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DISTRIBUTION, BIOMASS, AND DEMOGRAPHICS OF COASTAL PELAGIC FISHES IN THE CALIFORNIA CURRENT ECOSYSTEM DURING SUMMER 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 (ATM) used by NOAA's Southwest Fisheries Science Center (SWFSC) for direct assessments of the dominant species of coastal pelagic species (CPS; i.e.: Pacific Sardine *Sardinops sagax*, Northern Anchovy *Engraulis mordax*, Pacific Mackerel *Scomber japonicus*, Jack Mackerel *Trachurus symmetricus*, Pacific Herring *Clupea pallasii*, and Round Herring, *Etrumeus acuminatus*) in the California Current Ecosystem off the west coast of the United States (U.S.) and Mexico (MX); and 2) estimates of the biomasses, distributions, and demographics of those CPS encountered in the survey area between 6 July and 15 October 2021.

The core survey region, which was sampled by NOAA ship *Reuben Lasker* (hereafter, *Lasker*), the Mexican research vessel *Dr. Jorge Carranza Fraser* (hereafter *Carranza*), and three wind-powered uncrewed surface vehicles (Explorer USVs; Saildrone, Inc.), spanned most of the continental shelf between Cape Flattery, WA and Punta Abreojos, MX. Throughout the core region, *Lasker*, *Carranza*, and USVs sampled along transects oriented approximately perpendicular to the coast, from the shallowest navigable depth (~25 m) to either a distance of 35 nmi or to the 1,000 ftm (~1830 m) isobath, whichever is farthest. In the SCB, transects were extended to approximately 75 nmi. Because sampling by *Lasker* and USVs in water shallower than ~15 m was deemed inefficient, unsafe, or both, fishing vessels *Lisa Marie* and *Long Beach Carnage* were used to estimate the biomass of CPS in the nearshore region of U.S. waters. The vessels sampled along 5 nmi-long transects spaced 5 nmi apart off the mainland coast of the U.S. between Cape Flattery, WA and San Diego, CA, as well as around Santa Cruz and Santa Catalina Islands in the Southern CA Bight.

The biomasses, distributions, and demographics for each species and stock are for the survey area and period and therefore may not represent the entire population or stock. No nearshore sampling was conducted off Baja CA, so nearshore biomass estimates are for U.S. waters only.

The estimated biomass of the northern stock of Northern Anchovy was 8,031 t ($CI_{95\%}$ = 1,624 - 15,893 t, CV = 34%). In the core region, biomass was 5,587 t ($CI_{95\%}$ = 1,346 - 10,099 t, CV = 41%), and in the nearshore region, biomass was 2,444 t ($CI_{95\%}$ = 278 - 5,794 t, CV = 56%), or 30% of the total biomass. The northern stock ranged from approximately Westport, WA to Cape Mendocino, CA and standard length (L_S) ranged from 10 to 17 cm with modes at 14 cm in the core region and 11 cm in the nearshore region.

The estimated biomass of the central stock of Northern Anchovy was 2,721,689 t ($CI_{95\%}$ = 1,218,459 - 3,353,289 t, CV = 19%). In the core region, biomass was 2,619,046 t ($CI_{95\%}$ = 1,155,189 - 3,202,921 t, CV = 20%), and in the nearshore region, biomass was 102,642 t ($CI_{95\%}$ = 63,270 - 150,367 t, CV = 22%), or 3.8% of the total biomass. The central stock ranged from approximately Cape Mendocino to Punta Eugenia and L_S ranged from 7 to 16 cm with modes at 11 cm in the core region and 10 cm in the nearshore region.

The estimated biomass of the northern stock of Pacific Sardine was 47,721 t ($CI_{95\%}$ = 14,016 - 90,475 t, CV = 42%). In the core region, biomass was 47,278 t ($CI_{95\%}$ = 13,836 - 89,017 t, CV = 42%), and in the nearshore region, biomass was 443 t ($CI_{95\%}$ = 180 - 1,458 t, CV = 81%), or 0.93% of the total biomass. Within the survey area, the northern stock ranged from approximately Astoria, OR to Fort Bragg, CA with some Pacific Sardine observed in the nearshore region between Bodega Bay, CA and San Francisco, CA. L_S ranged from 16 to 29 cm with modes between 24 and 27 cm in the core region and between 7 and 9 cm in the nearshore region.

The estimated biomass of the southern stock of Pacific Sardine was 196,609 t ($CI_{95\%}$ = 60,237 - 346,360 t, CV = 35%). In the core region, biomass was 165,119 t ($CI_{95\%}$ = 42,428 - 301,836 t, CV = 41%), and in the nearshore region, biomass was 31,490 t ($CI_{95\%}$ = 17,809 - 44,524 t, CV = 22%), or 16% of the total biomass. Within the survey area, the southern stock ranged from approximately Monterey Bay, CA to Punta Eugenia. L_S ranged from 8 to 21 cm with modes between 9 and 11 cm and 14 and 15 cm in both the core and nearshore regions.

The estimated biomass of Pacific Mackerel was 21,998 t ($CI_{95\%}$ = 15,367 - 34,300 t, CV = 20%). In the core region, biomass was 20,491 t ($CI_{95\%}$ = 15,067 - 31,724 t, CV = 21%), and in the nearshore region, biomass was 1,507 t ($CI_{95\%}$ = 300 - 2,576 t, CV = 39%), or 6.9% of the total biomass. Pacific Mackerel ranged from approximately Astoria to Punta Eugenia, but was mostly south of Point Conception, CA. Fork length (L_F)

ranged from 9 to 38 cm with two modes, between 20 and 24 cm and at 34 cm, in the core region, and at 14 and 20 cm in the nearshore region.

The estimated biomass of Jack Mackerel was 569,793 t ($CI_{95\%}$ = 310,939 - 941,151 t, CV = 28%). In the core region, biomass was 562,052 t ($CI_{95\%}$ = 305,551 - 929,246 t, CV = 28%), and in the nearshore region, biomass was 7,741 t ($CI_{95\%}$ = 5,388 - 11,905 t, CV = 22%), or 1.4% of the total biomass. Jack Mackerel were present throughout the survey area from Cape Flattery to Punta Eugenia, but most were north of Cape Mendocino. L_F ranged from 4 to 51 cm with modes at approximately 14, 28, 35, and 51 cm.

The estimated biomass of Pacific Herring was 67,920 t ($CI_{95\%}$ = 14,913 - 134,879 t, CV = 40%). In the core region, biomass was 52,224 t ($CI_{95\%}$ = 9,111 - 106,564 t, CV = 50%), and in the nearshore region, biomass was 15,697 t ($CI_{95\%}$ = 5,802 - 28,315 t, CV = 38%), or 23% of the total biomass. Pacific Herring ranged from approximately Cape Flattery to Cape Mendocino. L_F ranged from 8 to 24 cm with modes at 21 cm in the core region and 15 cm in the nearshore region.

The estimated biomass of Round Herring was 18,848 t ($CI_{95\%}$ = 5,071 - 32,421 t, CV = 40%), all observed in the core region off central Baja CA from approximately El Rosario to Punta Abreojos. L_F ranged from 14 to 30 cm with modes at 17 and 25 cm.

The total estimated biomass of eight stocks (six species) within the survey area was 3,652,609 t. Of this 75% (2,721,689 t) was attributed to the central stock of Northern Anchovy. Contributions by other stocks were Jack Mackerel (16%), southern stock of Pacific Sardine (5%), Pacific Herring (1.9%), northern stock of Pacific Sardine (1.3%), Pacific Mackerel (0.6%), Round Herring (0.5%), and northern stock of Northern Anchovy (0.2%).

1 Introduction

In the California Current Ecosystem (CCE), multiple 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. These populations, which can change by an order of magnitude within a few years, 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 off OR, WA, and Vancouver Island (Zwolinski *et al.*, 2012, and references therein, **Fig. 1**). 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 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 (Zwolinski *et al.*, 2012). For example, the transition zone chlorophyll front [TZCF; Polovina *et al.* (2001)] may delineate the offshore and southern limit of both Pacific Sardine and Pacific Mackerel habitat (e.g., Demer *et al.*, 2012; Zwolinski *et al.*, 2012), and juveniles may have nursery areas in the Southern CA Bight (SCB), downstream of upwelling regions. In contrast, Northern Anchovy spawn predominantly during winter and closer to the coast 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 reproductive and feeding behaviors, affinity to certain oceanographic or seabed habitats, and its population size.

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 United States (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 (Demer *et al.*, 2012; 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 zooplankton (Hewitt and Demer, 2000).

This document, and references herein, 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, multi-frequency echosounders, probe-sampled oceanographic conditions, pumped samples of fish eggs, and trawl-net catches of juvenile and adult CPS. The survey area is initially defined with consideration to the potential habitat of a priority stock or stock assemblage, e.g., that for the northern stock of Pacific Sardine (**Fig. 1**) or the northern or central stock of Northern Anchovy. The survey area is further expanded to encompass as much of the potential habitat as possible for other CPS present off the West Coast of the U.S. and Baja CA, Mexico, as time permits.

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.*, 2009b).

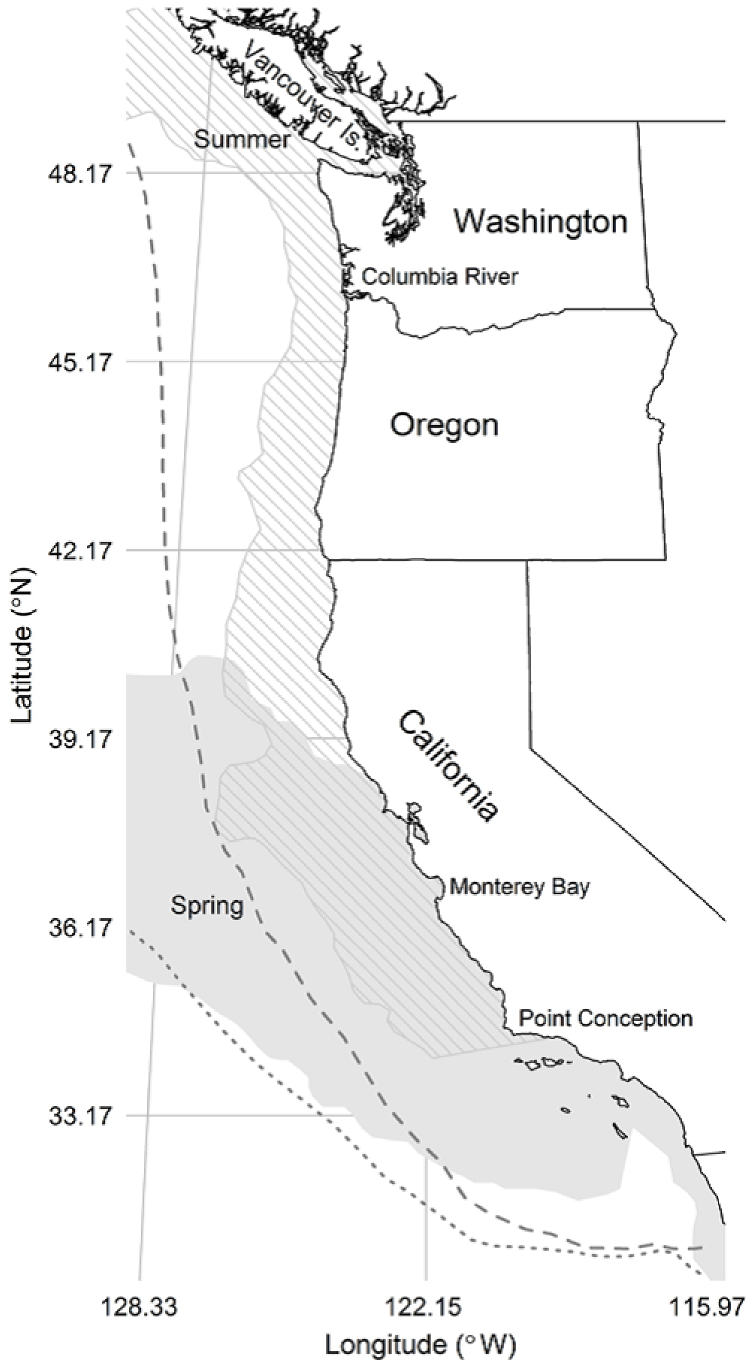

Figure 1: Conceptual spring (shaded region) and summer (hashed region) distributions of potential habitat for the northern stock of Pacific Sardine along the west coasts of Mexico, the United States, and Canada. The dashed and dotted lines represent, respectively, the approximate summer and spring positions of the 0.2 mg m^{-3} chlorophyll-a concentration isoline. This isoline appears to oscillate in synchrony with the transition zone chlorophyll front (TZCF, Polovina *et al.*, 2001) and the offshore limit of the northern stock Pacific Sardine potential habitat (Zwolinski *et al.*, 2011). Mackerels are found within and on the edge of the same oceanographic habitat (e.g., Demer *et al.*, 2012; Zwolinski *et al.*, 2012). The TZCF may delineate the offshore and southern limit of both Pacific Sardine and Pacific Mackerel distributions, and juveniles may have nursery areas in the SCB, downstream of upwelling regions.

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.*, 2009b; 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 seawater, 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.

The primary objectives of the SWFSC's ATM surveys are to survey the distributions and abundances of CPS, krill, and their abiotic environments in the CCE. Typically, spring surveys are conducted during 25-40 days-at-sea (DAS) between March and May, and summer surveys are conducted during 50-90 DAS between June and October. In spring, the ATM surveys focus primarily on the northern stock of Pacific Sardine and the central stock of Northern Anchovy. In summer, the ATM surveys also include the northern stock of Northern Anchovy and Pacific Herring. During spring and summer, the biomasses of other CPS (e.g., Pacific Mackerel, Jack Mackerel, and Round Herring) present in the survey area are estimated.

In summer 2021, the ATM survey performed in U.S. waters aboard *Lasker* was augmented with coordinated sampling by fishing vessels *Lisa Marie* and *Long Beach Carnage* to estimate the biomasses of CPS in nearshore regions, where sampling by *Lasker* was not possible or safe. In addition, three wind-powered uncrewed surface vessels (Explorer USVs; Saildrone, Inc.) conducted acoustic sampling along adaptive transects not sampled by *Lasker*. Finally, acoustic and trawl sampling was coordinated with the Mexican research vessel *Dr. Jorge Carranza Fraser* (hereafter, *Carranza*) off Baja CA, MX, between El Rosario and Punta Abreojos.

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 abundances, biomasses, size structures, and distributions of CPS, specifically the northern and southern stocks of Pacific Sardine; the central and northern stocks of Northern Anchovy, Pacific Mackerel, Jack Mackerel, Pacific Herring, and Round Herring for the core and nearshore survey regions. Additional details about the survey may be found in the survey report (Renfree *et al.*, 2022).

This survey was conducted with the approval of the Secretaria de Relaciones Exteriores (SRE, Diplomatic note CTC/1312/2021), the Instituto Nacional de Estadística y Geografía (INEGI; Permit: EG0082021), and the Comisión Nacional de Acuacultura y Pesca (CONAPESCA; Permit: PPFE/DGOPA-073/21).

2 Methods

2.1 Sampling

2.1.1 Design

The summer 2021 survey was conducted principally using *Lasker* and *Carranza*. The sampling domain, or core region, between Cape Flattery, WA and Punta Abreojos, MX, was defined by the conceptual distribution of potential habitat for the northern stock of Pacific Sardine in summer (**Fig. 1**), but also encompassed the anticipated distributions of the southern stock of Pacific Sardine and the central and northern stocks of Northern Anchovy off the west coasts of the U.S., Mexico, and Canada. It also spanned portions of the Pacific Mackerel, Jack Mackerel, Pacific Herring, and Round Herring populations. East to west, the sampling domain extends from the coast to at least the 1,000 ftm (~1830 m) isobath (**Fig. 2**). Considering the expected distribution of the target species, the acceptable uncertainty in biomass estimates, and the available ship time (86 days at sea, DAS), the principal survey objectives were the estimations of biomasses for the northern and southern stocks of Pacific Sardine and the northern and central stocks of Northern Anchovy in the survey region. Additionally, biomass estimates were sought for Pacific Mackerel, Jack Mackerel, Pacific Herring, and Round Herring in the survey region.

The transects are perpendicular to the coast, extending from the shallowest navigable depth (~25 m) to either a distance of 35 nmi or to the 1,000 ftm isobath, whichever is farthest (**Fig. 2**). When CPS are observed within the westernmost 3 nmi of a transect, that transect and the next one to the south are extended in 5-nmi increments until no CPS are observed in the last 3 nmi of the extension.

To increase the spatial sampling resolution, acoustic sampling was conducted by USVs (SD-1036, SD-1055, and SD-1059) on transects interstitial to *Lasker* transects from Cape Flattery, WA to Crescent City, CA and from Point Arena, CA to Point Conception, CA (yellow lines, **Fig. 2**). To ensure sampling of the western most extents of the CPS distributions, USVs (SD-1036 and SD-1059) were also used to sample offshore extensions of *Lasker*'s transects in the SCB.

To estimate the abundances and biomasses of CPS close to shore, in shallow water, or both, where *Lasker* and USVs could not efficiently or safely navigate or trawl, acoustic and purse seine sampling was conducted nearshore between Cape Flattery and San Diego using two fishing vessels equipped with echosounders (magenta lines, **Fig. 2**). *Lisa Marie* sampled 5-nmi-long transects spaced 5 nmi apart between Cape Flattery and Bodega Bay. *Long Beach Carnage* sampled 5-nmi-long transects spaced 5 nmi apart between Bodega Bay and San Diego, and 2.5-nmi-long transects spaced 2.5 nmi apart around Santa Cruz and Santa Catalina Islands in the SCB.

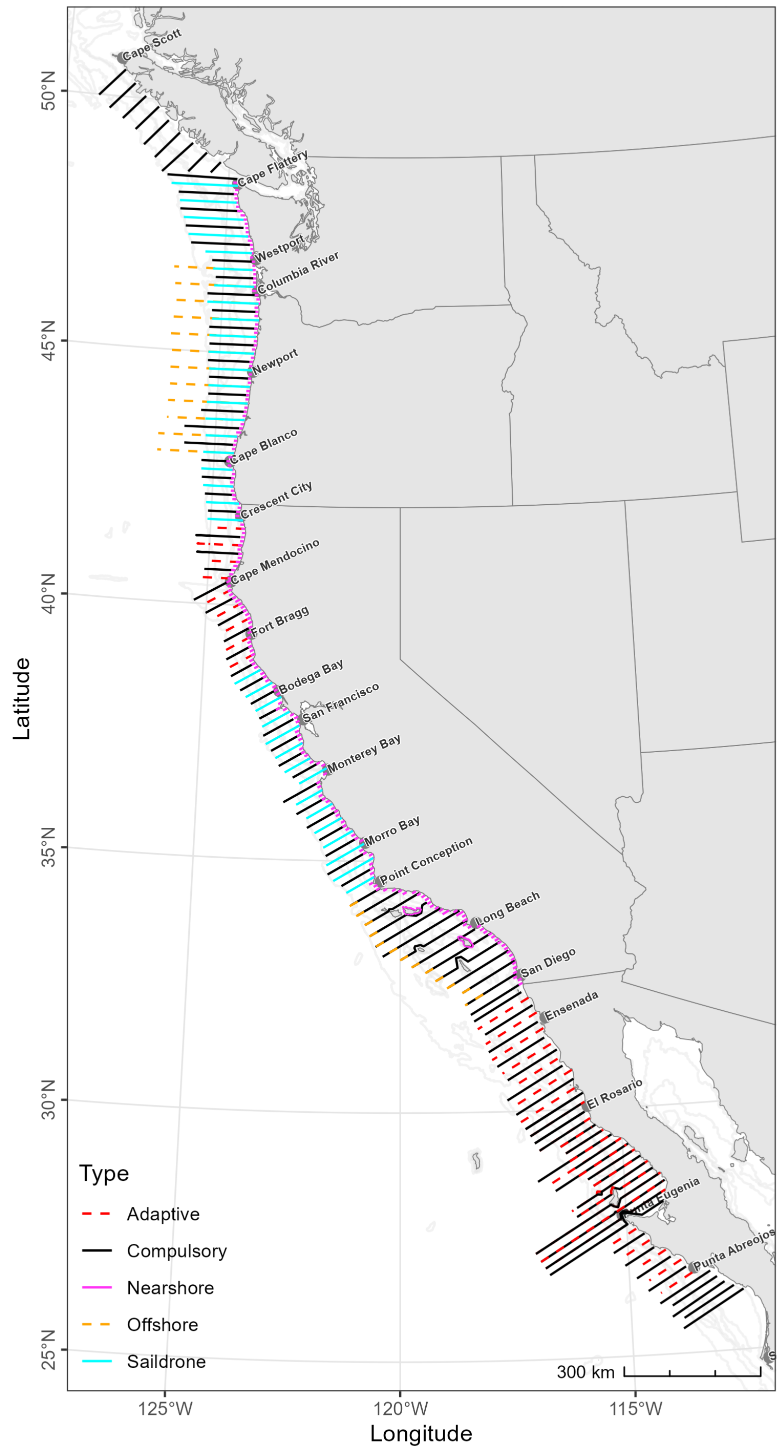

Figure 2: Planned compulsory and adaptive transects sampled by *Lasker* and *Carranza*; interstitial and offshore transects sampled by USVs; and nearshore transects sampled by *Lisa Marie* and *Long Beach Carnage*. Isobaths (light gray lines) are 50, 200, 500, and 2,000 m (or approximately 27, 109, 273, and 1,094 ftm, respectively).

2.1.2 Acoustic

2.1.2.1 Acoustic equipment

2.1.2.1.1 ***Lasker*** Multi-frequency Wide-Bandwidth Transceivers (18-, 38-, 70-, 120-, 200-, and 333-kHz Simrad 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. 3**). The keel was retracted (transducers at ~5-m depth) during calibration, and extended to the intermediate position (transducers at ~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 at ~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), scanning sonar (Simrad SX90; Kongsberg), acoustic Doppler current profiler and echosounder (Simrad EC150-3C, Kongsberg), and a separate ADCP (Ocean Surveyor OS75; Teledyne RD Instruments). Transducer position and motion were measured at 5 Hz using an inertial motion unit (Applanix POS-MV; Trimble).

2.1.2.1.2 ***Carranza*** Multi-frequency General Purpose Transceivers (18-, 38-, 70-, 120-, and 200-kHz Simrad EK60 GPTs; Kongsberg) were configured with split-beam transducers (Simrad ES18, ES38B, ES70-7C, ES120-7C, and ES200-7C; Kongsberg) mounted on the bottom of a retractable keel, ~4 m beneath the water surface.

2.1.2.1.3 ***Lisa Marie*** The SWFSC's General Purpose Transceiver (38-kHz Simrad EK60 GPT; Kongsberg) was connected to the vessel's hull-mounted split-beam transducer (Simrad ES38B; Kongsberg; not shown).

2.1.2.1.4 ***Long Beach Carnage*** The SWFSC's multi-frequency General Purpose Transceivers (38-, 70-, 120-, and 200-kHz Simrad EK60 GPTs; Kongsberg) were configured with the SWFSC's split-beam transducers (Simrad ES38-12, ES70-7C, ES120-7C and ES200-7C; Kongsberg) mounted in a multi-frequency transducer array (MTA4) on the bottom of a pole (**Fig. 4**).

2.1.2.1.5 **USVs** On the three USVs (SD-1036, SD-1055, and SD-1059), miniature Wide-Bandwidth Transceivers (Simrad WBT-Mini; Kongsberg) were configured with gimbaled, keel-mounted, dual-frequency transducers (Simrad ES38-18|200-18C; Kongsberg) containing a split-beam 38-kHz transducer and single-beam 200-kHz transducer with nominally 18° beamwidths.

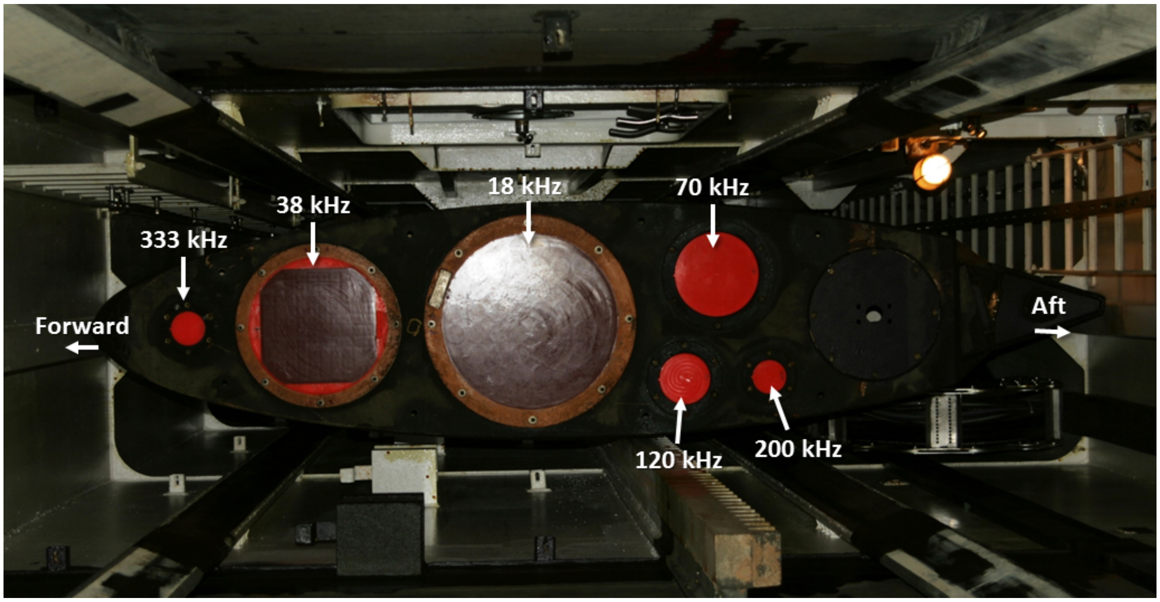

Figure 3: Echosounder transducers mounted on the bottom of the retractable centerboard on *Lasker*. During the survey, the centerboard was extended, typically positioning the transducers ~2 m below the keel at a water depth of ~7 m.

Figure 4: 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 17 June while the vessel was docked at 10th Avenue Marine Terminal, San Diego Bay (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 (i.e., continuous wave or narrowband mode) and FM mode (i.e., frequency modulation or broadband mode). The reference target was a 38.1-mm diameter sphere made from tungsten carbide (WC) with 6% cobalt binder material (WC38.1; *Lasker* sphere #1); for FM mode, additional calibrations were conducted for the 120, 200, and 333-kHz echosounders using a 25-mm WC sphere (WC25). Prior to the calibrations, temperature and salinity were measured to a depth of 10 m using a handheld probe (Pro2030, YSI) 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 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 WBTs were configured using the calibration results via the control software (Simrad EK80 v2.0.0; Kongsberg; **Table 1**). Calibration results for WBTs in FM mode are presented in the survey report (Renfree *et al.*, 2022).

Table 1: Wide-Bandwidth Transceiver (Simrad EK80 WBT; Kongsberg) information, pre-calibration settings, and post-calibration beam model results (below the horizontal line). Prior to the survey, on-axis gain (G_0), beam angles, angle offsets, and S_A Correction ($S_A$corr) values from calibration results were entered into the WBT control software (Simrad EK80; 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	2000	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	23.05	25.75	27.41	26.57	26.51	25.46
S_a Correction ($S_a$corr)	dB re 1	-0.1542	-0.0084	-0.163	-0.1956	-0.255	-0.1546
RMS	dB	0.0475	0.0774	0.0731	0.0624	0.134	0.3166
3-dB Beamwidth Along. (α_{-3dB})	deg	10.39	6.86	6.68	6.57	6.66	6.35
3-dB Beamwidth Athw. (β_{-3dB})	deg	10.39	6.87	6.68	6.57	6.59	6.31
Angle Offset Along. (α_0)	deg	-0.03	0.01	-0.03	0	0	-0.01
Angle Offset Athw. (β_0)	deg	-0.01	-0.06	-0.03	0.01	0	0.08

2.1.2.2.2 ***Carranza*** The 18, 38, and 70-kHz GPTs aboard *Carranza* were calibrated on 29 and 30 January, 2022, using either a 63-mm-diameter copper (Cu63) or a WC38.1 standard sphere, depending on the frequency. Calibrations were unsuccessful for the 120 and 200-kHz GPTs, and therefore results from the most recent calibration, conducted in September 2020, were used. Beam model results (**Table 2**) were entered into the EK80 software.

