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DISTRIBUTION, BIOMASS, AND DEMOGRAPHY OF COASTAL PELAGIC FISHES IN THE CALIFORNIA CURRENT ECOSYSTEM DURING SUMMER 2016 BASED ON ACOUSTIC-TRAWL SAMPLING

Kevin L. Stierhoff, Juan P. Zwolinski, and David A. Demer

NOAA Fisheries
SWFSC Fisheries Resources Division
8901 La Jolla Shores Drive
La Jolla, CA 92037

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Executive Summary

This report provides: 1) a detailed description of the acoustic-trawl method (ATM) used by NOAA's Southwest Fisheries Science Center (SWFSC) to estimate the population sizes of the dominant species of coastal pelagic species (CPS), i.e., Pacific Sardine *Sardinops sagax*, Northern Anchovy *Engraulis mordax*, Pacific Mackerel *Scomber japonicus*, Jack Mackerel *Trachurus symmetricus*, and Pacific Herring *Clupea pallasii*, in the California Current Ecosystem (CCE) off the west coast of North America; and 2) estimates of the biomasses, distributions, and demographies of those CPS in the survey area between 28 June and 22 September 2016. The survey area spanned most of the continental shelf between the northern tip of Vancouver Island, British Columbia (BC) and San Diego, CA. Throughout the survey area, NOAA Ship *Reuben Lasker* (hereafter, *Lasker*) sampled along transects oriented approximately perpendicular to the coast, from the shallowest navigable depth (~30-m depth) to either a distance of 35 nmi or to the 1,000 fm (~1830 m) isobath, whichever is farthest.

This analysis was conducted during 2020 using methods developed in 2017 to standardize the calculations and reporting of ATM-survey results. Any minor differences between these and previously reported results are explained by differences in target strength models used (i.e., for Northern Anchovy and Pacific Herring), automated and more consistent post-strata definitions, and improved echo classification methods.

For the summer 2016 survey area and period, the estimated biomass of the northern stock (sub-population) of Northern Anchovy was 6,575 t ($CI_{95\%}$ = 2,480 - 11,596 t, CV = 36%). The northern stock was distributed from approximately Cape Flattery, WA, to Tillamook, OR, and standard length (L_S) ranged from 11 to 16 cm with a mode at ~15 cm.

The estimated biomass of the central stock of Northern Anchovy was 150,907 t ($CI_{95\%}$ = 32,843 - 317,457 t, CV = 51%), which was not significantly different from the estimate of 151,558 t (CV = 41%) presented in Zwolinski et al. (2017). The central stock was distributed from approximately Bodega Bay, CA, to San Diego, CA, but its biomass was greatest off Big Sur, CA, and scattered throughout the Southern California Bight (SCB). L_S ranged from 4 to 15 cm with a mode at 11 cm.

The estimated biomass of the northern stock of Pacific Sardine was 80,902 t ($CI_{95\%}$ = 10,807 - 142,953 t, CV = 43%), which was not significantly different from the estimate of 78,776 t (CV=54%) presented in Hill et al. (2017). The northern stock ranged from central Vancouver Island to Morro Bay, but was greatest off Vancouver Island and Big Sur, CA. L_S ranged from 6 to 27 cm with modes at 19 and 25 cm.

The estimated biomass of the southern stock of Pacific Sardine in the survey area was 323 t ($CI_{95\%}$ = 11.3 - 663 t, CV = 51%). The southern stock was distributed in a small area off Los Angeles, CA. L_S ranged from 13 to 20 cm with modes at 15 and 19 cm.

The estimated biomass of Pacific Mackerel was 32,956 t ($CI_{95\%}$ = 8,987 - 62,808 t, CV = 43%). Pacific Mackerel was distributed throughout the survey area, from central Vancouver Island to San Diego, CA, but was greatest between Big Sur and San Diego. Fork length. (L_F) ranged from 8 to 36 cm with modes at 16 and 20 cm.

The estimated biomass of Jack Mackerel was 134,989 t ($CI_{95\%}$ = 70,359 - 199,265 t, CV = 25%). Jack Mackerel was distributed throughout the survey area, but biomass was greatest between Cape Flattery and Crescent City, CA. L_F ranged from 5 to 56 cm with modes at 12, 28, and 50 cm.

The estimated biomass of Pacific Herring was 68,466 t ($CI_{95\%}$ = 46,829 - 99,009 t, CV = 20%). Pacific Herring was distributed from approximately Cape Scott, BC, to Coos Bay, OR, but biomass was greatest between central Vancouver Island and Westport, WA. L_F ranged from 6 to 24 cm with modes at 16 and 22 cm.

To investigate the CPS biomass in areas where *Lasker* could not safely navigate, acoustically sampled biomass densities along the easternmost portions of transects 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, which can change by an order of magnitude within a few years, represent important prey for marine mammals, birds, and larger migratory fishes (Field *et al.*, 2001), and are targets of commercial fisheries.

During summer and fall, the northern stock of Pacific Sardine typically migrates 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 northern stock of Pacific Sardine typically migrates to its spawning grounds, generally off central and southern California (Demer *et al.*, 2012) and occasionally off Oregon and Washington (Lo *et al.*, 2011). These migrations vary in extent with population sizes, fish ages and lengths, and oceanographic conditions. For example, the transition zone chlorophyll front (TZCF, Polovina *et al.*, 2001) may delineate the offshore and southern limit of both Pacific Sardine and Pacific Mackerel habitat (e.g., Demer *et al.*, 2012; Zwolinski *et al.*, 2012), and juveniles may have nursery areas in the SCB, downstream of upwelling regions. In contrast, Northern Anchovy spawn predominantly during winter and closer to the coast where seasonal down-welling increases retention of their eggs and larvae (Bakun and Parrish, 1982). Pacific Herring spawn in intertidal beach areas (Love, 1996). The northern stock of Northern Anchovy is located off 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, 1974, 1977; Smith, 1978). Following a two-decade hiatus, the ATM was reintroduced in the CCE in spring 2006 to sample the then abundant Pacific Sardine population (Cutter and Demer, 2008). Since 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 into the annual Pacific Sardine stock assessments (Hill *et al.*, 2017; Kuriyama *et al.*, 2020). Additionally, ATM survey results are applied to estimate the abundances, demographies, and distributions of epipelagic and semi-demersal fishes (e.g., Swartzman, 1997; Williams *et al.*, 2013; Zwolinski *et al.*, 2014) and plankton (Hewitt and Demer, 2000).

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

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

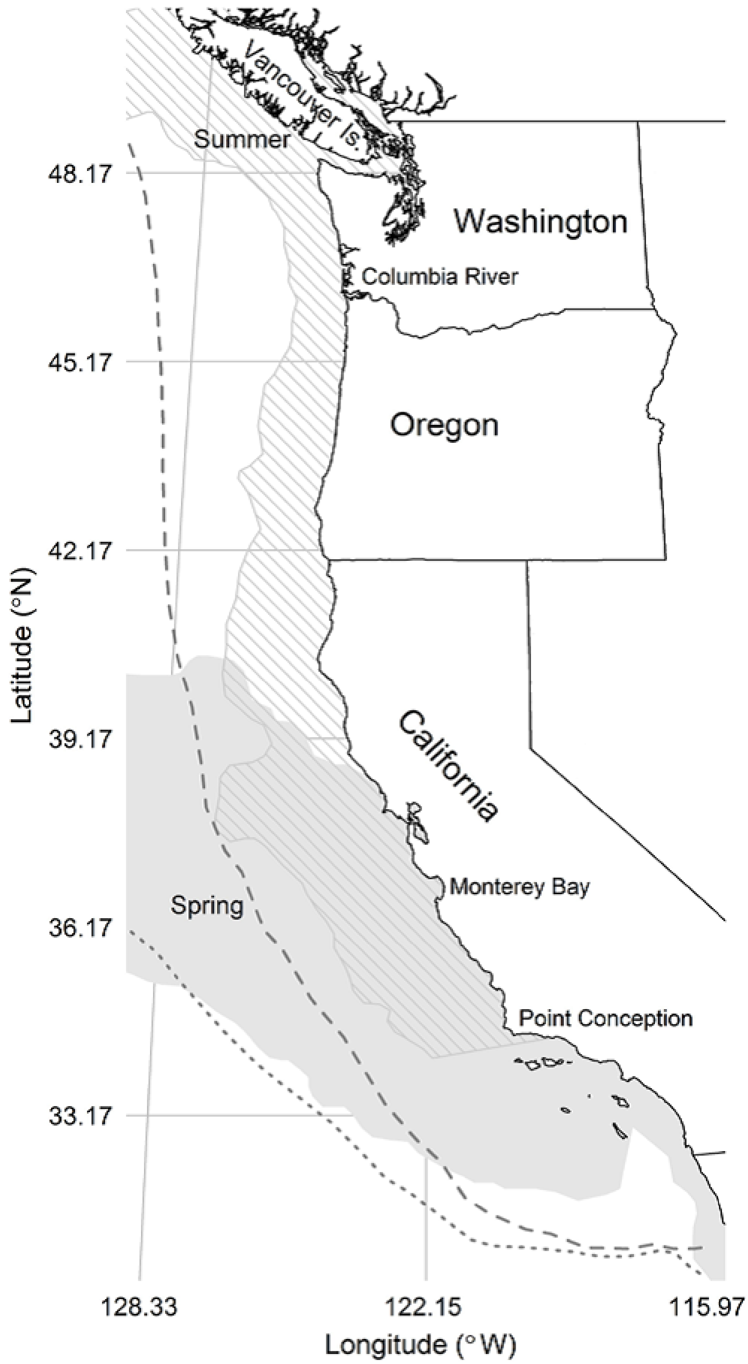


Figure 1: Conceptual spring (shaded region) and summer (hatched region) distributions of northern stock Pacific Sardine habitat along the west coasts of Mexico, the United States, and Canada. The dashed and dotted lines represent, respectively, the approximate summer and spring position of the 0.2 mg 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 habitat (Zwolinski *et al.*, 2014).

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

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

The primary objectives of the SWFSC's ATM surveys are to survey the distributions and abundances of CPS, krill, and their abiotic environments in the CCE. Typically, spring surveys are conducted during 25-40 days-at-sea (DAS) between March and May, and summer surveys are conducted during 50-80 DAS between June and October. In spring, the ATM surveys focus primarily on the northern stock of Pacific Sardine and the central stock of Northern Anchovy. Spring surveys do not always occur annually. In summer, the ATM surveys also focus on the northern stock of Northern Anchovy. During spring and summer, the biomasses of other CPS (e.g., Pacific Mackerel, Jack Mackerel, and Pacific Herring) present in the survey area are estimated. The SWFSC strives to conduct summer surveys annually.

In summer 2016, an ATM survey was performed to sample the west coast of North America, from the northern tip of Vancouver Island, British Columbia (BC) to San Diego, CA, to estimate the biomass distributions and demographies of the CPS in the CCE, together with their biotic and abiotic habitats. Presented here are: 1) a detailed description of the ATM used to survey CPS in the CCE off the west coast of North America; and 2) estimates of the abundance, biomass, size structure, and distribution of CPS, specifically the northern and southern stock of Pacific Sardine; the northern and central stock of Northern Anchovy; Pacific Mackerel; Jack Mackerel; and Pacific Herring for the survey area and period. Additional details about the CPS sampling may be found in the cruise report (Stierhoff *et al.*, 2018).

2 Methods

2.1 Data collection

2.1.1 Survey design

The summer 2016 survey was conducted using NOAA Ship *Reuben Lasker* (hereafter, *Lasker*). The sampling domain, between Cape Scott, British Columbia, at the northern end of Vancouver Island and San Diego, CA, was defined by the potential habitat of the northern stock of Pacific Sardine in the CCE at the beginning of the survey (**Fig.** 2**a**), but also spanned all or portions of the anticipated population distributions of other CPS throughout the survey (**Fig.** 2**b-d**). East to west, the sampling domain extends from the coast to at least the 1,000 fm (~1830 m) isobath (**Fig.** 3). Considering the expected distribution of the target species, the acceptable uncertainty in biomass estimates, and the available ship time (80 days at sea, DAS), the principal survey objectives were the estimations of biomass for the northern and southern stocks of Pacific Sardine and the northern and central stocks of Northern Anchovy. Additionally, biomass estimates were sought for Pacific Mackerel, Jack Mackerel, and Pacific Herring 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 over-sample areas with low biomass. In these situations, the survey domain may be first surveyed with coarse resolution, and then sampling may be added in areas with the most biomass (Manly *et al.*, 2002). This two-stage approach results in smaller estimates of variance compared to those from random systematic or fully random sampling designs (Francis, 1984).

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

For example, 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 fm isobath, whichever is farthest (**Fig.** 3). Because the sampling domain spans beyond the area of distribution of the various stocks the estimation of variance requires post-stratification to remove areas of no abundance (see **Section** 2.3.1). This post-survey stratification reduces the sampling variance without introducing sampling bias.

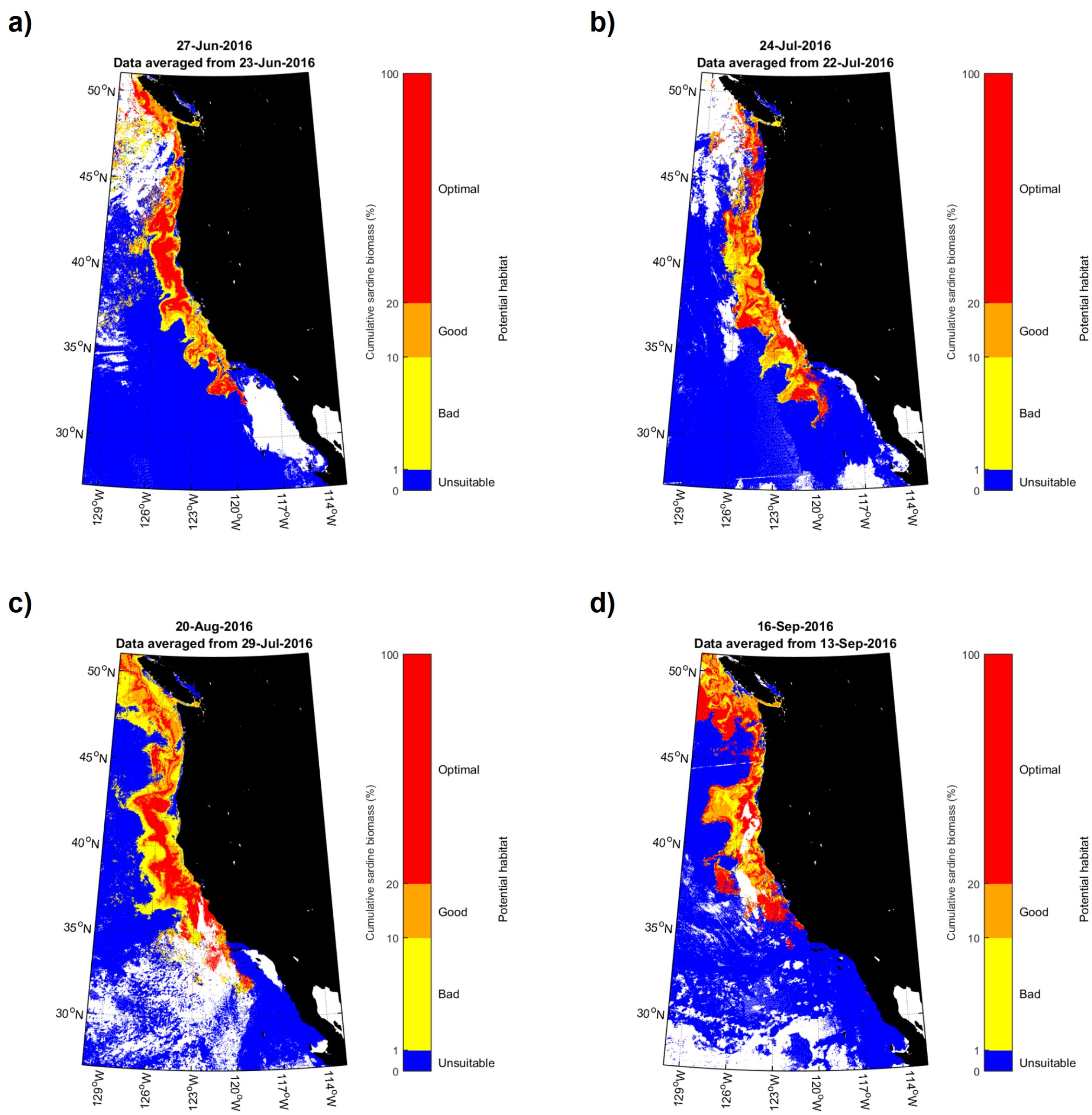


Figure 2: Distribution of potential habitat for the northern stock of Pacific Sardine (a) before, (b, c) during, and (d) at the end of the summer 2016 survey.

