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DISTRIBUTION, BIOMASS, AND DEMOGRAPHY OF COASTAL PELAGIC FISHES IN THE CALIFORNIA CURRENT ECOSYSTEM DURING SUMMER 2019 BASED ON ACOUSTIC-TRAWL SAMPLING

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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*, and Pacific Herring *Clupea pallasii*) in the California Current Ecosystem (CCE) off the west coast of North America; and 2) estimates of the biomasses, distributions, and demographies of those CPS in the survey area between 13 June and 9 September 2019. The core survey region spanned most of the continental shelf between the northern tip of Vancouver Island, British Columbia (BC) and San Diego, CA. Throughout the core region, NOAA Ship *Reuben Lasker* (hereafter, *Lasker*) sampled along transects oriented approximately perpendicular to the coast, from the shallowest navigable depth (~30 m) to either a distance of 35 nmi or to the 1,000 fathom (~1830 m) isobath, whichever is farthest. To estimate the biomass of CPS in the nearshore region, to ~10 m depth, where sampling by *Lasker* is unsafe, two fishing vessels (F/Vs *Lisa Marie* and *Long Beach Carnage*) and one unmanned surface vehicle (USV) sampled along 5 nmi-long transects spaced 5 nmi-apart along the mainland coast between Cape Flattery, WA and San Diego, CA, and around Santa Cruz and Santa Catalina Island in the Southern CA Bight (SCB).

For the survey area and period, the estimated biomass of the northern stock of Northern Anchovy was 1,811 t ($CI_{95\%}$ = 374 - 3,909 t, CV = 41%). In the core region, biomass was 1,513 t ($CI_{95\%}$ = 371 - 3,034 t, CV = 47%), and in the nearshore region, biomass was 299 t ($CI_{95\%}$ = 2.71 - 875 t, CV = 84%), or 16% of the total biomass. The northern stock ranged from approximately Westport, WA to Coos Bay, OR and standard length (L_S) ranged from 12 to 18 cm with modes at 15 and 17 cm.

The estimated biomass of the central stock of Northern Anchovy was 810,634 t ($CI_{95\%}$ = 587,317 - 1,066,265 t, CV = 13%). In the core region, biomass was 769,154 t ($CI_{95\%}$ = 559,915 - 984,059 t, CV = 14%), and in the nearshore region, biomass was 41,480 t ($CI_{95\%}$ = 27,402 - 82,206 t, CV = 34%), or 5.1% of the total biomass. The central stock ranged from approximately Fort Bragg to San Diego, CA and L_S ranged from 6 to 16 cm with modes at 8 and 12 cm.

The estimated biomass of the northern stock of Pacific Sardine was 33,632 t ($CI_{95\%}$ = 21,957 - 46,870 t, CV = 19%). In the core region, biomass was 33,138 t ($CI_{95\%}$ = 21,653 - 46,051 t, CV = 19%), and in the nearshore region, biomass was 494 t ($CI_{95\%}$ = 305 - 820 t, CV = 28%), or 1.5% of the total biomass. The northern stock ranged from approximately Astoria, OR to Morro Bay, CA. L_S ranged from 14 to 29 cm with modes at 17 and 24 cm.

The estimated biomass of the southern stock of Pacific Sardine was 14,890 t ($CI_{95\%}$ = 3,488 - 30,022 t, CV = 33%). In the core region, biomass was 8,322 t ($CI_{95\%}$ = 1,945 - 17,422 t, CV = 47%), and in the nearshore region, biomass was 6,568 t ($CI_{95\%}$ = 1,542 - 12,600 t, CV = 45%), or 44% of the total biomass. The southern stock ranged from approximately Pt. Conception to San Diego. L_S ranged from 8 to 19 cm with a mode at 16 cm.

The estimated biomass of Pacific Mackerel was 26,577 t ($CI_{95\%}$ = 12,783 - 38,849 t, CV = 22%). In the core region, biomass was 24,643 t ($CI_{95\%}$ = 12,161 - 35,162 t, CV = 24%), and in the nearshore region, biomass was 1,934 t ($CI_{95\%}$ = 622 - 3,687 t, CV = 40%), or 7.3% of the total biomass. Pacific Mackerel ranged from approximately Astoria to Cape Mendocino, and from Morro Bay to San Diego. Fork length (L_F) ranged from 5 to 35 cm with a modes at 8 and 32 cm.

The estimated biomass of Jack Mackerel was 391,993 t ($CI_{95\%}$ = 233,793 - 536,870 t, CV = 20%). In the core region, biomass was 385,801 t ($CI_{95\%}$ = 231,500 - 527,538 t, CV = 20%), and in the nearshore region, biomass was 6,192 t ($CI_{95\%}$ = 2,293 - 9,333 t, CV = 30%), or 1.6% of the total biomass. Jack Mackerel ranged from approximately Westport to Bodega Bay, CA, and from Morro Bay to San Diego. Fork length (L_F) ranged from 3 to 52 cm with modes at 7, 21-22, and 28-32 cm.

The estimated biomass of Pacific Herring was 269,989 t ($CI_{95\%}$ = 126,306 - 479,736 t, CV = 34%). In the core region, biomass was 267,792 t ($CI_{95\%}$ = 125,864 - 476,899 t, CV = 35%), and in the nearshore region, biomass was 2,197 t ($CI_{95\%}$ = 442 - 2,838 t, CV = 31%), or 0.81% of the total biomass. Pacific Herring ranged from approximately Cape Scott, BC to Coos Bay and L_F ranged from 13 to 25 cm with modes at 15 and 22 cm.

In **Appendix B** is an exploration of the potential magnitudes of CPS biomasses in the region farther offshore than the aforementioned core and nearshore survey regions. Offshore biomasses were sampled by *Lasker* and two USVs along 100 nmi-long transect extensions spaced 80 nmi-apart between Florence, OR and San Diego.

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 that 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 Pacific Sardine stock typically migrates south to its spawning grounds, generally off central and southern California (Demer *et al.*, 2012) and occasionally off Oregon and Washington (Lo *et al.*, 2011). These migrations vary in extent with population size; fish age and length; and oceanographic conditions. For example, the transition zone chlorophyll front (TZCF; Polovina *et al.*, 2001) may delineate the offshore and southern 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 California Bight, 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 Washington and Oregon and the central stock is located off Central and Southern California. Whether a species migrates or remains in an area depends on its reproductive and feeding behaviors and affinity to certain oceanographic or seabed habitats.

Acoustic-trawl method (ATM) surveys, which combine information collected with echosounders and nets, were introduced to the CCE more than 45 years ago to survey CPS off the west coast of the U.S. (Mais, 1974, 1977; Smith, 1978). Following a two-decade hiatus, the ATM was reintroduced in the CCE in spring 2006 to sample the then abundant Pacific Sardine population (Cutter and Demer, 2008). Since then, this sampling effort has continued and expanded through annual or semi-annual surveys (Zwolinski *et al.*, 2014). Beginning in 2011, the ATM estimates of Pacific Sardine abundance, age structure, and distribution have been incorporated in the annual assessments of the northern stock (Hill *et al.*, 2017). Additionally, ATM survey results are applied to estimate the abundances, demographies, and distributions of epipelagic and semi-demersal fishes (e.g., Swartzman, 1997; Williams *et al.*, 2013; Zwolinski *et al.*, 2014) and plankton (Hewitt and Demer, 2000).

This document, 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, calibrated multifrequency 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 central or northern stock other 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., 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.*, 2009).

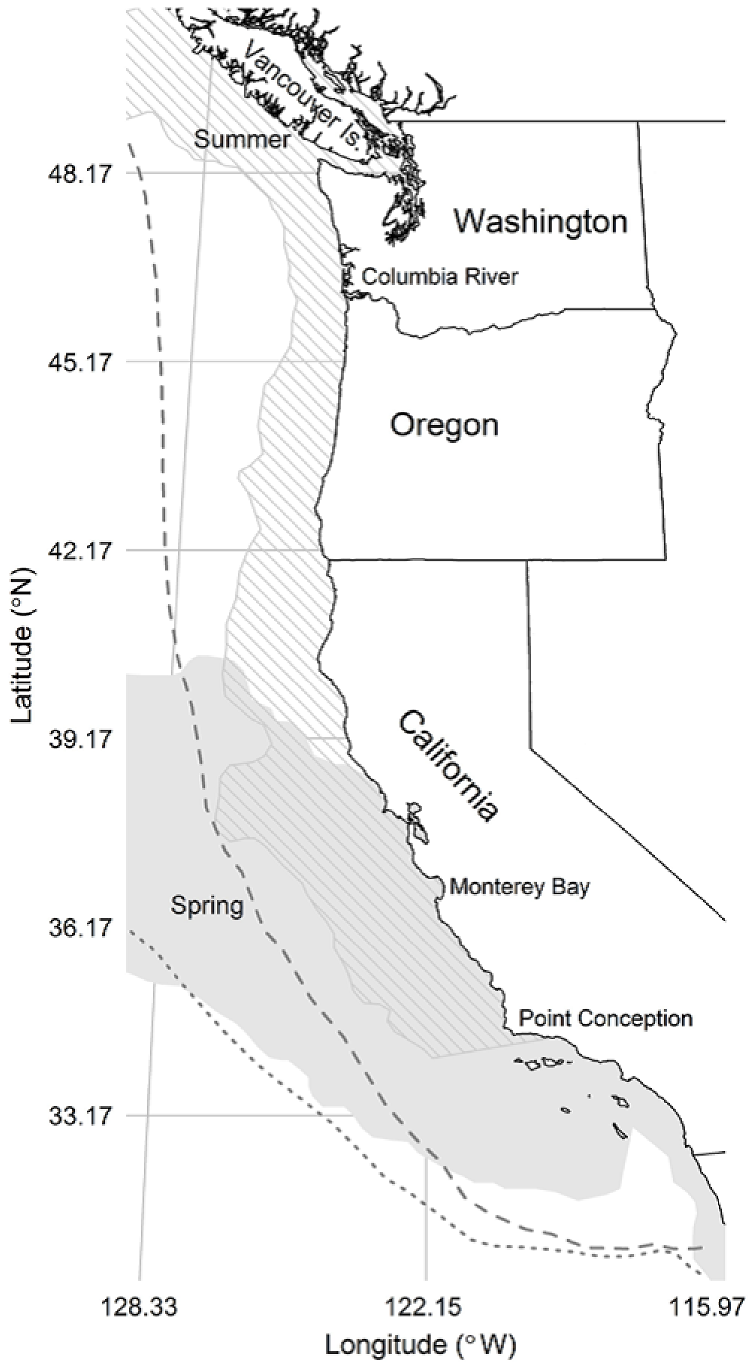

Figure 1: Conceptual spring (shaded region) and summer (hashed region) distributions of potential habitat for the northern stock of Pacific Sardine along the west coasts of Mexico, the United States, and Canada. The dashed and dotted lines represent, respectively, the approximate summer and spring positions 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 Southern California Bight (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.*, 2009; Renfree *et al.*, 2009). Variations in echo intensity across frequencies, known as echo spectra, often indicate the taxonomic groups contributing to the echoes. The CPS, with highly reflective swim bladders, create high intensity echoes of sound pulses at all echosounder frequencies (e.g., Conti and Demer, 2003). In contrast, krill, with acoustic properties closer to those of the surrounding sea-water, produce lower intensity echoes, particularly at lower frequencies (e.g., Demer *et al.*, 2003). The echo energy attributed to CPS, based on empirical echo spectra (Demer *et al.*, 2012), are apportioned to species using trawl-catch proportions (Zwolinski *et al.*, 2014).

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

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 50-80 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 focus on the northern stock of Northern Anchovy. During spring and summer, the biomasses of other CPS (e.g., Pacific Mackerel, Jack Mackerel, and Pacific Herring) present in the survey area are estimated.

In summer 2019, the ATM survey performed aboard *Lasker* was augmented with coordinated sampling by two fishing vessels, *Lisa Marie* and *Long Beach Carnage*, and three Saildrone USVs to estimate the biomasses of CPS in offshore and nearshore regions where sampling by *Lasker* was not possible or safe.

Presented here are 1) a detailed description of the ATM used to survey CPS in the CCE off the west coast of North America; and 2) estimates of the abundance, biomass, size structure, and distribution of CPS, specifically the northern and southern stock of Pacific Sardine; the northern and central stock of Northern Anchovy; Pacific Mackerel; Jack Mackerel; and Pacific Herring for the core and nearshore survey regions. Estimates of the abundance, biomass, size structure, and distribution of CPS in the offshore survey region is presented in **Appendix B**. Additional details about the survey may be found in the survey report (Stierhoff *et al.*, 2020).

2 Methods

2.1 Data collection

2.1.1 Survey design

The summer 2019 survey was conducted principally using *Lasker*. The sampling domain, between Cape Scott, British Columbia at the northern end of Vancouver Island and San Diego, CA, was defined by the modeled distribution of potential habitat for the northern stock of Pacific Sardine at the beginning of the survey (**Fig. 2a**), and information recently gathered from other research projects [e.g., California Cooperative Oceanic Fisheries Investigations (CalCOFI) samples] or the fishing industry (e.g., catch and bycatch data). This area encompassed the anticipated distributions of the northern stock of Pacific Sardine and the central and northern stocks of Northern Anchovy off the west coasts of the U.S. and Canada from approximately San Diego, CA to Cape Scott, BC, but also spanned portions of the southern stock of Pacific Sardine, Pacific Mackerel, Jack Mackerel, and Pacific Herring (**Fig. 2b-d**). East to west, the sampling domain extends from the coast to at least the 1,000 fathom (~1830 m) isobath (**Fig. 3**). Considering the expected distribution of the target species, the acceptable uncertainty in biomass estimates, and the available ship time (77 days at sea, DAS), the principal survey objectives were the estimations of biomass for the northern and southern stocks of Pacific Sardine and the northern and central stocks of Northern Anchovy in the survey regions. Additionally, biomass estimates were sought for Pacific Mackerel, Jack Mackerel, and Pacific Herring in the survey regions.

Additional sampling was conducted: 1) nearshore along 5-nmi-long transects spaced 5 nmi apart between San Francisco and Pt. Conception using a wind- and solar-powered unmanned surface vehicle (USV; Saildrone, Inc.) equipped with dual-frequency (38 and 200 kHz) echosounders (orange lines, **Fig. 3**); and 2) offshore by *Lasker* and two USVs along 21 ~100-nmi-long transects between central OR and San Diego (solid black and dashed green lines, **Fig. 3**). The goal of the nearshore sampling was to estimate the abundance and biomass of the central stock of Northern Anchovy and northern stock of Pacific Sardine close to shore, in shallow water, or both, where *Lasker* could not safely navigate. The goal of the offshore sampling was to estimate the abundance and biomass of CPS in areas not routinely sampled during past ATM surveys. Detailed methods from the offshore sampling is presented in **Appendix B.1**.

Systematic surveys are used to estimate biomasses of clustered populations with strong geographical trends (Fewster *et al.*, 2009). However, when sampling small, dispersed populations, systematic designs may oversample areas with low biomass. In these situations, the survey domain may be first surveyed with coarse resolution, and then sampling may be added in areas with the most biomass (Manly *et al.*, 2002). This two-stage approach results in smaller estimates of variance compared to those from random systematic or fully random sampling designs (Francis, 1984).

The survey of CPS in the CCE merges the concepts of systematic and adaptive sampling designs in a novel, one-stage hybrid design. The survey includes a grid of compulsory, parallel transects spaced by either 10 or 20 nmi. The location of the 10-nmi-spaced compulsory grid is decided *a priori* and applied in areas with high diversity and abundance during past surveys. The sampling intensity in the compulsory grid is fixed, constituting a systematic design. Elsewhere, the maximum transect spacing is 20 nmi, but transect spacing may be adaptively decreased where CPS echoes, eggs, or catches are observed in high densities. An adaptive event adds a minimum of three transects to the 20-nmi-compulsory design to create a stratum with a minimum of seven contiguous 10-nmi-spaced transects.

During CPS surveys progressing from north to south, if CPS are observed during a compulsory 20-nmi-spaced transect, an adaptive transect is added 10 nmi to the north. After completion of the first adaptive transect, a second one is added 20 nmi to the south. This is followed by a compulsory transect and then a third adaptive transect. If CPS are encountered on the following compulsory transect, then an additional adaptive transect is added. If not, the next compulsory transect is sampled. This approach is an efficient application of the available sampling effort to optimize the precision of estimated biomass for patchily distributed populations within the survey domain.

Because the sampling density is adaptively increased in areas with CPS, the inherent sampling heterogeneity requires post-stratification (see **Section 2.4.1**). This combination of adaptive sampling and post-survey stratification reduces the sampling variance without introducing sampling bias. The transects are perpendicular to the coast, extending from the shallowest navigable depth (~30 m) to either a distance of 35 nmi or to the 1,000 fathom isobath, whichever is farthest (**Fig. 3**). 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.

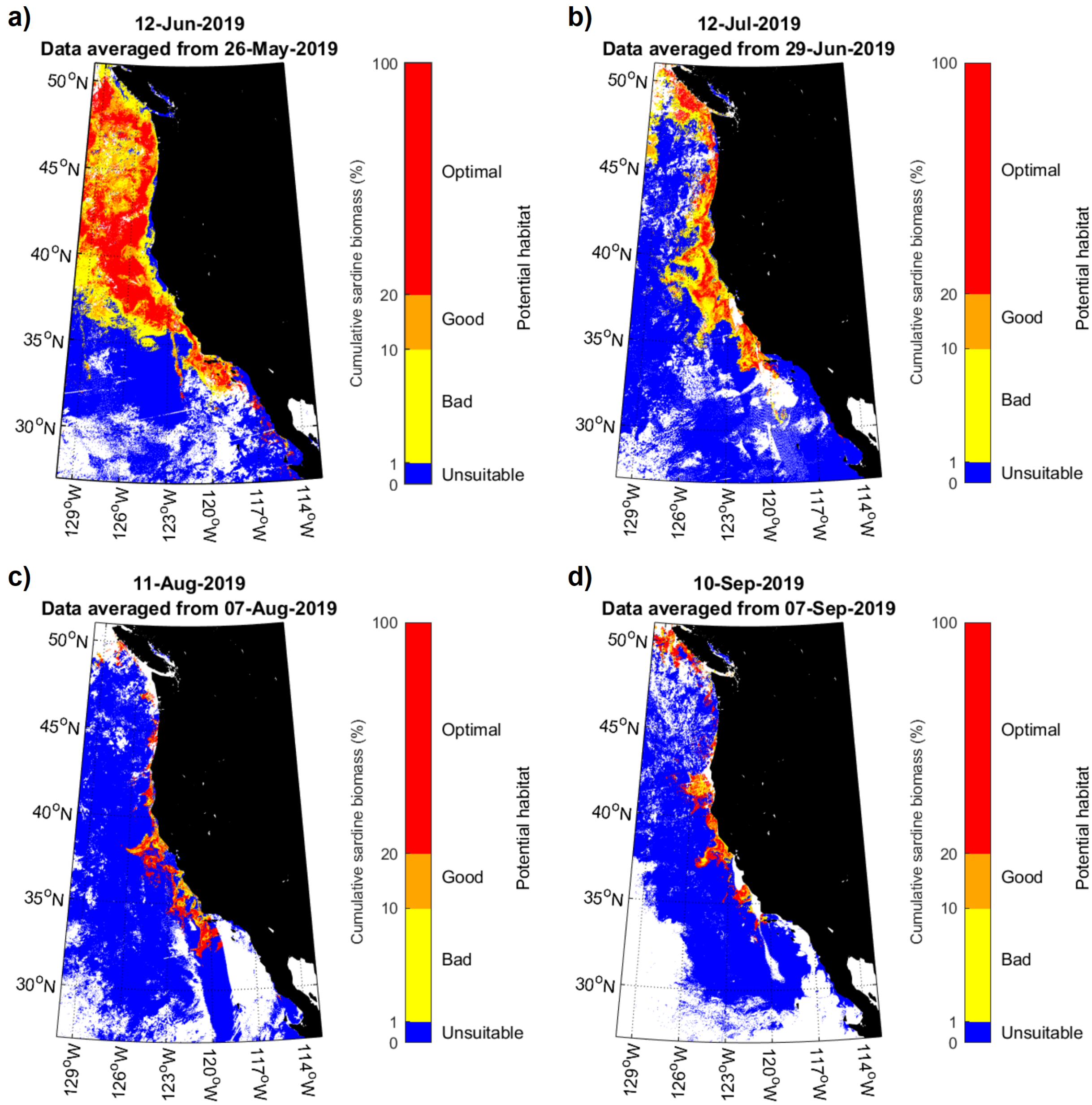

Figure 2: Distribution of potential habitat for the northern stock of Pacific Sardine (a) before, (b, c) during, and (d) at the end of the summer 2019 survey.

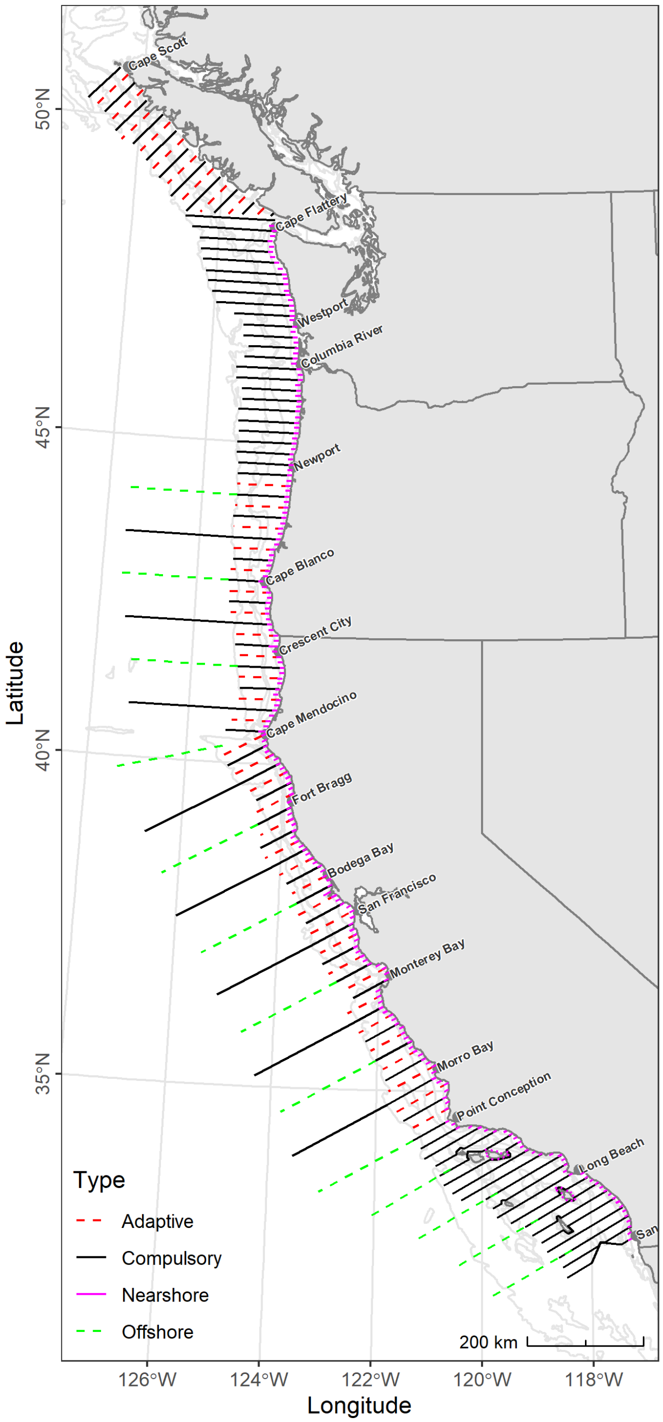

Figure 3: Planned compulsory (solid black lines) and adaptive (dashed red lines) transect lines to be sampled by *Lasker*; offshore extensions to compulsory acoustic transects sampled by USVs (dashed green lines); and nearshore transect lines sampled by USVs and fishing vessels (solid magenta lines). Isobaths (light gray lines) are placed at 50, 200, 500, and 2,000 m (or approximately 25, 100, 250, and 1,000 fathoms).

2.1.2 Acoustic sampling

2.1.2.1 Acoustic equipment On *Lasker*, multi-frequency General Purpose Transceivers (18- and 38-kHz EK60 GPTs; Simrad) and Wideband Transceivers (70-, 120-, 200-, and 333-kHz EK80 WBTs; Simrad) were configured with split-beam transducers (ES18-11, ES38B, ES70-7C, ES120-7C, ES200-7C, and ES333-7C, respectively; Simrad). The transducers were mounted on the bottom of a retractable keel or "centerboard" (**Fig. 4**). The keel was retracted (transducers ~5-m depth) during calibration, and extended to the intermediate position (transducers ~7-m depth) during the survey. Exceptions were made during shallow water operations, when the keel was retracted; or during times of heavy weather, when the keel was extended (transducers ~9-m depth) to provide extra stability and reduce the effect of weather-generated noise. In addition, acoustic data were also collected using a multibeam echosounder (ME70, Simrad), multibeam sonar (MS70, Simrad), and scanning sonar (SX90, Simrad). Transducer position and motion were measured at 5 Hz using an inertial motion unit (POS-MV, Trimble/Applanix).

On the three USVs (SD-1045, SD-1046, and SD-1047), a miniature Wide Band Transceiver (WBT Mini, Simrad) was configured with a gimbaled, keel-mounted, dual-frequency transducer (ES38-18|200-18C, Simrad), containing a split-beam 38 kHz and single-beam 200 kHz with nominally 18° beamwidths. On *Lisa Marie*, the SWFSC's echosounder (Simrad EK60 GPT) was connected to the vessel's hull-mounted 38-kHz split-beam transducer (Simrad ES38-B). On *Long Beach Carnage*, the SWFSC's multi-frequency echosounders (38-, 70-, 120-, and 200-kHz EK60 GPTs; Simrad) were configured with the SWFSC's multi-frequency transducer array (MTA4) with split-beam transducers (ES38-12, ES70-7C, ES120-7C and ES200-7C; Simrad) mounted on the bottom of a pole.

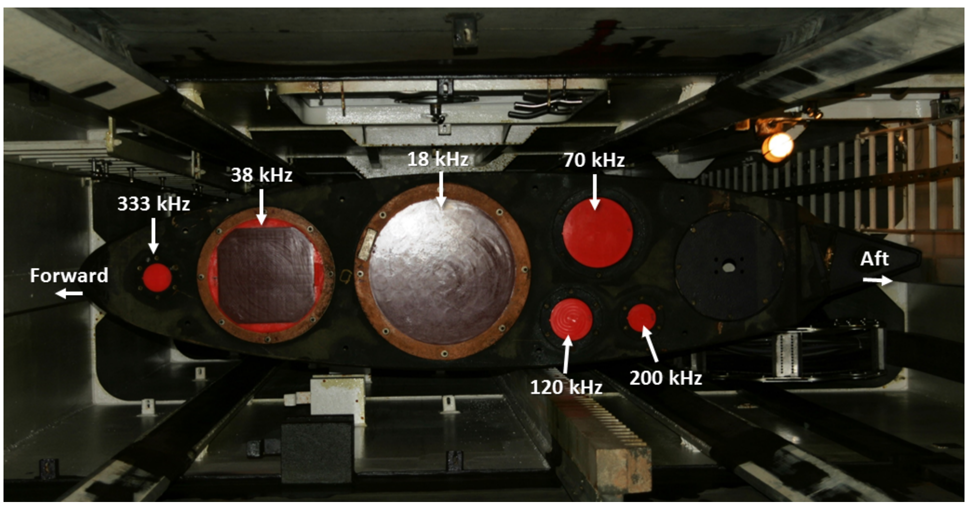

Figure 4: Echosounder transducers mounted on the bottom of the retractable centerboard on *Lasker*. During the survey, the centerboard was extended, typically positioning the transducers at ~2 m below the keel at a water depth of ~7 m.

2.1.2.2 Echosounder calibrations

2.1.2.2.1 ***Lasker*** First, the transducer integrities were verified through transducer-impedance measurements in water and air using an inductance-capacitance-resistance (LCR) meter (Agilent E4980A) and custom software (Matlab, MathWorks). The impedance magnitude ($|Z|$,), phase (θ, °), conductance (G, S), susceptance (B, S), resistance (R,), and reactance (X,) were measured over broadband frequency ranges for each transducer quadrants connected in parallel. Impedance measurements are presented in the survey report (Stierhoff *et al.*, 2020).

