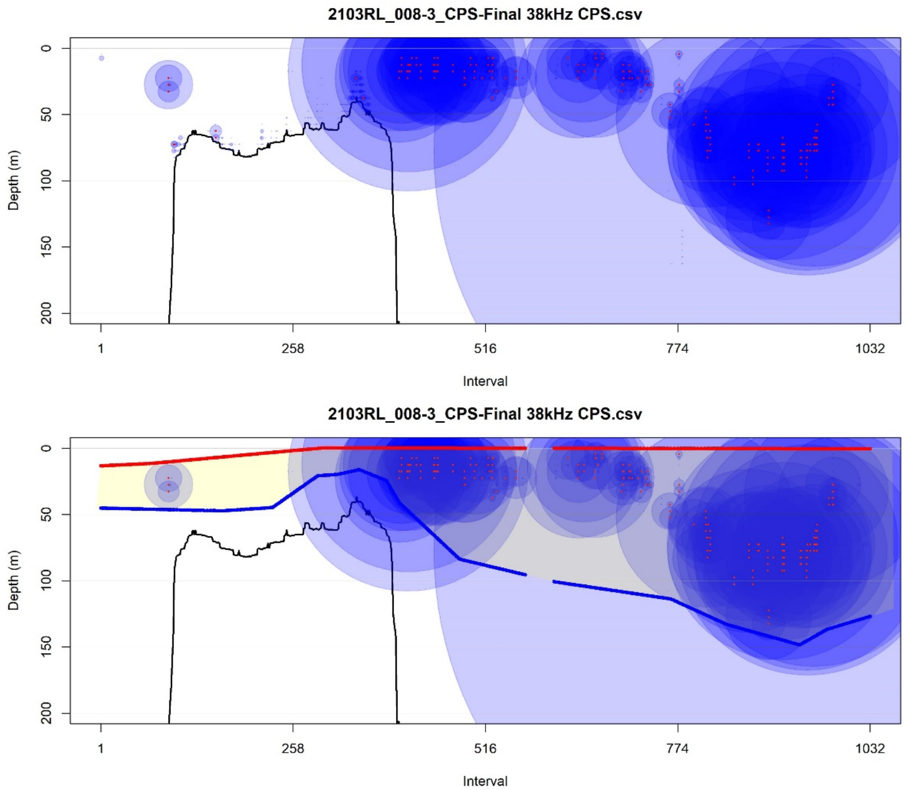

Figure 9: (Top) Integrated echo energy versus depth for all "CPS-like" targets and, (Bottom) integrated echo energy versus depth excluding likely rockfishes and near-surface reverberation (images created in R, R Core Team, 2021). Both images show the seabed (black line), and the final upper (red line) and lower (blue line) integration depths by interval.

2.2.5 Quality assurance and quality control

The largest 38-kHz integrated backscattering coefficient values (s_A, m^2 nmi^{-2}) were graphically examined to identify potential errors in the integrated data from Echoview processing (e.g., when a portion of the seabed was accidentally integrated). If found, errors were corrected and data were re-integrated prior to use for biomass estimation.

2.2.6 Echo integral partitioning and acoustic inversion

For fishes with swimbladders, the acoustic backscattering cross-section of an individual (σ_{bs}, m^2) depends on many factors but mostly on the acoustic wavelength and the swimbladder size and orientation relative to the incident sound pulse. For echosounder sampling in this survey, σ_{bs} is a function of the dorsal-surface area of the swimbladder and was approximated by a function of fish length, i.e.:

$$\sigma_{bs} = 10^{\frac{m\ \log_{10}(L)+b}{10}}, \tag{4}$$

where m and b are frequency and species-specific parameters that are obtained theoretically or experimentally (see references below). TS, a logarithmic representation of σ_{bs}, is defined as:

$$TS = 10\ \log_{10}(\sigma_{bs}) = m\ \log_{10}(L) + b. \tag{5}$$

TS has units of dB re 1 m^2 if defined for an individual, or dB re 1 m^2 kg^{-1} if defined by weight. The following equations for $TS_{38\text{kHz}}$ were used in this analysis:

$$TS_{38\text{kHz}} = -14.90 \times \log_{10}(L_T) - 13.21, \text{ for Pacific Sardine;} \tag{6}$$

$$TS_{38\text{kHz}} = -11.97 \times \log_{10}(L_T) - 11.58561, \text{ for Pacific and Round Herring;} \tag{7}$$

$$TS_{38\text{kHz}} = -13.87 \times \log_{10}(L_T) - 11.797, \text{ for Northern Anchovy; and} \tag{8}$$

$$TS_{38\text{kHz}} = -15.44 \times \log_{10}(L_T) - 7.75, \text{ for Pacific and Jack Mackerels,} \tag{9}$$

where the units for total length (L_T) is cm and TS is dB re 1 m^2 kg^{-1}.

Equations (6) and (9) were derived from echosounder measurements of σ_{bs} from in situ fish, and measures of L_T and W from concomitant catches of South American Pilchard (*Sardinops ocellatus*) and Horse Mackerel (*Trachurus trachurus*) off South Africa (Barange *et al.*, 1996). Because mackerels have similar TS (Peña, 2008), Equation (9) is used for both Pacific and Jack Mackerels. For Pacific Herring, Equation (7) was derived from that of Thomas et al. (2002) measured at 120 kHz with the following modifications: 1) the intercept used here was calculated as the average intercept of Thomas et al.'s spring and fall regressions; 2) the intercept was compensated for swimbladder compression after Zhao et al. (2008) using the average depth for Pacific Herring of 44 m; and 3) the intercept was increased by 2.98 dB to account for the change of frequency from 120 to 38 kHz (Saunders *et al.*, 2012). Equation (7) was also used for Round Herring. For Northern Anchovy, Equation (8) was derived from that of Kang et al. (2009), after compensation of the swimbladder volume (Ona, 2003; Zhao *et al.*, 2008) for the average depth of Northern Anchovy observed in summer 2016 (19 m, Zwolinski *et al.*, 2017).

To calculate $TS_{38\text{kHz}}$, L_T was estimated from measurements of L_S or L_F using linear relationships between length measurements derived from specimens collected in the CCE (Palance *et al.*, 2019): for Pacific Sardine, $L_T = 0.3574 + 1.149L_S$; for Northern Anchovy, $L_T = 0.2056 + 1.1646L_S$; for Pacific Mackerel, $L_T = 0.2994 + 1.092L_F$; for Jack Mackerel $L_T = 0.7295 + 1.078L_F$; and for Pacific Herring $L_T = -0.105 + 1.2L_F$. Since length-length conversions were not available for Round Herring, L_T was approximated from L_F using the equation for Pacific Herring. Individual weights can be estimated from L_T using the length-weight relationships described in Palance et al. (2019).

The proportions of species in a trawl cluster were considered representative of the proportions of species in the vicinity of the cluster. Therefore, the proportion of the echo-integral from the e-th species (P_e) in an ensemble of s species can be calculated from the species catches $N_1, N_2, ..., N_s$ and the respective average backscattering cross-sections $\sigma_{bs_1}, \sigma_{bs_2}, ..., \sigma_{bs_s}$ (Nakken and Dommasnes, 1975). The acoustic proportion for the e-th species in the a-th trawl (P_{ae}) is:

$$P_{ae} = \frac{N_{ae} \times \overline{w}_{ae} \times \overline{\sigma}_{bs,ae}}{\sum_{e=1}^{s_a}(N_{ae} \times \overline{w}_{ae} \times \overline{\sigma}_{bs,ae})}, \tag{10}$$

where $\overline{\sigma}_{bs,ae}$ is the arithmetic counterpart of the average target strength ($\overline{TS}_{ae}$) averaged for all n_{ae} individuals of species e in the random sample of trawl a:

$$\overline{\sigma}_{bs,ae} = \frac{\sum_{i=1}^{n_{ae}} 10^{(TS_i/10)}}{n_{ae}}, \tag{11}$$

and $\overline{w}_{ae}$ is the average weight: $\overline{w}_{ae} = \sum_{i=1}^{n_{ae}} w_{aei}/n_{ae}$. The total number of individuals of species e in a trawl a (N_{ae}) is obtained by: $N_{ae} = \frac{n_{ae}}{w_{s,ae}} \times w_{t,ae}$, where $w_{s,ae}$ is the weight of the n_{ae} individuals sampled randomly, and $w_{t,ae}$ is the total weight of the respective species' catch.

The trawls within a cluster were combined to reduce sampling variability (see **Section 2.2.7**), and the number of individuals caught from the e-th species in a cluster g (N_{ge}) was obtained by summing the catches across the h trawls in the cluster: $N_{ge} = \sum_{a=1}^{h_g} N_{ae}$. The backscattering cross-section for species e in the g-th cluster with a trawls is then given by:

$$\overline{\sigma}_{bs,ge} = \frac{\sum_{a=1}^{h_g} N_{ae} \times \overline{w}_{ae} \times \overline{\sigma}_{bs,ae}}{\sum_{a=1}^{s_g} N_{ae} \times \overline{w}_{ae}}, \tag{12}$$

where:

$$\overline{w}_{ge} = \frac{\sum_{a=1}^{h_g} N_{ae} \times \overline{w}_{ae}}{\sum_{a=1}^{h_g} N_{ae}}, \tag{13}$$

and the proportion (P_{ge}) is;

$$P_{ge} = \frac{N_{ge} \times \overline{w}_{ge} \times \overline{\sigma}_{bs,ae}}{\sum_{e=1}^{s} (N_{ge} \times \overline{w}_{ge} \times \overline{\sigma}_{bs,ge})}. \tag{14}$$

2.2.7 Trawl clustering and species proportioning

The catches of trawls that occurred on the same night were combined into a trawl cluster. Biomass densities (ρ) were calculated for 100-m transect intervals by dividing the integrated area backscatter coefficients for each CPS species by the mean backscattering cross-sectional area (MacLennan *et al.*, 2002) estimated in the nearest trawl cluster. Survey data were post-stratified to account for spatial heterogeneity in sampling effort and biomass density in a similar way to that performed for Pacific Sardine (Zwolinski *et al.*, 2016).

For a generic 100-m long acoustic interval, the area backscattering coefficient for species e: $s_{A,e} = s_{A,cps} \times P_{ge}$, where P_{ge} is the species acoustic proportion of the nearest trawl cluster (Equation (14)), was used to estimate the biomass density ($\rho_{w,e}$) (MacLennan *et al.*, 2002; Simmonds and MacLennan, 2005) for every 100-m interval, using the size and species composition of the nearest (space and time) trawl cluster (**Fig. 10**):

$$\rho_{w,e} = \frac{s_{A,e}}{4\pi\overline{\sigma}_{bs,e}}. \tag{15}$$

The biomass densities were converted to numerical densities using: $\rho_{n,e} = \rho_{w,e}/\overline{w}_e$, where $\overline{w}_e$ is the corresponding mean weight. Also, for each acoustic interval, the biomass or numeric densities are partitioned into length classes according to the species' length distribution in the respective trawl cluster.

2.3 Data analysis

2.3.1 Post-stratification

The transects were used as sampling units (Simmonds and Fryer, 1996). Because each species does not generally span the entire survey area (Demer and Zwolinski, 2017; Zwolinski *et al.*, 2014), the sampling domain was stratified for each species and stock. Strata were defined by uniform transect spacing (sampling intensity) and either presences (positive densities and potentially structural zeros) or absences (real zeros) of species biomass. Each stratum has: 1) at least three transects, with approximately equal spacing, 2) fewer than three consecutive transects with zero-biomass density, and 3) bounding transects with zero-biomass density (**Fig. 11**). This approach tracks stock patchiness and creates statistically-independent, stationary, post-sampling strata (Johannesson and Mitson, 1983; Simmonds *et al.*, 1992). For Northern Anchovy, we define the separation between the northern and central stock at Cape Mendocino (40.4 °N).