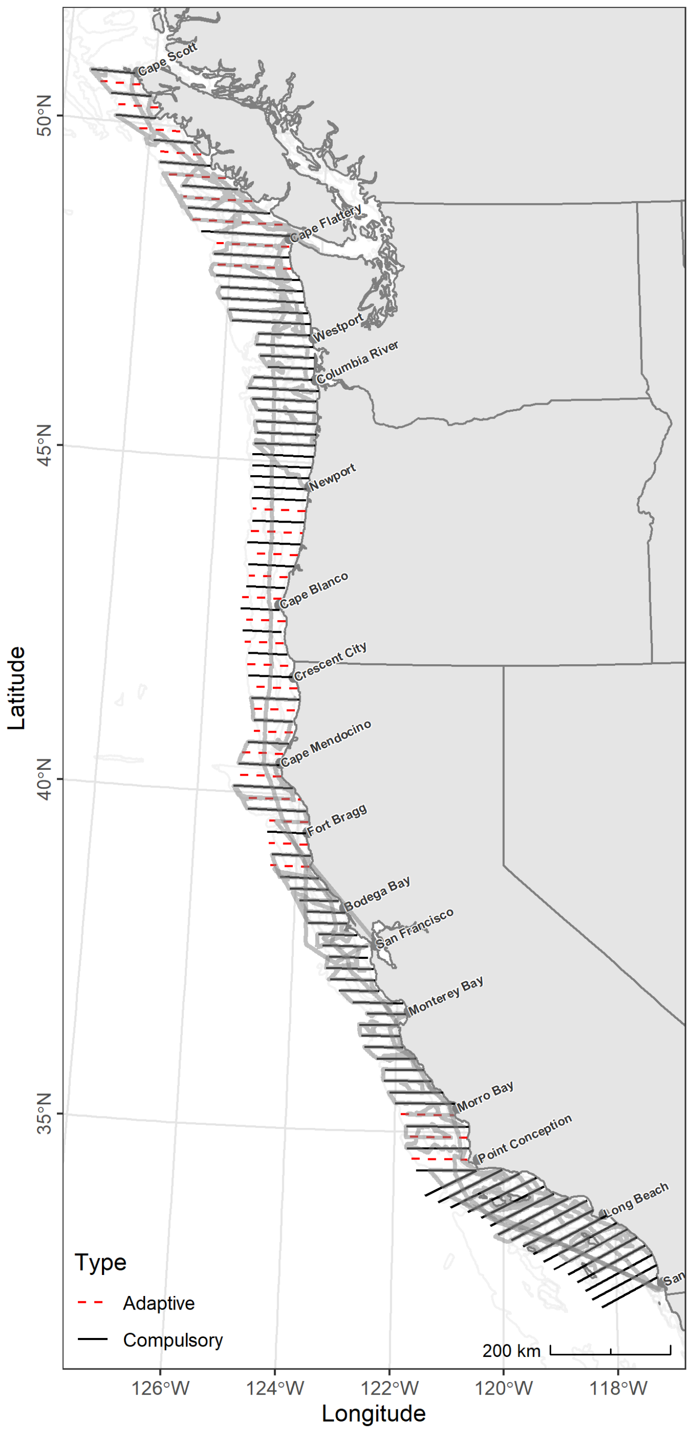


Figure 3: Planned compulsory (solid black lines) and adaptive (dashed red lines) transect lines. Isobaths (light gray lines) are shown at 50, 200, 500, and 2,000 m (~1,000 fm).

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, also known as a "centerboard" (**Fig.** 4). The keel was retracted (transducers ~5-m depth) during calibration, and extended to the intermediate position (transducers ~7-m depth) during the survey. Exceptions were made during shallow water operations, when the keel was retracted; or during times of heavy weather, when the keel was extended (transducers ~9-m depth) to provide extra stability and reduce the effect of weather-generated noise. In addition, acoustic data were also collected using 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).

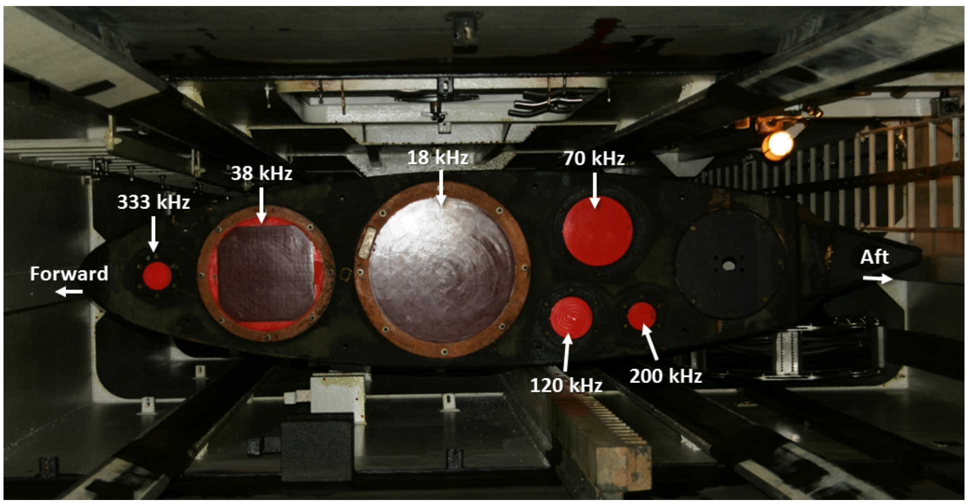


Figure 4: Echosounder transducers mounted on the bottom of the retractable centerboard on *Lasker*. During the survey, the centerboard was extended, typically positioning the transducers at ~2-m below the keel at a water depth of ~7 m.

2.1.2.2 Echosounder 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 ($|Z|$, Ω), phase (θ, °), conductance (G, S), susceptance (B, S), resistance (R, Ω), and reactance (X, Ω) were measured at the operational frequencies with the transducer quadrants connected in parallel.

The echosounders aboard *Lasker* were calibrated on 24 June while the vessel was docked at 10th Avenue Marine Terminal, San Diego Bay (32.6956 °N, -117.15278 °W) using the standard sphere technique (Demer *et al.*, 2015). The reference target was a 38.1-mm diameter sphere made from tungsten carbide (WC) with 6% cobalt binder material (WC38.1; *Lasker* sphere #1). A CTD was cast to measure temperature and salinity versus depth, to estimate sound speeds at the transducer and sphere depths, and the time-averaged sound speed and absorption coefficients for the range between them. The theoretical target strength (TS; dB re 1 m^2) of the sphere was calculated using the Standard Sphere Target Strength Calculator[1] and values for the sphere, sound-pulse, and seawater properties. The sphere was positioned throughout the main lobe of each of the transducer beams using three motorized downriggers, two on one side of the vessel and one on the other. 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.

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

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

	Units	Frequency (kHz)					
		18	38	70	120	200	333
Model		ES18-11	ES38B	ES70-7C	ES120-7C	ES200-7C	ES333-7C
Serial Number		2116	31296	233	783	513	124
Transmit Power (p_{et})	W	2000	2000	750	250	105	50
Pulse Duration (τ)	ms	1.024	1.024	1.024	1.024	1.024	1.024
On-axis Gain (G_0)	dB re 1	22.52	24.74	27.14	26.71	27.24	25.59
S_{a} Correction (S_{a}corr)	dB re 1	-0.65	-0.66	-0.32	-0.36	-0.26	-0.41
Bandwidth (W_{f})	Hz	1570	2430	2860	3030	3090	3110
Sample Interval	m	0.196	0.196	0.196	0.196	0.196	0.196
Eq. Two-way Beam Angle (Ψ)	dB re 1 sr	-17.3	-20.6	-20.4	-20.3	-20.3	-19.8
Absorption Coefficient (α_{f})	dB km^{-1}	1.8	6.9	20.4	45.3	77.9	113.4
Angle Sensitivity Along. (Λ_α)	Elec.°/Geom.°	13.9	21.9	23	23	23	23
Angle Sensitivity Athw. (Λ_β)	Elec.°/Geom.°	13.9	21.9	23	23	23	23
3-dB Beamwidth Along. ($\alpha_{-3\mathrm{dB}}$)	deg	11.2	7.12	6.46	6.43	6.29	6.17
3-dB Beamwidth Athw. ($\beta_{-3\mathrm{dB}}$)	deg	10.94	7.09	6.48	6.46	6.53	6.84
Angle Offset Along. (α_0)	deg	-0.09	-0.02	0.03	-0.03	0	-0.08
Angle Offset Athw. (β_0)	deg	-0.11	-0.05	-0.01	0.01	0.07	-0.11
Theoretical TS (TS_{theory})	dB re 1 m^2	-42.4	-42.36	-41.65	-39.84	-38.84	-37.43
Ambient Noise	dB re 1 W	-128	-145	-154	-160	-161	-137
On-axis Gain (G_0)	dB re 1	22.61	24.9	27.07	26.64	26.95	25.33
S_{a} Correction (S_{a}corr)	dB re 1	-0.76	-0.74	-0.43	-0.36	-0.32	-0.4
RMS	dB	0.37	0.21	0.19	0.25	0.66	0.91
3-dB Beamwidth Along. ($\alpha_{-3\mathrm{dB}}$)	deg	10.87	6.88	6.49	6.49	6.08	5.97
3-dB Beamwidth Athw. ($\beta_{-3\mathrm{dB}}$)	deg	11.07	6.95	6.5	6.51	6.22	6.55
Angle Offset Along. (α_0)	deg	-0.15	0.06	0.06	-0.02	-0.02	-0.06
Angle Offset Athw. (β_0)	deg	-0.14	0.02	-0.05	0.05	0.1	-0.04

2.1.2.3 Data collection Computer clocks were synchronized with the GPS clock (UTC) using synchronization software (SymmTime; Symmetricon, Inc.). 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 1,000 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., 1606RL), the acoustic system (e.g., EK60, ME70), and the logging commencement date and time from the GPT-control software. For example, an EK60 file generated by the GPT-control software (ER60 v2.4.3, Simrad) is named `1606RL_EK60-D20160628-T172429.raw`.

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 a synchronization system (K-Sync, 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) cast at stations, or cast from the vessel while underway (UnderwayCTD, Oceanscience). These data were used to calculate the harmonic mean sound speed (Demer *et al.*, 2015) for estimating ranges to the sound scatterers, and frequency-specific sound absorption coefficients for compensating signal attenuation of the sound pulse between the transducer and scatters (Simmonds and MacLennan, 2005) (see **Section** 2.2.2). These data also 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, data from a subset of these sensors, logged with a standardized format at 1-min resolution, are available on the internet via NOAA's ERDDAP data server[2].

2.1.4 Fish egg sampling

During daytime, fish eggs were sampled using a continuous underway fish egg sampler (CUFES, Checkley *et al.*, 1997), which collects water and plankton at a rate of ~640 l min^{-1} from an intake at ~3-m depth on the hull of the ship. The particles in the sampled water were sieved by a 505-μm mesh. Pacific Sardine, Northern Anchovy, Jack Mackerel, and Pacific Hake (*Merluccius productus*) eggs were identified to species, counted, and logged. Eggs from other species 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 durations of the initial stages of egg phases is short for most fish species, the egg distributions inferred from CUFES are assumed to indicate the nearby presence of actively spawning fish, and were used in combination with CPS echoes to select trawl locations.

2.1.5 Trawl sampling

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

2.1.5.1 Sampling gear The trawl net, a Nordic 264 rope trawl (NET Systems, Bainbridge Island, WA; **Fig.** 5**a,b**), was towed at the surface for 45 min at a speed of 3.5-4.5 kn. The net has a rectangular opening with an area of ~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 are foam-filled and the trawl headrope is lined with floats so the trawl tows at the surface.

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

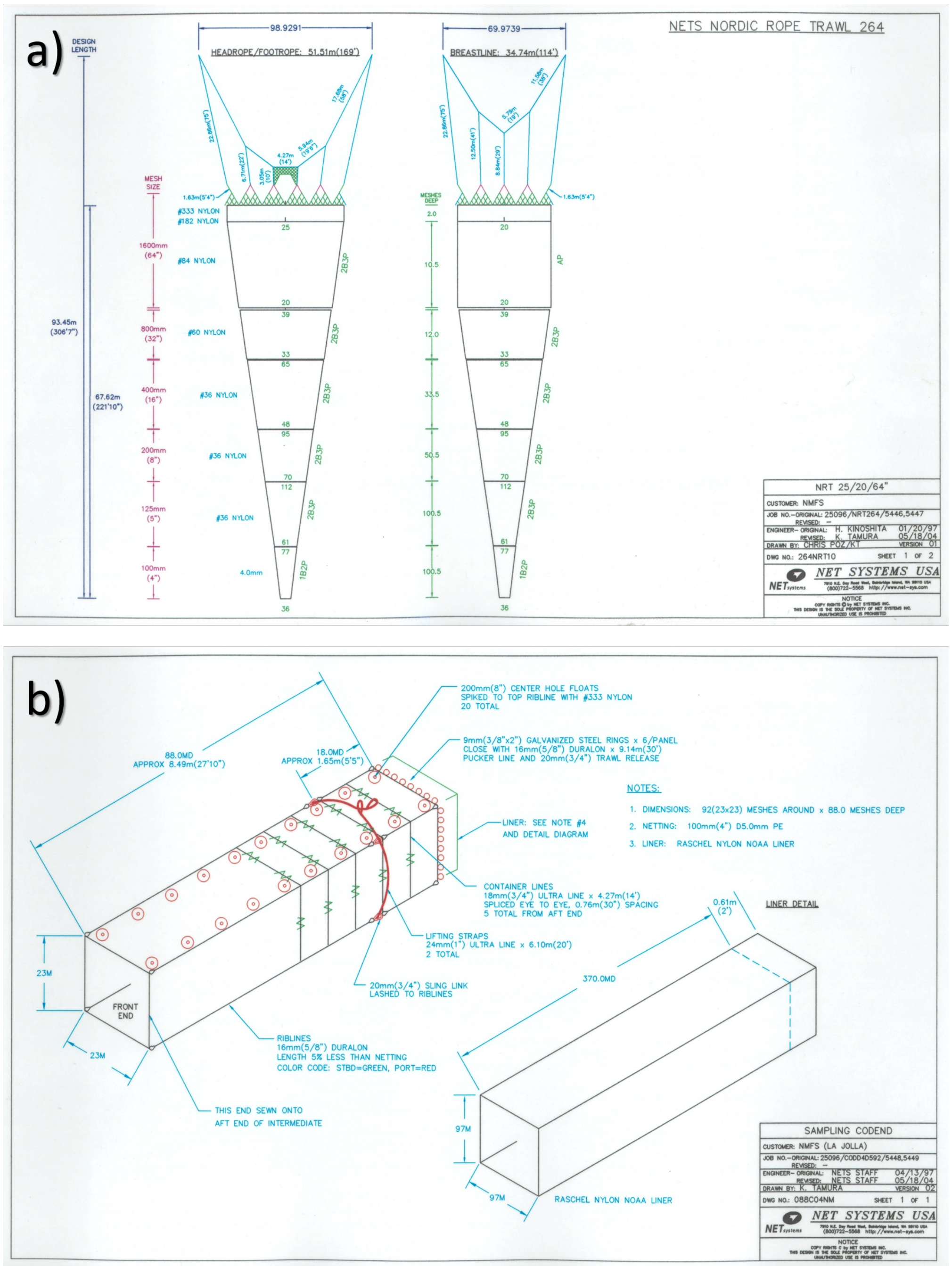


Figure 5: Schematic drawings of the a) body and b) codend of the Nordic 264 rope trawl net.

2.1.5.2 Sampling locations Up to three nighttime (i.e., 30 min after sunset to 30 min before sunrise) surface trawls, typically spaced 10-nmi apart, were conducted in areas where echoes from putative CPS schools were observed earlier that day (**Fig.** 6). Each evening, trawl locations were selected by an acoustician who monitored CPS echoes and a member of the trawl group who measured the densities of CPS eggs in the CUFES. The locations were provided to the watch officers who charted the proposed trawl sites.

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

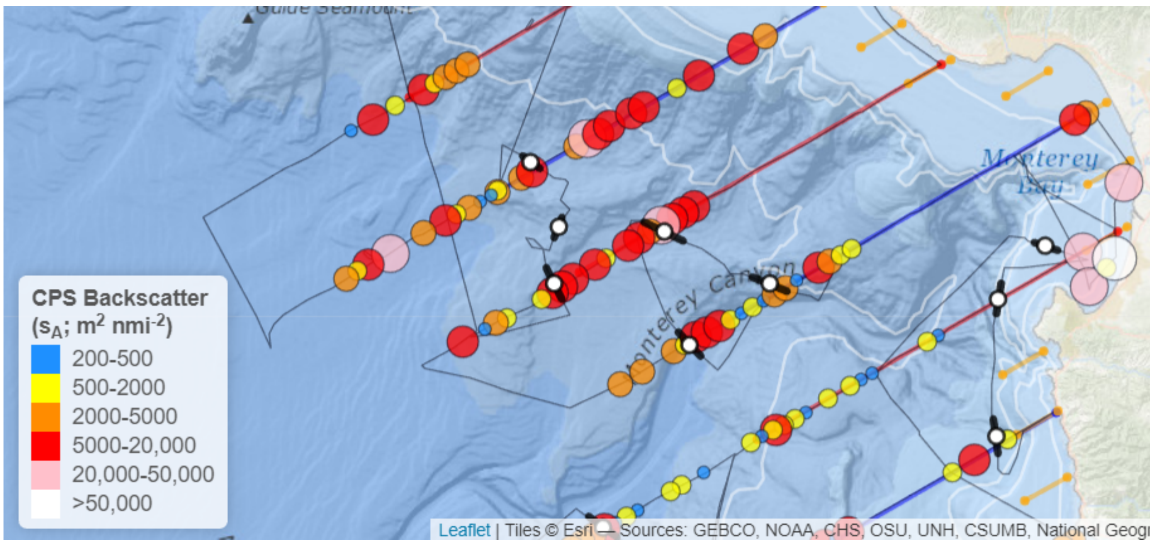


Figure 6: Example of trawl paths (bold, black lines) relative to 38-kHz integrated backscattering coefficients (s_A, m^2 nmi^{-2}; averaged over 2000-m distance intervals and from 5 to 70 m deep) from putative CPS schools (colored points).