Table 2: General Purpose Transceiver (Simrad EK60 GPT; Kongsberg) beam model results estimated from calibrations of the echosounders aboard *Carranza* using either a Cu63 (for 18 kHz) or WC38.1 (for 38, 70, 120, and 200 kHz). Results for the 120 and 200-kHz GPTs are from a calibration conducted in September 2020. Prior to the survey, calibrated on-axis gain (G_0), beam angles, angle offsets, and S_a Correction ($S_a$corr) values were entered into the GPT-control software (Simrad EK80; Kongsberg).

		Frequency (kHz)				
	Units	18	38	70	120	200
Model		ES18	ES38B	ES70-7C	ES120-7C	ES200-7C
Transmit Power (p_{et})	W	2000	2000	750	150	150
Pulse Duration (τ)	ms	1.024	1.024	1.024	0.512	0.512
Eq. Two-way Beam Angle (Ψ)	dB re 1 sr	-17	-20.7	-20.7	-20.7	-20.7
On-axis Gain (G_0)	dB re 1	20.1	23.19	24.69	25.85	25.65
S_a Correction ($S_a$corr)	dB re 1	0.0156	-0.4741	-0.0758	-0.3386	-0.2414
RMS	dB	0.2746	0.1291	0.2075	0.2279	0.2912
3-dB Beamwidth Along. (α_{-3dB})	deg	10.91	7.14	6.98	6.82	6.93
3-dB Beamwidth Athw. (β_{-3dB})	deg	11.27	7.54	7.42	6.98	7.24
Angle Offset Along. (α_0)	deg	-0.18	-0.04	0.08	0.16	-0.06
Angle Offset Athw. (β_0)	deg	0.12	0.04	-0.1	-0.11	-0.25

2.1.2.2.3 ***Lisa Marie*** The 38-kHz GPT aboard *Lisa Marie* was calibrated on 5 June 2021 using a WC38.1 standard sphere while the vessel was anchored in Yaquina Bay near Newport, OR (44.6249, -124.0370). Calibration results for *Lisa Marie* are presented in **Table 3**.

Table 3: General Purpose Transceiver (Simrad EK60 GPT; Kongsberg) beam model results estimated from a standard sphere (WC38.1) calibration of echosounders used aboard *Lisa Marie*. 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; Kongsberg).

		Frequency (kHz)
	Units	38
Model		ES38B
Transmit Power (p_{et})	W	2000
Pulse Duration (τ)	ms	1.024
Eq. Two-way Beam Angle (Ψ)	dB re 1 sr	-20.7
On-axis Gain (G_0)	dB re 1	22.13
S_a Correction ($S_a$corr)	dB re 1	-0.502
RMS	dB	0.0656
3-dB Beamwidth Along. (α_{-3dB})	deg	6.74
3-dB Beamwidth Athw. (β_{-3dB})	deg	6.72
Angle Offset Along. (α_0)	deg	-0.03
Angle Offset Athw. (β_0)	deg	-0.01

2.1.2.2.4 *Long Beach Carnage* The 38, 70, 120, and 200 kHz EK60 GPTs aboard *Long Beach Carnage* were calibrated using a WC38.1 standard sphere, on 13 October 2021, in a tank at the SWFSC (Demer *et al.*, 2015). Calibration results for *Long Beach Carnage* are presented in **Table 4**.

Table 4: 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, angle offsets, and S_a Correction ($S_a$corr) values were entered into the GPT-control software (Simrad EK80, Kongsberg).

	Units	Frequency (kHz) 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	21.64	26.38	26.09	26.7
S_a Correction ($S_a$corr)	dB re 1	-0.6954	-0.2888	-0.4357	-0.2541
RMS	dB	0.0684	0.0446	0.0862	0.0654
3-dB Beamwidth Along. (α_{-3dB})	deg	12.55	6.83	6.88	6.78
3-dB Beamwidth Athw. (β_{-3dB})	deg	12.62	6.76	6.81	6.79
Angle Offset Along. (α_0)	deg	-0.02	0.04	0.15	-0.04
Angle Offset Athw. (β_0)	deg	0.07	-0.01	0.03	0

2.1.2.2.5 USVs For three USVs, the echosounders were calibrated by Saildrone, Inc. while dockside in Alameda, CA, using a WC38.1 standard sphere. The data were processed by the SWFSC (Renfree *et al.*, 2019), and the results are presented in **Table 5**.

Table 5: Miniature Wide-Bandwidth Transceiver (Simrad WBT-Mini; Kongsberg) beam model results estimated from dockside calibrations of echosounders aboard USVs using a WC38.1.

	Units	Saildrone number (Frequency) 1036 (38)	1036 (200)	1055 (38)	1055 (200)	1059 (38)	1059 (200)
Echosounder SN		268641-07	268641-08	266972-07	266972-08	268632-07	268632-08
Transducer SN		110	110	127	127	131	131
Eq. Two-way Beam Angle (Ψ)	dB re 1 sr	-13.0	-11.8	-12.7	-11.7	-12.9	-12.0
Theoretical TS (TS_{theory})	dB re 1 m^2	-42.39	-38.83	-42.40	-38.85	-42.40	-38.85
On-axis Gain (G_0)	dB re 1	19.06	18.52	19.30	18.92	18.99	18.96
S_a Correction ($S_a$corr)	dB re 1	0.01	0.04	-0.04	0.11	-0.02	0.05
RMS	dB	0.12	0.33	0.21	0.52	0.21	0.47
3-dB Beamwidth Along. (α_{-3dB})	deg	17.0	19.1	17.7	19.3	17.5	20.0
3-dB Beamwidth Athw. (β_{-3dB})	deg	17.1	19.9	17.6	20.2	16.8	18.3
Angle Offset Along. (α_0)	deg	0.3	0.0	0.2	0.4	0.1	0.6
Angle Offset Athw. (β_0)	deg	-0.2	-0.1	0.1	-0.2	-0.5	0.20

2.1.2.3 Data collection

During daytime aboard *Lasker*, 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 format (i.e., .raw) with a 1-GB 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 target strength estimation and species differentiation for CPS near the surface, and logged to 100 m to reduce data volume. For each acoustic instrument, the prefix for the file names is a concatenation of the survey name (e.g., 2107RL), the operational mode (CW or FM), and the logging commencement date and time from the EK80 software. For example, file generated by the EK80 software (v2.0.0) for a WBT operated in CW mode is named `2107RL-CW-D20210801-T125901.raw`.

To minimize acoustic interference, transmit pulses from the EK80, ME70, MS70, SX90, EC150-3C, and ADCP were triggered using a synchronization system (Simrad K-Sync; Kongsberg). The K-Sync trigger rate, and thus echosounder ping interval, was modulated by the EAL (Renfree and Demer, 2016) using the seabed depth measured using the 18-kHz echosounder. During daytime, the ME70, MS70, SX90, and ADCP were operated continuously, but only recorded at the discretion of the acoustician during 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 (SRD-500A; Sperry Marine), or both. Data from the ME70, MS70, and SX90 are not presented in this report.

On *Carranza*, the EK60 echosounders were triggered using a synchronization system (Simrad K-Sync). During daytime acoustic transects, no other acoustic sounders were operated. The ping interval and recording range were modulated based on the seabed depth, respectively: 0.25 s and 100 m for a depth of 0-50 m; 0.5 s and 150 m for a depth of 50-100 m; 0.75 s and 200 m for a depth of 100-150 m; 1 s and 300 m for a depth of 150-200 m; and 2 s and 500 m for a depth of 250-500 m.

On *Lisa Marie* and *Long Beach Carnage*, the EAL was used to control the EK80 software to modulate the echosounder recording ranges and ping intervals to avoid aliased seabed echoes. When the EAL was not utilized, the EK80 software recorded to 200 and 500 m, respectively, and used the maximum ping rate. Transmit pulses from the EK60s and fishing sonars were not synchronized. Therefore, the latter was secured during daytime acoustic transects.

On the USVs, the echosounders were programmed to transmit CW pulses to a range dependent on the transect depth. For deeper seabed depths, the ping interval was 2 s and the 38 and 200-kHz echosounders recorded to 1000 and 400 m, respectively. For shallower depths, the ping interval was 1 s and both echosounders recorded to 250 m. Once an hour, the echosounders would operate in passive mode and record three pings to obtain estimates of the background noise level.

2.1.3 Oceanographic

2.1.3.1 Conductivity and temperature versus depth (CTD)

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 scatterers (Simmonds and MacLennan, 2005) (see **Section 2.2.2**).

2.1.3.2 Scientific Computer System

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). During and after the survey, data from a subset of these sensors, logged with a standardized format at 1-min resolution, are available on the internet via NOAA's ERDDAP data server[1].

2.1.4 Fish-eggs

On *Lasker* and *Carranza*, fish eggs were sampled during the day using a continuous underway fish egg sampler (CUFES, Checkley *et al.*, 1997), which collects water and plankton at a rate of ~640 l min^{-1} from an intake at ~3-m depth on the hull of the ship. The particles 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 for *Lasker*, and 4 nmi at a speed of 8 kn for *Carranza*. Because the durations of the early egg stages are short for most fish species, the egg distributions inferred from CUFES indicated the nearby presence of actively spawning fish, and were used in combination with CPS echoes to select trawl locations.

2.1.5 Species and Demographics

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 about species composition, lengths, and weights.

2.1.5.1 Trawl gear

2.1.5.1.1 *Lasker* A Nordic 264 rope trawl (NET Systems, Bainbridge Island, WA; **Fig. 5a,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. Temperature-depth recorders (TDRs; RBRduet^3 T.D., RBR) were attached to the kite and footrope to evaluate trawl performance (**Fig. 7**).

2.1.5.1.2 *Carranza* A midwater Mesh Wing Trawl 25/25 (252MWT04i; NET Systems; **Figs. 6**) with equal top and bottom footrope lengths of 48.17 m, was towed for 45 minutes at 3.5 to 4 kn. The mesh size decreases from 1600 to 50 mm, and is constructed of multifilament nylon cloth and ultra-high molecular weight polyethylene (Vallarta-Zárate *et al.*, 2022). The cod-end is a 17-mm Raschel nylon cloth netting.

[1] https://coastwatch.pfeg.noaa.gov/erddap/index.html

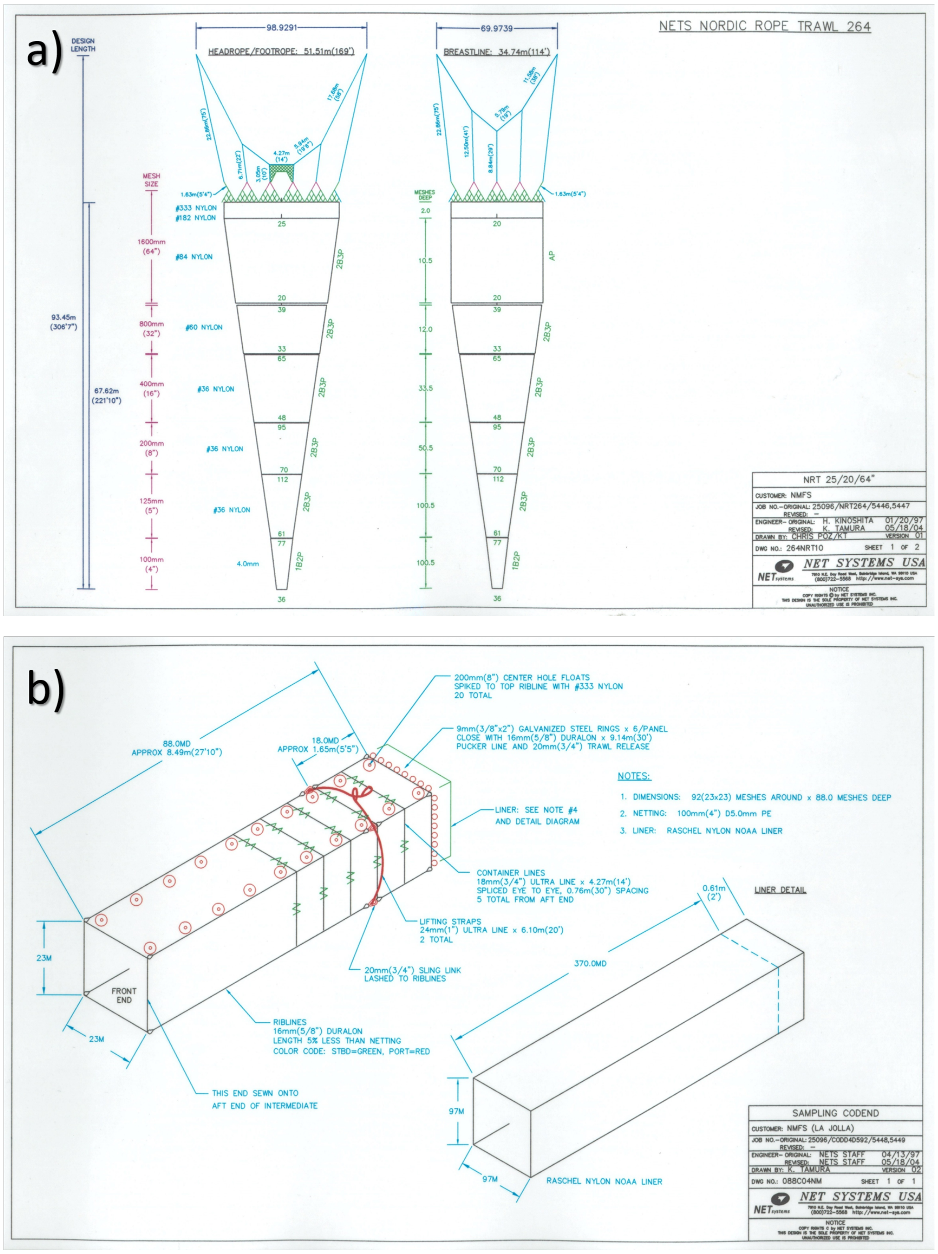

Figure 5: Schematic drawings of the Nordic 264 rope trawl a) net and b) cod-end.

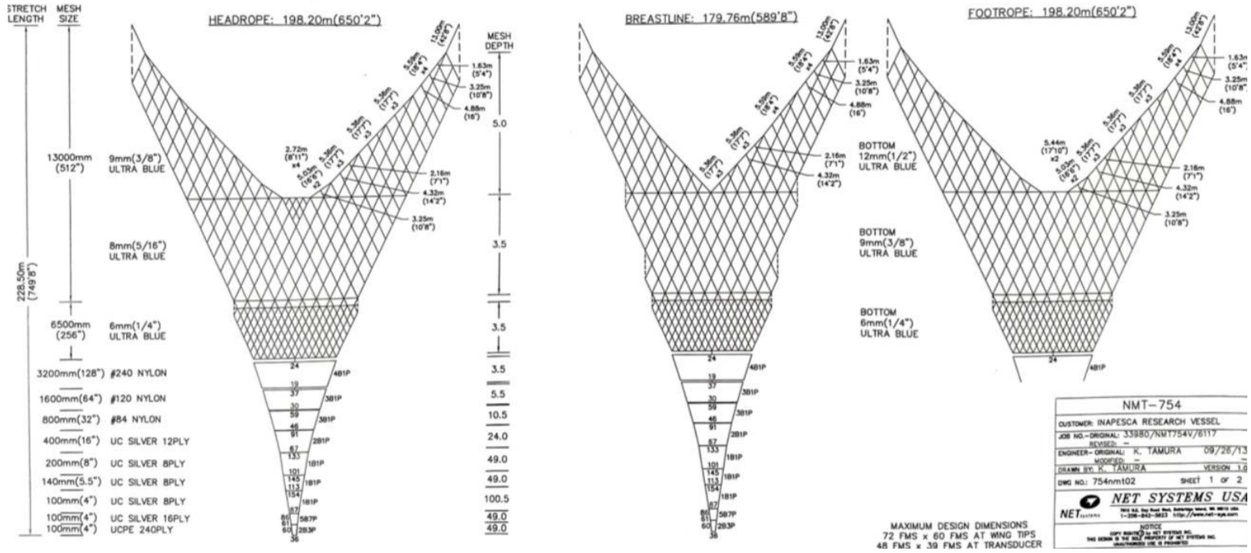

Figure 6: Schematic drawings of the Mesh Wing trawl net on *Carranza*.

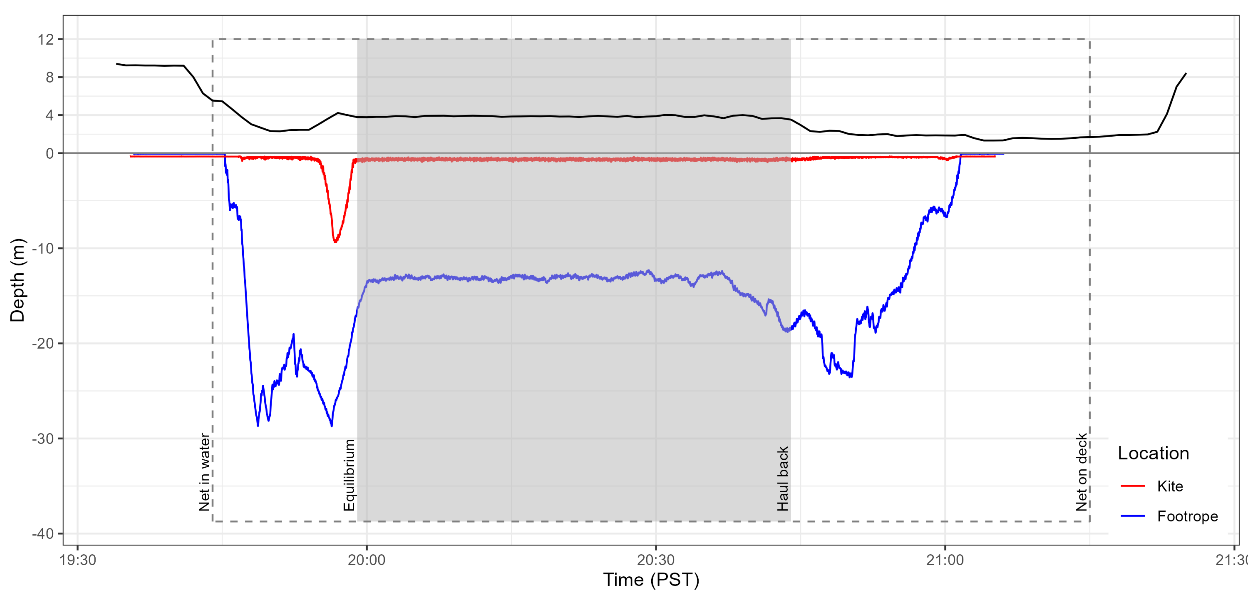

Figure 7: Example depths (m) of the trawl headrope (red line) and footrope (blue line) measured using temperature-depth recorders (TDRs) during the net deployment (dashed box) and when actively fishing (shaded region). The vessel speed over ground (kn, black line) was measured using the ship's GPS.

2.1.5.2 Sampling locations

2.1.5.2.1 ***Lasker*** Up to three nighttime (i.e., 30 min after sunset to 30 min before sunrise) surface trawls, typically spaced at least 10-nmi apart, were conducted in areas where echoes from putative CPS schools were observed earlier that day. Trawl locations were selected using one or more of 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. Each evening, trawl locations were selected by an acoustician who monitored CPS echoes and a biologist who measured the densities of CPS eggs in the CUFES. The locations were provided to the watch Officers who charted the proposed trawl sites.

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.

2.1.5.2.2 ***Carranza*** Up to three trawls were conducted each night following the same methods as described in **Section 2.1.5.2.1**, for *Lasker*.

2.1.5.3 Sample processing

2.1.5.3.1 ***Lasker*** 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. For Pacific Sardine and Northern Anchovy with 75 specimens or less, individual measurements of standard length (L_S) in mm and weight (w) in g were recorded. For Jack Mackerel, Pacific Mackerel, and Pacific Herring with 50 specimens or less, individual measurements of fork length (L_F) and w were recorded. In addition, sex and maturity were recorded for up to 75 Pacific Sardine and Northern Anchovy and up to 25 Jack and Pacific Mackerel. Ovaries were preserved for up to 10 specimens of each CPS species except Pacific Herring. Fin clips were removed from 50 Pacific Sardine and Northern Anchovy specimens from seven geographic zones (with boundaries at the Columbia River, Cape Mendocino, San Francisco Bay, Point Conception, San Diego, and San Quentin, Baja CA) and preserved in ethanol for genetic analysis. Otoliths were removed from all 50 Pacific Sardine in the subsample; for other CPS species except Pacific Herring, 25 otoliths were removed as equally as possible from the range of sizes present. 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.

2.1.5.3.2 ***Carranza*** A sample volume of approximately 15 kg was obtained from each haul. When the biological sample of the target species was less than this volume, the entire sample was processed. Subsequently, the CPS were identified and processed, first by measuring the L_S of each individual in the sample. Then, a proportion of each size interval was obtained with respect to the total number of organisms analyzed, to obtain a subsample for biological sampling that reflects the size distribution observed in the overall sample. The subsample was then processed to obtain specimen length, weight, sex, sexual maturity, fat content, stomach content, and gonadal weight. Otoliths were extracted for future age analysis.

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.** 8) 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. Trawl data from *Carranza* were checked for errors after the survey was completed.

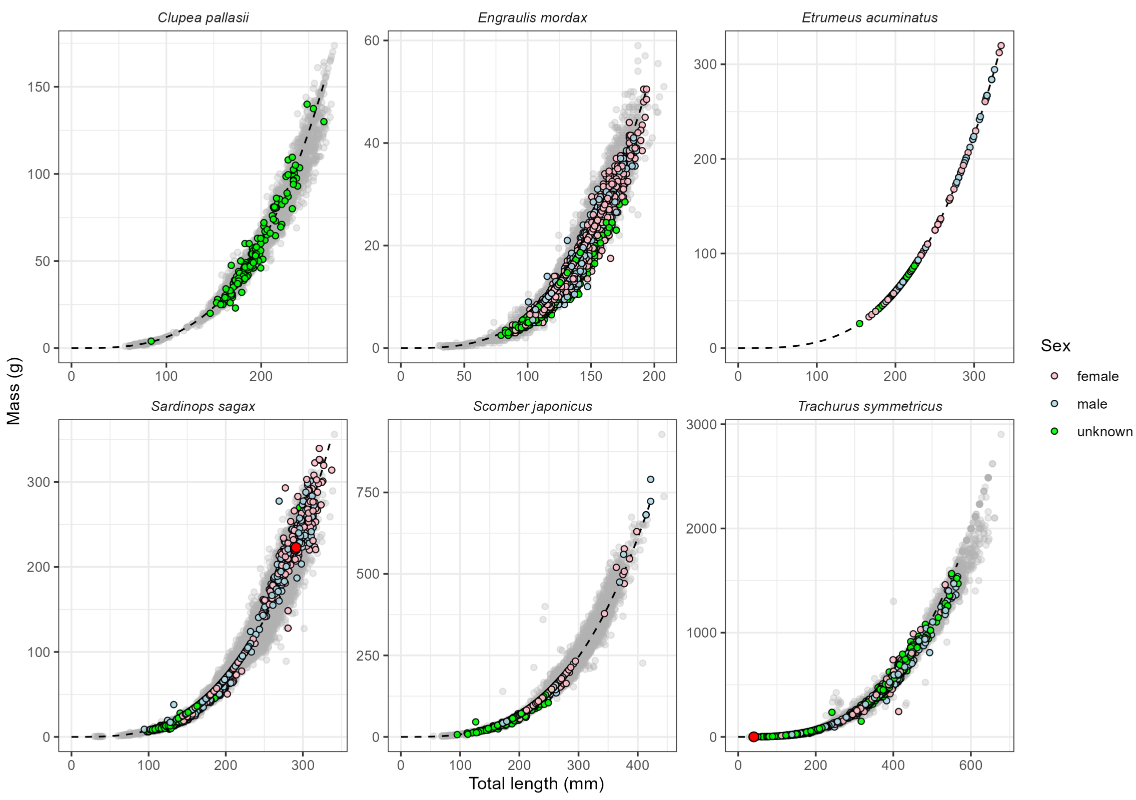

Figure 8: Specimen length-versus-weight from the current survey (colored points, by sex) compared to those from previous SWFSC surveys during the same season (gray points, all sexes) and models [dashed lines; Palance *et al.* (2019)].

2.1.6 Purse-seine

Purse seine nets were set to provide information about size, age, and species composition of fishes observed in the echosounders mounted on the fishing vessels that sampled the nearshore region. *Lisa Marie* used an approximately 440-m-long and 40-m-deep net with 17-mm-wide mesh (A. Blair, pers. comm.). *Long Beach Carnage* used an approximately 200-m-long and 27-m-deep net with 17-mm-wide mesh; a small section on the back end of the net had 25-mm-wide mesh (R. Ashley, pers. comm.). Specimens collected by *Lisa Marie* and *Long Beach Carnage* were processed by the WA Department of Fish and Wildlife (WDFW) and CA Department of Fish and Wildlife (CDFW), respectively.

On *Lisa Marie*, as many as three purse seine sets were planned each day. For each set, three dip net samples, spatially separated as much as possible, were collected. For each dip net sample, all specimens were sorted, weighed, and counted to provide a combined weight and count for each. Next, all three dip net samples were combined and up to 50 specimens of each CPS species were randomly sampled to provide a combined weight for each set. Length (mm), L_S for Pacific Sardine and Northern Anchovy and L_F for all others, and weight (g) were measured for up to 50 randomly selected specimens of each species. Otoliths were extracted, macroscopic maturity stage was determined visually, and gonads were collected and preserved from female specimens.

On *Long Beach Carnage*, as many as three purse seine sets were conducted each day, including evenings. The total weight (tons) of the school was estimated by the captain. For each set, three dip net samples, spatially separated as much as possible, were collected. For each dip net sample, all specimens were sorted, weighed, and counted to provide a combined weight and count for each, and as many as 20 fish of each CPS species were chosen randomly throughout the sample, and combined for a random sample of 50 fish collected throughout the catch. The fish were then frozen for later analysis by CDFW biologists, yielding measures of individual fish and total sample weights (g); length (mm), L_S for Pacific Sardine and Northern Anchovy and L_F for all others; maturity; and otolith-derived ages. No female gonad samples were analyzed.

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; Echoview Software Pty Ltd.) and estimates of the sound speed and absorption coefficient 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 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 average samples in 1-m depth bins. Sound speed in each bin ($c_{w,i}$, 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 ($\bar{c}_w$, m s^{-1}) was calculated over the upper 70 m as:

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

where Δr is the depth of increment i (Seabird, 2013). Measurements of seawater temperature (t_w, °C), salinity (s_w, psu), depth, pH, and $\bar{c}_w$ are also used to calculate the mean species-specific absorption coefficients ($\bar{\alpha}_a$, dB m^{-1}) over the entire profile using equations in Francois and Garrison (1982), Ainslie and McColm (1998), and Doonan et al. (2003). Both $\bar{c}_w$ and $\bar{\alpha}_a$ 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 and plankton (**Figs. 9a, d**) were identified using a semi-automated data processing algorithm implemented using Echoview software (v12; Echoview Software Pty Ltd). 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 while rejecting at least 95% of the non-CPS backscatter (**Fig. 9**). Data from *Lasker*, *Carranza*, and *Long Beach Carnage* were processed using the following steps:

1. Match geometry of all S_v variables 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. 9b, 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.*, 2009a) 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: $VMR_{120\mathrm{kHz}} >$ -65 dB and $VMR_{200\mathrm{kHz}} >$ -65 dB. Diffuse backscattering layers have low VMR (Zwolinski *et al.*, 2010) whereas fish schools have high VMR (Demer *et al.*, 2009a);
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. 9c, 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.*, 2009a), 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.

Data from *Lisa Marie* were processed using the following steps:

1. Remove shorter-duration, transient noise (e.g., ship's asynchronous sonar) using the Impulse Noise Removal operator;
2. Remove longer-duration, transient noise (e.g., wave-hull collisions) using the Transient Noise Removal operator;
3. Compensate attenuated signals (e.g., from air-bubble attenuation) using the Attenuated Signal Removal operator;
4. Average the noise-free 38-kHz S_v echograms using non-overlapping 11-sample by 3-ping bins;
5. Compute the VMR using the difference between noise-filtered S_v (Step 3) and averaged S_v (Step 4);
6. Create a Boolean echogram mask using $VMR >$ -48 dB;
7. Expand the Boolean mask with a 7 pixel x 7 pixel dilation;
8. Performs Steps 12-17 from *Lasker* processing.

