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DISTRIBUTION, BIOMASS, AND DEMOGRAPHY OF COASTAL PELAGIC FISHES IN THE CALIFORNIA CURRENT ECOSYSTEM DURING SUMMER 2017 BASED ON ACOUSTIC-TRAWL SAMPLING

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Contents

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 fishes (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 19 June and 11 August 2017. The survey area spanned most of the continental shelf between the northern tip of Vancouver Island, British Columbia (BC) and Morro Bay, CA.

For the survey area and period, the estimated biomass of the northern stock of Northern Anchovy was 22,709 t ($\mathrm{CI}_{95\%}$ = 1,452 - 57,334 t, CV = 64%). The northern stock ranged from approximately Cape Flattery, WA to Newport, OR. Standard lengths (L_S) ranged from 4 to 16 cm with a mode at ~14 cm.

The estimated biomass of the central stock of Northern Anchovy was 153,460 t ($\mathrm{CI}_{95\%}$ = 2,628 - 264,009 t, CV = 45%). The central stock ranged from approximately Bodega Bay to Morro Bay, and L_S ranged from 4 to 16 cm with a modes at ~9 and 13 cm.

The estimated biomass of the northern stock of Pacific Sardine was 14,103 t ($\mathrm{CI}_{95\%}$ = 7,337 - 22,981 t, CV = 30%). The northern stock ranged from approximately Cape Flattery to Morro Bay, and L_S ranged from 6 to 27 cm with modes at ~9 and 22 cm.

The estimated biomass of Pacific Mackerel was 41,139 t ($\mathrm{CI}_{95\%}$ = 18,019 - 58,425 t, CV = 26%). Pacific Mackerel ranged from approximately Cape Flattery to Morro Bay. Fork lengths (L_F) ranged from 16 to 38 cm with modes at ~18 and 27 cm.

The estimated biomass of Jack Mackerel was 128,313 t ($\mathrm{CI}_{95\%}$ = 70,594 - 180,676 t, CV = 22%). Jack Mackerel ranged from approximately Cape Flattery to Morro Bay. L_F ranged from 3 to 53 cm, but most fish were between 20 and 34 cm.

The estimated biomass of Pacific Herring was 63,418 t ($\mathrm{CI}_{95\%}$ = 29,811 - 103,365 t, CV = 31%). Pacific Herring ranged from approximately Cape Scott, BC to Cape Mendocino, CA. L_F ranged from 8 to 25 cm with modes at ~13 and 21 cm.

To investigate the potential biomass of CPS in areas where the ship could not safely navigate, acoustically sampled biomass along the easternmost portions of transects in the survey areas were extrapolated to the 5-m isobath in the unsampled nearshore areas (**Appendix B**).

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 of these species can change by an order of magnitude within a couple 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 to feed in the productive coastal upwelling off Oregon, Washington, 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 to their 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 sizes, fish ages and lengths, and oceanographic conditions (Zwolinski *et al.*, 2012). 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 40 years ago to survey CPS off the west coast of the U.S. (Mais, 1977, 1974; 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 2006, 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 Pacific Sardine assessments (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., Zwolinski *et al.*, 2014; Cutter and Demer, 2008; Demer *et al.*, 2012; Mais, 1974). 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**), the central or northern stock of Northern Anchovy, or both. Presently, the extent of the available sampling effort is not sufficient to span the hypothesized ranges of Pacific and Jack Mackerel. Pacific Mackerel, for example, probably extend to the southern tip of Baja California and into the Gulf of California depending on oceanographic conditions (Fry and Roedel, 1949; Parrish and MacCall, 1978). While larger, older Jack Mackerel typically school in open ocean waters from Baja California to the Aleutian Islands, AK, the offshore limit of the population is unknown (MacCall and Stauffer, 1983).

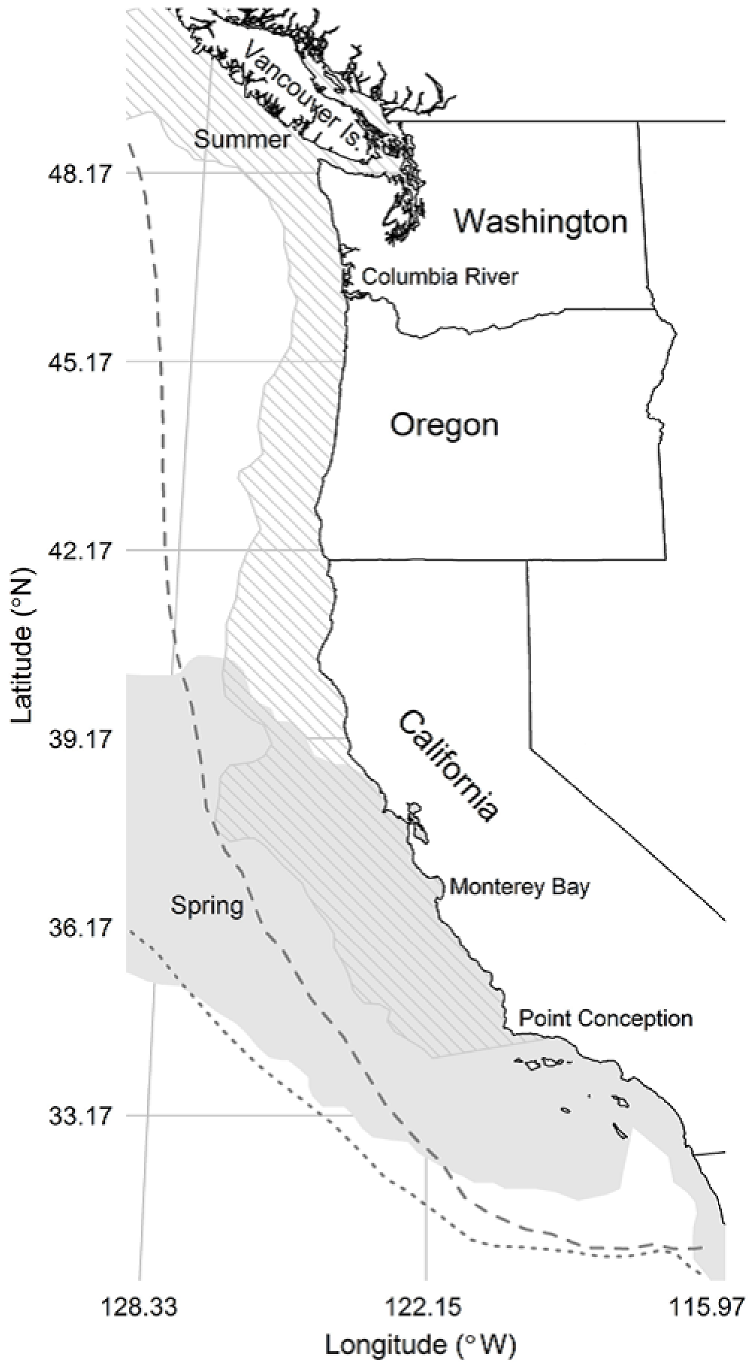

Figure 1: Conceptual spring and summer distributions of northern stock Pacific Sardine potential habitat along the west coasts of Mexico, the United States, and Canada. The dashed and dotted lines represent, respectively, the approximate summer and spring position of the 0.2 mg m^{-3} isoline of chlorophyll-a concentration. This isoline appears to oscillate in synchrony with the transition zone chlorophyll front (TZCF, Polovina *et al.*, 2001) and the offshore limit of the Pacific Sardine potential habitat (Zwolinski *et al.*, 2014). The TZCF may delineate the offshore and southern limit of both Pacific Sardine and Pacific Mackerel potential 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.

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).

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) and abundances and biomasses are estimated for the survey area.

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

In summer 2017, an ATM survey was performed to sample a portion of the west coast of North America, from the northern tip of Vancouver Island, British Columbia (BC) to Morro Bay, to estimate the biomass distributions and demographies of CPS, together with characterizations of their biotic and abiotic habitats. Presented here are estimates of the abundance, biomass, size structure, and distribution of the northern stock of Pacific Sardine; the northern and central stock of Northern Anchovy; Pacific Mackerel; Jack Mackerel; and Pacific Herring. Additional details about the survey may be found in the cruise report (Stierhoff *et al.*, 2018a).

2 Methods

2.1 Data collection

2.1.1 Survey design

The summer 2017 survey was conducted using the *Reuben Lasker* (hereafter, *Lasker*). The sampling domain, between Cape Scott, British Columbia at the northern end of Vancouver Island and Morro Bay, Central California, was defined by the potential habitat of the northern stock of Pacific Sardine in the CCE at the beginning of the survey (**Fig. 2a**), but also spanned all or large portions of the anticipated population distributions of other CPS. East to west, the sampling domain extends from the coast to at least the 1,000 fathom (~1830 m) isobath (**Fig. 3**, see Zwolinski *et al.*, 2014). Considering the expected distribution of the target species, the acceptable uncertainty in biomass estimates, and the available ship time (50 days at sea), the principal survey objectives were the estimations of biomass for the northern stock of Pacific Sardine and the northern stock of Northern Anchovy. Additionally, biomass estimates were sought for Pacific Mackerel, Jack Mackerel, Pacific Herring, and the central stock of Northern Anchovy (north of Point Conception) in the survey area.

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 using 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 of with high diversity and abundance. The sampling intensity in the compulsory grid is fixed, constituting a strictly 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 2.3.1**). 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 depth) to either a distance of 35 nmi or to the 1,000 fathom (~1830 m) 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. During the summer 2017 survey, sampling from *Lasker* was augmented with nine days of echosounder and sonar sampling from Fishing Vessel (F/V) *Lisa Marie* in nearshore areas off Washington and Oregon (**Fig. 4**).

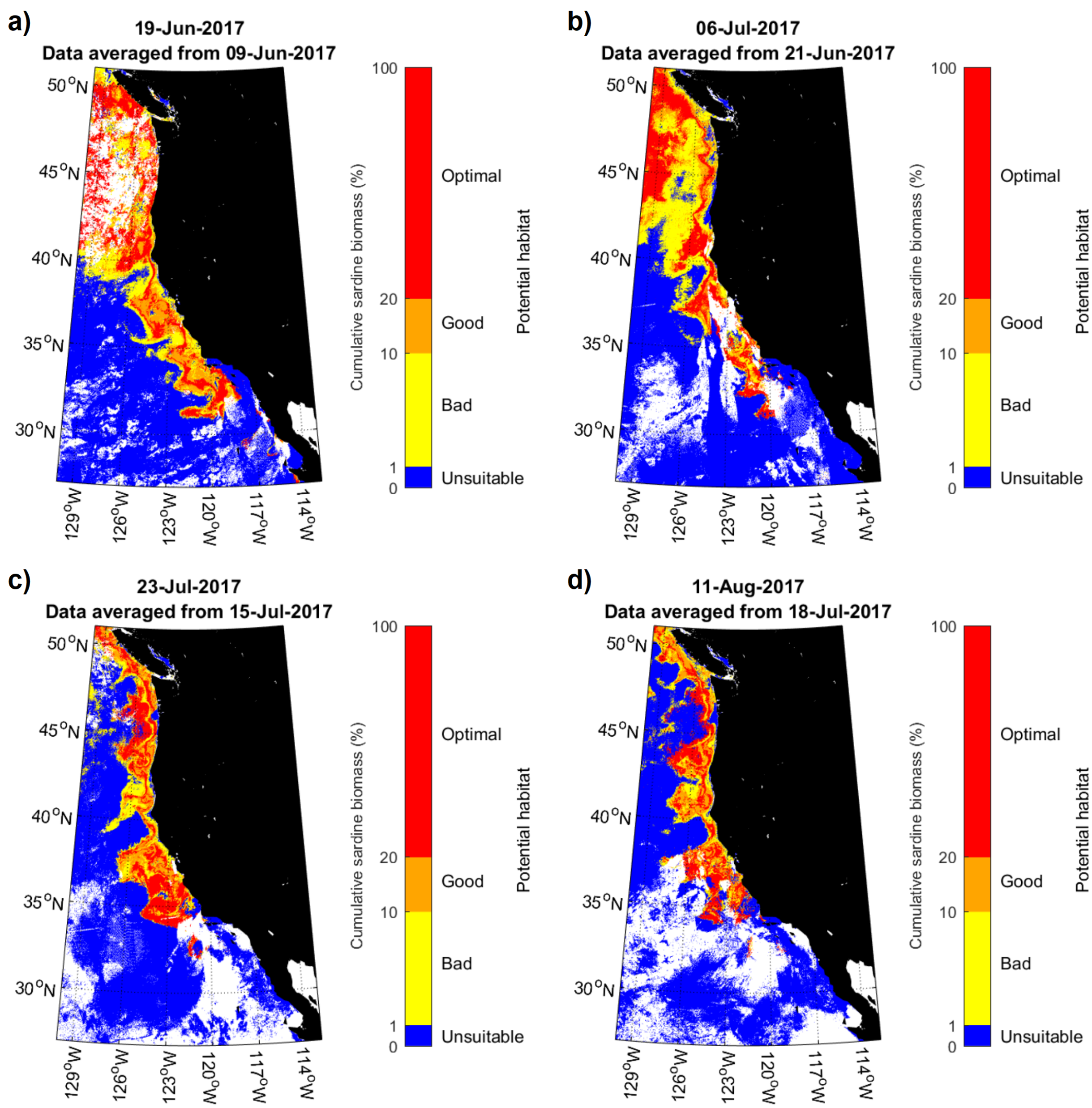

Figure 2: Distribution of potential habitat for the northern stock of Pacific Sardine (a) before, (b,c), during, and (d) at the end of the summer 2017 survey.

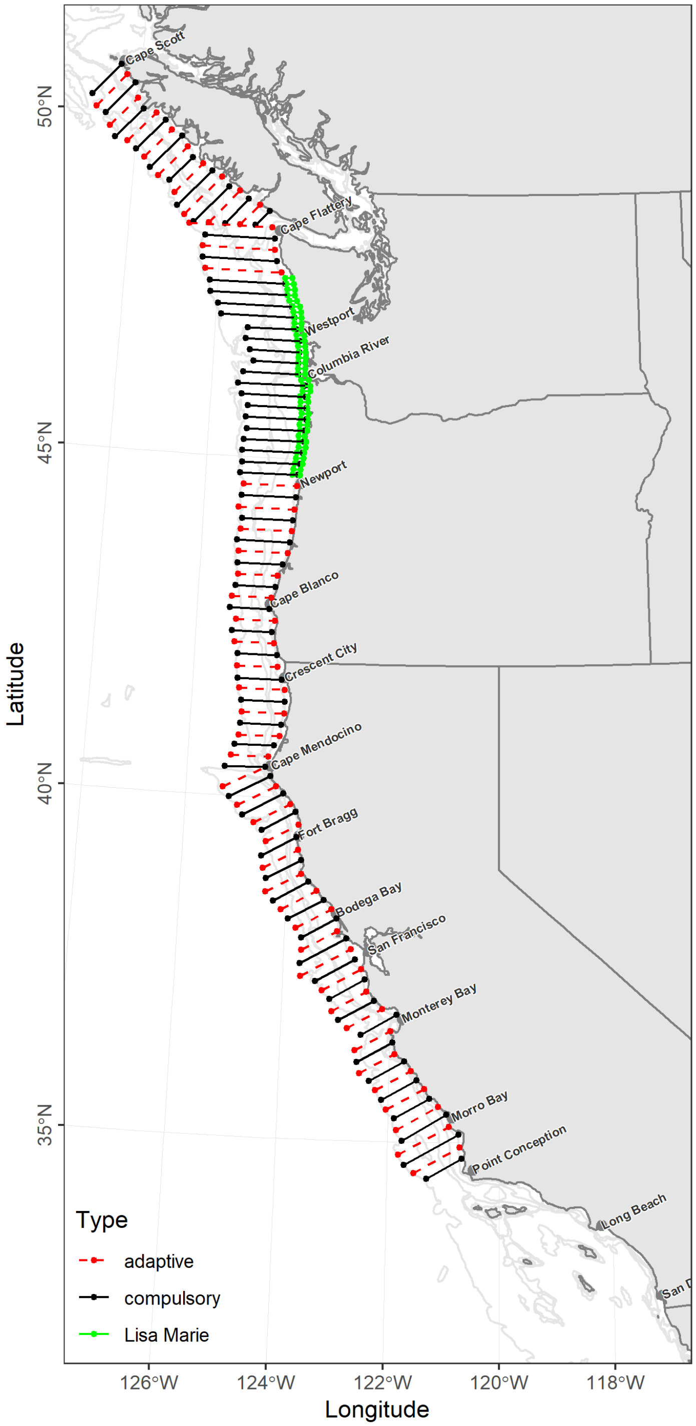

Figure 3: Planned compulsory (solid black lines), adaptive (dashed red lines), and nearshore transect lines (solid green lines). Isobaths (gray lines) are placed at 50, 200, 500, and 2,000 m (or approximately ~1,000 fathoms).

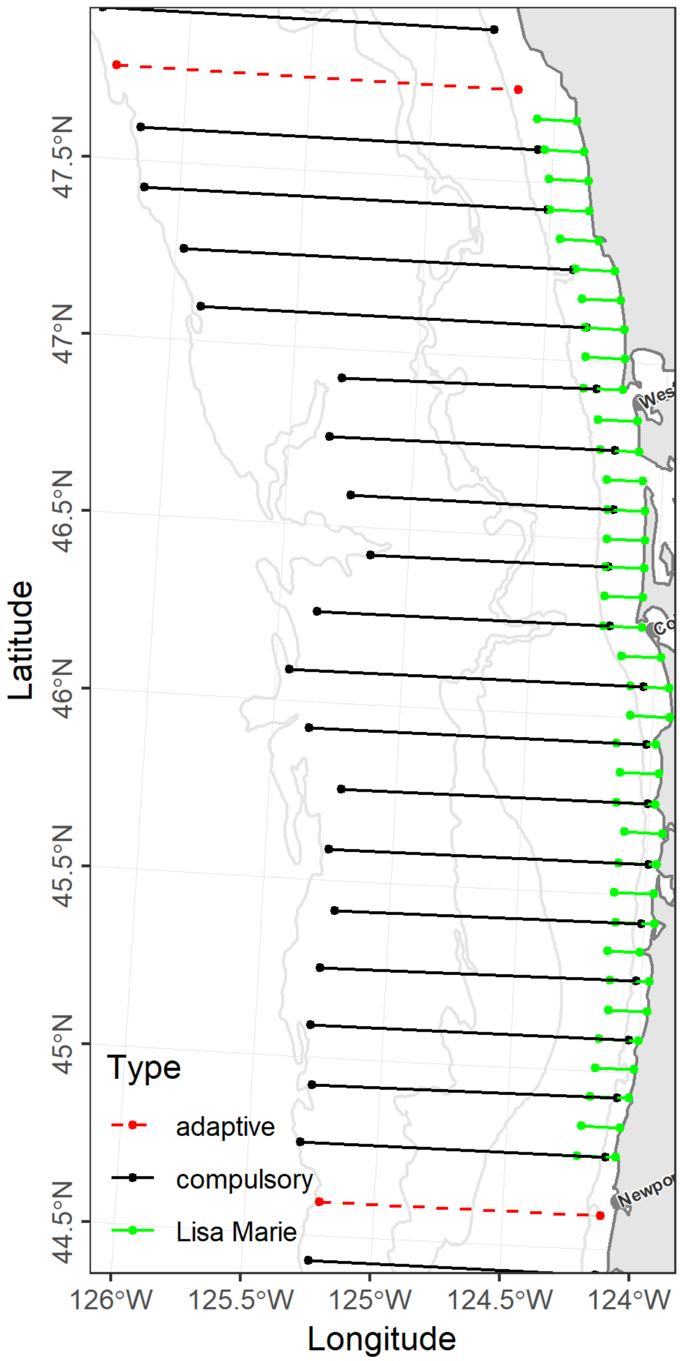

Figure 4: Planned compulsory (solid black lines), adaptive (dashed red lines), and nearshore transect lines (solid green lines) in the nearshore area sampled by both *Lasker* and F/V *Lisa Marie*.

2.1.2 Acoustic sampling

2.1.2.1 Acoustic equipment

On *Lasker*, multi-frequency (18, 38, 70, 120, 200, and 333 kHz) EK60 General Purpose Transceivers (GPT, Simrad) and EK80 Wideband Transceivers (WBT, Simrad) were configured with split-beam transducers (Models ES18-11, ES38B, ES70-7C, ES120-7C, ES200-7C, and ES333-7C; Simrad) mounted on the bottom of a retractable keel or "centerboard" (**Fig. 5**). 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 an ME70 multibeam echosounder (Simrad), MS70 multibeam sonar (Simrad), and SX90 omni-directional sonar (Simrad). Transducer position and motion were measured at 5 Hz using an inertial motion unit (POS-MV, Trimble/Applanix). The SWFSC's split-beam EK60 GPT (Simrad) aboard F/V *Lisa Marie* was connected to the vessel's ES38-B transducer.

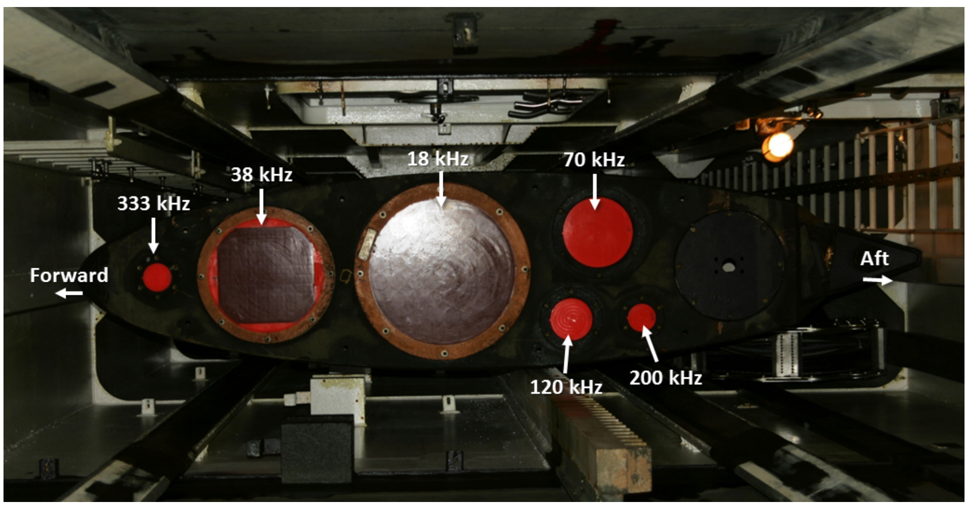

Figure 5: Echosounder transducers mounted on the bottom of the retractable centerboard on *Lasker*. During the survey, the centerboard was extended, typically positioning the transducers at ~2-m below the keel at a water depth of ~7 m.

2.1.2.2 Echosounder calibration

Prior to calibration, the integrity of each transducer was verified through impedance measurements of each transducer in water and air using an LCR meter (Agilent E4980A) and custom Matlab software. For each transducer, impedance magnitude ($|Z|$,), phase (θ, °), conductance (G, S), susceptance (B, S), resistance (R,), and reactance (X,) were measured at the operational frequencies with the transducer quadrants connected in parallel.

The echosounders were calibrated on 14 June 2017 (~2300 GMT) 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). The reference target was a 38.1-mm diameter sphere made from tungsten carbide (WC) with 6% cobalt binder material. 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 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. For each frequency, the calibration results (**Table 1**) were input to the echosounder software (ER60, Simrad) and recorded (.raw format) with the measures of received power and angles.