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 collected, sorted by species, weighed, and enumerated; and 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 75 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, 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 greater 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 and verified, or corrected. Missing length (L_{miss}) and weight (W_{miss}) measurements were estimated using the season-specific length-versus-weight relationships derived from catches during previous ATM surveys (Palance *et al.*, 2019), where $W_{miss} = \beta_0 L^{\beta_1}$, $L_{miss} = (W/\beta_0)^{(1/\beta_1)}$, and values for β_0 and β_1. To identify measurement or data-entry errors, length and weight data were graphically compared (**Fig.** 7) to measurements from previous surveys and models of season-specific length-versus-weight from previous surveys (Palance *et al.*, 2019). Outliers and missing values were flagged, reviewed by the trawl team, and mitigated. Catch data from aborted or otherwise unacceptable trawl hauls were removed.

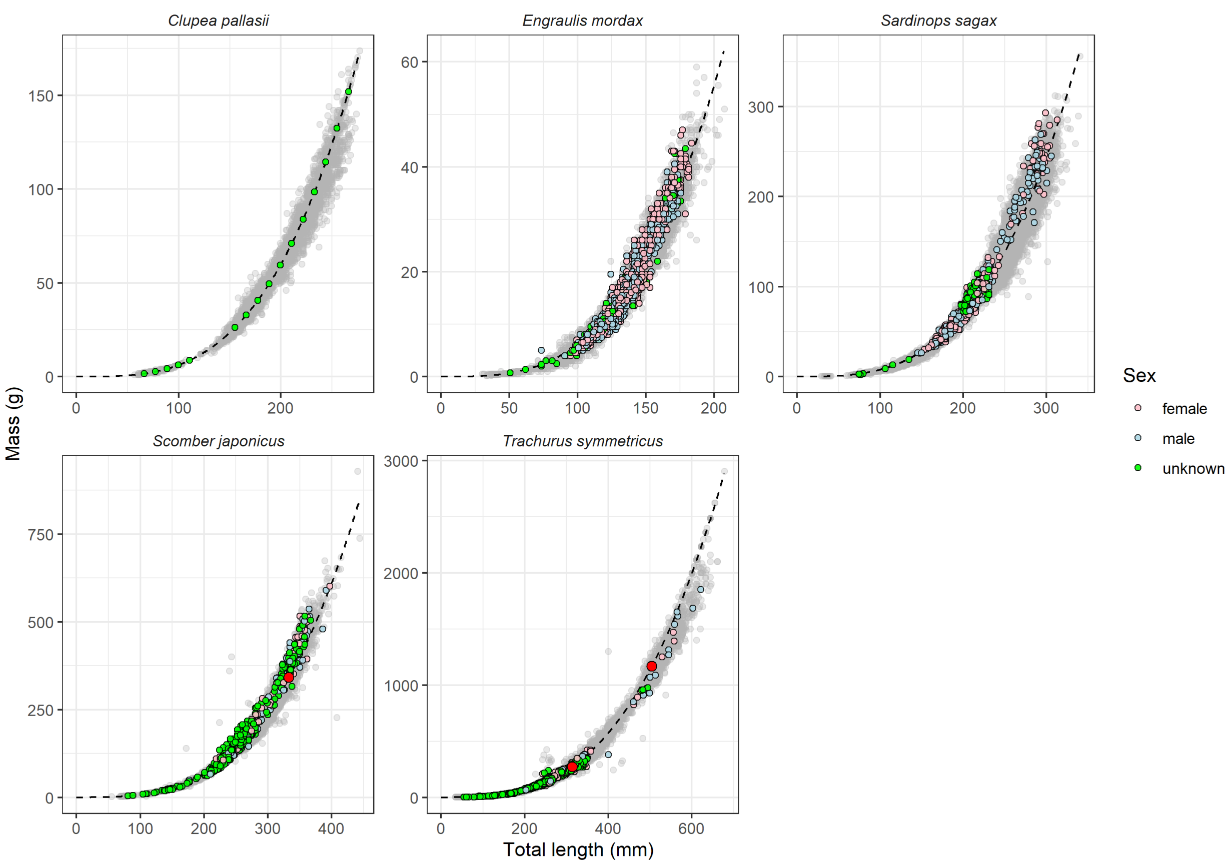


Figure 7: Specimen length-versus-weight from the current survey (colored points, by sex) compared to those from previous SWFSC surveys during the same season (gray points, all sexes) and models [dashed lines; Palance *et al.* (2019)]. Larger red points indicate specimens whose length was missing and was estimated from the model for that species. In 2016, the lengths of Pacific Herring (*Clupea pallasii*) were assigned to length bins and weights were not measured, so weight was estimated from the binned lengths using the model in Palance et al. (2019).

2.2 Data processing

2.2.1 Acoustic and oceanographic data

The calibrated echosounder data from each transect were processed using commercial software (Echoview v7.1.12, Echoview Software Pty Ltd.) and estimates of the sound speed and absorption coefficient calculated with contemporaneous data from CTD probes cast while stationary or underway (UCTD, see **Section** 2.1.3.1). Data collected along the daytime transects at speeds ≥ 5 kn were used to estimate CPS densities. Nighttime acoustic data were assumed to be negatively biased due to diel-vertical migration (DVM) and disaggregation of the target species' schools (Cutter and Demer, 2008), and therefore not used to estimate biomass.

2.2.2 Sound speed and absorption calculation

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

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

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

2.2.3 Echo-classification

Echoes from schooling CPS were identified using a semi-automated data processing algorithm implemented using Echoview software (v7.1.12). The filters and thresholds were based on a subsample of echoes from randomly selected CPS schools. The aim of the filter criteria is to retain at least 95% of the noise-free backscatter from CPS schools while rejecting at least 95% of the non-CPS backscatter (**Fig.** 8). The filter includes the following steps:

- Echograms of S_V were displayed;
- Estimate and subtract background noise using the built-in Echoview background noise removal function [De Robertis and Higginbottom (2007); **Fig.** 8**b,e**];
- Average the noise-free S_V echograms using non-overlapping 11-sample by 3-ping windows;
- For each pixel, compute: $S_{V,\mathrm{200kHz}}$ - $S_{V,\mathrm{38kHz}}$, $S_{V,\mathrm{120kHz}}$ - $S_{V,\mathrm{38kHz}}$, and $S_{V,\mathrm{70kHz}}$ - $S_{V,\mathrm{38kHz}}$;
- Create a Boolean echogram for S_V differences in the CPS range: $-13.85 < S_{V,\mathrm{70kHz}} - S_{V,\mathrm{38kHz}} < 9.89 \bigcap -13.55 < S_{V,\mathrm{120kHz}} - S_{V,\mathrm{38kHz}} < 9.37 \bigcap -13.51 < S_{V,\mathrm{200kHz}} - S_{V,\mathrm{38kHz}} < 12.53$;
- Compute the standard deviation (SD) of $S_{V,\mathrm{120kHz}}$ and $S_{V,\mathrm{200kHz}}$ using non-overlapping 11-sample by 3-ping windows;
- Expand the SD($S_{V,\mathrm{120kHz}}$) and SD($S_{V,\mathrm{200kHz}}$) echograms with a 7-pixel x 7-pixel dilation;

- Data collected when the ship approached or departed a sampling station, typically associated with a ship-speed less than 5 kn, were automatically marked as "bad data;"
- Create a Boolean echogram based on the SDs in the CPS range: SD($S_{V,200\mathrm{kHz}}$) > -60 dB $\bigcap$ SD($S_{V,120\mathrm{kHz}}$) > -60 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. 8c,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 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.

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*), or semi-demersal fish such as Pacific Hake and rockfishes (*Sebastes* spp.). When analyzing the acoustic-survey data, it was therefore necessary to filter "acoustic by-catch," i.e., backscatter not from the target species. To exclude echoes from mid-water, demersal, and benthic fishes, vertical temperature profiles were superimposed on the echo-integrated data for each transect. Mid-water echoes below the surface mixed layer were generally excluded (**Fig. 9**), unless they originate in well-defined schools as those commonly observed in areas dominated by Northern Anchovy. In areas dominated by Pacific Herring, for example off Vancouver Island, backscatter was integrated to a maximum depth of 75 m.

2.2.5 QA/QC

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

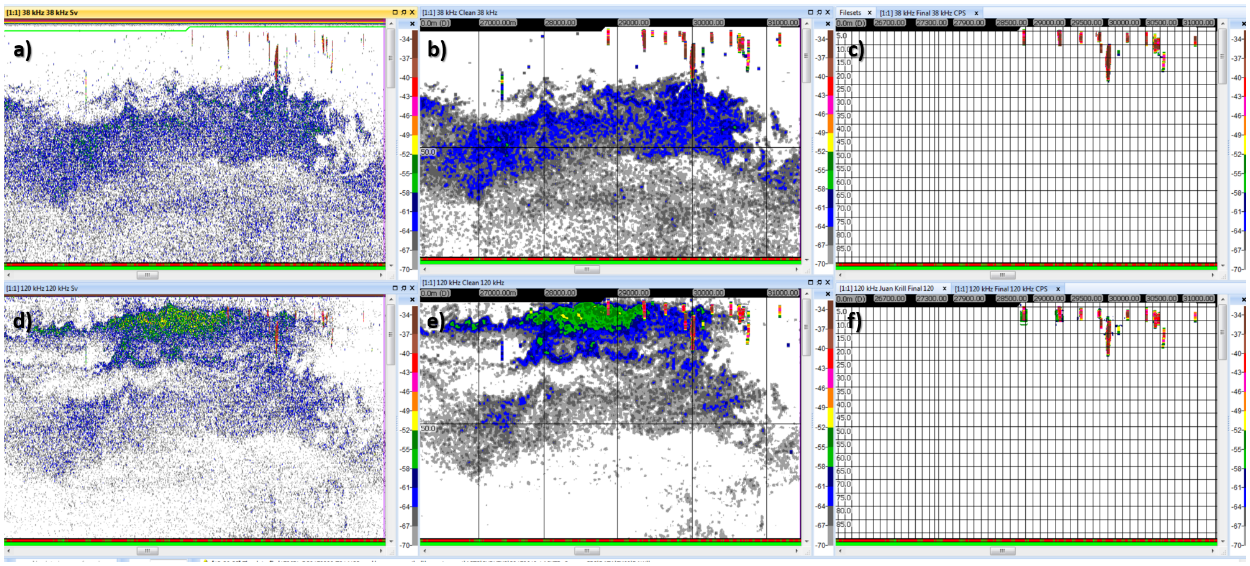


Figure 8: Echogram depicting CPS schools (red) and plankton aggregations (blue and green) at 38 kHz (top) and 120 kHz (bottom). Example data processing steps include the original echogram (left), after noise subtraction and bin-averaging (middle), and filtering to retain only putative CPS echoes (right).

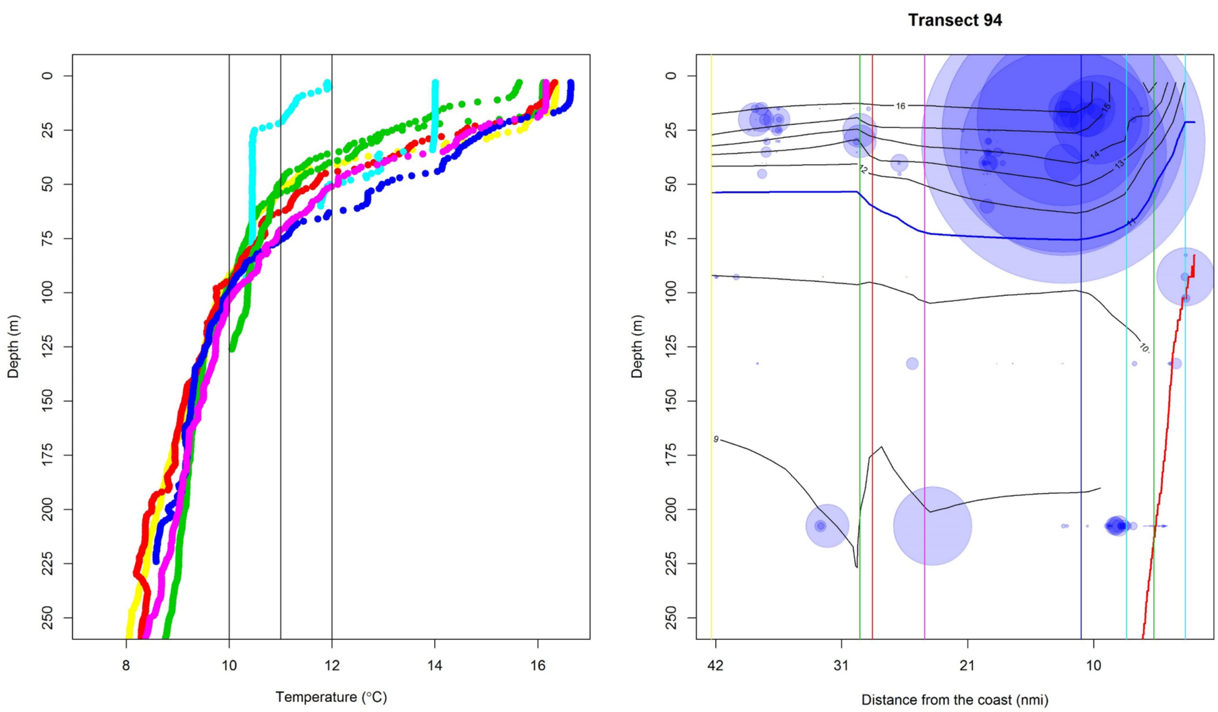


Figure 9: Temperature profiles (left) and the distribution of echoes from fishes with swimbladders (blue points, scaled by backscatter intensity; right) along an example acoustic transect. In this example, temperature profiles indicate an ~25-m deep mixed-layer above an ~20- to 30-m thermocline, so the 11 °C isotherm (bold blue line; right panel) was used to remove echoes from deeper, bottom-dwelling schools of non-CPS fishes with swimbladders. The proximity of the echoes to the seabed (bold red line; right panel) was also used to define the lower limit for vertical integration.

2.2.6 Echo integral partitioning and acoustic inversion

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

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

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

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

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

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

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

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

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

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

Equations (6) and (9) were derived from echosounder measurements of σ_{bs} 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 for Pacific Herring of 44 m; 3) the intercept was increased by 2.98 dB to account for the change of frequency from 120 to 38 kHz (Saunders *et al.*, 2012). For Northern Anchovy, Equation (8) was derived from that of Kang et al. (2009), after compensation of the swimbladder volume (Ona, 2003; Zhao *et al.*, 2008) for the average depth of Northern Anchovy observed in summer 2016 (19 m, Zwolinski *et al.*, 2017).

To calculate $TS_{38\text{kHz}}$, L_T (cm) was estimated from measurements of standard length (L_S) or fork length (L_F; cm) using linear relationships between length and weight derived from specimens collected in the CCE: for Pacific Sardine, $L_T = 1.157L_S + 0.724$; for Northern Anchovy, $L_T = 1.137L_S + 5.100$; for Pacific Mackerel, $L_T = 1.115L_F - 4.114$; for Jack Mackerel, $L_T = 1.100L_F + 0.896$; and for Pacific Herring, $L_T = 1.110L_F - 0.323$ (Palance *et al.*, 2019).