Data from the USVs were processed using the following steps:

1. Match geometry of the $S_{v,200\text{kHz}}$ to the $S_{v,38\text{kHz}}$;
2. Remove passive-mode pings;
3. Perform Steps 3-5 from *Lasker* processing;
4. For each pixel, compute: $S_{v,200\text{kHz}} - S_{v,38\text{kHz}}$;
5. Create a Boolean echogram for S_v differences in the CPS range: $-13.5 < S_{v,200\text{kHz}} - S_{v,38\text{kHz}} < 9.37$
6. Perform Steps 8-9 from *Lasker* processing;
7. Create a Boolean echogram mask using $VMR >$ -57 dB;
8. Performs Steps 11-17 from *Lasker* processing.

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 (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 filter "acoustic by-catch," i.e., backscatter not from the target species. To exclude echoes from mid-water, demersal, and benthic fishes, echograms were visually examined to exclude fish echoes where the seabed was hard and rugose, or where diffuse schools are observed offshore either near the surface or deeper than ~250 m (**Fig. 10**). In areas dominated by Pacific Herring, for example off Vancouver Island, backscatter was integrated to a maximum depth of 75 m.

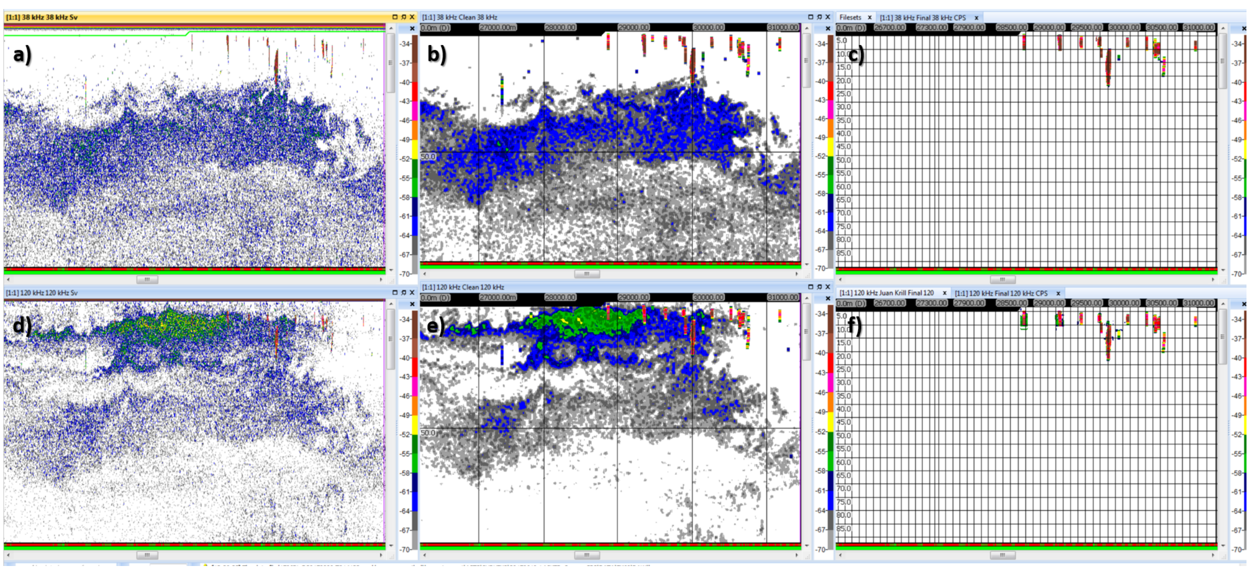

Figure 9: Two examples of echograms depicting CPS schools (red) and plankton aggregations (blue and green) at 38 kHz (top) and 120 kHz (bottom). Example data processing steps include the original echogram (a, d), after noise subtraction and bin-averaging (b, e), and after filtering to retain only putative CPS echoes (c, f).

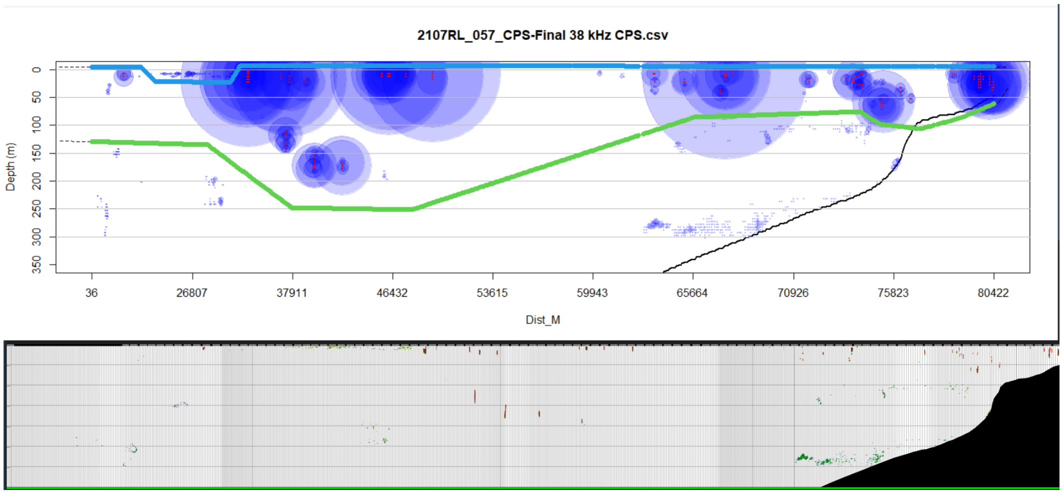

Figure 10: Echoes from fishes with swimbladders (blue points, scaled by backscatter intensity) along an example acoustic transect (top) and the corresponding echogram image (bottom). In this example, the upper (blue) and lower lines (green) indicate boundaries within which echoes were retained. When the lower boundary is deeper than the seabed (black line), echoes above the seabed are retained. Echoes from deep, bottom-dwelling schools of non-CPS fishes with swimbladders, and from diffuse scatterers near the surface were excluded. The proximity of the echoes to the seabed was also used to define the lower limit for vertical integration.

2.2.5 Quality Assurance and Quality Control

The largest 38-kHz integrated backscattering coefficients (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, not shown). 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 conducted 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:

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

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

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

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

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} for 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 and Round 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; 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). 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 and weight derived from specimens collected in the CCE (Palance *et al.*, 2019): for Pacific Sardine, $L_T = 0.3574 + 1.149 L_S$; for Northern Anchovy, $L_T = 0.2056 + 1.1646 L_S$; for Pacific Mackerel, $L_T = 0.2994 + 1.092 L_F$; for Jack Mackerel $L_T = 0.7295 + 1.078 L_F$; and for Pacific Herring $L_T = -0.105 + 1.2 L_F$. Since a conversion does not exist for Round Herring, the equation for Pacific Herring was used to estimate L_T.

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 ($\overline{TS}_{ae}$) 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 proportion

Trawls that occurred on the same night were assigned to 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 trawl cluster nearest in space. 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. 11**):

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

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 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. 12**). 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 (40.5 °N). For Pacific Sardine, the northern and southern stocks present in the survey area (Felix-Uraga *et al.*, 2004; Felix-Uraga *et al.*, 2005; Garcia-Morales *et al.*, 2012; Hill *et al.*, 2014) were separated using the Pacific Sardine potential habitat during the survey (**Fig. 13**). This separation may be further supported by distributions of L_S, a break in the distribution of Pacific Sardine biomass, which, in this survey, coincided geographically with San Francisco (37.7 °N, **Fig. 12**), or both.

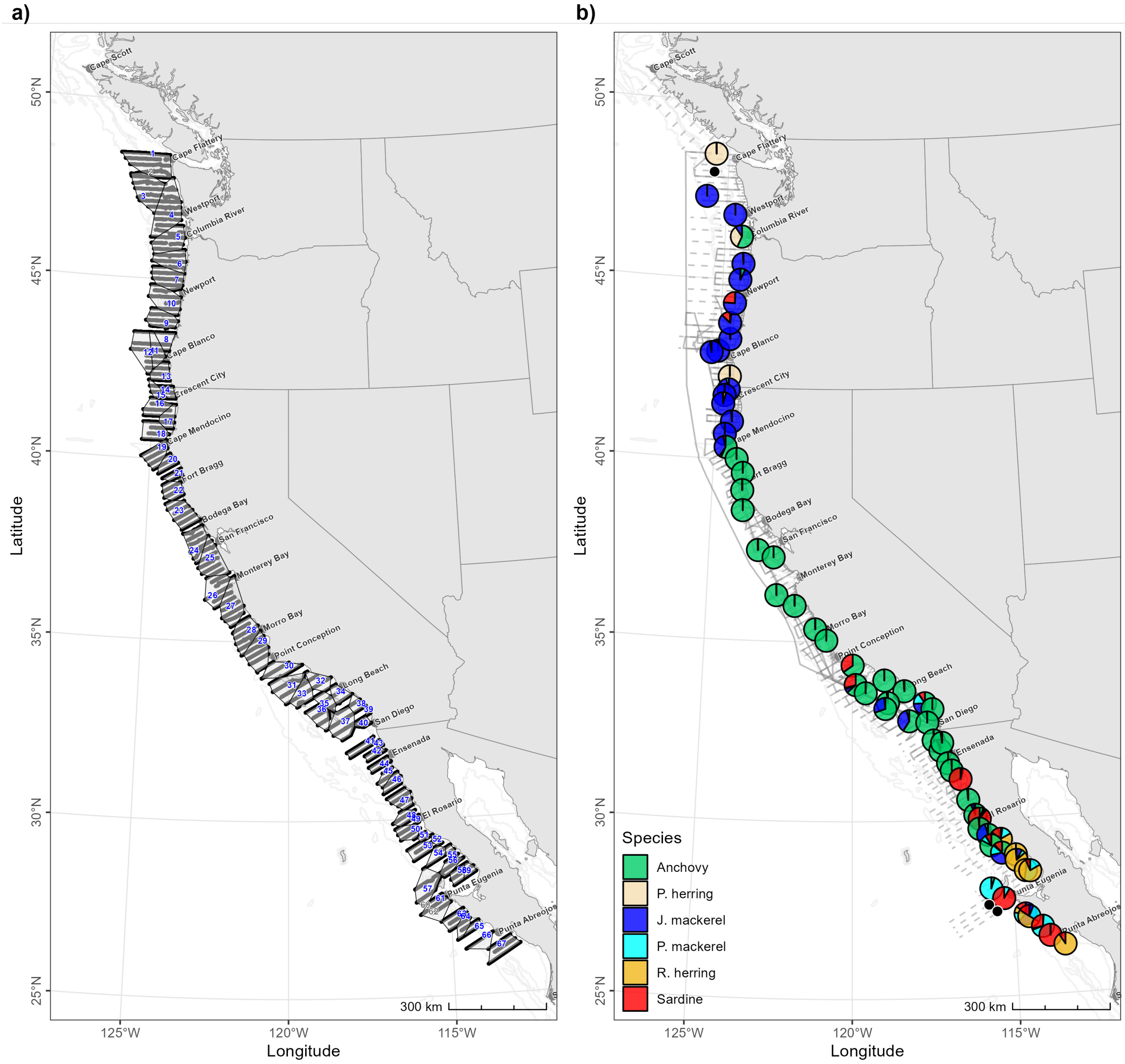

Figure 11: a) Polygons enclosing 100-m acoustic intervals from *Lasker* and *Carranza* assigned to each trawl cluster, and b) the acoustic proportions of CPS in trawl clusters. The numbers inside each polygon in panel a) are the cluster numbers, which are located at the average latitude and longitude of all trawls in that cluster. Black points in panel b) indicate trawl clusters with no CPS present.

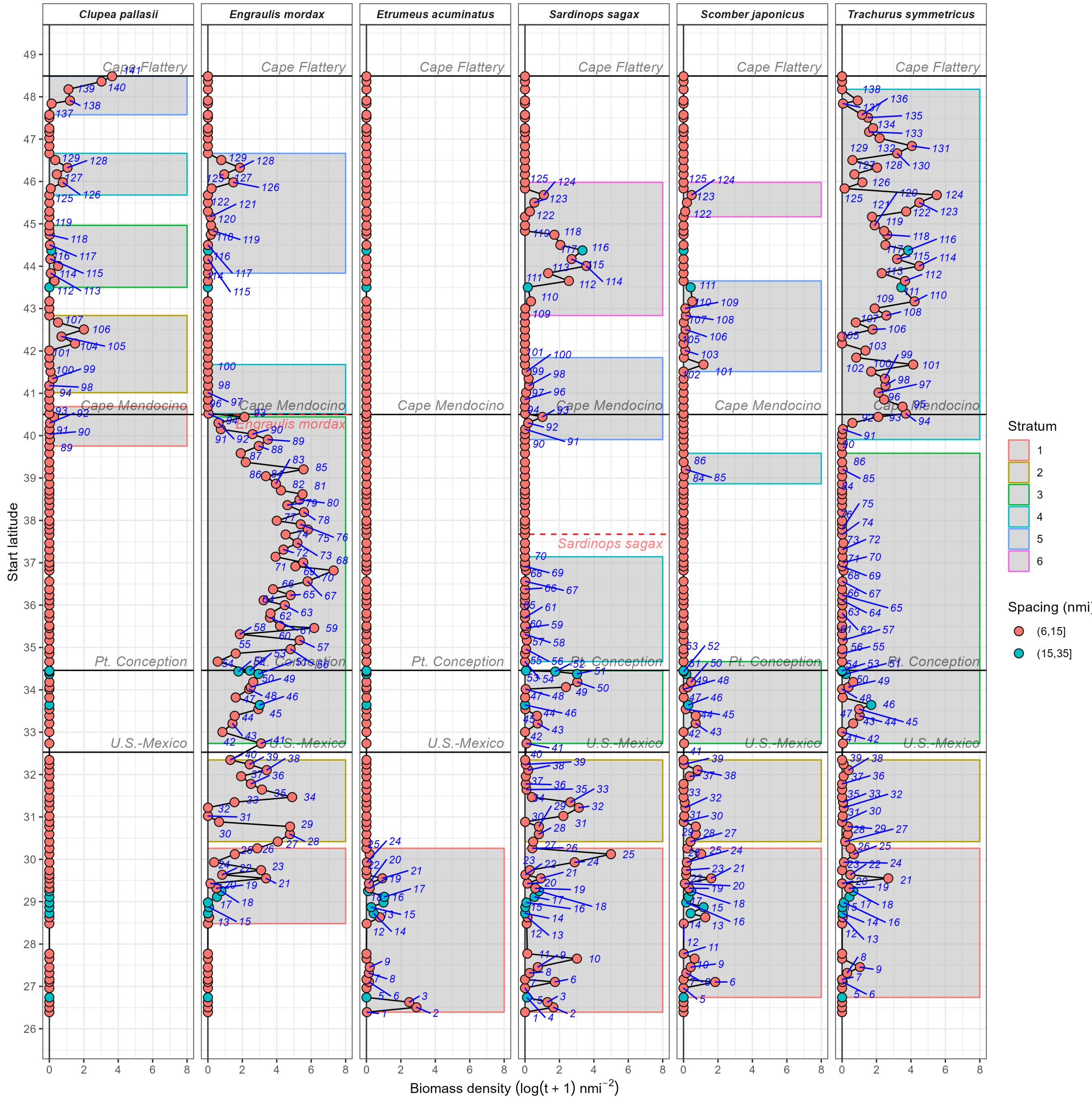

Figure 12: Biomass density ($\log_{10}(t\,\mathrm{nmi}^2 + 1)$) versus latitude (easternmost portion of each transect) and strata used to estimate biomass and abundance (shaded regions; outline indicates stratum number) for each species in the core survey region. Blue number labels correspond to transects with positive biomass ($\log_{10}(t + 1) > 0.01$). Point fills indicate transect spacing (nmi). Red dashed lines and text indicate the stock breaks for Northern Anchovy and Pacific Sardine.

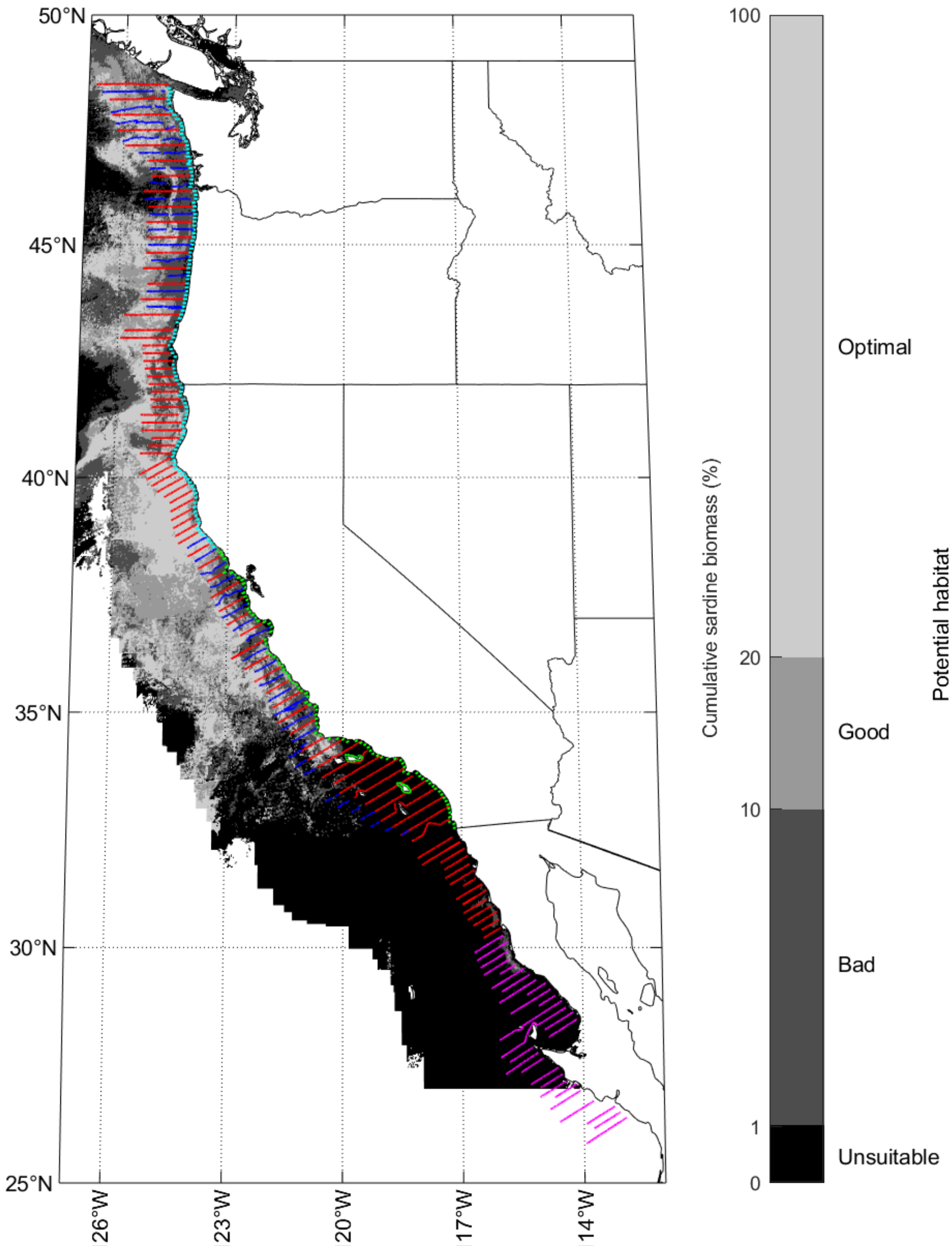

Figure 13: Distribution of potential habitat for the northern stock of Pacific Sardine, temporally aggregated using an average of the habitat centered $\pm 2°$ around the positions of *Lasker* (red lines), *Carranza* (magenta lines), *Lisa Marie* (cyan lines), *Long Beach Carnage* (green lines), and USVs (blue lines) throughout the survey. Areas in white correspond to no available data, e.g., cloud coverage preventing satellite-sensed observations.

2.3.2 Biomass and sampling precision estimation

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 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 for that used for biomass (Equation (17)), and multiplied by the stratum area to obtain abundance per length class.

2.3.4 Percent biomass per cluster contribution

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 summer 2021 survey was between Cape Flattery, WA and Punta Abreojos, MX between 05 July and 08 November 2021. In the core survey region that spanned this entire area (**Fig. 15**), *Lasker* (71 days at sea, DAS), *Carranza* (27 DAS), and the three USVs (198 mission days) sampled 141 east-west transects totaling 6,749 nmi. Catches from a total of 174 nighttime surface trawls were combined into 69 trawl clusters. One to six post-survey strata were defined for each species considering transect spacing and the densities of echoes attributed to each species.

The nearshore region spanned an area from approximately Cape Flattery, WA to San Diego, CA, including around Santa Cruz and Santa Catalina Islands. *Lisa Marie* (18 DAS) surveyed from approximately Cape Flattery, WA to Stewarts Point, CA with 121 east-west transects totaling 556 nmi and 30 purse seine sets (**Fig. 16**). *Long Beach Carnage* (16 DAS) surveyed from approximately Stewarts Point to San Diego, and around the Santa Cruz and Santa Catalina Islands, with 133 east-west transects totaling 475 nmi and 28 purse seine sets (**Fig. 17**). One to fifteen post-survey strata were defined considering transect spacing and the biomass densities. Biomasses and abundances were estimated for each species in both the core and nearshore survey areas.

Leg I

On 6 July, *Lasker* departed from 10th Avenue Marine Terminal in San Diego, CA at ~1700 (all times UTC). Prior to the transit toward northern Vancouver Island, the EC150-3C was calibrated northwest of the sea buoy outside San Diego Bay (32.6598 N, 117.3833 W). Throughout the transit, sampling was conducted during the day with CUFES, EK80s, ME70, MS70 and SX90. Due to departure delays and weather delays during transit, planned sampling off Vancouver Island was abandoned. On 12 July at ~1930, *Lasker* began acoustic sampling along Transect 140 off Cape Flattery, WA. On 18 July, after sampling most of Transect 116, *Lasker* transited south to Transect 108 and resumed sampling transects from south to north for the remainder of Leg I. On 22 July, acoustic sampling ceased after the completion of Transect 116 off Newport, OR. *Lasker* arrived at the Marine Operations-Pacific (MOC-P) Pier in Newport, OR at ~1730 to complete Leg I.

During Leg I, *Lisa Marie* sampled Transects 352 to 291, the nearshore region between Cape Flattery, WA to Coos Bay, OR, from 16 to 22 July. Two USVs (SD-1055 and SD-1059) sampled Transects 139 to 127, between Cape Flattery, WA to the Columbia River, from 11 to 26 July.

Leg II

On 27 July, after a two-day delay, *Lasker* departed from the Marine Operations-Pacific (MOC-P) Pier, Newport, OR, at ~1130 and transited south; acoustic sampling resumed along Transect 106 at ~1300 on 28 July. An Autonomous Spar Buoy Recorder (DASBR) was deployed for the SWFSC Marine Mammal and Turtle Division on 31 July before starting Transect 099. After completing Transect 099, *Lasker* transited to Humboldt Bay, CA to embark the Second Cook. On 13 August, acoustic sampling ceased after completion of Transect 057 off Point Estero, CA in Harmony Headlands State Park. On 15 August, *Lasker* arrived at the 10th Avenue Marine Terminal in San Diego Bay at ~1700 to complete Leg II.

During Leg II, *Lisa Marie* sampled Transects 289 to 231, the nearshore region between Coos Bay, OR to Fort Ross, CA, from 28 July to 5 August. *Long Beach Carnage* sampled Transects 230 to 176, the nearshore region between Fort Ross to Point Conception, CA, from 12 to 21 August. Two USVs (SD-1055 and SD-1059) sampled Transects 125 to 109, between the Columbia River to Coos Bay, OR, from 26 July to 10 August; two USVs (SD-1036 and SD-1055) then sampled Transects 080 to 062, between Point Arena, CA to Big Sur, CA, from 26 August to 6 September.

Leg III

On 8 September, *Lasker* departed from the fuel pier at the 10th Avenue Marine Terminal in San Diego, CA at ~1315 and began the transit to resume acoustic sampling along Transect 053 at ~1500. On 20 September, acoustic sampling ceased after the completion of Transect 039 off San Diego, CA. On 20 September, *Lasker* arrived at the 10th Avenue Marine Terminal at ~0300 to complete Leg III.

During Leg III, *Long Beach Carnage* sampled Transects 174 to 138, the nearshore region between Point Conception, CA to the U.S.-Mexico border, and the Santa Cruz and Santa Catalina Islands, from 12 to 19 September. Three USVs (SD-1036, SD-1055, and SD-1059) sampled Transects 060 to 040, between Big Sur and San Diego, from 6 to 24 September. Transects 051 to 040 were offshore extensions of the same transects sampled by *Lasker* in the core region.

Leg IV

On 25 September, *Lasker* departed from the 10th Avenue Marine Terminal in San Diego Bay at ~1730. Not yet having a permit to survey off Mexico, *Lasker* transited north toward Cape Blanco, OR to acoustically sample farther offshore on transects where CPS eggs and backscatter were observed previously. On 28 September, *Lasker* sought shelter from rough seas in Drake's Bay near San Francisco, CA. Prior to dropping anchor, a second calibration of the EC150-3C ADCP was conducted north of the shipping channel (37.8880 N, 122.8870 W). During this time, engineers tended to the thrust bearing on the propeller shaft that began leaking lubricant during the calibration. At ~1500 on 30 September, *Lasker* weighed anchor and continued the transit to Cape Blanco, OR. At ~1400 on 2 October, acoustic sampling resumed along Transect 107. On 4 October, after sampling a portion of Transect 113, the permit to survey off Mexico was received, *Lasker* promptly ceased acoustic sampling and turned south toward Mexico. On 7 October, Keighley Lane was put ashore via *Lasker*'s work boat, and then the ship continued toward the survey area off northern Baja CA. At ~1500 on 8 October, acoustic sampling resumed along Transect 031 near Tijuana, MX. On 14 October, acoustic sampling ceased after the completion of transect 018 off Las Flores, MX. On 15 October, *Lasker* arrived at the fuel pier at 10th Avenue Marine Terminal in San Diego at ~0630 to complete the survey.

During Leg IV, *Carranza* sampled Transects 055 to 027, between Las Flores to Punta Abreojos, MX, from 19 October to 8 November.

3.2 Acoustic backscatter

Acoustic backscatter ascribed to CPS was observed throughout the latitudinal range of the core survey area (**Fig. 15a**). Between approximately Fort Bragg and Pt. Conception, backscatter from CPS was present from near the coast to the shelf break, but was compressed along the coast to the north and south and around the Channel Islands in the SCB. Zero-biomass intervals were observed at the offshore end of each transect in the core region. The majority (greater than 90%) of the biomass for each species was apportioned using catch data from trawl clusters conducted within 30 nmi (**Fig. 14**).

Acoustic backscatter ascribed to CPS was also observed throughout the nearshore survey area (**Figs. 16a** and **17a**), but was most prevalent in transects sampled by *Lisa Marie* between Crescent City and Bodega Bay (**Fig. 16a**) and along transects sampled by *Long Beach Carnage* between Bodega Bay and San Francisco, between Big Sur and Long Beach, and around Santa Cruz Island (**Fig. 17a**).

3.3 Egg densities and distributions

Jack Mackerel and Pacific Sardine eggs were predominant in CUFES samples collected north of Monterey Bay, but were most abundant around Cape Blanco and the mouth of the Columbia River (**Fig. 15b**). Northern Anchovy eggs were predominant in the SCB and near El Rosario off the coast of Baja CA (**Fig. 15b**). Pacific Sardine eggs were also present in samples collected nearshore by *Carranza* in Sebastián Vizcaíno Bay and south of Punta Eugenia (**Fig. 15b**).

3.4 Trawl catch

Trawl catches from *Lasker* and *Carranza* were comprised of mostly Jack Mackerel north of Cape Mendocino, and Northern Anchovy to the south (**Fig. 15c**). Pacific Herring were present in several trawl clusters off the coast of WA and OR. Pacific Sardine were caught in relatively small numbers offshore of central OR, near Pt. Conception, and along Baja CA south of El Rosario (**Fig. 15c**). Pacific Mackerel were caught in the SCB and off Baja CA south of El Rosario (**Fig. 15c**). Round Herring were the predominant species in most trawl clusters between El Rosario and Punta Abreojos (**Fig. 15c**). Overall, the 174 trawls captured a combined 17,395 kg of CPS (11,679 kg of Northern Anchovy, 3,215 kg of Pacific Sardine, 194 kg of Pacific Mackerel, 1,986 kg of Jack Mackerel, 253 kg of Pacific Herring, and 66 kg of Round Herring).