Next, the echosounder systems aboard *Lasker* were calibrated between 30 April and 4 May 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 chirp 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); calibrations of WBTs in FM mode used both the WC38.1 and a smaller 25 mm WC sphere. A CTD was cast to measure temperature and salinity versus depth, to estimate sound speeds at the transducer and sphere depths, and the time-averaged sound speed and absorption coefficients for the range between them. The theoretical target strength (TS; dB re 1 m^2) of the sphere was calculated using the Standard Sphere Target Strength Calculator[1] and values for the sphere, sound-pulse, and seawater properties. The sphere was positioned throughout the main lobe of each of the transducer beams using three motorized downriggers, two on one side of the vessel and one on the other. The GPTs and WBTs were configured using the calibration results via the control software (EK80 v1.12.2, Simrad; **Table 1**). Calibration results for WBTs in FM mode are presented in the survey report (Stierhoff *et al.*, 2020) and are avaialble upon request.

Table 1: EK60 general purpose transceiver (GPT, Simrad) information, pre-calibration settings, and beam model results following calibration (below the horizontal line). Prior to the survey, on-axis gain (G_0), beam angles and angle offsets, and S_A Correction ($S_\mathrm{A}$corr) values from calibration results were entered into ER60.

		Frequency (kHz)					
	Units	18	38	70	120	200	333
Model		ES18-11	ES38B	ES70-7C	ES120-7C	ES200-7C	ES333-7C
Serial Number		2116	31206	233	783	513	124
Transmit Power (p_et)	W	2000	2000	600	200	90	31
Pulse Duration (τ)	ms	1.024	1.024	1.024	1.024	1.024	1.024
On-axis Gain (G_0)	dB re 1	21.31	25.38	27.61	27.07	27.69	23.97
S_a Correction ($S_\mathrm{a}$corr)	dB re 1	-0.84	0.09	0.04	-0.01	0.04	0
Bandwidth (W_f)	Hz	1570	-	-	-	-	-
Sample Interval	m	0.194	0.256	0.048	0.04	0.032	0.024
Eq. Two-way Beam Angle ( )	dB re 1 sr	-17.1	-20.4	-20.3	-20.2	-20.2	-19.6
Absorption Coefficient (α_f)	dB km^{-1}	2	7.953	22.304	45.536	72.175	101.978
Angle Sensitivity Along. (Λ_α)	Elec.°/Geom.°	13.9	-	-	-	-	-
Angle Sensitivity Athw. (Λ_β)	Elec.°/Geom.°	13.9	-	-	-	-	-
3-dB Beamwidth Along. ($\alpha_{-3\mathrm{dB}}$)	deg	12.15	6.99	6.7	6.46	6.28	6.29
3-dB Beamwidth Athw. ($\beta_{-3\mathrm{dB}}$)	deg	11.95	7.06	6.67	6.45	6.46	6.24
Angle Offset Along. (α_0)	deg	0	0.05	-0.04	0.08	-0.43	-0.02
Angle Offset Athw. (β_0)	deg	-0.24	0.04	-0.02	0.03	-0.04	0.04
Theoretical TS (TS_theory)	dB re 1 m^2	-42.36	-42.42	-41.61	-39.72	-38.86	-36.75
Ambient Noise	dB re 1 W	-128	-142	-148	-155	-140	-138
On-axis Gain (G_0)	dB re 1	22.5	24.78	27.46	26.76	26.9	25.76
S_a Correction ($S_\mathrm{a}$corr)	dB re 1	-0.6	-0.7089	-0.0354	-0.0165	-0.1015	-0.1205
RMS	dB	0.42	0.0728	0.059	0.0493	0.0814	0.1189
3-dB Beamwidth Along. ($\alpha_{-3\mathrm{dB}}$)	deg	11.07	6.93	6.73	6.53	6.6	6.46
3-dB Beamwidth Athw. ($\beta_{-3\mathrm{dB}}$)	deg	11.05	6.88	6.75	6.52	6.66	6.54
Angle Offset Along. (α_0)	deg	-0.05	0	-0.02	-0.12	0.46	0.06
Angle Offset Athw. (β_0)	deg	0	-0.07	0.02	0	0.03	-0.01

2.1.2.2.2 F/V *Lisa Marie* The 38-kHz GPT was calibrated using the standard sphere technique with a WC38.1 on 8 May while the vessel was anchored in Grays Harbor (46.9236, -124.1181). Two excursions of the WC38.1 sphere throughout the transducer beam were performed, then both excursions were combined and processed using EK80 software. Calibration results for *Lisa Marie* are presented in **Table 2**.

2.1.2.2.3 F/V *Long Beach Carnage* The echosounders were calibrated using the standard sphere technique with a WC38.1 in a tank at the SWFSC. Beam model results were entered into the GPT-control software and are presented in **Table 3**.

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

Table 2: General purpose transceiver (EK60 GPT, Simrad) beam model results estimated from a calibration of the echosounder aboard *Lisa Marie* using a WC38.1. On-axis gain (G_0), beam angles and angle offsets, and S_a Correction ($S_\mathrm{a}$corr) values from both excursions combined using the EK80 software were applied in Echoview during post-processing.

		Frequency (kHz)
	Units	38
On-axis Gain (G_0)	dB re 1	21.94
S_a Correction ($S_\mathrm{a}$corr)	dB re 1	-0.48
RMS		0.08
3-dB Beamwidth Along. ($\alpha_{-3\mathrm{dB}}$)	deg	6.96
3-dB Beamwidth Athw. ($\beta_{-3\mathrm{dB}}$)	deg	6.97
Angle Offset Along. (α_0)	deg	0.00
Angle Offset Athw. (β_0)	deg	0.01

Table 3: General purpose transceiver (EK60 GPT, Simrad) beam model results estimated from a tank calibration of echosounders aboard *Long Beach Carnage* using a WC38.1. Prior to the survey, calibrated on-axis gain (G_0), beam angles and angle offsets, and S_a Correction ($S_\mathrm{a}$corr) values were entered into the GPT-control software (EK80, Simrad).

		Frequency (kHz)			
	Units	38	70	120	200
Model		ES38-12	ES70-7C	ES120-7C	ES200-7C
On-axis Gain (G_0)	dB re 1	21.72	26.33	26.12	26.33
S_a Correction ($S_\mathrm{a}$corr)	dB re 1	-0.73	-0.3	-0.51	-0.21
RMS	dB	0.06	0.03	0.07	0.09
3-dB Beamwidth Along. ($\alpha_{-3\mathrm{dB}}$)	deg	12.47	6.78	6.78	6.99
3-dB Beamwidth Athw. ($\beta_{-3\mathrm{dB}}$)	deg	12.54	6.78	6.71	6.93
Angle Offset Along. (α_0)	deg	-0.06	0.18	0.06	-0.01
Angle Offset Athw. (β_0)	deg	0.06	-0.08	0.1	0.01

2.1.2.2.4 Unmanned surface vehicles The echosounders were calibrated while dockside by Saildrone, Inc. using the standard sphere technique with a WC38.1. The results were processed and derived by the SWFSC (Renfree *et al.*, 2019), applied in Echoview during post-processing, and are presented in **Table 4**.

Table 4: Wideband transceiver (EK80 WBT-Mini, Simrad) beam model results estimated from dockside calibrations of echosounders aboard USVs with a WC38.1. Calibrated on-axis gain (G_0), beam angles and angle offsets, and S_a Correction ($S_\mathrm{a}$corr) values were applied in Echoview during post-processing.

		Saildrone					
	Units	1045 (38)	1045 (200)	1046 (38)	1046 (200)	1047 (38)	1047 (200)
Echosounder SN		266969-07	266969-08	266960-07	266960-08	266961-07	266961-08
Transducer SN		126	126	129	129	125	125
Eq. Two-way Beam Angle ( )	dB re 1 sr	-13.0	-13.1	-13.2	-13.0	-12.8	-12.60
Theoretical TS (TS_theory)	dB re 1 m^2	-42.40	-39.08	-42.40	-39.08	-42.40	-39.08
On-axis Gain (G_0)	dB re 1	19.40	19.40	19.31	19.25	19.22	19.37
S_a Correction ($S_\mathrm{a}$corr)	dB re 1	0.01	0.01	0.00	-0.02	-0.01	-0.03
RMS	dB	0.34	0.26	0.55	0.24	0.17	0.23
3-dB Beamwidth Along. ($\alpha_{-3\mathrm{dB}}$)	deg	17.4	17.4	17.2	17.4	17.5	18.00
3-dB Beamwidth Athw. ($\beta_{-3\mathrm{dB}}$)	deg	16.8	16.5	16.3	16.8	17.3	17.70
Angle Offset Along. (α_0)	deg	0.2	0.4	0.0	0.2	-0.1	0.30
Angle Offset Athw. (β_0)	deg	0.0	0.5	0.1	-0.1	0.1	-0.20

2.1.2.3 Data collection Computer clocks were synchronized with the GPS clock (UTC) using synchronization software (NetTime[2]). The 18-kHz GPT, operated by a separate PC from the other echosounders, was programmed to track the seabed and output the detected depth to the ship's Scientific Computing System (SCS). The 38-, 70-, 120-, 200-, and 333-kHz echosounders were controlled by the ER60 Adaptive Logger (EAL[3], Renfree and Demer, 2016). The EAL optimizes the pulse interval based on the seabed depth, while avoiding aliased seabed echoes, and was programmed such that once an hour the echosounders would operate in passive mode and record three pings, for obtaining estimates of the background noise level. The echosounders collected data continuously throughout the survey, but transect sampling was conducted only during daylight hours, approximately between sunrise and sunset.

Measurements of volume backscattering strength (S_V; dB re 1 m^2 m^{-3}) and TS (dB re 1 m^2), indexed by time and geographic positions provided by GPS receivers, were logged to 60 m beyond the detected seabed range or to a maximum of 1000 m, and stored in Simrad format (i.e., .raw) with a 50-MB maximum file size. During daytime, the echosounders were set to operate in CW mode to remain consistent with echo integration methods used during prior surveys and to reduce data volume; at nighttime, echosounders were set to FM mode to improve target strength estimation and species differentiation for CPS near the surface. For each acoustic instrument, the prefix for the file names is a concatenation of the survey name (e.g., 1907RL), the operational mode (CW or FM), and the logging commencement date and time from the EK80 software. For example, file generated by the Simrad EK80 software (v1.12.2) for a WBT operated in CW mode is named `1907RL-CW-D20190723-T125901.raw`.

To minimize acoustic interference, transmit pulses from the EK60, EK80, ME70, MS70, SX90, and acoustic Doppler current profiler (ADCP; Ocean Surveyor Model OS75, Teledyne RD Instruments) were triggered using a synchronization system (K-Sync, Simrad). The K-Sync trigger rate, and thus echosounder ping interval, was modulated by the EAL using the 18-kHz seabed depth provided by the SCS. During daytime, the ME70, SX90, and ADCP were operated continuously, while the MS70 was only operated at times when CPS were present. At nighttime, only the EK60, EK80, and ADCP were operated. All other instruments that produce sound within the echosounder bandwidths were secured during daytime survey operations. Exceptions were made during stations (e.g., plankton sampling and fish trawling) or in shallow water when the vessel's command occasionally operated the bridge's 50- and 200-kHz echosounders (Furuno), the Doppler velocity log (Sperry Marine Model SRD-500A), or both. Data from the ME70, MS70, and SX90 are not presented in this report.

2.1.3 Oceanographic sampling

2.1.3.1 Conductivity and temperature versus depth (CTD) sampling Conductivity and temperature were measured versus depth to 350 m (or to within ~10 m of the seabed when less than 350 m) with calibrated sensors on a CTD rosette (Model SBE911+, Seabird) or underway probe [UnderwayCTD (UCTD), Oceanscience] cast from the vessel. Approximately 3-5 casts were planned along each acoustic transect, depending on transect length. These data were used to calculate the harmonic mean sound speed (Demer *et al.*, 2015) for estimating ranges to the sound scatterers, and frequency-specific sound absorption coefficients for compensating signal attenuation of the sound pulse between the transducer and scatters (Simmonds and MacLennan, 2005) (see **Section 2.3.2**). These data also indicated the depth of the surface mixed layer, above which most epipelagic CPS reside during the day, which is later used to determine the integration-stop depth and remove non-CPS backscatter during acoustic data processing (see **Section 2.3.4**).

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

[2] http://timesynctool.com
[3] https://swfsc.noaa.gov/eal/
[4] https://coastwatch.pfeg.noaa.gov/erddap/index.html

2.1.4 Fish egg sampling

During the day, fish eggs were sampled using 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. Because the duration of the initial stages of the egg phase is 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 Trawl sampling

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 Sampling gear The net, 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.

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

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

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

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

where $P_{w,e} = C_{S,e} / \sum_1^s C_{S,e}$, 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 each of the target species with 50 specimens or less, individual measurements of length in mm (standard length, L_S, for Pacific Sardine and Northern Anchovy, and fork length, L_F, for Pacific Herring and Jack and Pacific Mackerels) and total weight (w) in g were recorded. In addition, sex and maturity were recorded for up to 50 specimens from all species. 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 five different geographic zones (designated by J. Hyde and M. Craig, SWFSC) and preserved in ethanol for genetic analysis. Otoliths were removed from all 50 Pacific Sardine in the subsample; for other CPS species, 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.

2.1.5.4 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, verified, and corrected if found to be erroneous. Missing length (L_{miss}) and weight (W_{miss}) measurements were estimated using the season-specific length-versus-weight relationships (**Table 5**) derived from catches during previous ATM surveys (Palance *et al.*, 2019), where $W_{miss} = \beta_0 L^{\beta_1}$, $L_{miss} = (W/\beta_0)^{(1/\beta_1)}$, and values for β_0 and β_1. To identify measurement or data-entry errors, length and weight data were graphically compared (**Fig. 6**) to measurements from previous surveys and models of season-specific length-versus-weight from previous surveys (Palance *et al.*, 2019). Outliers and missing values were flagged, reviewed by the trawl team, and mitigated. Catch data from aborted or otherwise unacceptable trawl hauls were removed.

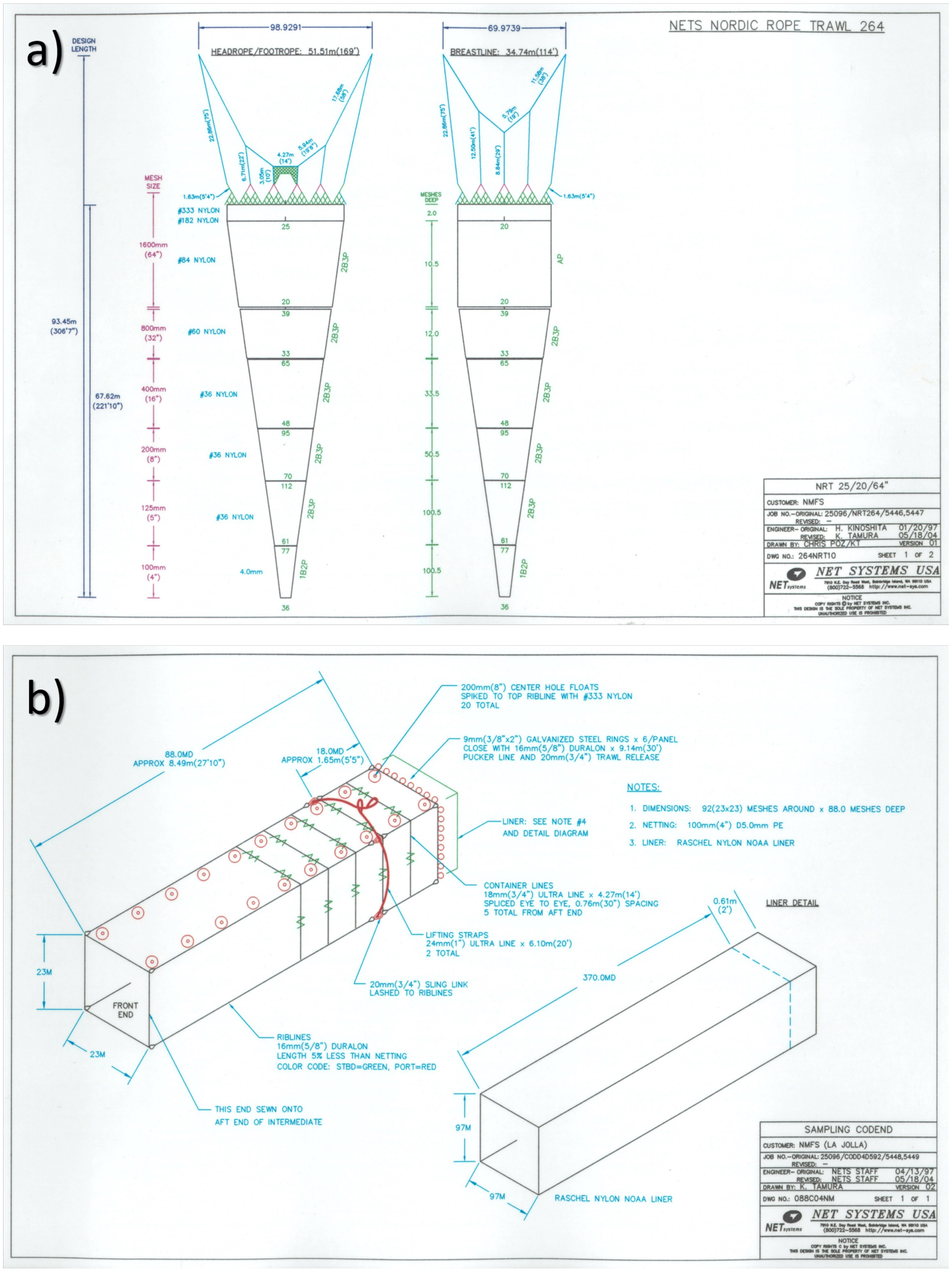

Figure 5: Schematic drawings of the Nordic 264 rope trawl a) net and b) cod-end.

Table 5: General linear model (GLM) coefficients describing the total length (L_T, mm) versus weight (W, g) relationships used to estimate missing lengths or weights, where: $L_T = (W/\beta_0)^{(1/\beta_1)}$ and $W = \beta_0 {L_T}^{\beta_1}$.

Common name	Scientific name	β_0	β_1
Pacific Herring	*Clupea pallasii*	1.965e-06	3.253318
Northern Anchovy	*Engraulis mordax*	2.873e-06	3.167299
Pacific Sardine	*Sardinops sagax*	4.551e-06	3.120841
Pacific Mackerel	*Scomber japonicus*	3.550e-06	3.165265
Jack Mackerel	*Trachurus symmetricus*	5.936e-06	3.069390

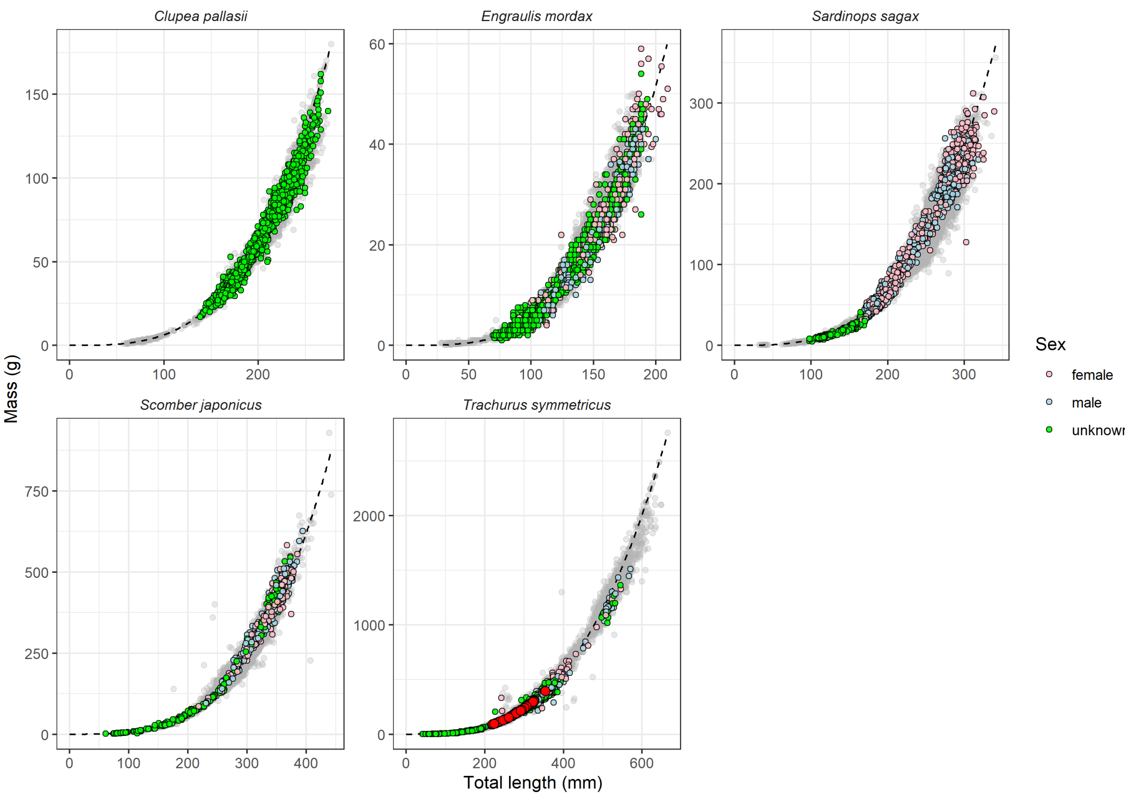

Figure 6: Specimen length-versus-weight from the current survey (colored points, by sex) compared to those from previous SWFSC surveys during the same season (gray points, all sexes). The dashed line represents the modeled length-versus-weight relationships for each species (unpublished data). Larger points indicate specimens whose length (red) or weight (blue) was missing and was estimated from the length-versus-weight relationships in **Table 5**.

2.2 Purse seine sampling

Purse seines 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.). All specimens collected by *Lisa Marie* and *Long Beach Carnage* were frozen and later processed by the Washington Department of Fish and Wildlife (WDFW) or California Department of Fish and Wildlife (CDFW), respectively.

On *Lisa Marie*, as many as three purse seine sets per day were planned during daylight hours. For each set, three dip net samples, spatially separated as much as possible, were collected. For each dip net sample, Pacific Sardine, Northern Anchovy, Jack Mackerel, Pacific Mackerel, and Pacific Herring were sorted, weighed, and counted to provide a combined weight and count for each species. Next, all three dip net samples were combined and up to 50 specimens were randomly sampled to provide a combined weight for each set. The length (mm; L_S for Pacific Sardine and Northern Anchovy and L_F for all others) and weight was measured for up to 25 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*, a maximum of one set per day was planned during daylight hours. In the event of abundant CPS or an unsuccessful daytime set, a set was made at night. For each set, three dip net samples, spatially separated as much as possible, were collected, and specimens were frozen for later analysis by CDFW biologists. The total weight (tons) of the school was estimated by the captain. After the survey, each dip net sample was sorted, weighed, and counted to provide a combined weight and count for each species. Next, all three dip net samples were combined and up to 50 specimens were randomly sampled to provide a combined weight for each set. The length (mm; L_S for Pacific Sardine and Northern Anchovy and L_F for all others) and weight was measured for up to 50 randomly selected specimens of each species. Otoliths were extracted and macroscopic maturity stage was determined visually. Since samples were frozen, no gonad samples were analyzed from female specimens.

2.3 Data processing

2.3.1 Acoustic and oceanographic data

The calibrated echosounder data from each transect were processed using commercial software (Echoview v10.0, 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 (DVM) and disaggregation of the target species' schools (Cutter and Demer, 2008).

2.3.2 Sound speed and absorption calculation

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

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

where $\mathit{\Delta} r$ is the depth of increment i (Seabird, 2013). Measurements of seawater temperature (t_w, °C), salinity (s_w, psu), depth, pH, and $\overline{c}_w$ are also used to calculate the mean species-specific absorption coefficients ($\overline{\alpha}_a$, dB m^{-1}) over the entire profile using equations in Francois and Garrison (1982), Ainslie and McColm (1998), and Doonan et al. (2003). Both $\overline{c}_w$ and $\overline{\alpha}_a$ are later used to estimate ranges to the sound scatterers to compensate the echo signal for spherical spreading and attenuation during propagation of the sound pulse from the transducer to the scatterer range and back (Simmonds and MacLennan, 2005). The CTD rosette, when cast, also provides measures of fluorescence and dissolved oxygen concentration versus depth, which may be used to estimate the vertical dimension of Pacific Sardine potential habitat (Zwolinski *et al.*, 2011), particularly the depth of the upper-mixed layer where most epipelagic CPS reside. The latter information is used to inform echo classification (see **Section 2.3.3**).

2.3.3 Echo-classification

Echoes from schooling CPS were identified using a semi-automated data processing algorithm implemented using Echoview software (v10.0). The filters and thresholds were based on a subsample of echoes from randomly selected CPS schools. The aim of the filter criteria is to retain at least 95% of the noise-free backscatter from CPS schools while rejecting at least 95% of the non-CPS backscatter (**Fig. 7**). Data from *Lasker* and *Long Beach Carnage* were processed using the following steps:

1. Match geometry of the 70-, 120-, 200-, and 333-kHz S_v to the 38-kHz S_v;
2. Remove passive-mode pings;
3. Estimate and subtract background noise using the background noise removal function (De Robertis and Higginbottom, 2007) in Echoview (**Figs. 7b, 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: $S_{v,200\text{kHz}} - S_{v,38\text{kHz}}$, $S_{v,120\text{kHz}} - S_{v,38\text{kHz}}$, and $S_{v,70\text{kHz}} - S_{v,38\text{kHz}}$;
7. Create a Boolean echogram for S_v differences in the CPS range: $-13.85 < S_{v,70\text{kHz}} - S_{v,38\text{kHz}} < 9.89$ and $-13.5 < S_{v,120\text{kHz}} - S_{v,38\text{kHz}} < 9.37$ and $-13.51 < S_{v,200\text{kHz}} - S_{v,38\text{kHz}} < 12.53$;
8. Compute the 120- and 200-kHz Variance-to-Mean Ratios ($VMR_{120\text{kHz}}$ and $VMR_{200\text{kHz}}$, respectively, Demer *et al.*, 2009) using the difference between noise-filtered S_v (Step 3) and averaged S_v (Step 4);
9. Expand the $VMR_{120\text{kHz}}$ and $VMR_{200\text{kHz}}$ echograms with a 7 pixel x 7 pixel dilation;
10. Create a Boolean echogram based on the VMRs in the CPS range: $VMR_{120\text{kHz}} >$ -65 dB and $VMR_{200\text{kHz}} >$ -65 dB. Diffuse backscattering layers have low VMR (Zwolinski *et al.*, 2010) whereas fish schools have high VMR (Demer *et al.*, 2009);
11. Intersect the two Boolean echograms to create an echogram with "TRUE" samples for candidate CPS schools and "FALSE" elsewhere;
12. Mask the noise-reduced echograms using the CPS Boolean echogram (**Figs. 7c, f**);
13. Create an integration-start line 5 m below the transducer (~10 m depth);
14. Create an integration-stop line 3 m above the estimated seabed (Demer *et al.*, 2009), or to the maximum logging range (e.g., 1000 m), whichever is shallowest;
15. Set the minimum S_v threshold to -60 dB (corresponding to a density of approximately three 20-cm-long Pacific Sardine per 100 m^3);
16. Integrate the volume backscattering coefficients (s_V, m^2 m^{-3}) attributed to CPS over 5-m depths and averaged over 100-m distances;
17. Output the resulting nautical area scattering coefficients (s_A; m^2 nmi^{-2}) and associated information from each transect and frequency to comma-delimited text (.csv) files.

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 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: $-3 < S_{v,200\text{kHz}} - S_{v,38\text{kHz}} < 9.37$;
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.

2.3.4 Removal of non-CPS backscatter

In addition to echoes from target CPS, echoes may also be present from other CPS (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, vertical temperature profiles were superimposed on the echo-integrated data for each transect. Echoes below the surface mixed layer were excluded from the CPS analysis (**Fig. 8**). In areas dominated by Pacific Herring, for example off Vancouver Island, backscatter was integrated to a maximum depth of 75 m.