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

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

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

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

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

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

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

where:

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

and the proportion (P_{ge}) is;

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

2.2.7 Trawl clustering and species proportions

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

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

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

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

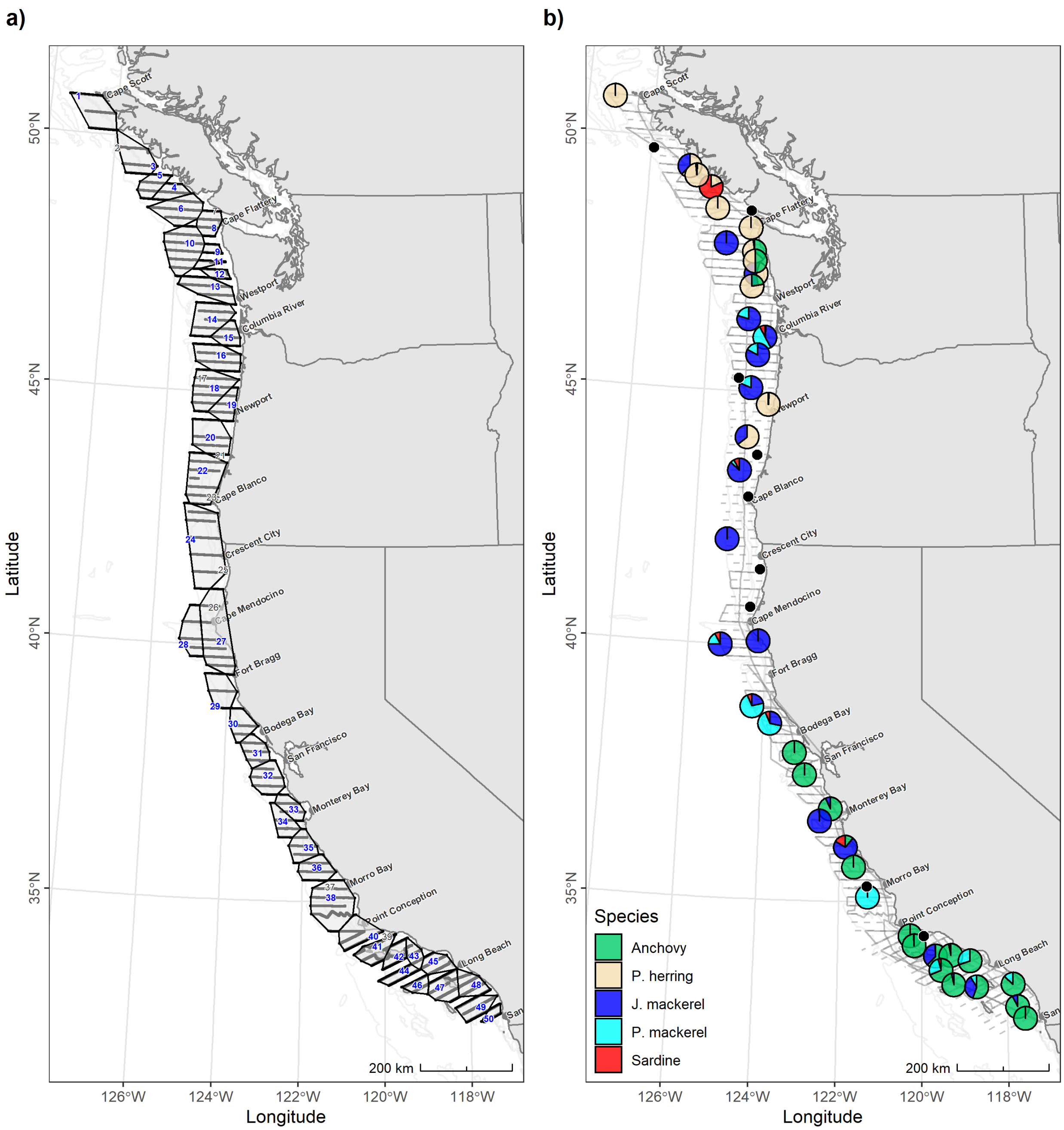


Figure 10: a) Polygons enclosing 100-m acoustic intervals assigned to each trawl cluster and b) the proportion (by weight) of CPS in each trawl cluster. The numbers inside each polygon in panel a) are the cluster numbers, which are located at the average latitude and longitude of all trawls in that cluster. 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. 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 (**Figs.** 11, 12). This approach tracks stock patchiness and creates statistically-independent, stationary, post-sampling strata (Johannesson and Mitson, 1983; Simmonds *et al.*, 1992). For Northern Anchovy, we define the separation between the northern and central stock at Cape Mendocino (40.4 °N). For Pacific Sardine, we define the separation between the northern and southern stock by the boundary between their respective potential oceanographic habitats (Demer and Zwolinski, 2014; Zwolinski *et al.*, 2011), in this case at Point Conception (34.7 °N).

2.3.2 Estimation of biomass and sampling precision

For each stratum and stock, the biomass (B, kg) of each species was estimated by:

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

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

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

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

The 95% confidence intervals ($\mathrm{CI}_{95\%}$) for the mean biomass densities ($\hat{D}$) were estimated as the 0.025 and 0.975 percentiles of the distribution of 1,000 bootstrap survey-mean biomass densities. Coefficient of variation (CV, %) values were obtained by dividing the bootstrapped standard error by the mean estimate (Efron, 1981). Total biomass in the survey area was estimated as the sum of the biomasses in each stratum, and the associated sampling variance was calculated as the sum of the variances across strata.

2.3.3 Abundance- and biomass-at-length estimates

The numerical densities by length class (**Section** 2.2.7) were averaged for each stratum in a similar way for that used for biomass (Equation (17)), and 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 (**Appendix** A) was calculated as:

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

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

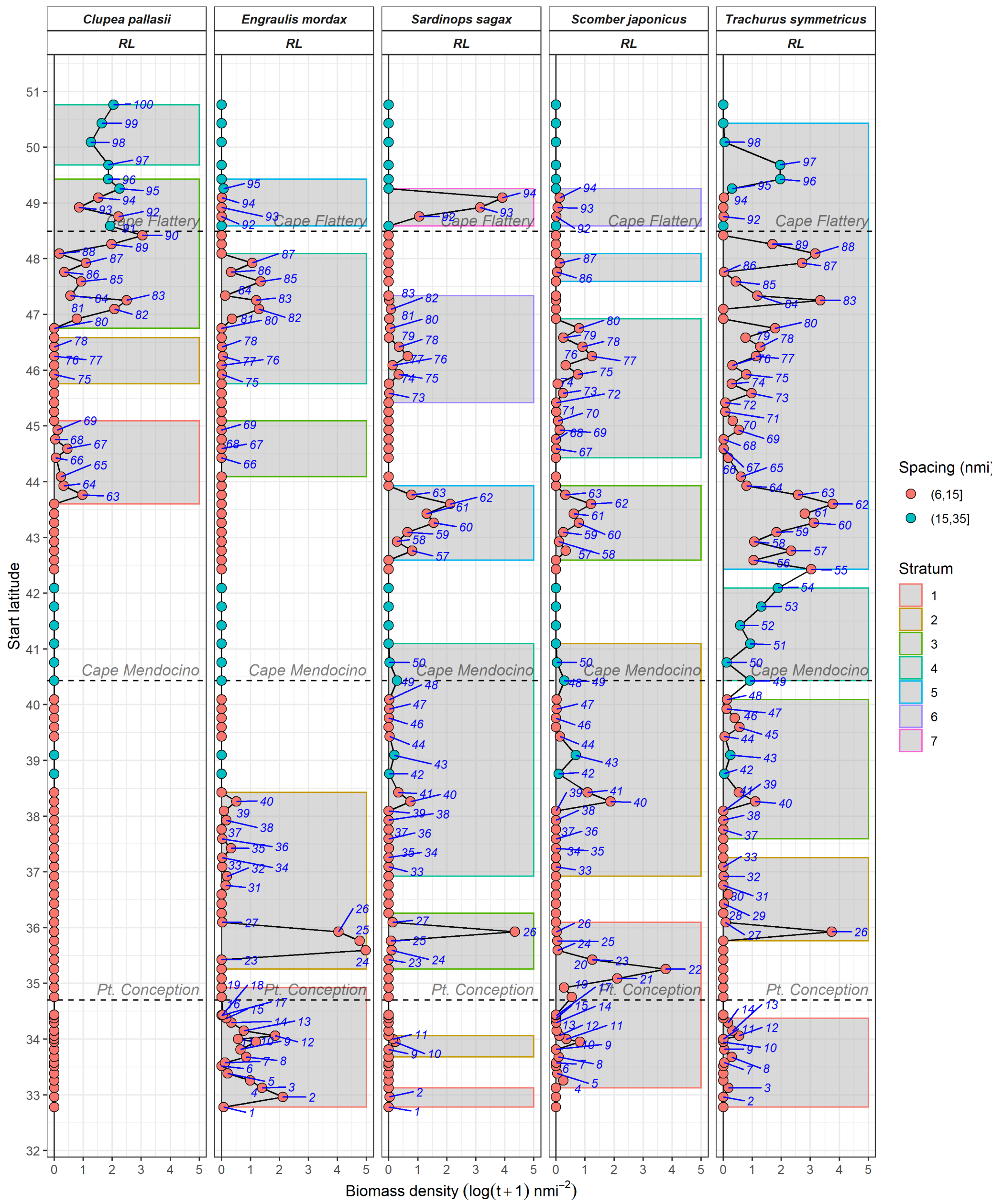


Figure 11: Acoustic biomass density ($\log_{10}(t+1)$ nmi^{-2}) versus latitude (easternmost portion of each transect) and strata used to estimate biomass and abundance (shaded regions; outline indicates stratum number) for each species and survey vessel (RL = *Lasker*). Strata with no outline were not included because of too few specimens ($<$ 1 individual), trawl clusters ($<$ 1 cluster), or both. Blue numbers label transects with positive biomass ($\log_{10}(t+1) > 0.01$). Point colors indicate transect spacing (nmi). Dashed horizontal lines indicate biogeographic landmarks delineating stocks of Northern Anchovy and Pacific Sardine.

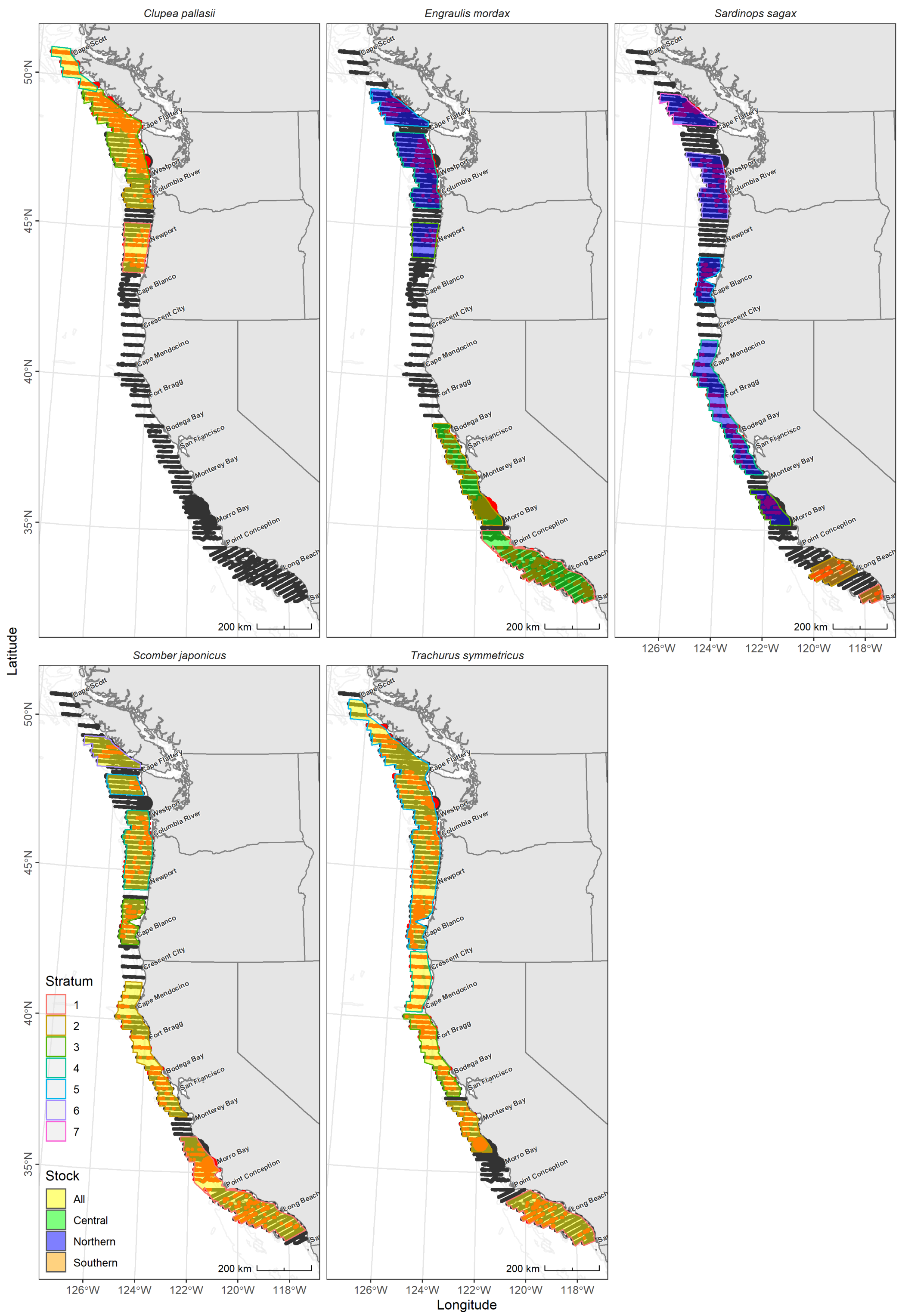


Figure 12: Post-survey strata polygons (outline indicates stratum number; fill indicates the species' stock designation) used to estimate the biomasses of CPS. Point sizes indicate the relative intensity (s_A; m^2 nmi^{-2}) of acoustic backscatter from all CPS (black points) and individual species (red points).

3 Results

3.1 Sampling effort and allocation

The summer 2016 survey took place between Cape Scott, BC and San Diego, CA, during 80 DAS between 27 June and 16 September 2016. Acoustic sampling was conducted by *Lasker* along 100 daytime east-west transects that totaled 4,590 nmi. Catches from a total of 118 nighttime surface trawls were combined into 50 trawl clusters. As many as seven post-survey strata were defined for each species and stock considering transect spacing and the densities of echoes attributed to CPS. Biomasses and abundances were estimated for each species and stock.

Leg I
On 28 June 2016, *Lasker* departed San Diego, CA, and transited to Neah Bay, WA. On 4 July, *Lasker* arrived in Neah Bay, WA; personnel were exchanged via small boat and *Lasker* resumed the transit toward Cape Scott. *Lasker* arrived at transect 001 at ~0100 (all times UTC) on 6 July to begin survey operations. On 16 July, acoustician Steve Sessions was replaced by acoustician Kevin Stierhoff via small boat in Westport, WA. Transect 035 was completed at ~1400 on 22 July, and *Lasker* arrived at NOAA Marine Operations Center-Pacific (MOC-P) in Newport, OR, at ~2300 on 22 July to complete Leg I.

Leg II
On 27 July, *Lasker* departed from MOC-P in Newport, OR, at ~1430 and arrived at the start of transect 035 at ~1900 near Cascade Head, CA, to resume survey operations. On 31 July at ~2245, the EK-MUX stopped functioning. The survey resumed using only the EK60 until ~0600 on 1 August when the EK-MUX was repaired. On 8 August, *Lasker* arrived at Pier 32 in San Francisco, CA, at ~0530, completing Leg II. Repairs to the damaged pipe was scheduled to occur prior to Leg III.

Leg III
On 20 August, *Lasker* departed from Pier 32 in San Francisco, CA, at ~0130, and arrived at transect 071 near Point Cabrillo at ~1700 on 20 August to resume survey operations. Rough seas and high winds were encountered on 29 August. Consequently, the ship slowed to 7 kn and began tacking on 30 August to minimize roll and preserve data quality. Only one trawl was successfully conducted on 29 August due to weather. *Lasker* arrived at 10th Ave Marine Terminal in San Diego, CA, on 2 September at ~1600, completing Leg III.

Leg IV
On 6 September, *Lasker* departed from 10th Ave Marine Terminal in San Diego, CA, at ~2000, and arrived at transect 102 at ~1330 on 7 September to resume survey operations. On 16 September, *Lasker* arrived at 10th Ave Marine Terminal in San Diego, CA, at ~1800, completing the survey.

3.2 Acoustic backscatter

The majority of acoustic backscatter ascribed to CPS was observed: along the coast of Vancouver Island; between the Strait of Juan de Fuca and Tillamook, OR; around Cape Blanco, and between Monterey, CA, and Morro Bay (**Fig.** 13**a**). To a lesser extent, CPS backscatter was observed around the northern Channel Islands in the SCB (**Fig.** 13**a**). The majority (~90%) of acoustic biomass for each species was apportioned using catch data from trawl clusters conducted within a distance of $\leq$ 15-20 nmi (**Fig.** 14).

3.3 Egg densities and distributions

Northern Anchovy eggs were most abundant in the CUFES samples inshore between Cape Flattery and Tillamook, OR, and between Bodega Bay and Monterey, CA (**Fig.** 13**b**). Lower densities of Jack Mackerel eggs were observed: offshore of central Vancouver Island; offshore between Cape Flattery and Newport, OR; and to a lesser extent inshore between Fort Bragg CA, and Monterey, CA, and inshore around Point Conception (**Fig.** 13**b**). Pacific Sardine eggs observed in the CUFES were most abundant offshore of central Vancouver Island and around the northern Channel Islands in the SCB (**Fig.** 13**b**). Fewer Pacific Sardine eggs were observed off southern Oregon and near Cape Mendocino. There was little overlap in the distributions of Northern Anchovy and Pacific Sardine eggs in the CUFES. The concentrations of Northern Anchovy eggs in the CUFES samples were coincident with CPS backscatter off the coast of Washington and the concentration of Pacific Sardine eggs were coincident with backscatter in the SCB.

3.4 Trawl catch

Jack Mackerel comprised the greatest proportion of catch in trawl clusters between Westport, WA, and Fort Bragg, CA (**Fig.** 13**c**). Pacific Herring comprised the greatest proportion of catch in trawl clusters: inshore along the coast of Vancouver Island; between Cape Flattery and Westport, WA; and around Newport, OR (**Fig.** 13**c**). Northern Anchovy were predominantly found in trawl clusters located inshore between Bodega Bay and Morro Bay, and throughout the SCB; some were present inshore between Cape Flattery and Westport, WA (**Fig.** 13**c**). Trawl clusters that contained Pacific Sardine were collected: off central Vancouver Island, near the Columbia River plume; near Cape Blanco; between Cape Mendocino and Bodega Bay; and off Big Sur. Overall, the 118 trawls captured a combined 9,273 kg of CPS (519 kg of Northern Anchovy, 1,533 kg of Pacific Sardine, 2,711 kg of Pacific Mackerel, 4,360 kg of Jack Mackerel, and 150 kg Pacific Herring).