3.5 Purse seine catch

3.5.1 *Lisa Marie*

Pacific Herring were predominant, by weight, in purse seine samples collected by *Lisa Marie* nearshore off WA, OR, and CA north of Cape Mendocino (**Fig. 16b**). Between Cape Mendocino and Bodega Bay, Northern Anchovy were most abundant (**Fig. 16b**). The purse seine was only deployed when schools were present, so purse seine sampling was sparse along portions of the WA and OR coast (**Fig. 16b**). Overall, the 30 seines captured a combined 17.7 kg of CPS (3.86 kg of Northern Anchovy, 13.8 kg of Pacific Herring, and 0.04 kg of Pacific Sardine; and no Pacific or Jack Mackerel).

3.5.2 *Long Beach Carnage*

Northern Anchovy were predominant, by weight, in purse seine samples collected by *Long Beach Carnage* nearshore off central CA between Cape Mendocino and Monterey Bay, and in the SCB between Los Angeles and Long Beach (**Fig. 17b**). Pacific Sardine were predominant between Big Sur and Pt. Conception; between Long Beach and San Diego; and around Santa Cruz and Santa Catalina Islands (**Fig. 17b**). Some Pacific Mackerel were collected between Oceanside, CA and San Diego and around Santa Cruz and Santa Catalina Islands. Jack Mackerel were collected between Big Sur and Morro Bay, and off San Diego (**Fig. 17b**). Overall, dip net samples from 28 seines totaled 63.1 kg of CPS (29.2 kg of Pacific Sardine, 20.6 kg of Pacific Mackerel, kg of Jack Mackerel, and 5.8 kg of Northern Anchovy; and no Pacific Herring).

3.5.3 Combined catch

In some areas, purse seine sets were sparse (**Figs. 16b** and **17b**). To estimate biomass in the nearshore region, acoustic intervals were assigned the species proportions from the nearest purse seine set or trawl haul (not trawl cluster), whichever was closest (**Fig. 18b**).

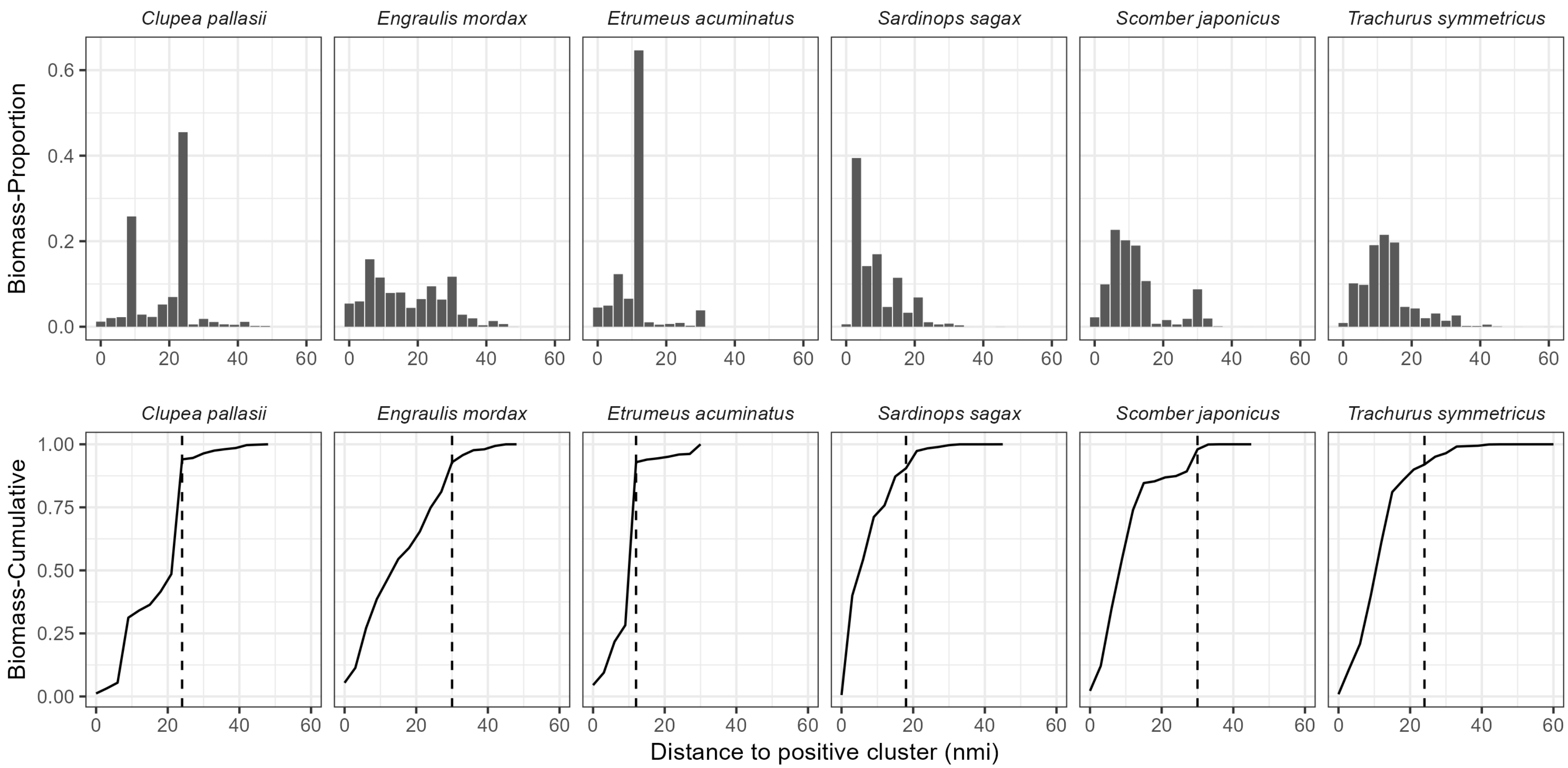

Figure 14: Proportion (top) and cumulative proportion (bottom) of biomass versus distance to the nearest positive trawl cluster. Dashed vertical lines (bottom) represent the cluster distance where cumulative biomass equals 90%.

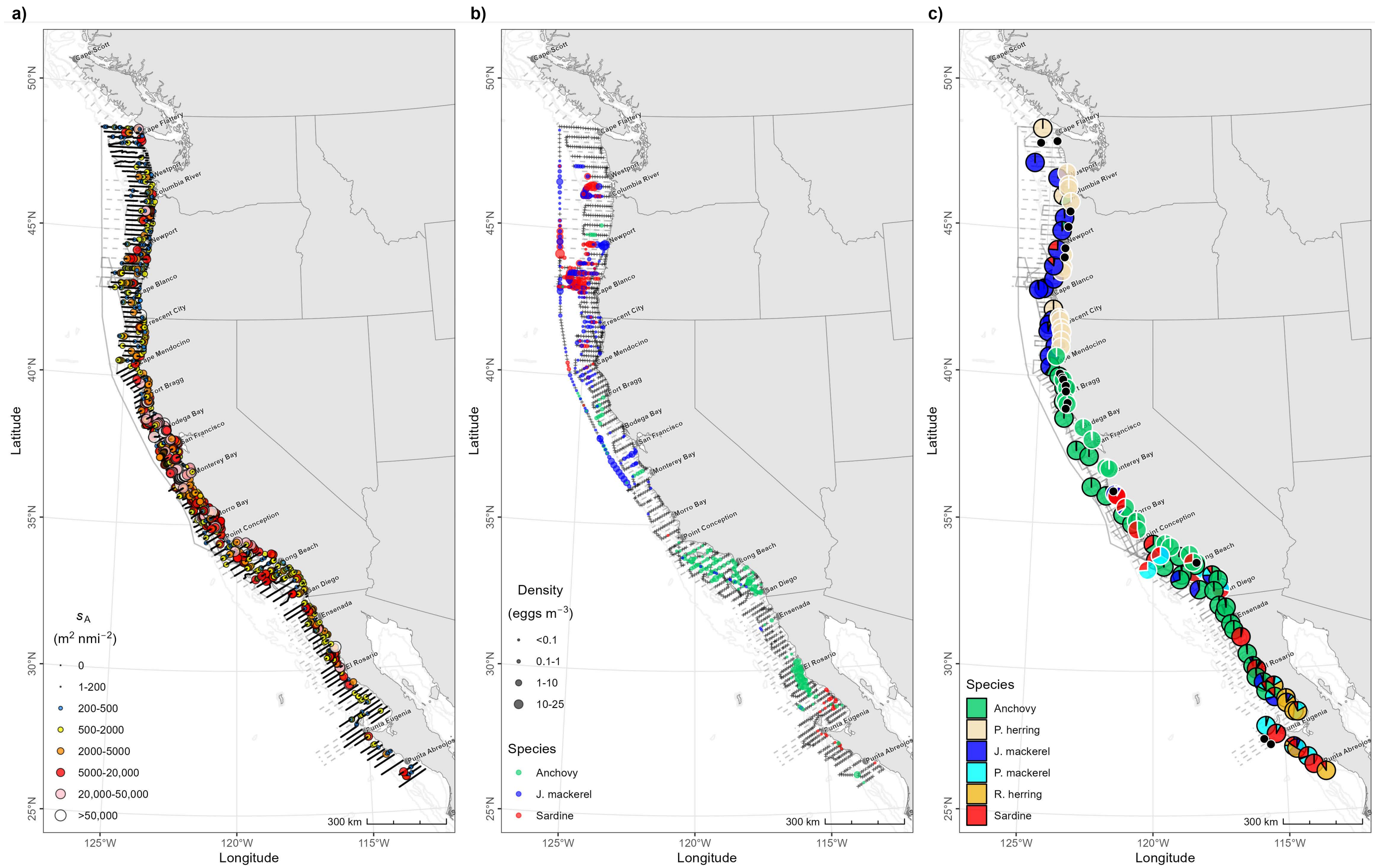

Figure 15: Spatial distributions of: a) 38-kHz integrated backscattering coefficients (s_A, m^2 nmi^{-2}; averaged over 2000-m distance intervals) ascribed to CPS; b) CUFES egg density (eggs m^{-3}) for Northern Anchovy, Pacific Sardine, and Jack Mackerel; and c) acoustic proportions of CPS in trawl clusters (black outline) and purse seine sets (white outline). Black points indicate trawl clusters or purse seine sets with no CPS.

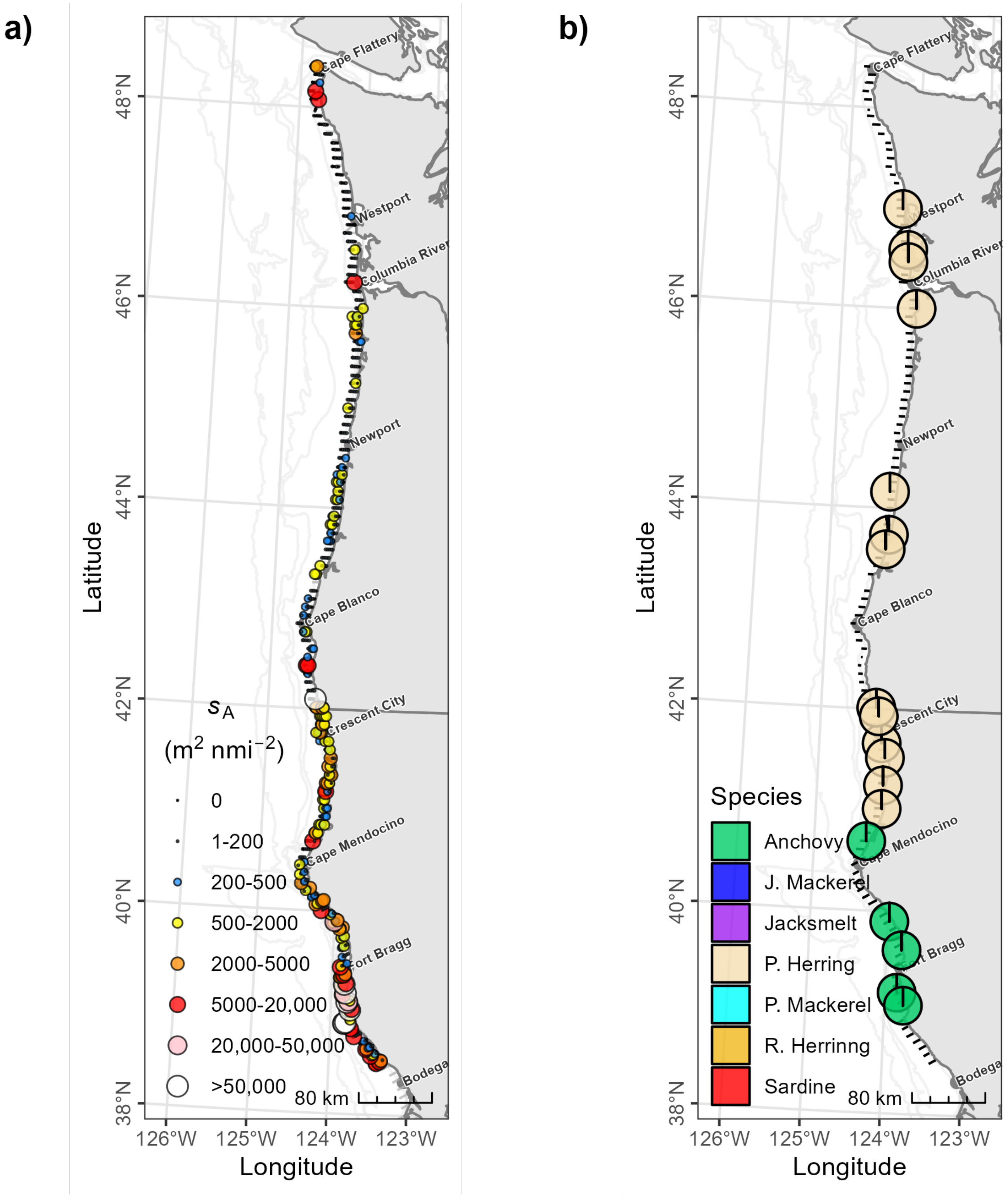

Figure 16: Nearshore survey transects sampled by *Lisa Marie* overlaid with the distributions of: a) 38-kHz integrated backscattering coefficients (s_A, m^2 nmi^{-2}; averaged over 2000-m distance intervals) ascribed to CPS; and b) the proportions, by weight, of CPS in each purse seine catch. Species with low catch weights may not be visible at this scale.

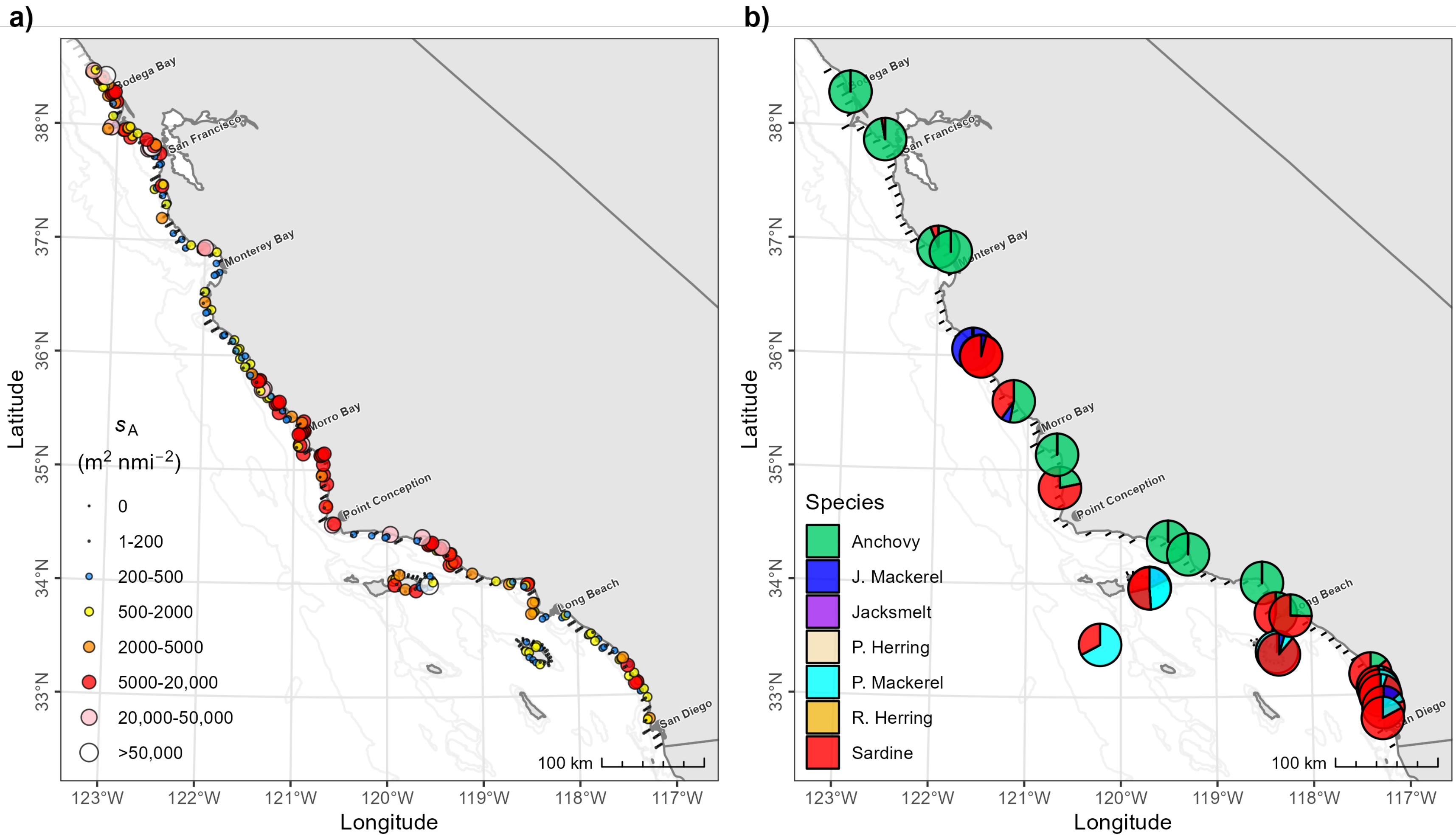

Figure 17: Nearshore transects sampled by *Long Beach Carnage* overlaid with the distributions of: a) 38-kHz integrated backscattering coefficients (s_A, m^2 nmi^{-2}; averaged over 2000-m distance intervals) ascribed to CPS; and b) the proportions, by weight, of CPS in each purse seine catch. Species with low catch weights may not be visible at this scale.

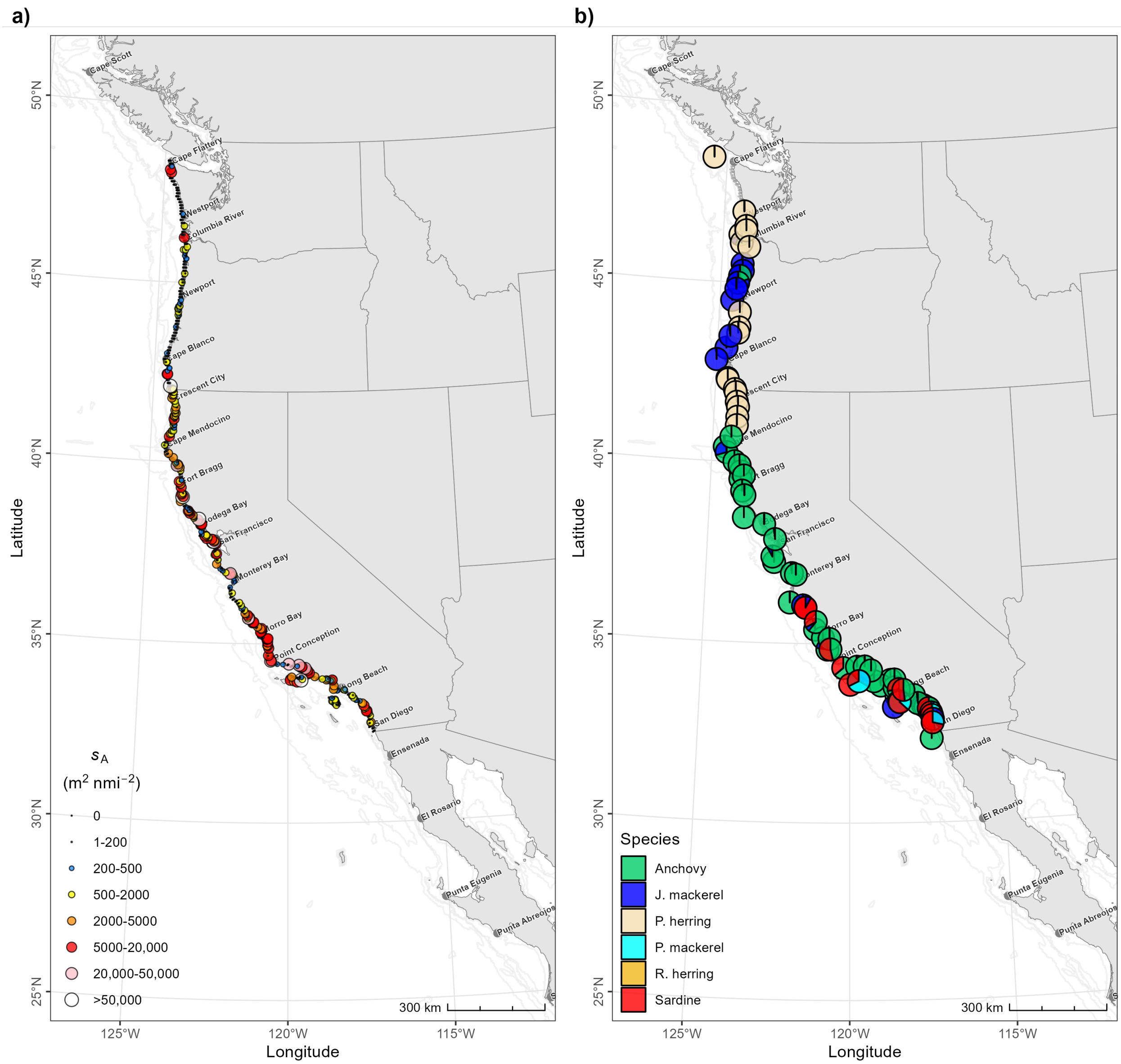

Figure 18: Spatial distributions of: a) 38-kHz integrated backscattering coefficients (s_A, m^2 nmi^{-2}; averaged over 2000-m distance intervals) ascribed to CPS from nearshore sampling; and b) acoustic proportions of CPS in purse seine and trawl samples.

3.6 Biomass distribution and demographics

The biomasses, distributions, and demographics for each species and stock are for the survey area and period and therefore may not represent the entire population. No nearshore sampling was conducted off Baja CA, so nearshore biomass estimates are for U.S. waters only.

3.6.1 Northern Anchovy

3.6.1.1 Northern stock

The total estimated biomass of the northern stock of Northern Anchovy was 8,031 t ($CI_{95\%}$ = 1,624 - 15,893 t, CV = 34%; **Table 6**). In the core region, biomass was 5,587 t ($CI_{95\%}$ = 1,346 - 10,099 t, CV = 41%; **Table 6**); the stock was distributed throughout the survey area from approximately Westport to Cape Mendocino (**Fig. 19a**). L_S ranged from 10 to 17 cm with a single mode at 14 cm (**Table 7**, **Fig. 20**). In the nearshore region, biomass was 2,444 t ($CI_{95\%}$ = 278 - 5,794 t, CV = 56%; **Table 6**), comprising 30% of the total biomass, and was also distributed between Westport to Cape Mendocino (**Fig. 19b**). L_S had a single mode at 11 cm (**Table 7**, **Fig. 20**).

Table 6: Biomass estimates (metric tons, t) and their precisions (upper and lower 95% confidence intervals, $CI_{95\%}$; and coefficients of variation, CVs) for the northern 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	4	3,410	8	345	2	67	20	2	52	67
	5	8,517	18	857	3	776	5,566	1,330	10,078	42
	All	11,927	26	1,202	4	842	5,587	1,346	10,099	41
Nearshore	8	38	5	11	1	1	2,378	100	5,717	58
	10	66	6	13	1	633	65	1	155	63
	11	82	4	18	1	141	1	0	3	53
	All	186	15	42	3	776	2,444	278	5,794	56
All	**-**	**12,112**	**41**	**1,244**	**7**	**1,618**	**8,031**	**1,624**	**15,893**	**34**

Table 7: Abundance versus standard length (L_S, cm) for the northern 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	0
8	0	0
9	0	0
10	89,801	0
11	2,835,162	185,921,529
12	2,471,003	430
13	20,180,156	62,504
14	93,604,788	665,980
15	52,929,473	727,550
16	4,110,560	286,918
17	214,957	31,832
18	0	0
19	0	0
20	0	0

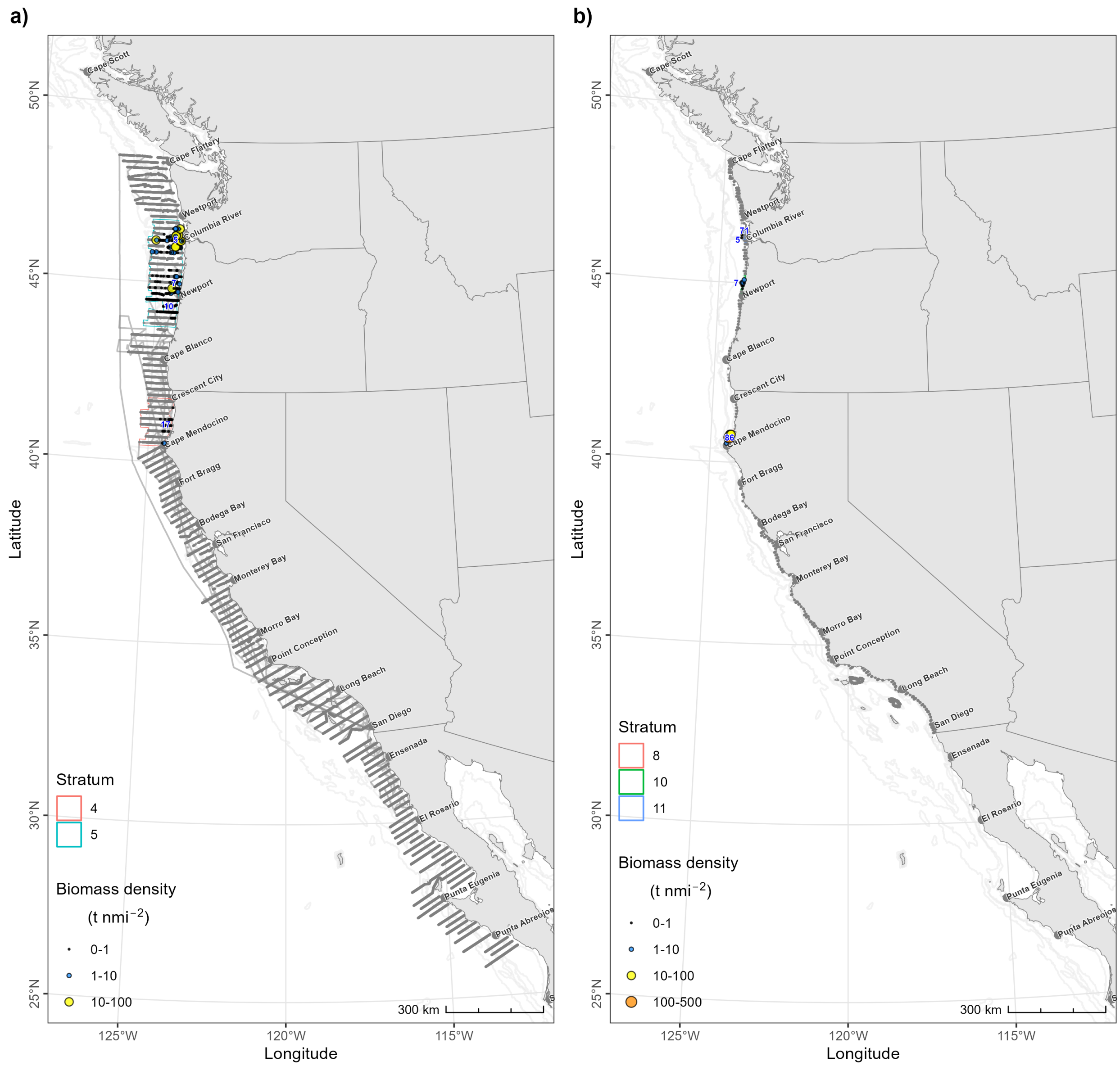

Figure 19: Biomass densities (colored points) of the northern stock of Northern Anchovy (*Engraulis mordax*), per stratum, in the a) core and b) nearshore survey regions. The blue numbers represent the locations of trawl clusters in each stratum (colored polygons) with at least one Northern Anchovy. Thick gray lines represent acoustic transects.