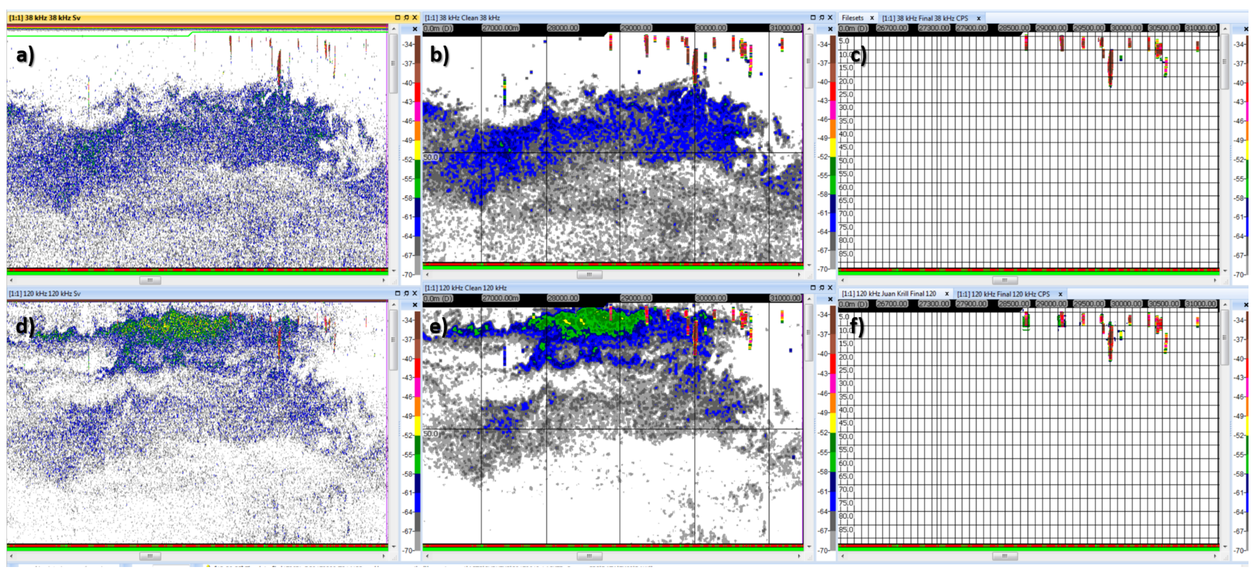

Figure 7: Two examples of echograms depicting CPS schools (red) and plankton aggregations (blue and green) at 38 kHz (top) and 120 kHz (bottom). Example data processing steps include the original echogram (a, d), after noise subtraction and bin-averaging (b, e), and after filtering to retain only putative CPS echoes (d, f).

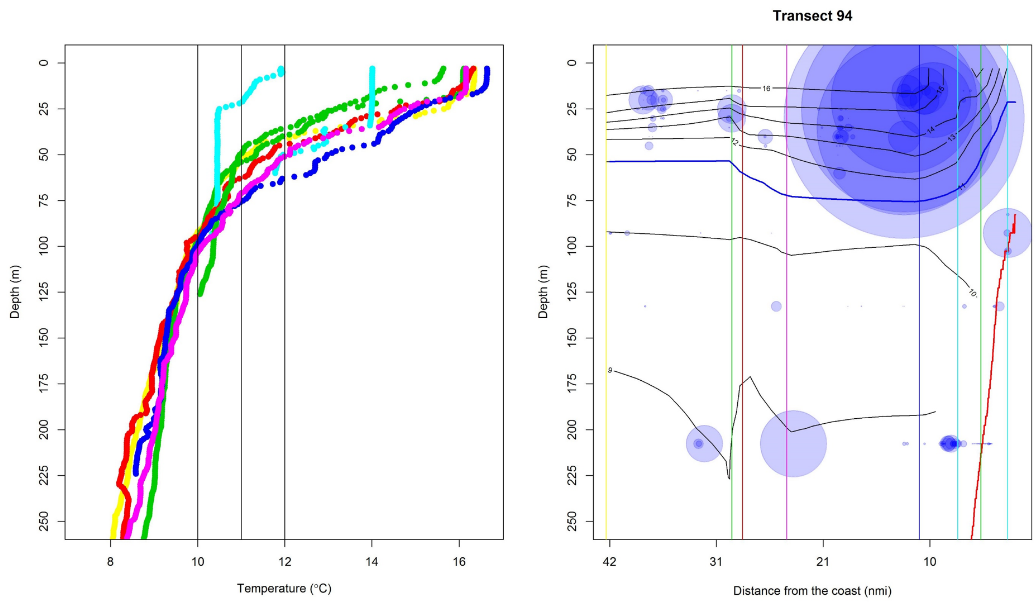

Figure 8: Temperature profiles (left) and the distribution of echoes from fishes with swimbladders (blue points, scaled by backscatter intensity; right) along an example acoustic transect. In this example, temperature profiles indicate an ~25 m-deep mixed-layer above an ~20-30 m thermocline, so the 11 °C isotherm (bold, blue line; right panel) was used to remove echoes from deeper, bottom-dwelling schools of non-CPS fishes with swimbladders. The proximity of the echoes to the seabed (bold, red line; right panel) was also used to define the lower limit for vertical integration.

2.3.5 Quality Assurance and Quality Control

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

2.3.6 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:

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

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

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

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

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 in situ σ_{bs} and measures of L_T and W from concomitant catches of South American Pilchard (*Sardinops ocellatus*) and Horse Mackerel (*Trachurus trachurus*) off South Africa (Barange *et al.*, 1996). Because mackerels have similar TS (Peña, 2008), Equation (9) is used for both Pacific and Jack Mackerels. For Pacific Herring, Equation (7) was derived from that of Thomas et al. (2002) measured at 120 kHz with the following modifications: 1) the intercept used here was calculated as the average intercept of Thomas et al.'s spring and fall regressions; 2) the intercept was compensated for swimbladder compression after Zhao et al. (2008) using the average depth for Pacific Herring of 44 m; 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 $TS_{38\mathrm{kHz}}$, L_T (cm) was estimated from measurements of standard length (L_S) or fork length (L_F; cm) using linear relationships between length and weight derived from specimens collected in the CCE: 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 $L_T = -0.105 + 1.2 L_F$.

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

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

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

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

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

The trawls within a cluster were combined to reduce sampling variability (see **Section 2.3.7**), 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;

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

2.3.7 Trawl clustering and species proportions

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. 9**):

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

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.

2.4 Data analysis

2.4.1 Post-stratification

The transects were used as sampling units (Simmonds and Fryer, 1996). Because each species does not generally span the entire survey area (Demer and Zwolinski, 2017; Zwolinski *et al.*, 2014), the sampling domain was stratified for each species and stock. Strata were defined by uniform transect spacing (sampling intensity) and either presences (positive densities and potentially structural zeros) or absences (real zeros) of species biomass. Each stratum has: 1) at least three transects, with approximately equal spacing, 2) fewer than three consecutive transects with zero-biomass density, and 3) bounding transects with zero-biomass density (**Fig. 10**). This approach tracks stock patchiness and creates statistically-independent, stationary, post-sampling strata (Johannesson and Mitson, 1983; Simmonds *et al.*, 1992). For Northern Anchovy, we define the separation between the northern and central stock at Cape Mendocino (40.4 °N). For Pacific Sardine, the northern and southern stocks that were likely present in the survey area (Felix-Uraga *et al.*, 2005, 2004; Garcia-Morales *et al.*, 2012; Hill *et al.*, 2014) were separated using the approximate satellite-derived sea-surface temperature (SST) isoline of 16.7° (Demer and Zwolinski, 2014), which in this survey coincided geographically with Point Conception (34.7 °N) and the northern Channel Islands (**Fig. 2**) and also a break in the distribution of Pacific Sardine biomass (**Fig. 10**).

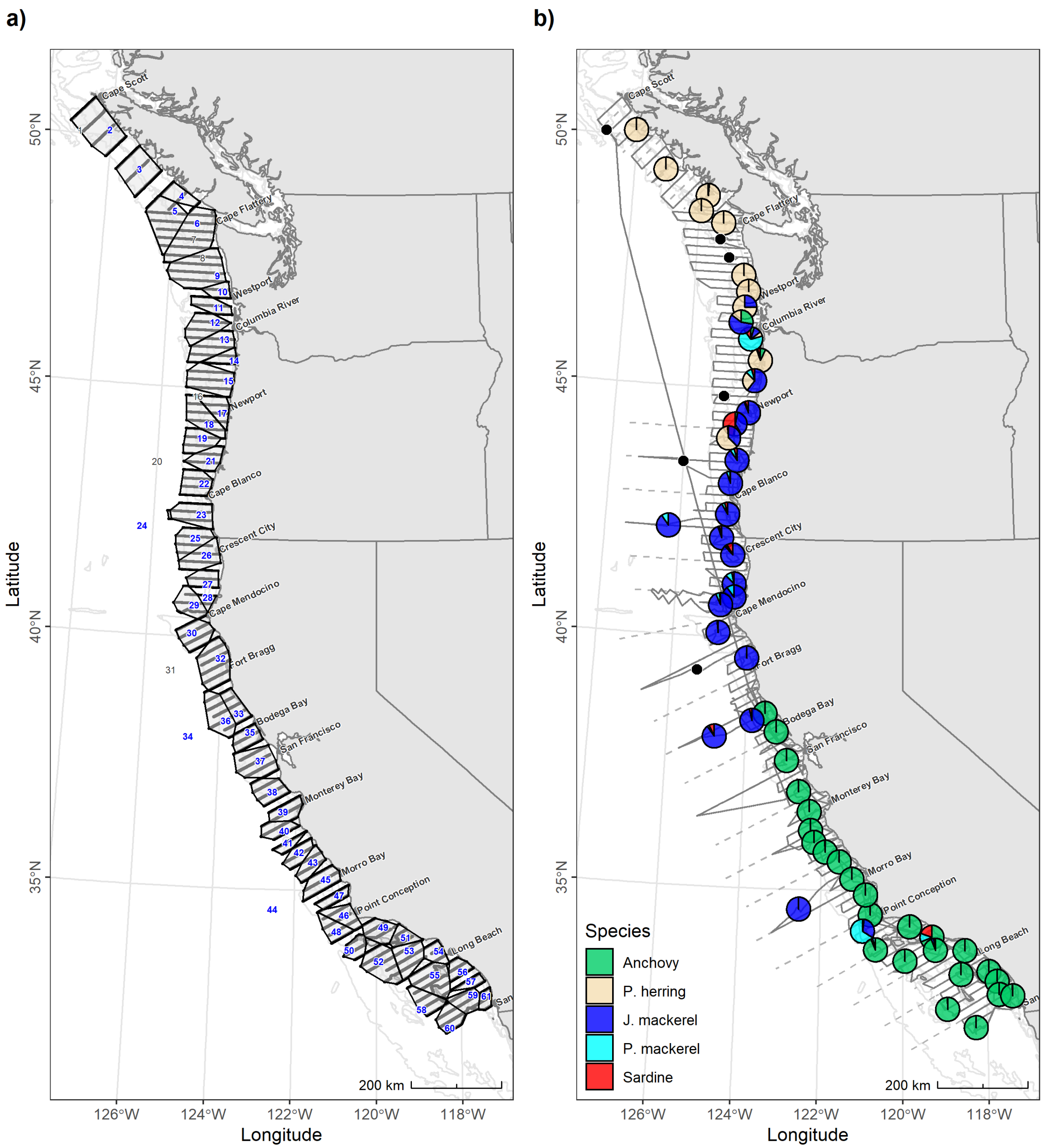

Figure 9: a) Polygons enclosing 100-m acoustic intervals assigned to each trawl cluster, and b) the acoustic proportions of CPS in trawl clusters. The numbers inside each polygon in panel a) are the cluster numbers, which are located at the average latitude and longitude of all trawls in that cluster. Black points in panel b) indicate trawl clusters with no CPS present.

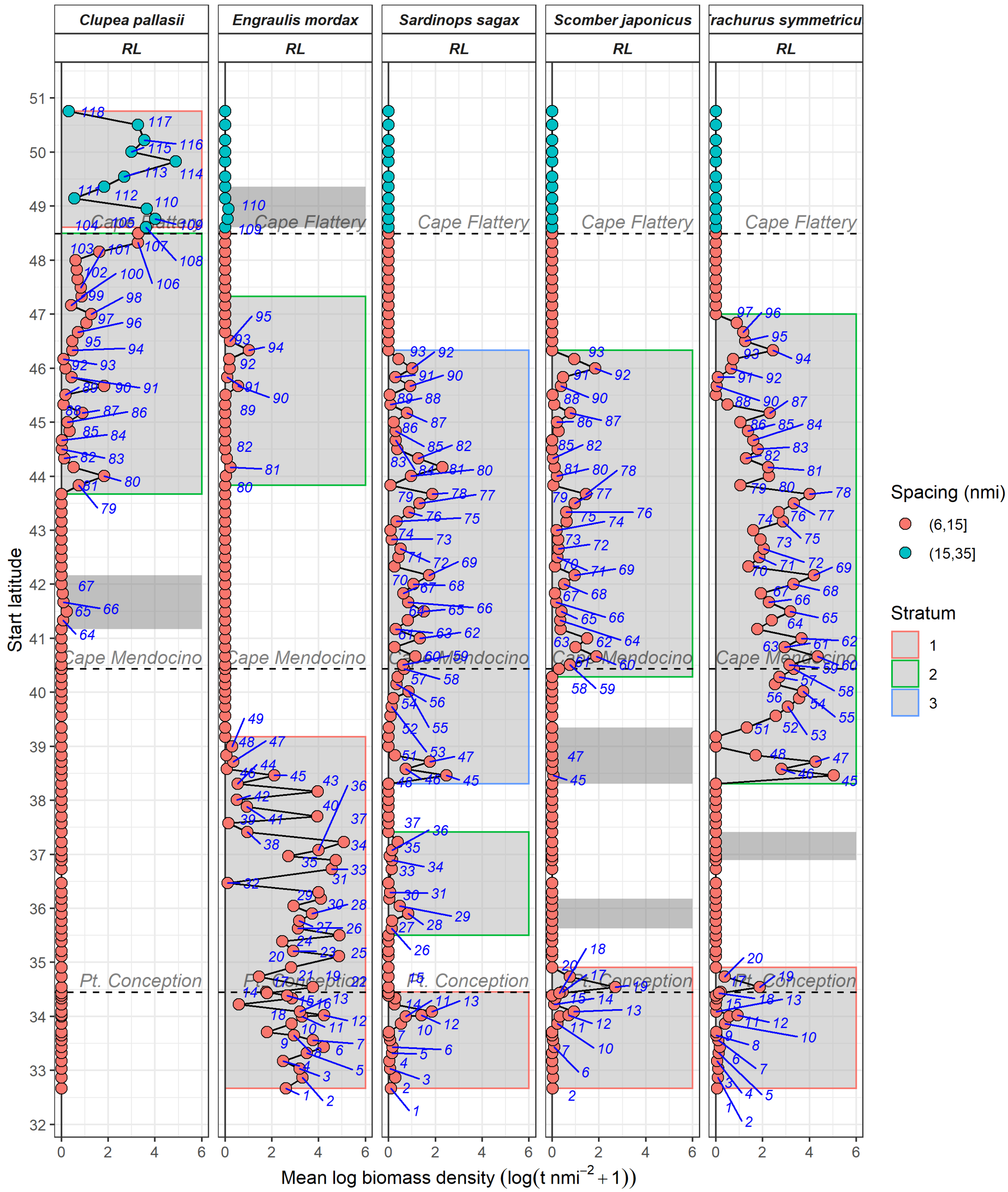

Figure 10: Biomass density ($\log_{10}(t\,\text{nmi}^2 + 1)$) versus latitude (easternmost portion of each transect) and strata used to estimate biomass and abundance (shaded regions; outline indicates stratum number) for each species and survey vessel (labels above plots; *RL* = *Lasker*). Strata with no outline were not included because of too few specimens (< 10 individuals), trawl clusters (< 2 clusters), or both. Blue number labels correspond to transects with positive biomass ($\log_{10}(t + 1) > 0.01$). Point fills indicate transect spacing (nmi). Dashed horizontal lines indicate prominent biogeographic landmarks used to delineate stock boundaries for Northern Anchovy and Pacific Sardine, and also the approximate boundary between U.S. and Canadian waters at Cape Flattery.

2.4.2 Estimation of biomass and sampling precision

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

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

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

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

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

The 95% confidence intervals ($CI_{95\%}$) 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.

2.4.3 Abundance- and biomass-at-length estimates

The numerical densities by length class (**Section 2.3.7**) were averaged for each stratum in a similar way for that used for biomass (Equation (17)), and raised to the stratum area to obtain abundance per length class.

2.4.4 Percent contribution of biomass per cluster

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

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

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

3 Results

3.1 Sampling effort and allocation

The summer 2019 survey took place between Cape Scott, Vancouver Island and San Diego during 77 DAS between 12 June and 10 September 2019. In the core survey area, acoustic sampling was conducted along 118 daytime east-west transects that totaled 5,941 nmi. Catches from a total of 163 nighttime surface trawls were combined into 61 trawl clusters. As many as three post-survey strata were defined considering transect spacing and the densities of echoes attributed to CPS. In the nearshore survey area, acoustic sampling was conducted along 193 daytime east-west transects (78 by *Lisa Marie* off WA and OR, 56 by the USV off northern and central CA, and 59 by *Long Beach Carnage* in the SCB) that totaled 777 nmi. As many as eleven post-survey strata were defined considering transect spacing and the densities of echoes attributed to CPS. Biomasses and abundances were estimated for each species in both the core and nearshore survey areas.

Leg I
On 13 June, *Lasker* departed from the Exploratorium (Pier 15) in San Francisco, CA at ~1800 (all times UTC) and began the transit to northern Vancouver Island. Throughout the transit, sampling was conducted during the day with CUFES, EK60s, EK80s, ME70, MS70 and SX90. On 17 June, *Lasker* arrived at the first offshore station off Cape Scott, British Columbia at ~1230 to begin acoustic sampling along transect 129. On 1 July, acoustic sampling ceased after the completion of transect 84 off Newport, OR. On 2 July, *Lasker* arrived at the Marine Operations-Pacific (MOC-P) Pier in Newport at ~2100 to complete Leg I.

On 21 June, Greg Shaughnessy (Ocean Gold Seafoods) embarked *Lasker* from *Lisa Marie* to observe survey operations. At the same time, Josiah Renfree boarded *Lisa Marie* to remedy minor issues with the echosounder before rejoining *Lasker*. At ~1900 on 25 June, Mr. Shaughnessy disembarked and was put ashore in Westport, WA via *Lasker*'s skiff.

Leg II
On 8 July, *Lasker* departed from MOC-P Pier in Newport, OR, at ~0000. Acoustic sampling resumed at ~0145 on 8 July along transect 083 south of Newport, OR. On 24 July, acoustic sampling ceased after the completion of transect 050 off Albion, CA. On 25 July, *Lasker* arrived at Pier 30/32 in San Francisco, CA at ~1300 to complete Leg II.

Leg III

On 30 July, *Lasker* departed from Pier 30/32 in San Francisco at ~1300 and transited to transect 049 north of the Point Arena lighthouse. Trawling was conducted during the evening of 30 July, prior to resuming acoustic sampling along transect 049 on 31 July. Intermittent malfunctions of the trawl winch encoders reduced trawl sampling from 1-2 August. Increased malfunctions of the trawl-winch encoders prohibited trawling from 3-6 August. On 6 August, the trawl winches were repaired and normal sampling resumed. On 16 August, acoustic sampling ceased after the completion of transect 023 off Morro Bay. On 17 August, *Lasker* arrived at the 10th Avenue Marine Terminal in San Diego, CA at ~1400 to complete Leg III.

Leg IV

On 22 August, *Lasker* departed from 10th Avenue Marine Terminal in San Diego at ~1500. Training on the ship's dynamic-positioning system was performed in San Diego Harbor until ~2000, after which *Lasker* transited to transect 019 off Pismo Beach. On 23 August, at ~1700, *Lasker* deployed a benthic acoustic lander off Pt. Conception, then resumed acoustic sampling along transect 019 at ~1800. On 1 September, *Lasker*'s fog horn was repaired using parts received from ashore via skiff. At ~1500 on 1 September, the UCTD probe was lost when a small vessel running parallel to the ship made a sharp turn across the stern and severed the line. At ~0200 on 7 September, acoustic sampling ceased after the completion of transect 001 off San Diego. *Lasker* arrived at the 10th Avenue Marine Terminal in San Diego at ~2100 on 8 September to complete the survey.

3.2 Acoustic backscatter

Acoustic backscatter ascribed to CPS was observed throughout the core survey area, but was most prevalent off southwest Vancouver Island and Cape Flattery; nearshore between the Columbia River and Cape Mendocino; and throughout the entire survey area between Cape Blanco and San Diego (**Fig. 11a**). Acoustic backscatter ascribed to CPS was also observed throughout the nearshore survey area, but was most prevalent near the Columbia River and Newport (**Fig. 12a**); around Cape Mendocino, Pt. Reyes, and between Monterey and Morro Bay (**Fig. 12a**); and throughout the SCB (**Fig. 12a**). The majority (greater than 90%) of biomass for each species was apportioned using catch data from trawl clusters conducted within a distance of $\leq$ 20 nmi (**Fig. 13**).

3.3 Egg densities and distributions

Northern Anchovy eggs were abundant in CUFES samples nearshore off the Columbia River; offshore north of Newport; and offshore between approximately San Francisco and Morro Bay (**Fig. 11b**). Pacific Sardine eggs were abundant nearshore between the Columbia River and Cape Blanco; and offshore between Cape Blanco and Cape Mendocino (**Fig. 11b**). Jack Mackerel eggs were observed between approximately Newport and Cape Mendocino, offshore between approximately San Francisco and Morro Bay, and in the southern portion of the SCB (**Fig. 11b**). Between Newport and Cape Mendocino, Jack Mackerel eggs were coincident with Pacific Sardine Eggs (**Fig. 11b**).

3.4 Trawl catch

Pacific Herring catches were predominant, by weight, in trawl samples collected off Vancouver Island and nearshore off WA, north of the Columbia River (**Fig. 11c**). Jack Mackerel dominated the trawl catches between approximately Newport and Bodega Bay (**Fig. 11c**). Northern Anchovy was the predominant species in trawl catches from inshore and offshore between Bodega Bay and San Diego. Pacific Sardine were caught in relatively small numbers between the Columbia River and Cape Mendocino, near Bodega Bay, and around the northern Channel Islands in the SCB (**Fig. 11c**). A few Pacific Mackerel were caught along the OR and northern CA coasts, and offshore near Bodega Bay and Pt. Conception (**Fig. 11c**). Overall, the 163 trawls captured a combined 23,043 kg of CPS (16,057 kg of Northern Anchovy, 723 kg of Pacific Sardine, 656 kg of Pacific Mackerel, 4,096 kg of Jack Mackerel, and 1,512 kg Pacific Herring).

3.5 Purse seine catch

Jack Mackerel and Pacific Herring were predominant, by weight, in purse seine samples collected off WA and OR by *Lisa Marie* (**Fig. 12b**). Overall, the 30 seines captured a combined 82.6 kg of CPS (2.02 kg of Northern Anchovy, 5.79 kg of Pacific Sardine, 52.6 kg of Jack Mackerel, 22.3 kg Pacific Herring; no Pacific Mackerel were collected).

Pacific Sardine were predominant, by weight, in purse seine samples collected off southern CA by *Long Beach Carnage* (see Stierhoff *et al.*, 2020). Overall, the seven seines captured a combined 15.7 kg of CPS (0.0042 kg of Northern Anchovy, 14.3 kg of Pacific Sardine, 1.41 kg of Pacific Mackerel,; no Jack Mackerel, or Pacific Herring were collected).

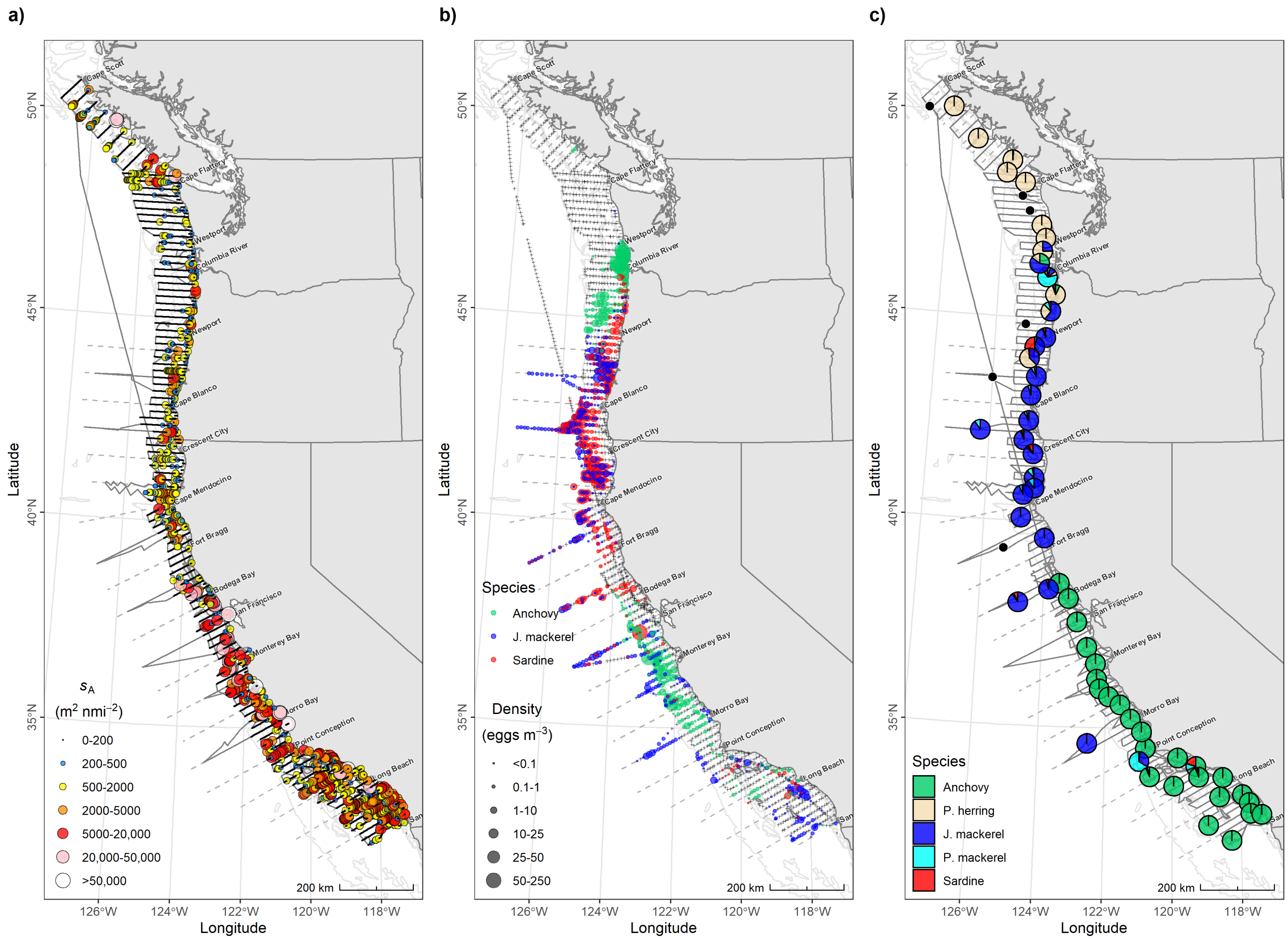

Figure 11: Spatial distributions of: a) 38-kHz integrated backscattering coefficients (s_A, m^2 nmi^{-2}; averaged over 2000-m distance intervals and from 5 to 70 m deep) ascribed to CPS; b) CUFES egg density (eggs m^{-3}) for Northern Anchovy, Pacific Sardine, and Jack Mackerel; and c) acoustic proportions of CPS in trawl clusters (black points indicate trawl clusters with no CPS).