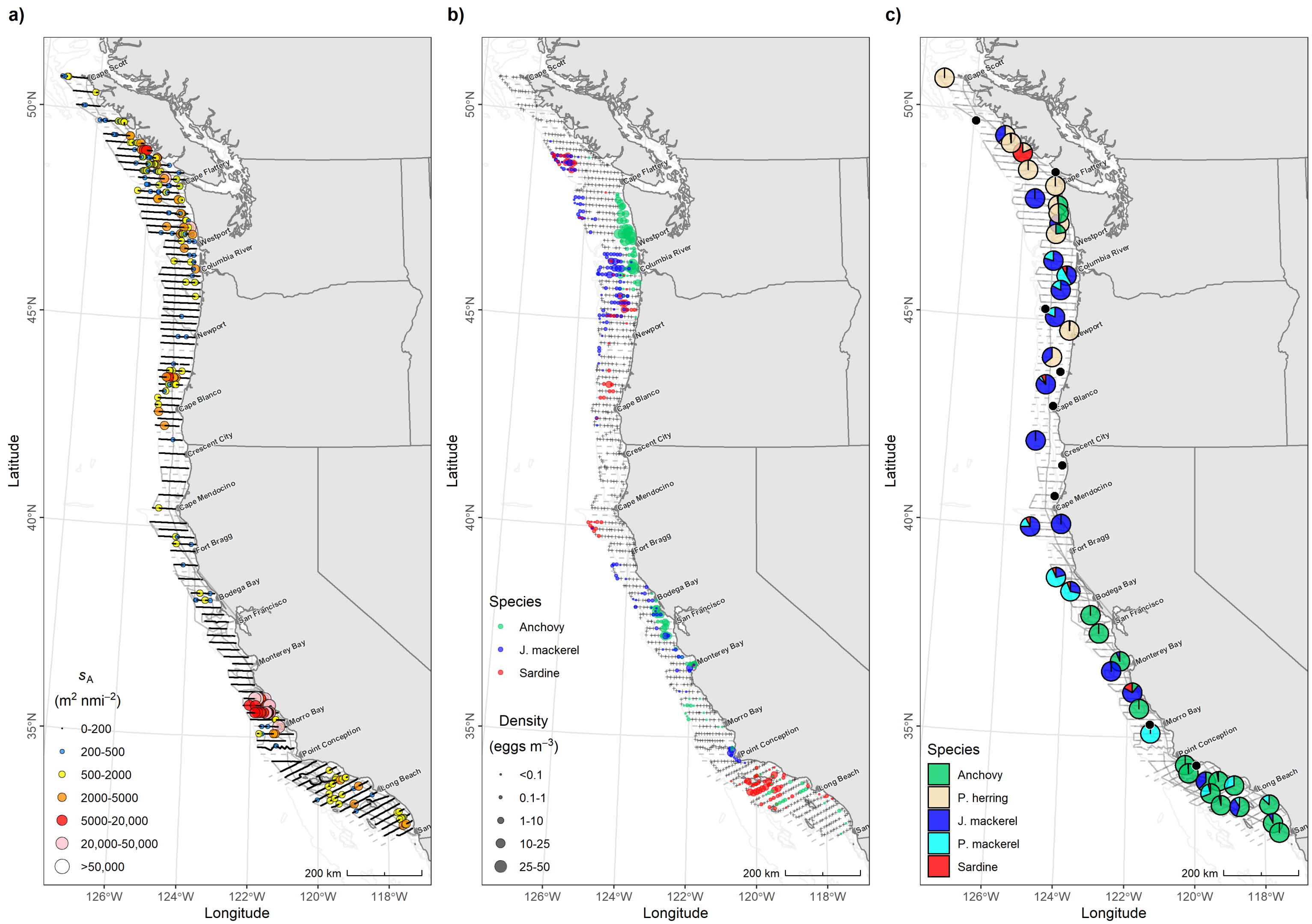


Figure 13: Spatial distributions of: a) 38-kHz integrated backscattering coefficients (s_A, m^2 nmi^{-2}; averaged over 2000-m distance intervals and from 5 to 70 m deep) ascribed to CPS; b) CUFES egg density (eggs m^{-3}) for Northern Anchovy, Pacific Sardine, and Jack Mackerel; and c) acoustic proportions of CPS in trawl clusters (see Equation (14); black points indicate trawl clusters with no CPS).

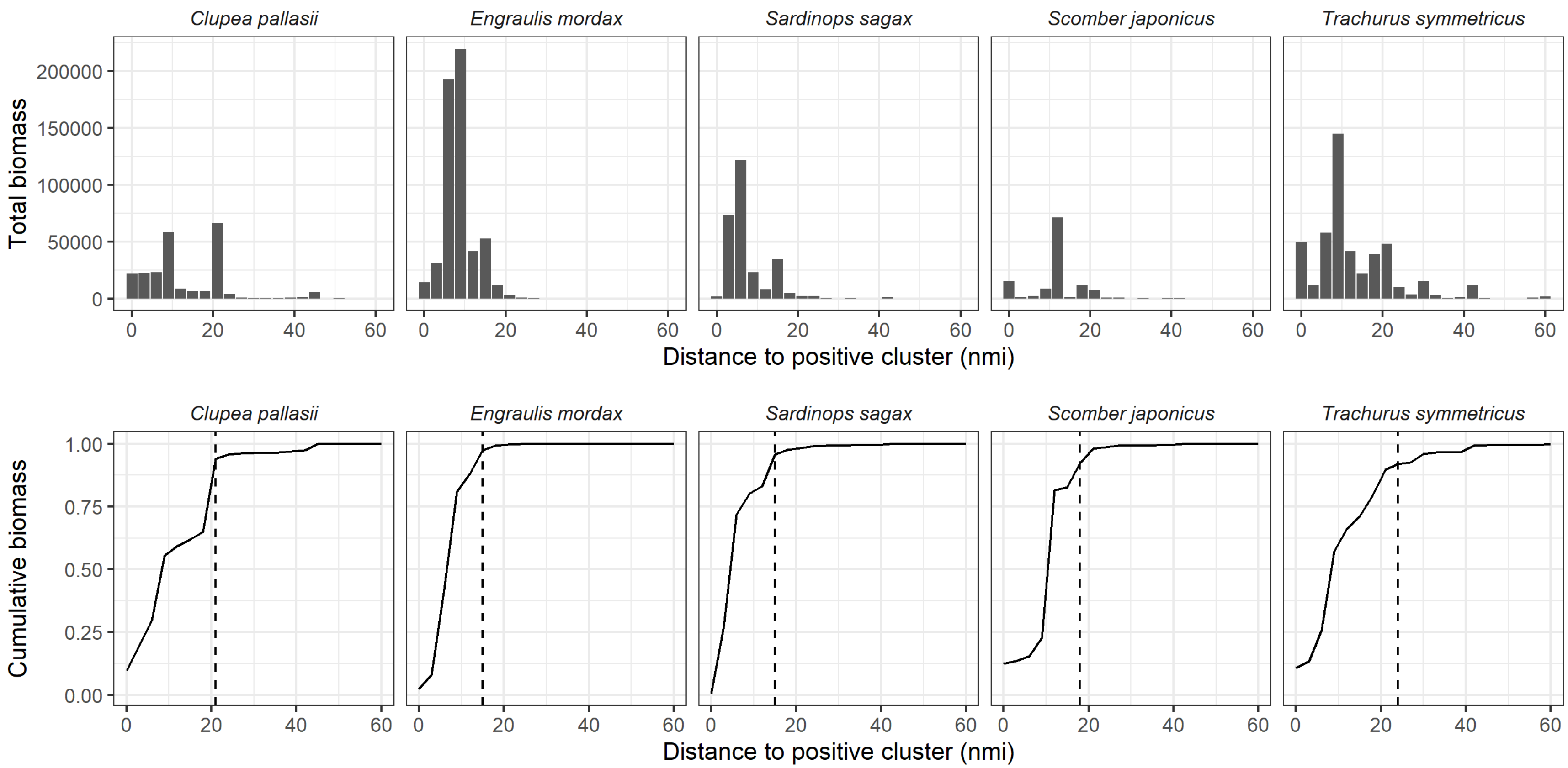


Figure 14: Total (top) and cumulative (bottom) acoustic biomass (t) versus distance to the nearest positive trawl cluster.

3.5 Biomass distribution and demography

3.5.1 Northern Anchovy

3.5.1.1 Northern stock The total estimated biomass ($\hat{B}$) of the northern stock of Northern Anchovy was 6,575 t ($CI_{95\%}$ = 2,480 - 11,596 t, CV = 36%; **Table 2**), and was distributed from approximately Cape Flattery to Tillamook, OR (**Fig. 15a**). The L_S ranged from 11 to 16 cm with a mode at 15 cm (**Table 4**, **Fig. 16**). Extrapolation of the northern stock of Northern Anchovy biomass into the unsampled, nearshore waters is presented in **Appendix B.3.1.1**.

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

Species		Stratum				Trawl		Biomass			
Name	Stock	Number	Area	Transects	Distance	Clusters	Individuals	$\hat{B}$	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Engraulis mordax	Northern	3	3,351	6	586	1	2	5	0	13	68
		4	8,198	15	1,660	5	1,727	6,505	2,419	11,498	36
		5	4,249	6	736	2	5	65	4	164	67
		All	15,798	27	2,981	8	1,734	6,575	2,480	11,596	36

3.5.1.2 Central stock The total estimated biomass of the central stock of Northern Anchovy was 150,907 t ($CI_{95\%}$ = 32,843 - 317,457 t, CV = 51%; **Table 3**). The stock was distributed from approximately Bodega Bay to San Diego, CA, but biomass was greatest off Big Sur and scattered throughout the SCB (**Fig. 17a**). L_S ranged from 4 to 15 cm with a mode at 11 cm (**Table 5**, **Fig. 18**). Extrapolation of the central stock of Northern Anchovy biomass into the unsampled, nearshore waters is presented in **Appendix B.3.1.2**.

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

Species		Stratum				Trawl		Biomass			
Name	Stock	Number	Area	Transects	Distance	Clusters	Individuals	$\hat{B}$	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Engraulis mordax	Central	1	10,748	20	2,203	11	6,305	13,372	6,234	21,305	29
		2	6,886	19	1,326	5	18,854	137,534	20,366	306,682	56
		All	17,634	39	3,529	16	25,159	150,907	32,843	317,457	51

Table 4: Abundance versus standard length (L_S, cm) for the northern stock of Northern Anchovy (*Engraulis mordax*) in the survey region.

Species	Stock	L_S	Abundance
Engraulis mordax	Northern	1	0
		2	0
		3	0
		4	0
		5	0
		6	0
		7	0
		8	0
		9	0
		10	0
		11	398,313
		12	5,076,879
		13	6,373,381
		14	82,092,485
		15	93,752,799
		16	6,475,185
		17	0
		18	0
		19	0
		20	0

Table 5: Abundance versus standard length (L_S, cm) for the central stock of Northern Anchovy (*Engraulis mordax*) in the survey region.

Species	Stock	L_S	Abundance
Engraulis mordax	Central	1	0
		2	0
		3	0
		4	201,057
		5	1,809,517
		6	10,171,636
		7	10,213,614
		8	119,689,413
		9	830,060,821
		10	3,087,640,798
		11	6,446,239,518
		12	1,170,748,671
		13	151,476,699
		14	2,535,570
		15	136,428
		16	0
		17	0
		18	0
		19	0
		20	0

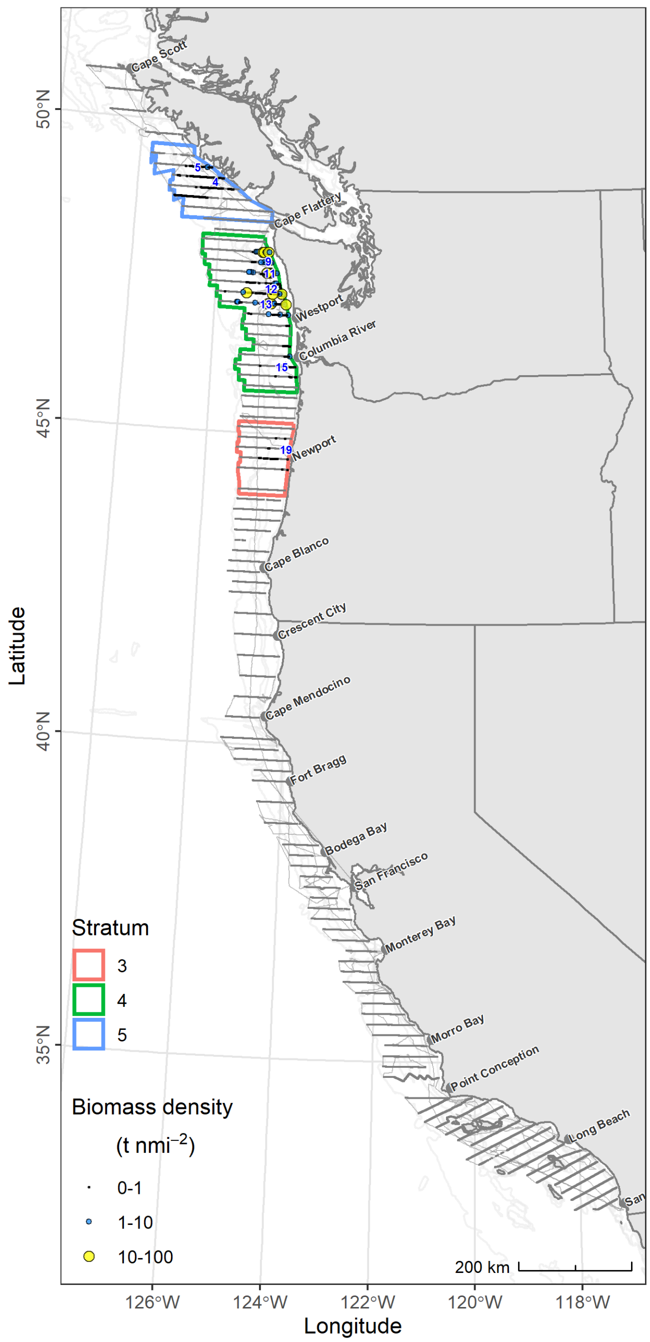


Figure 15: Biomass densities of the northern stock of the Northern Anchovy (*Engraulis mordax*) in the survey region. The blue numbers represent the locations of trawl clusters with at least one Northern Anchovy. The gray line represents the vessel track.

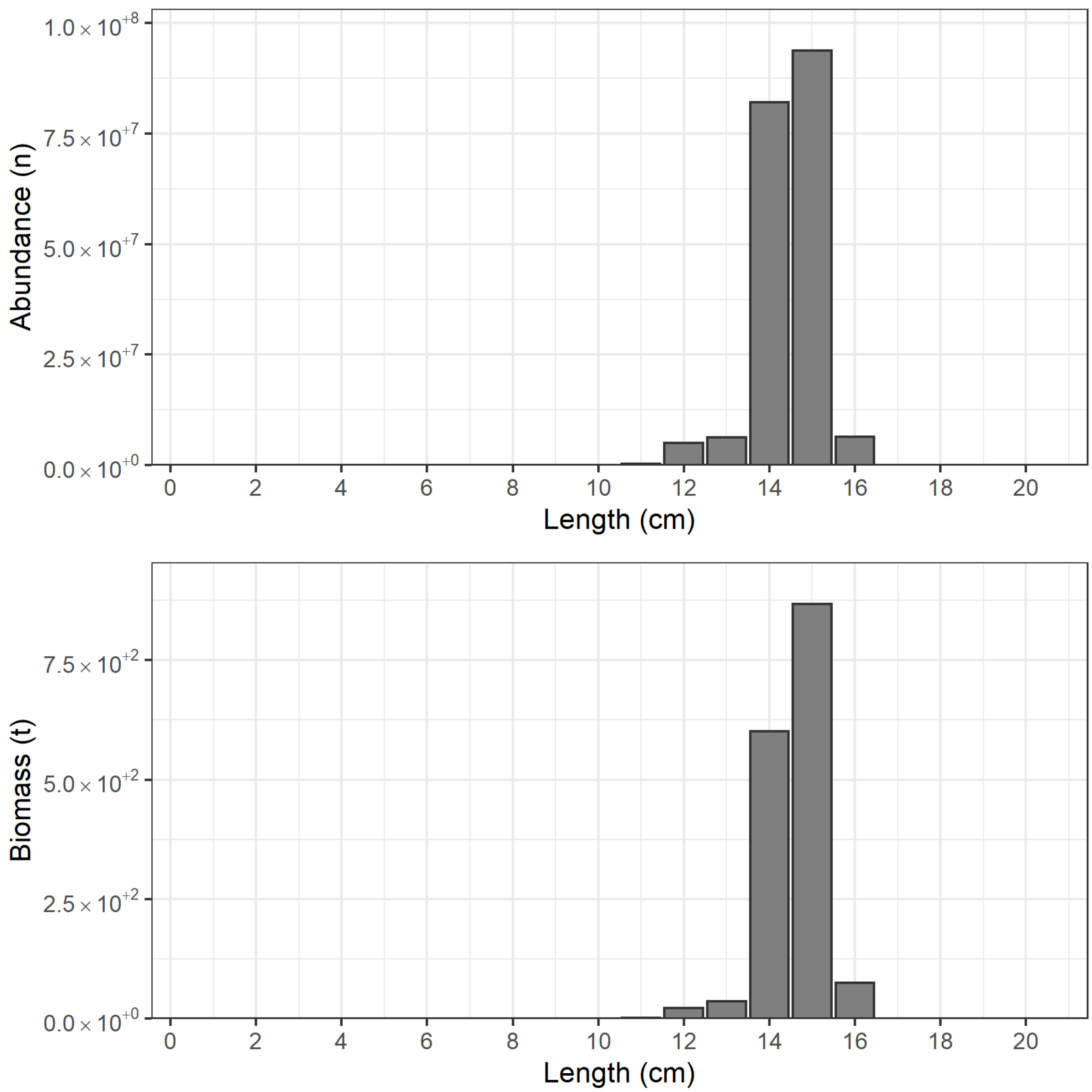


Figure 16: Abundance (n, number of fish) versus standard length (L_S, upper panel) and biomass (t) versus L_S (lower panel) for the northern stock of Northern Anchovy (*Engraulis mordax*) in the survey region.