The echosounder aboard F/V *Lisa Marie* was calibrated on 22 June 2017 while on anchor near Westport, WA (46.9223 °N, -124.1127 °W) using the standard sphere techinque. The reference target was a 38.1-mm diameter sphere made from tungsten carbide (WC) with 6% cobalt binder material (**Table 1**).

Table 1: EK60 general purpose transceiver (GPT, Simrad) information, pre-calibration settings, and beam model results following calibration (below the horizontal line) for *Lasker* and F/V *Lisa Marie*. Prior to the survey, on-axis gain (G_0), beam angles and angle offsets, and S_A Correction ($S_A$corr) values from calibration results were entered into ER60.

		Frequency (kHz)						
		Reuben Lasker						*Lisa Marie*
Frequency (f, kHz)	Units	18	38	70	120	200	333	38
Model		ES18-11	ES38B	ES70-7C	ES120-7C	ES200-7C	ES333-7C	ES38B
Serial Number		2116	31206	233	783	513	124	-
Transmit Power (p_{et})	W	2000	2000	750	250	110	40	2000
Pulse Duration (τ)	ms	1.024	1.024	1.024	1.024	1.024	1.024	1.024
On-axis Gain (G_0)	dB re 1	22.74	24.99	27.4	26.64	27.46	25.63	22
S_{A} Correction (S_{A}corr)	dB re 1	-0.66	-0.72	-0.38	-0.43	0.21	-0.26	0
Bandwidth (W_{f})	Hz	1570	2430	2860	3030	3090	3110	2430
Sample Interval	m	0.195	0.195	0.195	0.195	0.195	0.195	0.191
Eq. Two-way Beam Angle ( )	dB re 1 sr	-17.1	-20.4	-20.2	-20.1	-20.1	-19.6	-20.6
Absorption Coefficient (α_{f})	dB km^{-1}	1.8	7.1	20.4	43.9	75.3	104.1	8.5
Angle Sensitivity Along. (Λ_{α})	Elec.°/Geom.°	13.9	21.9	23	23	23	23	21.9
Angle Sensitivity Athw. (Λ_{β})	Elec.°/Geom.°	13.9	21.9	23	23	23	23	21.9
3-dB Beamwidth Along. ($\alpha_{-3\mathrm{dB}}$)	deg	10.62	7.03	6.5	6.44	6.72	6.45	7.1
3-dB Beamwidth Athw. ($\beta_{-3\mathrm{dB}}$)	deg	10.74	7.03	6.49	6.48	6.96	6.65	7.1
Angle Offset Along. (α_0)	deg	-0.08	0.06	0.05	-0.03	-0.03	-0.05	0
Angle Offset Athw. (β_0)	deg	-0.23	-0.03	-0.06	0	0.16	-0.05	0
Theoretical TS (TS_{theory})	dB re 1 m^2	-42.44	-42.38	-41.63	-39.77	-38.81	-36.68	-42.38
Ambient Noise	dB re 1 W	-128	-145	-154	-160	-161	-137	-
On-axis Gain (G_0)	dB re 1	21.31	24.95	27.07	26.65	27.24	24.83	22.22
S_{A} Correction (S_{A}corr)	dB re 1	-0.84	-0.65	-0.41	-0.24	-0.15	-0.15	-0.38
RMS	dB	0.39	0.26	0.3	0.31	0.48	0.64	0.3
3-dB Beamwidth Along. ($\alpha_{-3\mathrm{dB}}$)	deg	12.15	6.79	6.42	6.4	6.4	6.35	7.02
3-dB Beamwidth Athw. ($\beta_{-3\mathrm{dB}}$)	deg	11.95	6.93	6.47	6.49	6.36	6.84	6.77
Angle Offset Along. (α_0)	deg	0	0.05	-0.01	-0.03	-0.05	-0.03	-0.01
Angle Offset Athw. (β_0)	deg	-0.24	-0.02	-0.03	0.04	0.12	0	-0.02

2.1.2.3 Data collection

Computer clocks were synchronized with the GPS clock (GMT) using synchronization software (NetTime[1]). Echosounder pulses were transmitted simultaneously at all frequencies, at variable intervals controlled by the EK Adaptive Logger (EAL, Renfree and Demer, 2016). The EAL continuously monitors the echosounder data, detects the seabed depth, and optimizes the echosounder transmit intervals and logging ranges while avoiding aliased seabed echoes. A custom multiplexer (EK-MUX, SWFSC AST) was used to alternate transmissions from the EK60 and EK80 echosounders for the purposes of comparing data obtained from the respective echosounders. The echosounders collected data continuously throughout the survey, but transect sampling was conducted only during daylight hours, approximately between sunrise and sunset.

Measurements of volume backscattering strength (S_V; dB re 1 m^2 m^{-3}) and TS (dB re 1 m^2), indexed by time and geographic positions provided by GPS receivers, were logged to 60 m beyond the detected seabed range or to a maximum of 350 m, and stored in Simrad format (i.e., .raw) with a 50-MB maximum file size. For each acoustic instrument, the prefix for the file names is a concatenation of the survey name (e.g., 1707RL), the acoustic system (e.g., EK60, EK80, ME70), and the logging commencement date and time from the GPT-control software. For example, an EK60 file generated by the Simrad ER60 software (V2.4.3) is named `1707RL_EK60-D20170619-T222508.raw`.

[1] http://timesynctool.com

To minimize acoustic interference, transmit pulses from the ME70, MS70, SX90, and acoustic Doppler current profiler (Ocean Surveyor Model OS75, Teledyne RD Instruments) were triggered using the K-Sync synchronization system (Simrad). 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), Doppler velocity log (Model SRD-500A, Sperry Marine), or both.

2.1.3 Oceanographic sampling

2.1.3.1 Conductivity and temperature versus depth (CTD) sampling

Day and night, conductivity and temperature versus depth were measured 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, Oceanscience) cast from the vessel. 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). These data also provided indication of the depth of the upper-mixed layer where most epipelagic CPS reside during the day, and used to remove non-CPS backscatter (see **Section 2.2.4**).

2.1.3.2 Scientific Computer System sampling

While underway, information about the position and direction (e.g., latitude, longitude, speed, course over ground, and heading), weather (air temperature, humidity, wind speed and direction, and barometric pressure), and sea-surface oceanography (e.g., temperature, salinity, and fluorescence) were measured continuously and logged using_ Lasker_'s Scientific Computer System (SCS). During and after the survey, a 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[2].

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. Sardine, Northern Anchovy, Jack Mackerel, and Pacific Hake (*Merluccius productus*) eggs were identified to species, counted, and logged. Eggs from other species 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 indicate the nearby presence of actively spawning fish, and are 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, surface 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]https://coastwatch.pfeg.noaa.gov/erddap/index.html

2.1.5.1 Sampling gear

The trawl net, a Nordic 264 rope trawl (NET Systems, Bainbridge Island, WA; **Fig. 6a,b**), was towed 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.

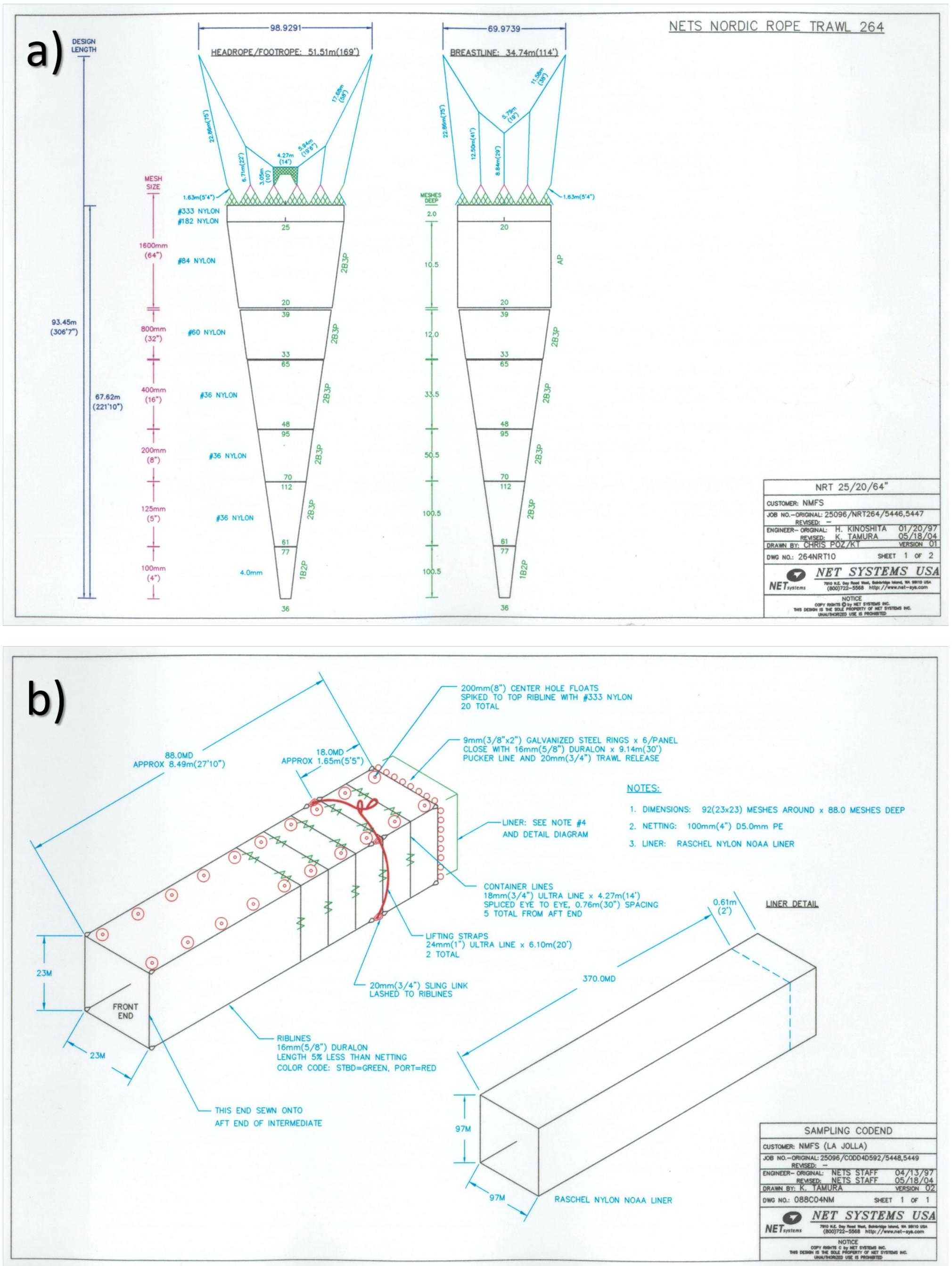

Figure 6: Schematic drawings of the a) net body and b) codend of the Nordic 264 rope trawl.

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 putative echoes from CPS schools were observed earlier that day (**Fig. 7**). 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 samples. 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 potential 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.

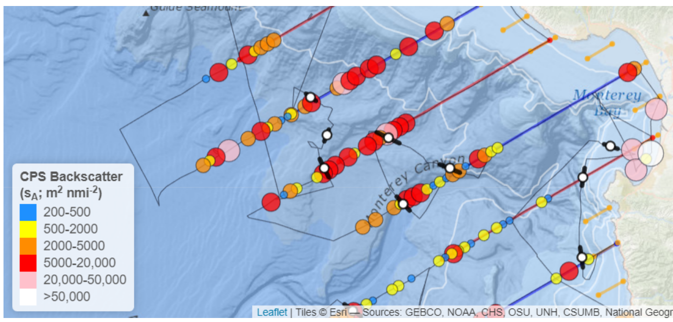

Figure 7: Example of trawl paths (bold, black lines) relative to 38-kHz integrated backscattering coefficients (s_A, m^2 nmi^{-2}; averaged over 2000-m distance intervals and from 5 to 70-m deep) from putative epipelagic CPS schools (colored points).

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 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, and gonads were examined macroscopically to determine sex and reproductive stage. With the exception of Pacific Herring, the female gonads of a representative subsample of each target species were removed and preserved, and otoliths were collected for subsequent age determination. The same procedure was applied to a random sample of 50 specimens if the total number of specimens available was higher than 50.

2.1.5.4 QA/QC

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 and weight measurements were estimated using the season-specific length versus weight relationships derived from catches during previous ATM surveys (unpublished data), where $W_{miss} = \beta_0 L^{\beta_1}$, $L_{miss} = (W/\beta_0)^{(1/\beta_1)}$, and values for β_0 and β_1 in **Table 2**. To identify measurement or data-entry errors, length and weight data were graphically compared (**Fig. 8**) to measurements from previous surveys and models of season-specific length versus weight from previous surveys (unpublished data). Outliers and missing values were flagged, reviewed by the trawl team, and mitigated. Catch data from aborted or otherwise unacceptable trawl hauls were removed.

Table 2: 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 $W = \beta_0 {L_T}^{\beta_1}$.

Scientific name	β_0	β_1
Clupea pallasii	1.965e-06	3.253318
Engraulis mordax	2.873e-06	3.167299
Sardinops sagax	4.551e-06	3.120841
Scomber japonicus	3.550e-06	3.165265
Trachurus symmetricus	5.936e-06	3.069390

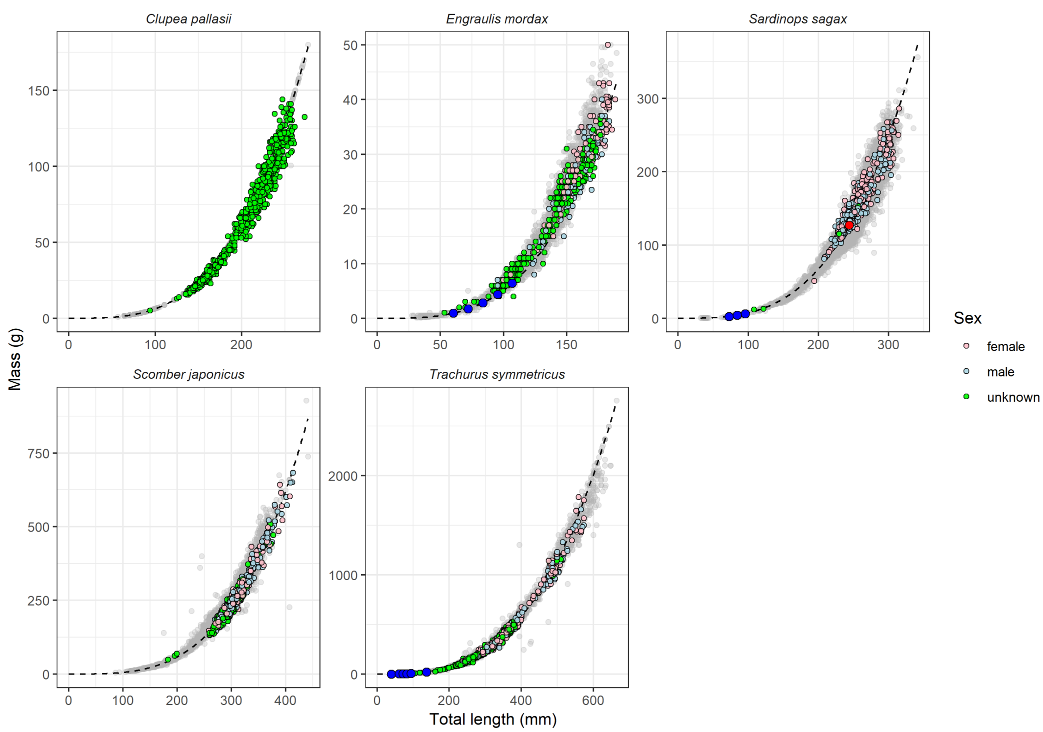

Figure 8: Specimen length versus weight from the current survey (colored points, by sex) compared to those from previous SWFSC surveys during the same season (gray points, all sexes). The dashed line represents the modeled length-versus-weight relationships for each species (unpublished data). Larger points indicate specimens whose length (red) or weight (blue) was missing and was estimated from the length-versus-weight relationships.

2.2 Data processing

2.2.1 Acoustic and oceanographic data

The calibrated echosounder data from each transect were processed using commercial software (Echoview V8.0.76.30859, 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**). Data collected along the daytime transects at speeds $\geq$ 5 kn are used to estimate CPS densities. Nighttime acoustic data are assumed to be negatively biased due to diel-vertical migration (DVM) and disaggregation of the target species' schools (Cutter and Demer, 2008).

2.2.2 Sound speed and absorption calculation

Depth derived from pressure in CTD casts was used to bin samples into 1-m depth increments. Sound speed in each increment ($c_{w,i}$, m s^{-1}) was estimated from the average salinity, density, and pH (if measured, else pH = 8; Chen and Millero, 1977; Seabird, 2013). The harmonic sound speed in the water column ($\overline{c}_w$, m s^{-1}) was calculated over the analysis depth range for CPS (i.e., 10-70 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 also provides measures of fluorescence and dissolved oxygen concentration versus depth, which may be used to estimate the vertical dimension of Pacific Sardine potential habitat (Zwolinski *et al.*, 2011), particularly the depth of the upper-mixed layer where most epipelagic CPS reside. The latter information is used to inform echo classification (see **Section 2.2.3**).

2.2.3 Echo-classification

Echoes from schooling CPS were identified using a semi-automated data processing algorithm implemented using Echoview software (V8.0.76.30859). 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. 9**). The filter includes the following steps:

- Estimate and subtract background noise using the built-in Echoview background noise removal function (De Robertis and Higginbottom, 2007, **Fig. 9b,e**);
- Average the noise-free S_v echograms using non-overlapping 11-sample by 3-ping windows;
- Expand the averaged, noise-reduced S_v echograms with a 7 pixel x 7 pixel dilation;
- For each pixel, compute: $S_{v,200\mathrm{kHz}}$ - $S_{v,38\mathrm{kHz}}$, $S_{v,120\mathrm{kHz}}$ - $S_{v,38\mathrm{kHz}}$, and $S_{v,70\mathrm{kHz}}$ - $S_{v,38\mathrm{kHz}}$;
- Create a Boolean echogram for S_v differences in the CPS range: $-13.85 < S_{v,70\mathrm{kHz}} - S_{v,38\mathrm{kHz}} < 9.89 \bigcap -135.5 < S_{v,120\mathrm{kHz}} - S_{v,38\mathrm{kHz}} < 9.37 \bigcap -13.51 < S_{v,200\mathrm{kHz}} - S_{v,38\mathrm{kHz}} < 12.53$;
- Compute the standard deviation (SD) of $S_{v,120\mathrm{kHz}}$ and $S_{v,200\mathrm{kHz}}$ using non-overlapping 11-sample by 3-ping windows;
- Expand the SD($S_{v,120\mathrm{kHz}}$) and SD($S_{v,200\mathrm{kHz}}$) echograms with a 7 pixel x 7 pixel dilation;
- Create a Boolean echogram based on the SDs in the CPS range: SD($S_{v,200\mathrm{kHz}}$) > -65 dB $\bigcap$ SD($S_{v,120\mathrm{kHz}}$) > -65 dB. Diffuse backscattering layers (Zwolinski *et al.*, 2010) have low standard deviations, whereas fish schools have high standard deviations (Demer *et al.*, 2009);
- Intersect the two Boolean echograms. The resulting echogram has samples with "TRUE" for candidate CPS schools and "FALSE" elsewhere;

- Mask the noise-reduced echograms using the CPS Boolean echogram (**Fig. 9c, f**);
- Create an integration-start line at a range of 3 m from the transducer (~10 m depth);
- Create an integration-stop line 3 m above the seabed (Demer *et al.*, 2009), or to the maximum logging range (e.g., 350 m), whichever is shallowest;
- Set the minimum S_v threshold to -60 dB (corresponding to a density of approximately three fish per 100 m^3 in the case of 20-cm-long Pacific Sardine);
- Integrate the volume backscattering coefficients (s_V, m^2 m^{-3}) attributed to CPS over 5-m depths and averaged over 100-m distances;
- Remove regions where vessel speed was $\leq$ 5 kn (i.e., "on station"); and
- Output the resulting nautical area scattering coefficients (s_A; m^2 nmi^{-2}) and associated information from each transect and frequency to comma-delimited text (.csv) files.

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

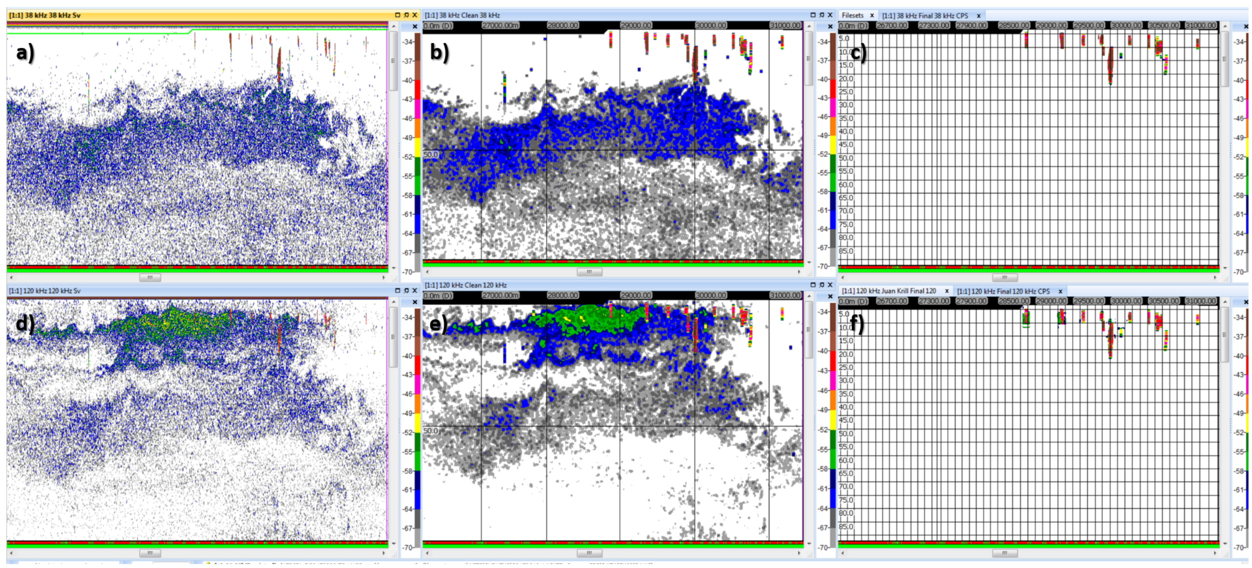

Figure 9: Echogram depicting CPS schools (red) and plankton aggregations (blue and green) at 38 kHz (top) and 120 kHz (bottom). Example data processing steps include the original echogram (left), after noise subtraction and bin-averaging (middle), and filtering to retain only putative CPS echoes (right).

2.2.4 Removal of non-CPS backscatter

In addition to echoes from target CPS, echoes may also be present from other CPS (Pacific Saury, *Cololabis saira*), semi-demersal fish such as Pacific Hake (*M. productus*), and rockfishes (*Sebastes* spp.). When analyzing the acoustic-survey data, it is 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 are superimposed on the echo-integrated data for each transect. Echoes below the surface mixed layer are excluded from the CPS analysis (**Fig. 10**). In areas dominated by Pacific Herring, for example off Vancouver Island, backscatter was integrated to a maximum depth of 75 m. This depth range aims to minimize integration of bottom-dwelling fish like ling-cod and multiple species of rockfishes (Richards *et al.*, 1991).