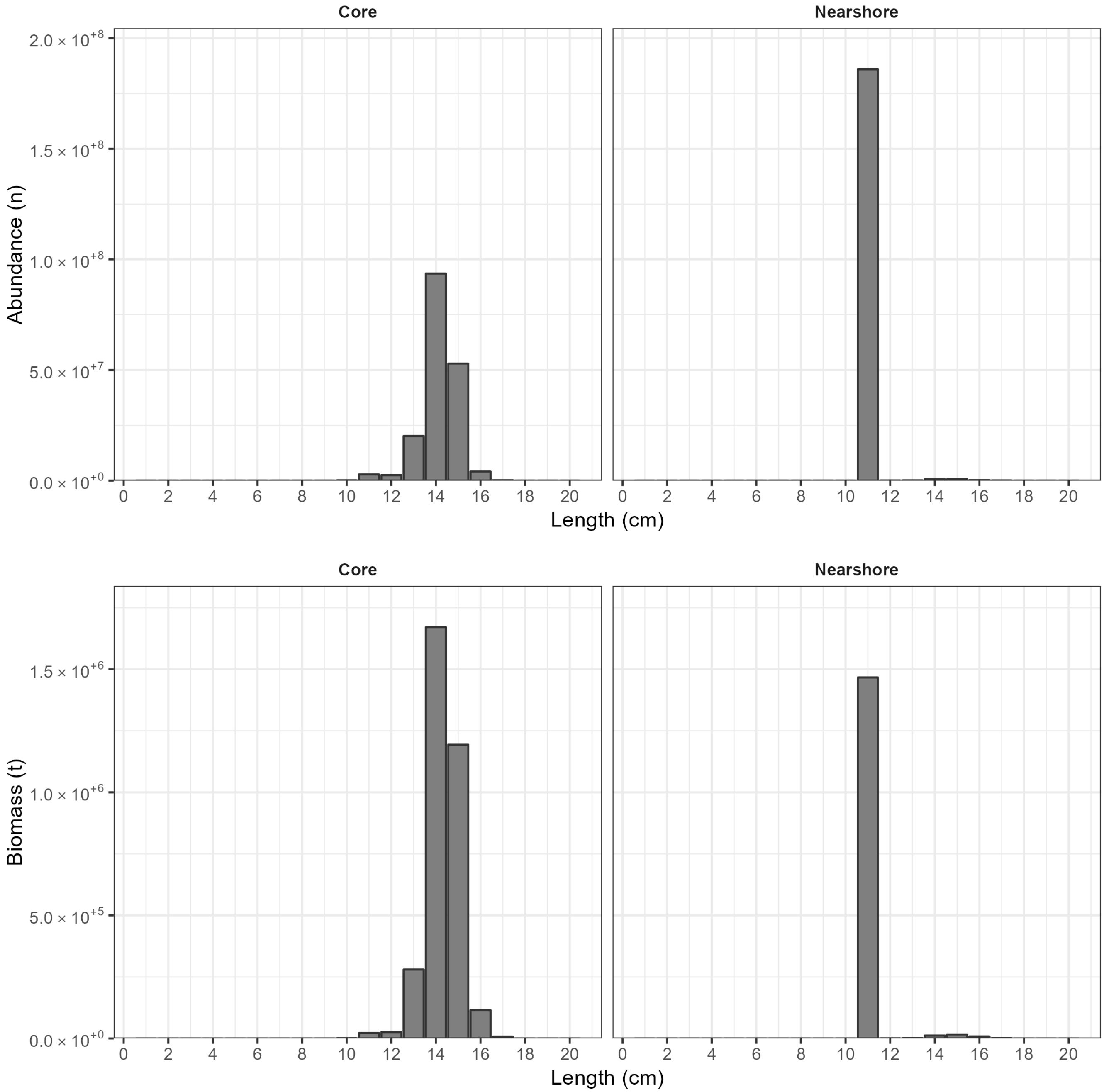

Figure 20: Abundance versus standard length (L_S, upper panels) and biomass (t) versus L_S (lower panels) for the northern stock of Northern Anchovy (*Engraulis mordax*) in the core and nearshore survey regions.

3.6.1.2 Central stock

The total estimated biomass of the central stock of Northern Anchovy was 2,721,689 t ($CI_{95\%}$ = 1,218,459 - 3,353,289 t, CV = 19%; **Table 8**), of which 6% was observed in Mexican waters. In the core region, biomass was 2,619,046 t ($CI_{95\%}$ = 1,155,189 - 3,202,921 t, CV = 20%; **Table 8**); the stock was distributed throughout most of the survey area from Cape Mendocino to Punta Eugenia (**Fig. 21a**). L_S ranged from 7 to 16 cm with a single mode at 11 cm (**Table 9**, **Fig. 22**). In the nearshore region, biomass was 102,642 t ($CI_{95\%}$ = 63,270 - 150,367 t, CV = 22%; **Table 8**), comprising 3.8% of the total biomass, and was distributed between Cape Mendocino and San Diego (**Fig. 21b**). The nearshore length distribution was similar to that in the core region (**Table 9**, **Fig. 22**).

Table 8: Biomass estimates (metric tons, t) and their precisions (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	8,021	15	803	8	103,451	30,514	2,029	53,955	44
	2	5,070	14	513	8	55,772	122,424	42,655	177,097	28
	3	27,386	53	2,524	22	686,368	2,466,108	1,048,403	3,069,511	21
	All	40,476	82	3,840	37	845,591	2,619,046	1,155,189	3,202,921	20
Nearshore	1	36	2	8	-	-	4	0	8	75
	2	529	49	112	15	88,448	45,691	29,424	56,230	15
	3	338	31	77	6	81,819	51,332	17,916	99,318	41
	4	98	5	10	2	14,218	23	0	49	57
	5	85	10	19	1	5,571	43	15	76	37
	6	85	3	6	-	-	28	0	88	85
	7	139	25	29	9	108,017	5,523	3,085	8,499	26
	All	1,309	125	260	31	298,073	102,642	63,270	150,367	22
All	**-**	**41,786**	**207**	**4,100**	**68**	**1,143,665**	**2,721,689**	**1,218,459**	**3,353,289**	**19**

Table 9: 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	40,168,328
7	86,939,784	196,213,862
8	483,998,812	239,735,623
9	3,789,443,745	2,950,630,613
10	48,454,264,303	5,400,584,625
11	66,811,790,406	1,187,373,052
12	32,351,108,953	315,161,624
13	16,808,066,667	90,683,361
14	5,937,156,588	17,198,513
15	613,289,539	3,775,701
16	6,721,401	77
17	0	0
18	0	0
19	0	0
20	0	0

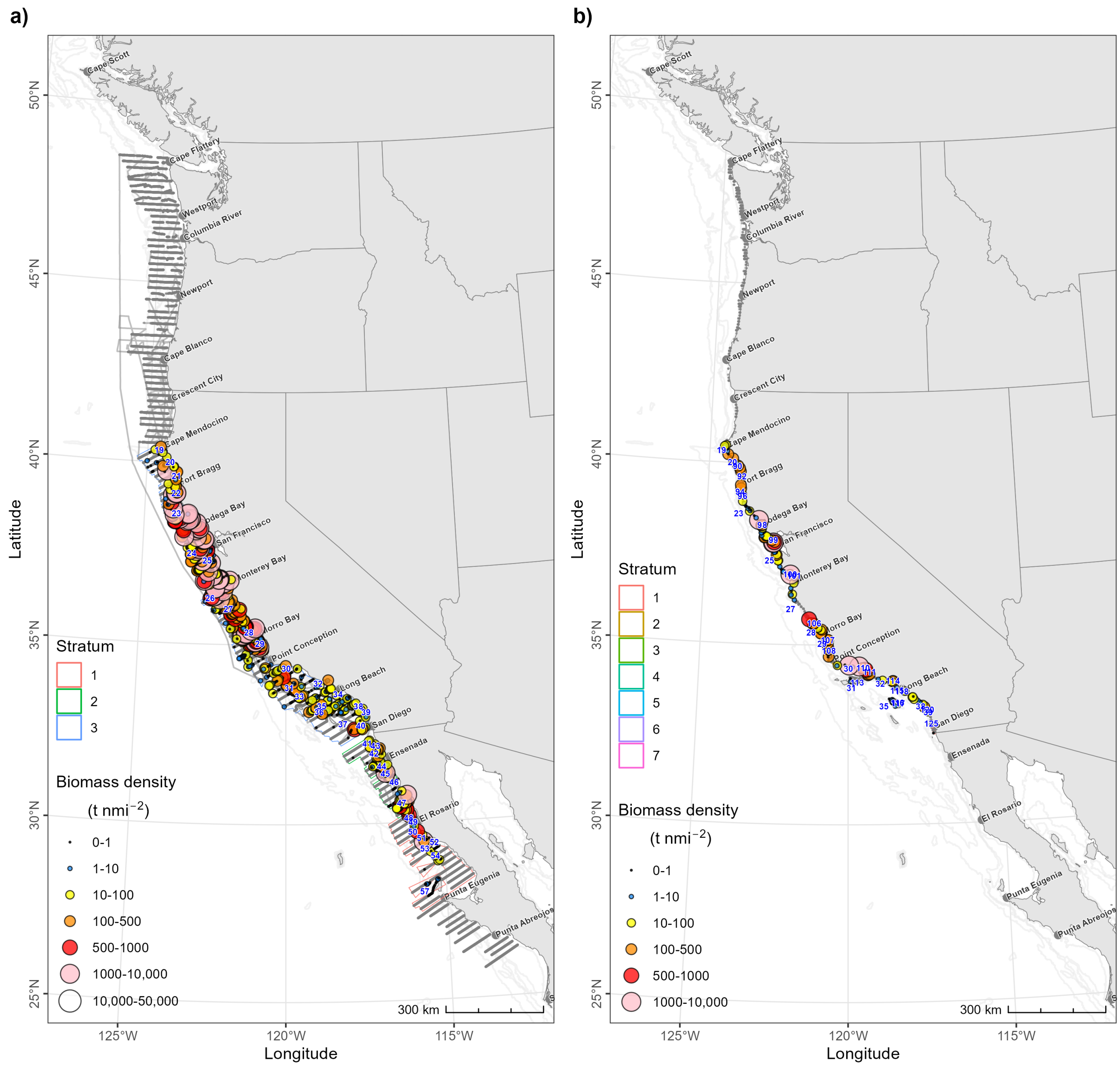

Figure 21: Biomass densities (colored points) of central stock of Northern Anchovy (*Engraulis mordax*), per stratum, in the a) core and b) nearshore survey regions. The blue numbers represent the locations of trawl clusters in each stratum (colored polygons) with at least one Northern Anchovy. Thick gray lines represent acoustic transects.

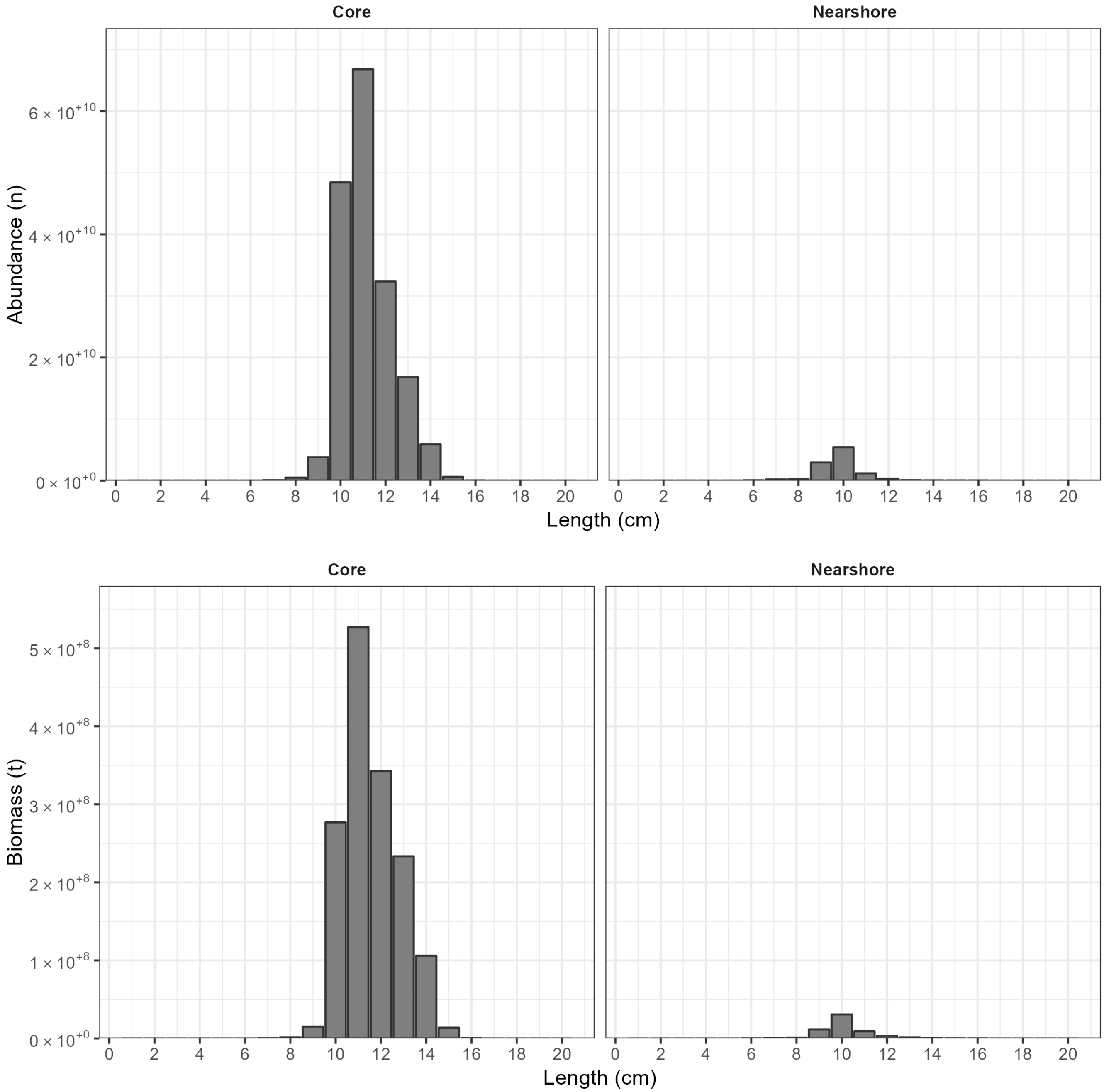

Figure 22: Abundance versus standard length (L_S, upper panels) and biomass (t) versus L_S (lower panels) for the central stock of Northern Anchovy (*Engraulis mordax*) in the core and nearshore survey regions.

3.6.2 Pacific Sardine

3.6.2.1 Northern stock

The total estimated biomass of the northern stock of Pacific Sardine was 47,721 t ($\text{CI}_{95\%}$ = 14,016 - 90,475 t, CV = 42%; **Table 10**). In the core region, biomass was 47,278 t ($\text{CI}_{95\%}$ = 13,836 - 89,017 t, CV = 42%; **Table 10**), and was distributed from approximately Astoria, OR to Ft. Bragg, CA and was most abundant off the central OR coast between Newport and Cape Blanco (**Fig. 23a**). L_S ranged from 16 to 29 cm with a mode between 24 and 27 cm (**Table 11**, **Fig. 24**). In the nearshore region, biomass was 443 t ($\text{CI}_{95\%}$ = 180 - 1,458 t, CV = 81%; **Table 10**), comprising 0.93% of the total biomass. It was distributed between Astoria and San Francisco, but biomass was greatest near San Francisco (**Fig. 23b**). Nearly all of the biomass in the nearshore region was comprised of individuals between 7 and 9 cm (**Table 11**, **Fig. 24**).

Table 10: Biomass estimates (metric tons, t) and their precisions (upper and lower 95% confidence intervals, $\text{CI}_{95\%}$; and coefficients of variation, CVs) for the northern 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	$\hat{B}$	$\text{CI}_{L,95\%}$	$\text{CI}_{U,95\%}$	CV
Core	5	6,021	14	585	3	7	1,266	257	2,950	61
	6	9,979	19	957	4	1,001	46,012	12,313	87,893	43
	All	16,000	33	1,542	7	1,008	47,278	13,836	89,017	42
Nearshore	1	89	6	23	1	2	421	150	1,429	85
	2	36	5	8	1	3	9	1	18	50
	3	74	9	14	2	24	0	0	1	49
	4	83	6	16	1	6	13	0	32	69
	All	283	26	60	5	35	443	180	1,458	81
All	**-**	**16,283**	**59**	**1,602**	**12**	**1,043**	**47,721**	**14,016**	**90,475**	**42**

Table 11: Abundance versus standard length (L_S, cm) for the northern 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	57,734,243
8	0	0
9	0	57,734,243
10	0	0
11	0	0
12	0	0
13	0	0
14	0	0
15	0	7,535
16	214,320	0
17	440,119	0
18	3,386,512	20,404
19	0	0
20	6,987,344	40,808
21	1,397,885	5
22	7,779,624	20
23	24,922,247	59
24	43,918,181	10
25	34,028,589	2,020
26	48,737,938	1,008
27	44,357,543	3,008
28	8,590,298	0
29	229,892	0
30	0	0

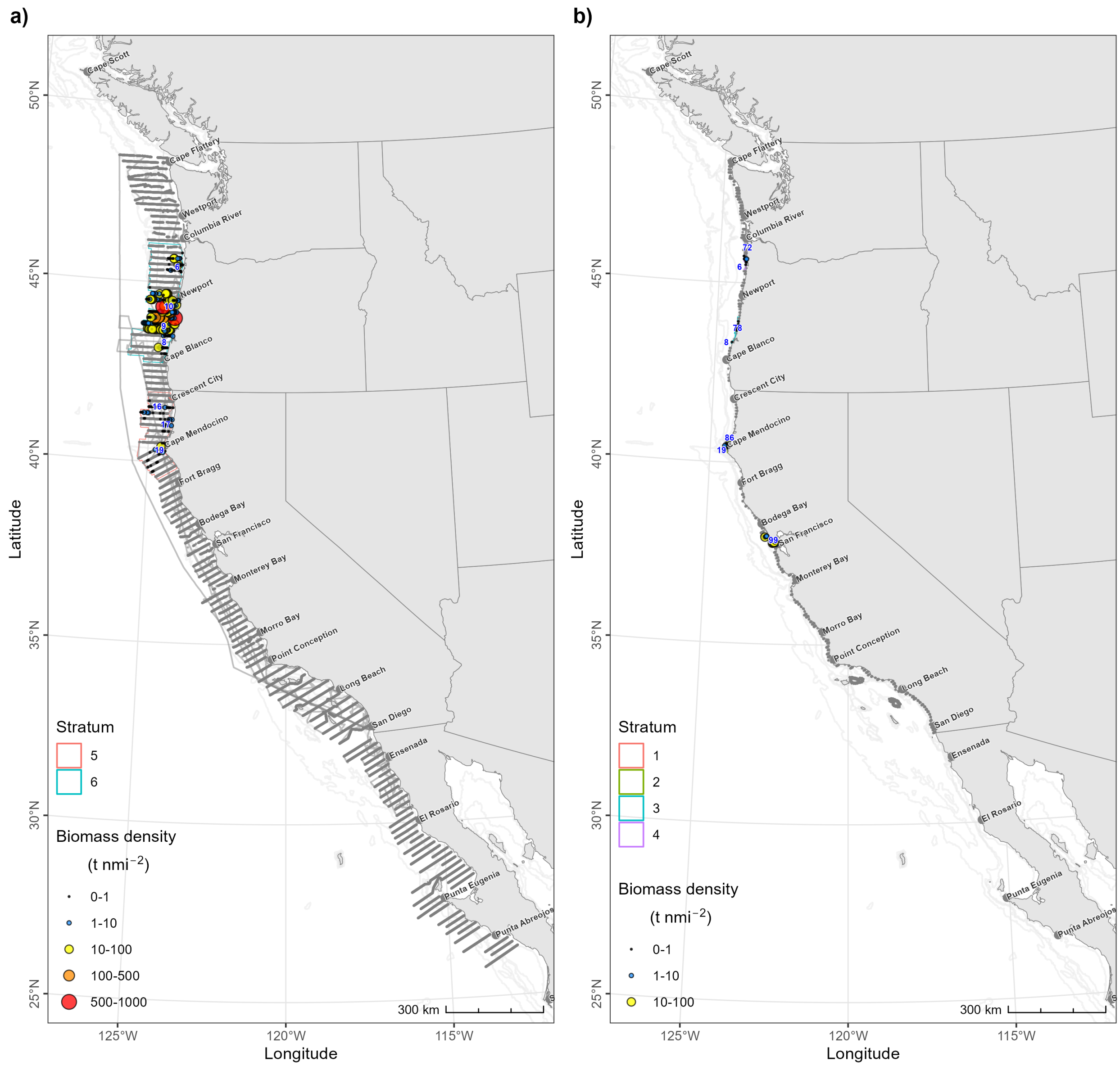

Figure 23: Biomass densities (colored points) of the northern stock of Pacific Sardine (*Sardinops sagax*), per stratum, in the a) core and b) nearshore survey regions. The blue numbers represent the locations of trawl clusters in each stratum (colored polygons) with at least one Pacific Sardine. Thick gray lines represent acoustic transects.

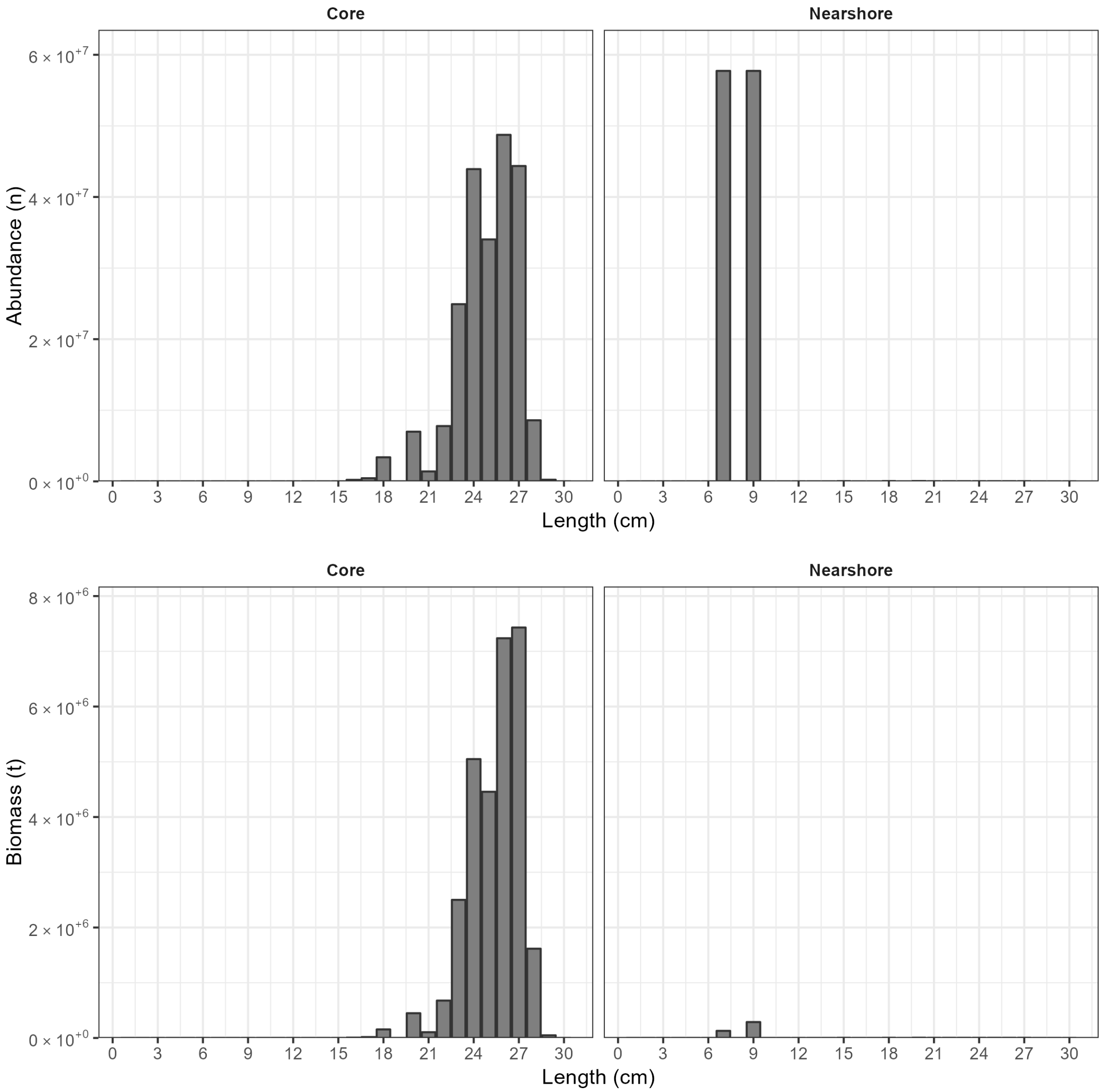

Figure 24: Estimated abundance (upper panel) and biomass (lower panel) versus standard length (L_S, cm) for the northern stock of Pacific Sardine (*Sardinops sagax*) in the core and nearshore survey regions.

3.6.2.2 Southern stock

The total estimated biomass of the southern stock of Pacific Sardine was 196,609 t ($CI_{95\%}$ = 60,237 - 346,360 t, CV = 35%; **Table 12**), of which 73% was observed in Mexican waters. In the core region, biomass was 165,119 t ($CI_{95\%}$ = 42,428 - 301,836 t, CV = 41%; **Table 12**), and was distributed from approximately San Francisco to Punta Eugenia (**Fig. 25a**). L_S ranged from 8 to 21 cm with two modes, between 9 and 11 cm and between 14 and 15 cm (**Table 13**, **Fig. 26**). In the nearshore region, biomass was 31,490 t ($CI_{95\%}$ = 17,809 - 44,524 t, CV = 22%; **Table 12**), comprising 16% of the total biomass. The nearshore biomass was distributed between San Francisco and San Diego, but was mostly between Big Sur and Pt. Conception, between Oceanside, CA and San Diego, and around Santa Cruz and Santa Catalina Islands (**Fig. 25b**). The length distribution nearshore was similar to that in the core region (**Table 13**, **Fig. 26**).