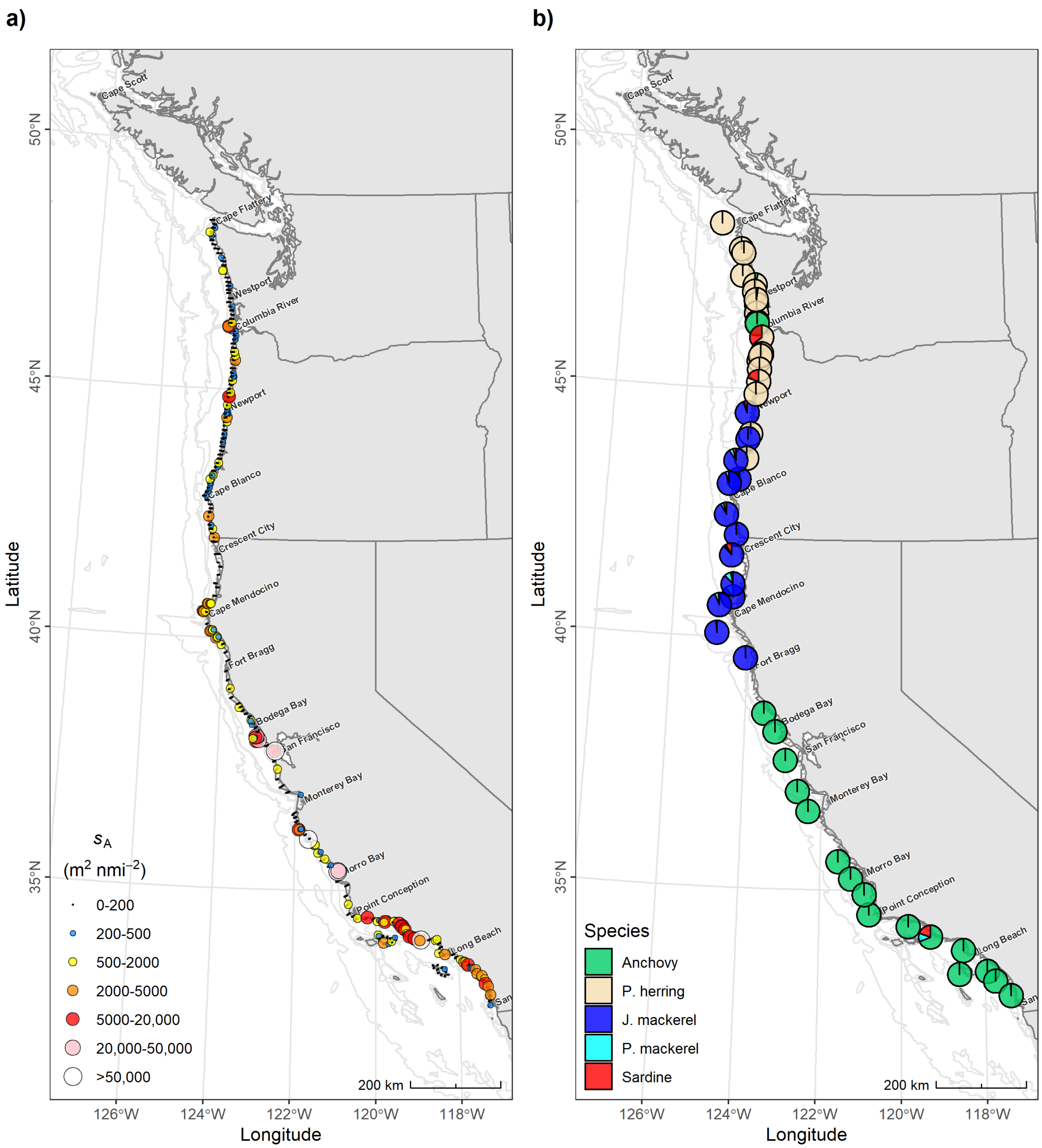

Figure 12: Spatial distributions of: a) 38-kHz integrated backscattering coefficients (s_A, m^2 nmi^{-2}; averaged over 2000-m distance intervals and from 5 to 70 m deep) ascribed to CPS from nearshore sampling and b) acoustic proportions of CPS in purse seine sets (off WA and OR) and trawl clusters (off CA).

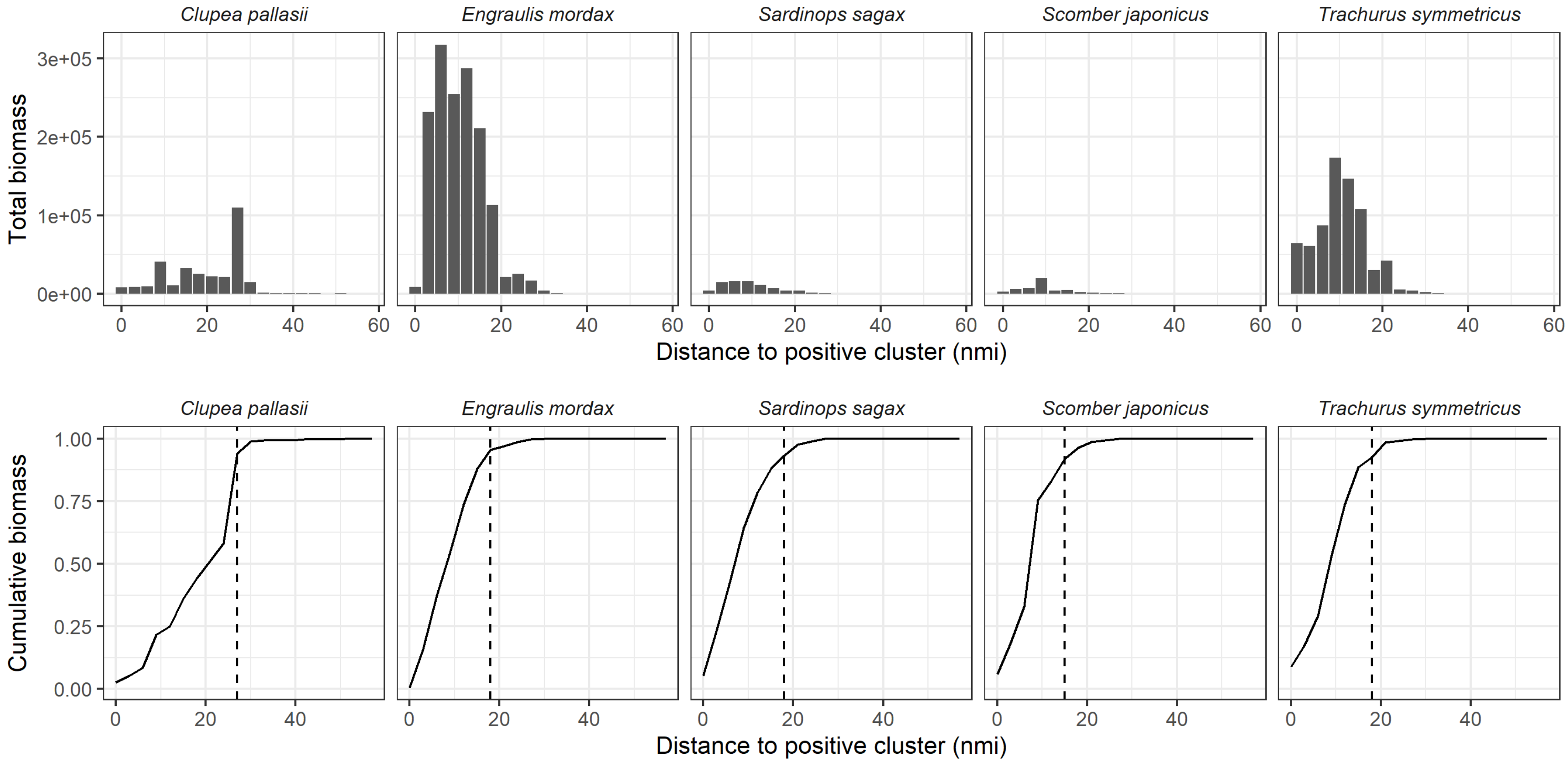

Figure 13: Total (top) and cumulative (bottom) biomass(t) versus distance to the nearest positive trawl cluster. Dashed vertical lines (bottom) represent the cluster distance where cumulative biomass equals 90%.

3.6 Biomass distribution and demography

3.6.1 Northern Anchovy

3.6.1.1 Northern stock The total estimated biomass of the northern stock of Northern Anchovy was 1,811 t ($CI_{95\%}$ = 374 - 3,909 t, CV = 41%). In the core survey region, biomass was 1,513 t ($CI_{95\%}$ = 371 - 3,034 t, CV = 47%; **Table 6**), and was distributed from approximately Westport to Coos Bay, OR (**Fig. 14a**). The L_S ranged from 12 to 18 cm with modes at 15 and 17 cm (**Table 8**, **Fig. 15**). In the nearshore region, biomass was 299 t ($CI_{95\%}$ = 2.71 - 875 t, CV = 84%; **Table 6**), was distributed between approximately Westport and Florence (**Fig. 14b**), and had a similar length distribution to the core region (**Table 8**, **Fig. 15**). Biomass in the nearshore region comprised 16% of the total biomass.

Table 6: Biomass estimates (metric tons, t) and their precision (upper and lower 95% confidence intervals, $CI_{95\%}$; and coefficient of variation, CV) for the northern stock of Northern Anchovy (*Engraulis mordax*) in the core and nearshore survey regions. Stratum areas are nmi^2.

Species		Stratum					Trawl		Biomass			
Name	Stock	Region	Number	Area	Transects	Distance	Clusters	Individuals	$\hat{B}$	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Engraulis mordax	Northern	Core	2	11,568	22	1,159	6	904	1,513	371	3,034	47
			All	11,568	22	1,159	6	904	1,513	371	3,034	47
		Nearshore	5	27	7	6	1	552	3	0	7	53
			6	81	6	17	2	51	295	0	872	85
			7	95	9	22	2	6	1	0	2	57
			All	203	22	45	5	609	299	3	875	84

3.6.1.2 Central stock The total estimated biomass of the central stock of Northern Anchovy was 810,634 t ($CI_{95\%}$ = 587,317 - 1,066,265 t, CV = 13%). In the core region, biomass was 769,154 t ($CI_{95\%}$ = 559,915 - 984,059 t, CV = 14%; **Table 7**); the stock was distributed from approximately Fort Bragg to San Diego, CA, but biomass was greatest between San Francisco and Pt. Conception (**Fig. 16a**). L_S ranged from 6 to 16 cm with modes at 8 and 12 cm (**Table 9**, **Fig. 17**). In the nearshore region, biomass was 41,480 t ($CI_{95\%}$ = 27,402 - 82,206 t, CV = 34%; **Table 7**), was distributed between approximately Fort Bragg and San Diego (**Fig. 16b**), and had a similar length distribution to the core region (**Table 9**, **Fig. 17**). Biomass in the nearshore region comprised 5.1% of the total biomass.

Table 7: Biomass estimates (metric tons, t) and their precision (upper and lower 95% confidence intervals, $CI_{95\%}$; and coefficient of variation, CV) for the central stock of Northern Anchovy (*Engraulis mordax*) in the core and nearshore survey regions. Stratum areas are nmi^2.

Species		Stratum					Trawl		Biomass			
Name	Stock	Region	Number	Area	Transects	Distance	Clusters	Individuals	$\hat{B}$	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Engraulis mordax	Central	Core	1	26,251	50	2,739	26	1,358,039	769,154	559,915	984,059	14
			All	26,251	50	2,739	26	1,358,039	769,154	559,915	984,059	14
		Nearshore	1	203	31	53	7	450,478	8,571	4,118	12,010	24
			2	89	11	22	2	102,930	809	132	1,783	56
			3	83	11	22	2	242,455	113	40	183	33
			4	172	20	15	8	247,960	31,988	20,059	73,111	44
			All	548	73	112	16	1,043,824	41,480	27,402	82,206	34

Table 8: Abundance versus standard length (L_S, cm) for the northern stock of Northern Anchovy (*Engraulis mordax*) in the core and nearshore survey regions.

Species	Stock	SL	Region: Core	Region: Nearshore
Engraulis mordax	Northern	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	16,993
		10	0	50,978
		11	0	0
		12	49,190	492
		13	299,065	326,080
		14	2,541,544	3,228,318
		15	9,729,609	3,249,404
		16	5,741,315	1,138,668
		17	10,354,442	163,150
		18	2,517,405	0
		19	0	0
		20	0	0

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.

Species	Stock	L_S	Region: Core	Region: Nearshore
Engraulis mordax	Central	1	0	0
		2	0	0
		3	0	0
		4	0	0
		5	0	0
		6	1,327,146,647	17,802,831
		7	17,037,319,882	465,643,154
		8	23,764,446,374	963,228,674
		9	14,505,847,274	177,527,133
		10	5,558,883,914	142,677,265
		11	7,235,447,927	372,722,919
		12	7,346,805,051	410,219,190
		13	5,349,671,276	486,197,534
		14	2,587,963,418	245,922,379
		15	272,519,042	18,689,015
		16	9,350,727	6,378,313
		17	0	0
		18	0	0
		19	0	0
		20	0	0

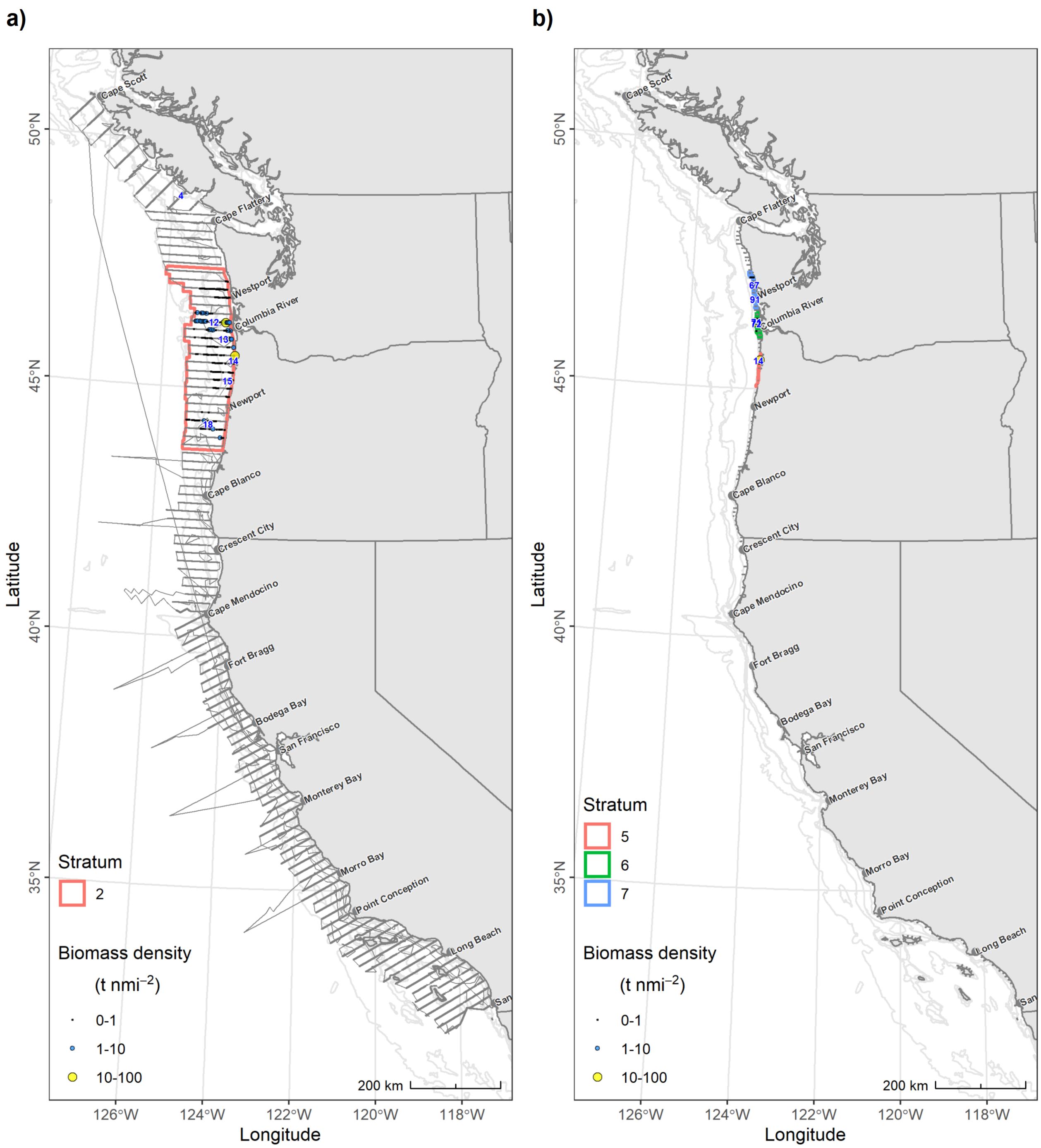

Figure 14: Biomass densities of northern stock of Northern Anchovy (*Engraulis mordax*), per strata, in the a) core and b) nearshore survey regions. The blue numbers represent the locations of trawl clusters with at least one Northern Anchovy. The gray line represents the vessel track.

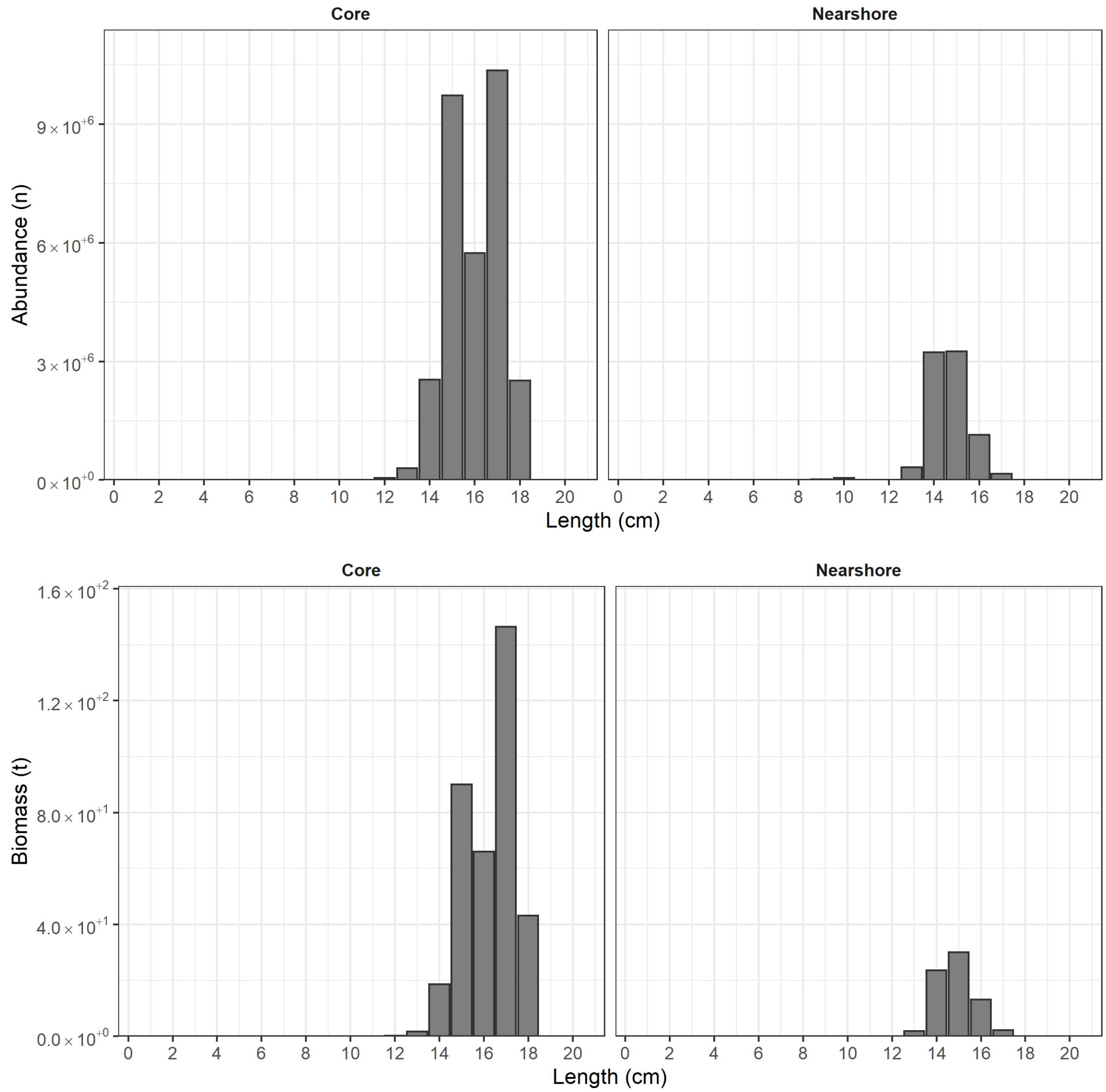

Figure 15: Abundance versus standard length (L_S, upper panel) and biomass (t) versus L_S (lower panel) for the northern stock of Northern Anchovy (*Engraulis mordax*) in the core and nearshore survey regions.

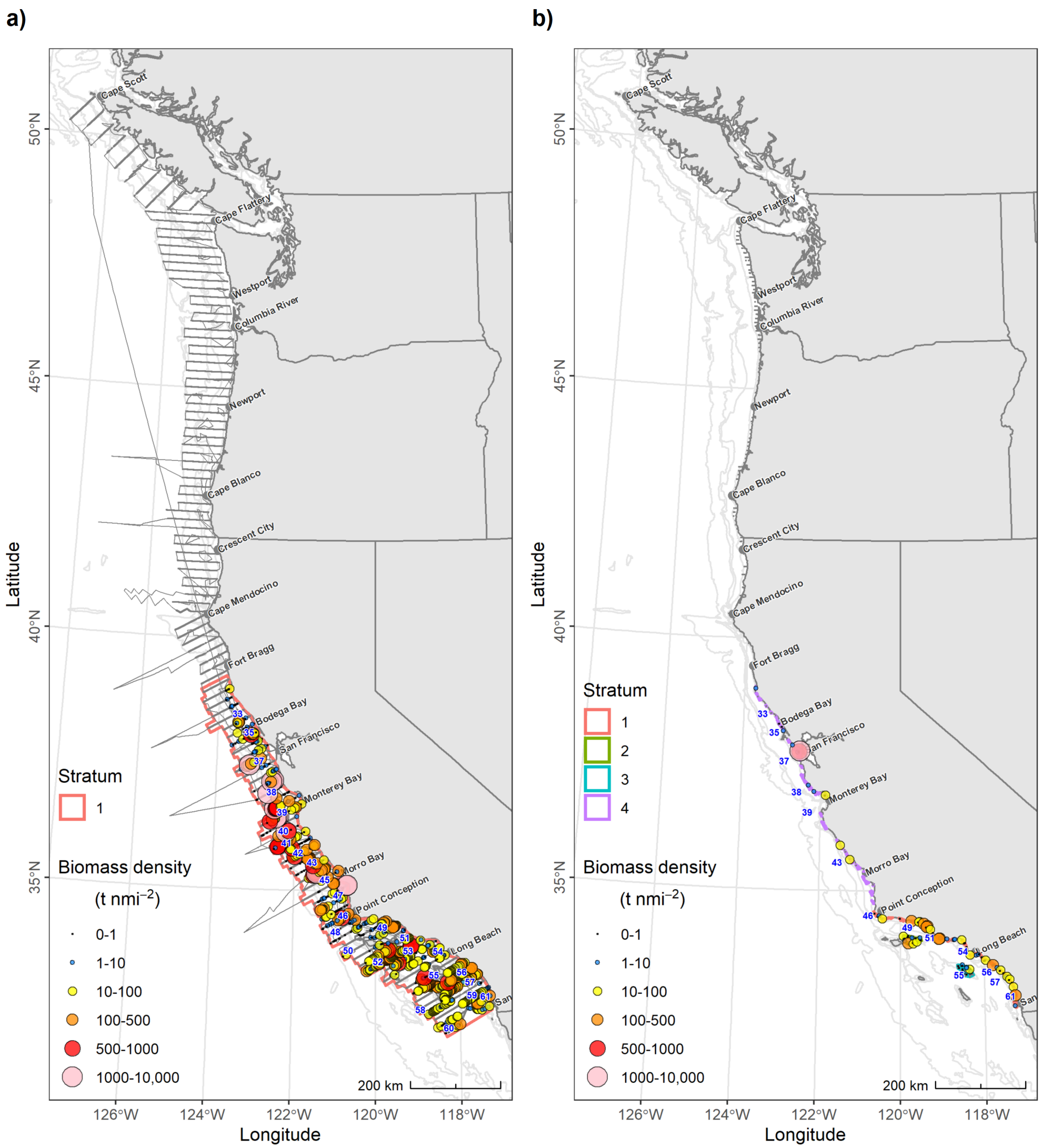

Figure 16: Biomass densities of central stock of Northern Anchovy (*Engraulis mordax*), per strata, in the a) core and b) nearshore survey regions. The blue numbers represent the locations of trawl clusters with at least one Northern Anchovy. The gray line represents the vessel track.

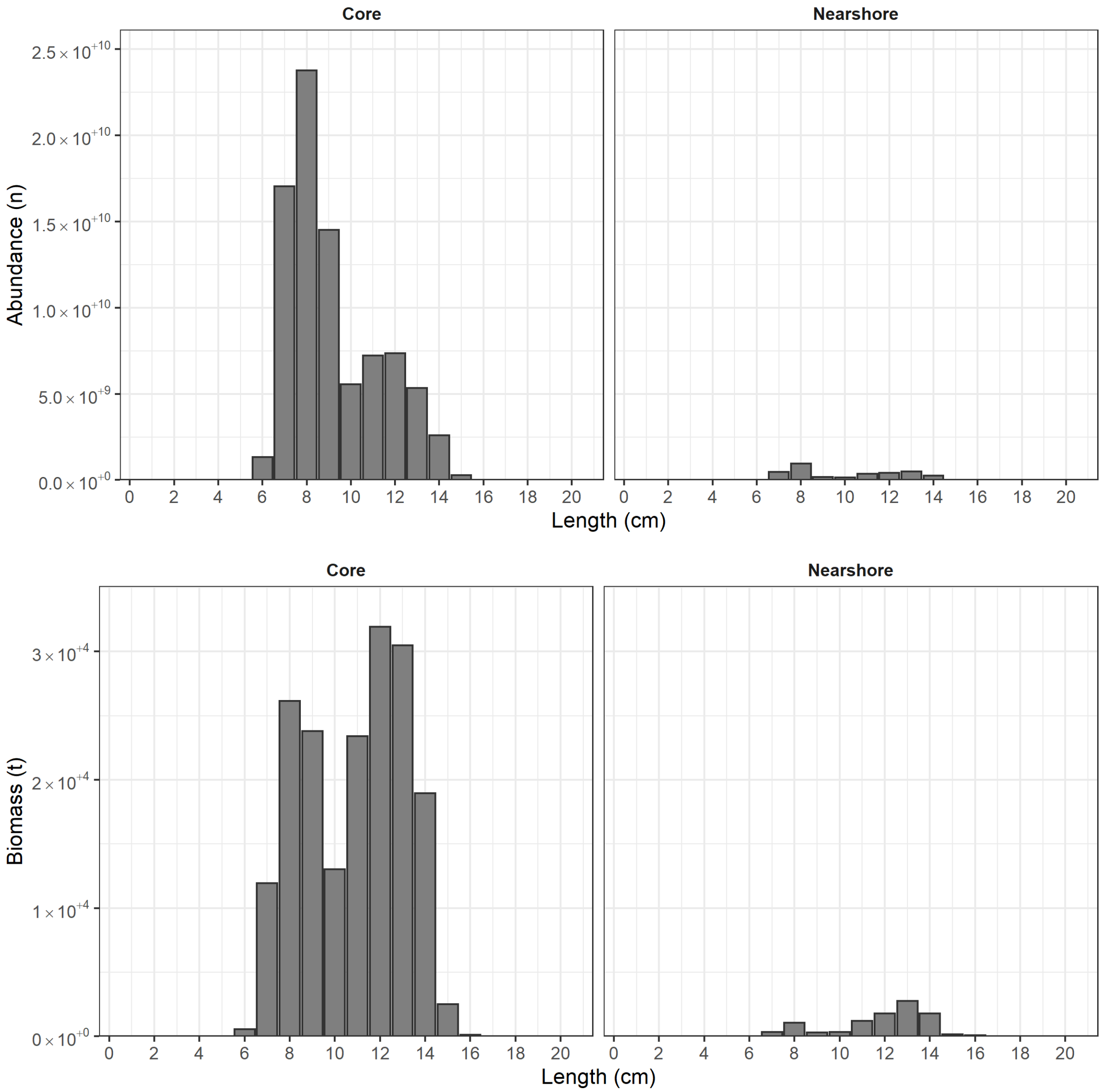

Figure 17: Abundance versus standard length (L_S, upper panel) and biomass (t) versus L_S (lower panel) for the central stock of Northern Anchovy (*Engraulis mordax*) in the core and nearshore survey regions.