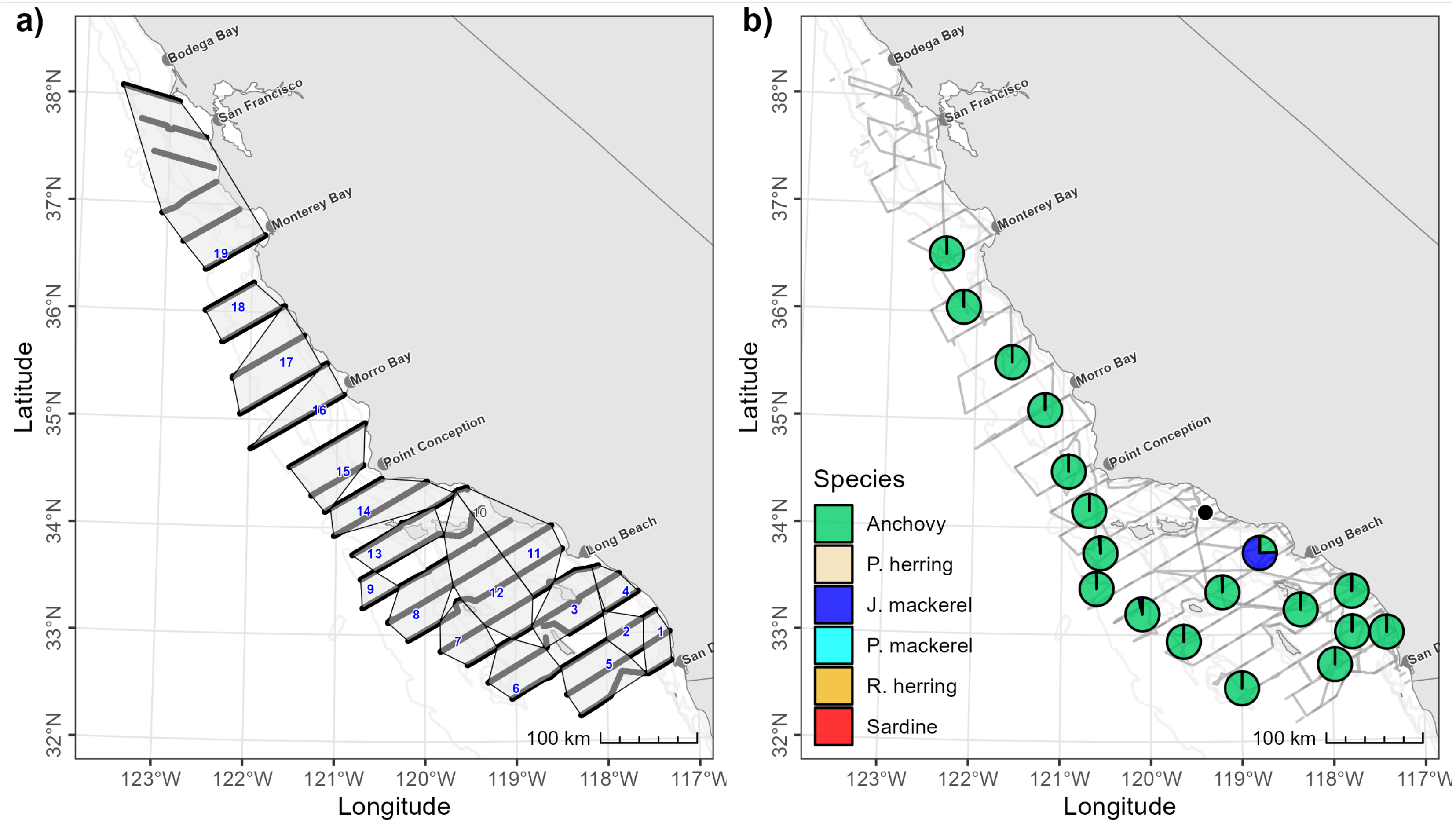

Figure 10: a) Polygons enclosing 100-m acoustic intervals from *Lasker* assigned to each trawl cluster, with its number located at the center of mass of all trawls in that cluster; and b) the acoustic proportions of CPS in trawl clusters, and the location of trawl cluster 10 with no CPS (black point).

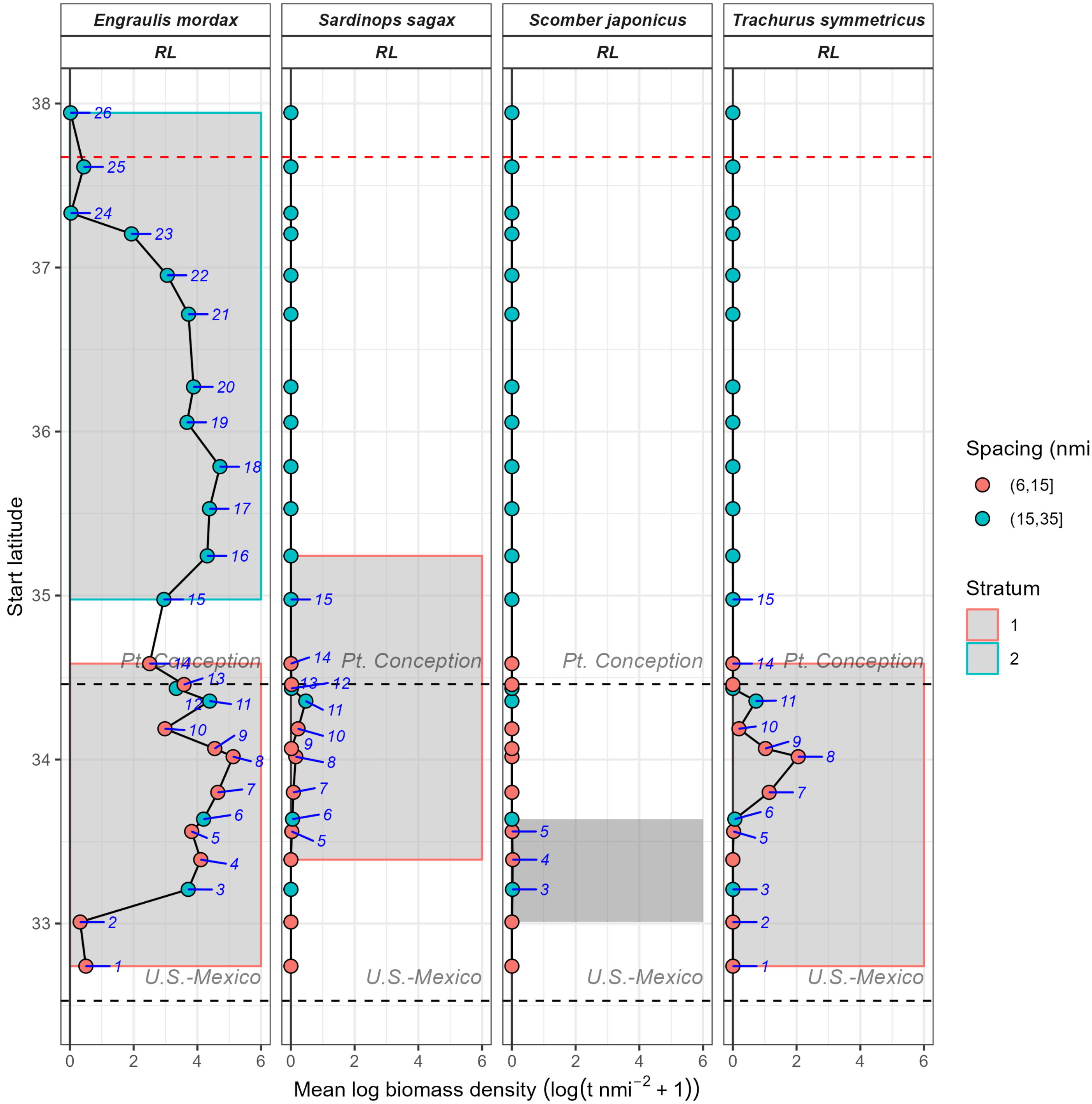

Figure 11: Biomass density ($\log(t\,\text{nmi}^2 + 1)$) versus latitude (easternmost portion of each transect) and strata used to estimate biomass and abundance (shaded regions; outline indicates stratum number) for each species and survey vessel (labels above plots; RL = *Lasker*). Strata with no outline were not included because of too few specimens (< 10 individuals), trawl clusters (< 2 clusters), or both. Blue number labels correspond to transects with positive biomass ($\log_{10}(t + 1) > 0.01$). Point fills indicate transect spacing (nmi).

2.3.2 Estimation of biomass and sampling precision

For each stratum and stock, the biomass ($\hat{B}$; kg) of each species was estimated by:

$$\hat{B} = A \times \hat{D}, \tag{16}$$

where A is the stratum area (nmi^2) and $\hat{D}$ is the estimated mean biomass density (kg nmi^{-2}):

$$\hat{D} = \frac{\sum_{l=1}^{k} \overline{\rho}_{w,l} c_l}{\sum_{l=1}^{k} c_l}, \tag{17}$$

where $\overline{\rho}_{w,l}$ is the mean biomass density of the species on transect l, c_l is the transect length, and k is the total number of transects. The variance of $\hat{B}$ is a function of the variability of the transect-mean densities and associated lengths. Treating transects as replicate samples of the underlying population (Simmonds and Fryer, 1996), the variance was calculated using bootstrap resampling (Efron, 1981) based on transects as sampling units. Provided that each stratum has independent and identically-distributed transect means (i.e., densities on nearby transects are not correlated, and they share the same statistical distribution), bootstrap or other random-sampling estimators provide unbiased asymptotic estimates of variance.

The 95% confidence intervals ($\mathrm{CI}_{95\%}$) for the mean biomass densities ($\hat{D}$) were estimated as the 0.025 and 0.975 percentiles of the distribution of 1000 bootstrap survey-mean biomass densities. Coefficient of variation (CV, %) values were obtained by dividing the bootstrapped standard error by the mean estimate (Efron, 1981). Total biomass in the survey area was estimated as the sum of the biomasses in each stratum, and the associated sampling variance was calculated as the sum of the variances across strata.

2.3.3 Abundance- and biomass-at-length estimation

The numerical densities by length class (**Section 2.2.7**) were averaged for each stratum in a similar way as that used for biomass in Equation (17), and multiplied by the stratum area to obtain abundance per length class.

2.3.4 Percent contribution of abundance per cluster

The percent contribution of each cluster to the estimated abundance in a stratum (**Appendix A**) was calculated as:

$$\frac{\Sigma_{i=1}^{l} \overline{\rho}_{ci}}{\Sigma_{c=1}^{C} \Sigma_{i=1}^{l} \overline{\rho}_{ci}}, \tag{18}$$

where $\overline{\rho}_{ci}$ is the numerical density in interval i represented by the nearest trawl cluster c.

3 Results

3.1 Sampling effort and allocation

The spring 2021 survey spanned the area between San Francisco and San Diego, and was completed in 25 DAS, between 20 March and 14 April 2021. In the core area, sampled by *Lasker*, acoustic sampling was conducted along 26 daytime east-west transects that totaled 1,639 nmi. Catches from a total of 49 nighttime surface trawls were combined into 19 trawl clusters. As many as two post-survey strata were defined considering transect spacing and the densities of echoes attributed to each species. In the nearshore survey area, acoustic sampling by *Long Beach Carnage* was conducted along 61 daytime, east-west transects totaling 191 nmi. As many as five post-survey strata were defined considering transect spacing and the densities of echoes attributed to CPS. Biomasses and abundances were estimated for each species in the core and nearshore survey areas.

3.2 Acoustic backscatter

Acoustic backscatter ascribed to CPS was observed throughout the core survey area, but was most prevalent south of Monterey Bay, especially offshore of the SCB, south of the northern Channel Islands (**Fig. 12a**). Multiple transects were extended (**Appendix B**) to ensure zero-biomass intervals at their offshore ends. Acoustic backscatter ascribed to CPS was also observed throughout the nearshore survey area, but was most prevalent between Long Beach and Oceanside (**Fig. 12a**). Greater than 90% of the biomass for each species was apportioned using catch data from trawl clusters within 30 nmi (**Fig. 13**).

3.3 Egg densities and distributions

Northern Anchovy eggs were abundant in CUFES samples south of Monterey Bay, but were most abundant and coincident with the acoustic backscatter in the offshore portions of transects south of Point Conception (**Fig. 12b**). A few samples in the SCB contained Pacific Sardine eggs, mostly along the southeast coast of Santa Catalina Island (**Fig. 12b**). No Jack Mackerel eggs were observed.

3.4 Trawl catch

Northern Anchovy was the predominant species in all but one of the trawl clusters (**Fig. 12c**). Relatively small numbers of Pacific Sardine were collected offshore of the northern Channel Islands and east of San Nicolas Island (too few to view in **Fig. 12c**). Jack Mackerel were present in several trawls offshore in the SCB, and one near Long Beach, and small numbers of Pacific Mackerel were caught west of San Nicolas Island (also too few to view in **Fig. 12c**). Overall, the 49 trawls captured a combined 4,293 kg of CPS (4,290 kg of Northern Anchovy, 1.32 kg of Pacific Sardine, 0.556 kg of Pacific Mackerel, 1.13 kg of Jack Mackerel, and no Pacific or Round Herring).

3.5 Purse seine catch

Pacific Sardine were predominant, by weight, in purse seine samples collected in the SCB by *Long Beach Carnage* (**Fig. 12c**). Overall, the 10 seines resulted in a combined sample of 15.7 kg of CPS (2.5 kg of Northern Anchovy, 12.3 kg of Pacific Sardine, 0.944 kg of Pacific Mackerel, and no Jack Mackerel, Pacific Herring, or Round Herring).