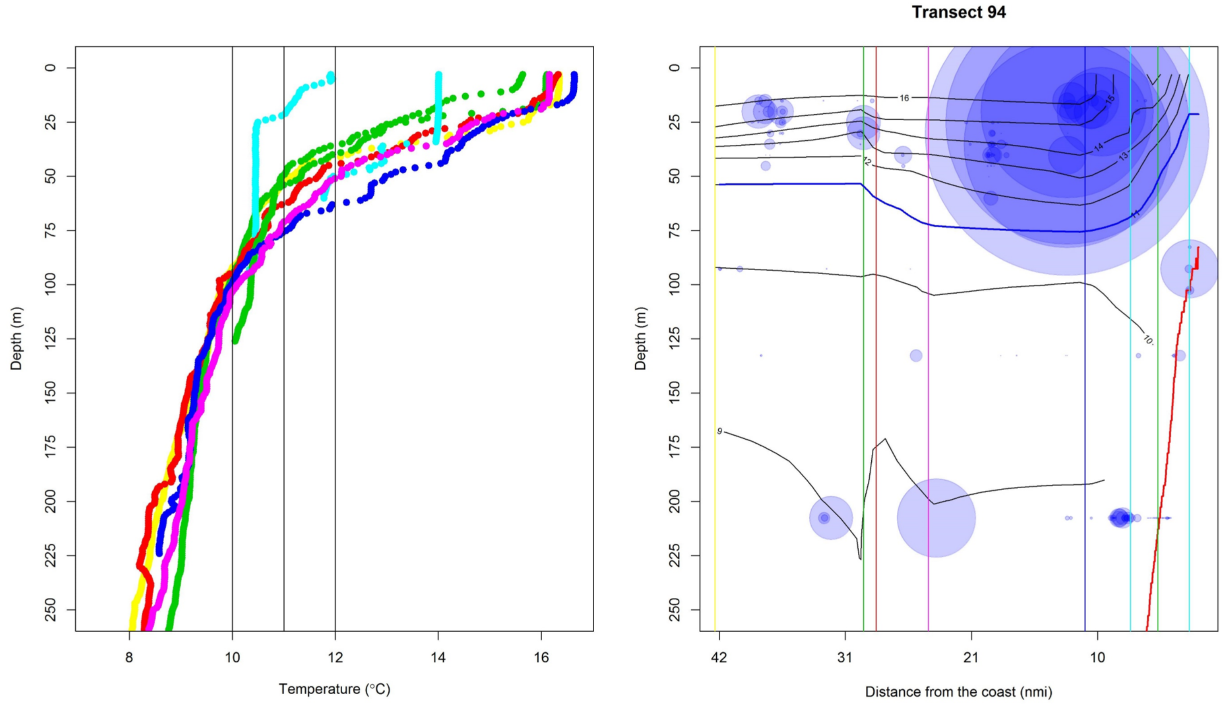

Figure 10: Water column characteristics (left) and the distribution of echoes from fishes with swimbladders (right) along an example acoustic transect. In this example, temperature profiles indicate an ~25 m-deep mixed-layer above an ~20-30 m thermocline, so the 11 °C isotherm (bold, blue line; right 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) is also used to define the lower limit for vertical integration.

2.2.5 Removal of surface noise

After reviewing echograms from transects conducted aboard F/V *Lisa Marie*, backscatter attributed to bubble noise in the upper 5 m (**Fig. 11**) was removed from all acoustic transect intervals prior to biomass estimation.

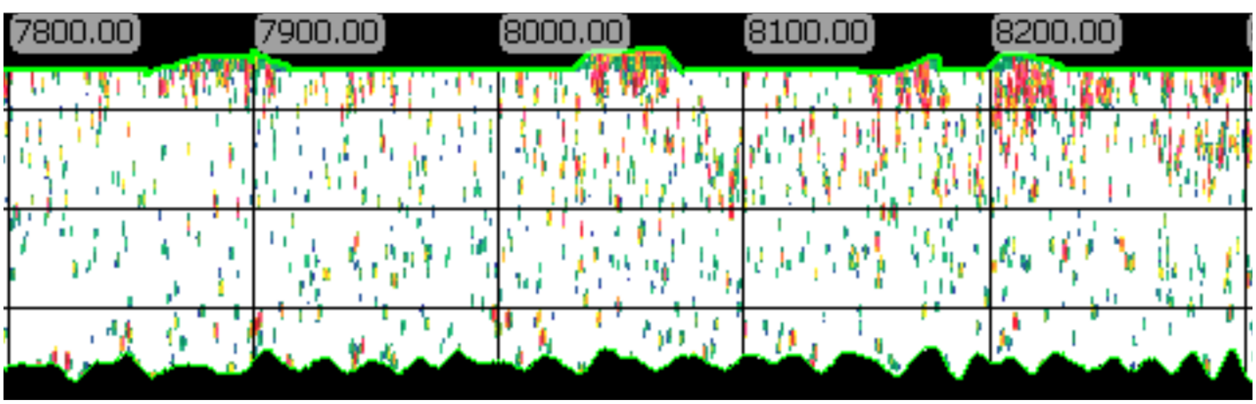

Figure 11: An example of backscatter from bubble noise in the upper 5 m of echograms from a transect conducted by F/V *Lisa Marie*.

2.2.6 QA/QC

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, **Fig. 12**). If found, errors were corrected and data were re-integrated prior to use for biomass estimation.

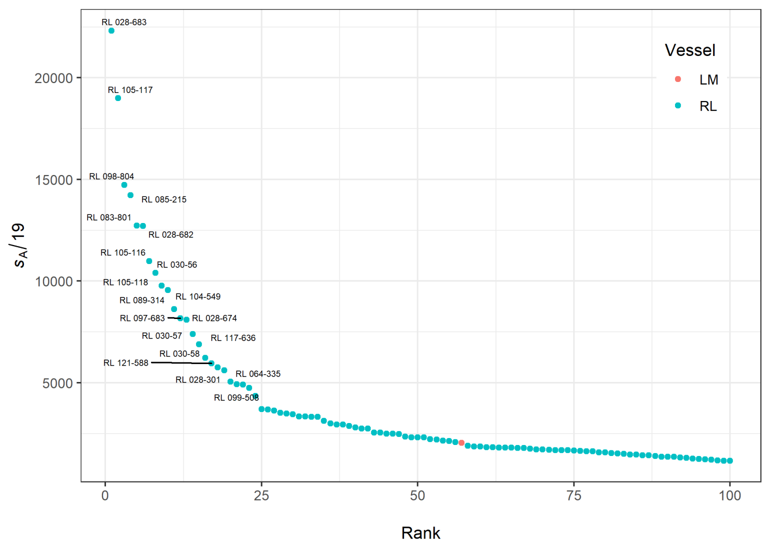

Figure 12: Ranked 38-kHz integrated backscattering coefficient values (s_A, m^2 nmi^{-2}; n = 100), labeled with the vessel name (*RL* = *Lasker*, *LM* = F/V *Lisa Marie*), transect number, and echogram distance interval. The s_A values for the 100-m intervals are divided by 19 for scaling to the traditional elementary distance sampling unit (EDSU) length of 1 nmi.

2.2.7 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 can be approximated by a function of fish length, such as:

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

where m and b are frequency and species-specific parameters, and are obtained theoretically or experimentally. The target strength (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 by individual or dB re 1 m^2 kg^{-1} if defined by weight. The following equations for TS_{38kHz} were used in these analyses:

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

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

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

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

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 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 of 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 (Ona, 2003; Zhao *et al.*, 2008) for the average depth of Northern Anchovy, 19 m, observed in summer 2016 (Zwolinski *et al.*, 2017).

To calculate $TS_{38\mathrm{kHz}}$, L_T (cm) was estimated from measurements of L_S or L_F (cm) using linear relationships between length and weight derived from specimens collected in the CCE: for Pacific Sardine, $L_T = 0.3574 + 1.149L_S$; for Northern Anchovy, $L_T = 0.2056 + 1.1646L_S$; for Pacific Mackerel, $L_T = 0.2994 + 1.092L_F$; for Jack Mackerel $L_T = 0.7295 + 1.078L_F$; and for Pacific Herring $L_T = -0.105 + 1.2L_F$.

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

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

where:

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

and the proportion (P_{ge}) is;

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

2.2.8 Trawl clustering and species proportions

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

For a generic 100-m long acoustic interval, the area backscattering coefficient for species e: $s_{A,e} = s_{A,cps} \times P_e$, where P_e is the species acoustic proportion Equation (14) of the nearest trawl cluster, 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 night's trawl cluster (**Fig. 13**):

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

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.

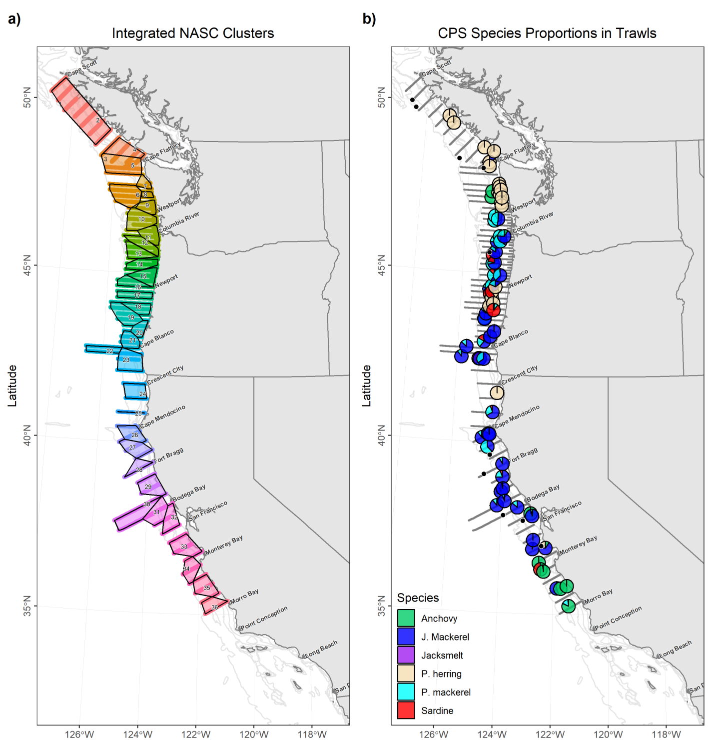

Figure 13: a) Polygons enclosing 100-m acoustic intervals assigned to each trawl cluster, and b) the proportion (by weight) of CPS in each trawl cluster. The numbers inside each polygon in panel a) are the cluster numbers, which are located at the average latitude and longitude of all trawls in that cluster. Black points in panel b) indicate trawl clusters with no CPS present.

2.3 Data analysis

2.3.1 Post-stratification

The transects were used as sampling units (Simmonds and Fryer, 1996). Because each species does not generally span the entire survey area (Demer and Zwolinski, 2017; Zwolinski *et al.*, 2014), the sampling domain was stratified for each species and stock. Strata were defined by uniform transect spacing (sampling intensity) and either presences (positive densities and potentially structural zeros) or absences (real zeros) of species biomass (**Figs. 14**, **15**). 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. 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 (latitude = 40.43052 °N). For Pacific Sardine, we define the separation between the northern and southern stock at Point Conception (latitude = 34.448266 °N).

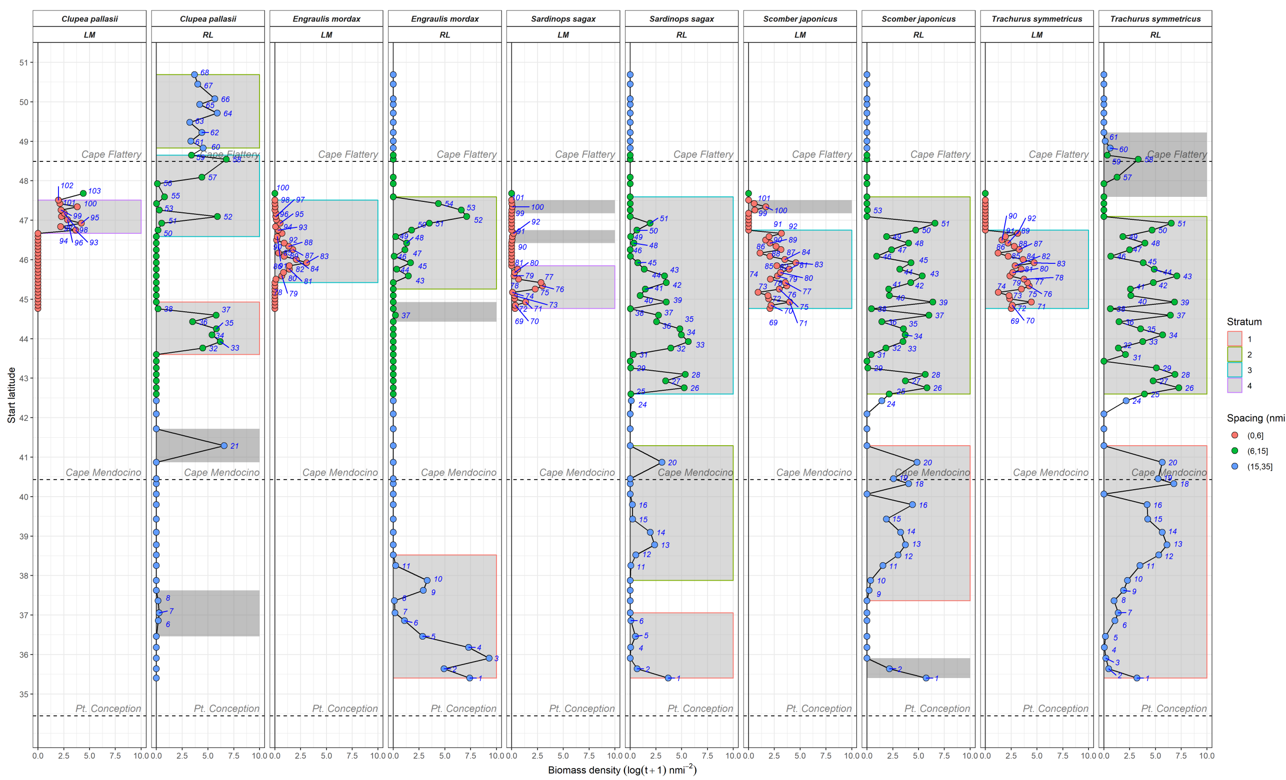

Figure 14: Acoustic biomass density ($\log_{10}(t+1)$ nmi^{-2}) versus latitude (easternmost portion of each transect) and strata used to estimate biomass and abundance (shaded regions; outline indicates stratum number) for each species and survey vessel (labels above plots; *RL* = *Lasker*, *LM* = F/V *Lisa Marie*). Blue number labels correspond to the transect numbers with positive biomass ($\log_{10}(t+1) > 0.01$). Point fills indicate transect spacing (nmi), which is used to identify sampling intensity. Dashed lines indicate prominent biogeographic landmarks used to delineate stock boundaries (e.g., Cape Mendocino to separate the central and northern stocks of Northern Anchovy, and Point Conception to separate the northern and southern stocks of Pacific Sardine).

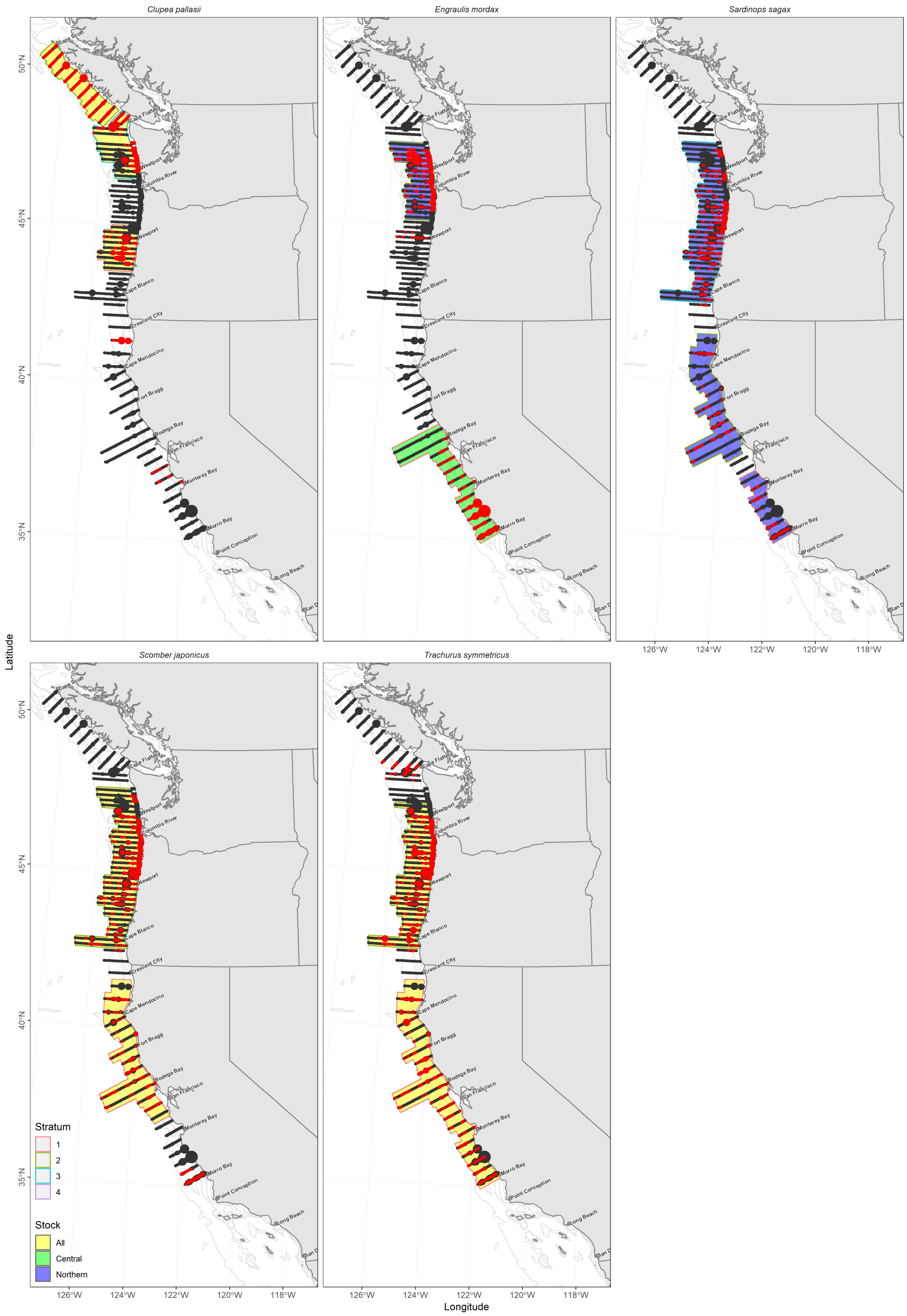

Figure 15: Post-survey stratification and the location of stratum polygons used to estimate the biomasses of CPS. Point sizes indicate the relative intensity (s_A; m^2 nmi^{-2}) of acoustic backscatter from all CPS (black points) and individual species (red points). Polygon outline colors indicate stratum number and fill colors indicate the species' stock designation.

2.3.2 Estimation of biomass and sampling precision

For each stratum and stock, the biomass (B; kg) of each species is 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 ($\text{CI}_{95\%}$) 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 errors by the point estimates (Efron, 1981). Total biomass in the survey area was estimated as the sum of the biomasses in each stratum, and the associated sampling variance was calculated as the sum of the variances across strata.

2.3.3 Abundance- and biomass-at-length estimates

The numerical densities by length class (**Section 2.2.8**) are 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.

2.3.4 Percent contribution of acoustic biomass per cluster

The percent contribution of each cluster to the estimated abundance in a stratum was calculated as:

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

where ρ_{ci} is the numerical density in interval i represented by the nearest trawl cluster c (**Appendix A**).

2.3.5 Extrapolation of biomass to unsampled nearshore areas

To investigate the potential biomass of CPS in areas where *Lasker* could not safely navigate, acoustically sampled biomass along the easternmost portions of transects in the survey areas were extrapolated to the 5-m isobath in the unsampled nearshore areas (see **Appendix B**).

3 Results

3.1 Sampling effort and allocation

The summer 2017 survey took place between Cape Scott, Vancouver Island and Morro Bay during 50 DAS between 19 June and 11 August 2017. Acoustic sampling was done on 103 daytime east-west transects that totaled 3,506 nmi. Catches from a total of 84 nighttime surface trawls were combined into 36 trawl clusters. As many as four post-survey strata were defined considering transect spacing and the densities of echoes attributed to CPS. Biomasses and abundances were estimated for each species.

During Leg I, *Lasker* departed from the 10th Avenue Marine Terminal in San Diego, CA on 19 June 2017 and arrived at the north end of Vancouver Island, BC on 25 June to begin survey operations. *Lasker* and F/V *Lisa Marie* conducted coordinated sampling between Westport and Newport to quantify nearshore CPS. F/V *Lisa Marie* conducted parallel transects with *Lasker* on transects 4, 12, 16, and 26. On 8 July, F/V *Lisa Marie* completed acoustic sampling and returned to Westport on 9 July. On 13 July, survey operations for *Lasker* during Leg I ceased near Newport, and the ship transited to port in San Francisco, CA.

During Leg II, *Lasker* departed from San Francisco on 18 July and commenced sampling near Waldport, OR on 20 July. On 10 August, survey operations ceased near Morro Bay and the ship transited back to port in San Diego to complete the survey.

3.2 Acoustic backscatter

The majority of acoustic backscatter ascribed to CPS was observed along the coast of Vancouver Island; between La Push, WA (north of Westport) and Cape Blanco; around Cape Mendocino; and between Big Sur and Morro Bay (**Fig. 16a**). To a lesser extent, CPS backscatter was observed along the central CA coast between Fort Bragg and Bodega Bay (**Fig. 16a**). Some acoustic backscatter ascribed to CPS was also observed by F/V *Lisa Marie* nearshore between La Push, WA and Newport (**Fig. 16a**). The majority (~90%) of acoustic biomass for each species was apportioned using catch data from trawl clusters conducted within a distance of $\leq$ 25 nmi (**Fig. 17**).

3.3 Egg densities and distributions

Northern Anchovy eggs were most abundant in the CUFES samples offshore of Westport and south of the Columbia River plume, between WA and OR (**Fig. 16b**). Lower densities of Jack Mackerel eggs were observed from Westport to Cape Blanco, off Bodega Bay, and to a lesser extent between San Francisco and Monterey (**Fig. 16b**). Pacific Sardine eggs observed in the CUFES were most abundant offshore near the Columbia River to Cape Blanco; some Pacific Sardine eggs were present in CUFES between Crescent City and Bodega Bay (**Fig. 16b**). There was little overlap in the distribution of Northern Anchovy and Pacific Sardine eggs in CUFES. The concentrations of Northern Anchovy and Pacific Sardine eggs in the CUFES were coincident with CPS backscatter.