3.6.2 Pacific Sardine

3.6.2.1 Northern stock The total estimated biomass of the central stock of Pacific Sardine was 33,632 t ($CI_{95\%}$ = 21,957 - 46,870 t, CV = 19%). In the core region, biomass was 33,138 t ($CI_{95\%}$ = 21,653 - 46,051 t, CV = 19%; **Table 10**), and was distributed from approximately Astoria to Morro Bay (**Fig. 18a**). L_S ranged from 14 to 29 cm with modes at 17 and 24 cm (**Table 12**, **Fig. 19**). In the nearshore region, biomass was 494 t ($CI_{95\%}$ = 305 - 820 t, CV = 28%; **Table 10**); was distributed between the Columbia River and Fort Bragg, and to a lesser extent between Half Moon Bay and Morro Bay (**Fig. 18b**); and had a similar length distribution to the core region (**Table 12**, **Fig. 19**). Biomass in the nearshore region comprised 1.5% of the total.

Table 10: Biomass estimates (metric tons, t) and their precision (upper and lower 95% confidence intervals, $CI_{95\%}$; and coefficient of variation, CV) for the northern stock of Pacific Sardine (*Sardinops sagax*) in the core and nearshore survey regions. Stratum areas are nmi^2.

Species		Stratum					Trawl		Biomass			
Name	Stock	Region	Number	Area	Transects	Distance	Clusters	Individuals	$\hat{B}$	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Sardinops sagax	Northern	Core	2	5,972	14	611	6	1,183	1,443	484	2,733	43
			3	22,615	51	2,286	16	3,758	31,695	19,946	44,635	20
			All	28,587	65	2,898	22	4,941	33,138	21,653	46,051	19
		Nearshore	1	66	12	15	2	45	14	4	23	33
			2	26	4	8	1	48	6	0	11	35
			3	21	6	4	1	96	220	46	496	59
			4	27	7	6	3	370	47	7	112	62
			5	79	6	16	1	101	182	122	277	22
			6	62	6	6	3	74	4	1	7	36
			7	40	4	2	3	139	10	0	25	66
			8	54	4	7	2	766	10	2	20	51
			All	376	49	64	16	1,638	494	305	820	28

3.6.2.2 Southern stock The total estimated biomass of the southern stock of Pacific Sardine was 14,890 t ($CI_{95\%}$ = 3,488 - 30,022 t, CV = 33%). In the core region, biomass was 8,322 t ($CI_{95\%}$ = 1,945 - 17,422 t, CV = 47%; **Table 11**), and was distributed from approximately Pt. Conception to San Diego (**Fig. 20a**). L_S ranged from 8 to cm with a mode at 16 cm (**Table 13**, **Fig. 21**). In the nearshore region, biomass was 6,568 t ($CI_{95\%}$ = 1,542 - 12,600 t, CV = 45%; **Table 11**), and was distributed between Pt. Conception and San Diego, but biomass was greatest between Santa Barbara and Malibu (**Fig. 20b**). The length distribution was similar to the core region (**Table 13**, **Fig. 21**). Biomass in the nearshore region comprised 44% of the total.

Table 11: Biomass estimates (metric tons, t) and their precision (upper and lower 95% confidence intervals, $CI_{95\%}$; and coefficient of variation, CV) for the southern stock of Pacific Sardine (*Sardinops sagax*) in the core and nearshore survey regions. Stratum areas are nmi^2.

Species		Stratum					Trawl		Biomass			
Name	Stock	Region	Number	Area	Transects	Distance	Clusters	Individuals	$\hat{B}$	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Sardinops sagax	Southern	Core	1	12,871	18	1,370	11	2,798	8,322	1,945	17,422	47
			All	12,871	18	1,370	11	2,798	8,322	1,945	17,422	47
		Nearshore	9	191	29	49	6	2,624	6,427	1,397	12,490	46
			10	89	11	22	2	2,206	140	4	348	68
			11	83	11	22	2	147	0	0	0	33
			All	363	51	93	7	4,977	6,568	1,542	12,600	45

Table 12: Abundance versus standard length (L_S, cm) for the northern stock of Pacific Sardine (*Sardinops sagax*) in the core and nearshore survey regions.

			Region	
Species	Stock	L_S	Core	Nearshore
Sardinops sagax	Northern	1	0	0
		2	0	0
		3	0	0
		4	0	0
		5	0	0
		6	0	0
		7	0	0
		8	0	0
		9	0	0
		10	0	0
		11	0	0
		12	0	49,756
		13	0	913,690
		14	4,739,631	3,111,165
		15	41,539,498	2,244,507
		16	59,579,268	51,702
		17	90,576,517	18,503
		18	32,295,316	10,850
		19	14,385,176	21,607
		20	6,519,870	21,556
		21	6,730,283	39,314
		22	2,482,943	29,508
		23	9,275,903	67,714
		24	30,709,103	548,743
		25	30,803,378	509,572
		26	10,187,719	87,388
		27	2,374,336	40,269
		28	907,076	1,537
		29	9,303	166
		30	0	0

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	
Species	Stock	L_S	Core	Nearshore
Sardinops sagax	Southern	1	0	0
		2	0	0
		3	0	0
		4	0	0
		5	0	0
		6	0	0
		7	0	0
		8	497,435	13,440
		9	3,660,256	106,106
		10	11,616,128	381,638
		11	7,336,842	388,785
		12	4,608,336	708,666
		13	9,256,003	423,622
		14	2,523,284	79,942
		15	24,205,290	17,389,890
		16	80,469,647	81,874,774
		17	27,074,202	22,328,575
		18	8,098,813	2,480,953
		19	1,506,947	0
		20	0	0
		21	0	0
		22	0	0
		23	0	0
		24	0	0
		25	0	0
		26	0	0
		27	0	0
		28	0	0
		29	0	0
		30	0	0

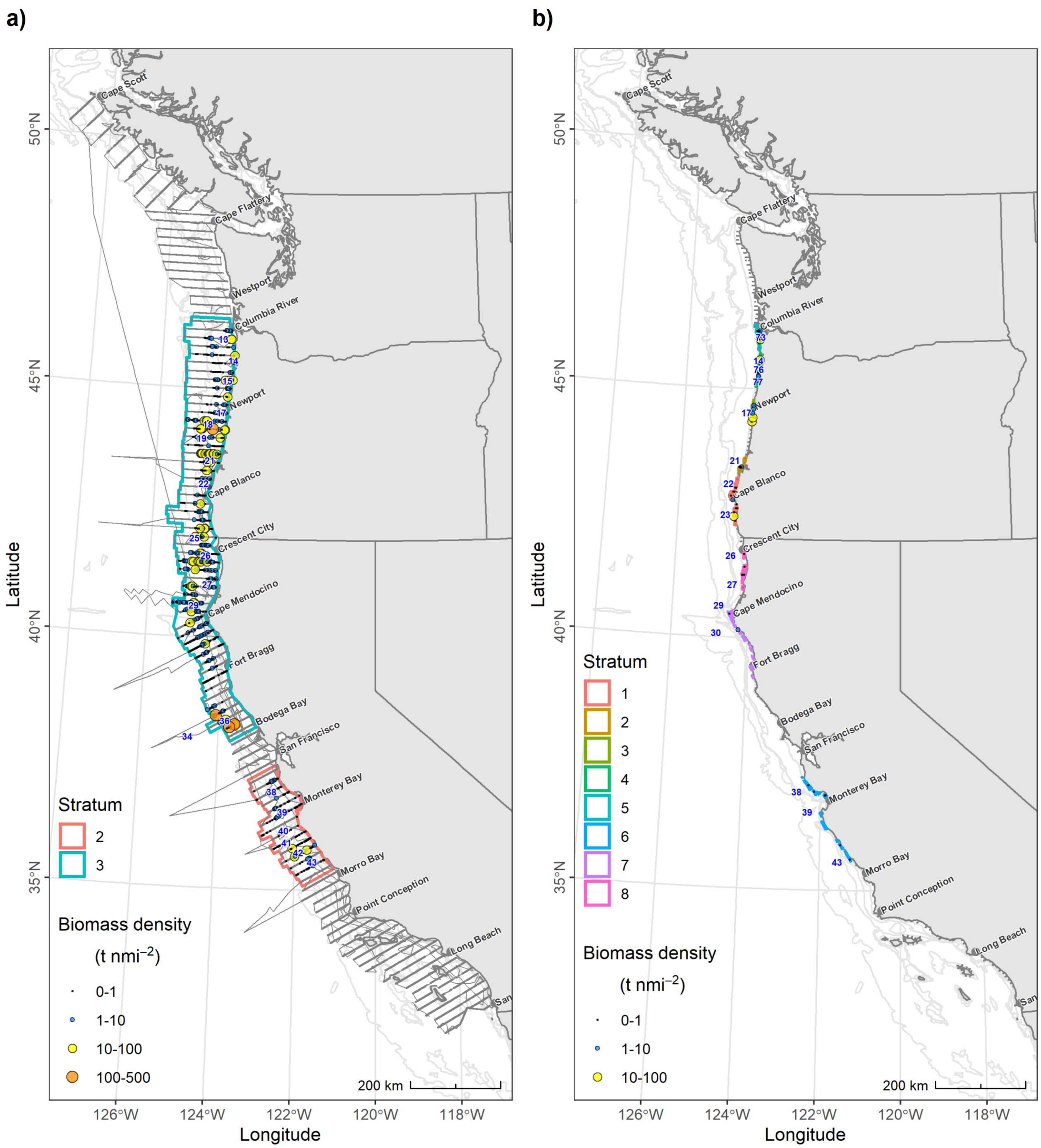

Figure 18: Biomass densities of the northern stock of Pacific Sardine (*Sardinops sagax*), per strata, in the a) core and b) nearshore survey regions. The blue numbers represent the locations of trawl clusters with at least one Pacific Sardine. The gray line represents the vessel track.

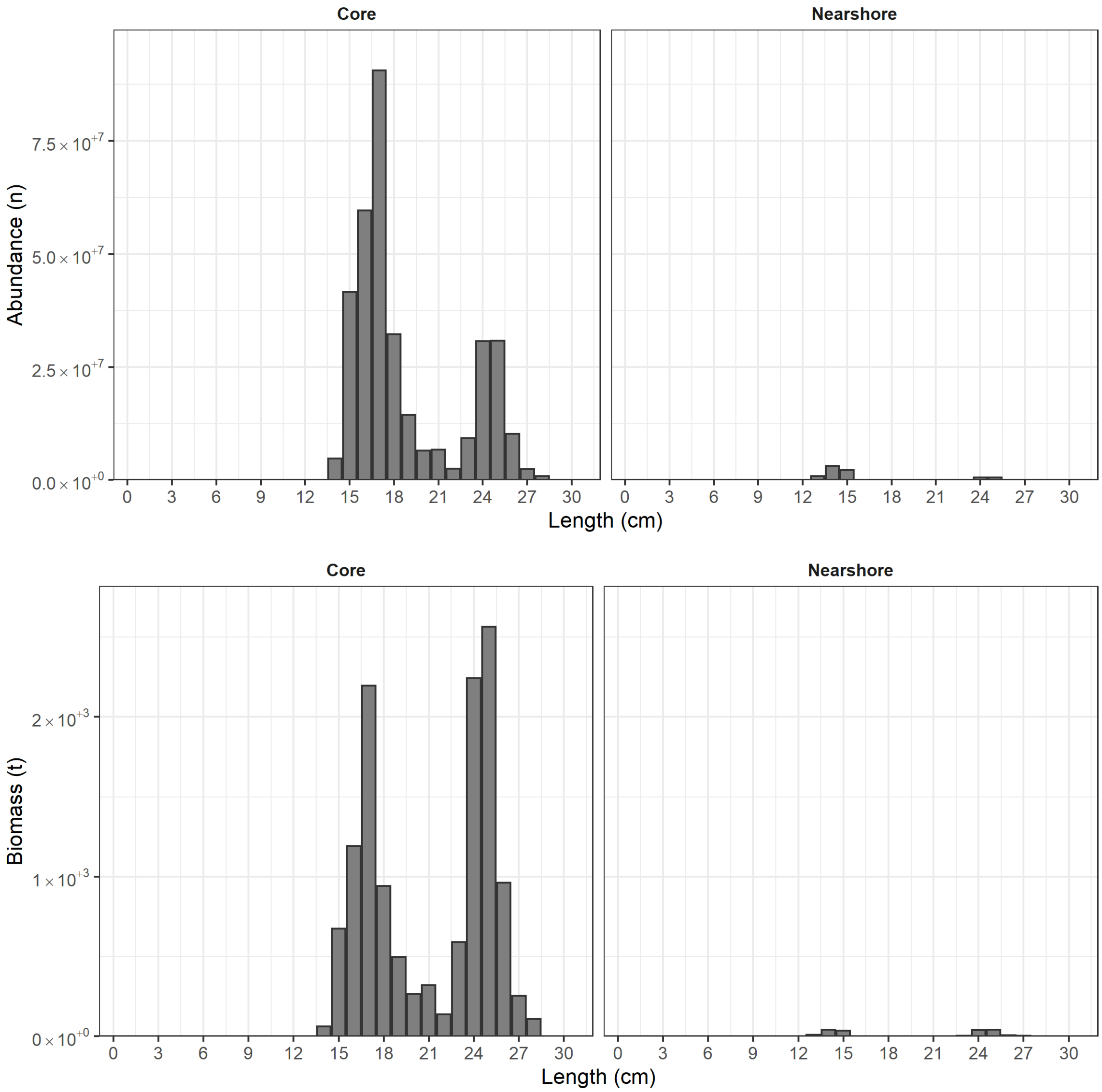

Figure 19: Estimated abundance (upper panel) and biomass (lower panel) versus standard length (L_S, cm) for the northern stock of Pacific Sardine (*Sardinops sagax*) in the core and nearshore survey regions.

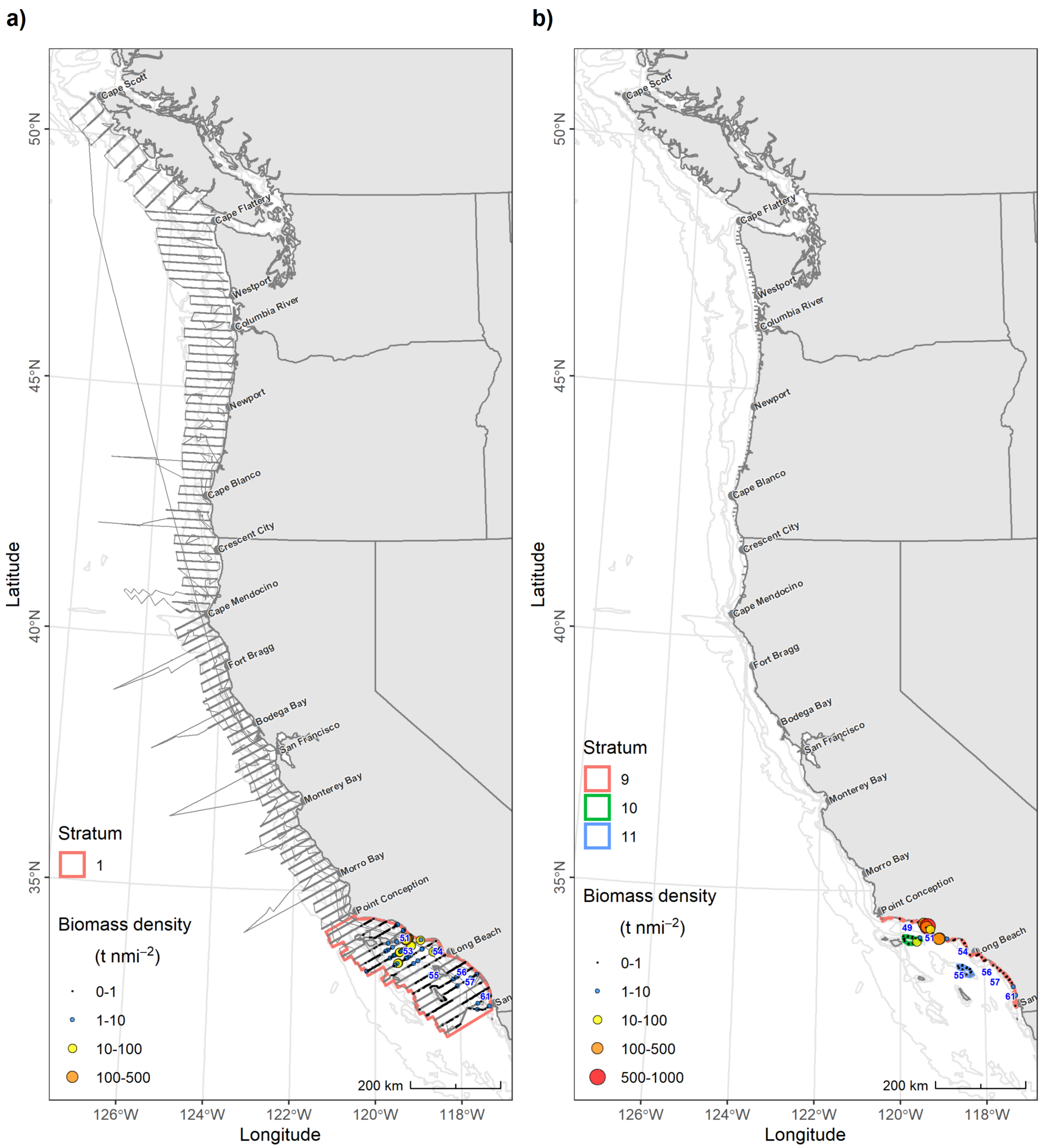

Figure 20: Biomass densities of the southern stock of Pacific Sardine (*Sardinops sagax*), per strata, in the a) core and b) nearshore survey regions. The blue numbers represent the locations of trawl clusters with at least one Pacific Sardine. The gray line represents the vessel track.

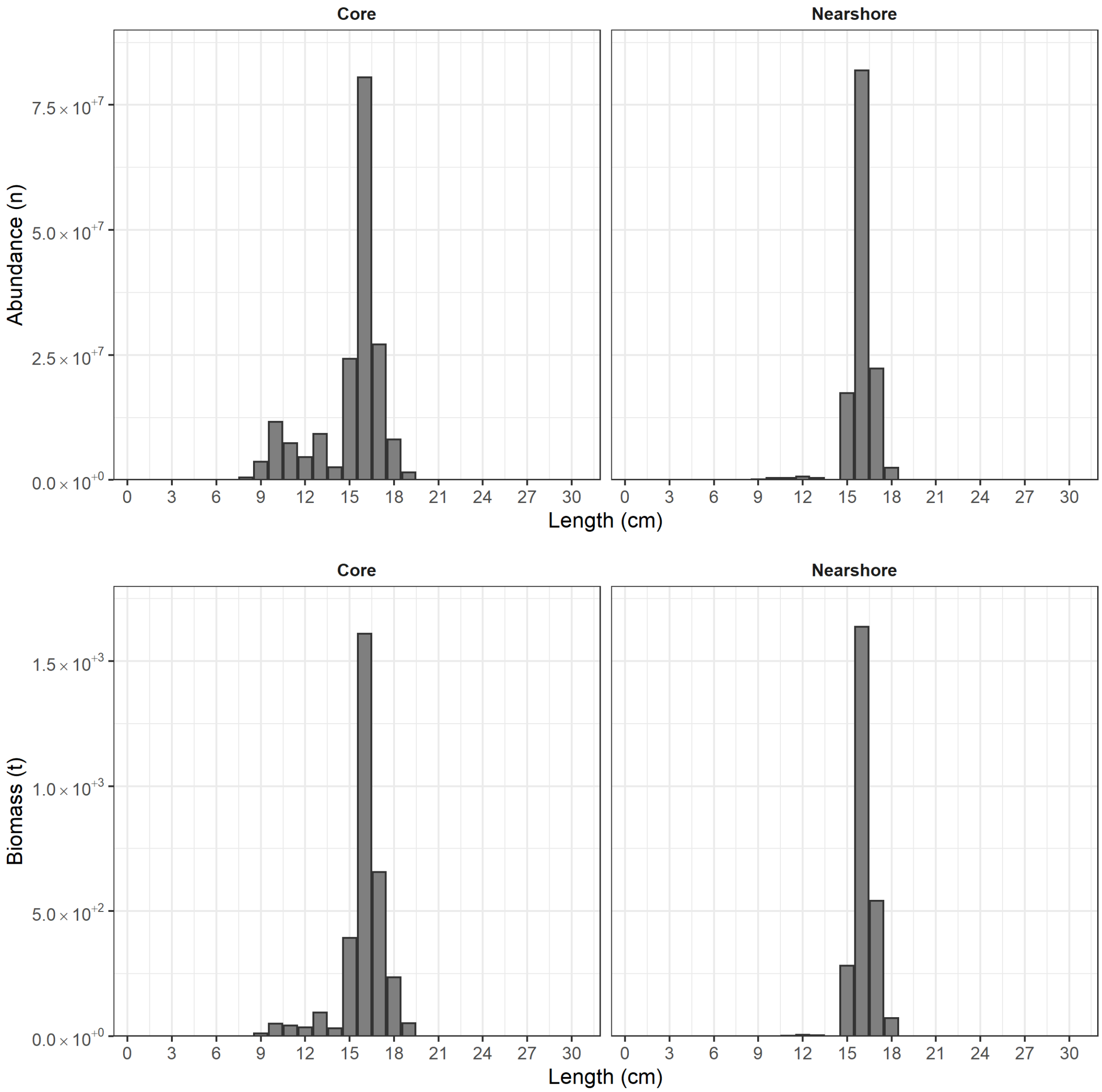

Figure 21: Estimated abundance (upper panel) and biomass (lower panel) versus standard length (L_S, cm) for the southern stock of Pacific Sardine (*Sardinops sagax*) in the core and nearshore survey regions.

3.6.3 Pacific Mackerel

The total estimated biomass of Pacific Mackerel was 26,577 t ($CI_{95\%}$ = 12,783 - 38,849 t, CV = 22%). In the core region, biomass was 24,643 t ($CI_{95\%}$ = 12,161 - 35,162 t, CV = 24%; **Table 14**), was distributed from approximately Astoria to Cape Mendocino in the north, and from Morro Bay to San Diego in the south (**Fig. 22a**). L_F ranged from 5 to 35 cm with modes at 8 and 32 cm (**Table 15**, **Fig. 23**). In the nearshore region, biomass was 1,934 t ($CI_{95\%}$ = 622 - 3,687 t, CV = 40%; **Table 14**, **Fig. 22b**); was distributed between the Columbia River and Cape Mendocino in the north, and between approximately Santa Barbara and San Diego in the SCB (**Fig. 23**); and had a similar length distribution to that in the core region (**Table 15**). Biomass in the nearshore region comprised 7.3% of the total.

Table 14: Biomass estimates (metric tons, t) and their precision (upper and lower 95% confidence intervals, $CI_{95\%}$; and coefficient of variation, CV) for Pacific Mackerel (*Scomber japonicus*) in the core and nearshore survey regions. Stratum areas are nmi^2.

Species		Stratum					Trawl		Biomass			
Name	Stock	Region	Number	Area	Transects	Distance	Clusters	Individuals	$\hat{B}$	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Scomber japonicus	All	Core	1	14,065	21	1,492	10	530	8,723	1,380	15,835	45
			2	17,626	38	1,776	14	1,556	15,920	8,640	25,064	27
			All	31,691	59	3,268	24	2,086	24,643	12,161	35,162	24
		Nearshore	1	161	26	46	5	302	1,664	376	3,418	46
			2	89	5	10	1	270	92	5	211	62
			3	83	11	22	2	33	0	0	0	33
			4	66	12	15	2	45	16	4	32	43
			5	26	4	8	1	19	4	0	6	35
			6	27	7	6	1	18	1	0	2	53
			7	2	1	0	-	-	0	0	0	-
			8	87	7	10	4	206	157	6	393	69
			All	542	73	117	14	894	1,934	622	3,687	40

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

			Region	
Species	Stock	L_F	Core	Nearshore
Scomber japonicus	All	1	0	0
		2	0	0
		3	0	0
		4	0	0
		5	296,144	0
		6	0	0
		7	200,640,771	0
		8	345,307,364	0
		9	30,788,833	0
		10	143,986,379	0
		11	97,858,749	0
		12	383,133	15,013
		13	536,420	11,626
		14	1,041,906	26,964
		15	1,587,746	311,456
		16	1,002,811	11,969
		17	3,649,037	15,110
		18	5,126,647	97
		19	5,211,842	7,700
		20	1,113,602	1,419,182
		21	3,279,640	2,270,536
		22	2,786,942	3,689,621
		23	2,711,288	3,122,010
		24	3,316,014	2,838,819
		25	1,670,607	294,932
		26	2,780,942	315,243
		27	2,827,690	39,011
		28	3,659,899	25,213
		29	3,986,931	40,484
		30	4,947,168	56,138
		31	8,512,281	149,188
		32	10,739,942	136,006
		33	7,666,153	61,453
		34	2,841,991	14,296
		35	95,669	156
		36	0	0
		37	0	0
		38	0	0
		39	0	0
		40	0	0

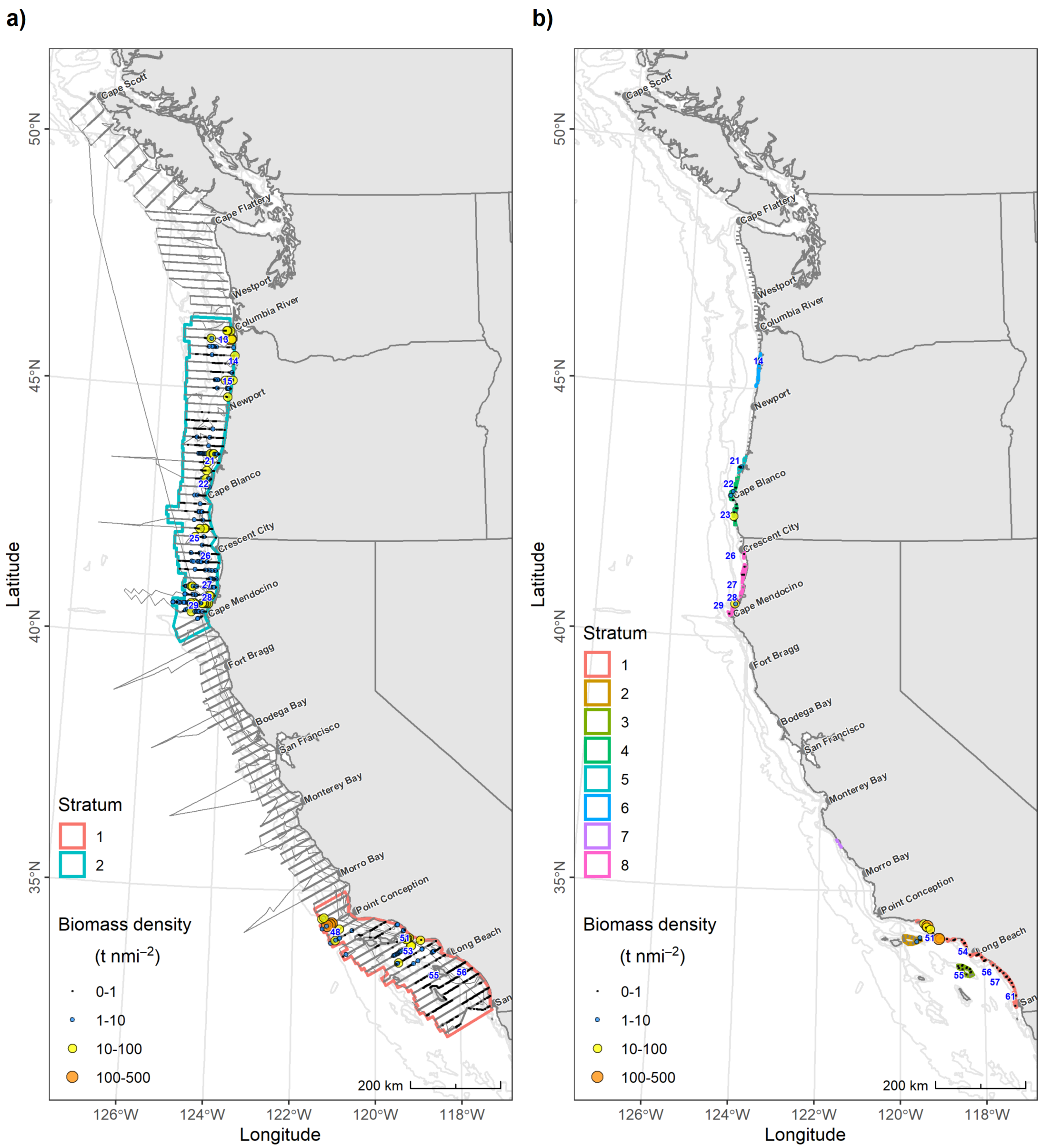

Figure 22: Biomass densities of the Pacific Mackerel (*Scomber japonicus*), per strata, in the a) core and b) nearshore survey regions. The blue numbers represent the locations of trawl clusters with at least one Pacific Mackerel. The gray line represents the vessel track.