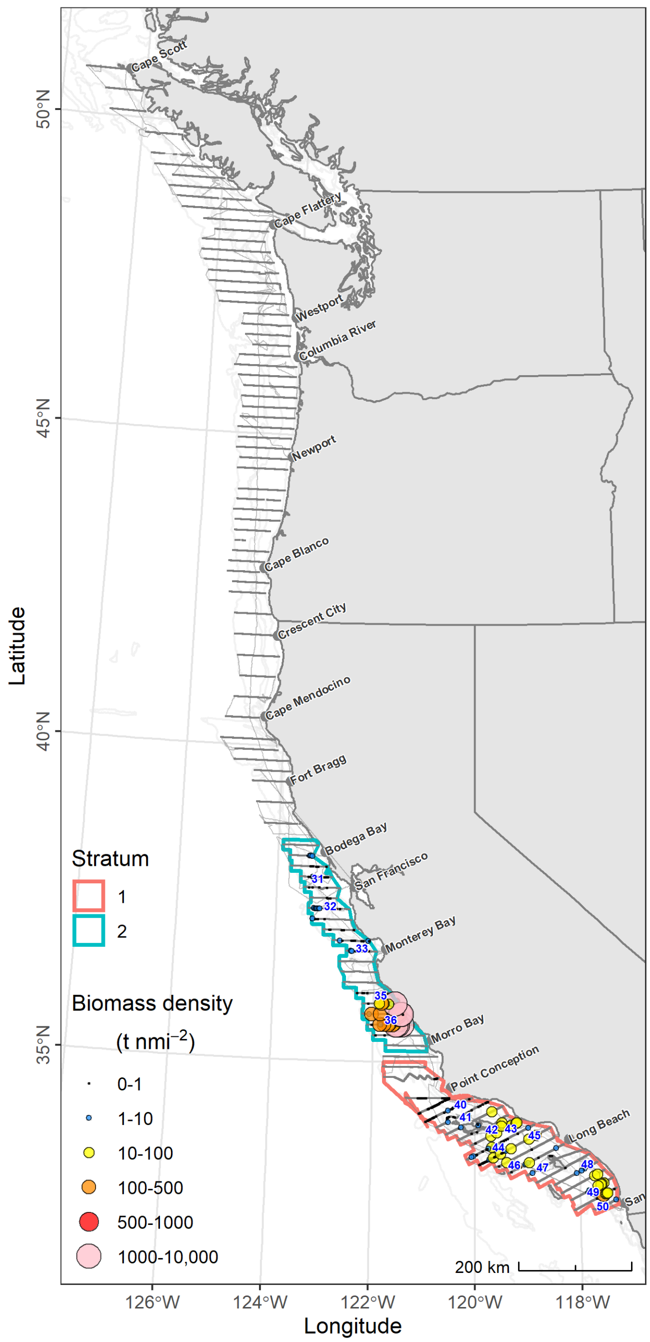


Figure 17: Biomass densities of the central stock of Northern Anchovy (*Engraulis mordax*), per strata, in the survey region. The blue numbers represent the locations of trawl clusters with at least one Northern Anchovy. The gray line represents the vessel track.

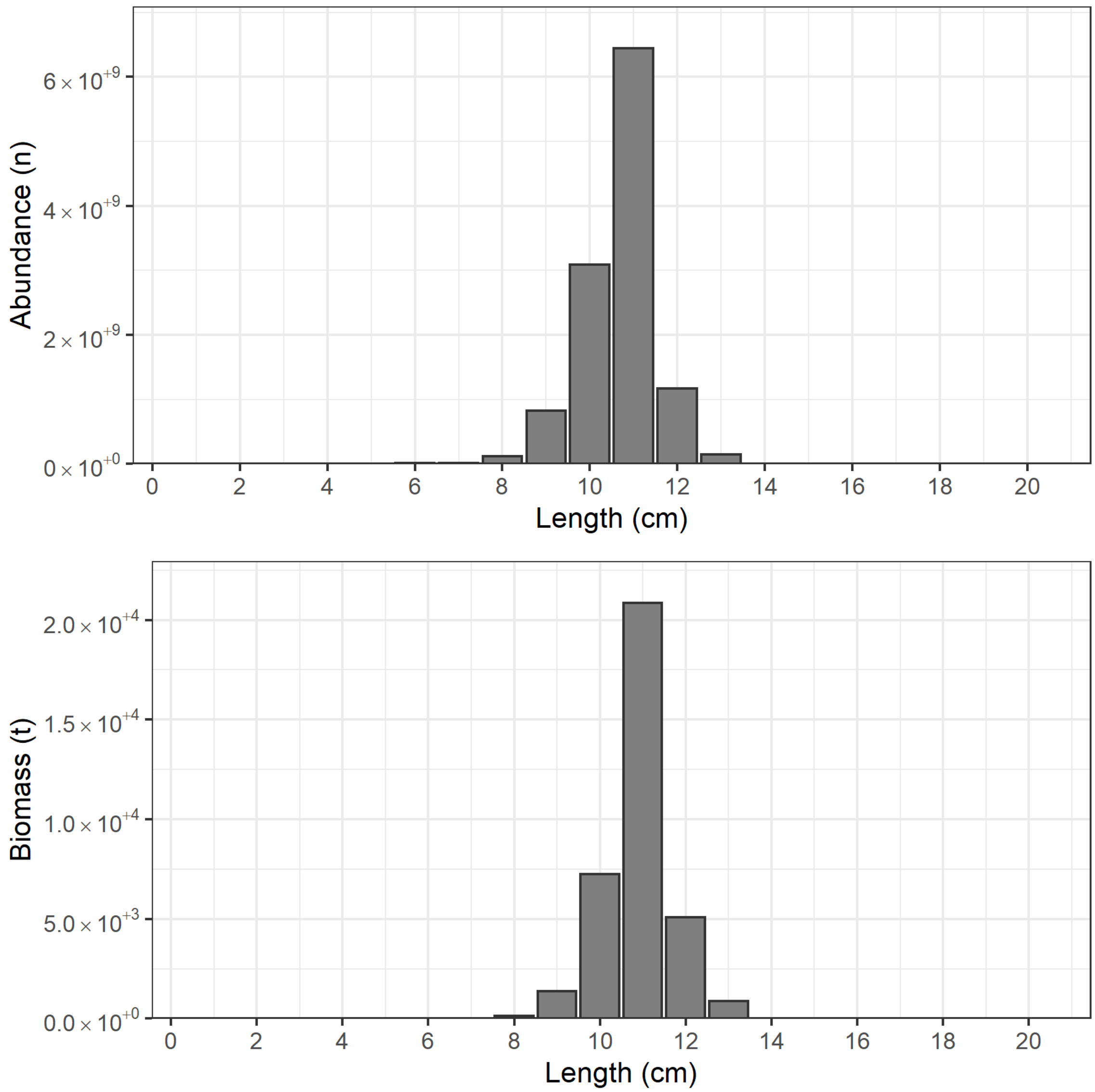


Figure 18: Abundance (n, number of fish) versus L_S (upper panel) and biomass (t) versus L_S (lower panel) for the central stock of Northern Anchovy (*Engraulis mordax*) in the survey region.

3.5.2 Pacific Sardine

3.5.2.1 Northern stock The total estimated biomass of the northern stock of Pacific Sardine was 80,902 t ($CI_{95\%}$ = 10,807 - 142,953 t, CV = 43%; **Table** 6), and was distributed from central Vancouver Island to Morro Bay, but was greatest off Vancouver Island and Big Sur (**Fig.** 19**a**). L_S ranged from 6 to 27 cm with modes at ~19 and 25 cm (**Table** 8, **Fig.** 20). Extrapolation of the northern stock of Pacific Sardine biomass into the unsampled, nearshore waters is presented in **Appendix B.3.2.1**.

Table 6: Biomass estimates (metric tons, t) and their precision (upper and lower 95% confidence intervals, $CI_{95\%}$; and coefficient of variation, CV) for the northern stock of Pacific Sardine (*Sardinops sagax*) in the survey region. Stratum areas are nmi^2.

Species		Stratum				Trawl		Biomass			
Name	Stock	Number	Area	Transects	Distance	Clusters	Individuals	$\hat{B}$	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Sardinops sagax	Northern	3	2,740	7	555	2	8	26,032	71	80,873	89
		4	9,267	20	1,406	5	4,752	832	143	1,434	41
		5	3,030	9	608	1	3,793	5,880	1,900	11,188	43
		6	6,547	13	1,357	4	1,692	987	211	1,811	44
		7	3,862	5	649	1	4,871	47,171	1,029	101,807	58
		All	25,446	54	4,575	13	15,116	80,902	10,807	142,953	43

3.5.2.2 Southern stock The total estimated biomass of the southern stock of Pacific Sardine was 323 t ($CI_{95\%}$ = 11.3 - 663 t, CV = 51%; **Table** 7), and was located in a small area off Los Angeles, CA (**Fig.** 21**a**). L_S ranged from 13 to 20 cm with modes at 15 and 19 cm (**Table** 9, **Fig.** 22). Extrapolation of the southern stock of Pacific Sardine biomass into the unsampled, nearshore waters is presented in **Appendix B.3.2.2**.

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

Species		Stratum				Trawl		Biomass			
Name	Stock	Number	Area	Transects	Distance	Clusters	Individuals	$\hat{B}$	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Sardinops sagax	Southern	1	1,105	3	233	1	1	11	0	29	73
		2	3,239	5	656	2	30	312	0	643	53
		All	4,344	8	890	3	31	323	11	663	51

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

Species	Stock	L_S	Abundance
Sardinops sagax	Northern	1	0
		2	0
		3	0
		4	0
		5	0
		6	1,857,219
		7	5,571,657
		8	0
		9	1,857,219
		10	1,857,219
		11	0
		12	1,857,219
		13	126,054
		14	755,590
		15	11,781,543
		16	92,231,534
		17	412,485,283
		18	223,013,229
		19	358,409,977
		20	5,872,043
		21	782,225
		22	2,497,497
		23	2,127,898
		24	4,212,596
		25	6,160,658
		26	4,589,748
		27	614,217
		28	0
		29	0
		30	0

Table 9: Abundance versus standard length (L_S, cm) for the southern stock of Pacific Sardine (*Sardinops sagax*) in the survey region.

Species	Stock	L_S	Abundance
Sardinops sagax	Southern	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	346,739
		14	720,196
		15	1,036,754
		16	622,052
		17	207,351
		18	795,422
		19	1,176,142
		20	414,701
		21	0
		22	0
		23	0
		24	0
		25	0
		26	0
		27	0
		28	0
		29	0
		30	0

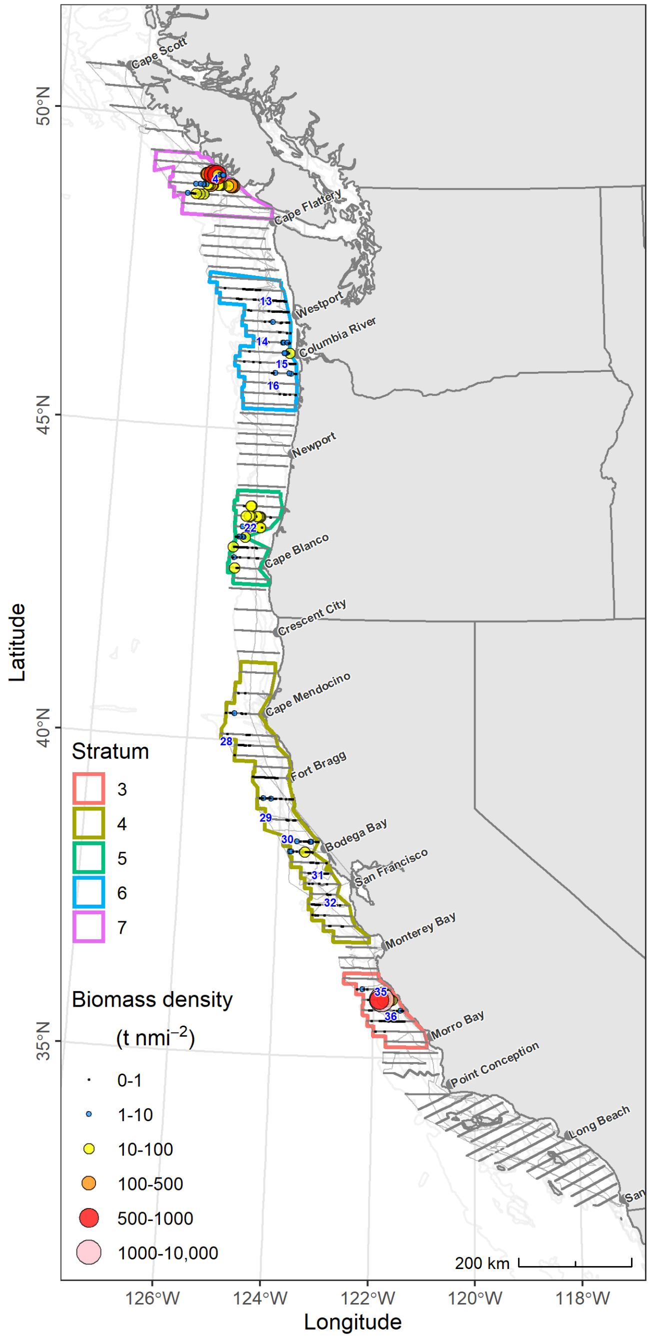


Figure 19: Biomass densities of the northern stock of Pacific Sardine (*Sardinops sagax*), per strata, in the survey region. The blue numbers represent the locations of trawl clusters with at least one Pacific Sardine. The gray line represents the vessel track.

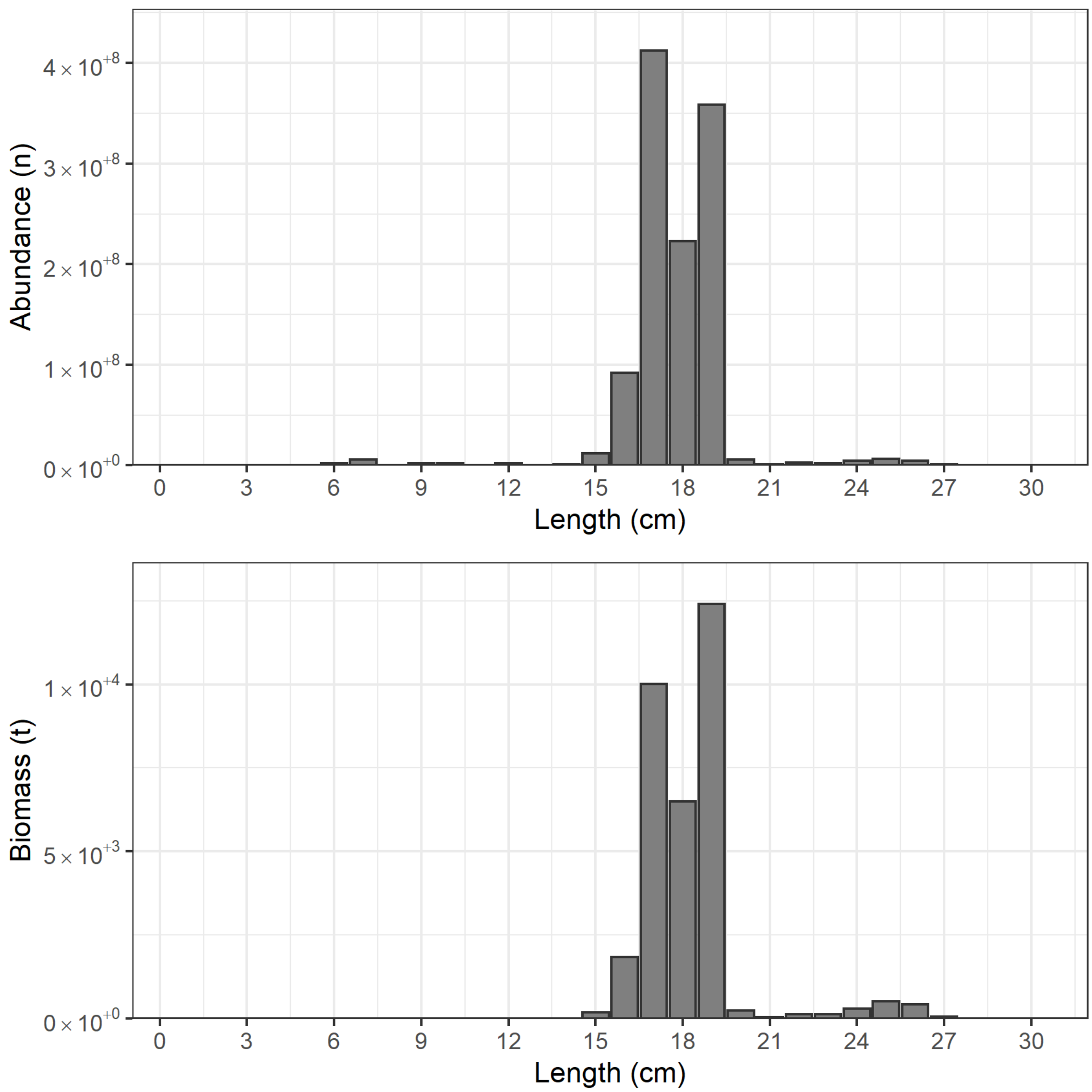


Figure 20: Abundance (n, number of fish) versus L_S (upper panel) and biomass (t) versus L_S (lower panel) for the northern stock of Pacific Sardine (*Sardinops sagax*) in the survey region.