3.4 Trawl catch

Jack Mackerel comprised the greatest proportion of catch in trawl samples between the Columbia River and Monterey Bay (**Fig. 16c**). Pacific Herring comprised the greatest proportion of catch in trawl samples inshore along the coast of Vancouver Island, between Cape Flattery and Westport, and around Newport (**Fig. 16c**). Northern Anchovy were predominantly found in trawls conducted between Monterey and Morro Bay, with some present north of Westport and near Bodega Bay (**Fig. 16c**). The few trawl samples that contained Pacific Sardine were collected offshore south of Newport and in one trawl offshore near Monterey. Overall, the 84 trawls captured a combined 6,245 kg of CPS (2,103 kg of Northern Anchovy, 404 kg of Pacific Sardine, 1,023 kg of Pacific Mackerel, 2,027 kg of Jack Mackerel, and 687 kg Pacific Herring).

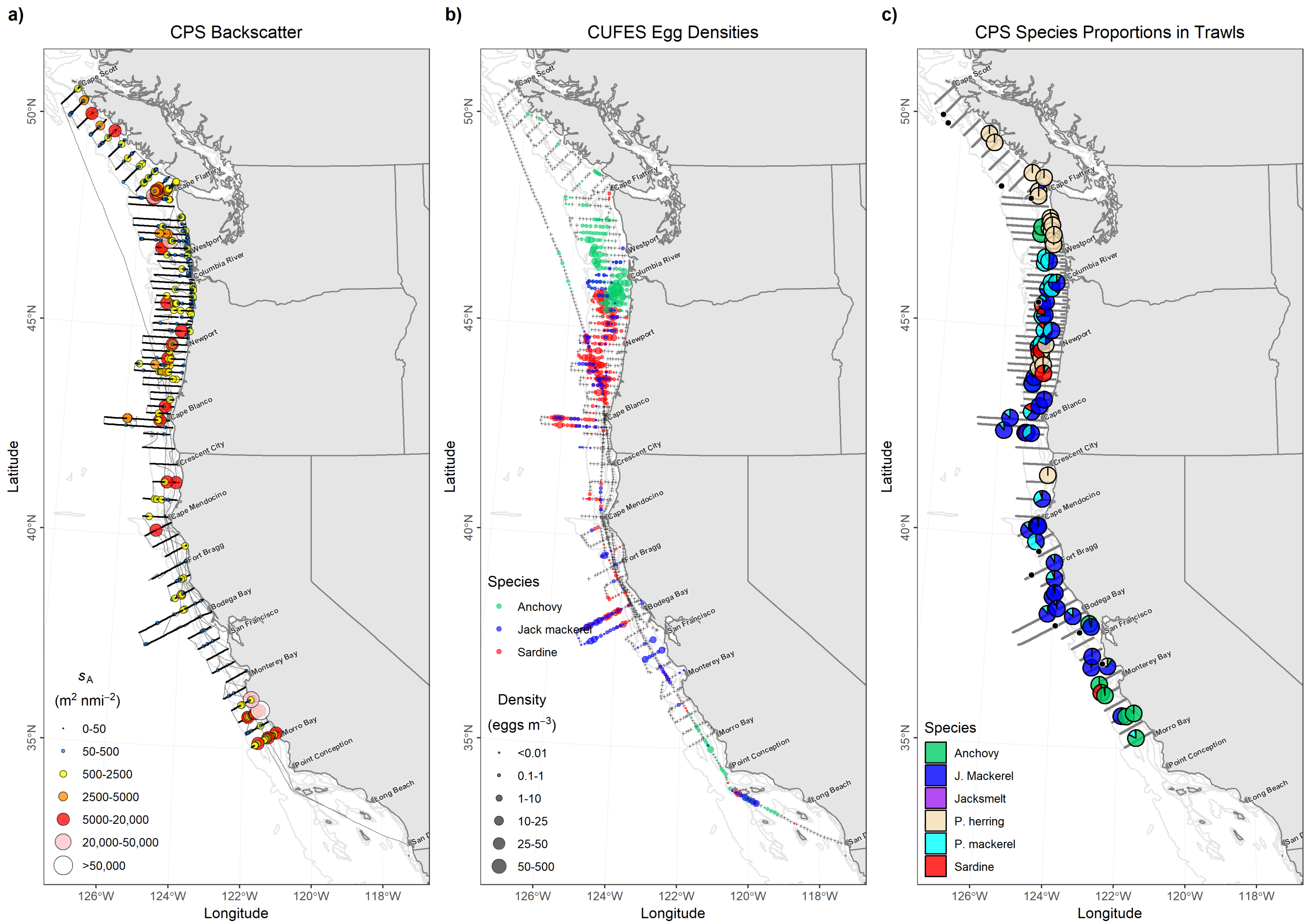

Figure 16: Spatial distributions of: a) 38-kHz integrated backscattering coefficients (s_A, m^2 nmi^{-2}; averaged over 2000-m distance intervals and from 5 to 70-m deep) ascribed to CPS; b) CUFES egg density (eggs m^{-3}) for Northern Anchovy, Pacific Sardine, and Jack Mackerel; and c) proportions of CPS in trawl clusters (black points indicate trawls with no CPS).

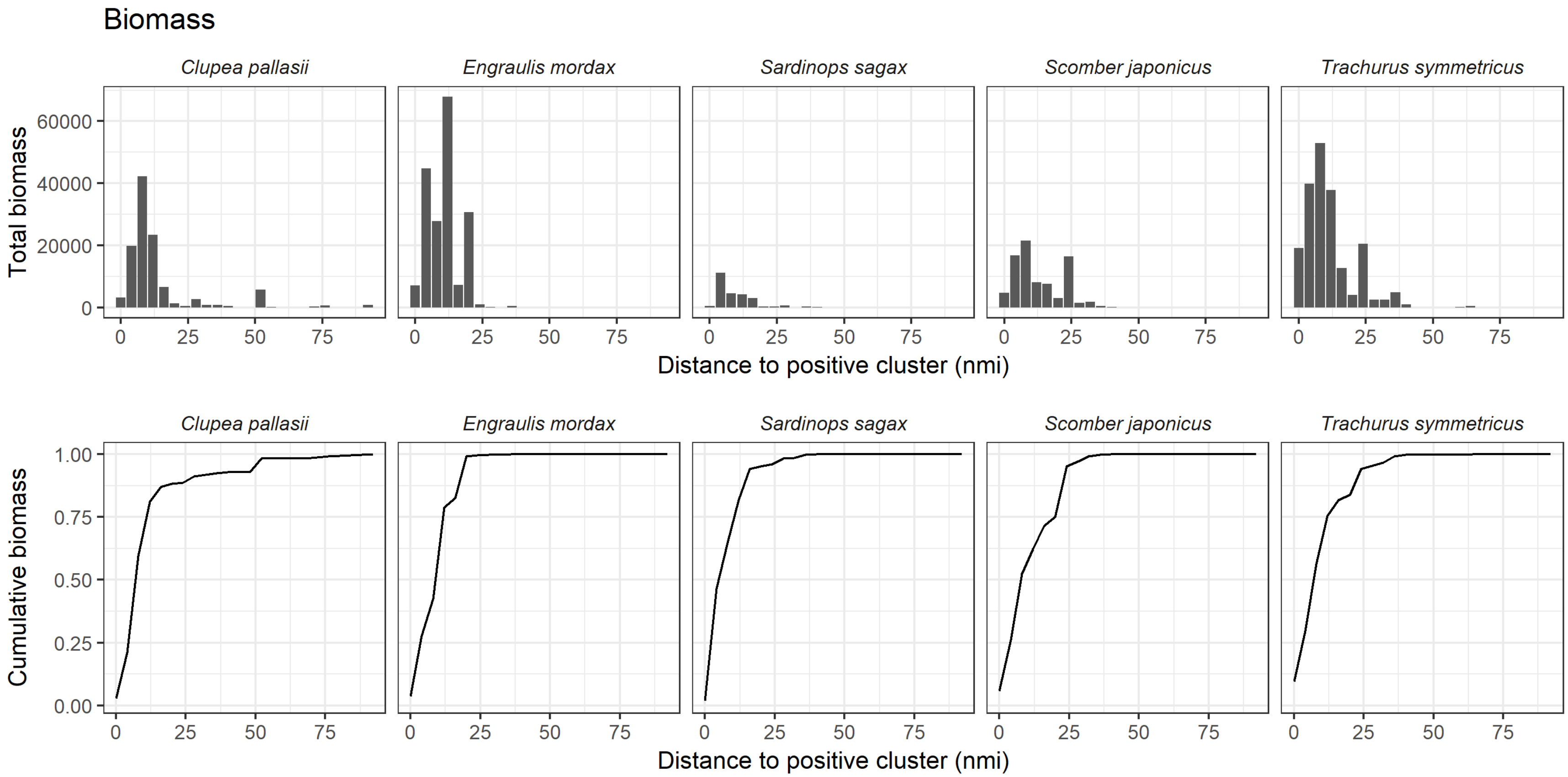

Figure 17: Total (top) and cumulative (bottom) acoustic biomass (t) versus distance to the nearest positive trawl cluster.

3.5 Biomass distribution and demography

3.5.1 Northern Anchovy

3.5.1.1 Northern stock

The estimated biomass of the northern stock of Northern Anchovy was 22,709 t ($CI_{95\%}$ = 1,452 - 57,334 t, CV = 64%; **Table 3**). The northern stock ranged from approximately Cape Flattery to Newport (**Fig. 18**). L_S ranged from 4 to 16 cm with a mode at ~14 cm (**Table 5**, **Fig. 19**).

Table 3: Biomass estimates (metric tons, t) and their precision (upper and lower 95% confidence intervals, $CI_{95\%}$; standard deviation, SD; and coefficient of variation, CV) for the northern stock of Northern Anchovy (*Engraulis mordax*). Mean biomasses are the point estimates. Stratum areas are nmi^2.

Species		Stratum				Trawl		Biomass			
Name	Stock	Number	Area	Transects	Distance	Clusters	Individuals	Mean	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Engraulis mordax	Northern	2	7,915	15	787	7	982	22,607	1,392	57,262	64
		3	693	26	141	6	964	102	40	179	34
		All	8,609	41	928	7	1,945	22,709	1,452	57,334	64

3.5.1.2 Central stock

The estimated biomass of the central stock of Northern Anchovy was 153,460 t ($CI_{95\%}$ = 2,628 - 264,009 t, CV = 45%; **Table 4**). The central stock ranged from approximately Bodega Bay to Morro Bay (**Fig. 20**). L_S ranged from 4 to 16 cm with modes at ~9 and 12-13 cm (**Table 6**, **Fig. 21**).

Table 4: Biomass estimates (metric tons, t) and their precision (upper and lower 95% confidence intervals, $CI_{95\%}$; standard deviation, SD; and coefficient of variation, CV) for the central stock of Northern Anchovy (*Engraulis mordax*). Mean biomasses are the point estimates. Stratum areas are nmi^2.

Species		Stratum				Trawl		Biomass			
Name	Stock	Number	Area	Transects	Distance	Clusters	Individuals	Mean	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Engraulis mordax	Central	1	11,350	12	578	5	86,143	153,460	2,628	264,009	45
		All	11,350	12	578	5	86,143	153,460	2,628	264,009	45

Table 5: Estimated abundance (upper panel) and biomass (lower panel) versus standard length (L_S, cm) for the northern stock of Northern Anchovy (*Engraulis mordax*).

Stock	L_S	Abundance
Northern	1	0
	2	0
	3	0
	4	0
	5	0
	6	0
	7	0
	8	0
	9	0
	10	0
	11	2,508,429
	12	352,140
	13	38,622,475
	14	333,241,263
	15	297,910,631
	16	2,079,827
	17	0
	18	0
	19	0
	20	0

Table 6: Estimated abundance (upper panel) and biomass (lower panel) versus standard length (L_S, cm) for the central stock of Northern Anchovy (*Engraulis mordax*).

Stock	L_S	Abundance
Central	1	0
	2	0
	3	0
	4	1,491,102
	5	5,258,743
	6	14,313,025
	7	5,807,935
	8	329,109,882
	9	1,818,405,723
	10	872,893,159
	11	234,063,154
	12	2,631,008,139
	13	2,905,452,584
	14	106,004,589
	15	105,824,824
	16	0
	17	0
	18	0
	19	0
	20	0

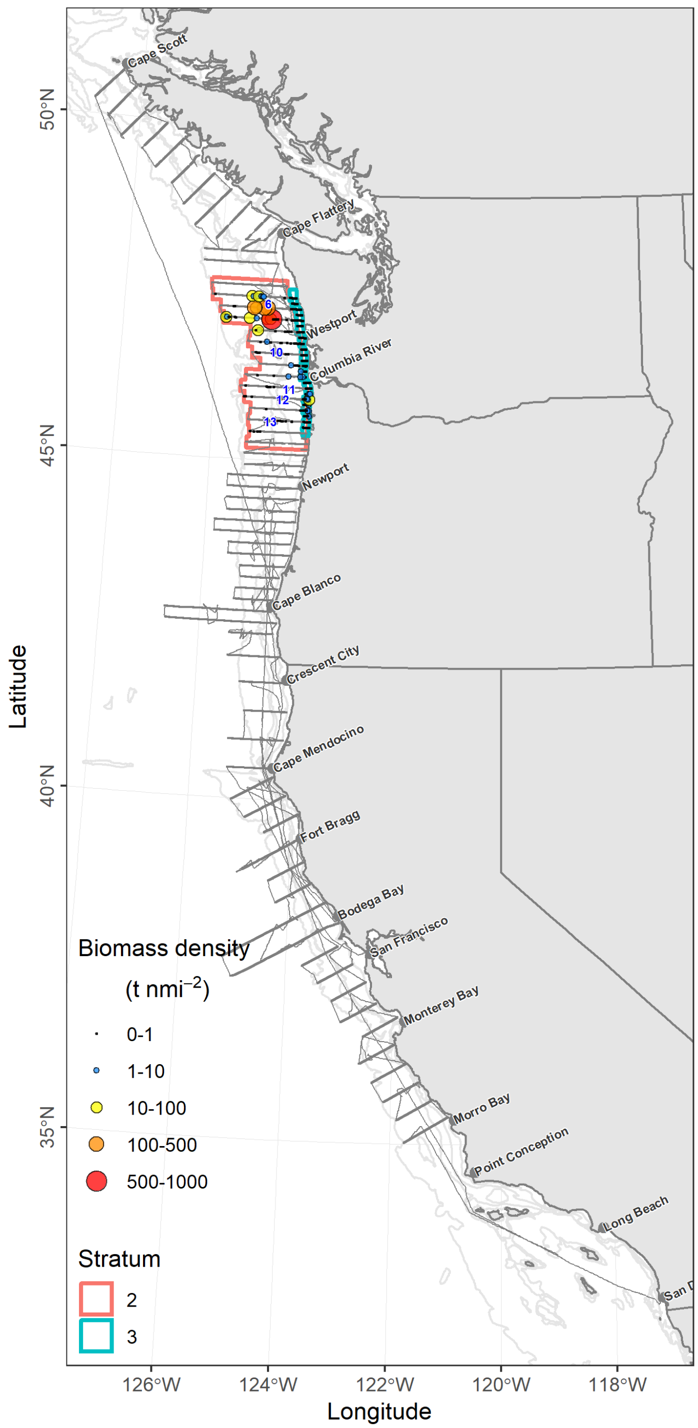

Figure 18: Biomass densities of northern stock of Northern Anchovy (*Engraulis mordax*), per strata, throughout the survey region. The blue numbers represent the locations of trawl clusters with at least one anchovy. The gray line represents the vessel track.

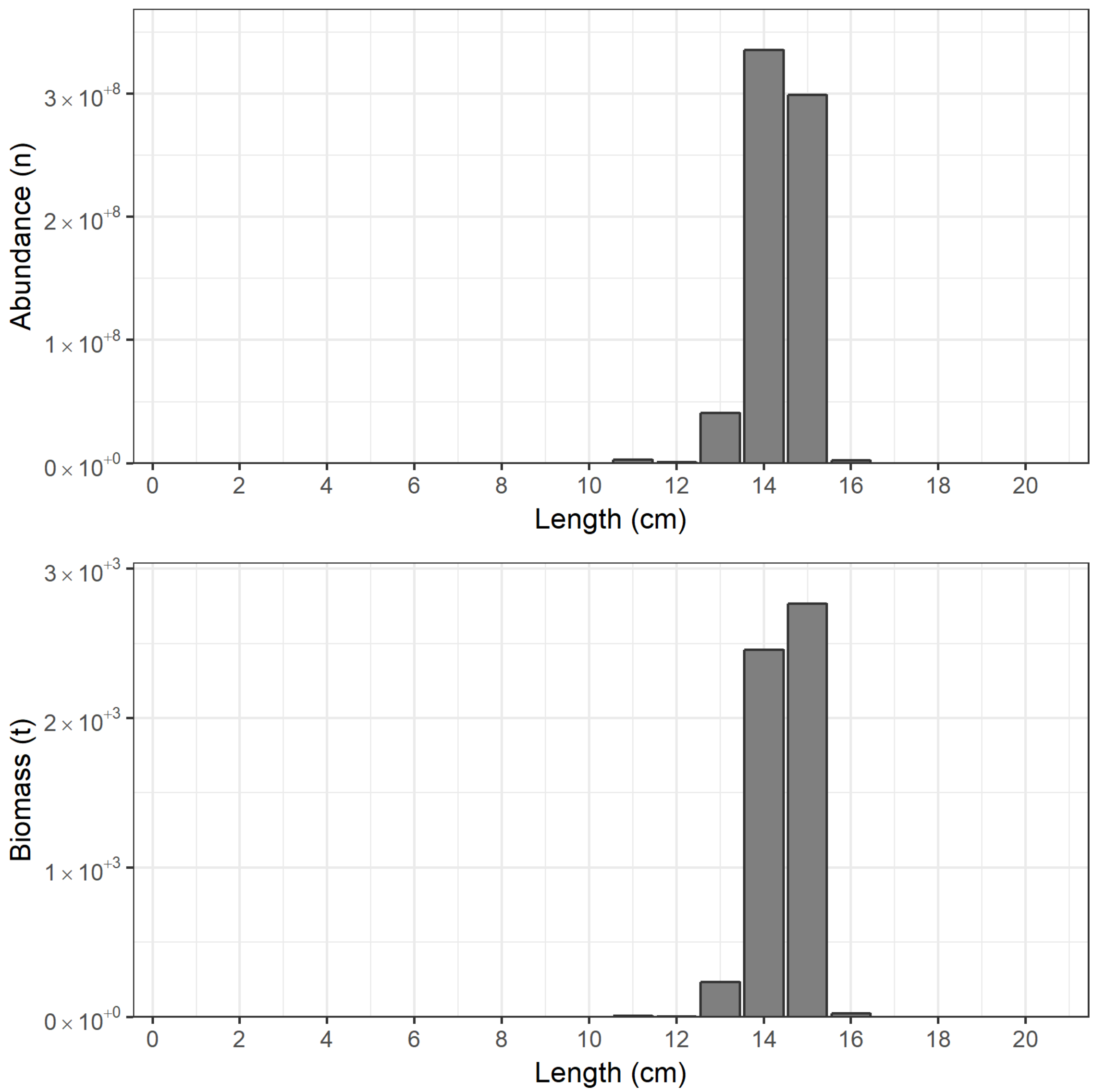

Figure 19: Abundance versus standard length (L_S, upper panel) and biomass (t) versus L_S (lower panel) for the northern stock of Northern Anchovy (*Engraulis mordax*) in the survey area.

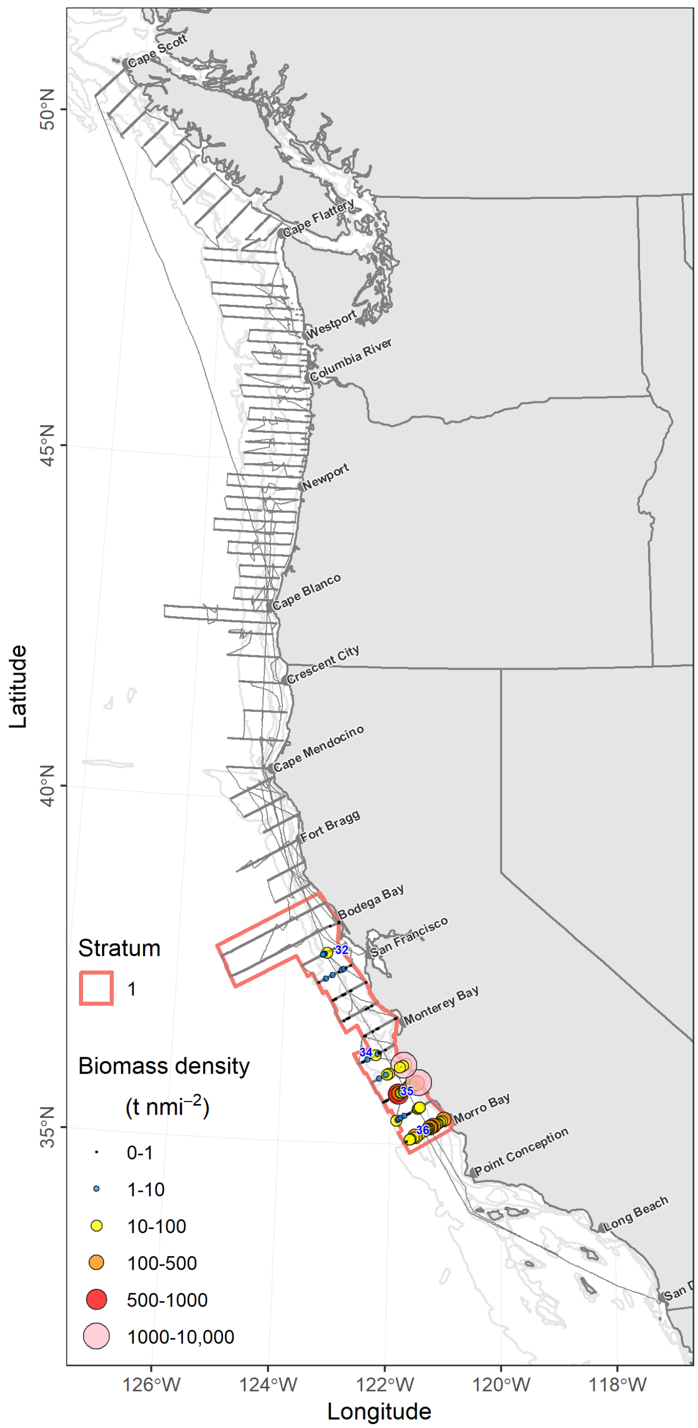

Figure 20: Biomass densities of central stock of Northern Anchovy (*Engraulismordax*), per strata, throughout the survey region. The blue numbers represent the locations of trawl clusters with at least one anchovy. The gray line represents the vessel track.