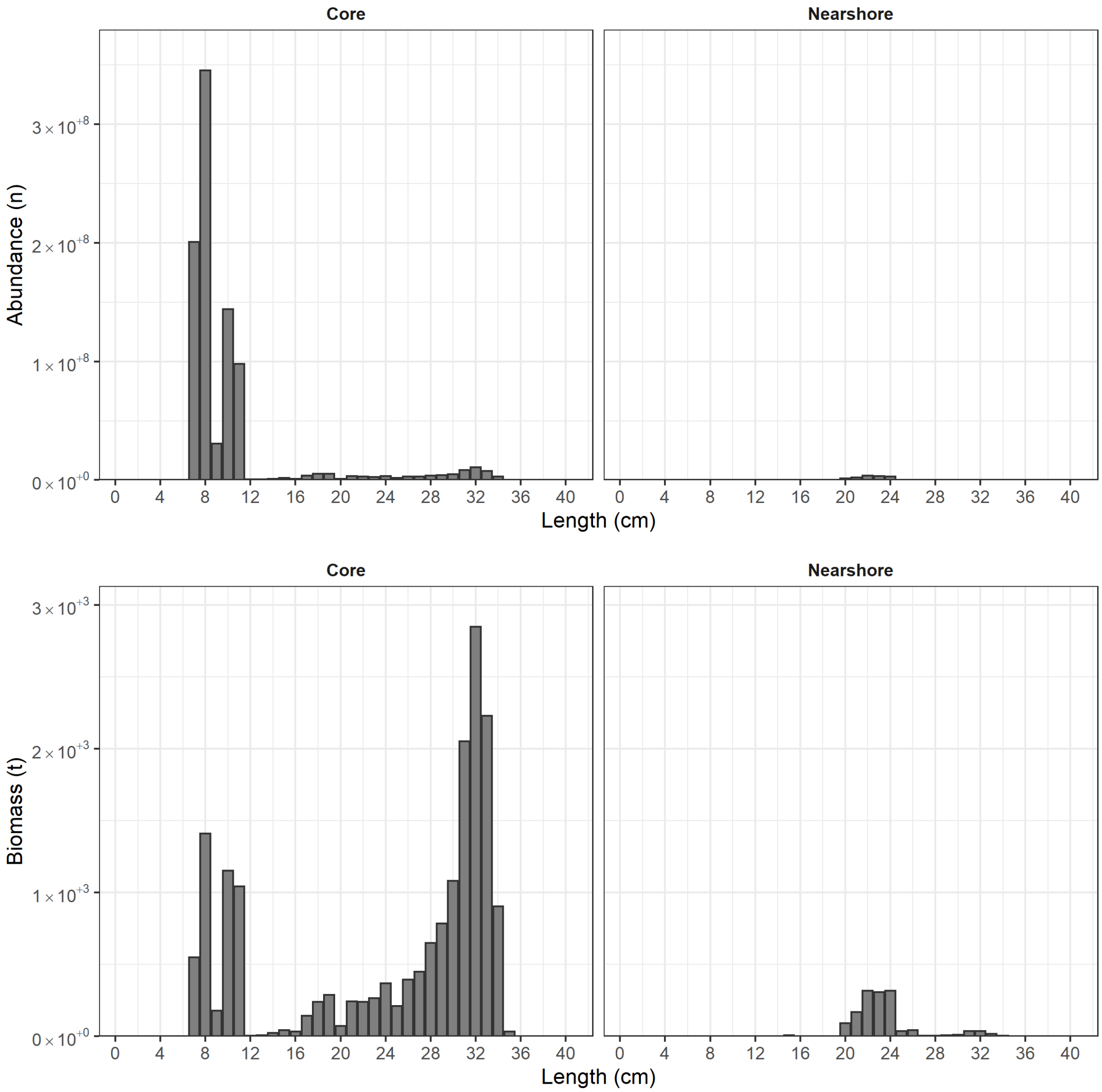

Figure 23: Estimated abundance (upper panel) and biomass (lower panel) versus fork length (L_F, cm) for Pacific Mackerel (*Scomber japonicus*) in the core and nearshore survey regions.

3.6.4 Jack Mackerel

The total estimated biomass of Jack Mackerel was 391,993 t ($CI_{95\%}$ = 233,793 - 536,870 t, CV = 20%). In the core region, biomass was 385,801 t ($CI_{95\%}$ = 231,500 - 527,538 t, CV = 20%; **Table 16**), was distributed from approximately Westport to Bodega Bay in the north, and from Morro Bay to San Diego in the south, but biomass was greatest between Cape Blanco and Bodega Bay (**Fig. 24a**). L_F ranged from 3 to 52 cm, with modes at 7, 21-22, and 28-32 cm (**Table 17**, **Fig. 25**). In the nearshore region, biomass was 6,192 t ($CI_{95\%}$ = 2,293 - 9,333 t, CV = 30%; **Table 16**, **Fig. 24b**); was distributed between Westport and Fort Bragg, and to a lesser extent in the SCB between Santa Barbara and San Diego (**Fig. 25**); and had a length distribution similar to the core region (**Table 17**). Biomass in the nearshore region comprised 1.6% of the total.

Table 16: Biomass estimates (metric tons, t) and their precision (upper and lower 95% confidence intervals, $CI_{95\%}$; and coefficient of variation, CV) for Jack Mackerel (*Trachurus symmetricus*) in the core and nearshore survey regions. Stratum areas are nmi^2.

Species		Stratum					Trawl		Biomass			
Name	Stock	Region	Number	Area	Transects	Distance	Clusters	Individuals	$\hat{B}$	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
		Core	1	14,065	21	1,492	13	492	5,227	1,458	8,926	36
			2	24,512	55	2,476	19	13,071	380,574	226,671	521,611	20
			All	38,576	76	3,968	32	13,563	385,801	231,500	527,538	20
		Nearshore	1	161	26	46	5	99	8	4	11	23
			2	89	5	10	1	1	0	0	0	62
			3	83	11	22	2	106	0	0	0	33
			4	111	19	27	5	1,357	1,176	611	1,597	21
			5	27	5	7	1	15	298	43	560	46
Trachurus symmetricus	All		6	21	6	4	1	495	2,451	514	5,526	59
			7	10	3	2	-	-	0	0	0	-
			8	16	2	2	1	1	0	0	0	22
			9	168	11	13	7	4,435	2,258	243	4,696	55
			All	687	88	132	20	6,509	6,192	2,293	9,333	30

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

			Region	
Species	Stock	L_F	Core	Nearshore
		1	0	0
		2	0	0
		3	568,976	0
		4	14,481,100	3,044
		5	33,760,779	68,715
		6	138,442,292	29,141
		7	154,863,074	12,177
		8	126,882,792	36,973
		9	20,297,064	10,226
		10	8,592,889	7,751
		11	5,443,081	791
		12	19,395,269	2,490
		13	5,062,165	3,159
		14	32,489,664	57,057
		15	22,695,913	27,507
		16	4,243,067	42,578
		17	1,388,675	42,433
		18	559,873	3,044
		19	959,792	93
		20	1,125,819	0
		21	169,074,505	20,616
		22	170,239,111	27,900
		23	13,004,115	57,884
		24	15,319,702	94,978
		25	43,127,216	237,900
		26	71,132,831	694,400
		27	89,506,776	1,756,631
		28	276,418,833	2,218,869
		29	143,782,582	2,013,803
		30	157,364,915	2,207,592
		31	140,634,493	2,995,833
		32	62,624,830	1,137,719
		33	41,123,356	514,268
		34	24,030,423	542,910
		35	7,351,718	248,454
		36	5,639,686	25,467
		37	7,225,241	27,326
		38	163,745	11,740
		39	0	0
		40	0	0
		41	0	0
		42	2,354,916	21,945
		43	0	0
		44	32,986	16,695
		45	32,986	29,268
		46	3,970,393	369,544
		47	3,161,457	459,620
		48	679,667	361,945
		49	2,046,539	135,470

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

Species	Stock	L_F	Core	Nearshore
		50	1,281,358	11,740
		51	0	0
		52	3,052,147	25,374
		53	0	143,870
		54	0	4,955
		55	0	0
		56	0	0
		57	0	0
		58	0	0
		59	0	0
		60	0	0

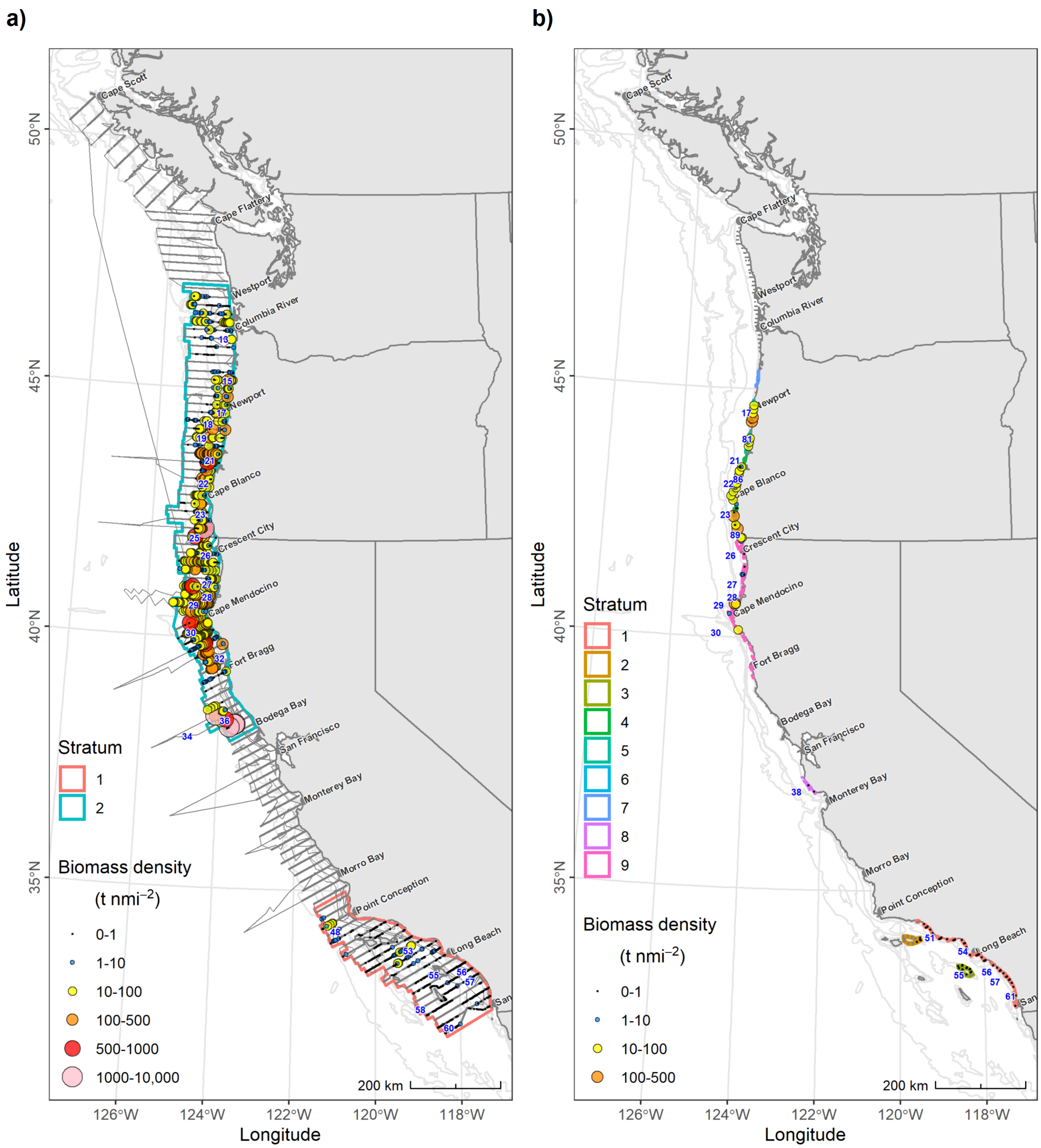

Figure 24: Biomass densities of Jack Mackerel (*Trachurus symmetricus*), per strata, in the a) core and b) nearshore survey regions. The blue numbers represent the locations of trawl clusters with at least one Jack Mackerel. The gray line represents the vessel track.

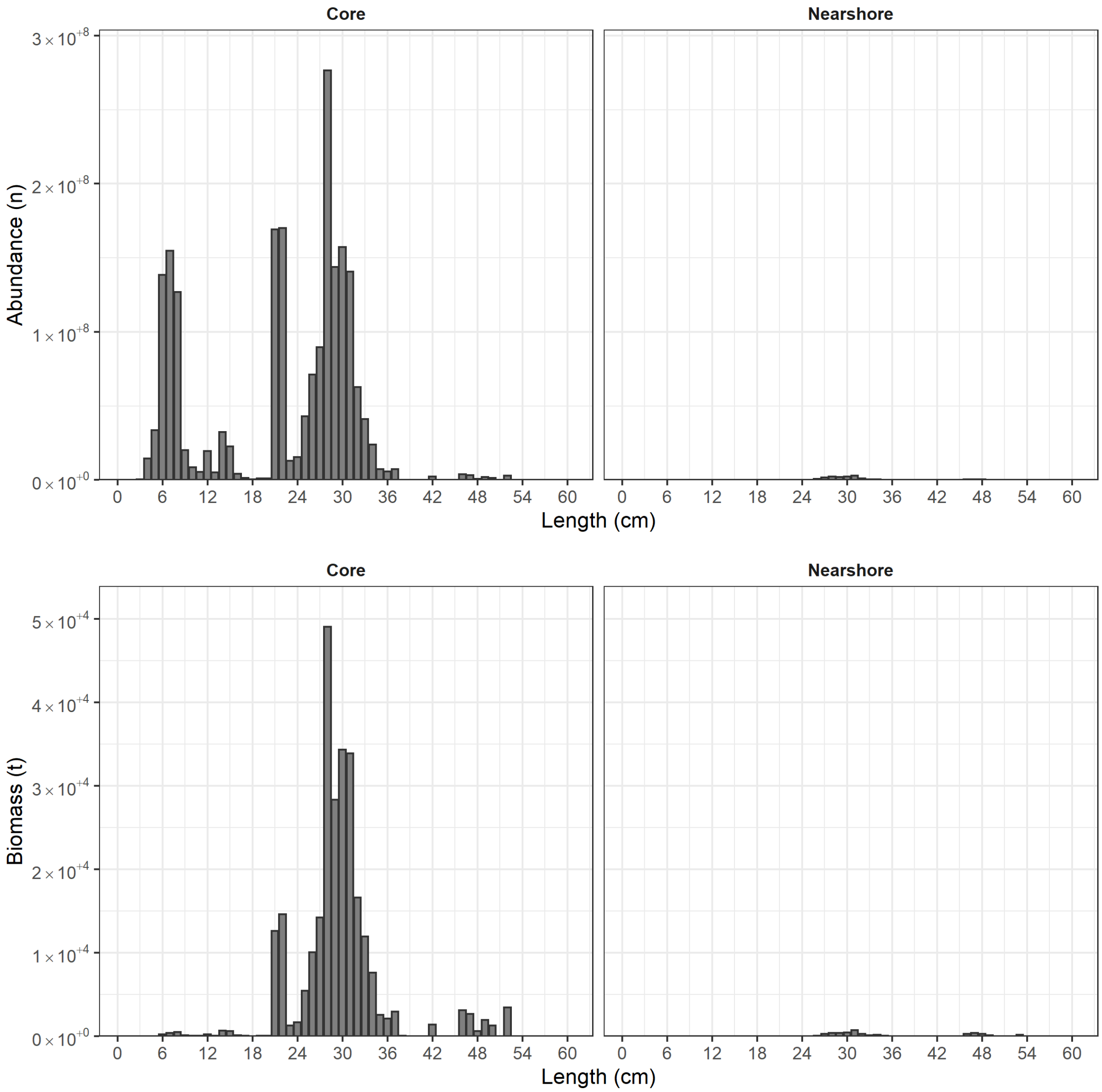

Figure 25: Estimated abundance (upper panel) and biomass (lower panel) versus fork length (L_F, cm) for Jack Mackerel (*Trachurus symmetricus*) in the core and nearshore survey regions.

3.6.5 Pacific Herring

The total estimated biomass of Pacific Herring was 269,989 t ($CI_{95\%}$ = 126,306 - 479,736 t, CV = 34%). In the core region, biomass was 267,792 t ($CI_{95\%}$ = 125,864 - 476,899 t, CV = 35%; **Table 18**), and was distributed from approximately Cape Scott to Coos Bay, but biomass was greatest off southern Vancouver Island and Cape Flattery (**Fig. 26a**). L_F ranged from 13 to 25 cm with modes at ~15 and 22 cm (**Table 19**, **Fig. 27**). In the nearshore region, biomass was 2,197 t ($CI_{95\%}$ = 442 - 2,838 t, CV = 31%; **Table 18**), was distributed between Cape Flattery and Florence (**Fig. 26b**) and had a similar length distribution to the core region (**Table 19**, **Fig. 27**). Biomass in the nearshore region comprised 0.81% of the total.

Table 18: Biomass estimates (metric tons, t) and their precision (upper and lower 95% confidence intervals, $CI_{95\%}$; and coefficient of variation, CV) for Pacific Herring (*Clupea pallasii*) in the core and nearshore survey regions. Stratum areas are nmi^2.

Species		Stratum					Trawl		Biomass			
Name	Stock	Region	Number	Area	Transects	Distance	Clusters	Individuals	$\hat{B}$	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Clupea pallasii	All	Core	1	7,179	11	367	5	12,355	210,987	66,544	387,859	41
			2	16,947	30	1,700	12	16,592	56,805	17,976	131,081	51
			All	24,126	41	2,067	15	28,948	267,792	125,864	476,899	35
		Nearshore	1	45	7	13	1	48	78	41	121	27
			2	441	50	93	19	12,285	2,118	375	2,777	32
			3	13	2	3	1	60	0	0	0	21
			All	499	59	109	21	12,392	2,197	442	2,838	31

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

Species	Stock	L_F	Region: Core	Region: Nearshore
Clupea pallasii	All	1	0	0
		2	0	0
		3	0	0
		4	0	0
		5	0	0
		6	0	0
		7	0	0
		8	0	0
		9	0	0
		10	0	0
		11	0	0
		12	0	0
		13	25,584,079	148,030
		14	110,473,748	3,556,324
		15	175,503,372	15,596,367
		16	57,413,013	16,839,960
		17	40,423,778	7,724,645
		18	68,193,328	4,558,671
		19	94,554,223	958,028
		20	237,658,270	178,925
		21	406,392,938	241,631
		22	1,318,928,244	185,384
		23	124,137,360	57,982
		24	58,621,150	8,349
		25	6,674,769	0
		26	0	0
		27	0	0
		28	0	0
		29	0	0
		30	0	0

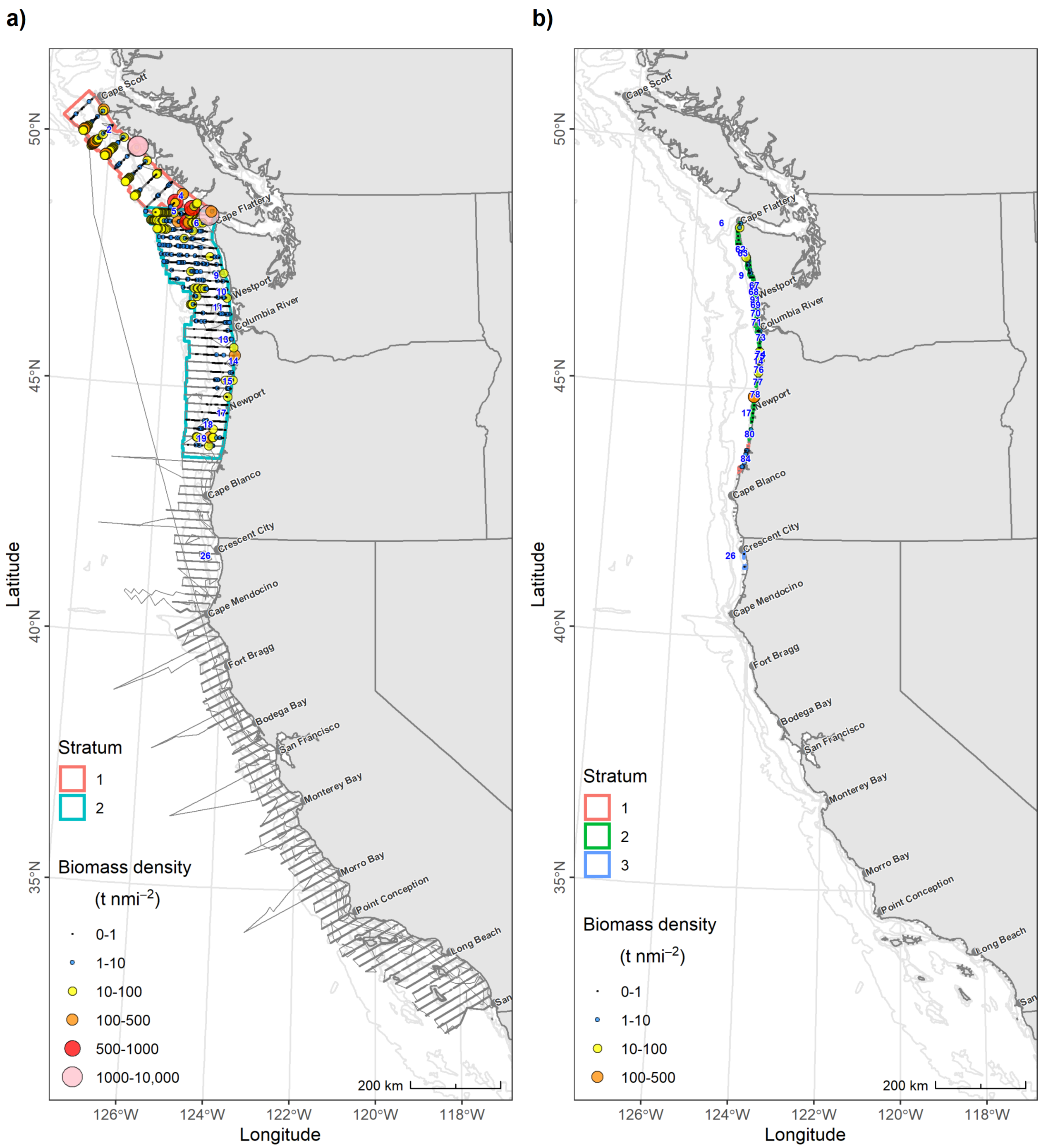

Figure 26: Biomass densities of Pacific Herring (*Clupea pallasii*), per strata, in the a) core and b) nearshore survey regions. The blue numbers represent the locations of trawl clusters with at least one Pacific Herring. The gray line represents the vessel track.

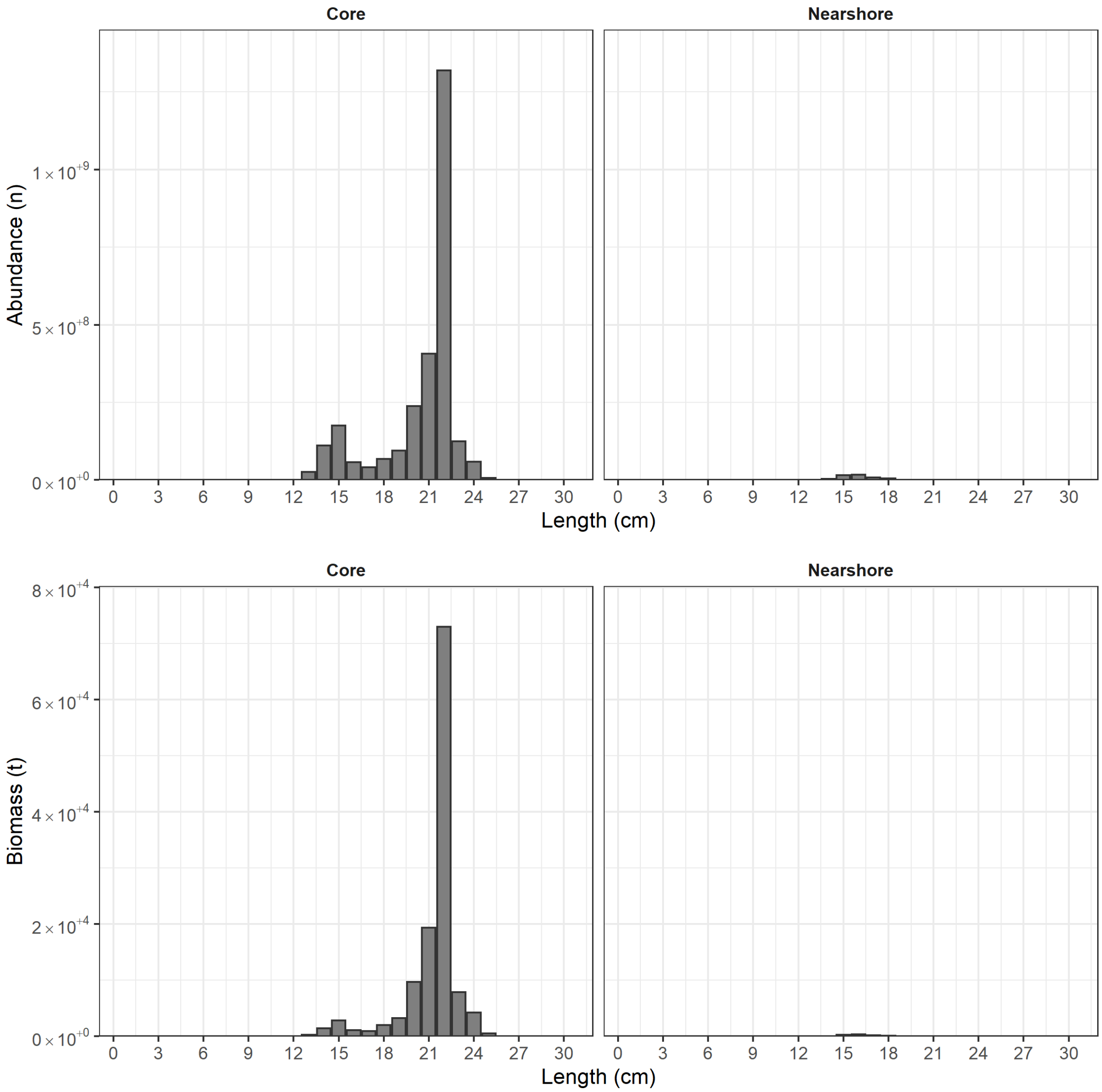

Figure 27: Estimated abundance (upper panel) and biomass (lower panel) versus fork length (L_F, cm) for Pacific Herring (*Clupea pallasii*) in the core and nearshore survey regions.