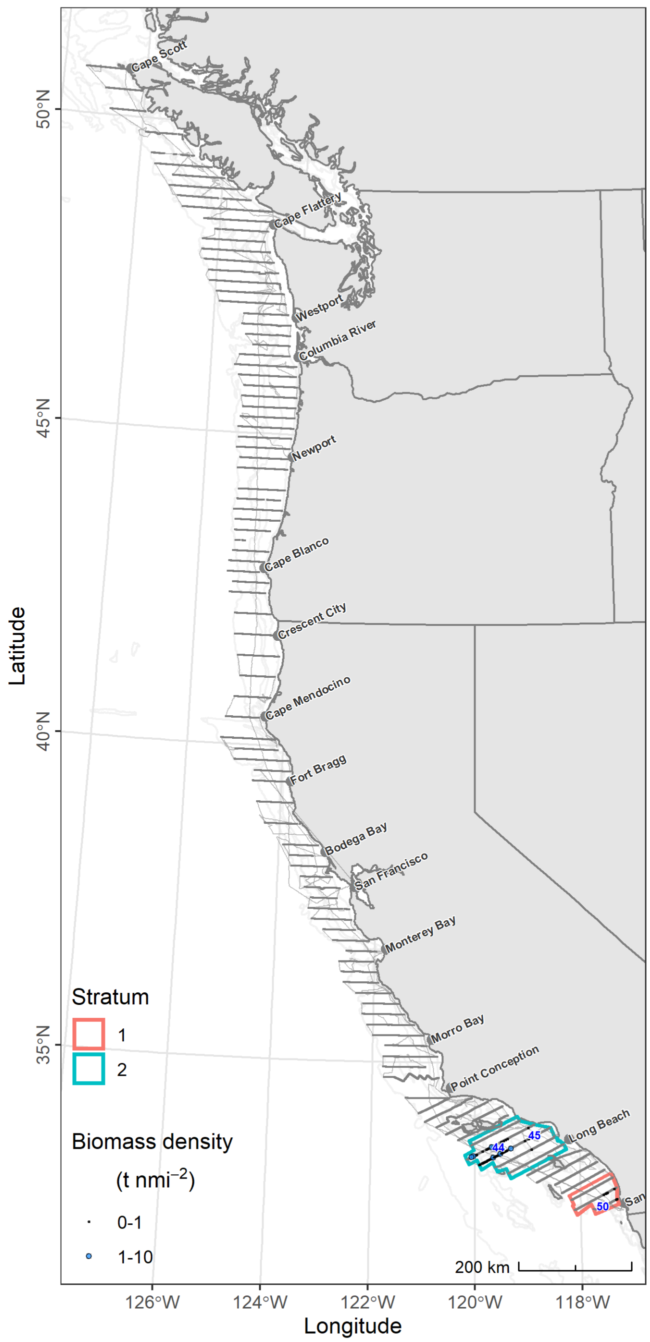


Figure 21: Biomass densities of the southern stock of Pacific Sardine (*Sardinops sagax*), per strata, in the survey region. The blue numbers represent the locations of trawl clusters with at least one Pacific Sardine. The gray line represents the vessel track.

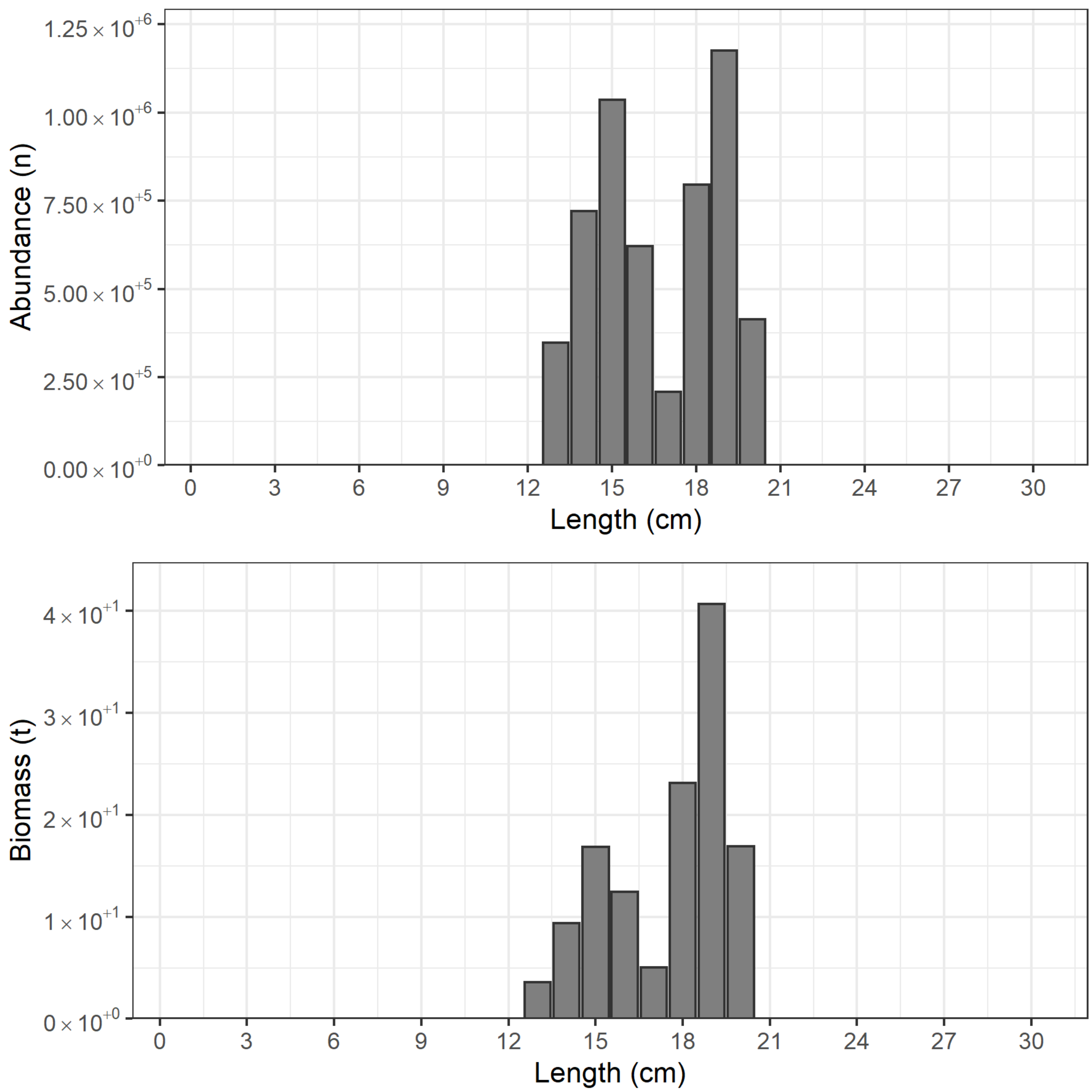


Figure 22: Abundance (n, number of fish) versus L_S (upper panel) and biomass (t) versus L_S (lower panel) for the southern stock of Pacific Sardine (*Sardinops sagax*) in the survey region.

3.5.3 Pacific Mackerel

The total estimated biomass of Pacific Mackerel was 32,956 t ($CI_{95\%}$ = 8,987 - 62,808 t, CV = 43%; **Table** 10), and was distributed throughout the survey area, from central Vancouver Island to San Diego, CA, but was greatest between Big Sur and San Diego, CA (**Fig.** 23**a**). L_F ranged from 8 to 36 cm with modes at 16 and 20 cm (**Table** 11, **Fig.** 24). Extrapolation of the Pacific Mackerel biomass into the unsampled, nearshore waters is presented in **Appendix B.3.3**.

Table 10: Biomass estimates (metric tons, t) and their precision (upper and lower 95% confidence intervals, $CI_{95\%}$; and coefficient of variation, CV) for Pacific Mackerel (*Scomber japonicus*) in the survey region. Stratum areas are nmi^2.

Species		Stratum				Trawl		Biomass			
Name	Stock	Number	Area	Transects	Distance	Clusters	Individuals	$\hat{B}$	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Scomber japonicus	All	1	13,034	25	2,652	10	152	23,970	2,401	55,358	59
		2	9,267	20	1,406	5	11,071	3,317	241	5,999	47
		3	3,030	9	608	1	636	1,865	602	3,548	43
		4	7,715	16	1,560	4	3,185	3,570	1,245	6,404	37
		5	2,531	4	507	1	8	103	0	258	68
		6	3,862	5	649	1	7	131	3	283	58
		All	39,439	79	7,382	22	15,059	32,956	8,987	62,808	43

Table 11: Abundance versus fork length (L_F, cm) for Pacific Mackerel (*Scomber japonicus*) in the survey region.

Species	Stock	L_F	Abundance
Scomber japonicus	All	1	0
		2	0
		3	0
		4	0
		5	0
		6	0
		7	0
		8	4,135,821
		9	0
		10	4,098,923
		11	495,151
		12	10,535
		13	513,877
		14	3,400,322
		15	140,120,589
		16	140,445,042
		17	564,583
		18	222,671
		19	2,221,024
		20	144,282,995
		21	12,701,738
		22	11,239,310
		23	11,193,303
		24	12,680,136
		25	4,932,855
		26	1,262,309
		27	792,413
		28	557,164
		29	1,034,678
		30	1,312,438
		31	1,617,476
		32	1,796,605
		33	1,306,108
		34	0
		35	89,120
		36	178,241
		37	0
		38	0
		39	0
		40	0

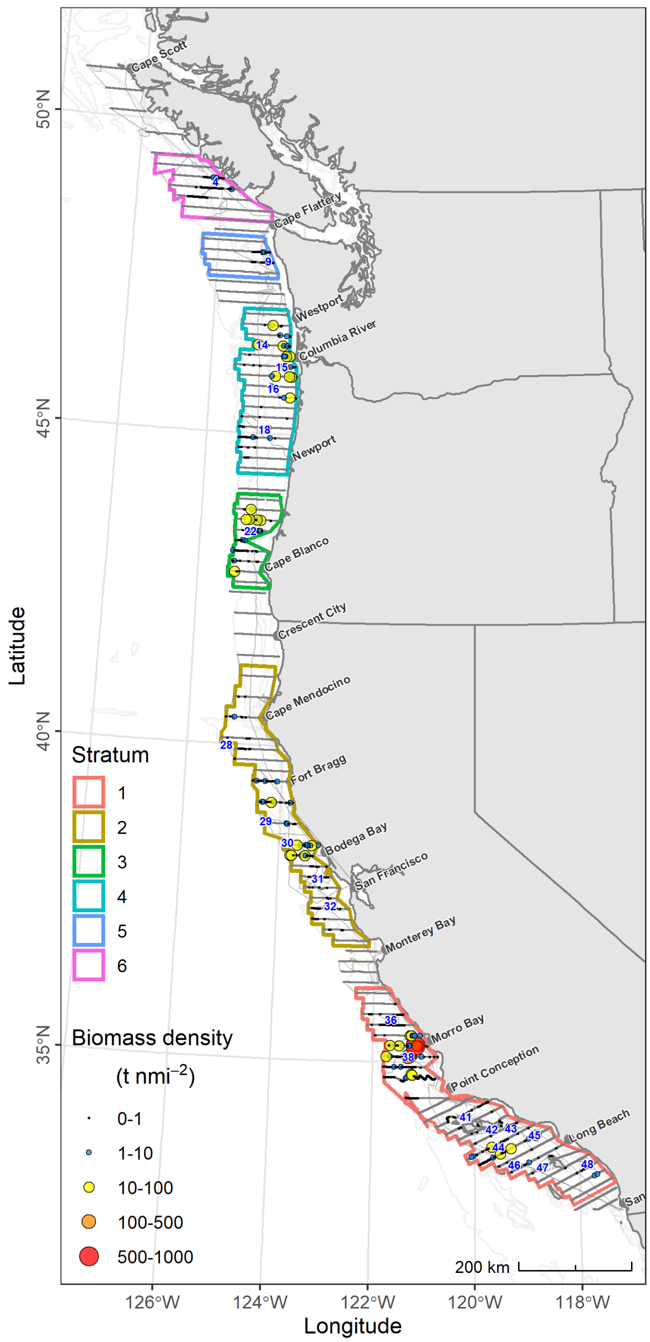


Figure 23: Biomass densities of Pacific Mackerel (*Scomber japonicus*), per strata, in the survey region. The blue numbers represent the locations of trawl clusters with at least one Pacific Mackerel. The gray line represents the vessel track.

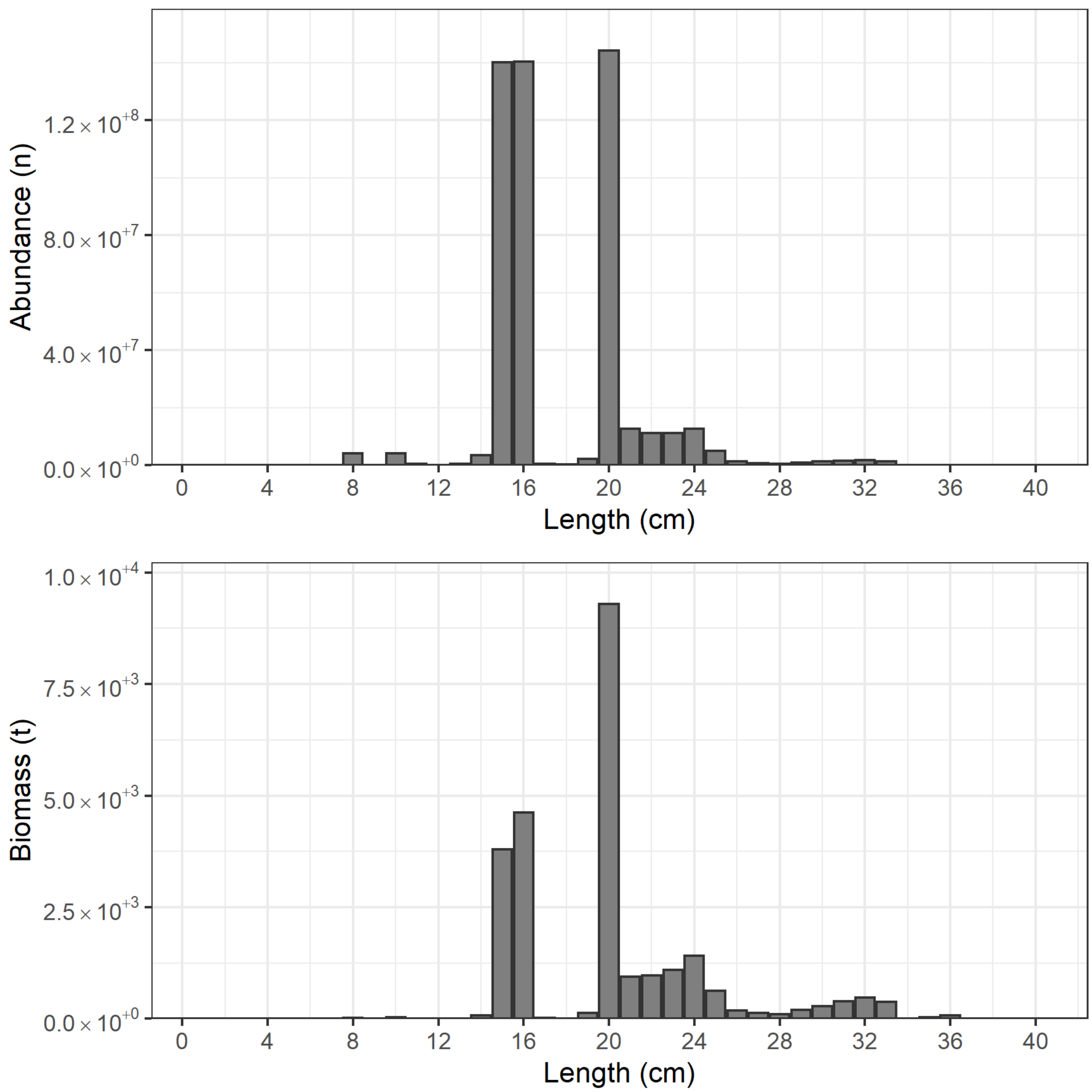


Figure 24: Abundance (n, number of fish) versus standard length (L_S, upper panel) and biomass (t) versus L_F (lower panel) for Pacific Mackerel (*Scomber japonicus*) in the survey region.