Table 12: 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	14,289	26	1,294	15	41,931	101,911	6,670	239,316	63
	2	5,070	14	513	8	41,776	17,875	1,171	37,515	52
	3	12,498	13	922	9	9,801	45,200	7,004	84,689	45
	4	6,895	18	762	3	56	133	40	247	40
	All	38,753	71	3,491	33	93,564	165,119	42,428	301,836	41
Nearshore	5	102	11	22	7	1,680	650	44	3,616	143
	6	105	10	23	3	1,497	2,079	5	1,626	22
	7	21	3	4	1	3	537	0	0	0
	8	312	28	68	8	5,917	0	10,583	35,973	71,642,602
	9	73	6	13	1	1	23,368	4	1,152	1
	10	13	2	5	1	2	1	0	3	77
	11	98	26	50	4	8,136	4,367	540	8,568	47
	12	85	8	16	1	49	486	24	1,300	78
	13	85	3	6	-	-	1	0	4	85
	All	893	97	207	23	17,286	31,490	17,809	44,524	22
All	**-**	**39,646**	**168**	**3,698**	**56**	**110,849**	**196,609**	**60,237**	**346,360**	**35**

Table 13: 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	8,772,207
8	3,838,225	60,623,910
9	10,434,702	200,346,679
10	582,969,085	162,013,561
11	683,275,263	22,271,482
12	32,627,309	63,647,368
13	801,663,335	26,308,788
14	1,145,792,676	32,228,668
15	944,971,353	247,071,398
16	472,197,290	171,365,102
17	365,624,380	66,288,359
18	50,260,440	10,877,191
19	15,087,496	3,736,057
20	4,634,754	164,171
21	418,011	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

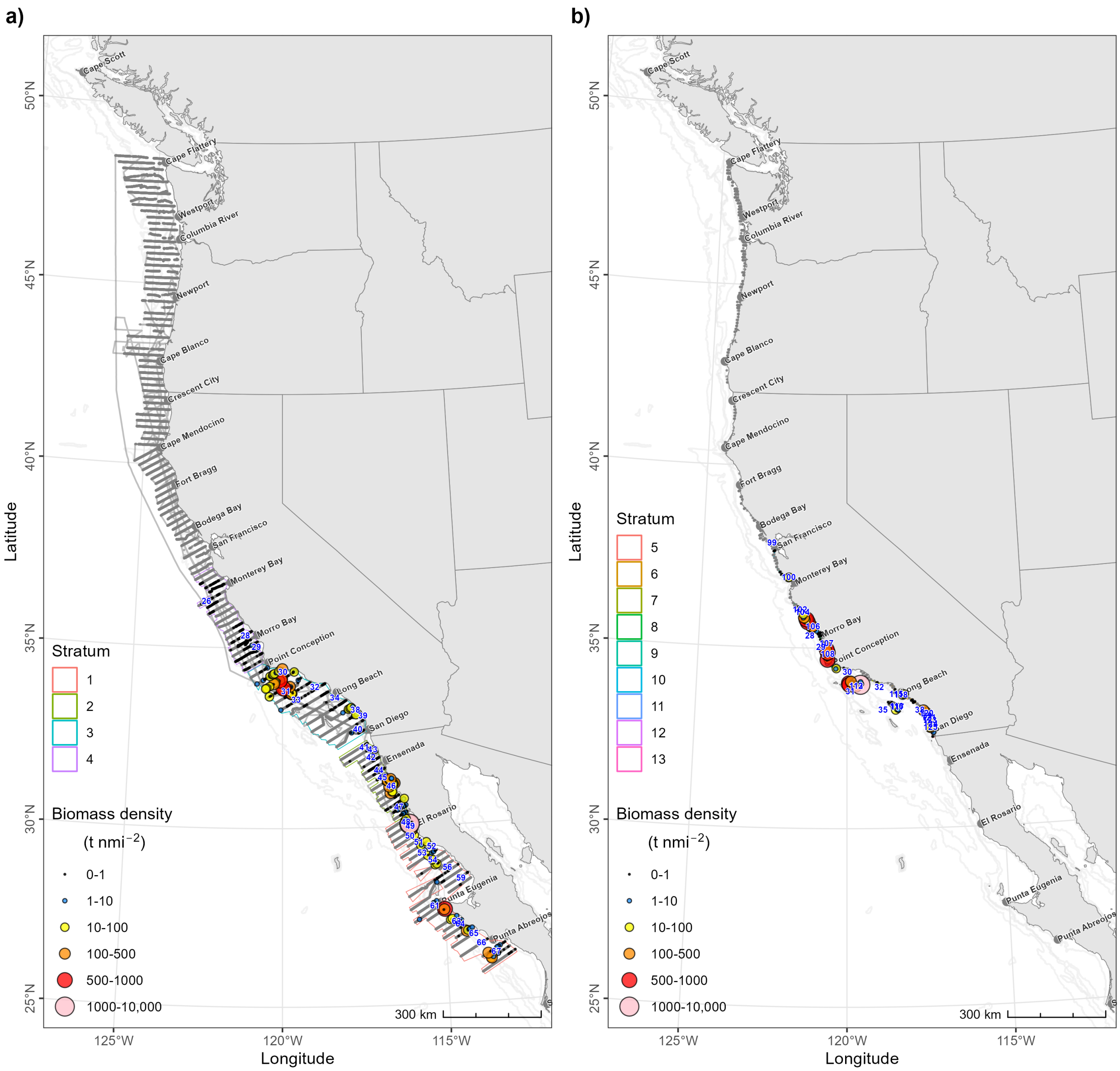

Figure 25: Biomass densities (colored points) of the southern stock of Pacific Sardine (*Sardinops sagax*), per stratum, in the a) core and b) nearshore survey regions. The blue numbers represent the locations of trawl clusters in each stratum (colored polygons) with at least one Pacific Sardine. Thick gray lines represent acoustic transects.

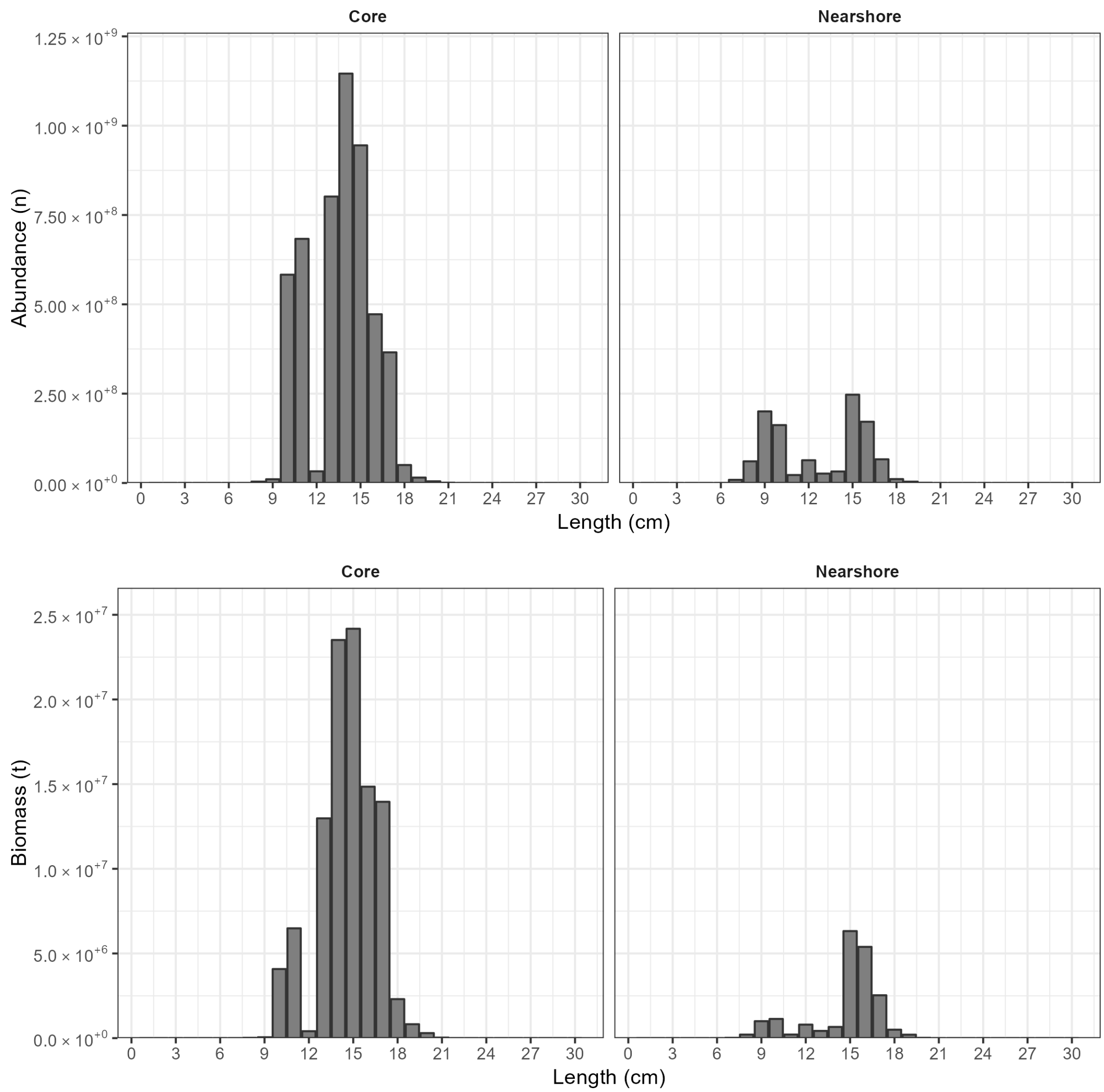

Figure 26: Estimated abundance (upper panels) and biomass (lower panels) versus standard length (L_S, cm) for the southern stock of Pacific Sardine (*Sardinops sagax*) in the core and nearshore survey regions.

3.6.3 Pacific Mackerel

The total estimated biomass of Pacific Mackerel was 21,998 t ($CI_{95\%}$ = 15,367 - 34,300 t, CV = 20%; **Table 14**), of which 69% was observed in Mexican waters. In the core region, biomass was 20,491 t ($CI_{95\%}$ = 15,067 - 31,724 t, CV = 21%) and was distributed from approximately Astoria to Punta Eugenia, but was primarily located south of Pt. Conception (**Fig. 27a**). L_F ranged from 9 to 38 cm with two modes, between 19 and 24 cm and at 34 cm (**Table 15**, **Fig. 28**). In the nearshore region, biomass was 1,507 t ($CI_{95\%}$ = 300 - 2,576 t, CV = 39%; **Table 14**, **Fig. 27b**), comprising 6.9% of the total biomass. It was distributed from Pt. Conception to San Diego, but was most abundant around Santa Cruz Island. The distribution of L_F had two modes at 14 and 20 cm.

Table 14: 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 survey 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
Core	1	12,482	23	1,144	15	1,184	12,930	8,011	22,874	30
	2	5,070	14	513	5	217	1,272	304	2,149	38
	3	12,884	14	960	11	612	3,643	1,422	7,113	40
	4	1,711	5	172	1	4	51	1	144	80
	5	6,329	13	580	3	5	2,064	651	4,174	45
	6	3,109	6	308	1	1	531	54	1,168	58
	All	41,584	75	3,677	35	2,022	20,491	15,067	31,724	21
Nearshore	1	189	18	40	6	491	286	14	602	59
	2	21	3	4	1	5	0	0	0	24
	3	54	6	11	1	7	58	0	81	37
	4	85	40	78	7	147	1,163	163	2,281	48
	All	348	67	133	14	649	1,507	300	2,576	39
All	**-**	**41,932**	**142**	**3,810**	**49**	**2,672**	**21,998**	**15,367**	**34,300**	**20**

Table 15: Abundance versus fork length (L_F, cm) for Pacific Mackerel (*Scomber japonicus*) in the core and nearshore survey regions.

	Region	
L_F	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	428,113	0
10	772,681	3,534
11	93,942	0
12	554,666	206,027
13	1,232,094	968,414
14	4,132,588	2,574,900
15	6,486,269	438,142
16	3,572,404	286,454
17	7,325,718	1,610,426
18	10,996,379	168,836
19	18,988,559	2,087,973
20	15,288,103	4,320,593
21	27,286,013	3,109,239
22	24,734,385	1,614,323
23	23,000,109	62,175
24	15,988,542	310,984
25	5,303,456	319,106
26	1,604,348	327,229
27	272,817	98,687
28	0	0
29	0	24,672
30	0	123,358
31	335,092	74,015
32	0	49,343
33	471,484	0
34	5,200,976	74,015
35	335,092	0
36	471,484	24,672
37	0	24,672
38	1,476,761	0
39	0	0
40	0	0

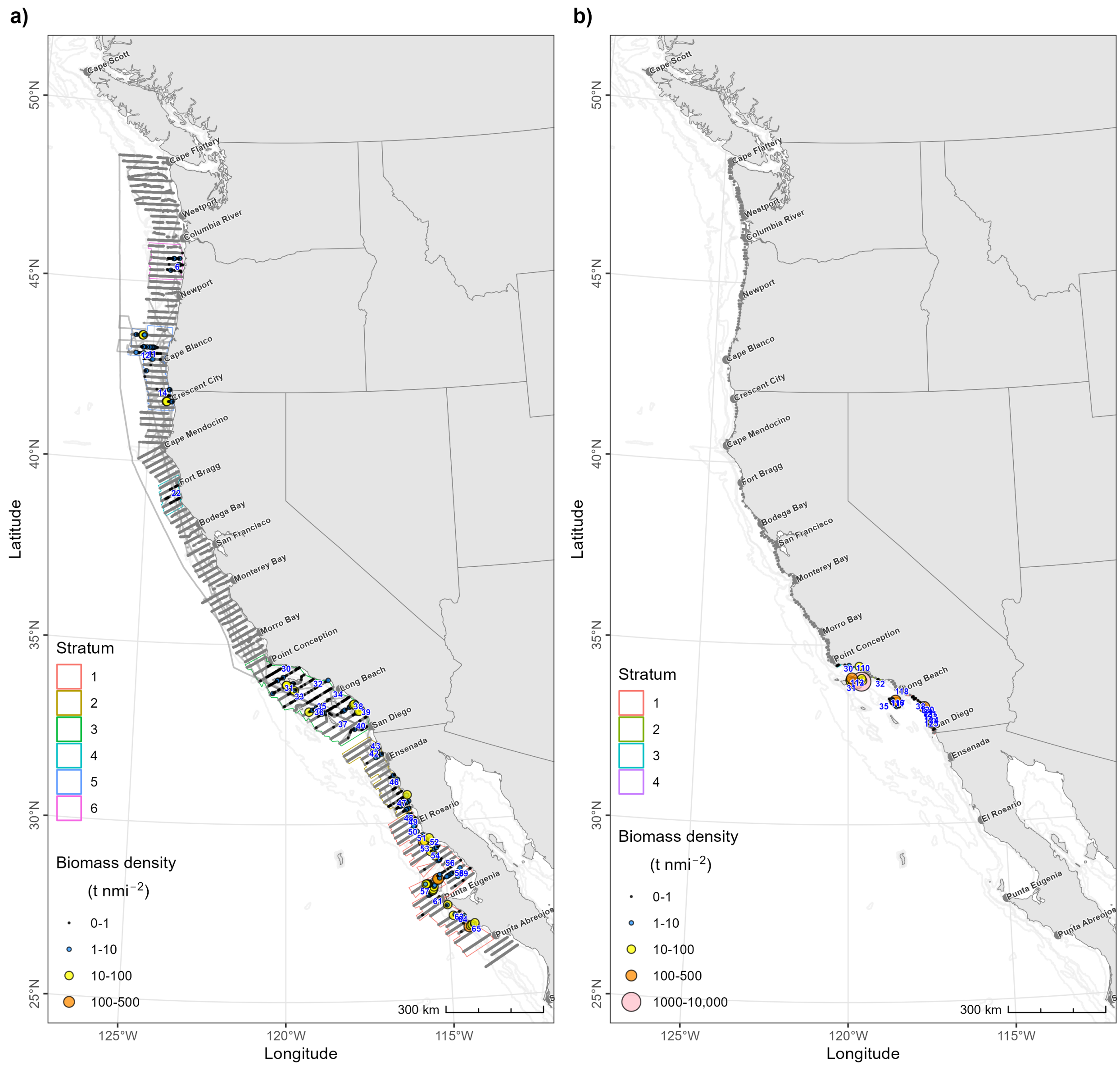

Figure 27: Biomass densities (colored points) of Pacific Mackerel (*Scomber japonicus*), per stratum, in the a) core and b) nearshore survey regions. The blue numbers represent the locations of trawl clusters in each stratum (colored polygons) with at least one Pacific Mackerel. Thick gray lines represent acoustic transects.

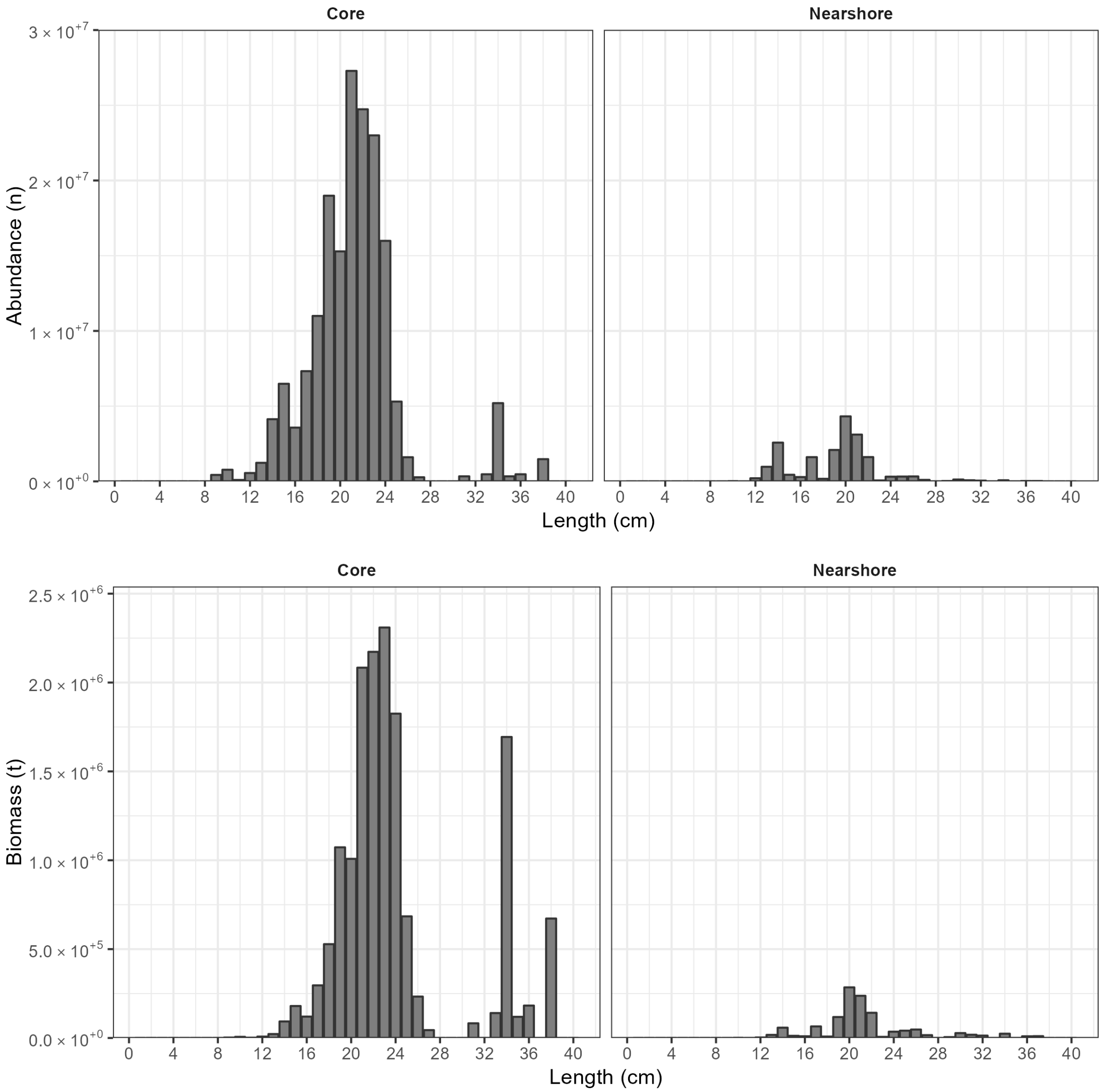

Figure 28: Estimated abundance (upper panels) and biomass (lower panels) versus fork length (L_F, cm) for Pacific Mackerel (*Scomber japonicus*) in the core and nearshore survey regions.

3.6.4 Jack Mackerel

The total estimated biomass of Jack Mackerel was 569,793 t ($CI_{95\%}$ = 310,939 - 941,151 t, CV = 28%; **Table 16**), of which 2% was observed in Mexican waters. In the core region, the biomass was 562,052 t ($CI_{95\%}$ = 305,551 - 929,246 t, CV = 28%; **Table 16**). It was distributed throughout the survey area from Cape Flattery to Punta Eugenia (**Fig. 29a**), but was most abundant north of Cape Mendocino. L_F ranged from 4 to 51 cm, with modes at 14, 28, 35, and 51 cm. (**Table 17**, **Fig. 30**). In the nearshore region, the biomass was 7,741 t ($CI_{95\%}$ = 5,388 - 11,905 t, CV = 22%; **Table 16**), comprising 1.4% of the total biomass. It was distributed from Astoria to San Diego, but was most abundant off the OR coast and around Santa Cruz Island (**Fig. 29b**), and had length modes at 14 and 19 cm (**Table 17**, **Fig. 30**).

Table 16: 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 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	12,482	23	1,144	11	4,076	10,859	1,357	24,905	63
	2	5,070	14	513	6	673	545	227	870	30
	3	24,979	47	2,285	14	1,429	8,985	4,998	21,809	47
	4	25,330	51	2,476	16	3,835	541,663	281,469	899,820	29
	All	67,860	135	6,418	46	10,013	562,052	305,551	929,246	28
Nearshore	1	178	19	38	3	904	579	3	1,626	80
	2	32	4	5	1	1	0	0	1	63
	3	71	7	17	-	-	1	0	2	77
	4	141	16	29	4	64	1,581	672	2,577	31
	5	67	5	16	1	5	56	0	164	84
	6	98	5	10	1	183	651	1	1,427	57
	7	98	13	25	1	50	456	15	1,294	75
	8	85	16	31	2	35	186	59	323	36
	9	85	3	6	-	-	83	0	264	85
	10	28	5	5	1	9	1	0	1	37
	13	72	11	16	2	880	1,546	264	3,881	57
	14	237	18	46	3	1,892	2,601	1,028	5,586	44
	15	82	4	18	1	2	1	0	2	53
	All	1,274	126	263	20	4,024	7,741	5,388	11,905	22
All	**-**	**69,134**	**261**	**6,681**	**66**	**14,038**	**569,793**	**310,939**	**941,151**	**28**

Table 17: Abundance versus fork length (L_F, cm) for Jack Mackerel (*Trachurus symmetricus*) in the core and nearshore survey regions.

	Region	
L_F	Core	Nearshore
1	0	0
2	0	0
3	0	0
4	280,632	338
5	2,062,391	338
6	4,860,516	676
7	6,733,056	338
8	542,275	0
9	7,058,874	110,206
10	4,597,515	919,019
11	13,913,568	2,265,771
12	14,482,417	1,278,409
13	42,724,673	8,065,073
14	113,679,317	26,798,372
15	103,052,147	10,327,027
16	67,470,817	2,025,655
17	51,149,448	643,187
18	10,076,673	1,327,326
19	17,141,128	9,558,912
20	3,837,999	1,933,340
21	12,479,081	2,066,256
22	4,266,860	3,796,789
23	13,375,030	220,661
24	4,759,182	16,781
25	7,851,458	14,669
26	22,983,581	61,307
27	45,174,571	143,230
28	57,527,819	77,642
29	25,224,398	49,712
30	19,714,103	39,186
31	18,610,500	43,482
32	31,874,028	95,492
33	54,424,849	128,532
34	78,467,259	240,208
35	81,419,608	237,863
36	72,894,282	349,861
37	60,584,829	214,751
38	59,298,273	316,660
39	48,069,532	251,108
40	39,492,448	202,296
41	25,846,916	147,464
42	26,426,397	134,664
43	14,953,734	67,671
44	16,846,201	51,057
45	9,357,325	38,293
46	4,385,870	25,529
47	4,385,870	25,529

Table 17: Abundance versus fork length (L_F, cm) for Jack Mackerel (*Trachurus symmetricus*) in the core and nearshore survey regions. *(continued)*

L_F	Core	Nearshore
48	16,198,492	74,660
49	15,294,147	87,424
50	29,181,868	49,131
51	24,396,454	24,059
52	0	0
53	0	0
54	0	0
55	0	0
56	0	0
57	0	0
58	0	0
59	0	0
60	0	0

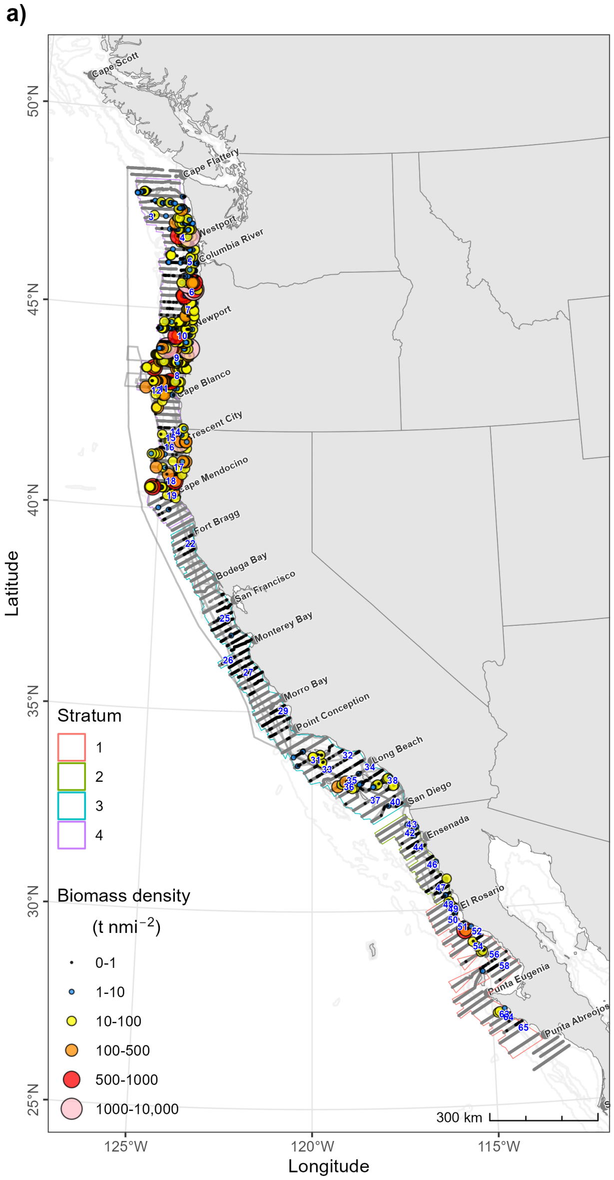

Figure 29: Biomass densities (colored points) of Jack Mackerel (*Trachurus symmetricus*), per stratum, in the a) core and b) nearshore survey regions. The blue numbers represent the locations of trawl clusters in each stratum (colored polygons) with at least one Jack Mackerel. Thick gray lines represent acoustic transects.

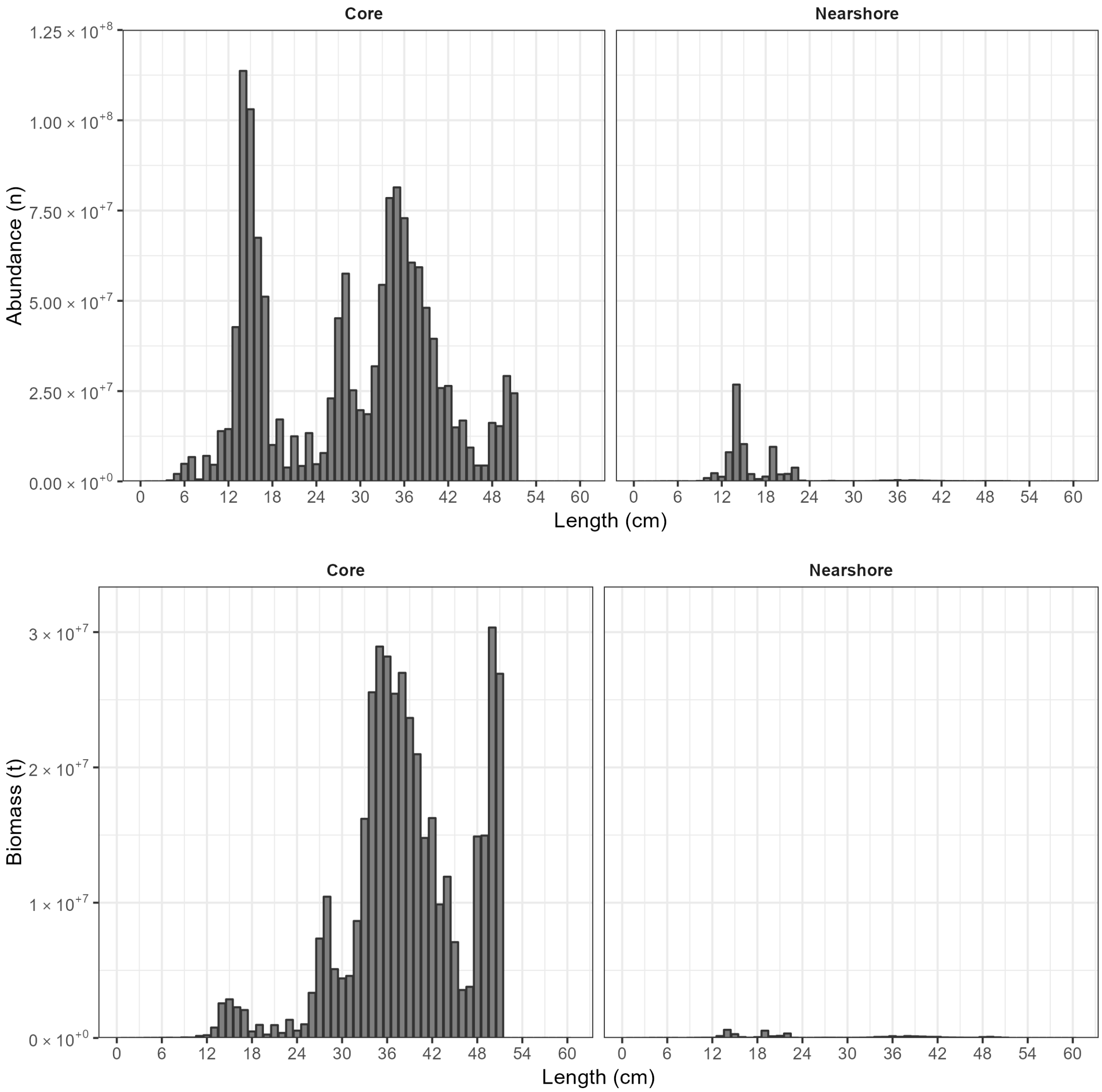

Figure 30: Estimated abundance (upper panel) and biomass (lower panel) versus fork length (L_F, cm) for Jack Mackerel (*Trachurus symmetricus*) in the core and nearshore survey regions.