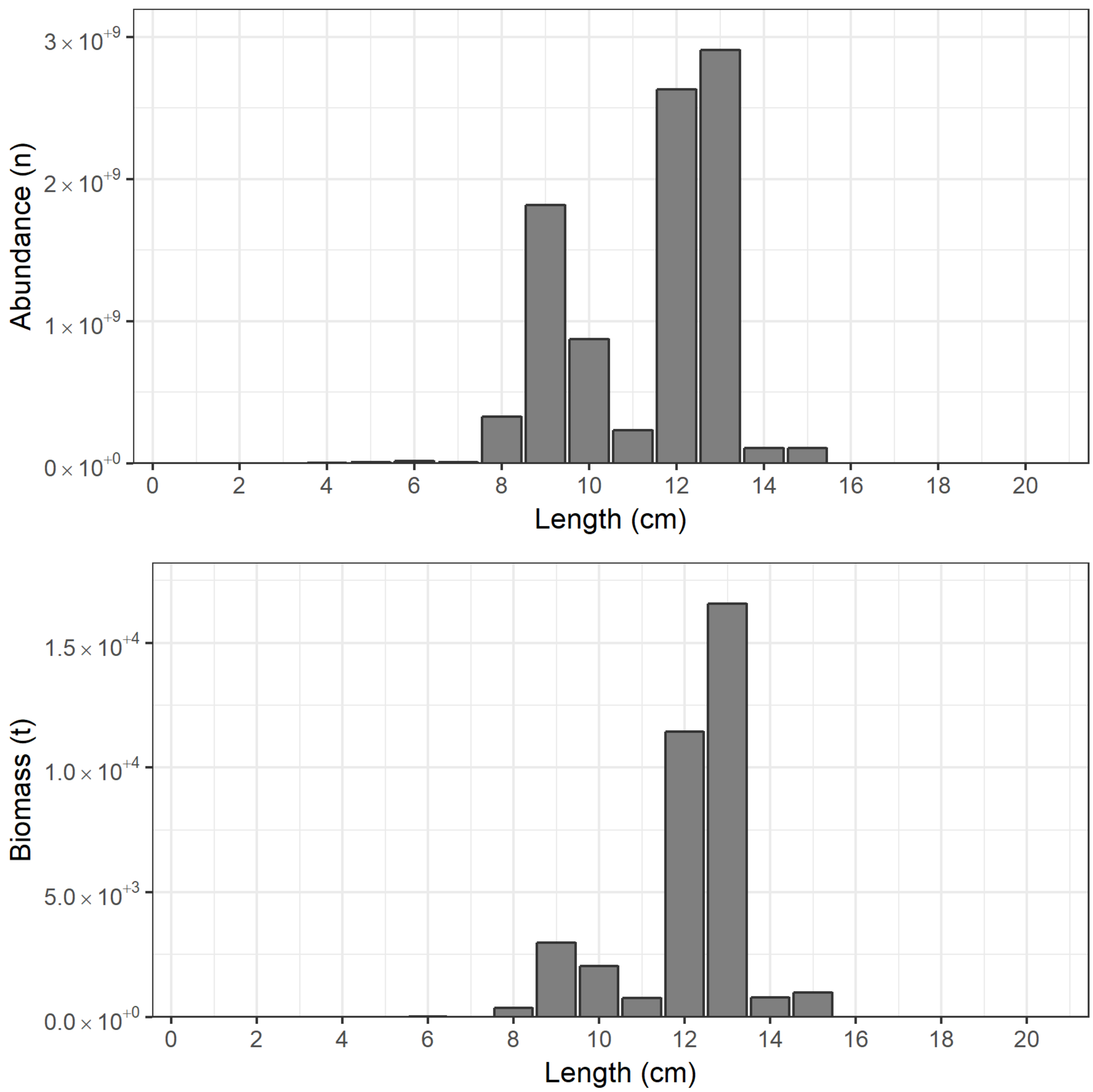

Figure 21: Abundance versus standard length (L_S, upper panel) and biomass (t) versus L_S (lower panel) for the central stock of Northern Anchovy (*Engraulis mordax*) in the survey area.

3.5.2 Pacific Sardine

3.5.2.1 Northern stock

The estimated biomass of the northern stock of Pacific Sardine was 14,103 t ($CI_{95\%}$ = 7,337 - 22,981 t, CV = 30%; **Table 7**). The northern stock ranged from approximately Cape Flattery to Morro Bay (**Fig. 22**). L_S ranged from 6 to 27 cm with modes at ~9-10 and 22 cm (**Table 8**, **Fig. 23**). Biomass were highest between Newport and Cape Blanco (**Fig. 22**).

Table 7: Biomass estimates (metric tons, t) and their precision (upper and lower 95% confidence intervals, $CI_{95\%}$; standard deviation, SD; and coefficient of variation, CV) for the northern stock of Pacific Sardine (*Sardinops sagax*). Mean biomasses are the point estimates. Stratum areas are nmi^2.

Species		Stratum				Trawl		Biomass			
Name	Stock	Number	Area	Transects	Distance	Clusters	Individuals	Mean	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
		1	5,078	7	260	2	10	847	20	2,910	91
		2	12,622	12	621	5	296	769	39	1,459	50
Sardinops sagax	Northern	3	17,221	31	1,714	12	2,320	12,337	5,524	21,648	34
		4	399	14	81	4	102	149	11	345	60
		All	35,320	64	2,676	19	2,728	14,103	7,337	22,981	30

Table 8: Abundance versus standard length (L_S, cm) for the northern stock of Pacific Sardine (*Sardinops sagax*).

Stock	L_S	Abundance
	1	0
	2	0
	3	0
	4	0
	5	0
	6	938,376
	7	1,407,563
	8	1,407,563
	9	37,458,127
	10	37,458,127
	11	0
	12	0
	13	0
	14	0
	15	0
Northern	16	0
	17	90
	18	2,646,754
	19	1,155,073
	20	10,902,914
	21	19,682,611
	22	32,775,963
	23	16,389,747
	24	2,446,053
	25	2,597,826
	26	4,135,409
	27	292,821
	28	0
	29	0
	30	0

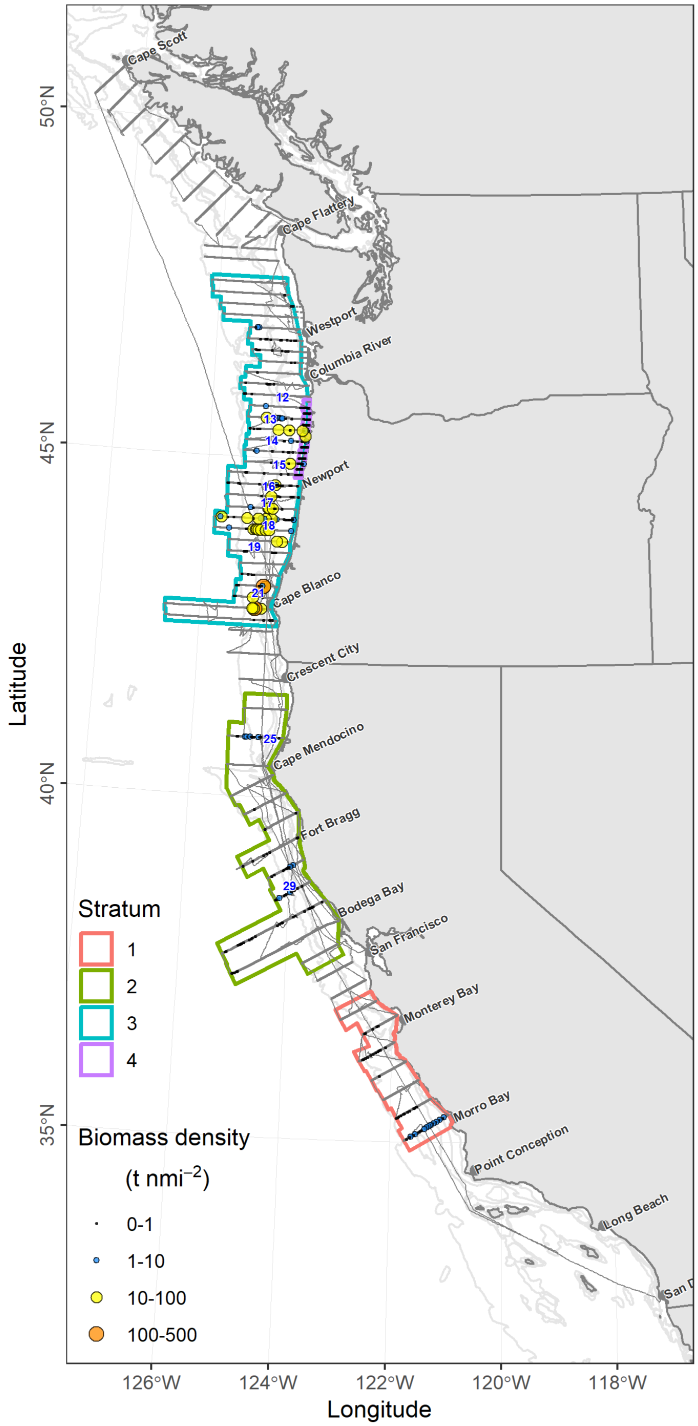

Figure 22: Biomass densities of the northern stock of Pacific Sardine (*Sardinops sagax*), per strata, throughout the survey region. The blue numbers represent the locations of trawl clusters with at least one sardine. The gray line represents the vessel track.

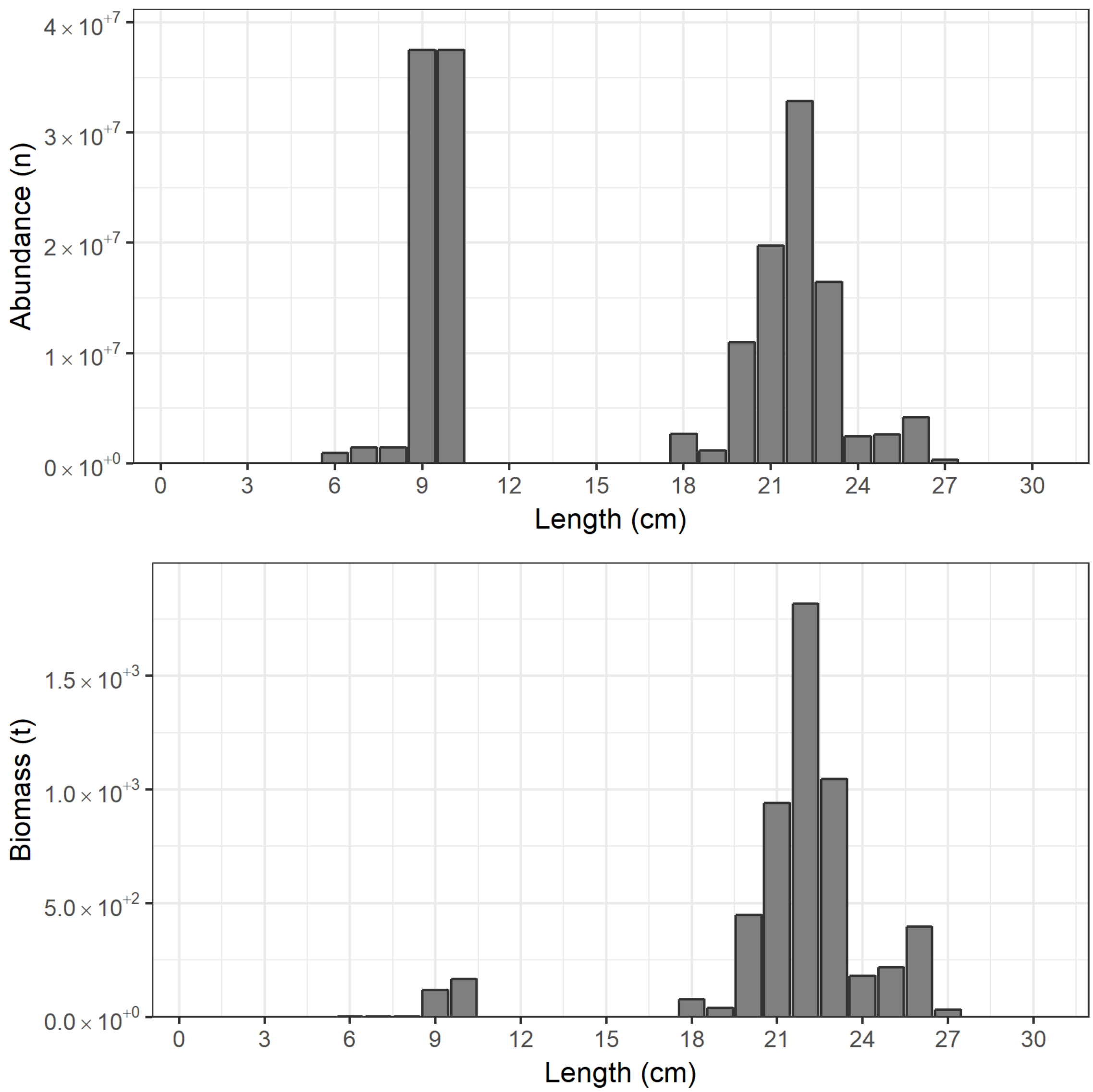

Figure 23: Estimated abundance (upper panel) and biomass (lower panel) versus standard length (L_S, cm) for the northern stock of Pacific Sardine (*Sardinops sagax*) in the survey area.

3.5.3 Pacific Mackerel

The estimated biomass of Pacific Mackerel was 41,139 t ($CI_{95\%}$ = 18,019 - 58,425 t, CV = 26%; **Table 9**). The Pacific Mackerel ranged from approximately Cape Flattery to Morro Bay (**Fig. 24**). L_F ranged from 16 to 38 cm with modes at ~18 and 27 cm (**Table 10**, **Fig. 25**). The biomass density was largest between Westport and Cape Blanco (**Fig. 24**).

Table 9: Biomass estimates (metric tons, t) and their precision (upper and lower 95% confidence intervals, $CI_{95\%}$; standard deviation, SD; and coefficient of variation, CV) for Pacific Mackerel (*Scomber japonicus*). Mean biomasses are the point estimates. Stratum areas are nmi^2.

Species		Stratum				Trawl		Biomass			
Name	Stock	Number	Area	Transects	Distance	Clusters	Individuals	Mean	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Scomber japonicus	All	1	13,987	14	691	8	1,619	7,875	2,121	12,626	34
		2	17,221	31	1,714	14	2,827	32,126	11,876	50,185	32
		3	666	25	136	6	2,173	1,138	624	1,749	25
		All	31,874	70	2,541	22	6,620	41,139	18,019	58,425	26

Table 10: Abundance versus fork length (L_F, cm) for Pacific Mackerel (*Scomber japonicus*).

Stock	L_F	Abundance
All	1	0
	2	0
	3	0
	4	0
	5	0
	6	0
	7	0
	8	0
	9	0
	10	0
	11	0
	12	0
	13	0
	14	0
	15	0
	16	0
	17	0
	18	0
	19	0
	20	0
	21	0
	22	0
	23	63,950
	24	4,307,611
	25	15,681,142
	26	38,091,584
	27	47,794,765
	28	36,028,892
	29	13,328,999
	30	5,232,239
	31	3,708,441
	32	5,918,203
	33	3,140,715
	34	1,457,915
	35	860,964
	36	575,634
	37	150,781
	38	89,099
	39	0
	40	0

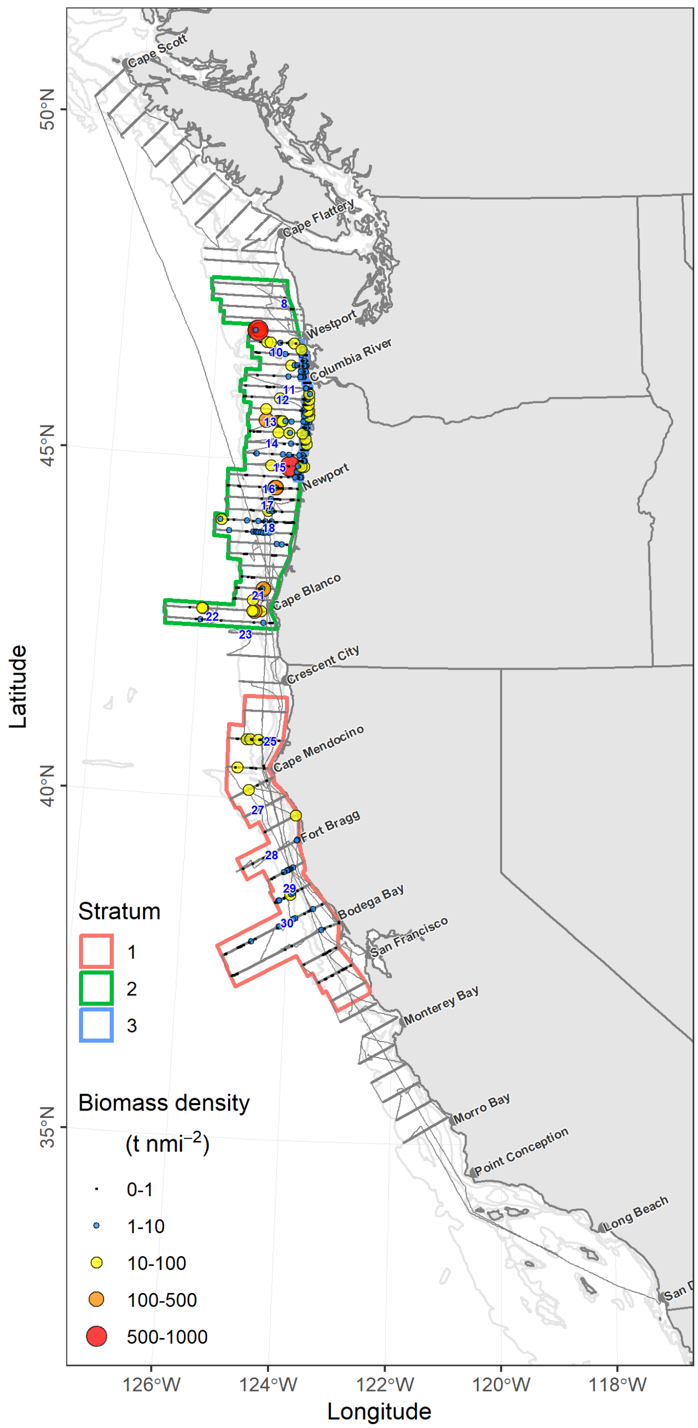

Figure 24: Biomass densities of the Pacific Mackerel (*Scomber japonicus*), per strata, throughout the survey region. The blue numbers represent the locations of trawl clusters with at least one Pacific Mackerel. The gray line represents the vessel track.

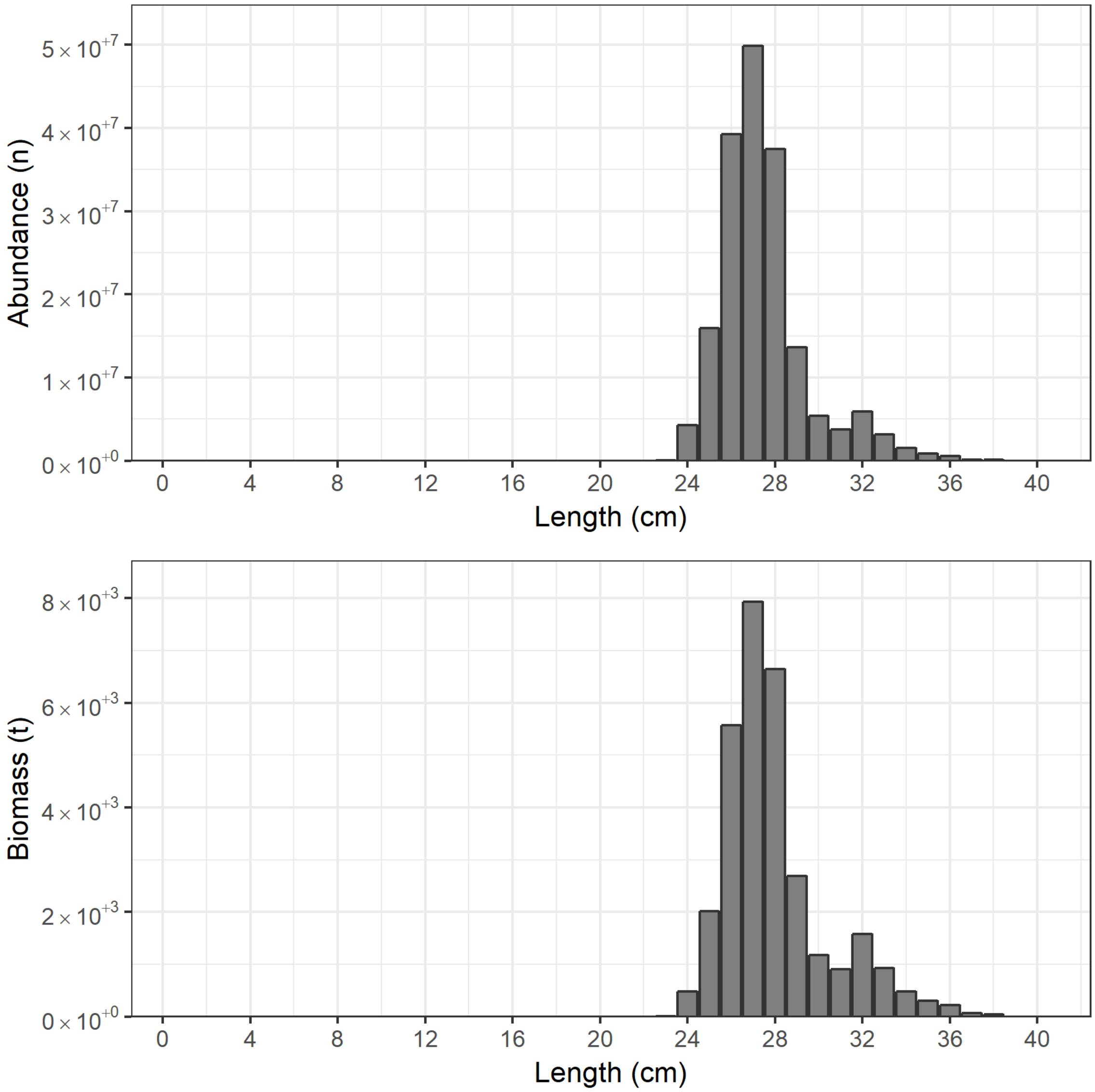

Figure 25: Estimated abundance (upper panel) and biomass (lower panel) versus fork length (L_F, cm) for Pacific Mackerel (*Scomber japonicus*) in the survey area.

3.5.4 Jack Mackerel

The estimated biomass of Jack Mackerel was 128,313 t ($CI_{95\%}$ = 70,594 - 180,676 t, CV = 22%; **Table 11**). The Jack Mackerel ranged from approximately Cape Flattery to Morro Bay (**Fig. 26**). L_F ranged from 3 to 53 cm, but mostly between 20 and 34 cm (**Table 12**, **Fig. 27**). The biomass density was largest between Westport and Cape Blanco, and between Cape Mendocino and Bodega Bay (**Fig. 26**).

Table 11: Biomass estimates (metric tons, t) and their precision (upper and lower 95% confidence intervals, $CI_{95\%}$; standard deviation, SD; and coefficient of variation, CV) for Jack Mackerel (*Trachurus symmetricus*). Mean biomasses are the point estimates. Stratum areas are nmi^2.

Species		Stratum				Trawl		Biomass			
Name	Stock	Number	Area	Transects	Distance	Clusters	Individuals	Mean	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Trachurus symmetricus	All	1	19,070	21	950	12	6,400	51,931	19,495	84,674	34
		2	15,294	28	1,521	14	2,758	74,841	35,102	117,534	30
		3	666	25	136	6	1,960	1,542	816	2,521	29
		All	35,030	74	2,608	26	11,117	128,313	70,594	180,676	22

Table 12: Abundance versus fork length (L_F, cm) for Jack Mackerel (*Trachurus symmetricus*).