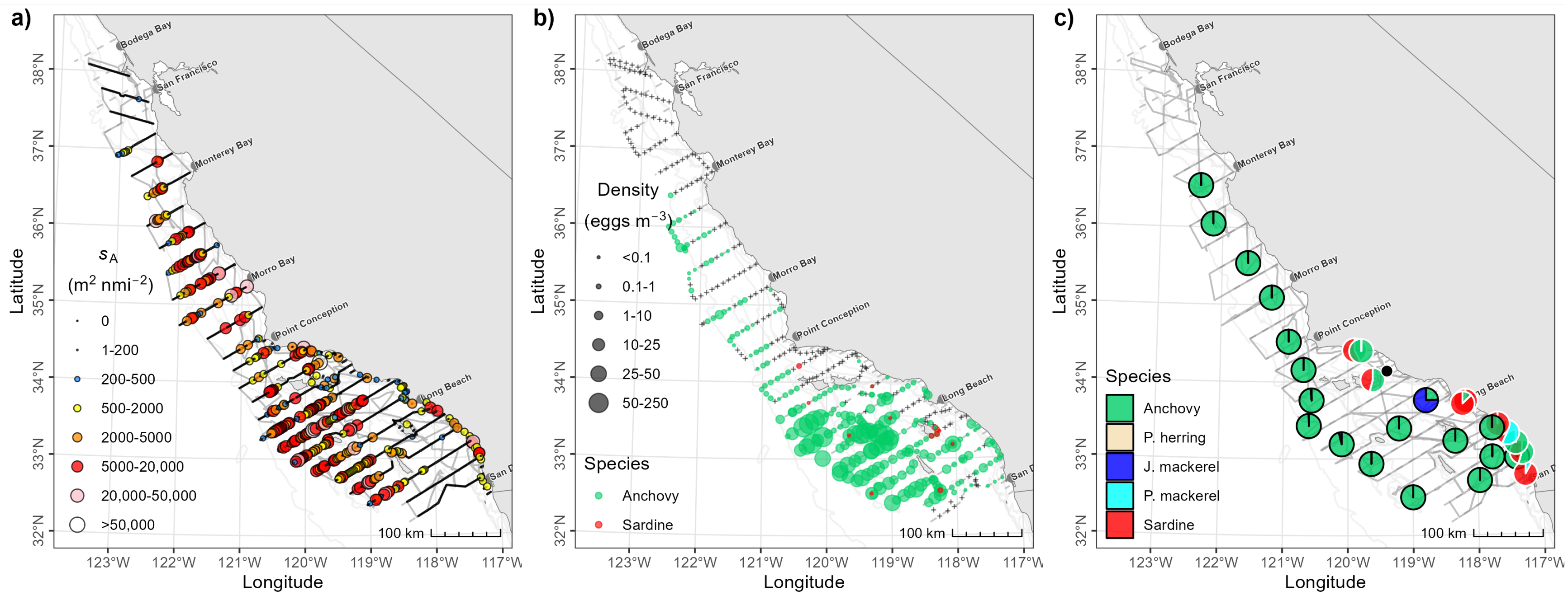

Figure 12: Spatial distributions of: a) 38-kHz integrated backscattering coefficients (s_A, m^2 nmi^{-2}; averaged over 2000-m distance intervals and from 5 to 350 m deep) observed by *Lasker* and *Long Beach Carnage* and ascribed to CPS; b) CUFES egg density (eggs m^{-3}) for Northern Anchovy, Pacific Sardine, and Jack Mackerel; and c) acoustic proportions of CPS in trawl clusters (black outline) and purse seines (white outline; black points indicate clusters or purse seines with no CPS).

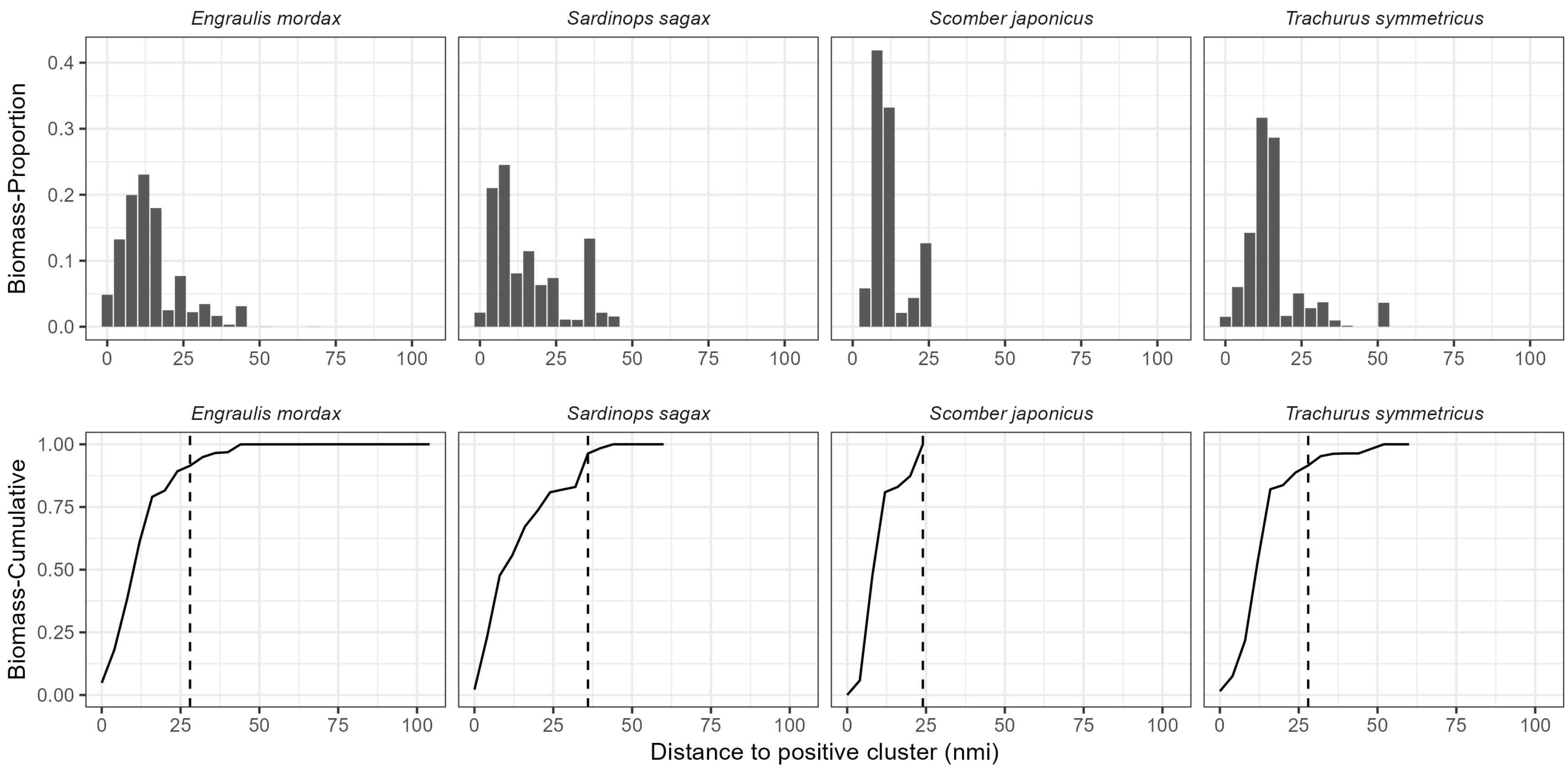

Figure 13: Proportion (top) and cumulative proportion (bottom) of biomass versus distance to the nearest positive trawl cluster. Dashed vertical lines (bottom) represent the cluster distance where cumulative biomass equals 90%.

3.6 Biomass distribution and demographics

3.6.1 Northern Anchovy

3.6.1.1 Central stock

The total estimated biomass of the central stock of Northern Anchovy in U.S. waters was 1,370,303 t ($CI_{95\%}$ = 1,076,749 - 1,959,163 t, CV = 16%). In the core region, sampled by *Lasker*, the biomass was 1,358,587 t ($CI_{95\%}$ = 1,070,094 - 1,940,986 t, CV = 17%; **Table 3**); the stock was distributed from north of Monterey Bay to San Diego (**Fig. 14a**). L_S ranged from 8 to 16 cm with a mode between 10 and 13 cm (**Table 4**, **Fig. 15**). In the nearshore region, sampled by *Long Beach Carnage*, the biomass was 11,716 t ($CI_{95\%}$ = 6,655 - 18,176 t, CV = 26%; **Table 3**), mostly distributed between Ventura and San Diego (**Fig. 14b**). Biomass in the nearshore region comprised 0.86% of the total biomass. The length distribution was similar to that in the core region (**Table 4**, **Fig. 15**).

Table 3: Biomass estimates (metric tons, t) and their precision (upper and lower 95% confidence intervals, $CI_{95\%}$; and coefficients of variation, CVs) for the central stock of Northern Anchovy (*Engraulis mordax*) in the core and nearshore survey regions. Stratum areas are nmi^2.

Stratum					Trawl		Biomass			
Region	Number	Area	Transects	Distance	Clusters	Individuals	$\hat{B}$	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Core	1	15,391	14	1,137	14	265,739	961,661	689,841	1,478,549	21
	2	9,559	12	502	5	18,432	396,926	243,128	627,099	26
	All	24,950	26	1,639	18	284,172	1,358,587	1,070,094	1,940,986	17
Nearshore	1	328	36	72	11	109,991	11,088	5,410	16,742	27
	2	75	10	20	2	100	440	360	2,144	105
	3	70	10	19	2	68	188	50	420	50
	All	473	56	110	12	110,159	11,716	6,655	18,176	26
All	**-**	**25,423**	**82**	**1,749**	**30**	**394,330**	**1,370,303**	**1,076,749**	**1,959,163**	**16**

Table 4: Abundance versus standard length (L_S, cm) for the central stock of Northern Anchovy (*Engraulis mordax*) in the core and nearshore survey regions.

	Region	
L_S	Core	Nearshore
1	0	0
2	0	0
3	0	0
4	0	0
5	0	0
6	0	0
7	0	3,595,242
8	762,238,601	321,952,670
9	9,632,798,691	896,905,365
10	29,286,125,416	243,563,227
11	17,923,875,332	38,018,647
12	17,321,267,534	37,572,450
13	11,181,245,156	24,013,255
14	4,512,360,465	1,302,202
15	906,295,154	156,840
16	200,632,184	0
17	0	0
18	0	0
19	0	0
20	0	0