4 Discussion

The principal objectives of the 77-day, Summer 2019 CCE Survey were to survey the northern stock of Pacific Sardine and the northern and central stock of Northern Anchovy. Then, as possible, estimates were also sought for Pacific Mackerel, Jack Mackerel, Pacific Herring, and the southern stock of Pacific Sardine. With the benefit of favorable weather and few technical problems, *Lasker* surveyed from the northern end of Vancouver Island to San Diego. South of the Strait of Juan de Fuca, all transects were spaced 10-nmi apart, which allowed the precise estimation of abundance for all five species of small pelagic fishes in the survey region.

Biomass estimates were derived using the best available data in each nearshore region. For example, both *Lisa Marie* and a USV conducted acoustic transects off the coasts of WA and OR; however, only *Lisa Marie* data in the overlapping region were used to estimate biomass because acoustic sampling was more contemporaneous with *Lasker* and there was no biological sampling from the USV to apportion backscatter. Purse seine catches from *Lisa Marie*, used to aportion backscatter from *Lisa Marie*, were consistent with trawl catches from *Lasker*. Purse seine sets from *Long Beach Carnage* did not adhere to the sampling protocol, which aimed to sample the proportions of CPS present in the acoustically sampled areas. For example, sets were occasionally conducted outside the areas where acoustic sampling occurred, and often the catch did not reflect the species composition of nearby trawls conducted by *Lasker* nor the contemporaneous observations in *Long Beach Carnage*'s log book entries. Therefore, species proportions from *Lasker*'s nearest trawl clusters were used to apportion nearshore backscatter from *Long Beach Carnage* in the SCB.

4.1 Biomass and abundance of CPS

4.1.1 Northern Anchovy

4.1.1.1 Northern stock The northern stock of Northern Anchovy is north of Cape Mendocino and south of Haida Gwaii, BC (~54 °N; Litz *et al.*, 2008). In summer 2019, the estimated stock biomass, 1,512.5 t ($CI_{95\%}$ = 371.44 - 3,034 t) in the core survey region was considerably lower than the estimate of 22,709 t ($CI_{95\%}$ = 1,452 - 57,334 t) (Zwolinski *et al.*, 2019) in summer 2017 and 24,419 t ($CI_{95\%}$ = 5,366 - 42,068 t) in summer 2018 (Stierhoff *et al.*, 2019).

4.1.1.2 Central stock The estimated biomass of the central stock of Northern Anchovy in the core survey region was 769,154 t ($CI_{95\%}$ = 559,915 - 984,059 t) in summer 2019, which was not different from the estimate of 723,826 t in summer 2018 ($CI_{95\%}$ = 533,548 - 1,015,782; Stierhoff *et al.*, 2019) but was a nearly five-fold increase from estimates in summer 2016 (151,558 t, $CI_{95\%}$ = 34,806 - 278,024; Zwolinski *et al.*, 2017) and summer 2017 (153,460 t, $CI_{95\%}$ = 2,628 - 264,009 t; Zwolinski *et al.*, 2019). The length distribution of the stock in summer 2019 had two modes (L_S ~8 and 12 cm), indicating the presence of two dominant year-classes.

4.1.2 Pacific Sardine

4.1.2.1 Northern stock The summer 2019 survey sampled most of the potential habitat for the northern stock of Pacific Sardine, and likely most of the stock. The estimated biomass of the northern stock of Pacific Sardine in the core survey region was 33,138 t ($CI_{95\%}$ = 21,653 - 46,051 t) in summer 2019, which was not different than the estimate of 25,148 t ($CI_{95\%}$ = 4,480 - 60,551; Stierhoff *et al.*, 2019) in summer 2018, but had a lower CV (19% versus 67% in 2018), likely due to the more even distribution of biomass throughout the sampling strata.

A gap in the length distribution of Pacific Sardine between 17 and 24 cm (and between 15 and 18 cm in 2018) is further evidence of poor recruitment in 2016. Similar to 2017 and 2018, few trawls with Pacific Sardine smaller than 10 cm indicates that recruitment was weak again in 2019.

In recent years, the distribution of the northern stock of Pacific Sardine has been fragmented and its migration has been abbreviated. Despite the recurrent presence of good potential habitat north of Vancouver Island during the summer months (see **Fig. 2**), the stock has not migrated there since 2013 (Zwolinski *et al.*, 2014).

4.1.2.2 Southern stock

The potential habitat of the northern stock of Pacific Sardine did not extend into the SCB at the time it was sampled (**Fig. 2c,d**). Therefore, the 8,322.4 t ($CI_{95\%}$ = 1,945.5 - 17,422 t) of biomass estimated there was attributed to the southern stock of Pacific Sardine. An unknown portion of the southern stock of Pacific Sardine may have extended in to Mexico.

4.1.3 Pacific Mackerel

In 2019, the estimated biomass of Pacific Mackerel in the core survey region was 24,643 t ($CI_{95\%}$ = 12,161 - 35,162 t), which was greater than the estimate of 8,000 t ($CI_{95\%}$ = 1,000-20,000 t) in summer 2013 (Zwolinski *et al.*, 2014) but lower than the estimates of 41,139 t ($CI_{95\%}$ = 18,019 -58,425 t) in 2017 (Zwolinski *et al.*, 2019) and 31,211 t ($CI_{95\%}$ = 18,309 - 45,106 t) in 2018 (Stierhoff *et al.*, 2019).

The species was distributed between Astoria and Cape Mendocino in the north and between Morro Bay and San Diego in the south. Their length distribution had modes at 8 and 32 cm. The first mode is indicative of a newly recruited cohort, while the largest mode, approaching the maximum length for Pacific Mackerel, probably includes fish from multiple year classes.

4.1.4 Jack Mackerel

In 2019, the estimated biomass of Jack Mackerel in the core survey region was 385,801 t ($CI_{95\%}$ = 231,500 - 527,538 t), which was three-fold higher that the estimate of 128,313 t ($CI_{95\%}$ = 70,594 -180,676 t) in summer 2017 (Zwolinski *et al.*, 2019), and was nearly 50% higher than the estimate of 202,471 t ($CI_{95\%}$ = 128,718 - 260,175 t) in summer 2018 (Stierhoff *et al.*, 2019). Their length distribution had three distinct modes indicating the presence of several distinct year classes. Jack Mackerel was the second most abundant species overall and was most abundant between Newport and Crescent City in the primary survey area, and offshore in the SCB.

4.1.5 Pacific Herring

Pacific Herring in the northeastern Pacific Ocean form a quasi-panmictic population (Beacham *et al.*, 2008), and when they are not spawning nearshore or in bays and estuaries, may be distributed farther offshore along the continental shelf or slope. There are at least four stocks of Pacific Herring off Vancouver Island and WA, separated by spawning times and locations (DFO, 2017; Stick *et al.*, 2014). The Yaquina Bay and Winchester Bay stocks inhabit waters between Newport and Cape Blanco (ODFW, 2013).

The estimated biomass of Pacific Herring in the core survey region off the coast of Vancouver Island, WA, and OR (267,792 t; $CI_{95\%}$ = 125,864 - 476,899 t) represented a more than three-fold increase over the estimates of 63,418 t ($CI_{95\%}$ = 29,811 - 103,365 t) in 2017 (Zwolinski *et al.*, 2019) and 79,053 t ($CI_{95\%}$ = 33,103 - 140,218 t) in 2018 (Stierhoff *et al.*, 2019). In 2019, Pacific Herring biomass spanned most of the continental shelf within the area sampled, compared to the more patchy and nearshore distribution of biomass observed in the 2017 and 2018 surveys.

The acoustic-trawl estimates of Pacific Herring are susceptible to uncertainty in species identification, because Pacific Herring may be both demersal and nearshore when spawning, and pelagic when farther offshore. When integrating backscatter over their possible range of depths, echoes may be included from a variety of species with swimbladders, such as a Pacific Hake and rockfishes (Stanley *et al.*, 2000, 1999), Lingcod (*Ophiodon elongatus*), Alaska Pollock (*Gadus chalcogrammus*), and others (Rutherford, 1996). To mitigate this potential source of uncertainty in the 2019 estimates of Pacific Herring biomass, the maximum integration depth was set to 75 m, similar to analyses conducted for summer 2018, which appeared to reflect a transition between the pelagic herring and other fish communities that occurred deeper.

4.2 Ecosystem dynamics: Forage fish community

The acoustic-trawl method (ATM) has been used worldwide to monitor the biomasses and distributions of pelagic and mid-water fish stocks worldwide (e.g., Coetzee *et al.*, 2008; Karp and Walters, 1994; Simmonds *et al.*, 2009). In the CCE, ATM surveys have been used to directly assess Pacific Hake (Edwards *et al.*, 2018; JTC, 2014), rockfishes (Demer, 2012a, 2012b, 2012c; Starr *et al.*, 1996), Pacific Herring (Thomas and

Thorne, 2003), and CPS (Hill *et al.*, 2017; Mais, 1974, 1977). Focused initially, in 2006, on Pacific Sardine (Cutter and Demer, 2008), the SWFSC's ATM surveys of CPS in the CCE have evolved to assess the five most abundant forage-fish species (Zwolinski *et al.*, 2014): Pacific Sardine, Northern Anchovy, Jack Mackerel, Pacific Mackerel, and Pacific Herring. The proportions of these stocks that are in water too shallow to be sampled by NOAA shops 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. 28, 29**). 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*[5]), Common Murres (*Uria aalge*), Brandt's Cormorants (*Phalacrocorax penicillatus*), and California sea lions (*Zalophus californianus*[6]) (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. 28, 29**).

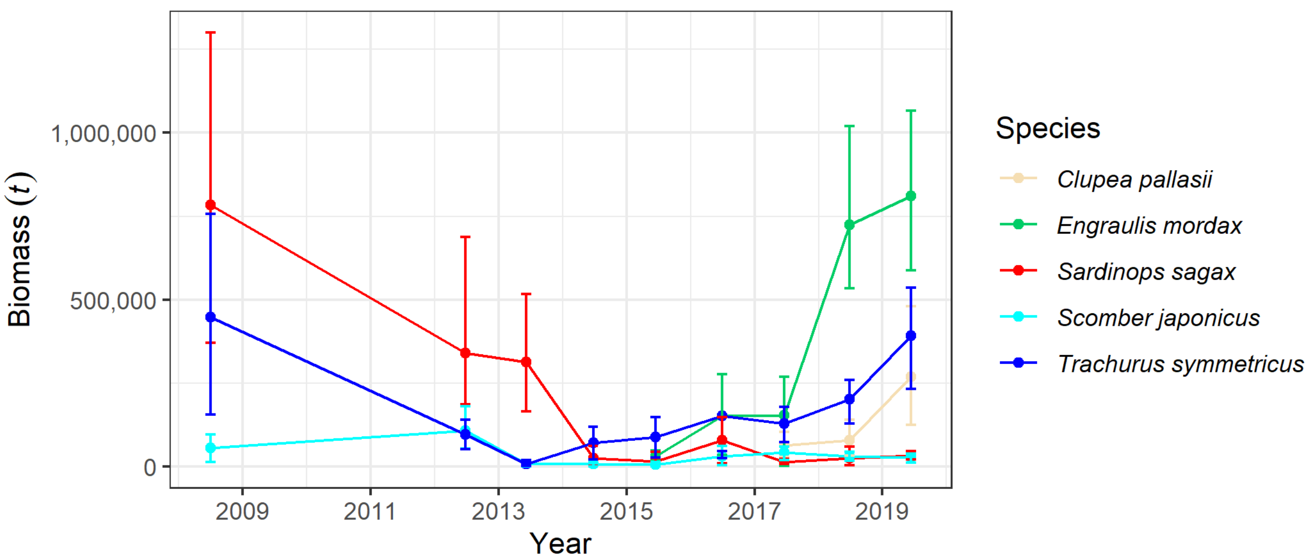

Figure 28: Estimated biomasses (t) of CPS in the CCE since 2008. Error bars are 95% confidence intervals.

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

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

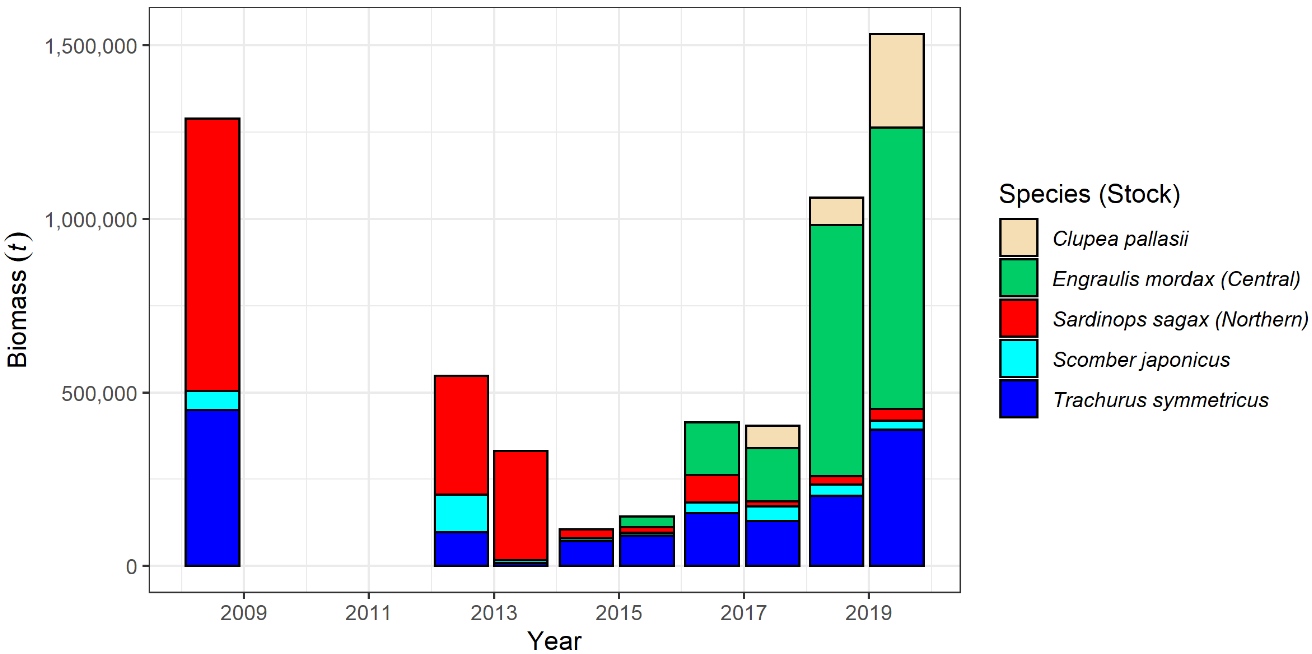

Figure 29: Cumulative biomass (t) for the five most abundant CPS in the CCE during summer. The forage-fish assemblage was dominated by Pacific Sardine prior to 2014 and by the central stock of Northern Anchovy after 2015. During the transition period with minimum forage-fish biomass, the U.S. fishery for Pacific Sardine was closed, NOAA recognized an unusual mortality event for California Sea lions, and multiple species of seabirds experienced reproductive failures.

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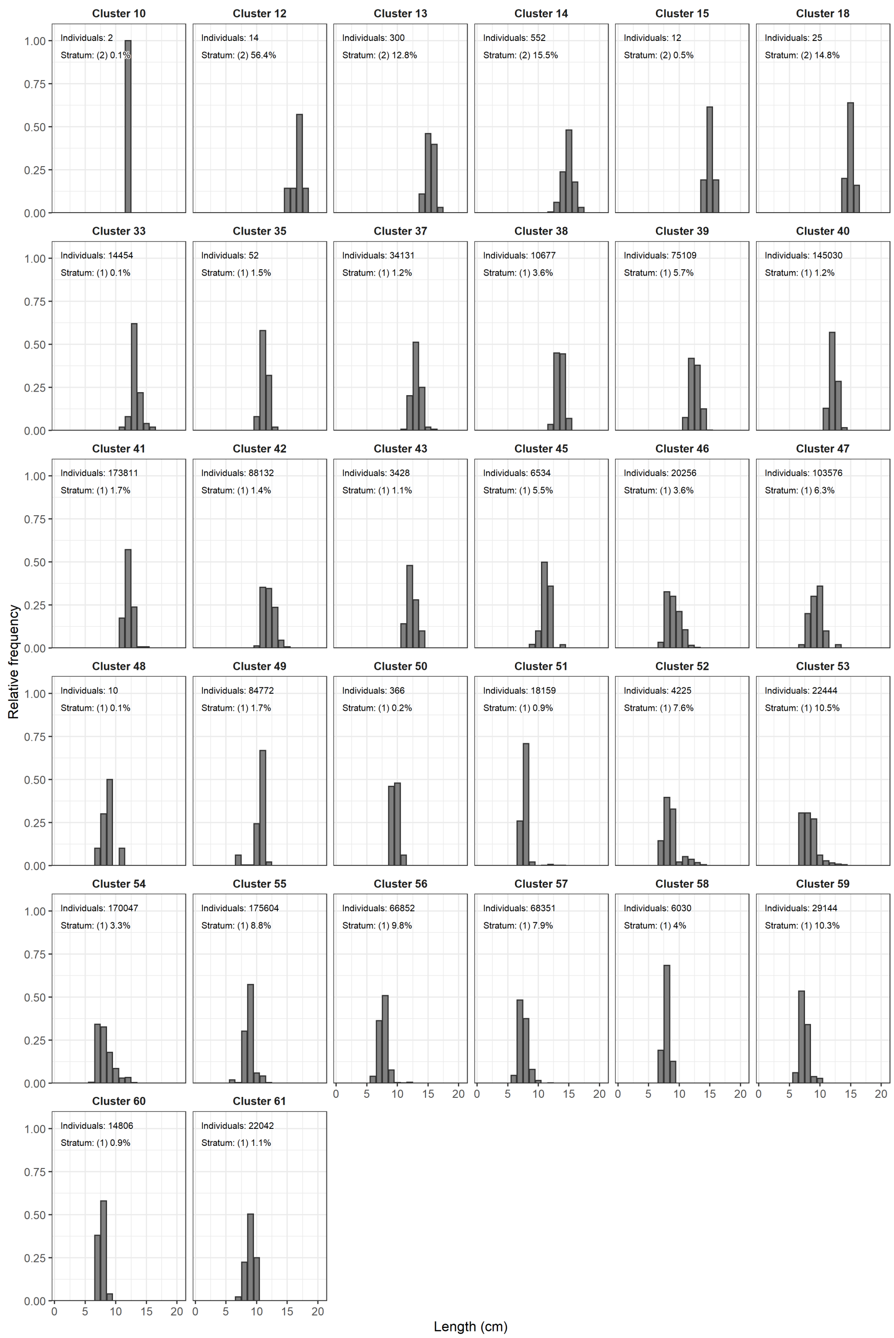
Appendix

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

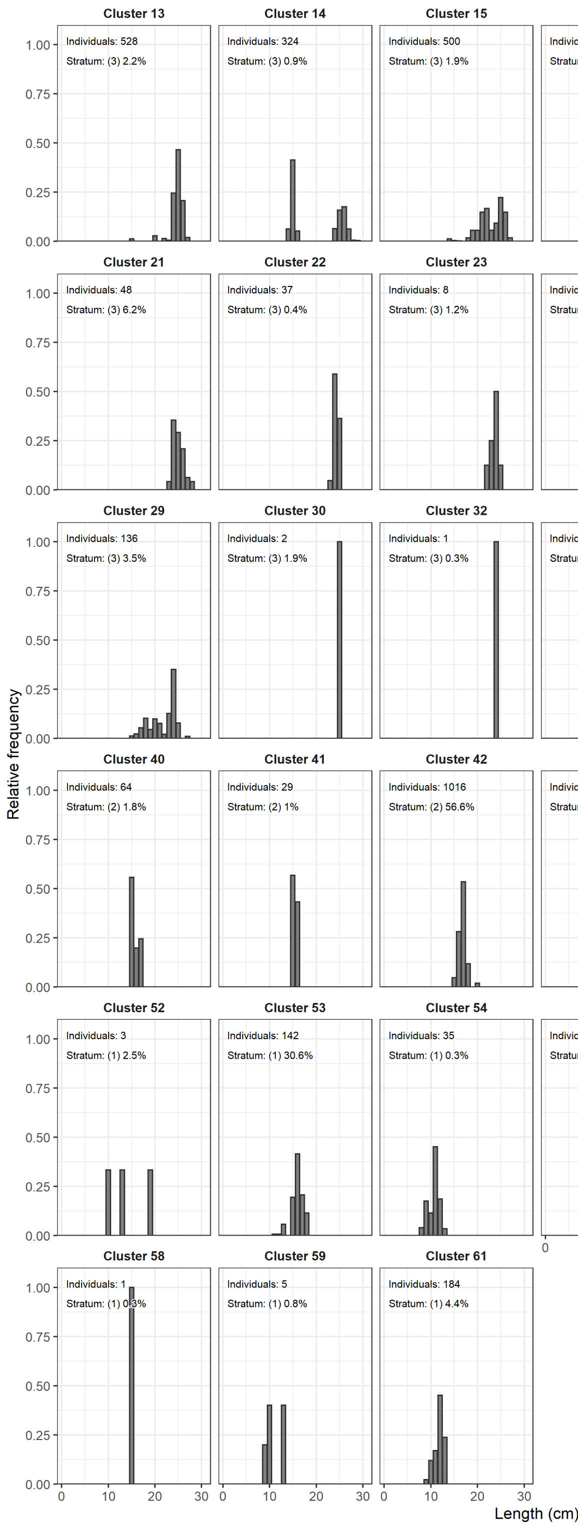
A.1 Northern Anchovy

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



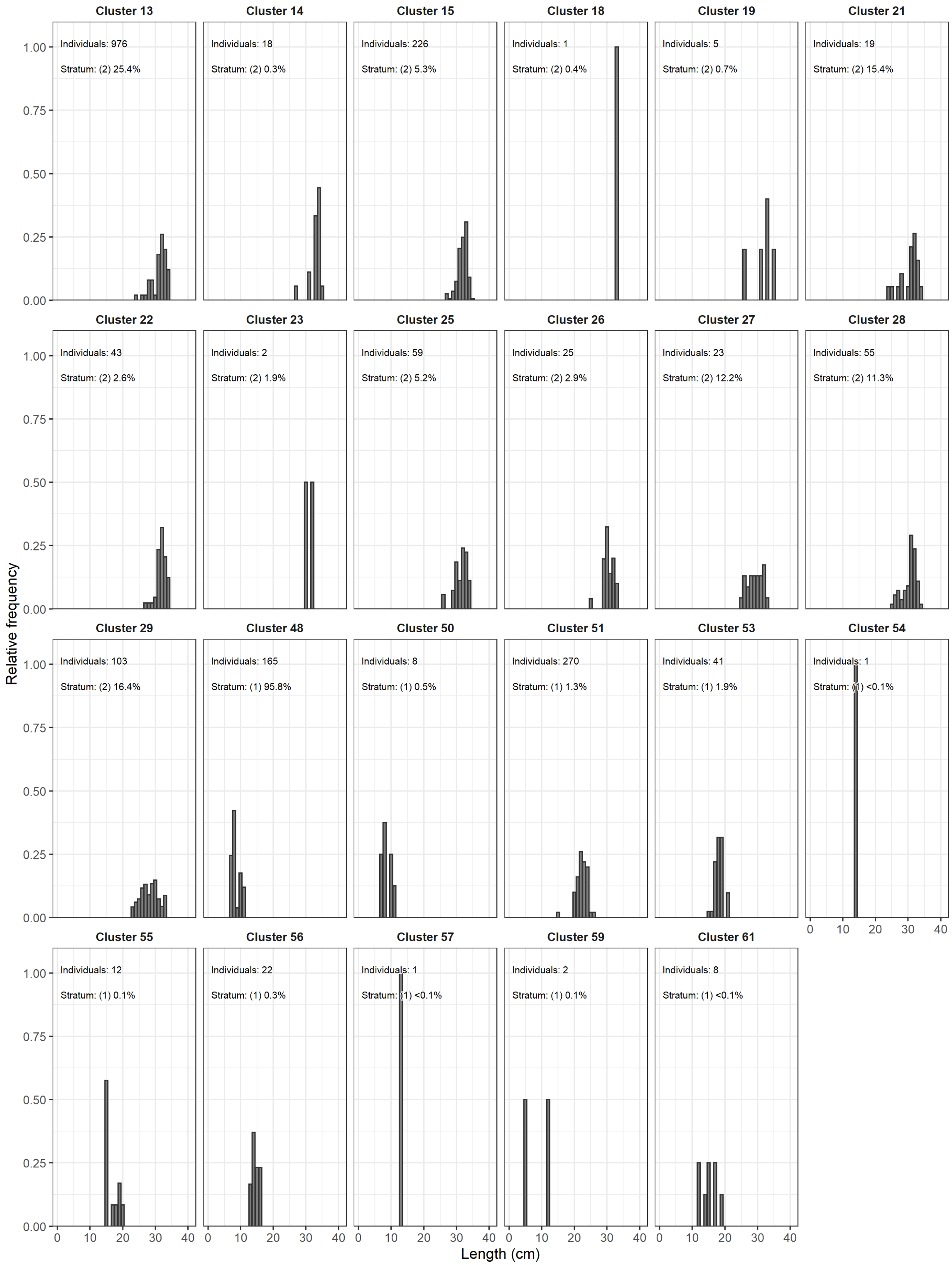
A.2 Pacific Sardine

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



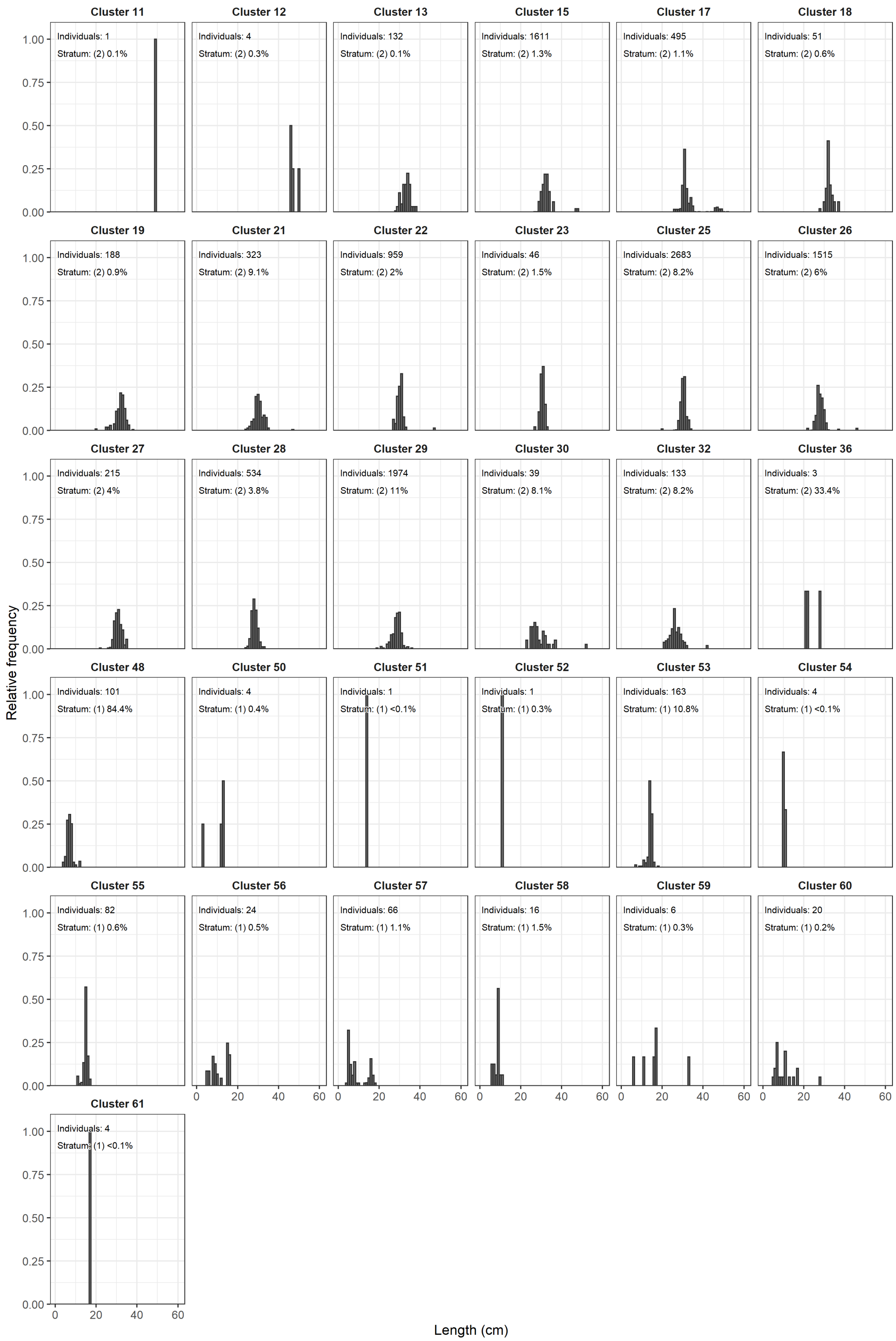
A.3 Pacific Mackerel

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.