Stock	L_F	Abundance
	1	0
	2	0
	3	6,899,360
	4	0
	5	6,899,360
	6	7,027,316
	7	4,663,552
	8	4,663,552
	9	545,062
	10	38,471,812
	11	0
	12	2,299,787
	13	0
	14	11,712
	15	77,755
	16	155,511
	17	155,511
	18	155,511
	19	233,266
	20	8,894,642
	21	21,326,133
	22	42,306,182
	23	42,010,832
	24	21,043,175
	25	10,975,035
	26	21,523,023
	27	27,210,766
	28	22,329,584
	29	24,133,561
	30	26,615,418
	31	26,231,512
	32	23,883,655
	33	31,207,555
	34	34,739,686
	35	10,669,152
	36	5,908,683
	37	4,457,600
	38	0
	39	311,874
	40	4,020,382
	41	512,610
	42	842,153
	43	575,389
	44	2,961,661
	45	2,835,613
	46	1,366,532
	47	1,429,106
	48	7,971,946
	49	55,192
	50	164,206
	51	219,398

Table 12: Abundance versus fork length (L_F, cm) for Jack Mackerel (*Trachurus symmetricus*). *(continued)*

Stock	L_F	Abundance
	52	283,666
	53	35,135
	54	0
	55	0
	56	0
	57	0
	58	0
	59	0
	60	0

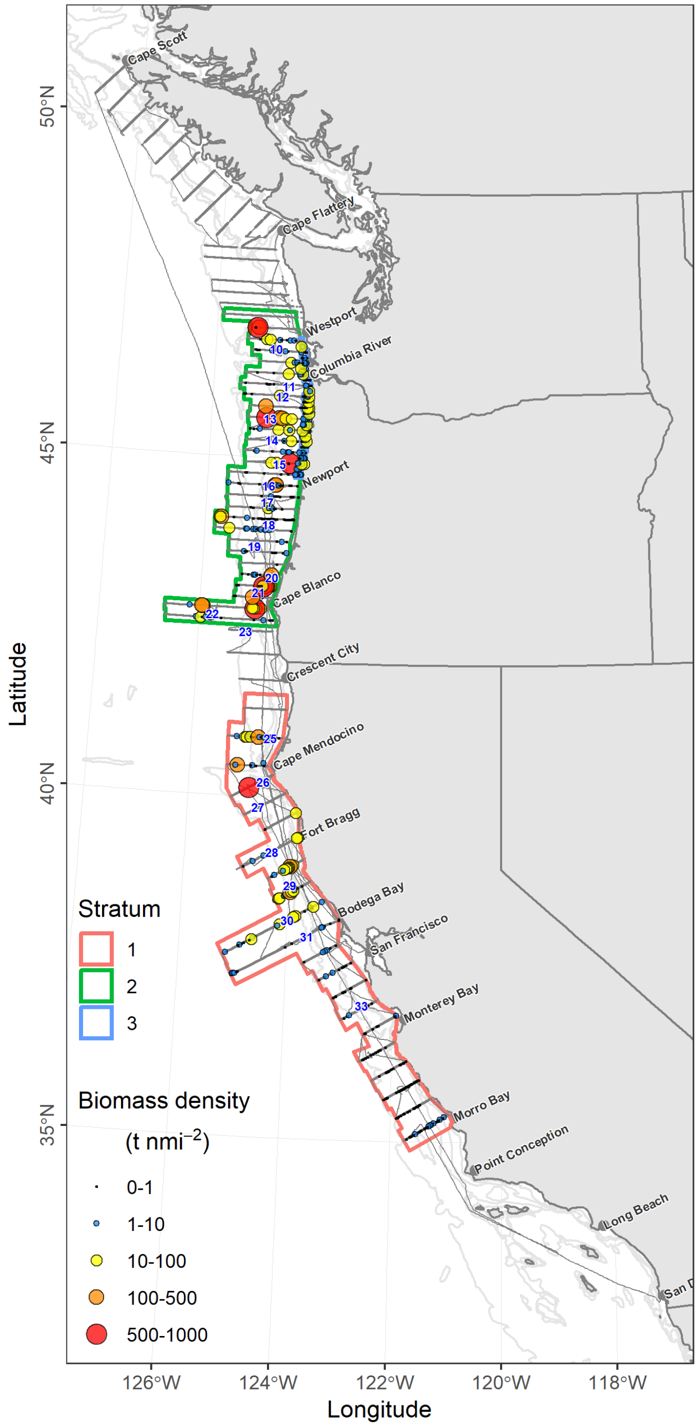

Figure 26: Biomass densities of Jack Mackerel (*Trachurus symmetricus*), per strata, throughout the survey region. The blue numbers represent the locations of trawl clusters with at least one Jack Mackerel. The gray line represents the vessel track.

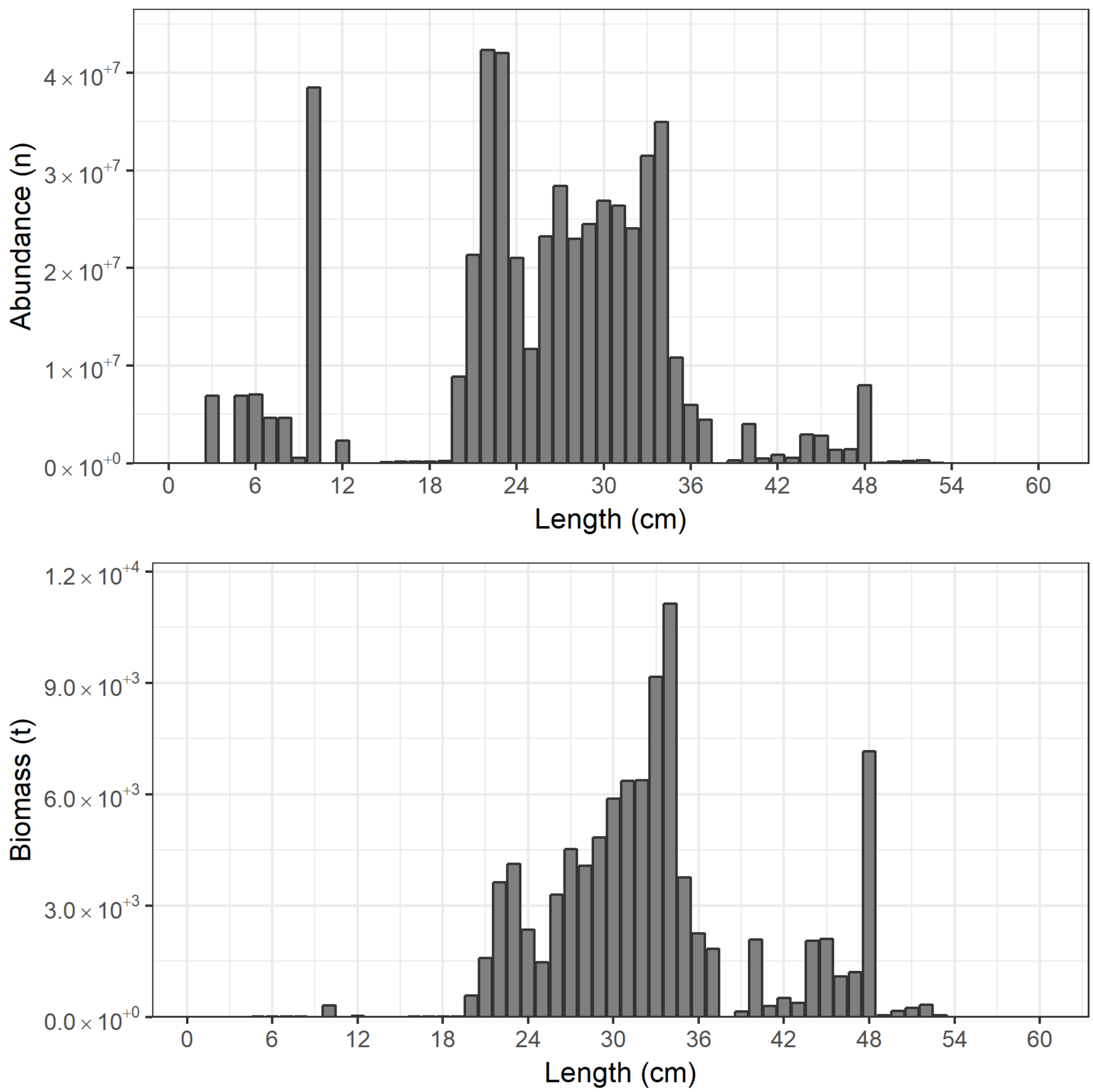

Figure 27: Estimated abundance (upper panel) and biomass (lower panel) versus fork length (L_F, cm) for Jack Mackerel (*Trachurus symmetricus*) in the survey area.

3.5.5 Pacific Herring

The estimated biomass of Pacific Herring was 63,418 t ($CI_{95\%}$ = 29,811 - 103,365 t, CV = 31%; **Table 13**). The Pacific Herring ranged from approximately Cape Scott to Cape Mendocino (**Fig. 28**). L_F ranged from 8 to 25 cm with modes at 13 and 21 cm (**Table 14**, **Fig. 29**). The biomass density was largest between Cape Scott and Cape Flattery; nearshore along the coast of WA; and between Newport and Coos Bay, OR (**Fig. 28**).

Table 13: Biomass estimates (metric tons, t) and their precision (upper and lower 95% confidence intervals, $CI_{95\%}$; standard deviation, SD; and coefficient of variation, CV) for Pacific Herring (*Clupea pallasii*). Mean biomasses are the point estimates. Stratum areas are nmi^2.

Species		Stratum				Trawl		Biomass			
Name	Stock	Number	Area	Transects	Distance	Clusters	Individuals	Mean	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Clupea pallasii	All	1	5,428	9	541	3	6,089	15,149	6,404	25,424	32
		2	6,688	9	335	3	554	22,097	9,005	38,331	34
		3	6,393	11	579	5	1,546	25,661	760	64,702	68
		4	294	11	60	3	1,078	510	245	754	26
		All	18,803	40	1,514	9	9,266	63,418	29,811	103,365	31

Table 14: Abundance versus fork length (L_F, cm) for Pacific Herring (*Clupea pallasii*).

Stock	L_F	Abundance
All	1	0
	2	0
	3	0
	4	0
	5	0
	6	0
	7	0
	8	0
	9	0
	10	0
	11	3,189,543
	12	7,482,810
	13	47,977,307
	14	81,441,138
	15	97,963,223
	16	53,036,870
	17	16,257,383
	18	14,972,396
	19	94,353,282
	20	102,148,279
	21	123,736,301
	22	129,749,786
	23	50,026,754
	24	1,711,392
	25	3,189,543
	26	0
	27	0
	28	0
	29	0
	30	0

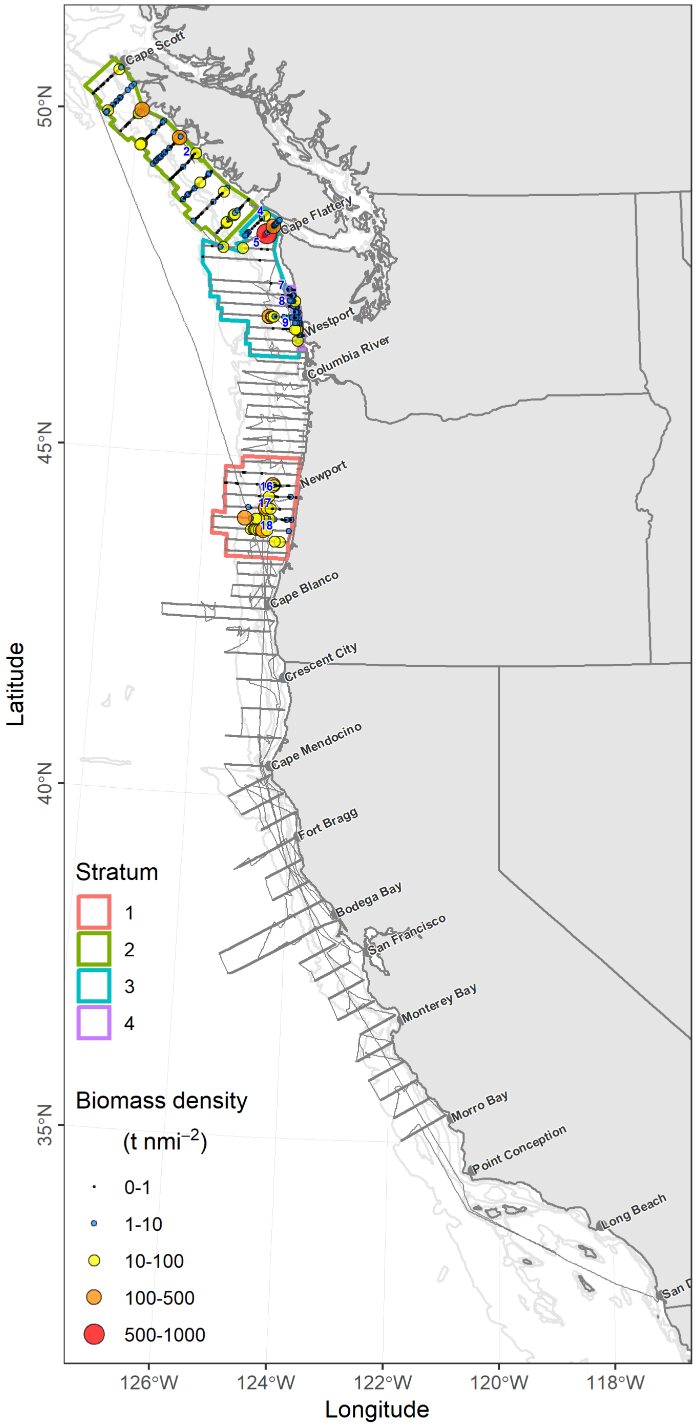

Figure 28: Biomass densities of Pacific Herring (*Clupea pallasii*), per strata, throughout the survey region. The blue numbers represent the locations of trawl clusters with at least one herring. The gray line represents the vessel track.

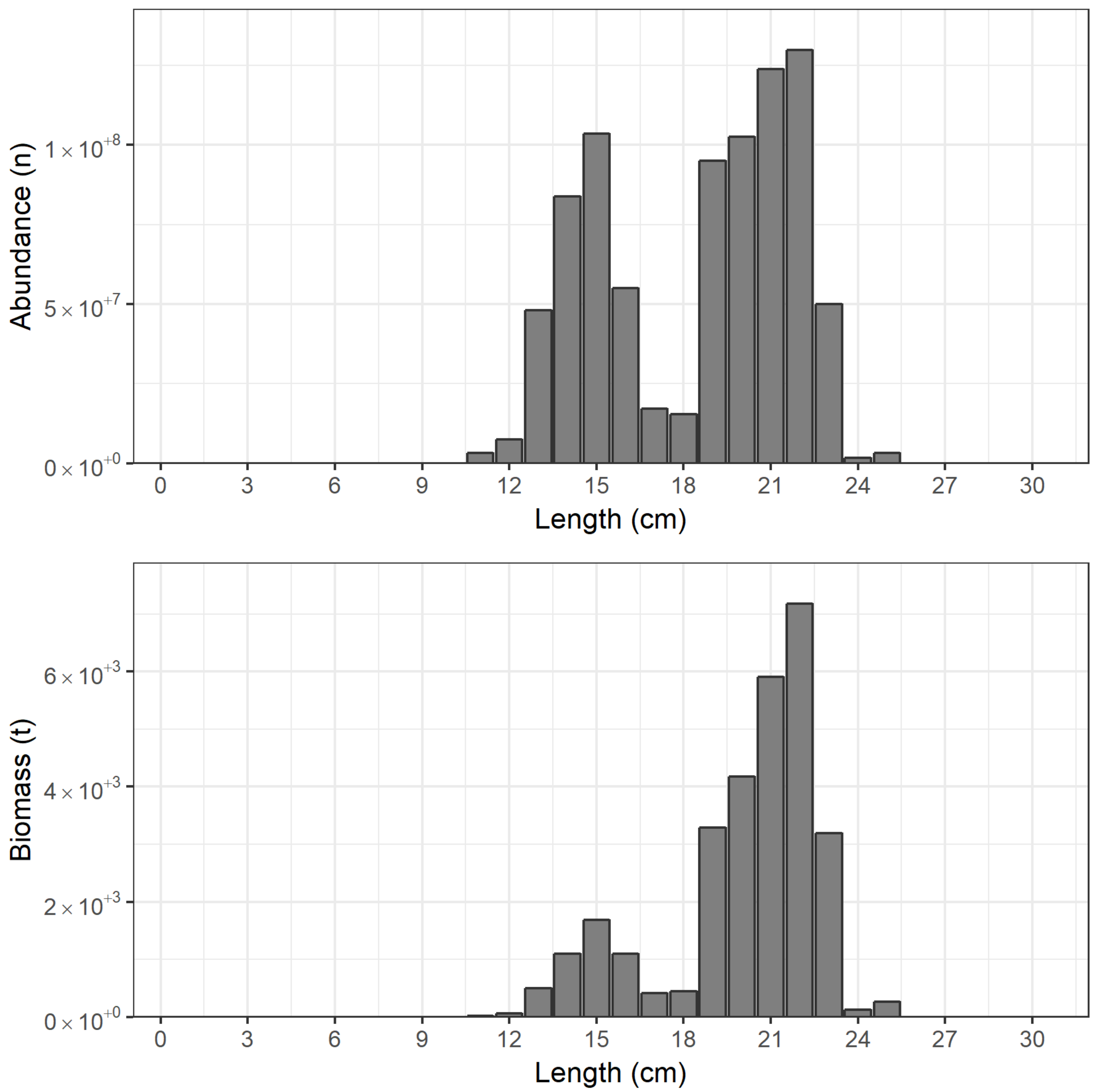

Figure 29: Estimated abundance (upper panel) and biomass (lower panel) versus fork length (L_F, cm) for Pacific Herring (*Clupea pallasii*) in the survey area.

4 Discussion

The principal objectives of the 50-day, Summer 2017 CCE Survey were to survey the northern stock of Pacific Sardine and the northern stock of Northern Anchovy. Then, as possible, estimates were also sought for the central stock of Northern Anchovy, Pacific Herring, Jack Mackerel, and Pacific Mackerel. The survey extended from the northern end of Vancouver Island to Morro Bay. Between the Strait of Juan de Fuca and Cape Mendocino, the 10-nmi transect spacing was sufficient to estimate the abundances of all five small pelagic fish species in the region. Farther south, the 20-nmi spacing covered more of the Jack Mackerel and Northern Anchovy populations that were predominantly in that region.

4.1 Biomass and abundance of CPS

4.1.1 Northern Anchovy

4.1.1.1 Northern stock

The lack of Northern Anchovy off Northern CA and Southern OR is likely the result of separate stocks: the northern stock, extending as far north as Haida Gwaii, BC (~54 °N; Litz *et al.*, 2008), and the central stock, found off Central and Southern CA (Smith and Hewitt, 1985). Thus, this survey provides the first biomass estimate for the northern stock, 22,709 t ($CI_{95\%}$ = 1,452 - 57,334 t). The stock dynamics may be characterized by an analysis of estimates from this survey with those from past (e.g., Stierhoff *et al.*, 2018b) and future annual surveys.

4.1.1.2 Central stock

In summer 2017, the estimated biomass of the central stock was generally similar to that observed in summer 2016, and around five times larger than estimates from summer 2015 (Zwolinski *et al.*, 2017). The length distribution of the central stock in summer 2017 had two modes, indicating the presence of at least two dominant year-classes. Although the summer 2017 survey was not designed to completely sample the central stock of Northern Anchovy, the estimated stock biomass was approximately equal to that estimated from the spring 2017 survey, from San Francisco to the U.S.-Mexico border (the authors, unpublished data). This suggests that both the spring and summer 2017 surveys sampled the majority of the central stock. Alternatively, approximately the same portion of the stock was unsampled north of San Francisco during spring and south of Point Conception during summer.

4.1.2 Pacific Sardine

4.1.2.1 Northern stock

The summer 2017 survey sampled most of the potential habitat for the northern stock of Pacific Sardine, and most likely the large majority of the stock. A gap in the length distribution of Pacific Sardine between 15 and 18 cm indicates poor recruitment in 2016. Accordingly, the stock abundance and biomass declined between 2016 and 2017, and the modal length increased from 17-19 to 21-23 cm. Few trawls with Pacific Sardine smaller than 10 cm indicates that recruitment was weak again in 2017.

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, the stock has not migrated there since 2013 (Zwolinski *et al.*, 2014). During the spring 2017 survey, few Pacific Sardine were in the expected spawning area off central and southern CA (Stierhoff *et al.*, 2017). The unusually high water temperature in the CCE may have induced the diminished stock to overwinter and spawn mostly off OR.

4.1.3 Pacific Mackerel

The biomass of Pacific Mackerel increased from 8,000 t ($CI_{95\%}$ = 1,000-20,000 t) in summer 2013 (Zwolinski *et al.*, 2014) to 41,139 t ($CI_{95\%}$ = 18,019 - 58,425 t) in 2017, and is now broadly distributed off the west coast of the U.S. Their length distribution had modes at approximately 17, 27, and 32 cm. The first two modes are indicative of distinct annual cohorts. The largest mode, approaching the maximum length for Pacific Mackerel, probably includes fish from multiple year classes.

4.1.4 Jack Mackerel

The biomass of Jack Mackerel increased from 9,000 t ($CI_{95\%}$ = 2,000-20,000 t) in summer 2013 (Zwolinski *et al.*, 2014) to 128,313 t ($CI_{95\%}$ = 70,594 - 180,676 t) in 2017. It was the second most abundant species overall and most abundant north of San Francisco.

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 (Stick *et al.*, 2014). The Yaquina Bay and Winchester Bay stocks inhabit waters between Newport and Cape Blanco (ODFW, 2013).

In summer 2017, the estimate of Pacific Herring biomass off the western coast of Vancouver Island was 22,097 t ($CI_{95\%}$ = 9,005 - 38,331 t), which was generally similar to the stock assessment in Canada (DFO, 2017). There are no published estimates to compare with the 2017 estimates of Pacific Herring biomass off WA and OR.

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 (*Sebastes* spp., Stanley *et al.*, 1999, 2000), Lingcod (*Ophiodon elongatus*), Alaska Pollock (*Gadus chalcogrammus*), and others (Rutherford, 1996). To mitigate this potential source of uncertainty in the 2017 estimates of Pacific Herring biomass, the maximum integration depth was set to 75 m, which appeared to reflect a transition between the pelagic herring and other fish communities that occurred deeper.

4.2 Conclusion

The acoustic-trawl methods (ATM) presented here have been used to monitor and directly assess some of the most valuable 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 the biomass and distributions of 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, 1977, 1974). Since 2006, ATM surveys of CPS have been evolving into comprehensive ecosystem surveys (Cutter and Demer, 2008). This assessment is in conformity with the multi-species nature of the survey design, and recognizes the advances made to the survey methodology to allow for the direct assessment of all or most species in the CPS community. When performed periodically, the results from these surveys allow assessing the CPS assemblage with unprecedented detail, providing timely and reliable information regarding the status of the exploited stocks, and their associated predators, prey, and environment.