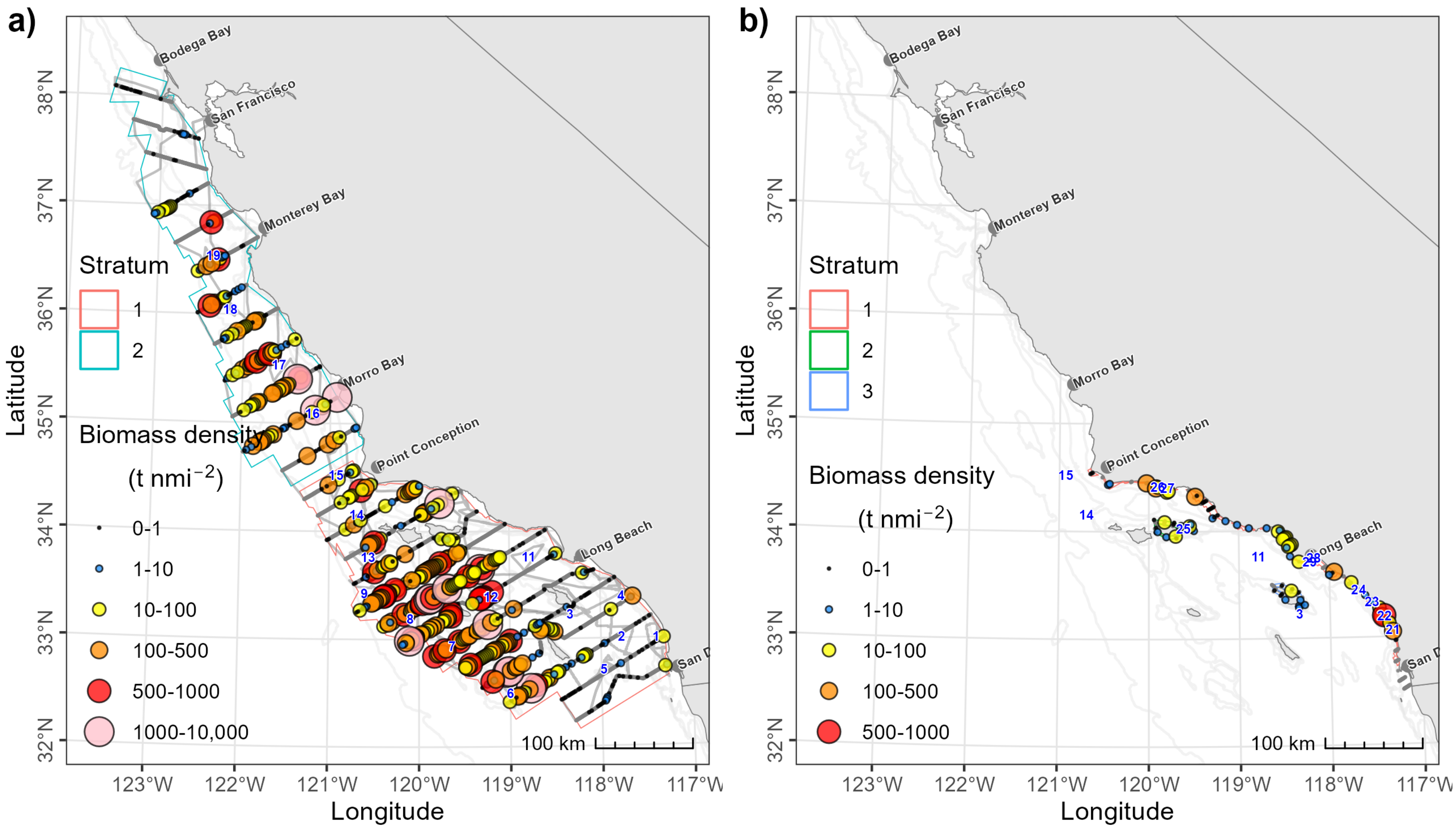

Figure 14: Biomass densities of the central stock of Northern Anchovy (*Engraulis mordax*), per strata, in the a) core and b) nearshore survey regions. The blue numbers represent the locations of trawl clusters or purse seines with at least one Northern Anchovy. The gray line represents the vessel tracks.

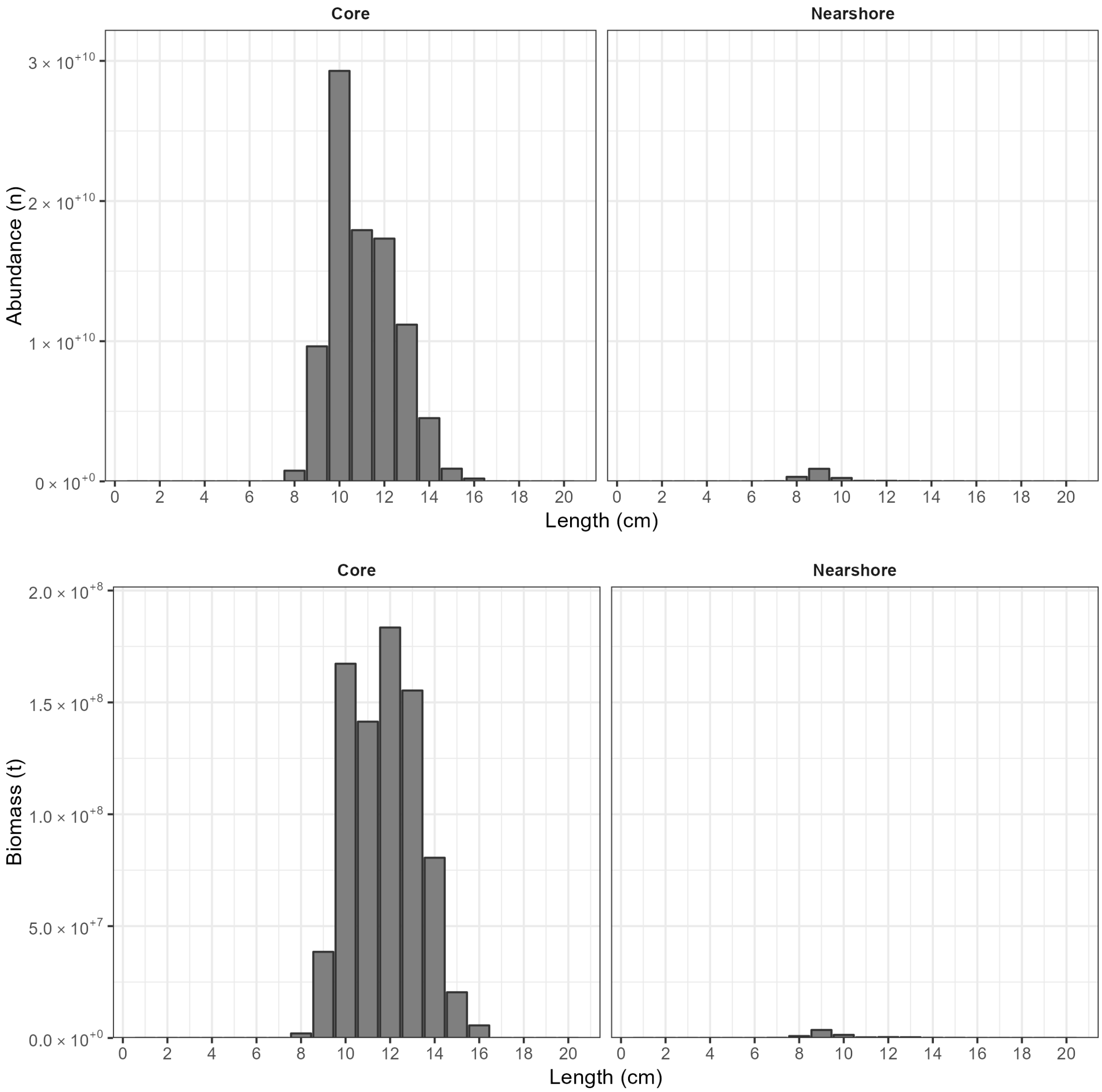

Figure 15: Abundance versus standard length (L_S, upper panel) and biomass (t) versus L_S (lower panel) for the central stock of Northern Anchovy (*Engraulis mordax*) in the core and nearshore survey regions.

3.6.2 Pacific Sardine

3.6.2.1 Southern stock

The total estimated biomass of the southern stock of Pacific Sardine in U.S. waters was 24,547 t ($CI_{95\%}$ = 7,697 - 38,339 t, CV = 29.3%; see **Section 4.1.2.1** for more details on the stock classification). In the core region, biomass was 1,504 t ($CI_{95\%}$ = 556 - 2,959 t, CV = 40%; **Table 5**), and was distributed from approximately Point Conception to Oceanside (**Fig. 16a**). L_S ranged from 12 to 20 cm with a mode at 13 cm (**Table 6**, **Fig. 17**). In the nearshore region, biomass was 23,043 t ($CI_{95\%}$ = 7,140 - 35,380 t, CV = 31%; **Table 5**), comprising 94% of the total biomass. It was distributed between Point Conception and San Diego, but most of it was near Santa Barbara, between Long Beach and Oceanside, and around Santa Cruz Island. These areas did not contain northern stock habitat (Zwolinski *et al.*, 2011), so none were ascribed to the northern stock. The length distribution was similar to that in the core region (**Table 6**, **Fig. 17**).

Table 5: Biomass estimates (metric tons, t) and their precisions (upper and lower 95% confidence intervals, $CI_{95\%}$; and coefficients of variation, CVs) for the southern stock of Pacific Sardine (*Sardinops sagax*) in the core and nearshore survey regions. Stratum areas are nmi^2.

Stratum					Trawl		Biomass			
Region	Number	Area	Transects	Distance	Clusters	Individuals	$\hat{B}$	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Core	1	14,466	13	1,021	5	53	1,504	556	2,959	40
	All	14,466	13	1,021	5	53	1,504	556	2,959	40
Nearshore	1	56	7	12	3	75	13,215	38	24,793	48
	2	77	6	17	1	32	91	17	144	38
	3	68	6	13	2	100	4,711	0	9,577	59
	4	123	14	27	4	200	3,858	376	5,172	33
	5	75	10	20	2	82	1,169	955	5,689	105
	All	399	43	89	10	489	23,043	7,140	35,380	31
All	**-**	**14,865**	**56**	**1,110**	**15**	**542**	**24,547**	**7,697**	**38,339**	**29**

Table 6: Abundance versus standard length (L_S, cm) for the southern stock of Pacific Sardine (*Sardinops sagax*) in the core and nearshore survey regions.

	Region	
L_S	Core	Nearshore
1	0	0
2	0	0
3	0	0
4	0	0
5	0	0
6	0	0
7	0	0
8	0	0
9	0	0
10	0	0
11	0	47,243,617
12	1,155,897	265,755,034
13	8,516,604	265,788,913
14	5,996,830	106,827,536
15	0	89,632,839
16	1,155,897	30,809,885
17	6,522,487	0
18	62,495	17,290,884
19	0	9,620,145
20	5,754,512	0
21	0	0
22	0	0
23	0	0
24	0	0
25	0	0
26	0	0
27	0	0
28	0	0
29	0	0
30	0	0

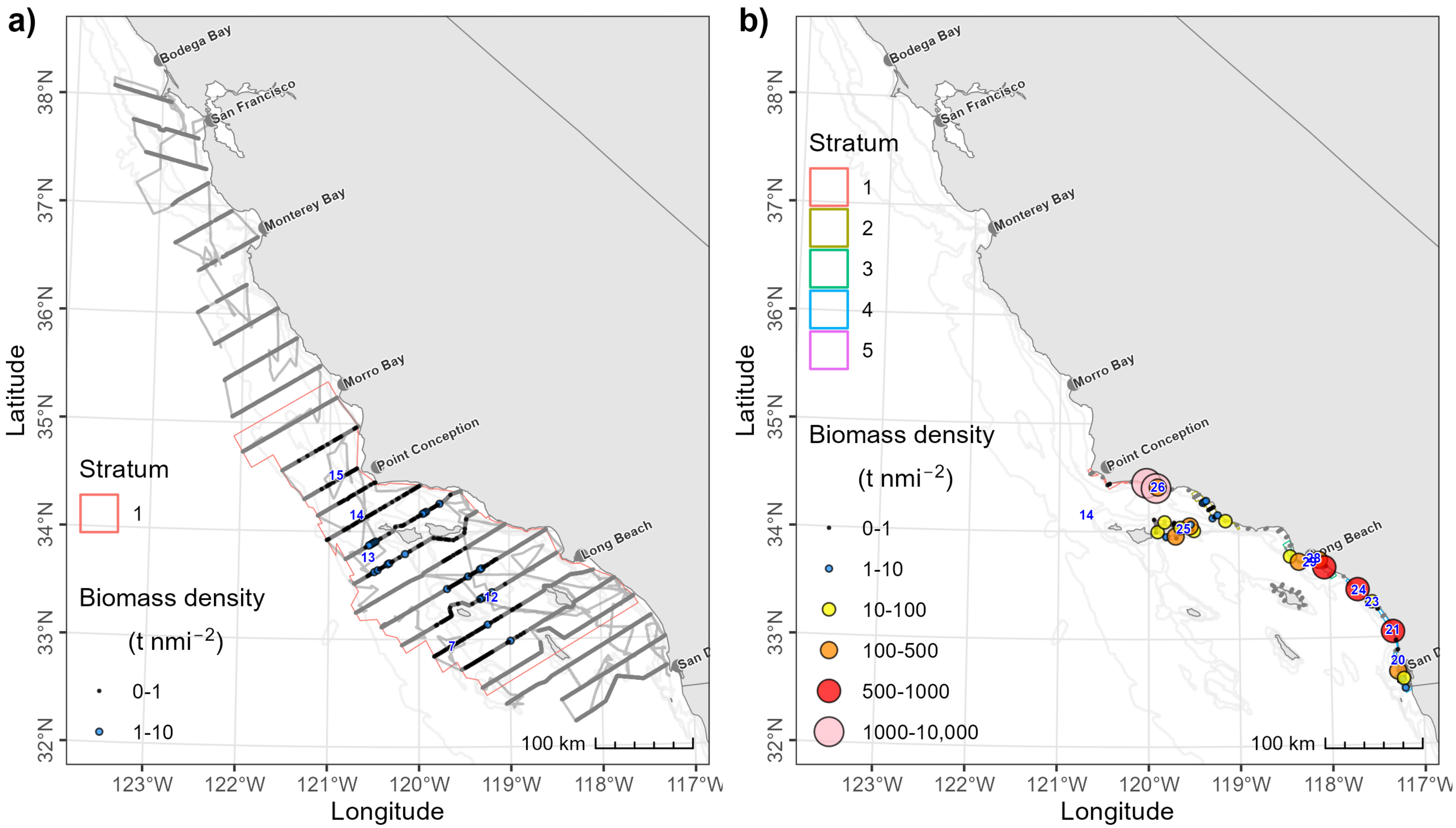

Figure 16: Biomass densities of the southern stock of Pacific Sardine (*Sardinops sagax*), per strata, in the a) core and b) nearshore survey regions. The blue numbers represent the locations of trawl clusters or purse seines with at least one Pacific Sardine. The gray lines represents the vessel tracks.