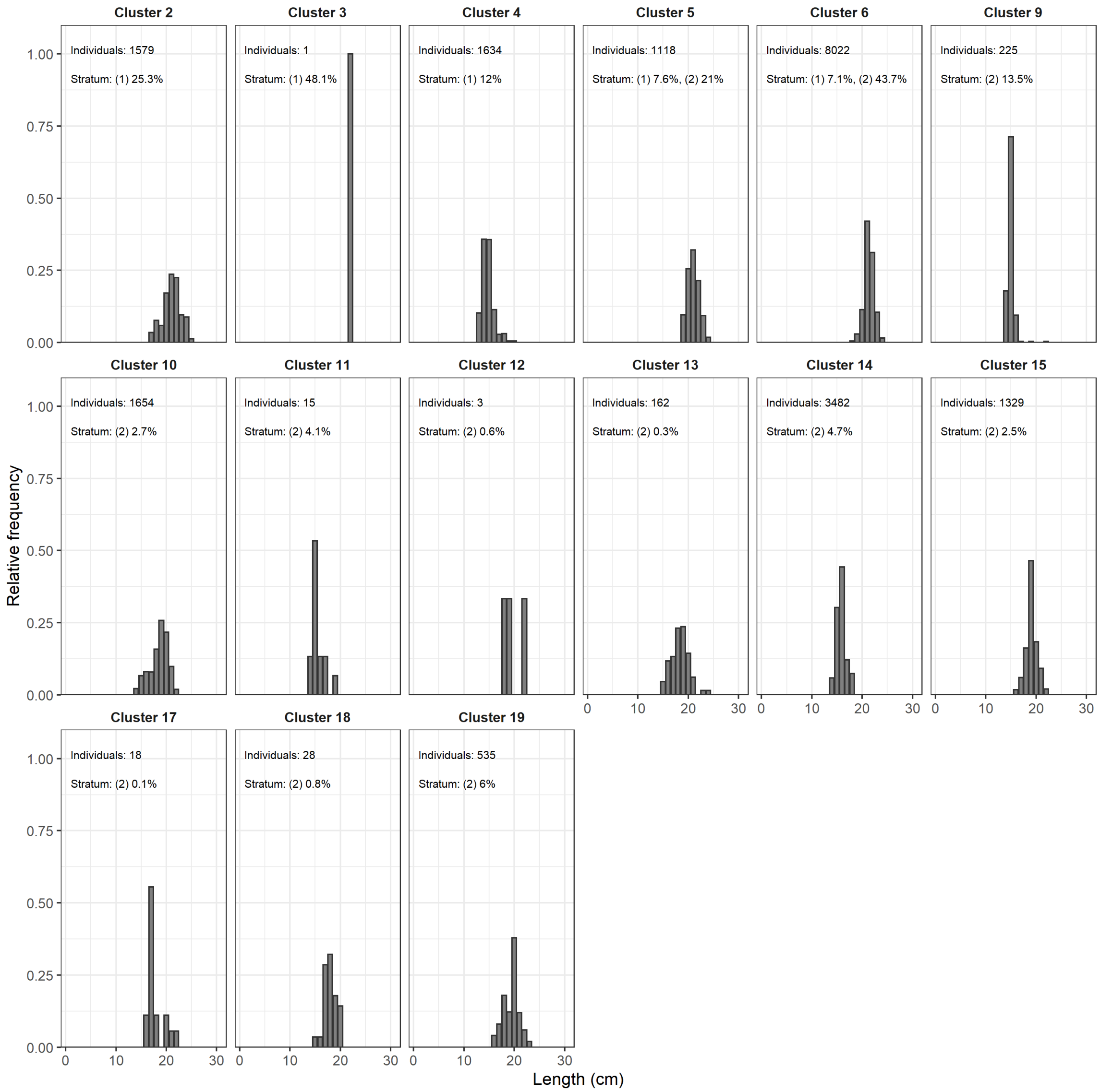
A.4 Jack Mackerel

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.



B Offshore biomass estimation

B.1 Methods

To estimate CPS biomass in offshore waters not routinely sampled during CCE surveys, sampling was also conducted by *Lasker* and two USVs (SD-1045 and SD-1046) along ~100 nmi-long extensions of compulsory transects spaced ~40 nmi-apart between approximately Florence, OR and San Diego (**Fig. 3**). Echosounder configurations and calibration results are described in **Section 2.1.2.2**. Details of the acoustic data processing and biomass estimation are described in **Section 2.3** and **Section 2.4**, respectively. In the offshore region, acoustic biomass was only computed for acoustic intervals that were <= 30 nmi from a positive trawl cluster; all other intervals, which was comparable to the distance that characterized 90% of the biomass in the core region and was thought to be representative of CPS scatterers in the region. Acoustic biomass from putative CPS schools in intervals >30 nmi from the nearest trawl cluster were not ascribed to any species.

B.2 Results

B.2.1 Acoustic sampling

In the offshore area between Florence, OR and San Diego, *Lasker* surveyed eight east-west transects totaling 699 nmi, and two USVs (SD-1045 and SD-1046) surveyed 13 east-west transects totaling 1,236 nmi. During Legs II and III (from 9 July to 6 August), the two USVs conducted daytime acoustic sampling along ~100 nmi-long transects with 80-nmi spacing in the offshore region between approximately Florence and Pt. Conception. From 6 to 12 August, one USV (SD-1046) conducted daytime acoustic sampling at 40-nmi spacing in the offshore region between approximately Pt. Conception and San Diego. Limiting the estimation of biomass to include only intervals withing 30 nmi of the nearest positive trawl cluster removed 80% of the intervals with backscatter from putative CPS schools, and 27% of the acoustic biomass estimated in those intervals.

B.2.2 Biomass distribution and demography

B.2.2.1 Northern Anchovy

B.2.2.1.1 Central stock Biomass of the central stock of Northern Anchovy in the offshore area was 69,209 t ($CI_{95\%}$ = 3,452 - 155,923 t, CV = 56%; **Table 20**, **Fig. 30**). The stock was distributed between approximately Fort Bragg and San Diego, and amounted to 8.5% of the biomass in the core and nearshore regions, assuming a similar conversion from integrated backscattering strength to biomass for all CPS.

Table 20: Biomass estimates (metric tons, t) and their precision (upper and lower 95% confidence intervals, $CI_{95\%}$; and coefficient of variation, CV) for the central stock of Northern Anchovy (*Engraulis mordax*) in the offshore region. Stratum areas are nmi^2.

Species		Stratum				Trawl		Biomass			
Name	Stock	Number	Area	Transects	Distance	Clusters	Individuals	$\hat{B}$	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Engraulis mordax	Central	1	29,364	9	742	10	449,621	44,777	120	120,454	74
		2	11,172	3	295	2	34,183	24,432	0	69,492	78
		All	40,536	12	1,037	12	483,803	69,209	3,452	155,923	56

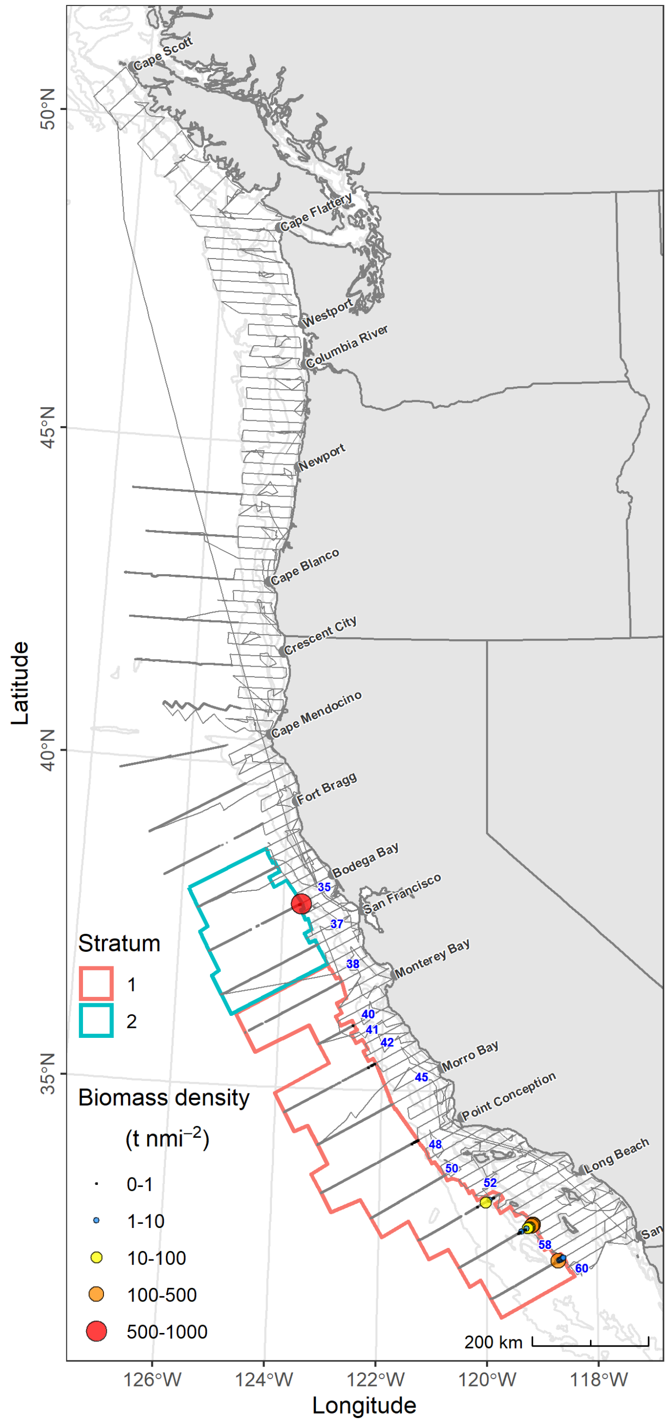


Figure 30: Biomass densities of central stock of Northern Anchovy (*Engraulis mordax*) in the offshore survey region. The blue numbers represent the locations of trawl clusters with at least one Northern Anchovy. The gray line represents the vessel track.

B.2.2.2 Pacific Sardine

B.2.2.2.1 Northern stock Biomass of the northern stock of Pacific Sardine in the offshore area was 1,771 t ($CI_{95\%}$ = 119 - 3,806 t, CV = 53%; **Table 21**, **Fig. 31**). The stock was distributed between Newport and Pt. Conception, and amounted to 5.3% of the biomass in the core and nearshore regions.

Table 21: Biomass estimates (metric tons, t) and their precision (upper and lower 95% confidence intervals, $CI_{95\%}$; and coefficient of variation, CV) for the northern stock of Pacific Sardine (*Sardinops sagax*) in the offshore region. Stratum areas are nmi^2.

Species		Stratum				Trawl		Biomass			
Name	Stock	Number	Area	Transects	Distance	Clusters	Individuals	$\hat{B}$	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Sardinops sagax	Northern	2	12,426	4	315	4	1,124	1	0	3	80
		3	19,212	4	402	4	579	1,770	117	3,805	53
		All	31,638	8	717	8	1,703	1,771	119	3,806	53

B.2.2.2.2 Southern stock Biomass of the southern stock of Pacific Sardine in the offshore area was 63.6 t ($CI_{95\%}$ = 9.25 - 150 t, CV = 60%; **Table 22**, **Fig. 32**). The stock was distributed between Pt. Conception and San Diego, and amounted to 0.43% of the biomass in the core and nearshore regions.

Table 22: Biomass estimates (metric tons, t) and their precision (upper and lower 95% confidence intervals, $CI_{95\%}$; and coefficient of variation, CV) for the southern stock of Pacific Sardine (*Sardinops sagax*) in the offshore region. Stratum areas are nmi^2.

Species		Stratum				Trawl		Biomass			
Name	Stock	Number	Area	Transects	Distance	Clusters	Individuals	$\hat{B}$	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Sardinops sagax	Southern	1	12,560	4	325	2	4	64	9	150	60
		All	12,560	4	325	2	4	64	9	150	60

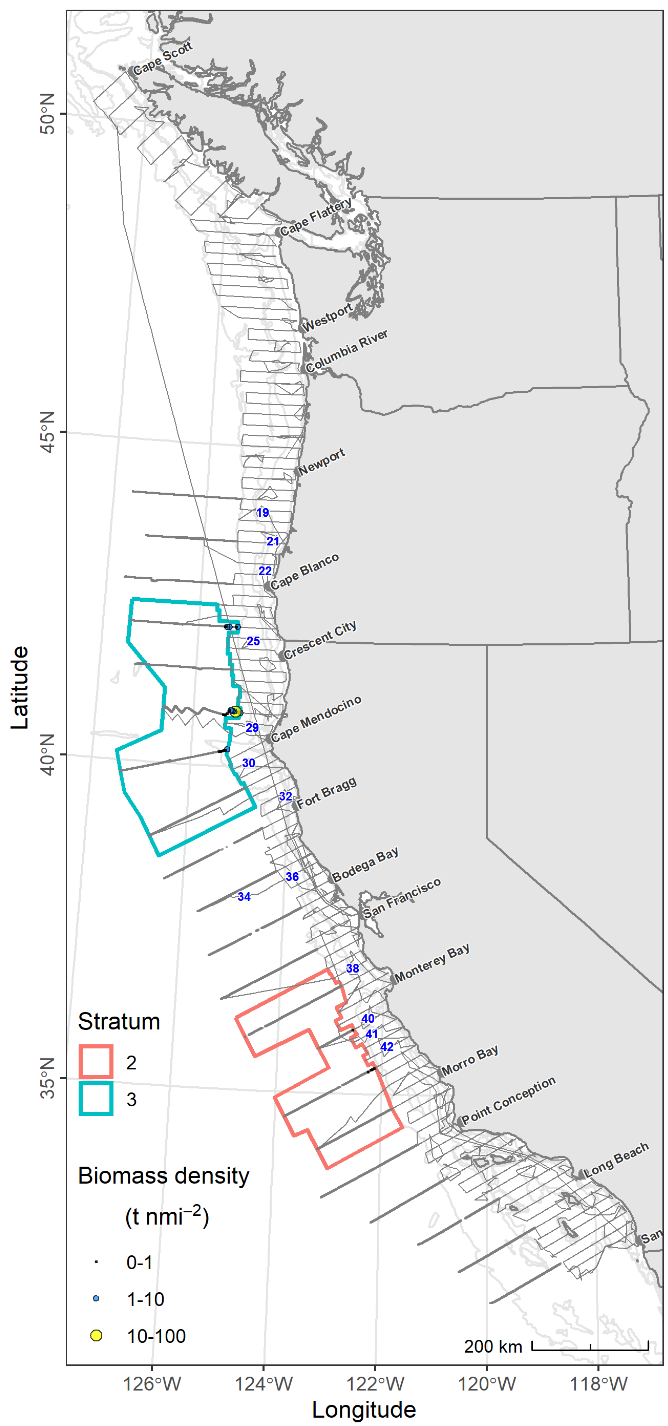


Figure 31: Biomass densities of northern stock of Pacific Sardine (*Sardinops sagax*) in the offshore survey region. The blue numbers represent the locations of trawl clusters with at least one Pacific Sardine. The gray line represents the vessel track.

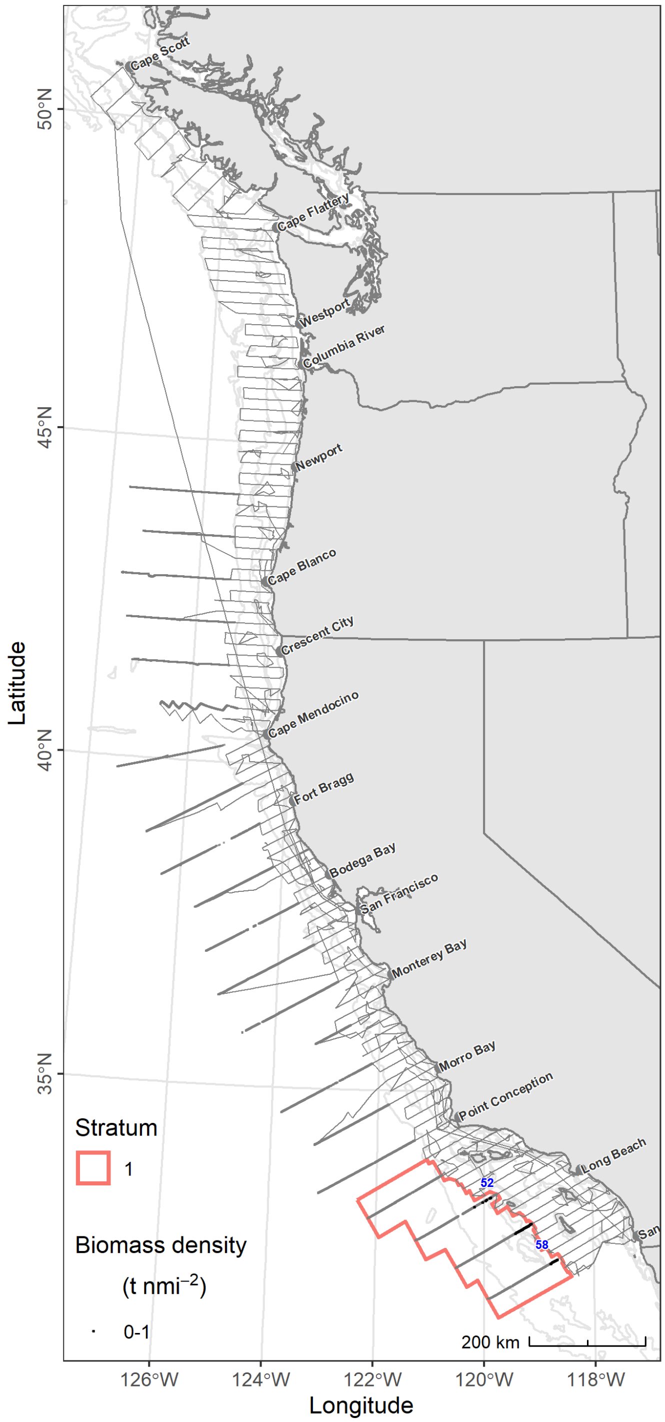


Figure 32: Biomass densities of southern stock of Pacific Sardine (*Sardinops sagax*) in the offshore survey region. The blue numbers represent the locations of trawl clusters with at least one Pacific Sardine. The gray line represents the vessel track.

B.2.2.3 Pacific Mackerel Biomass of Pacific Mackerel in the offshore area was 1,670 t ($CI_{95\%}$ = 5.29 - 4,894 t, CV = 71%; **Table 23**, **Fig. 33**). The stock was distributed between Newport and San Diego, and amounted to 6.3% of the biomass in the core and nearshore regions.

Table 23: Biomass estimates (metric tons, t) and their precision (upper and lower 95% confidence intervals, $CI_{95\%}$; and coefficient of variation, CV) for the Pacific Mackerel (*Scomber japonicus*) in the offshore region. Stratum areas are nmi^2.

Species		Stratum				Trawl		Biomass			
Name	Stock	Number	Area	Transects	Distance	Clusters	Individuals	$\hat{B}$	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Scomber japonicus	All	1	15,957	5	401	3	177	5	0	14	81
		2	13,918	3	297	3	163	1,665	0	4,893	71
		All	29,874	8	698	6	340	1,670	5	4,894	71

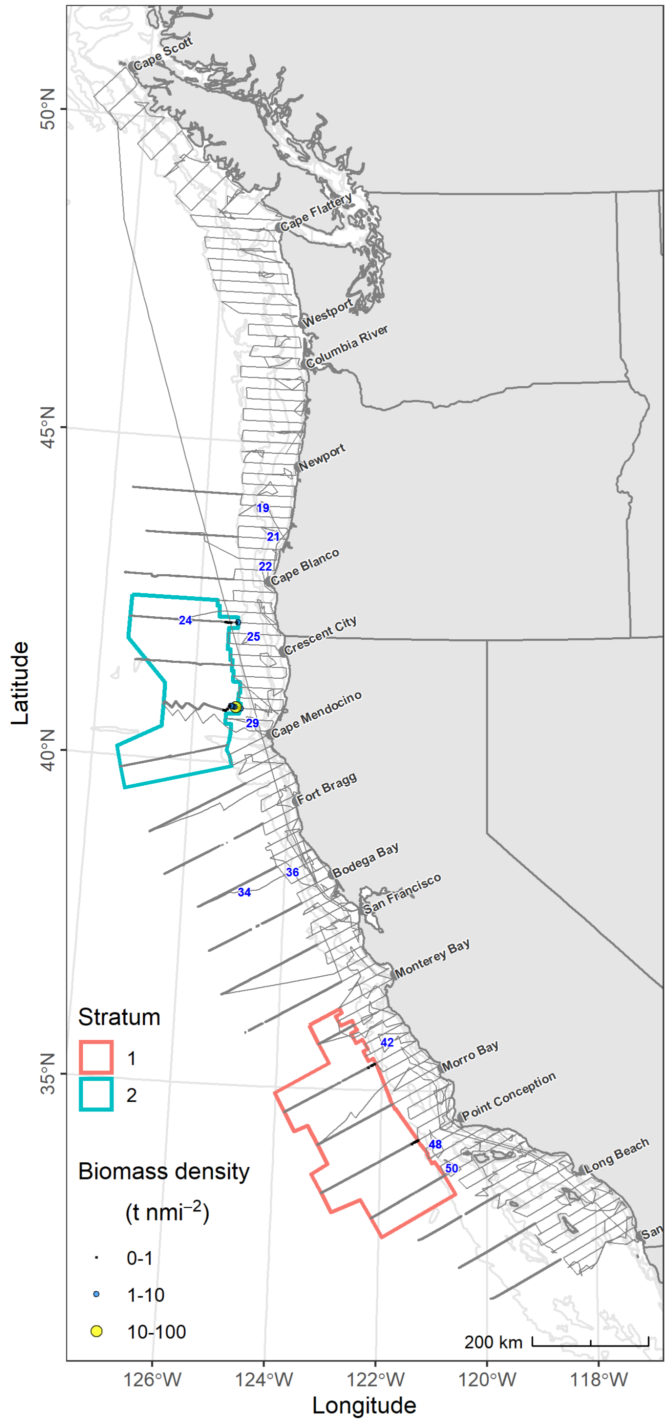


Figure 33: Biomass densities of Pacific Mackerel (*Scomber japonicus*) in the offshore survey region. The blue numbers represent the locations of trawl clusters with at least one Pacific Mackerel. The gray line represents the vessel track.

B.2.2.4 Jack Mackerel Biomass of Jack Mackerel in the offshore area was 40,921 t ($CI_{95\%}$ = 3,699 - 1e+05 t, CV = 60%; **Table 24**, **Fig. 34**). The stock was distributed between Newport and San Diego, and amounted to 10% of the biomass in the core and nearshore regions.

Table 24: Biomass estimates (metric tons, t) and their precision (upper and lower 95% confidence intervals, $CI_{95\%}$; and coefficient of variation, CV) for the Jack Mackerel (*Trachurus symmetricus*) in the offshore region. Stratum areas are nmi^2.

Species		Stratum				Trawl		Biomass			
Name	Stock	Number	Area	Transects	Distance	Clusters	Individuals	$\hat{B}$	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Trachurus symmetricus	All	1	24,020	7	606	6	147	265	8	569	56
		2	19,212	4	402	5	4,880	40,656	3,441	99,999	60
		All	43,232	11	1,008	11	5,028	40,921	3,699	100,235	60

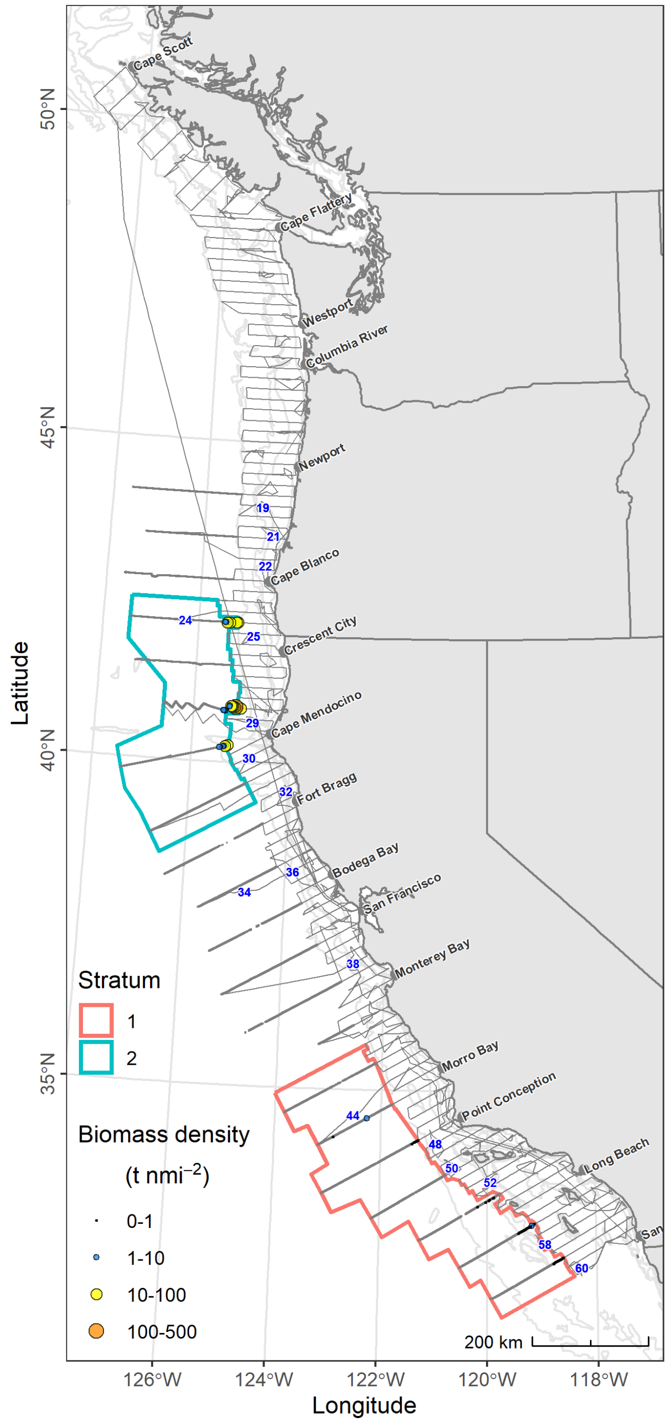


Figure 34: Biomass densities of Jack Mackerel (*Trachurus symmetricus*) in the offshore survey region. The blue numbers represent the locations of trawl clusters with at least one Jack Mackerel. The gray line represents the vessel track.

B.3 Discussion

Two USVs that surveyed acoustic transects offshore, where wind was ample, provided sampling that was coincident with that from *Lasker*, and increased the collection of acoustic backscatter data throughout approximately two-thirds of the survey area between Vancouver Island and San Diego. The offshore extension of compulsory transects sampled by *Lasker* posed logistical challenges, making it difficult at times to maintain survey progress along planned transects in the core survey area. Sparse trawl sampling in the offshore region resulted in the exclusion of 80% of the acoustic intervals that contained backscatter from putative CPS schools, but only a small proportion (27%) of the total acoustic biomass was observed in those intervals. Additional trawl samples in the offshore area would improve the partitioning of acoustic backscatter by species. Low density acoustic backscatter in the offshore area was expanded over a large areas in offshore strata, which resulted in the addition of 0.4% (Pacific Sardine) to 10% (Jack Mackerel) to the biomass estimates in the core and nearshore regions combined. The patchy distribution of acoustic backscatter in the offshore region resulted in biomass estimates with high CVs for all species (53-71%).