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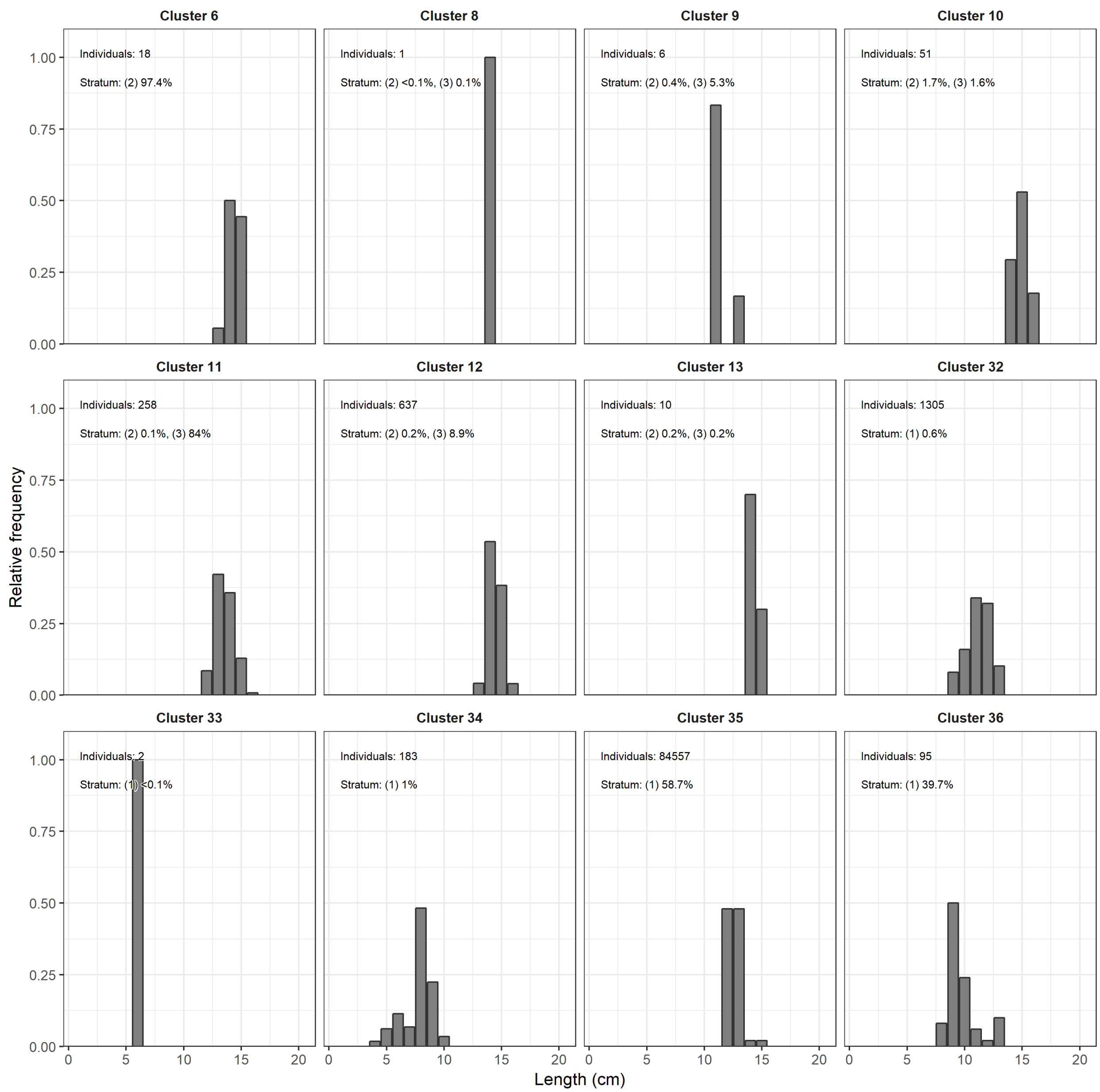
Appendix

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

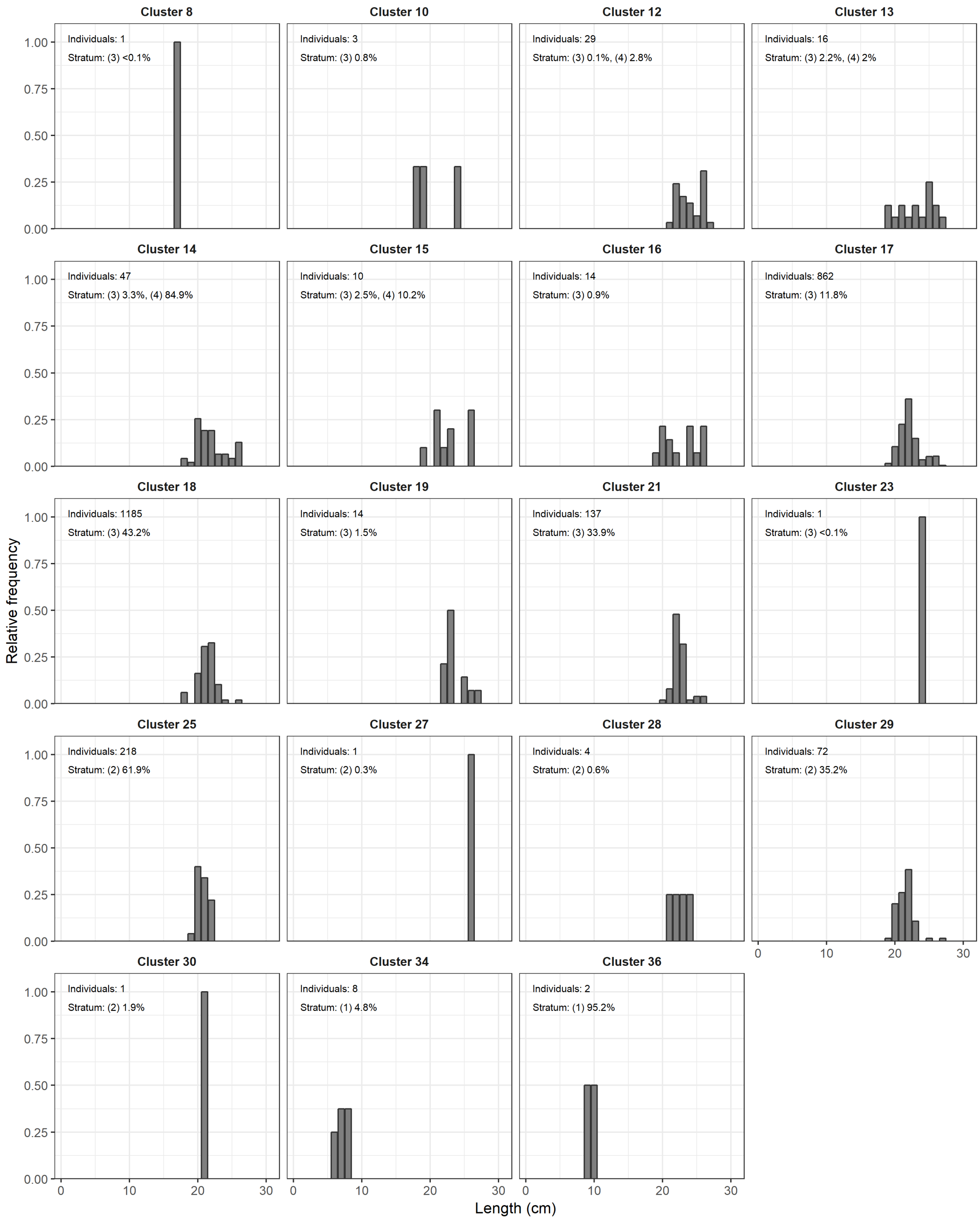
A.1 Northern Anchovy

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.



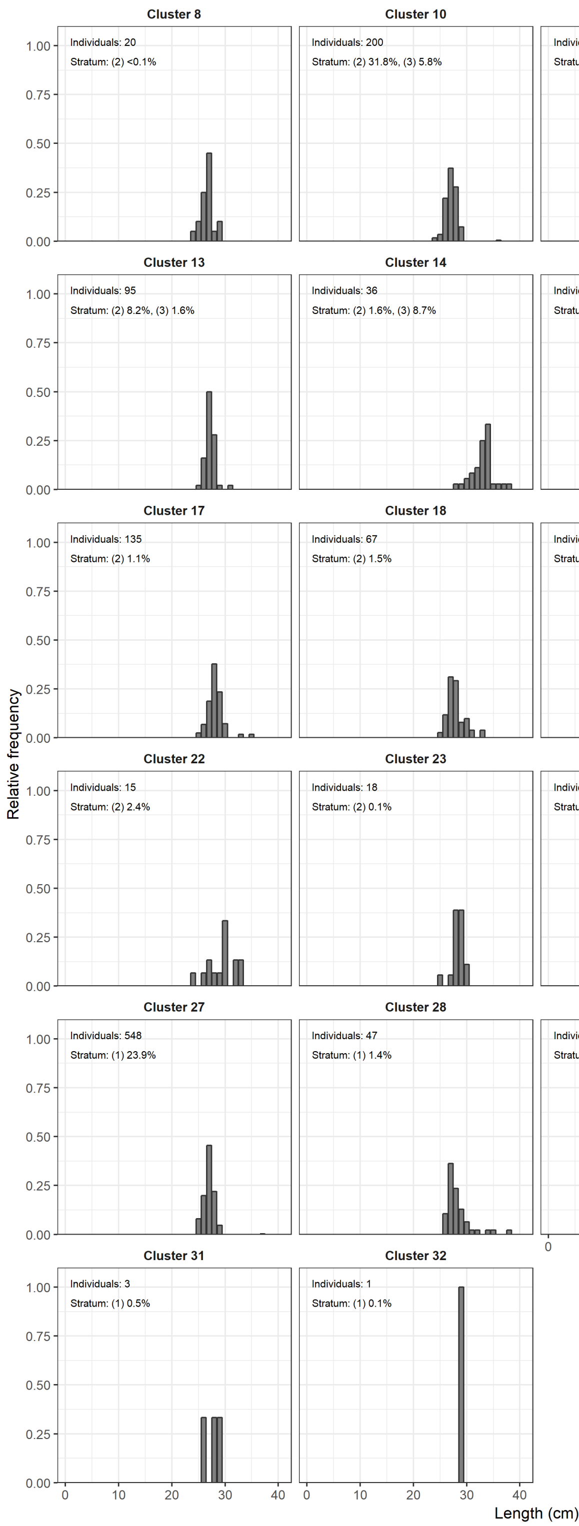
A.2 Pacific Sardine

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.



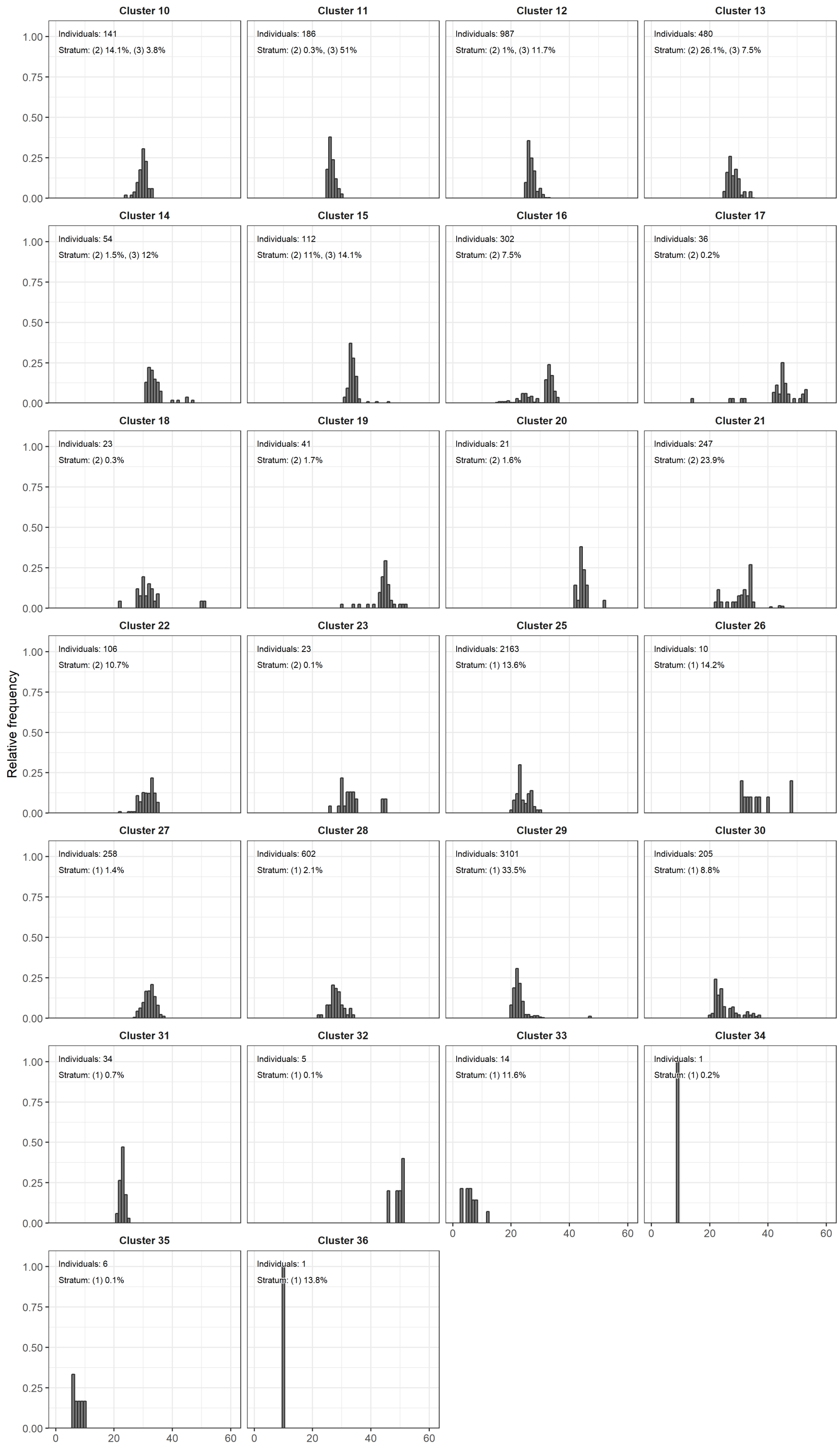
A.3 Pacific Mackerel

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.



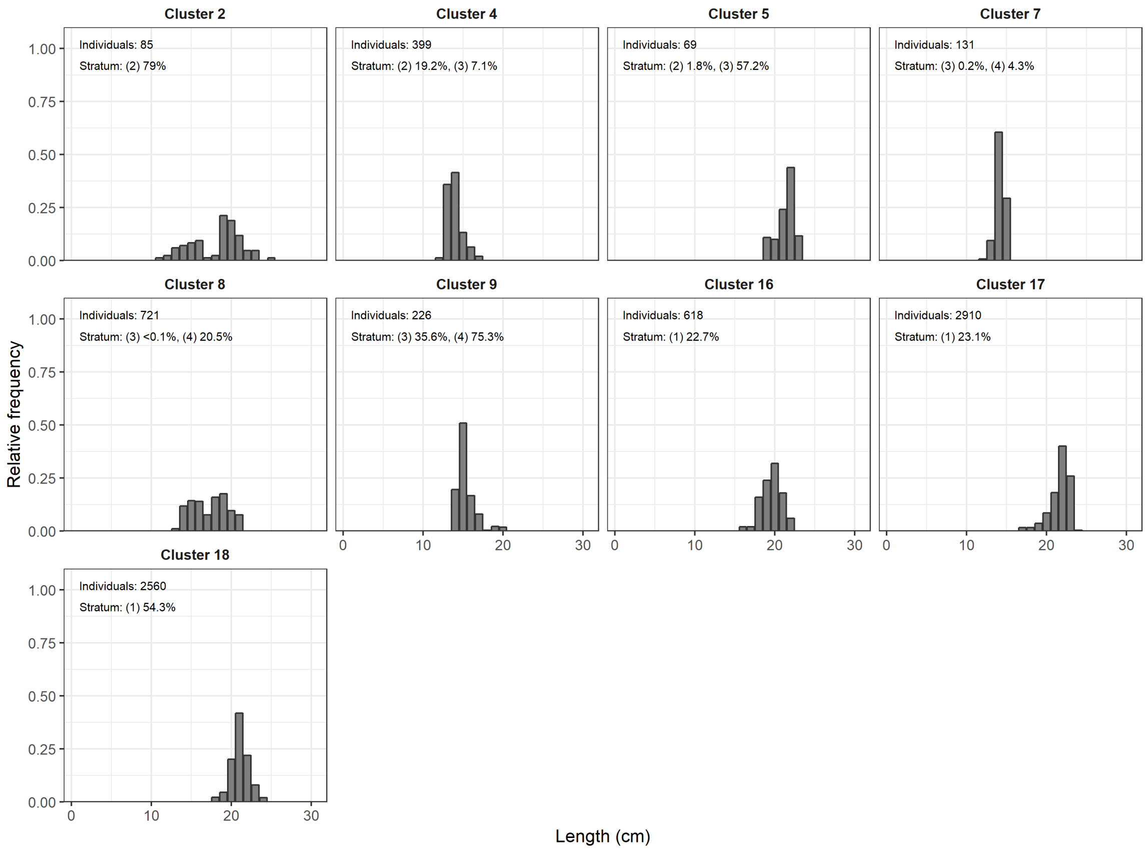
A.4 Jack Mackerel

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 Nearshore biomass estimation

B.1 Introduction

The ATM-estimates of CPS biomass are for the surveyed area and period. Any biomass outside of this sampling domain is unknown. To explore the potential magnitude of CPS biomass where the survey vessels did not sample, the survey data were extrapolated into the nearshore areas as described below.

B.2 Methods

Due to the shallow seabed and other nearshore hazards to navigation, acoustic sampling may not have encompassed the eastern extents of the stocks. To extrapolate biomasses into the unsampled area, distances were calculated for the projections of each transect to the 5-m isobath (**Fig. 30**). The biomass densities along these unsampled transect extensions were assigned the values measured along the sampled transects equal distances from the eastern ends of the transects. As done for the strata sampled offshore, the extrapolated biomasses in the unsampled nearshore strata were calculated using Equations (16) and (17).

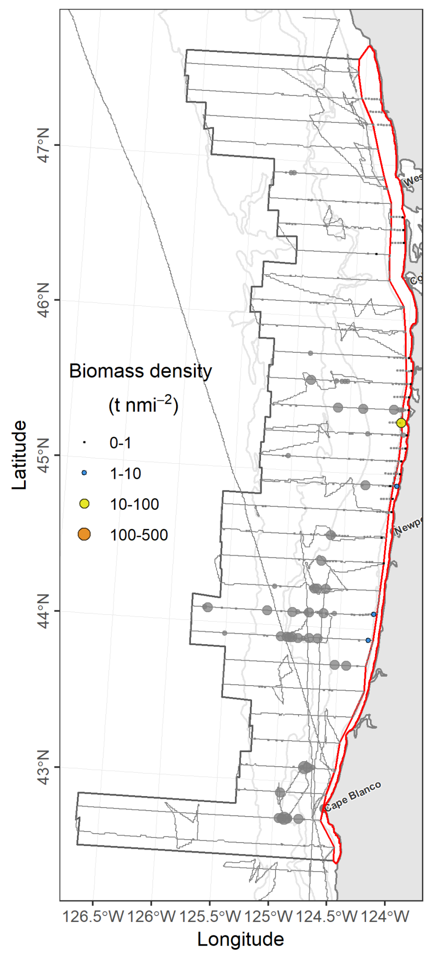


Figure 30: Example biomass densities of the northern stock of Pacific Sardine (*Sardinops sagax*), per strata, throughout the survey region (gray points) and the subset of biomass densities used to extrapolate biomass into the unsampled nearshore waters (colored points), and the corresponding offshore (dashed polygon) and nearshore (solid polygon) strata.

B.3 Results

B.3.1 Northern Anchovy

B.3.1.1 Northern stock

Extrapolation of the northern stock of Northern Anchovy biomass into the unsampled, nearshore waters amounts to 117 t ($CI_{95\%}$ = 7 - 179 t, CV = 41%; **Table 15**).

Table 15: Extrapolated biomasses (metric tons, t) and their precision (upper and lower 95% confidence intervals, $CI_{95\%}$; standard deviation, SD; and coefficient of variation, CV) for the northern stock of Northern Anchovy (*Engraulis mordax*) in the unsampled, nearshore waters. Mean biomasses are the point estimates. Stratum areas are nmi^2.

Species		Stratum				Trawl		Biomass			
Name	Stock	Number	Area	Transects	Distance	Clusters	Individuals	Mean	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Engraulis mordax	Northern	2	733	15	67	5	954	9	0	27	83
		3	89	26	18	6	964	108	4	163	43
		All	822	41	85	6	1,917	117	7	179	41

B.3.1.2 Central stock

Extrapolation of the central stock of Northern Anchovy biomass into the unsampled, nearshore waters amounts to 45,446 t ($CI_{95\%}$ = 454 - 48,240 t, CV = 30%; **Table 16**).

Table 16: Extrapolated biomasses (metric tons, t) and their precision (upper and lower 95% confidence intervals, $CI_{95\%}$; standard deviation, SD; and coefficient of variation, CV) for the central stock of Northern Anchovy (*Engraulis mordax*) in the unsampled, nearshore waters. Mean biomasses are the point estimates. Stratum areas are nmi^2.

Species		Stratum				Trawl		Biomass			
Name	Stock	Number	Area	Transects	Distance	Clusters	Individuals	Mean	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Engraulis mordax	Central	1	815	12	42	5	86,143	45,446	454	48,240	30
		All	815	12	42	5	86,143	45,446	454	48,240	30

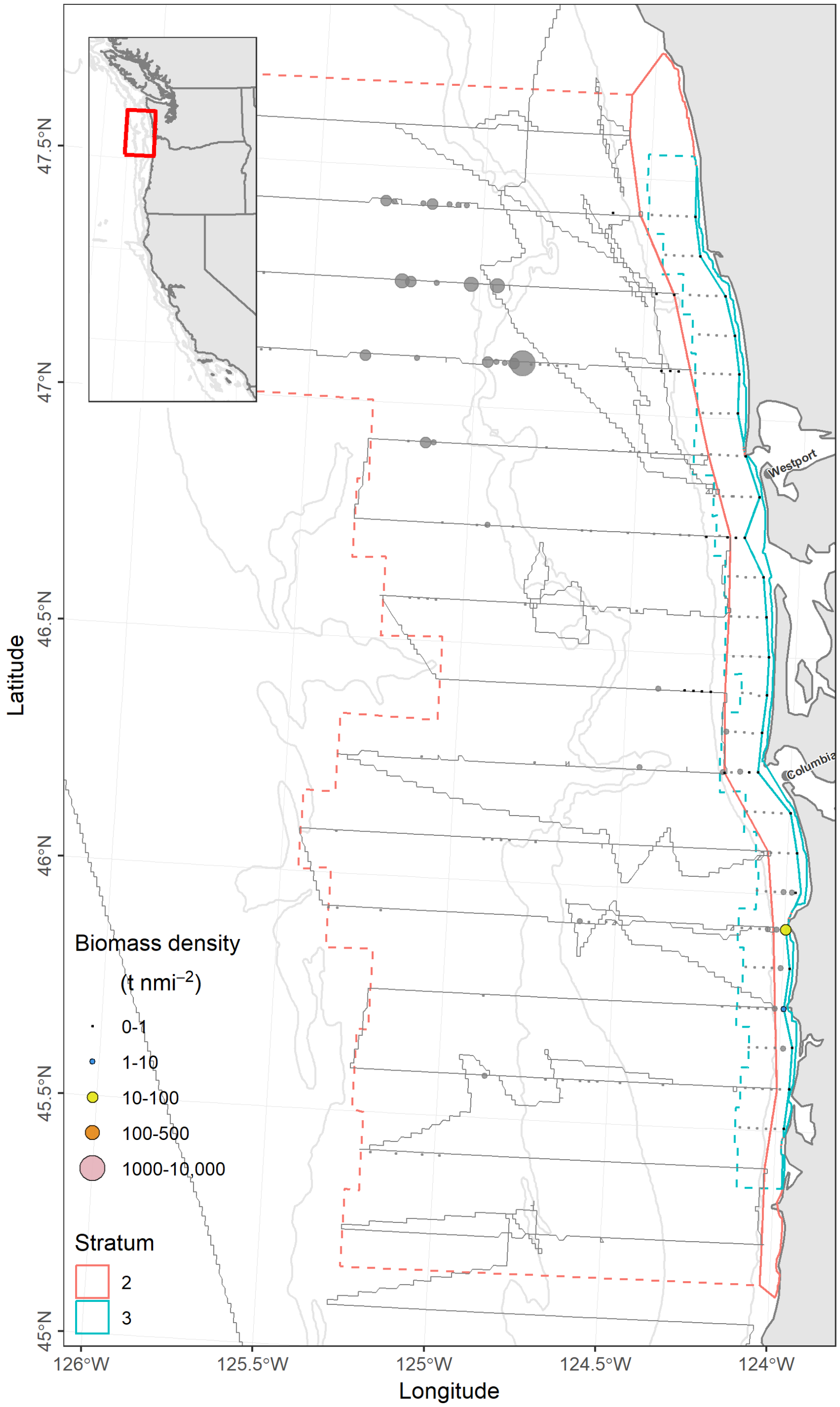


Figure 31: Biomass densities of the northern stock of Northern Anchovy (*Engraulis mordax*), per strata, throughout the survey region (gray points) and the subset of biomass densities used to extrapolate biomass into the unsampled nearshore waters (colored points), and the corresponding offshore (dashed polygon) and nearshore (solid polygon) strata.