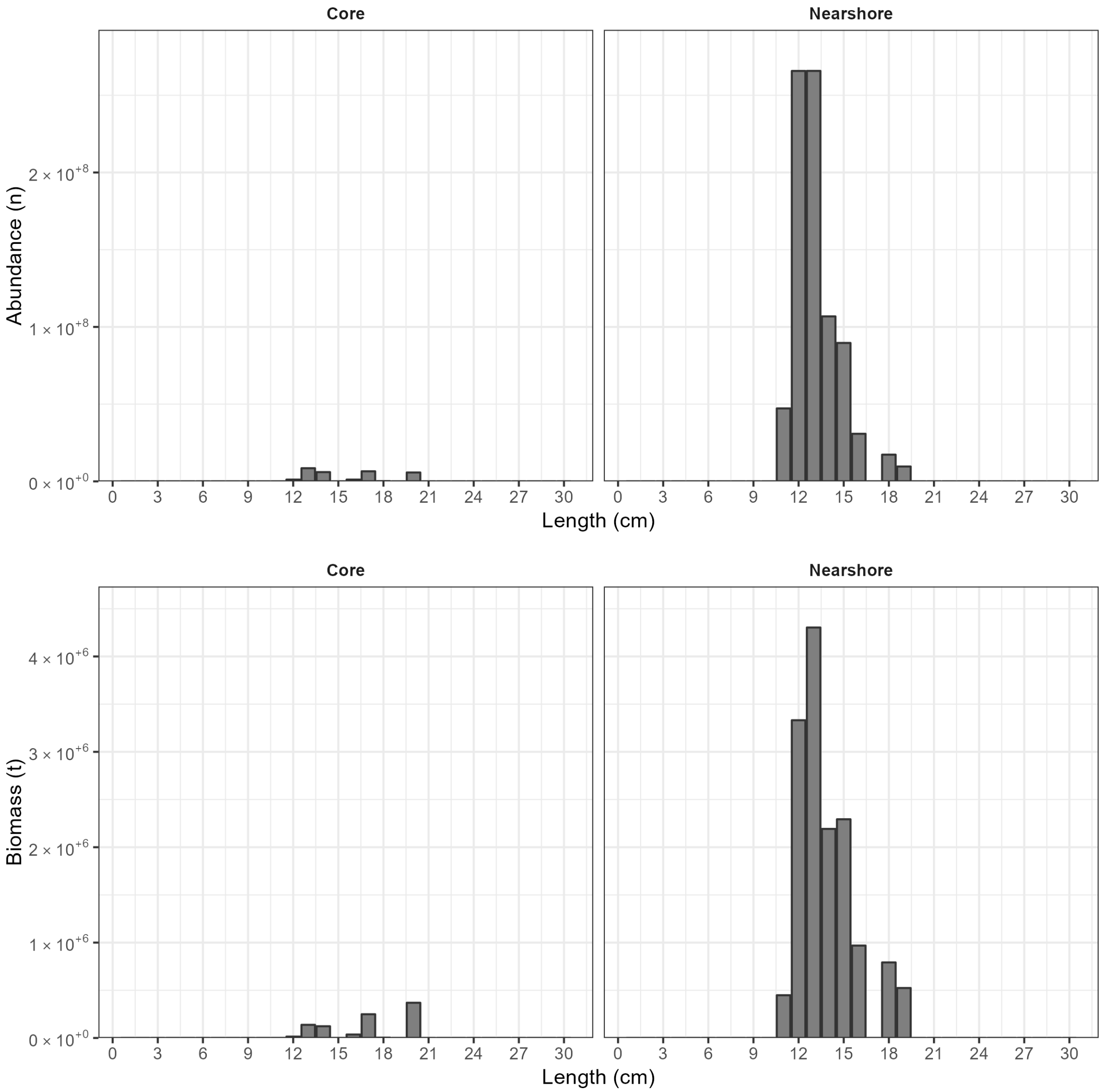

Figure 17: Estimated abundance (upper panel) and biomass (lower panel) versus standard length (L_S, cm) for the southern stock of Pacific Sardine (*Sardinops sagax*) in the core and nearshore survey regions.

3.6.3 Pacific Mackerel

In the nearshore region, the biomass of Pacific Mackerel in U.S. waters was 92.3 t ($CI_{95\%}$ = 7.43 - 221 t, CV = 64%; **Table 7**, **Fig. 18b**), distributed from San Clemente to San Diego. L_F ranged from 14 to 25 cm with a mode at 18 cm (**Table 8**, **Fig. 19**).

Table 7: Biomass estimates (metric tons, t) and their precisions (upper and lower 95% confidence intervals, $CI_{95\%}$; and coefficients of variation, CVs) for Pacific Mackerel (*Scomber japonicus*) in nearshore region. No Pacific Mackerel were caught in the core region. Stratum areas are nmi^2.

Stratum					Trawl		Biomass			
Region	Number	Area	Transects	Distance	Clusters	Individuals	$\hat{B}$	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Nearshore	1	33	4	6	1	12	74	0	191	78
	2	65	6	14	1	1	19	3	40	53
	All	98	10	21	2	13	92	7	221	64
All	**-**	**98**	**10**	**21**	**2**	**13**	**92**	**7**	**221**	**64**

Table 8: Abundance versus fork length (L_F, cm) for Pacific Mackerel (*Scomber japonicus*) in the nearshore survey region.

L_F	Abundance
1	0
2	0
3	0
4	0
5	0
6	0
7	0
8	0
9	0
10	0
11	0
12	0
13	0
14	82,749
15	0
16	0
17	421,761
18	661,990
19	0
20	0
21	82,749
22	0
23	0
24	0
25	82,749
26	0
27	0
28	0
29	0
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31	0
32	0
33	0
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35	0
36	0
37	0
38	0
39	0
40	0

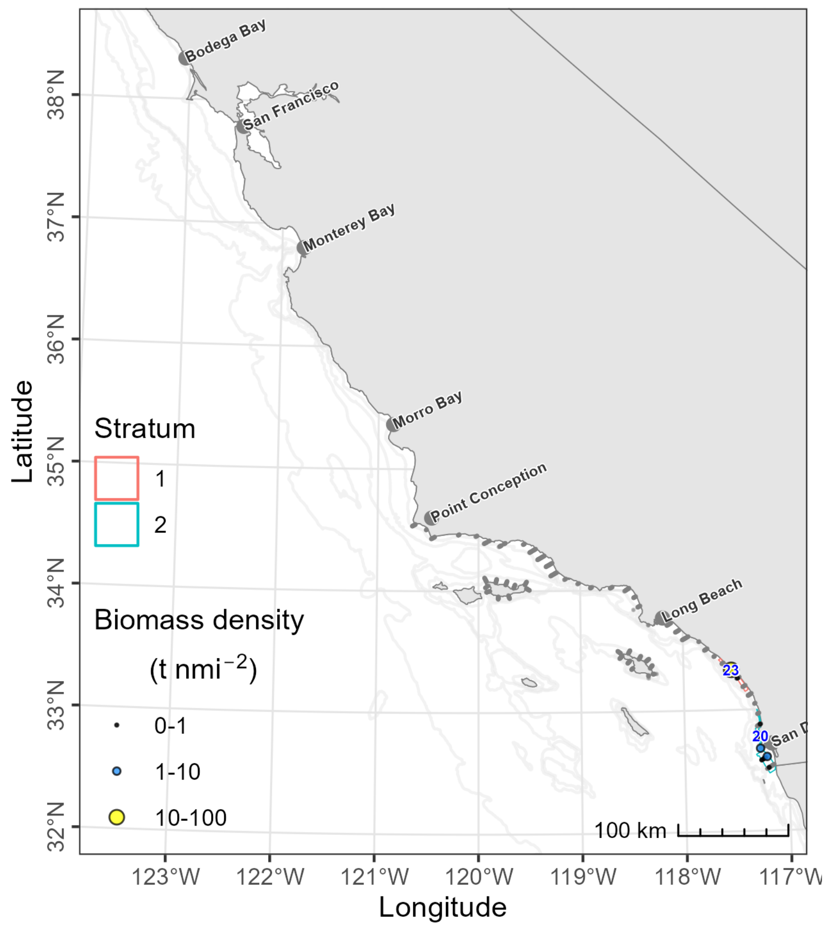

Figure 18: Biomass densities of the Pacific Mackerel (*Scomber japonicus*), per strata, in the nearshore survey regions. The blue numbers represent the locations of purse seines with at least one Pacific Mackerel. The gray line represents the vessel track.

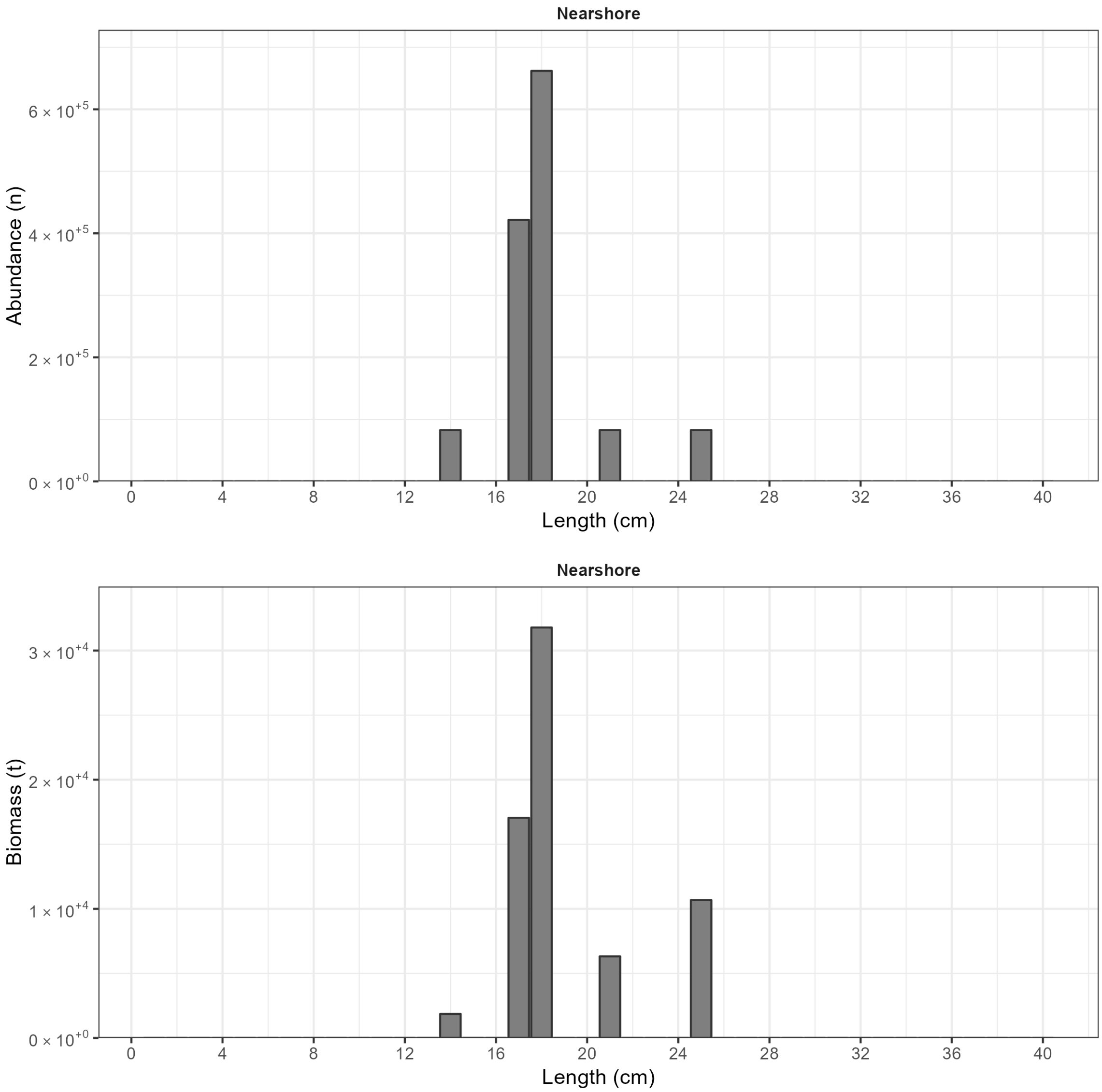

Figure 19: Estimated abundance (upper panel) and biomass (lower panel) versus fork length (L_F, cm) for Pacific Mackerel (*Scomber japonicus*) in the core and nearshore survey regions.