3.6.5 Pacific Herring

The total estimated biomass of Pacific Herring was 67,920 t ($CI_{95\%}$ = 14,913 - 134,879 t, CV = 40%; **Table 18**). In the core region, biomass was 52,224 t ($CI_{95\%}$ = 9,111 - 106,564 t, CV = 50%; **Table 18**). It was distributed from approximately Cape Flattery to Ft. Bragg, but was most abundant near Cape Flattery (**Fig. 31a**). L_F ranged from 8 to 24 cm, with a mode at 21 cm (**Table 19**, **Fig. 32**). In the nearshore region, biomass was 15,697 t ($CI_{95\%}$ = 5,802 - 28,315 t, CV = 38%; **Table 18**, **Fig. 31b**), comprising 23% of the total. It was also distributed from Cape Flattery to Ft. Bragg (**Fig. 32**), and had length modes at 8 and 15 cm (**Table 19**).

Table 18: Biomass estimates (metric tons, t) and their precisions (upper and lower 95% confidence intervals, $CI_{95\%}$; and coefficients of variation, CVs) for Pacific Herring (*Clupea pallasii*) 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	3,384	8	315	2	12	188	16	479	71
	2	4,769	12	483	2	22	4,211	417	8,923	55
	3	4,971	10	493	2	62	664	111	1,406	53
	4	3,340	7	328	3	68	1,827	451	3,251	39
	5	4,283	6	414	2	3,163	45,334	3,653	99,196	58
	All	20,748	43	2,034	10	3,327	52,224	9,111	106,564	50
Nearshore	1	66	11	14	2	12	5	1	10	49
	2	187	25	45	7	279	11,760	2,685	23,835	51
	3	154	16	32	4	83	920	489	1,847	39
	4	664	34	138	7	3,244	3,011	734	5,912	44
	All	1,070	86	229	20	3,618	15,697	5,802	28,315	38
All	**-**	**21,818**	**129**	**2,263**	**30**	**6,945**	**67,920**	**14,913**	**134,879**	**40**

Table 19: Abundance versus fork length (L_F, cm) for Pacific Herring (*Clupea pallasii*) in the core and nearshore survey regions.

	Region	
L_F	Core	Nearshore
1	0	0
2	0	0
3	0	0
4	0	0
5	0	0
6	0	0
7	0	4,552,731
8	1,183,927	8,239,843
9	0	3,296,641
10	0	1,397,521
11	0	2,795,041
12	0	3,787,973
13	1,183,927	23,036,151
14	19,784,820	43,923,859
15	66,737,427	153,079,304
16	46,196,101	87,257,933
17	56,251,442	47,992,696
18	72,931,008	6,897,493
19	113,280,779	4,729,756
20	103,475,973	3,898,976
21	153,355,358	5,705,125
22	34,491,991	1,295,120
23	11,497,330	431,707
24	483,718	0
25	0	0
26	0	0
27	0	0
28	0	0
29	0	0
30	0	0

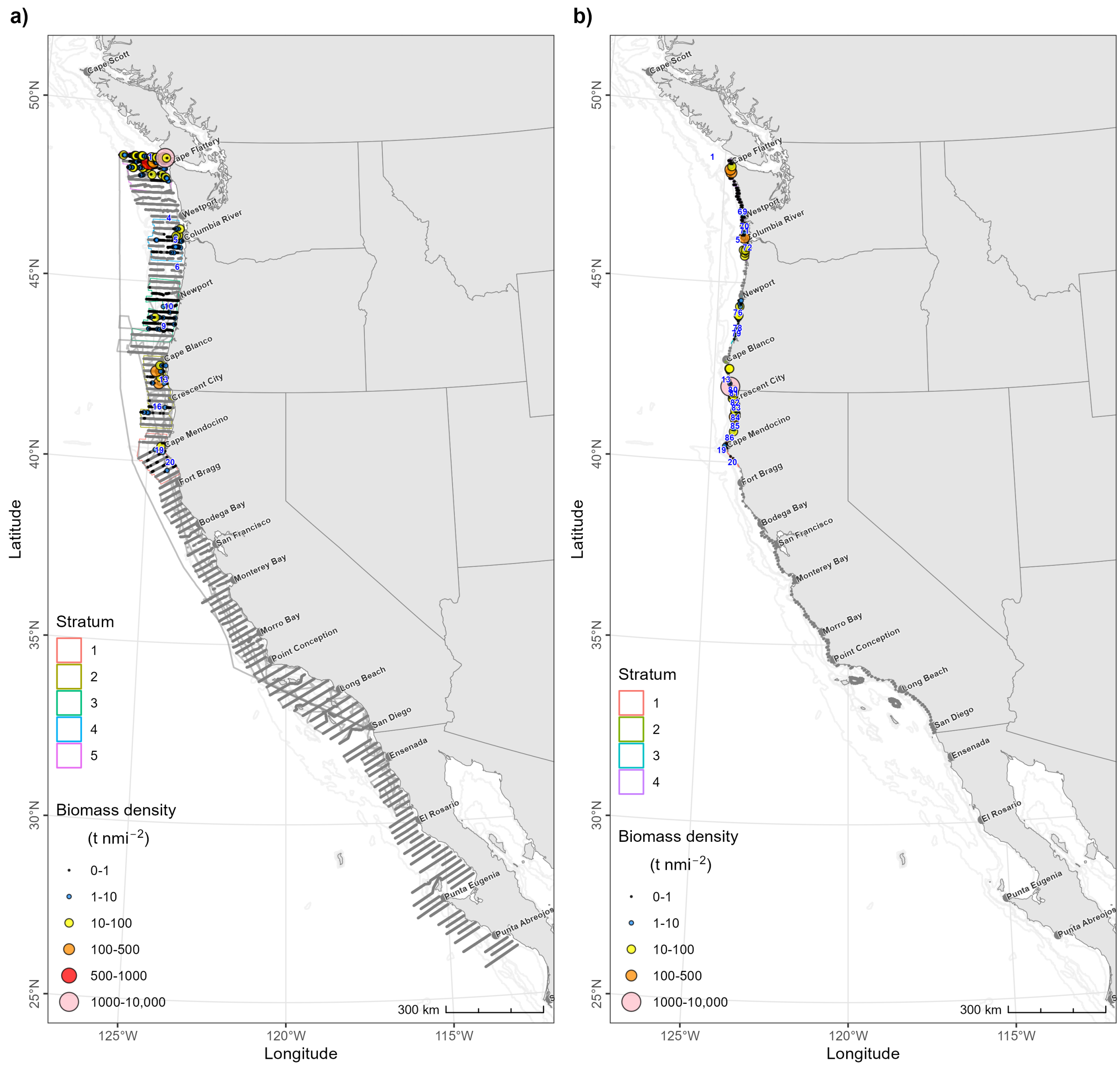

Figure 31: Biomass densities (colored points) of Pacific Herring (*Clupea pallasii*), per stratum, in the a) core and b) nearshore survey regions. The blue numbers represent the locations of trawl clusters in each stratum (colored polygons) with at least one Pacific Herring. Thick gray lines represent acoustic transects.

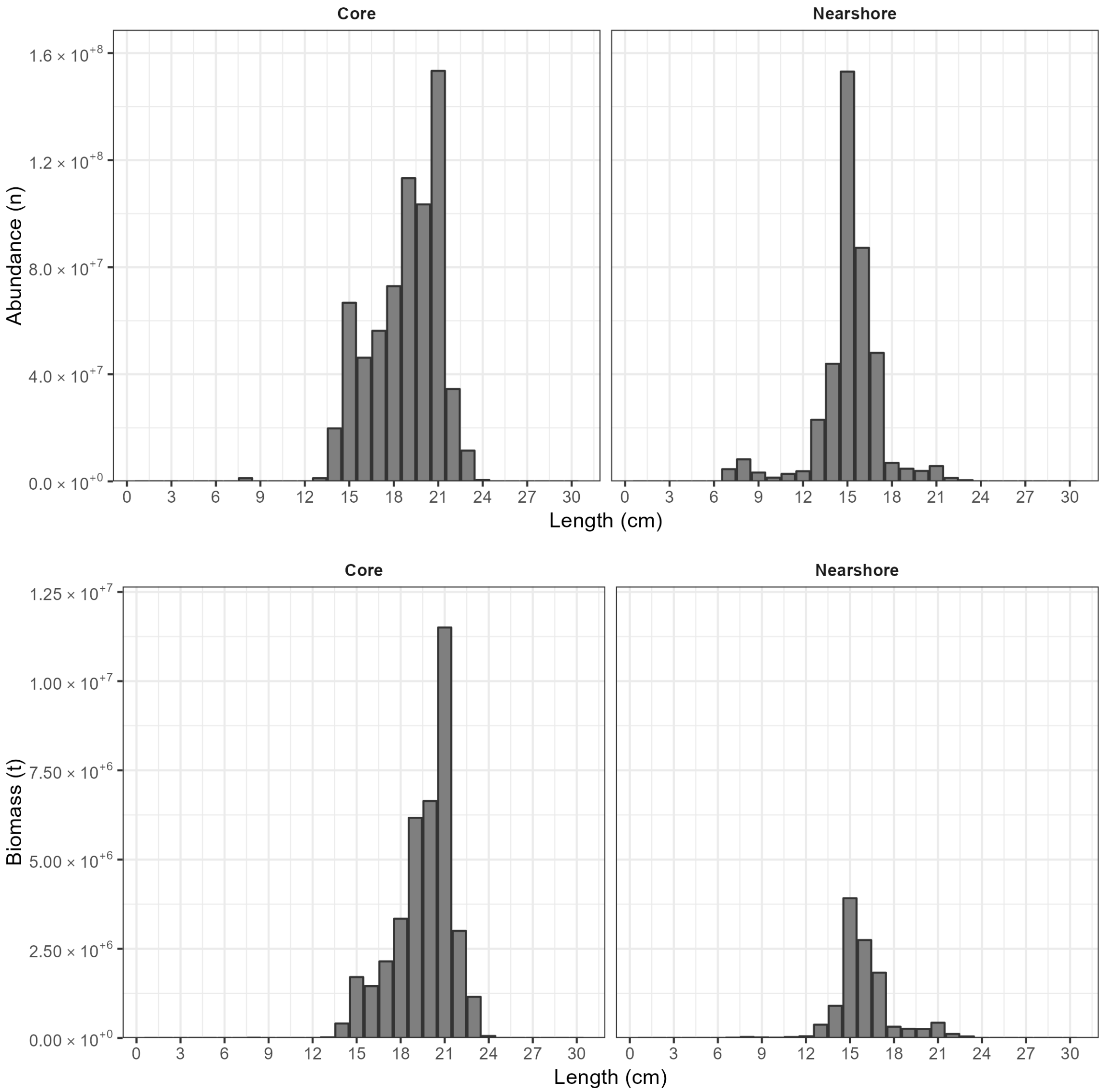

Figure 32: Estimated abundance (upper panel) and biomass (lower panel) versus fork length (L_F, cm) for Pacific Herring (*Clupea pallasii*) in the core and nearshore survey regions.

3.6.6 Round Herring

The total estimated biomass of Round Herring was 18,848 t ($CI_{95\%}$ = 5,071 - 32,421 t, CV = 40%), all in the core region (**Table 20**). The biomass was distributed from approximately El Rosario to Punta Eugenia (**Fig. 33a**). L_F ranged from 14 to 30 cm with modes at 17 and 25 cm (**Table 21**, **Fig. 34**).

Table 20: Biomass estimates (metric tons, t) and their precisions (upper and lower 95% confidence intervals, $CI_{95\%}$; and coefficients of variation, CVs) for Round Herring (*Etrumeus acuminatus*) in the core region. Stratum areas are nmi^2. No Round Herring were caught in the nearshore region.

Stratum					Trawl		Biomass			
Region	Number	Area	Transects	Distance	Clusters	Individuals	$\hat{B}$	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Core	1	14,289	26	1,294	13	722	18,848	5,071	32,421	40
Core	All	14,289	26	1,294	13	722	18,848	5,071	32,421	40
All	**-**	**14,289**	**26**	**1,294**	**13**	**722**	**18,848**	**5,071**	**32,421**	**40**

Table 21: Abundance versus fork length (L_F, cm) for Round Herring (*Etrumeus acuminatus*) in the core region. No Round Herring were caught in the nearshore 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	1,055,457
15	116,664
16	2,228,198
17	23,719,081
18	11,846,797
19	7,153,016
20	7,973,432
21	4,847,006
22	5,040,277
23	16,857,783
24	14,371,162
25	42,925,662
26	751,292
27	563,469
28	2,088,483
29	187,823
30	16,504

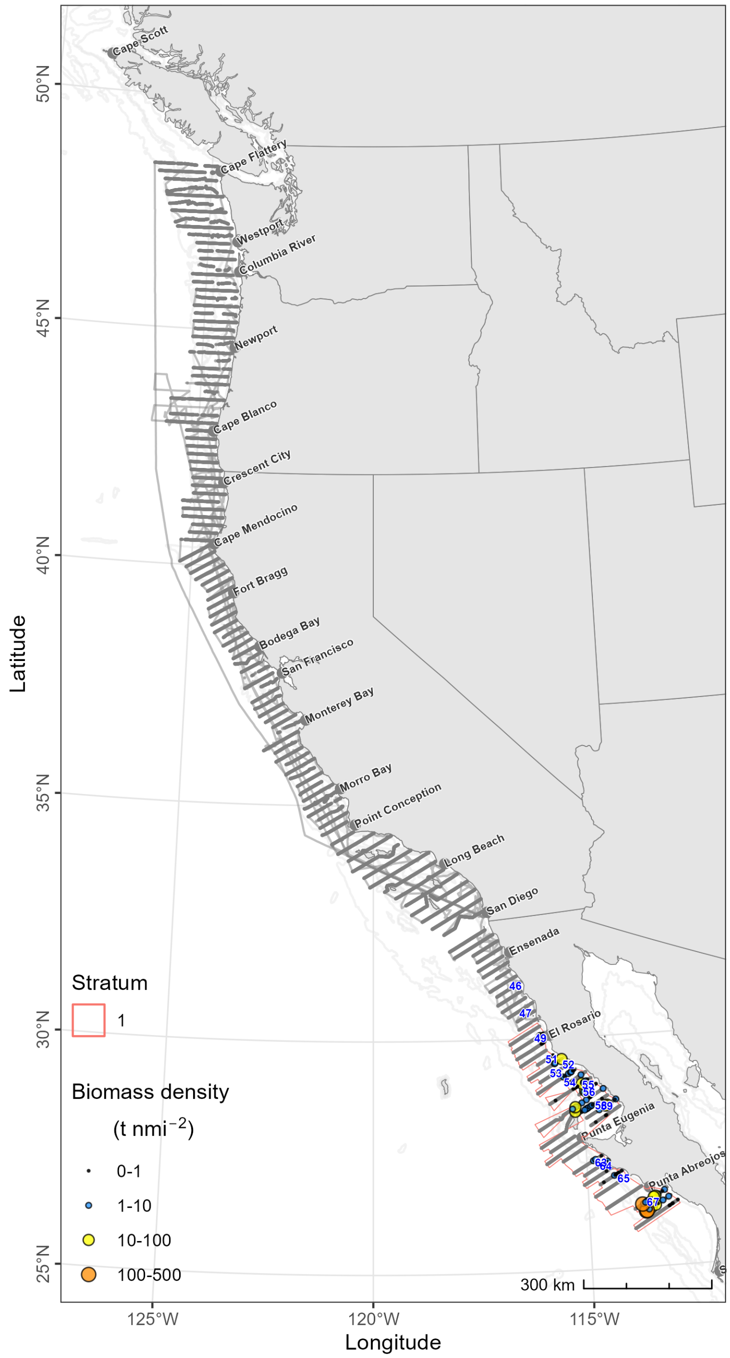

Figure 33: Biomass densities (colored points) of Round Herring (*Etrumeus acuminatus*), per stratum, in the core survey region. The blue numbers represent the locations of trawl clusters in each stratum (colored polygons) in each stratum (colored polygons) with at least one Pacific Herring. Thick gray lines represent acoustic transects. No Round Herring were caught in the nearshore region.

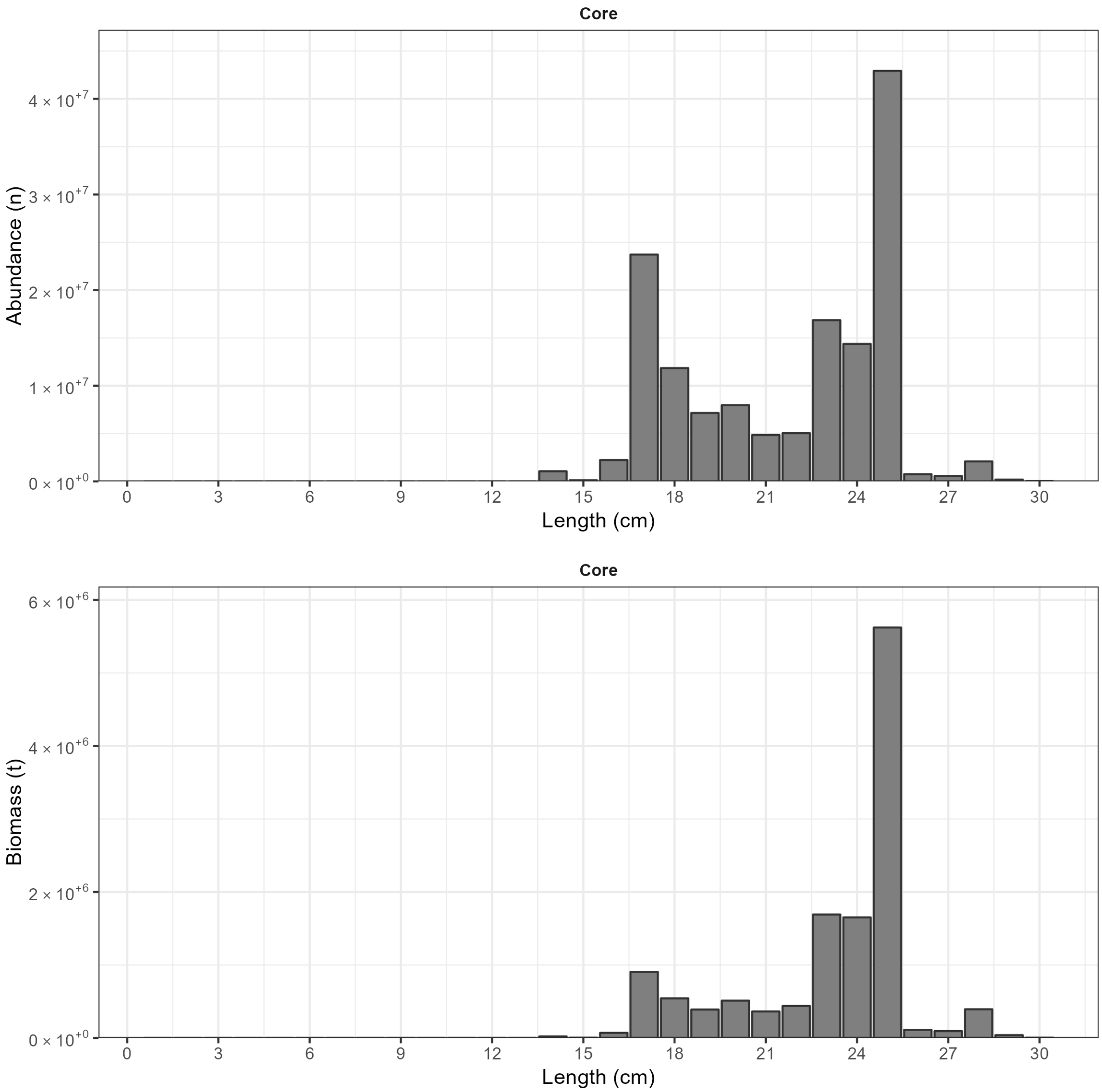

Figure 34: Estimated abundance (upper panel) and biomass (lower panel) versus fork length (L_F, cm) for Round Herring (*Etrumeus acuminatus*) in the core survey region. No Round Herring were caught in the nearshore region.

4 Discussion

The principal objectives of the 86-day, summer 2021 CCE Survey were to estimate the biomasses and distributions of the northern and southern stocks of Pacific Sardine and the northern and central stocks of Northern Anchovy. Secondary objectives were to produce estimates for Pacific Mackerel, Jack Mackerel, Pacific Herring, and Round Herring within the survey area at the time of the survey.

Despite inclement weather conditions, mechanical limitations, and logistical challenges related to the COVID-19 pandemic, *Lasker* surveyed from Cape Flattery to El Rosario off Baja CA, and *Carranza* extended the survey area from El Rosario to ~**10** nmi south of Punta Abreojos.

This is the first time that the SWFSC's ATM sampling was coordinated with INAPESCA's sampling from *Carranza*. This historic collaboration facilitated the sampling of multiple stocks that span the U.S.-Mexico border, and resulted in estimations of the biomasses and distributions of the entire central stock of Northern Anchovy and the entire southern stock of Pacific Sardine. Since no nearshore sampling was conducted off Baja CA, biomass estimates may be negatively biased in that region.

4.1 Biomass and abundance

4.1.1 Northern Anchovy

4.1.1.1 Northern stock The estimated biomass of the northern stock of Northern Anchovy in the survey region north of Cape Mendocino was 8,031 t ($CI_{95\%}$ = 1,624 - 15,893 t) in summer 2021. The northern stock biomass has comprised a small fraction (0.1 to 5.4%) of the total biomass in the ATM surveys conducted in the CCE since at least 2015 (Stierhoff *et al.*, 2021a).

4.1.1.2 Central stock The estimated biomass of the central stock of Northern Anchovy in the survey region was 2,721,689 t ($CI_{95\%}$ = 1,218,459 - 3,353,289 t) in summer 2021, and comprised 75% of the total CPS biomass in summer 2021. The biomass represents a ~2-fold increase over the 1,371,634 t estimated in spring 2021 (Zwolinski *et al.*, 2023) and a ~3.4-fold increase over the 810,634 t estimated for the stock, between San Diego and Fort Bragg, in summer 2019 (Stierhoff *et al.*, 2020). In summer 2021, 6% of the central stock Northern Anchovy biomass was observed in Mexican waters. In 2015, the ATM survey documented a large recruitment to the central stock of Northern Anchovy, and since 2018, the central stock of Northern Anchovy has been the dominant forage fish species in the survey area (**Figs. 36** and **37**).

4.1.2 Pacific Sardine

4.1.2.1 Northern stock Similar to spring 2021 (Zwolinski *et al.*, 2023), the boundary between the northern and southern stocks of Pacific Sardine was San Francisco, based foremost on associations with potential habitat but corroborated by the distributions of biomass density north and south of San Francisco Bay, and differences in length distribution (**Fig. 35**. The estimated biomass of 47,721 t ($CI_{95\%}$ = 14,016 - 90,475 t) in the survey region was a 40% increase in biomass compared to the 33,632 t estimated in summer 2019 (Stierhoff *et al.*, 2020). Since 2014, the ATM biomass of the northern stock of Pacific Sardine has remained less than the 150,000 t rebuilding target adopted by the Pacific Fishery Management Council in 2020[2] (**Figs. 36** and **37**).

[2] https://www.pcouncil.org/documents/2020/08/g-1-attachment-1-pacific-sardine-rebuilding-plan-preliminary-environmental-analysis.pdf/

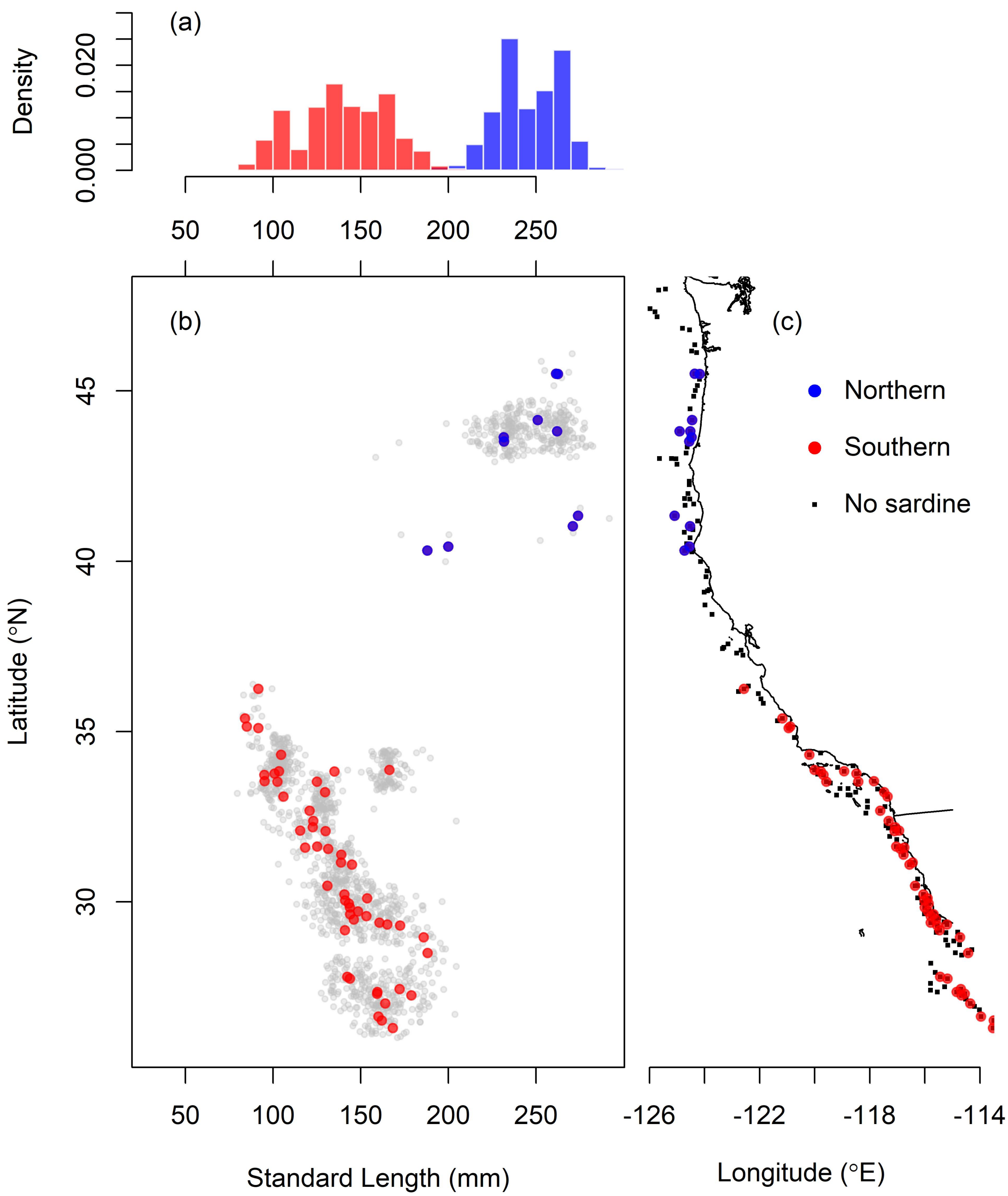

Figure 35: Differentiation of northern (blue) and southern (red) stocks of Pacific Sardine by: a) length distributions; b) individual (grey points) and catch-mean (colored points) lengths at the latitudes of their respective trawls; and c) geographic locations of trawls catches with (colored points) and without (black points) Pacific Sardine.

4.1.2.2 Southern stock

The estimated biomass of the southern stock of Pacific Sardine in the survey region was 196,609 t ($CI_{95\%}$ = 60,237 - 346,360 t). In summer 2021, 63,208 t (strata 2-4; 38% of the total biomass) of southern stock biomass was observed in U.S. waters, and the remaining 101,911 t (stratum 1; 62% of the total biomass) was observed off Baja CA. The southern stock was first observed in U.S. waters by the SWFSC's ATM surveys in 2016 (323 t, Stierhoff *et al.*, 2021b). Southern stock biomass in U.S. waters was 33,093 t in summer 2018 (Stierhoff *et al.*, 2019), and was 14,890 t in summer 2019 (Stierhoff *et al.*, 2020). The summer 2021 survey area was the first to survey south of the U.S.-Mexico border.