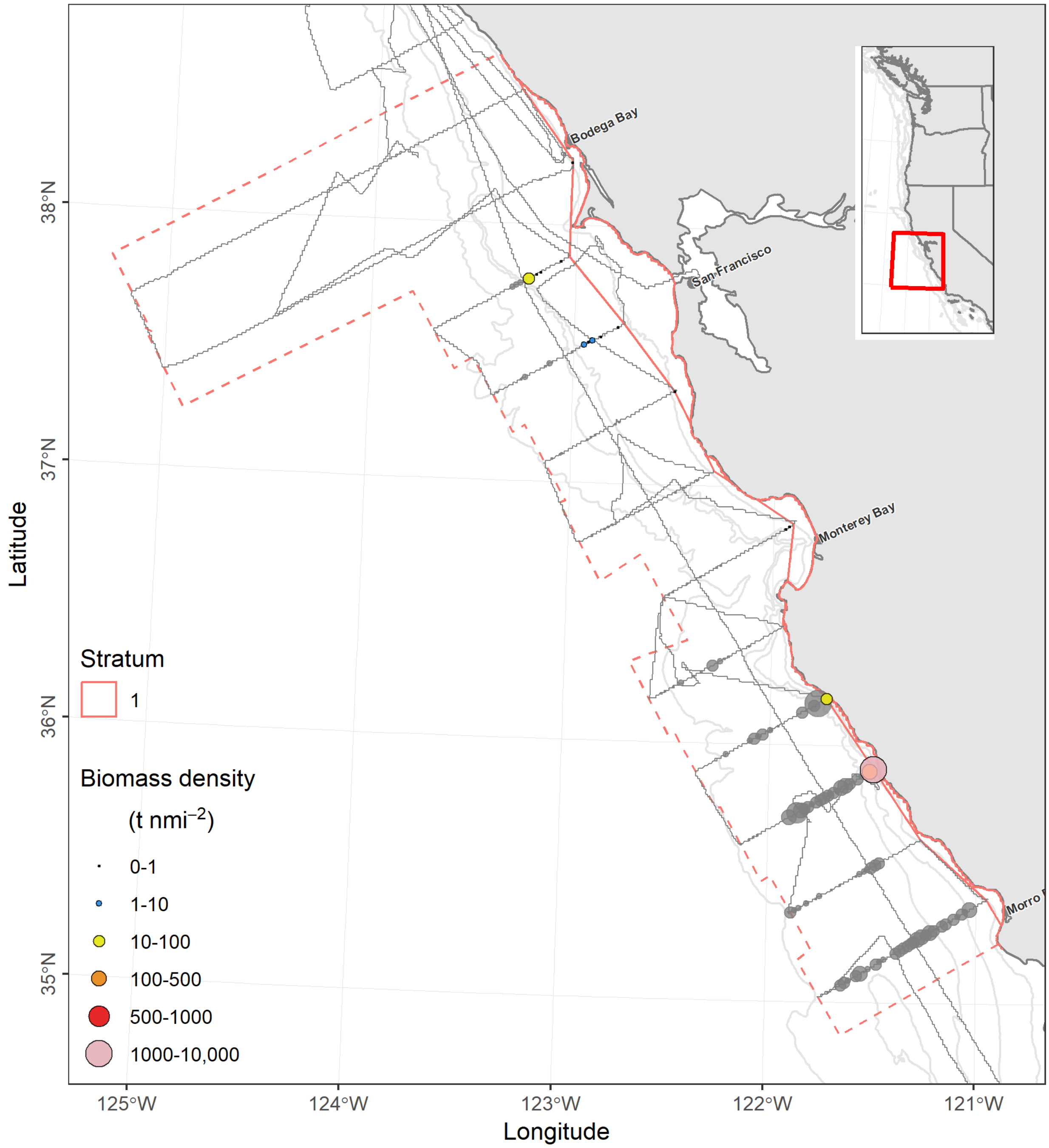


Figure 32: Biomass densities of the central stock of Northern Anchovy (*Engraulis mordax*), per strata, throughout the survey region (gray points) and the subset of biomass densities used to extrapolate biomass into the unsampled nearshore waters (colored points), and the corresponding offshore (dashed polygon) and nearshore (solid polygon) strata.

B.3.2 Pacific Sardine

B.3.2.1 Northern stock

Extrapolation of the northern stock of Pacific Sardine biomass into the unsampled, nearshore waters amounts to 146 t ($CI_{95\%}$ = 29 - 354 t, CV = 57%; **Table 17**).

Table 17: Extrapolated biomasses (metric tons, t) and their precision (upper and lower 95% confidence intervals, $CI_{95\%}$; standard deviation, SD; and coefficient of variation, CV) for the northern stock of Pacific Sardine (*Sardinops sagax*) in the unsampled, nearshore waters. Mean biomasses are the point estimates. Stratum areas are nmi^2.

Species		Stratum				Trawl		Biomass			
Name	Stock	Number	Area	Transects	Distance	Clusters	Individuals	Mean	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
		1	227	7	12	2	10	0	0	0	-
		2	580	12	39	4	295	0	0	0	-
Sardinops sagax	Northern	3	1,066	31	101	10	2,290	44	0	67	43
		4	46	14	9	4	102	103	15	326	79
		All	1,918	64	161	17	2,697	146	29	354	57

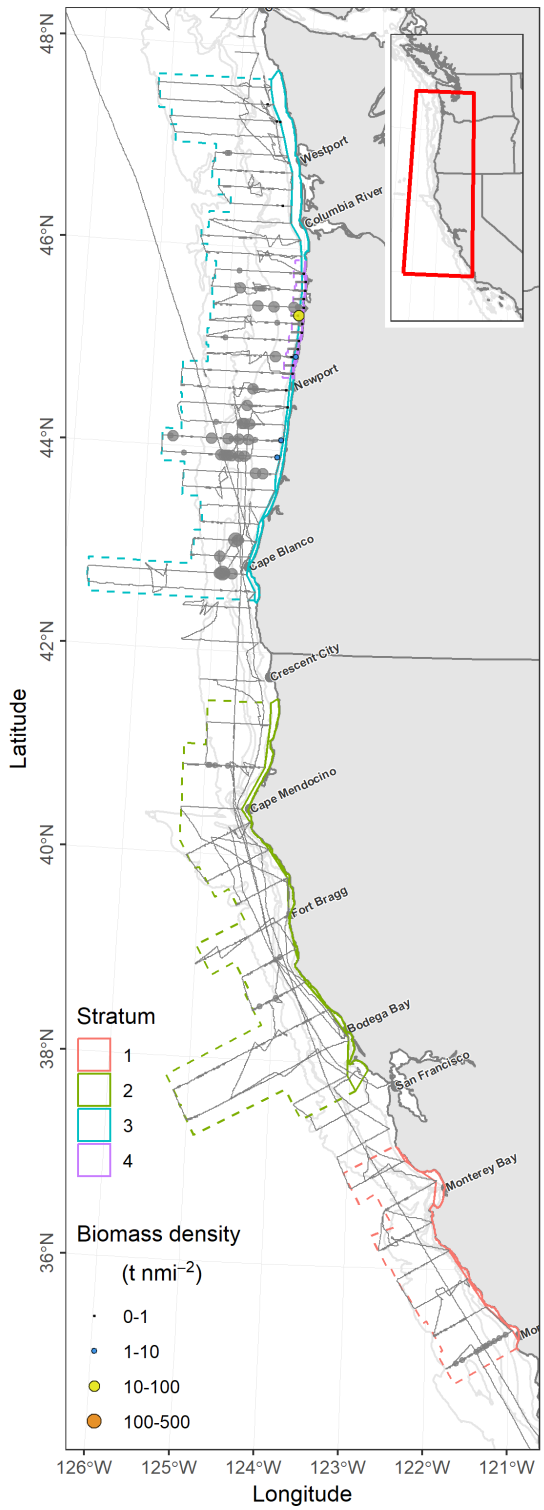


Figure 33: Biomass densities of the northern stock of Pacific Sardine (*Sardinops sagax*), per strata, throughout the survey region (gray points) and the subset of biomass densities used to extrapolate biomass into the unsampled nearshore waters (colored points), and the corresponding offshore (dashed polygon) and nearshore (solid polygon) strata.

B.3.3 Pacific Mackerel

Extrapolation of the Pacific Mackerel biomass into the unsampled, nearshore waters amounts to 1,105 t ($CI_{95\%}$ = 258 - 1,561 t, CV = 32%; **Table 18**).

Table 18: Extrapolated biomasses (metric tons, t) and their precision (upper and lower 95% confidence intervals, $CI_{95\%}$; standard deviation, SD; and coefficient of variation, CV) for Pacific Mackerel (*Scomber japonicus*) in the unsampled, nearshore waters. Mean biomasses are the point estimates. Stratum areas are nmi^2.

Species		Stratum				Trawl		Biomass			
Name	Stock	Number	Area	Transects	Distance	Clusters	Individuals	Mean	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Scomber japonicus	All	1	945	14	54	6	1,601	7	7	13	24
		2	1,066	31	101	11	2,708	119	2	404	93
		3	96	25	19	6	2,173	979	143	1,368	33
		All	2,107	70	175	18	6,482	1,105	258	1,561	32

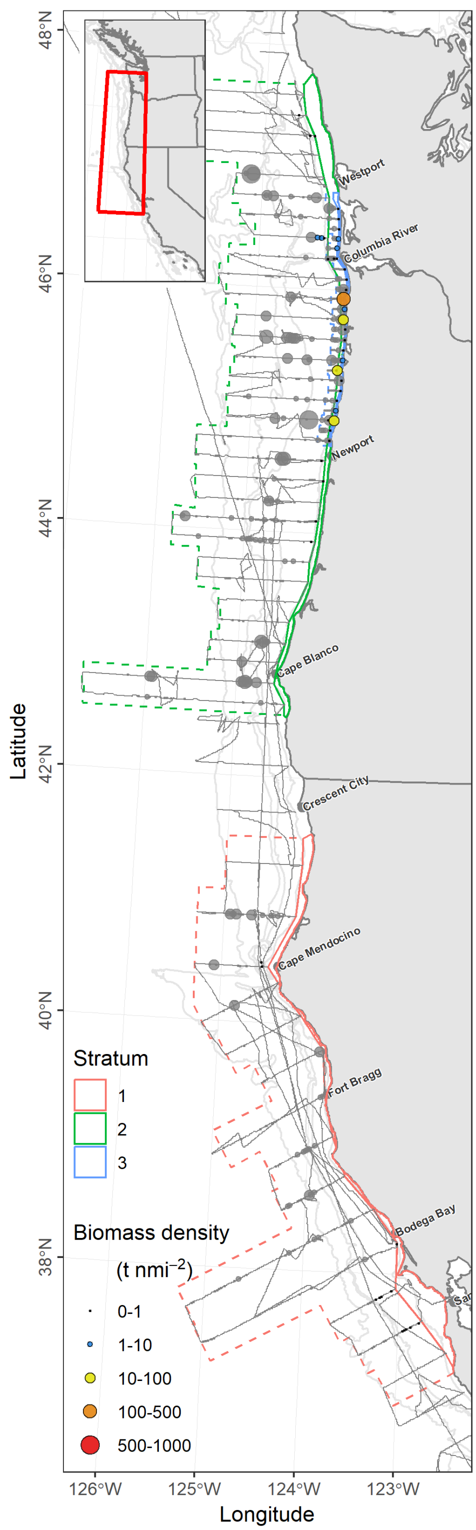


Figure 34: Biomass densities of Pacific Mackerel (*Scomber japonicus*), per strata, throughout the survey region (gray points) and the subset of biomass densities used to extrapolate biomass into the unsampled nearshore waters (colored points), and the corresponding offshore (dashed polygon) and nearshore (solid polygon) strata.

B.3.4 Jack Mackerel

Extrapolation of the Jack Mackerel biomass into the unsampled, nearshore waters amounts to 1,543 t ($CI_{95\%}$ = 622 - 2,324 t, CV = 29%, **Table 19**).

Table 19: Extrapolated biomasses (metric tons, t) and their precision (upper and lower 95% confidence intervals, $CI_{95\%}$; standard deviation, SD; and coefficient of variation, CV) for Jack Mackerel (*Trachurus symmetricus*) in the unsampled, nearshore waters. Mean biomasses are the point estimates. Stratum areas are nmi^2.

Species		Stratum				Trawl		Biomass			
Name	Stock	Number	Area	Transects	Distance	Clusters	Individuals	Mean	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Trachurus symmetricus	All	1	1,173	21	65	10	6,160	200	197	382	24
		2	836	28	81	11	2,131	113	3	426	100
		3	96	25	19	6	1,960	1,230	215	1,847	35
		All	2,104	74	165	22	10,252	1,543	622	2,324	29

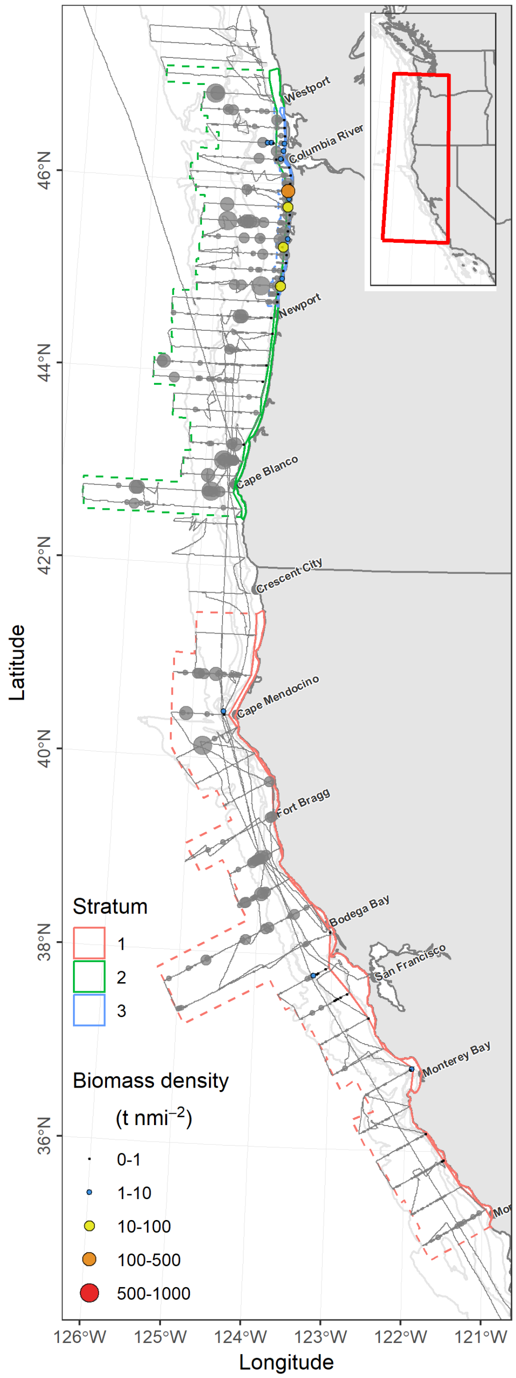


Figure 35: Biomass densities of Jack Mackerel (*Trachurus symmetricus*), per strata, throughout the survey region (gray points) and the subset of biomass densities used to extrapolate biomass into the unsampled nearshore waters (colored points), and the corresponding offshore (dashed polygon) and nearshore (solid polygon) strata.

B.3.5 Pacific Herring

Extrapolation of the Pacific Herring biomass into the unsampled, nearshore waters amounts to 7,410 t ($CI_{95\%}$ = 302 - 16,228 t, CV = 68%; **Table 20**).

Table 20: Extrapolated biomasses (metric tons, t) and their precision (upper and lower 95% confidence intervals, $CI_{95\%}$; standard deviation, SD; and coefficient of variation, CV) for Pacific Herring (*Clupea pallasii*) in the unsampled, nearshore waters. Mean biomasses are the point estimates. Stratum areas are nmi^2.

Species		Stratum				Trawl		Biomass			
Name	Stock	Number	Area	Transects	Distance	Clusters	Individuals	Mean	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
		1	176	9	18	3	6,089	69	0	161	63
		2	453	9	18	2	484	7,045	56	15,788	71
Clupea pallasii	All	3	746	11	58	5	1,546	133	14	259	48
		4	43	11	8	3	1,078	164	67	299	37
		All	1,418	40	102	9	9,197	7,410	302	16,228	68

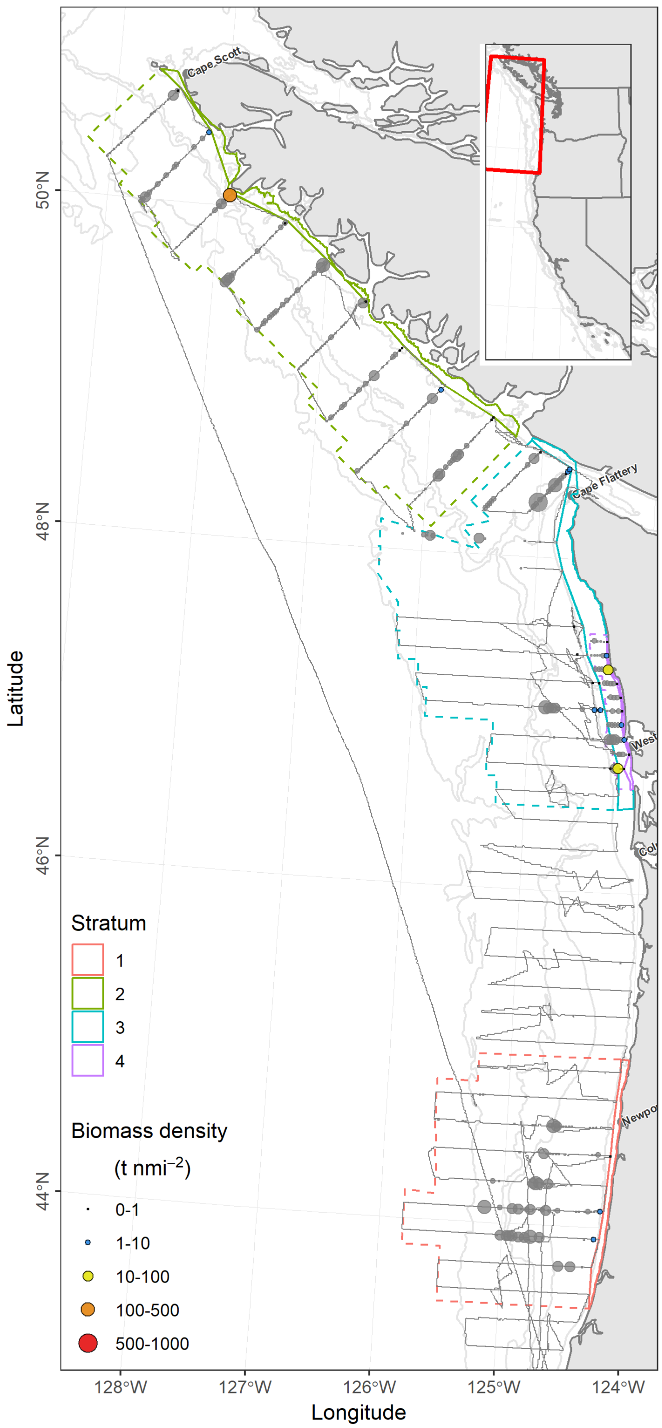


Figure 36: Biomass densities of Pacific Herring (*Clupea pallasii*), per strata, throughout the survey region (gray points) and the subset of biomass densities used to extrapolate biomass into the unsampled nearshore waters (colored points), and the corresponding offshore (dashed polygon) and nearshore (solid polygon) strata.

B.4 Discussion

To estimate the magnitude of the northern stock of Northern Anchovy biomass in nearshore areas where the ship could not safely operate (PFMC, 2018), the acoustic samples from *Lasker* were extrapolated to the 5-m isobath, and F/V *Lisa Marie* acoustically sampled transects to ~7-m depth. Estimates from both the extrapolated and the core areas of the survey totaled less than 1% of the estimated stock biomass. Most of the fishery landings of Northern Anchovy reflect nearshore catches, which were limited and caught opportunistically (ODFW, 2017).

The proportion of the central stock of Northern Anchovy in the unsampled nearshore areas was estimated by extrapolating the acoustic samples from *Lasker* to the 5-m isobath. Due to high Northern Anchovy densities on the eastern ends of multiple transects, the extrapolated proportion was ~33% of the total survey-estimated stock biomass. This extrapolation should not be considered an adjustment to the survey estimate, but rather evidence that the nearshore region needs to be sampled during future surveys.

To estimate the nearshore biomass of the Pacific Sardine stock off Oregon and Washington, the acoustic samples from *Lasker* were extrapolated to the 5-m isobath, and F/V *Lisa Marie* acoustically sampled transects to ~7-m depth. Estimates from both the extrapolation and the measurement total less than 1% of the estimated stock biomass. Off California, the extrapolation of acoustic samples from *Lasker* indicated there were no Pacific Sardine nearshore.

B.5 Conclusion

Acoustic samples were extrapolated from the easternmost extent of sampled transects to the 5-m isobath to estimate the biomass of CPS in unsampled, nearshore areas. In most cases, biomass estimated by extrapolation was low and comparable to estimates of biomass sampled directly using F/V *Lisa Marie*. For the central stock of Northern Anchovy, high biomass density along the nearshore portion of several transects indicates that the nearshore region should be sampled more thoroughly in future surveys.