3.6.4 Jack Mackerel

The total estimated biomass of Jack Mackerel in U.S. waters was 16,882 t ($CI_{95\%}$ = 3,783 - 41,209 t, CV = 57%), all in the core region (**Table 9**), and was distributed from approximately Point Conception to San Diego (**Fig. 20a**). L_F ranged from 9 to 23 cm with a mode at 13 cm (**Table 10**, **Fig. 21**).

Table 9: Biomass estimates (metric tons, t) and their precisions (upper and lower 95% confidence intervals, $CI_{95\%}$; and coefficients of variation, CVs) for Jack Mackerel (*Trachurus symmetricus*) in the core region. There were no Jack Mackerel caught in the nearshore region. Stratum area is nmi^2.

Stratum					Trawl		Biomass			
Region	Number	Area	Transects	Distance	Clusters	Individuals	$\hat{B}$	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Core	1	15,391	14	1,137	9	41	16,882	3,783	41,209	57
	All	15,391	14	1,137	9	41	16,882	3,783	41,209	57
All	**-**	**15,391**	**14**	**1,137**	**9**	**41**	**16,882**	**3,783**	**41,209**	**57**

Table 10: Abundance versus fork length (L_F, cm) for Jack Mackerel (*Trachurus symmetricus*) in the core survey region.

L_F	Abundance	L_F	Abundance
1	0	31	0
2	0	32	0
3	0	33	0
4	0	34	0
5	0	35	0
6	0	36	0
7	0	37	0
8	0	38	0
9	510	39	0
10	510	40	0
11	1,019	41	0
12	48,283	42	0
13	264,447,693	43	0
14	20,475,908	44	0
15	85,911,281	45	0
16	3,314,276	46	0
17	16,055,929	47	0
18	0	48	0
19	16,055,929	49	0
20	16,055,929	50	0
21	16,055,929	51	0
22	0	52	0
23	5,493,875	53	0
24	0	54	0
25	0	55	0
26	0	56	0
27	0	57	0
28	0	58	0
29	0	59	0
30	0	60	0

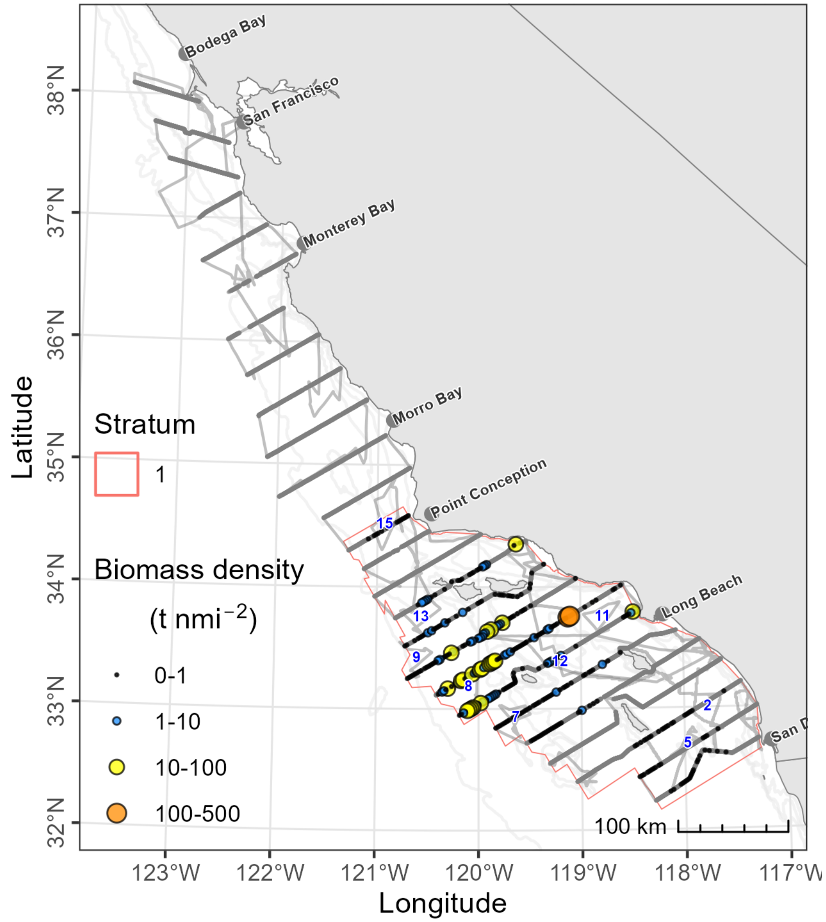

Figure 20: Biomass densities of Jack Mackerel (*Trachurus symmetricus*), per strata, in the core survey region. The blue numbers represent the locations of trawl clusters with at least one Jack Mackerel. The gray line represents the vessel track.

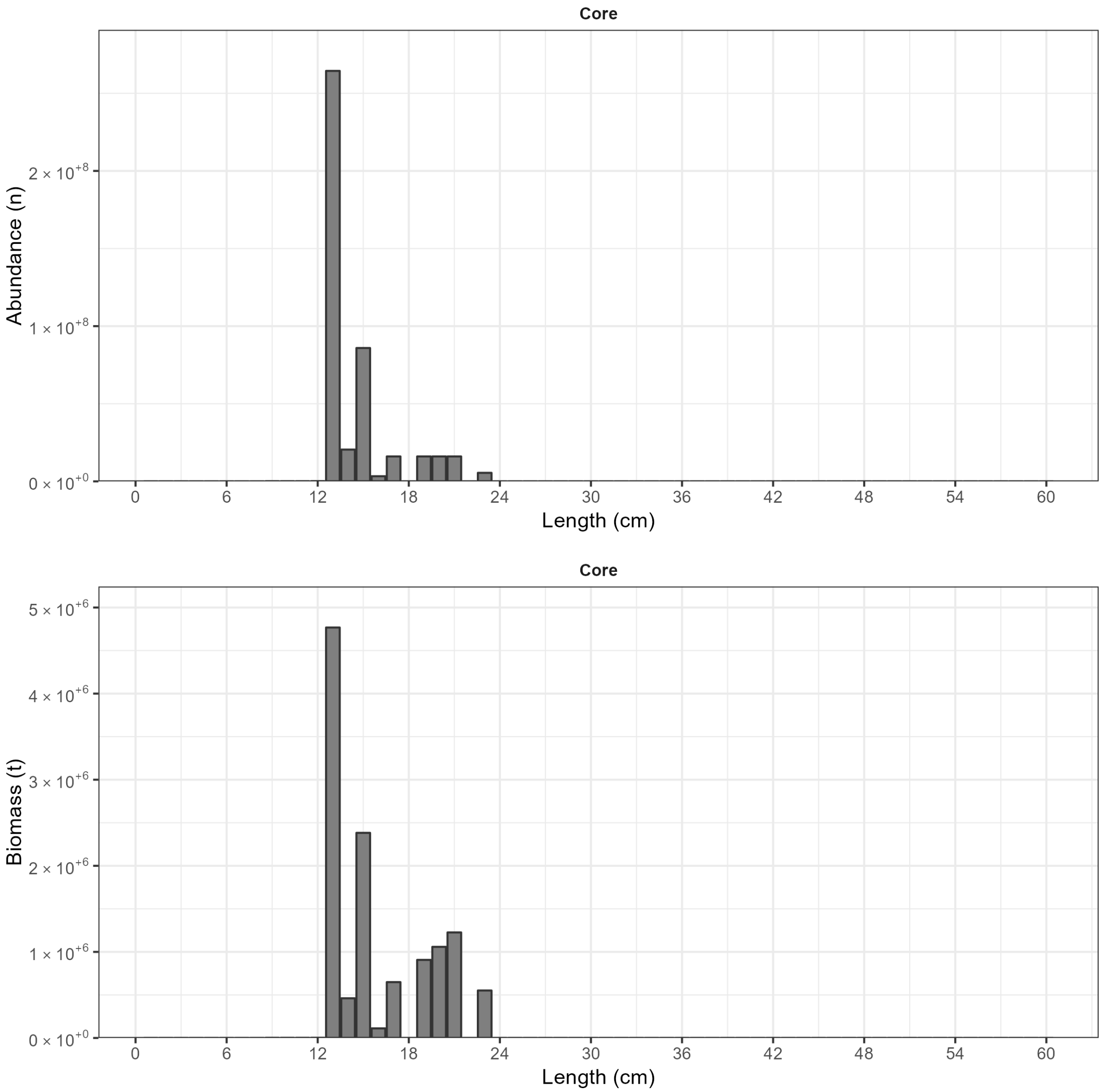

Figure 21: Estimated abundance (upper panel) and biomass (lower panel) versus fork length (L_F, cm) for Jack Mackerel (*Trachurus symmetricus*) in the core survey region. No Jack Mackerel were caught in the nearshore region.

4 Discussion

The principal objective of the Spring 2021 CPS survey was to assess the central stock of Northern Anchovy in U.S. waters. Then, as possible, estimates were also sought for Pacific Sardine, Pacific Mackerel, and Jack Mackerel in the survey area. With the benefits of favorable weather and few problems, *Lasker* surveyed from San Diego to San Francisco. All transects south of Point Conception, where the biomass of Northern Anchovy was expected to be greatest, were spaced 15-nmi apart to reduce the variance. North of Point Conception, transects were spaced 20-nmi apart to maximize the extent of the survey area within the available 25 DAS.

4.1 Biomass and abundance

4.1.1 Northern Anchovy

4.1.1.1 Central stock

The estimated biomass of the central stock of Northern Anchovy in the core survey region was 1,358,587 t ($CI_{95\%}$ = 1,070,094 - 1,940,986 t) in spring 2021, which is 60% more than the 810,634 t ($CI_{95\%}$ = 587,317 - 1,066,265) observed in summer 2019 (Stierhoff *et al.*, 2020b). In spring 2021, the distribution of L_S had one mode between 10 and 13 cm, likely corresponding to a 2020 cohort.

Although most *Lasker* transects had practically zero biomass density at their western ends, the declines are abrupt. The distribution of Northern Anchovy eggs from the spring 2021 CalCOFI survey (unpublished data) also shows this pattern, which indicates that the abundance of Northern Anchovy farther offshore of the survey area is likely small (**Appendix B**).

4.1.2 Pacific Sardine

4.1.2.1 Southern stock

The core survey area included some "good" and "optimal" habitat for the northern stock of Pacific Sardine, particularly north of Point Conception (**Fig. 2a**). However, the Pacific Sardine sampled in the SCB were exclusively in the nearshore region and around the northern Channel Islands, which had unsuitable habitat due to excessive chlorophyll-a concentration (**Fig. 2b**, **Fig. 22**). Therefore, the Pacific Sardine observed in the spring 2021 survey, with a biomass of 24,547 t ($CI_{95\%}$ = 7,697 - 38,339 t), were attributed to the southern stock. Pacific Sardine eggs were absent from the nearshore, suggesting that the Pacific Sardine, with a modal length between 12 and 13 cm, were immature, age-0 fish that likely recruited locally to the southern stock because their forecast growth matched the 16 to 18 cm lengths of Pacific Sardine sampled in the SCB in summer survey (Stierhoff *et al.*, 2023). Furthermore, it is likely that few or none of them migrated and recruited to the northern stock because there were no Pacific Sardine with comparable sizes in northern stock habitat sampled off OR and WA during summer 2021 (**Fig. 23**).