4.1.3 Pacific Mackerel

In summer 2021, the estimated biomass of Pacific Mackerel in the survey region was 21,998 t ($CI_{95\%}$ = 15,367 - 34,300 t), which is not different from the 26,577 t estimated in summer 2019, and is within the range of 8,000 t [summer 2013; Zwolinski *et al.* (2014)] to 42,423 t [summer 2017; Zwolinski *et al.* (2019)] estimated during summer surveys since 2013 (**Figs. 36** and **37**).

4.1.4 Jack Mackerel

In summer 2021, the estimated biomass of Jack Mackerel in the survey region, south of Cape Flattery, was 569,793 t ($CI_{95\%}$ = 310,939 - 941,151 t), which is 1.5-fold higher than 391,993 t estimated in summer 2019 (Stierhoff *et al.*, 2020). In summer 2021, Jack Mackerel was the second most abundant CPS overall, and comprised 16% of the total CPS biomass (**Figs. 36** and **37**).

4.1.5 Pacific Herring

In summer 2021, the estimated biomass of Pacific Herring in the survey region, south of Cape Flattery, was 67,920 t ($CI_{95\%}$ = 14,913 - 134,879 t). This was 25.2% of the 269,989 t estimated in summer 2019 (Stierhoff *et al.*, 2020), when the survey also included the west coast of Vancouver Island, Canada (Stierhoff *et al.*, 2020). The summer surveys in 2017 and 2018 also included Vancouver Island. However, in summers 2021, 2018 (Stierhoff *et al.*, 2019), and 2017 (Zwolinski *et al.*, 2019), the stock was closer to shore and more discontinuously distributed compared to summer 2019 when the stock spanned a greater portion of the continental shelf (Stierhoff *et al.*, 2020).

4.1.6 Round Herring

In summer 2021, the estimated biomass of Round Herring in the core survey region was 18,848 t ($CI_{95\%}$ = 5,071 - 32,421 t), and was observed entirely in the southernmost portion of the survey area surveyed by *Lasker* and *Carranza*, between El Rosario and Punta Abreojos. This was the first time the SWFSC's ATM survey has encountered Round Herring and estimated its biomass.

4.2 Ecosystem dynamics: Forage fish community

The acoustic-trawl method (ATM) has been used 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). In 2006, the SWFSC's ATM survey in the CCE was focused on Pacific Sardine (Cutter and Demer, 2008), but evolved to assess the five most abundant CPS (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 and USVs. Also, concurrent satellite- and ship-based measures of their biotic and abiotic habitats are used to provide an ecosystem perspective.

Collectively, these annual or bi-annual ATM surveys provide a unique insight into the dynamics of forage fishes in the CCE, including their distributions, abundances, interactions, and environments. For example, results from 2006 through 2013 indicate that Pacific Sardine dominated the CPS assemblage, but their biomass was declining (Demer and Zwolinski, 2012; Zwolinski and Demer, 2012) and their seasonal migration was contracting (Zwolinski *et al.*, 2014). Meanwhile, harvest rates for the declining stock increased (Demer and Zwolinski, 2017), and the total forage-fish biomass decreased to less than 200,000 t in 2014 and 2015 (**Figs. 36, 37**). The U.S. fishery for Pacific Sardine was closed in 2015 (National Marine Fisheries Service, 2015), and there were reports of mass strandings, deaths, and reproductive failures in Brown Pelicans (*Pelecanus occidentalis*[3]), Common Murres (*Uria aalge*), Brandt's Cormorants (*Phalacrocorax penicillatus*), and California sea lions (*Zalophus californianus*[4]) (McClatchie *et al.*, 2016), all of which depend on forage species. Since 2016, the forage-fish biomass has increased, mainly due to resurgences of Jack Mackerel and the now dominant central stock of Northern Anchovy (**Figs. 36, 37**), whose biomass primarily (2,466,108 t, or 94% of the total estimate biomass) occurred in U.S. waters. Between the summers of 2018 and 2021, the biomass of the southern stock of Pacific Sardine in U.S. waters has increased from 33,093 to 45,332 t.

[3] https://e360.yale.edu/features/brown_pelicans_a_test_case_for_the_endangered_species_act

[4] https://www.fisheries.noaa.gov/national/marine-life-distress/2013-2017-california-sea-lion-unusual-mortality-event-california

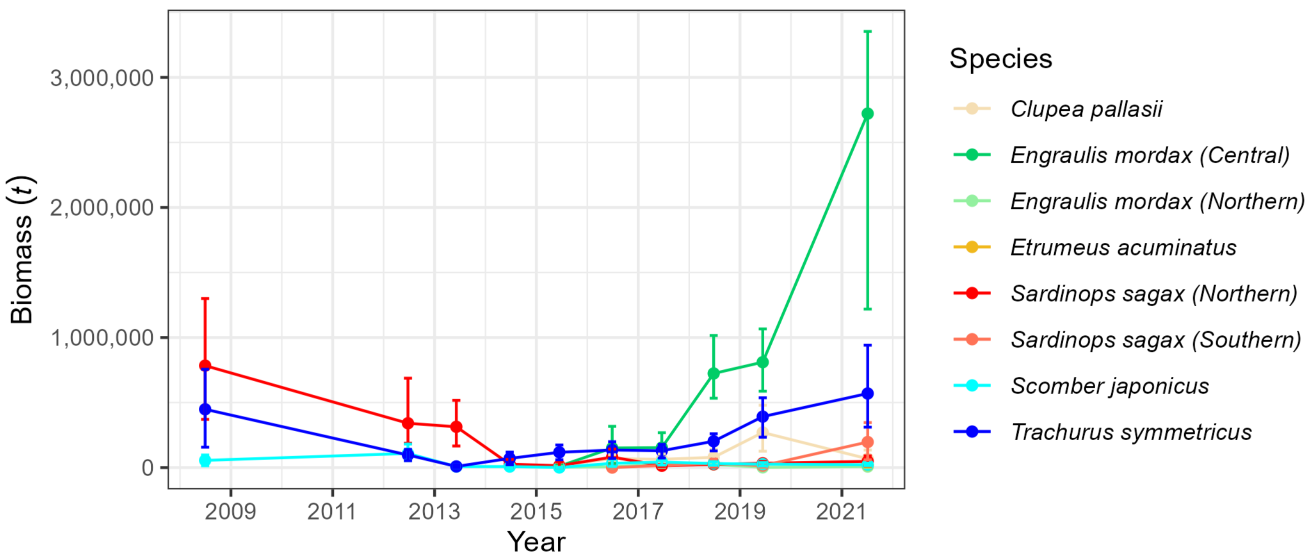

Figure 36: Estimated biomasses (t) of the eight most abundant CPS stocks (six species) in the CCE during summer since 2008. Surveys typically span the area between Cape Flattery and San Diego, but in some years also include Vancouver Island, Canada (2015-2019) and portions of Baja CA (2021). Error bars are 95% confidence intervals.

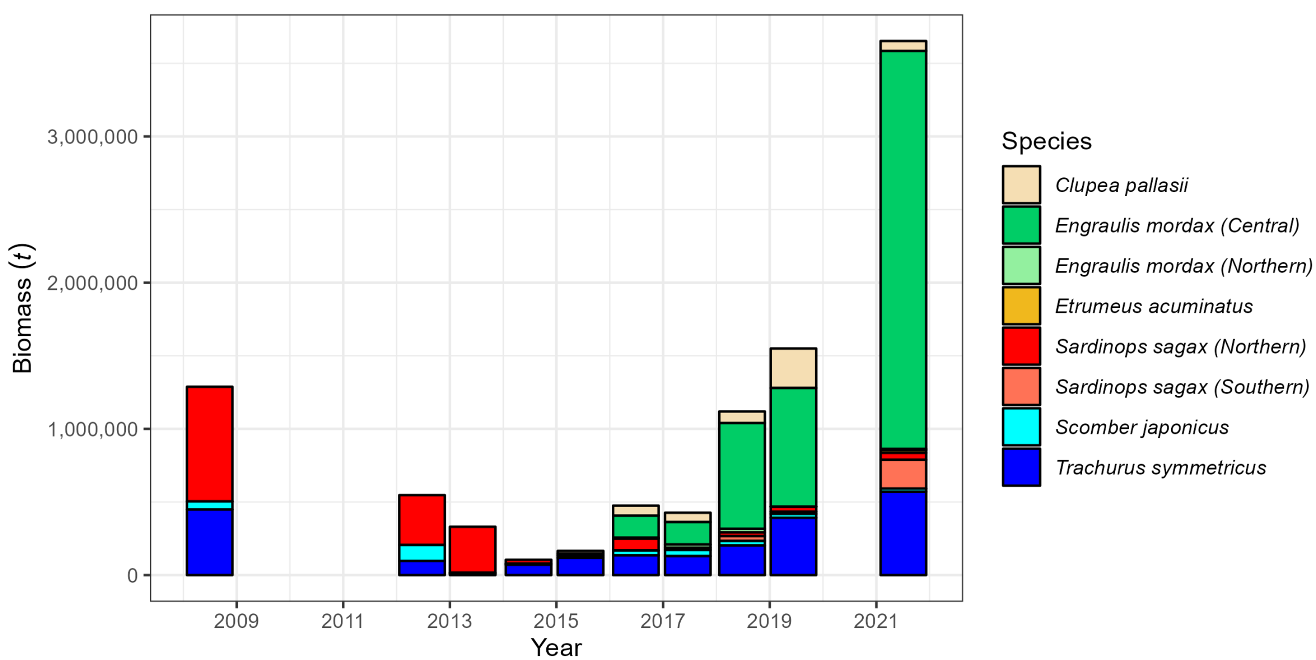

Figure 37: Cumulative estimated biomass (t) of the eight most abundant CPS stocks (six species) in the CCE during summer since 2008. Surveys typically span the area between Cape Flattery and San Diego, but in some years also include Vancouver Island, Canada (2015-2019) and portions of Baja CA (2021).

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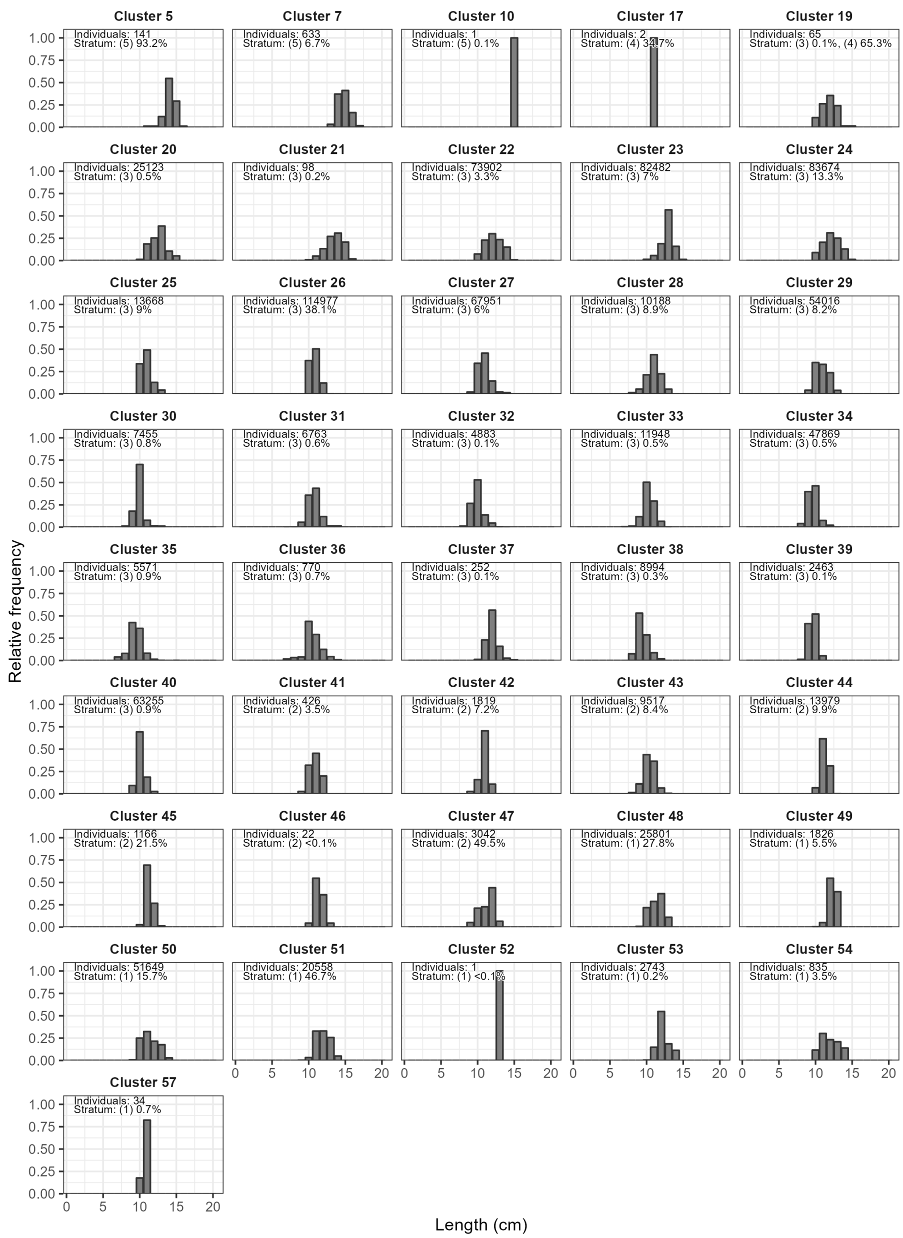
Appendix

A Length distributions and percent biomass by cluster

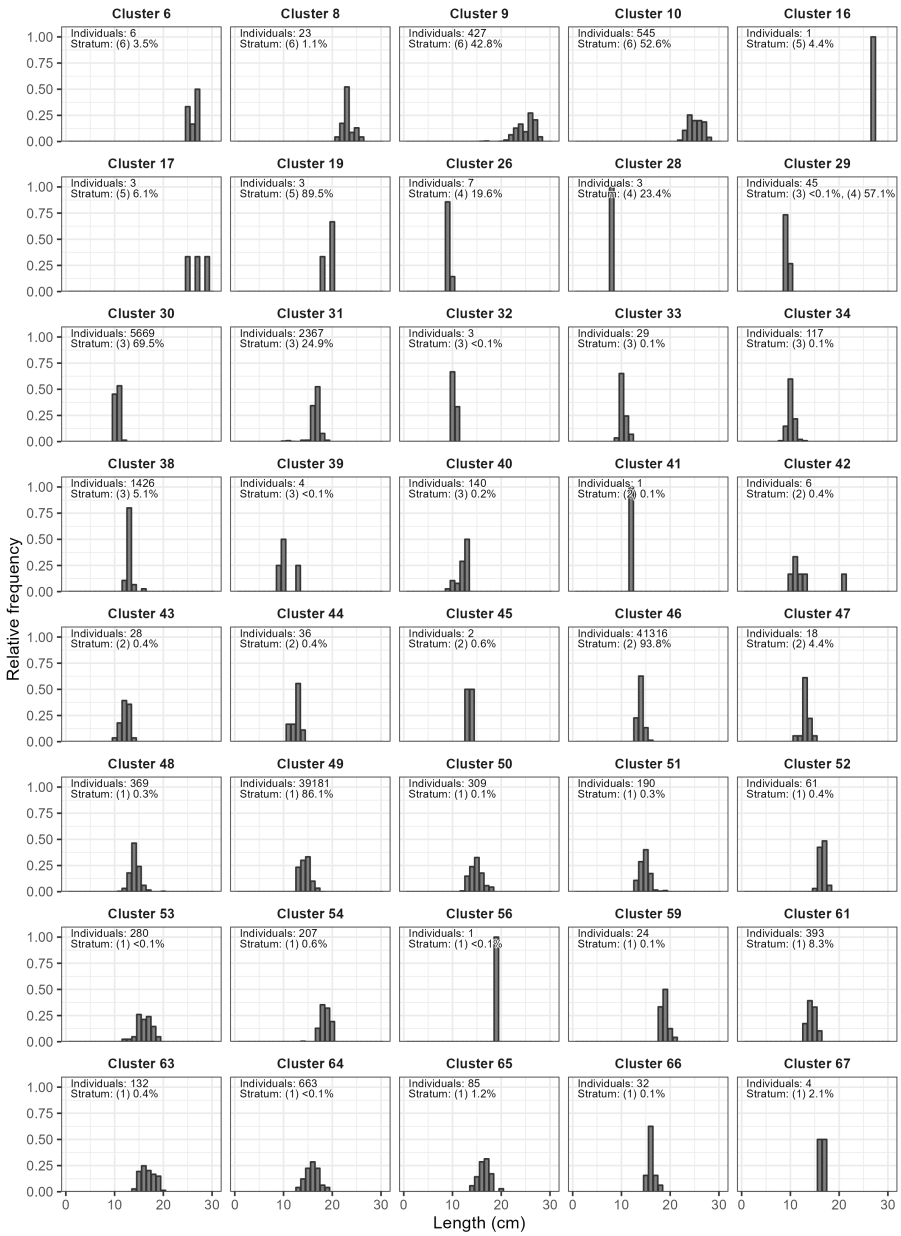
A.1 Northern Anchovy

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.



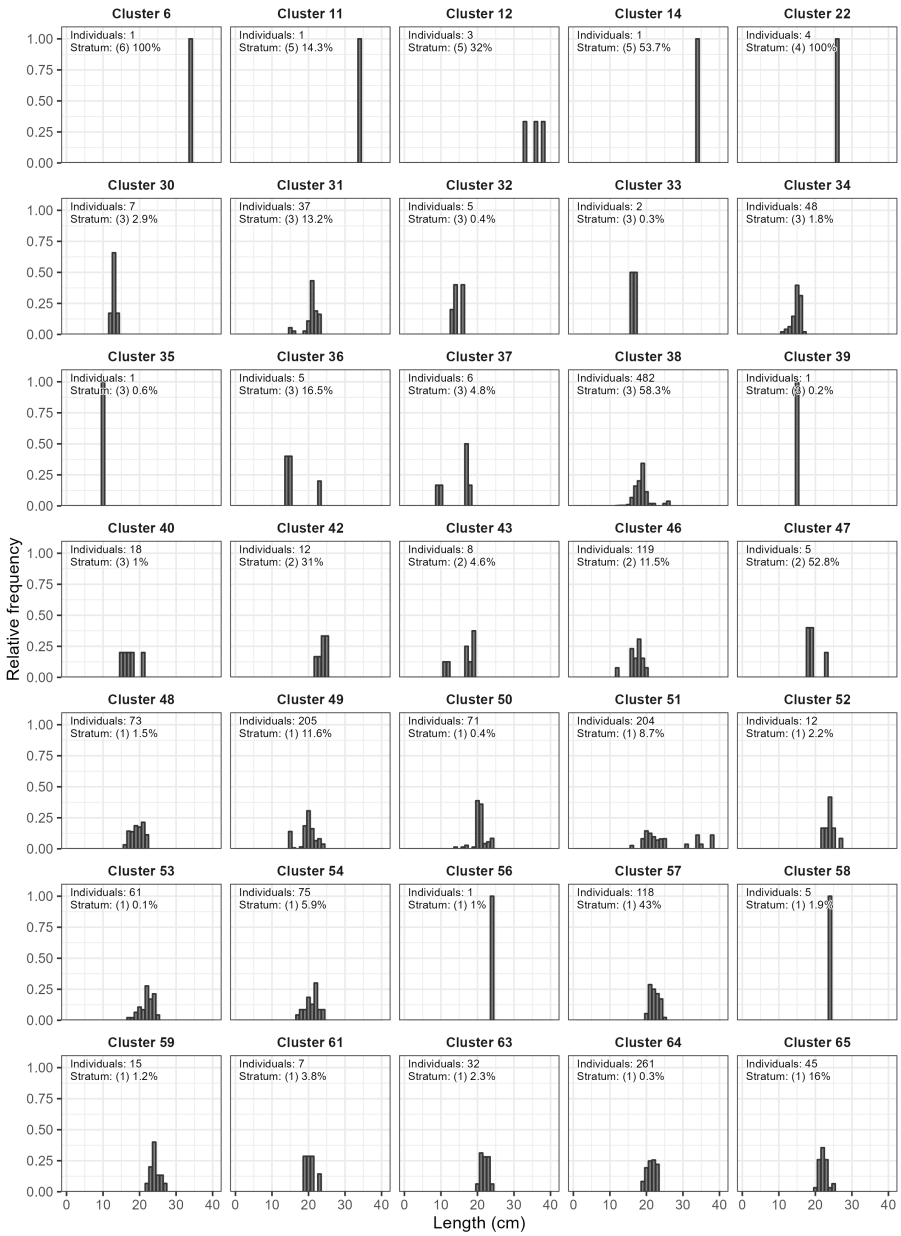
A.2 Pacific Sardine

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.



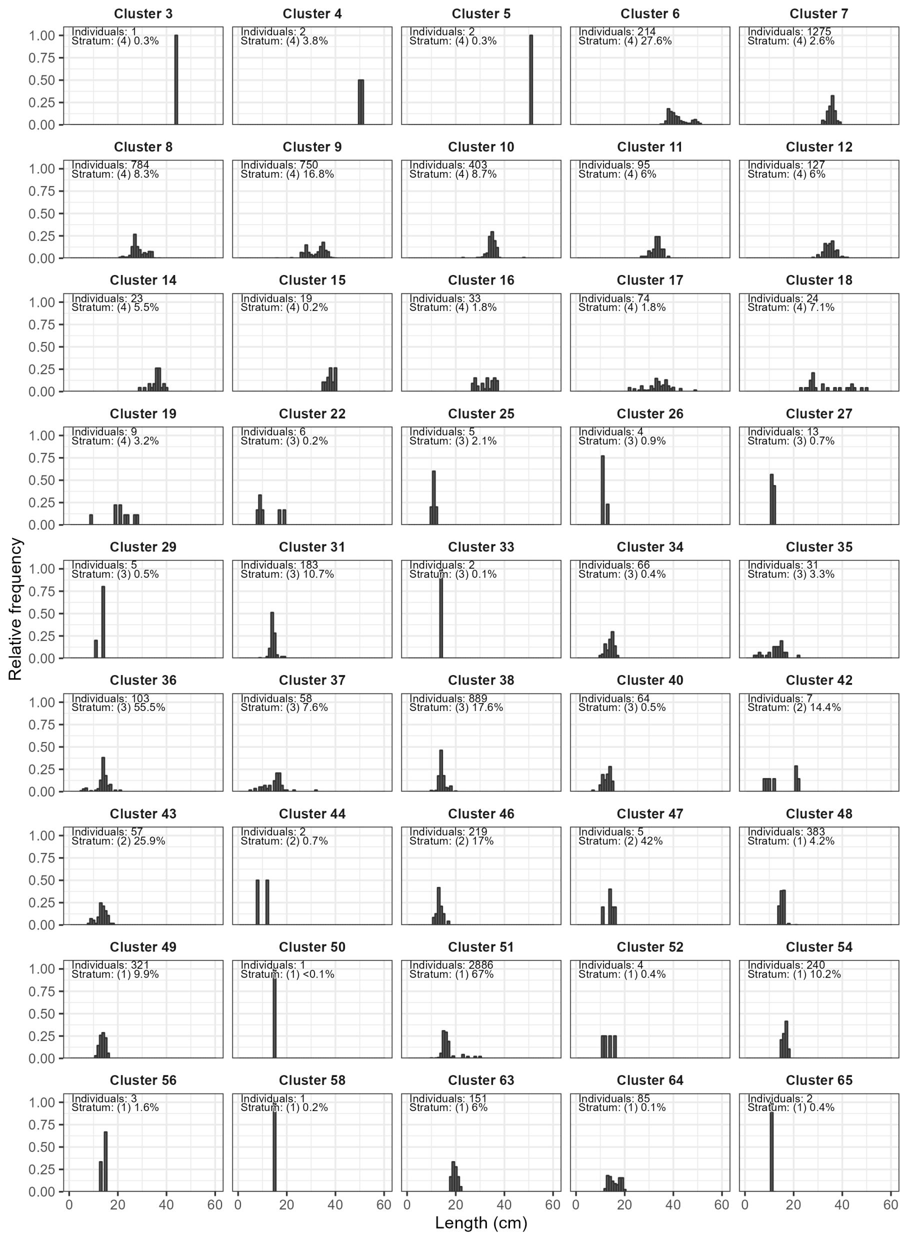
A.3 Pacific Mackerel

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



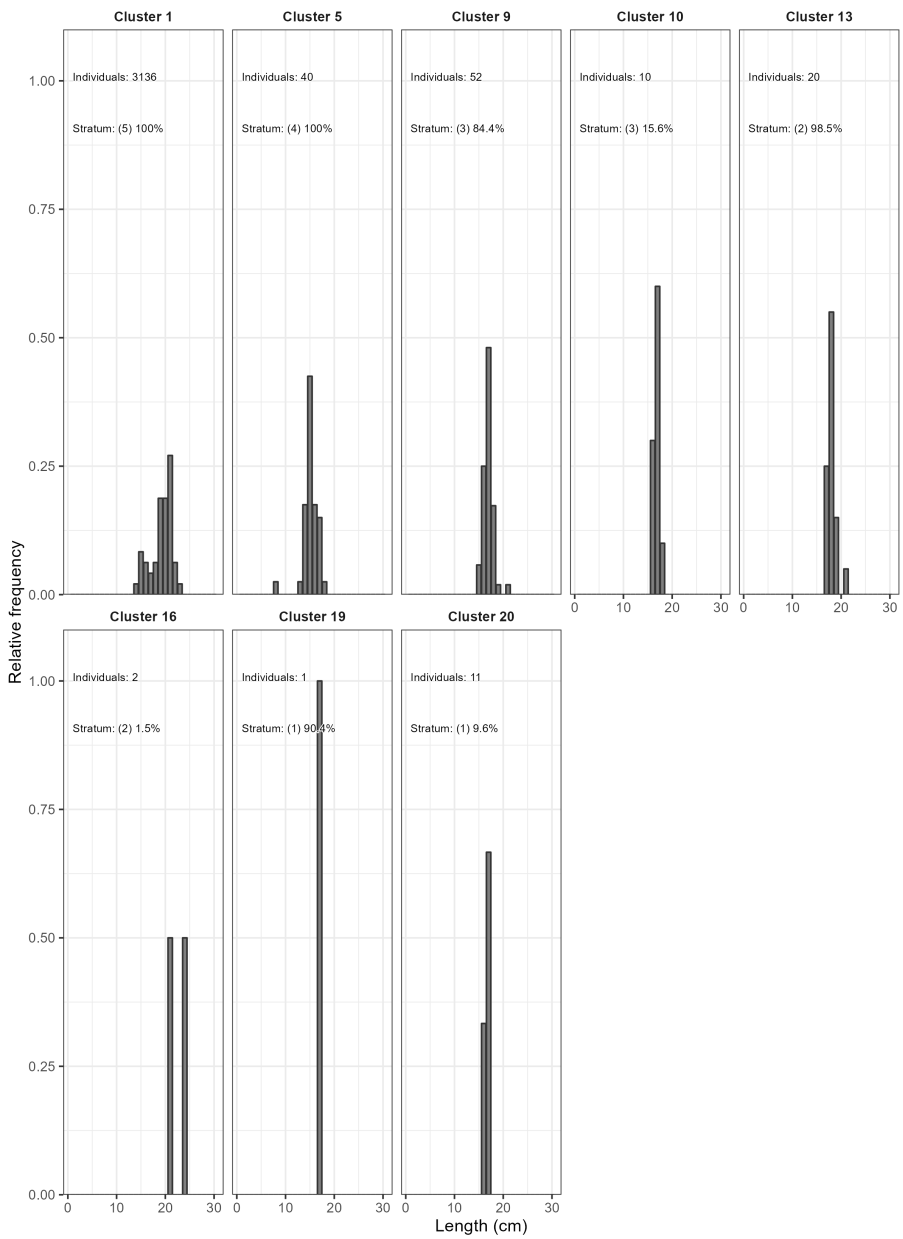
A.4 Jack Mackerel

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.



A.5 Pacific Herring

Fork length (L_F) frequency distributions of Pacific Herring (*Clupea pallasii*) per nighttime trawl cluster, annotated with the number of individuals caught and their percentage contributions to the abundance in each stratum.



A.6 Round Herring

Fork length (L_F) frequency distributions of Round Herring (*Etrumeus acuminatus*) per nighttime trawl cluster, annotated with the number of individuals caught and their percentage contributions to the abundance in each stratum.