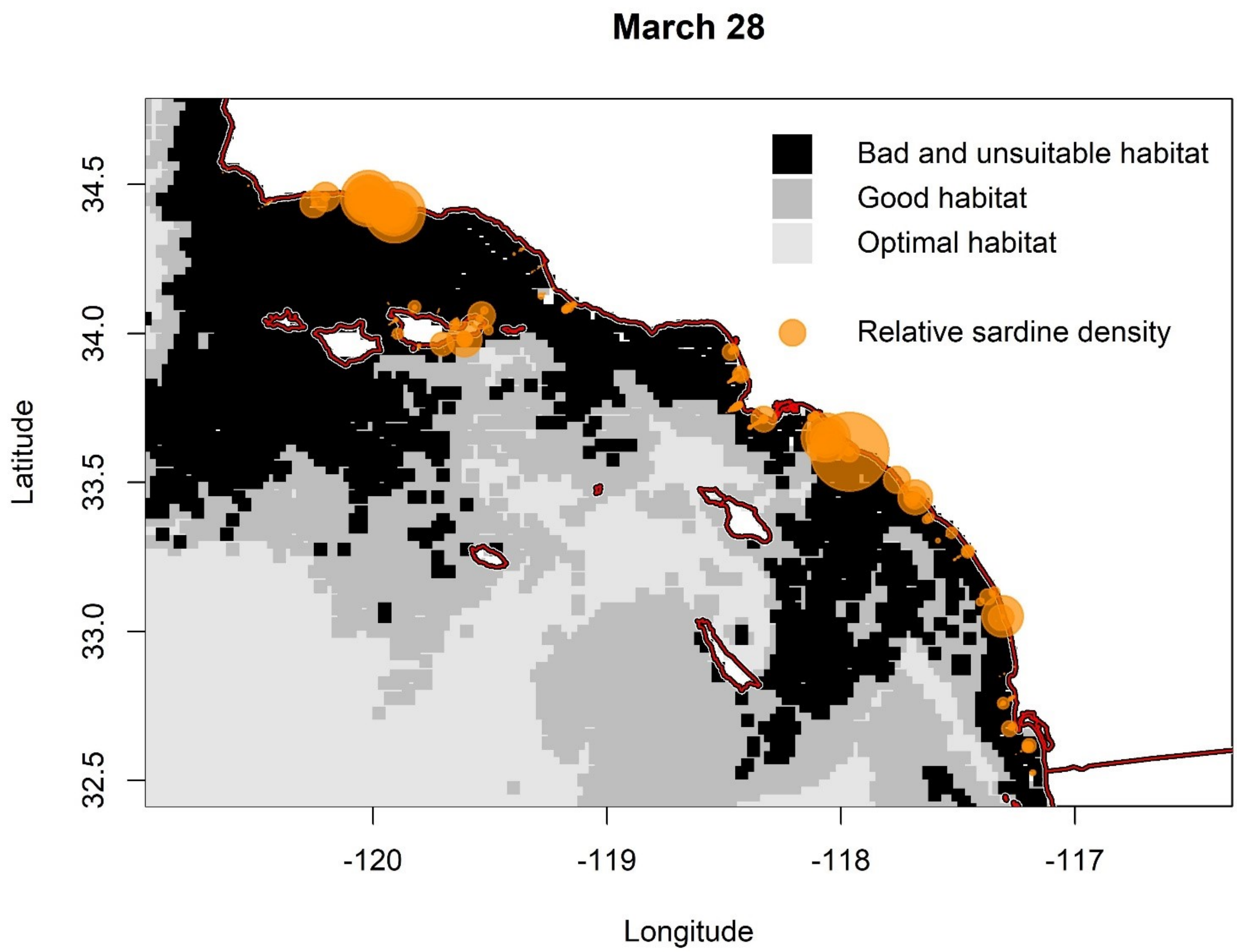

Figure 22: The spatial distribution of Pacific Sardine during the spring survey overlaid on the potential habitat for the northern stock (Zwolinski *et al.*, 2011), which is principally defined by a non-linear-combination of SST and the logarithm of chlorophyll-a concentration. Based on spring CalCOFI data from 1998 to 2009, the "optimal" and "good" areas include at least 90% of the northern stock Pacific Sardine biomass. During March 2021, the nearshore waters of the SCB included only "unsuitable" or "bad" habitat for the northern stock.

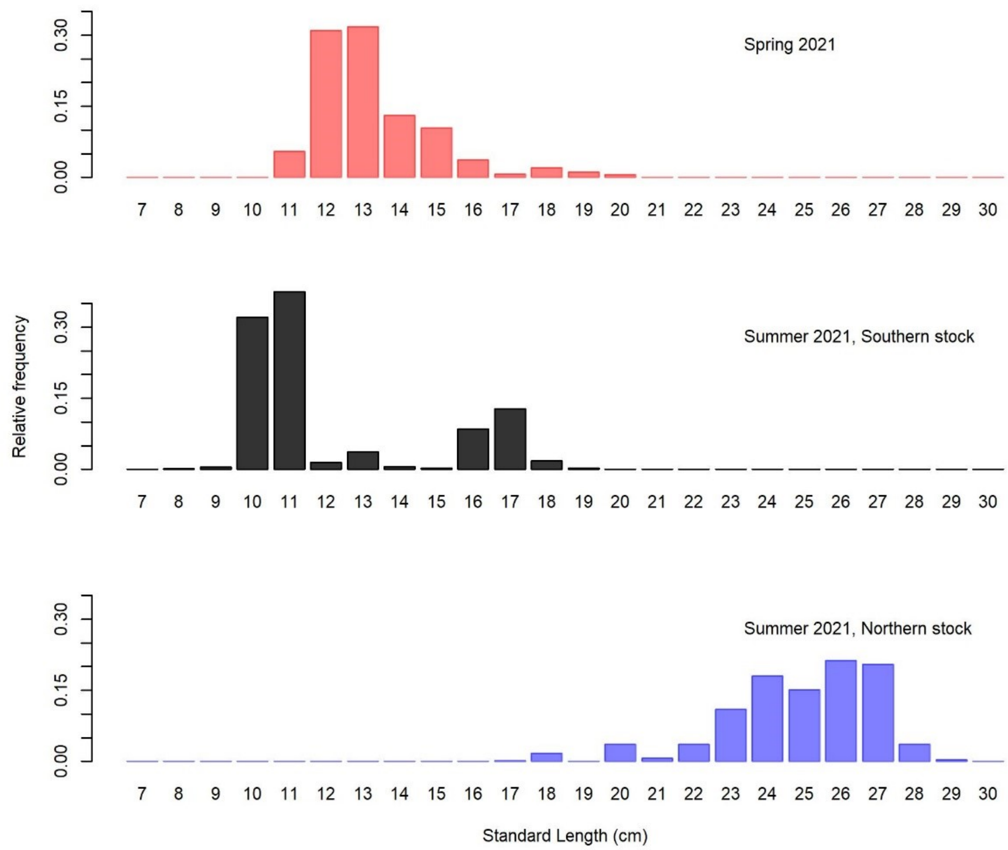

Figure 23: Relative abundance versus standard length (L_S) for Pacific Sardine (*Sardinops sagax*) estimated during the spring 2021 (top) and the summer 2021 survey (Stierhoff *et al.*, 2023), separated by putative southern (middle) and northern stocks (bottom).

4.1.3 Pacific Mackerel

There was a negligible amount of Pacific mackerel observed by *Lasker* and *Long Beach Carnage*. See the summer 2021 CCE biomass report (Stierhoff *et al.*, 2023) for a better indication of the status of this stock.

4.1.4 Jack Mackerel

The estimated biomass of Jack Mackerel in the core survey region was 16,882 t ($CI_{95\%}$ = 3,783 - 41,209 t), which is less than 5% of the biomass estimated in the summer 2019 survey. See the summer 2021 CCE biomass report (Stierhoff *et al.*, 2023) for a better indication of the status of this stock.

4.2 Ecosystem dynamics: Forage fish community

The ATM has been used worldwide to monitor the biomasses and distributions of pelagic and mid-water fish stocks worldwide (e.g., Coetzee *et al.*, 2008; Karp and Walters, 1994; Simmonds *et al.*, 2009). In the CCE, ATM surveys have been used to directly assess Pacific Hake (Edwards *et al.*, 2018; JTC, 2014), rockfishes (Demer, 2012a, 2012b, 2012c; Starr *et al.*, 1996), Pacific Herring (Thomas and Thorne, 2003), and CPS (Hill *et al.*, 2017; Mais, 1974, 1977). Focused initially, in 2006, on Pacific Sardine (Cutter and Demer, 2008), the SWFSC's ATM surveys of CPS in the CCE have evolved to assess the five most abundant forage-fish species (Zwolinski *et al.*, 2014): Pacific Sardine, Northern Anchovy, Jack Mackerel, Pacific Mackerel, and Pacific Herring. The proportions of these stocks that are in water too shallow to be sampled by NOAA ships are estimated using samples collected from fishing vessels (Stierhoff *et al.*, 2020b, this study) and USVs (Stierhoff *et al.*, 2020b). Also, concurrent satellite- and ship-based measures of their biotic and abiotic habitats are used to provide an ecosystem perspective.

The 2021 spring survey area encompassed the expected distribution of Northern Anchovy and spanned the waters between San Diego and San Francisco, out to 150 km off Southern CA. In the SCB, the sampling from *Lasker* was augmented by nearshore transects sampled by *Long Beach Carnage*. The reduced latitudinal extent of the spring survey, relative to previous years' summer surveys, only allowed an accurate assessment of the entire central stock of Northern Anchovy. Other CPS stocks were sampled partially, if at all. The estimated biomass of 1,358,587 t (CV = 16%) indicates that the central stock continued to grow since summer 2019, when it was estimated at 810,634 t (CV = 0.13, Stierhoff *et al.*, 2020b). Compared to Northern Anchovy, other CPS comprised an insignificant fraction of the overall biomass in the region. Noteworthy is the virtual absence of spawning Pacific Sardine. Prior to 2014, northern stock Pacific Sardine dominated the CPS fish assemblage, particularly during the spring in the SCB (Zwolinski *et al.*, 2014). In spring 2021, southern stock Pacific Sardine were the most abundant CPS in the SCB, mostly located within 3 nmi of the coast and, based on their lengths and virtually absent spawning, they were mostly sexually immature age-0 fish.

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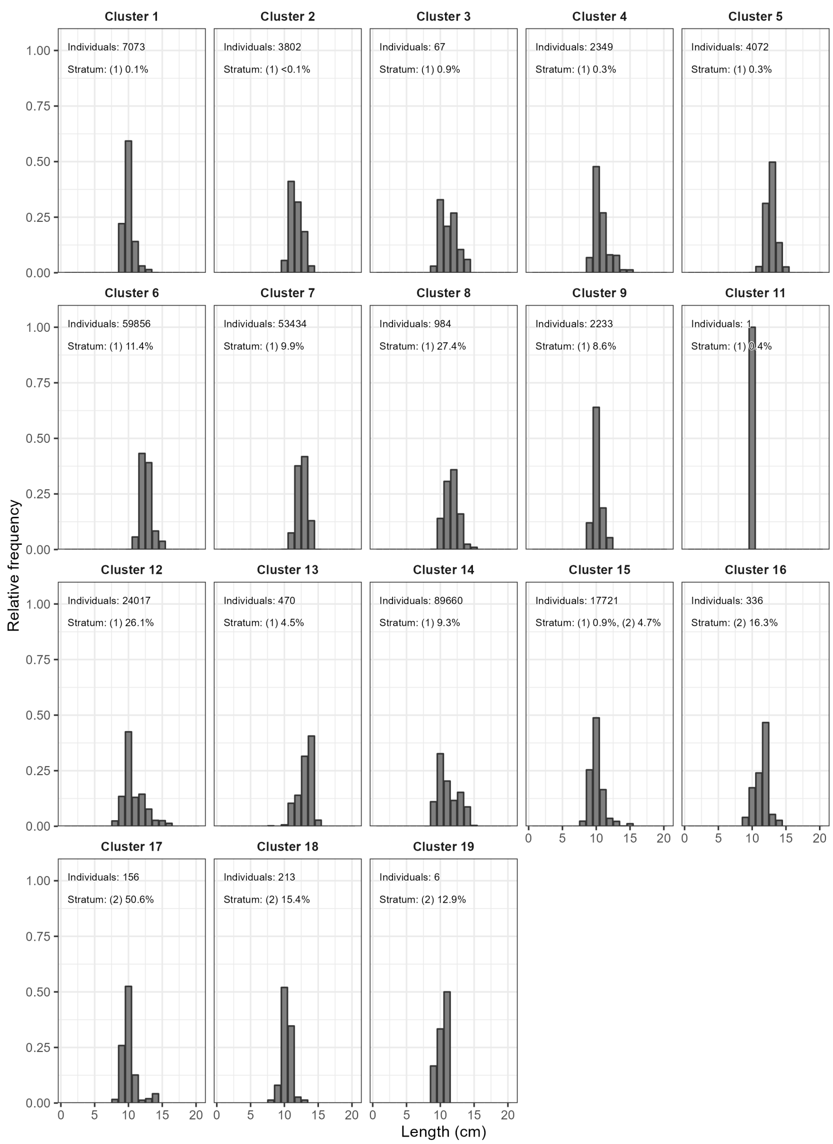
Appendix

A Length distributions and percent contribution to biomass by species and cluster

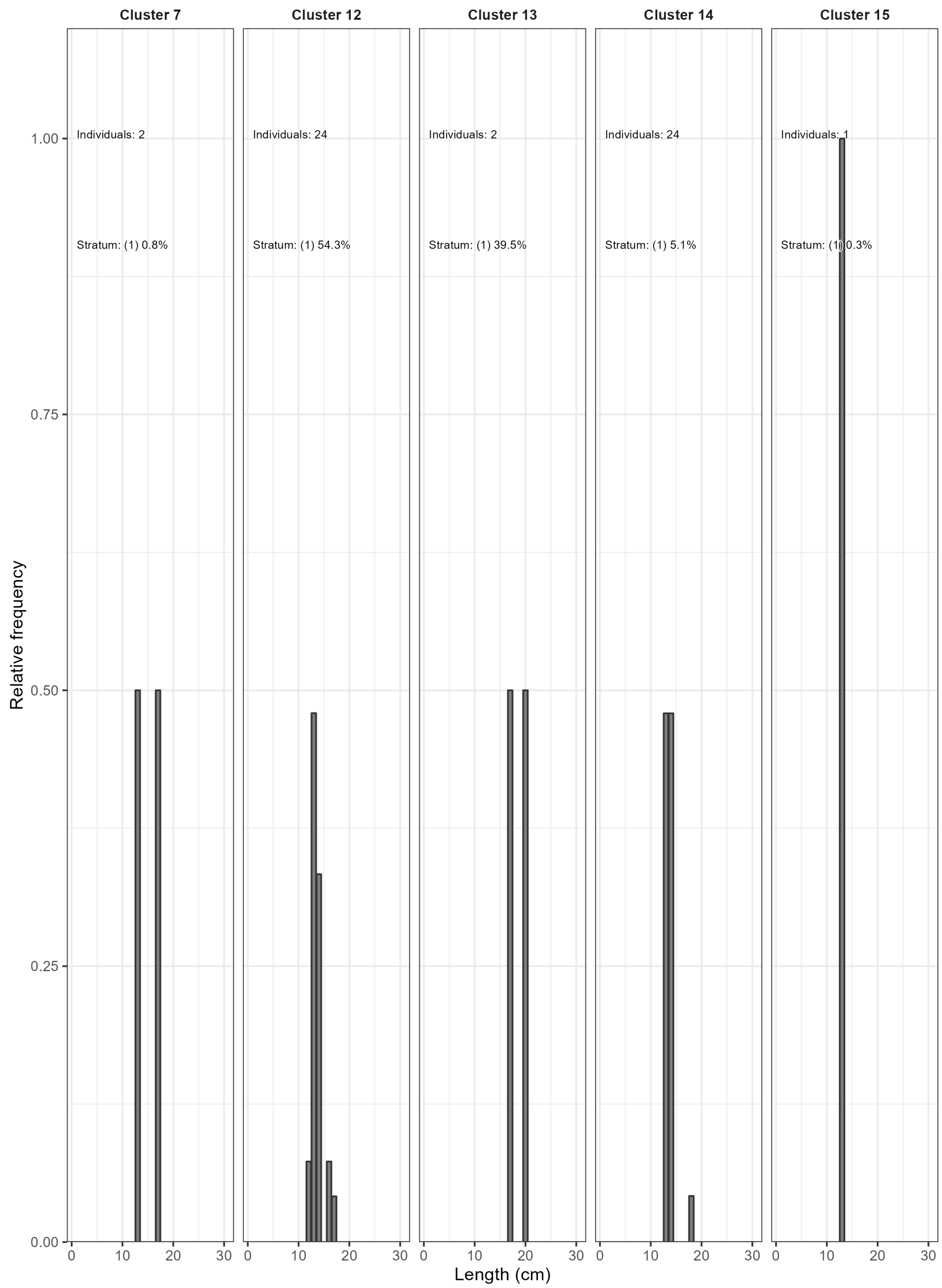
A.1 Northern Anchovy

Standard length (L_S) frequency distributions of Northern Anchovy (*Engraulis mordax*) per nighttime trawl cluster, annotated with the number of individuals caught and their percentage contributions to the abundance in each stratum.



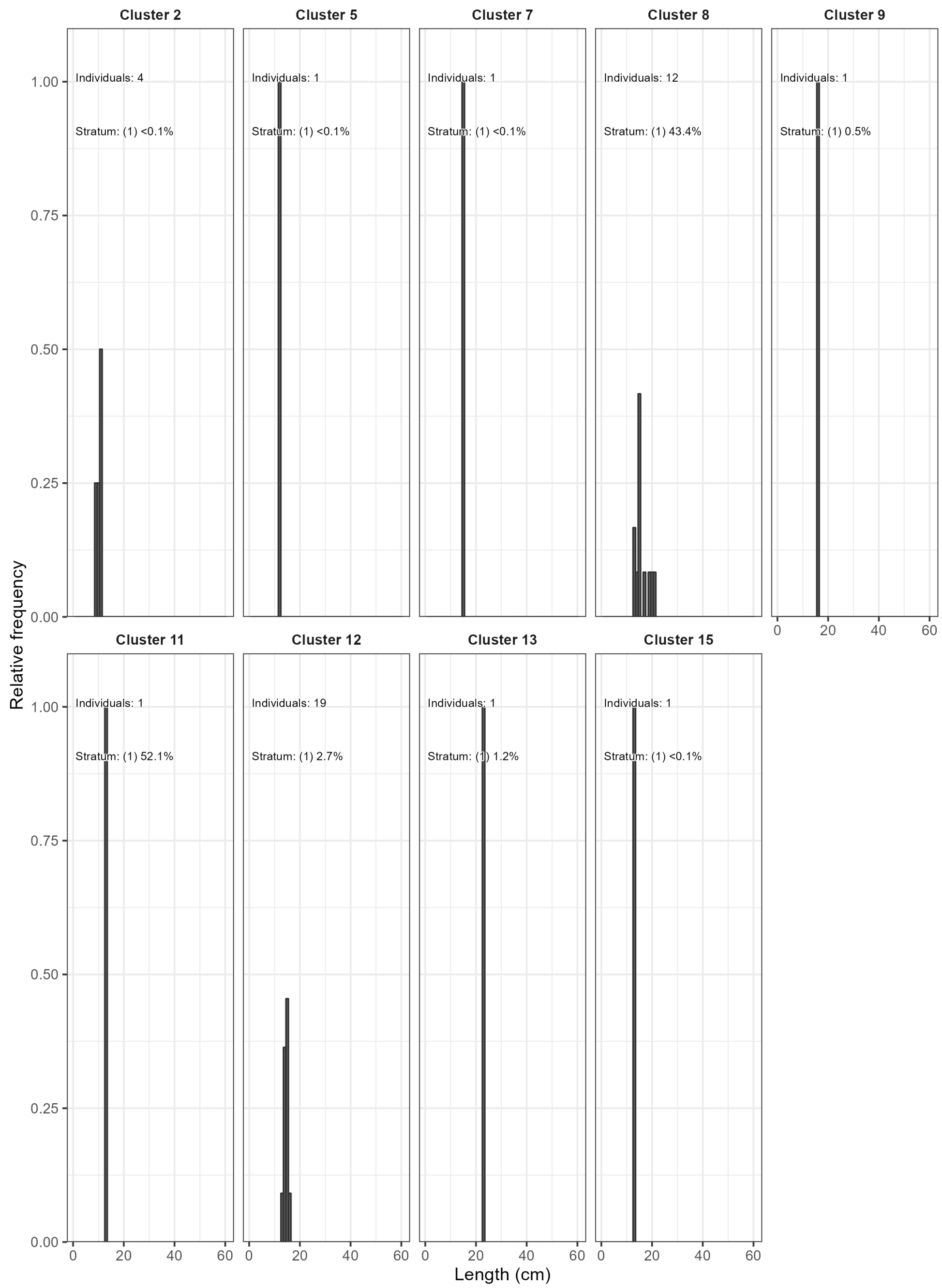
A.2 Pacific Sardine

Standard length (L_S) frequency distributions of Pacific Sardine (*Sardinops sagax*) per nighttime trawl cluster, annotated with the number of individuals caught and their percentage contributions to the abundance in each stratum.



A.3 Jack Mackerel

Fork length (L_F) frequency distributions of Jack Mackerel (*Trachurus symmetricus*) per nighttime trawl cluster, annotated with the number of individuals caught and their percentage contributions to the abundance in each stratum.



B Investigation of Northern Anchovy offshore of the surveyed area

The biomass of the central stock of Northern Anchovy occupied mostly the central to western sections of the survey area (**Fig. 14a**). Two lines of reason indicate that the estimated stock biomass was not substantially biased due to any unsampled Northern Anchovy farther offshore. First, and most significantly, there was practically zero biomass on the western ends of all the survey transects (**Fig. 24**). Second, there were few Northern Anchovy eggs west of the Spring 2021 CPS Survey area during the Spring 2021 CalCOFI[5] Survey (data available via ERDDAP[6]), less than a month later (**Fig. 24**).

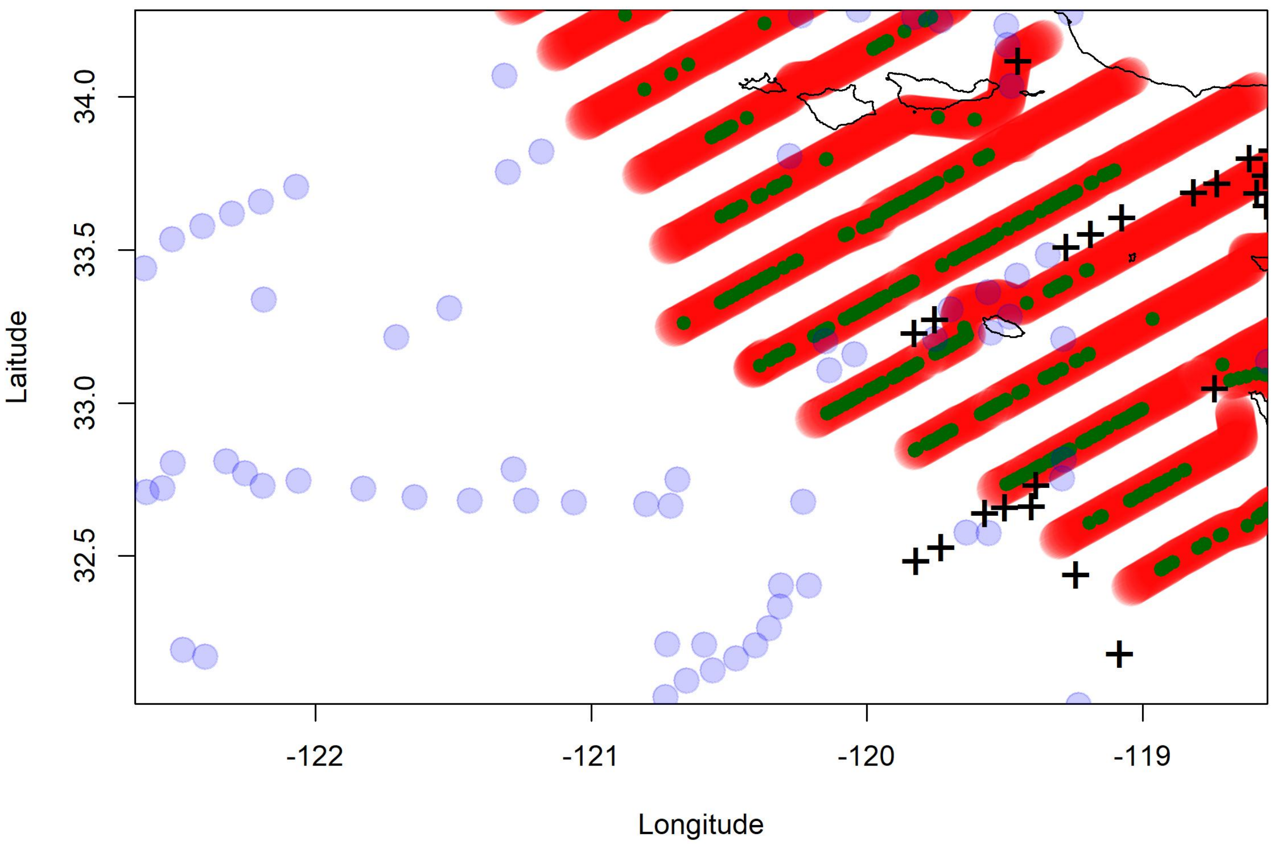


Figure 24: Distribution of Northern Anchovy inferred from the Spring 2021 CPS and CalCOFI surveys. From the CPS survey, the red circles represent the smallest biomass densities that sum to 5% of the total biomass, and the green circles represent the largest biomass densities that sum to 95% of the biomass. From the CalCOFI survey, less than one month later, the blue circles indicate the smallest densities of Northern Anchovy eggs that sum to 5% of the total Northern Anchovy eggs, and the “+” symbols indicate the largest densities of Northern Anchovy eggs that sum to 95% of the total Northern Anchovy eggs.

[5] https://calcofi.org/

[6] https://coastwatch.pfeg.noaa.gov/erddap/tabledap/erdCalCOFIcufes.html