3.5.4 Jack Mackerel

The total estimated biomass of Jack Mackerel was 134,989 t ($CI_{95\%}$ = 70,359 - 199,265 t, CV = 25%; **Table 12**), and was distributed throughout the survey area, but biomass was greatest between Cape Flattery and Crescent City, CA (**Fig. 25a**). L_F ranged from 5 to 56 cm, with modes at 12, 28, and 50 cm (**Table 13**, **Fig. 26**). Extrapolation of the Jack Mackerel biomass into the unsampled, nearshore waters is presented in **Appendix B.3.4**.

Table 12: Biomass estimates (metric tons, t) and their precision (upper and lower 95% confidence intervals, $CI_{95\%}$; and coefficient of variation, CV) for Jack Mackerel (*Trachurus symmetricus*) in the survey region. Stratum areas are nmi^2.

Species		Stratum				Trawl		Biomass			
Name	Stock	Number	Area	Transects	Distance	Clusters	Individuals	$\hat{B}$	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Trachurus symmetricus	All	1	8,136	15	1,732	7	101	1,054	324	1,866	37
		2	3,381	10	689	3	120	13,982	28	41,981	91
		3	5,593	13	920	5	7,544	1,773	652	2,833	31
		4	4,184	6	423	3	2,332	8,363	3,369	14,846	35
		5	23,375	45	4,418	12	12,601	109,817	50,673	169,884	28
		All	44,670	89	8,183	27	22,697	134,989	70,359	199,265	25

Table 13: Abundance versus fork length (L_F, cm) for Jack Mackerel (*Trachurus symmetricus*) in the survey region.

Species	Stock	L_F	Abundance
		1	0
		2	0
		3	0
		4	0
		5	11,725,663
		6	3,908,554
		7	3,908,554
		8	452,563,292
		9	317,553,012
		10	1,821,969
		11	316,682,423
		12	316,606,529
		13	1,830,585
		14	3,837,639
		15	10,299,441
		16	2,293,114
		17	1,293,918
		18	1,760,463
		19	4,913,905
		20	7,098,344
		21	8,789,513
		22	8,545,697
		23	6,188,791
		24	38,684,185
		25	6,260,209
		26	53,169,228
		27	23,345,048
		28	70,512,764
		29	34,075,281
		30	15,886,546
		31	8,352,145
		32	210,370
		33	0
		34	0
		35	0
		36	43,729
		37	0
		38	0
		39	0
		40	0
		41	1,254,492
		42	195,010
		43	2,452,189
		44	1,547,006
		45	2,469,896
		46	97,505
		47	0
		48	97,505
		49	195,010
		50	22,561,931

Table 13: Abundance versus fork length (L_F, cm) for Jack Mackerel (*Trachurus symmetricus*) in the survey region. *(continued)*

Species	Stock	L_F	Abundance
		51	7,149,712
		52	0
		53	0
		54	2,005,227
		55	0
		56	1,254,492
		57	0
		58	0
		59	0
		60	0

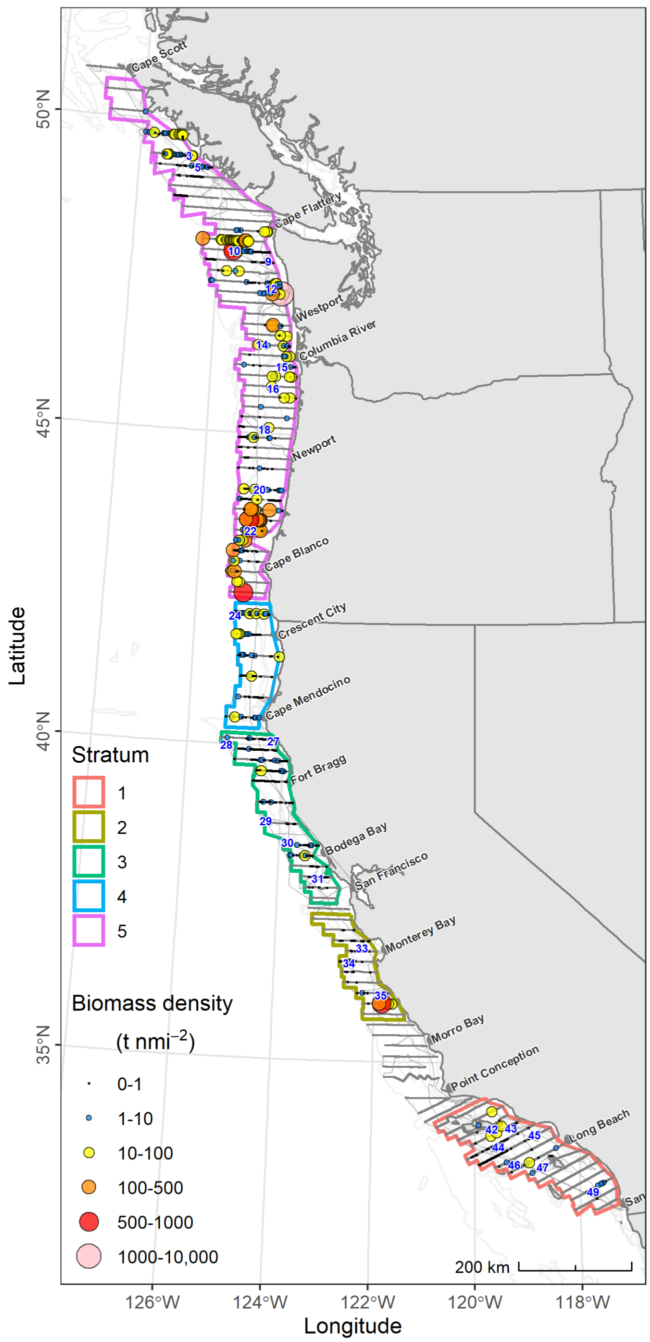


Figure 25: Biomass densities of Jack Mackerel (*Trachurus symmetricus*), per strata, in the survey region. The blue numbers represent the locations of trawl clusters with at least one Jack Mackerel. The gray line represents the vessel track.

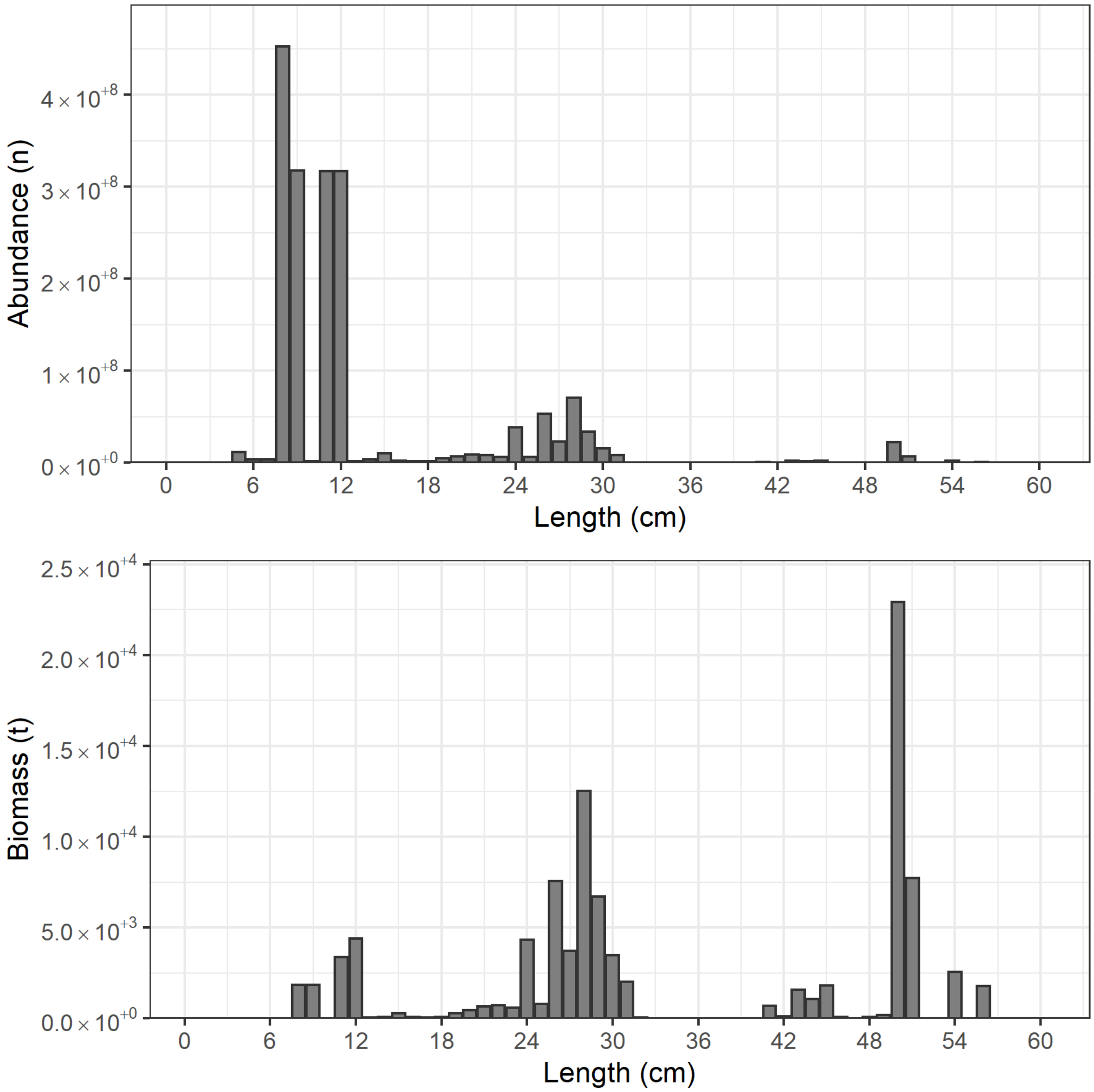


Figure 26: Abundance (n, number of fish) versus L_F (upper panel) and biomass (t) versus L_F (lower panel) for Jack Mackerel (*Trachurus symmetricus*) in the survey region.

3.5.5 Pacific Herring

The total estimated biomass of Pacific Herring was 68,466 t ($CI_{95\%}$ = 46,829 - 99,009 t, CV = 20%; **Table** 14), and was distributed from approximately Cape Scott to Coos Bay, OR, but biomass was greatest between central Vancouver Island and Westport, WA (**Fig.** 27**a**). L_F ranged from 6 to 24 cm with a broad distribution between 16 and 22 cm (**Table** 15, **Fig.** 28). Extrapolation of the Pacific Herring biomass into the unsampled, nearshore waters is presented in **Appendix B.3.5**.

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

Species		Stratum				Trawl		Biomass			
Name	Stock	Number	Area	Transects	Distance	Clusters	Individuals	$\hat{B}$	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Clupea pallasii	All	1	4,615	9	840	2	54	1,583	370	3,331	50
		2	2,853	6	578	1	4	2	0	3	41
		3	10,391	17	2,055	9	2,208	53,446	32,082	83,348	25
		4	2,768	4	294	2	143	13,436	9,298	17,887	16
		All	20,626	36	3,767	13	2,409	68,466	46,829	99,009	20

Table 15: Abundance versus fork length (L_F, cm) for Pacific Herring (*Clupea pallasii*) in the survey region.

Species	Stock	L_F	Abundance
Clupea pallasii	All	1	0
		2	0
		3	0
		4	0
		5	0
		6	852,443
		7	852,443
		8	35,673,834
		9	2,197,770
		10	116,757
		11	0
		12	0
		13	0
		14	18,883,659
		15	44,200,317
		16	123,583,484
		17	109,325,538
		18	89,620,176
		19	122,065,716
		20	138,828,036
		21	101,908,437
		22	112,239,036
		23	23,793,839
		24	852,443
		25	0
		26	0
		27	0
		28	0
		29	0
		30	0

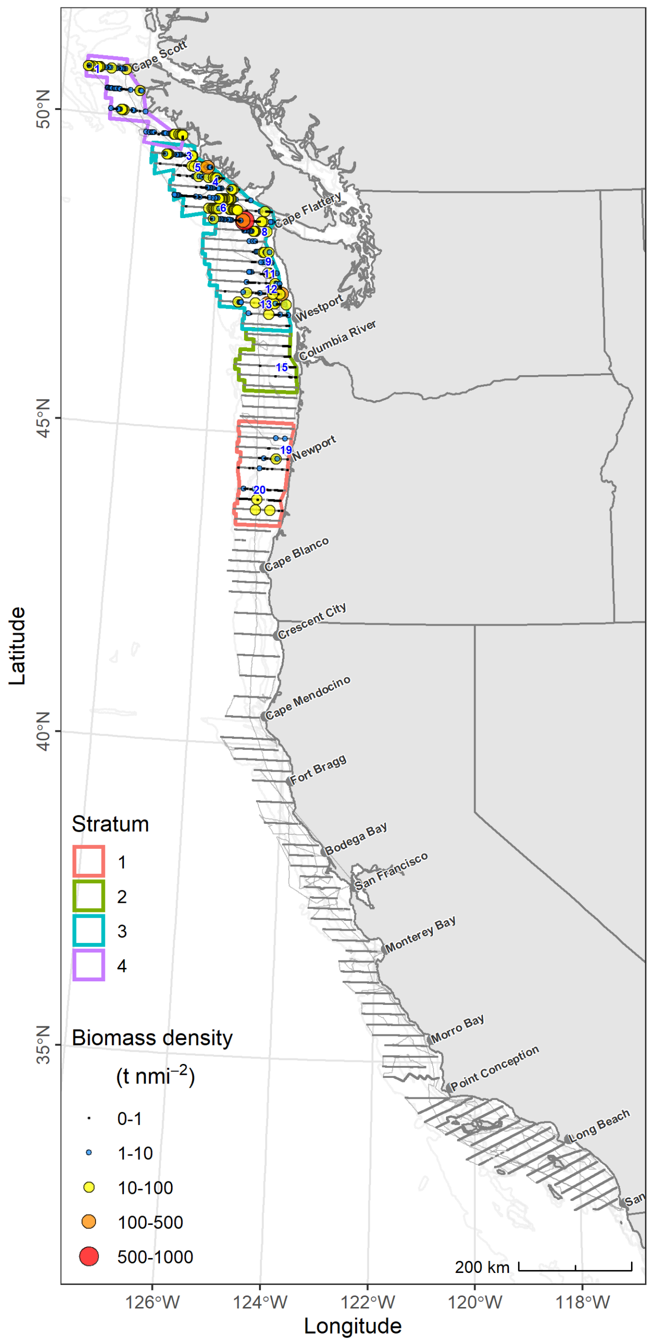
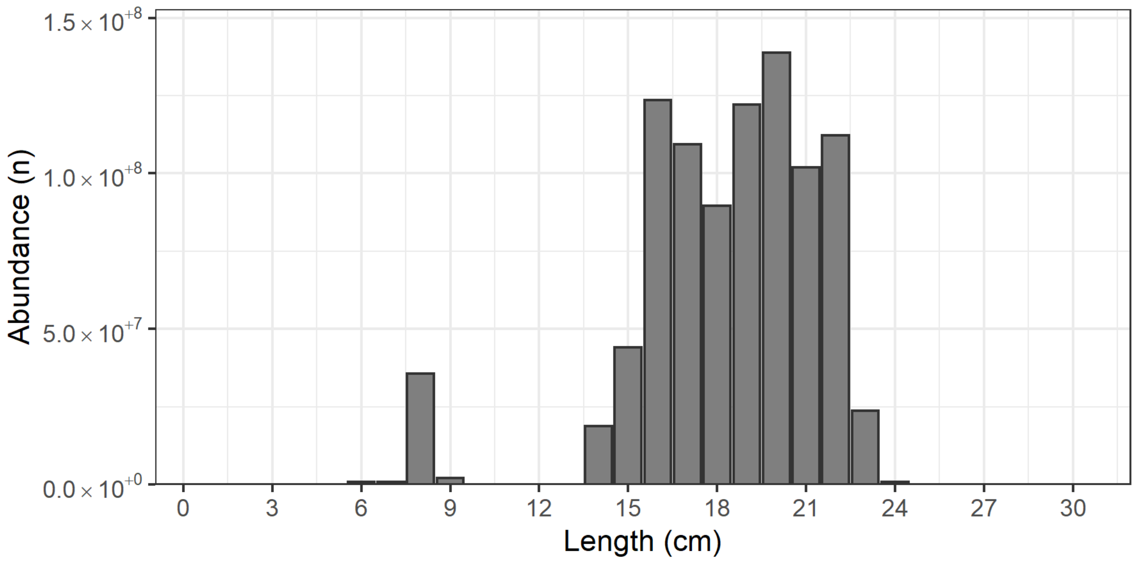


Figure 27: Biomass densities of Pacific Herring (*Clupea pallasii*), per strata, in the survey region. The blue numbers represent the locations of trawl clusters with at least one Pacific Herring. The gray line represents the vessel track.



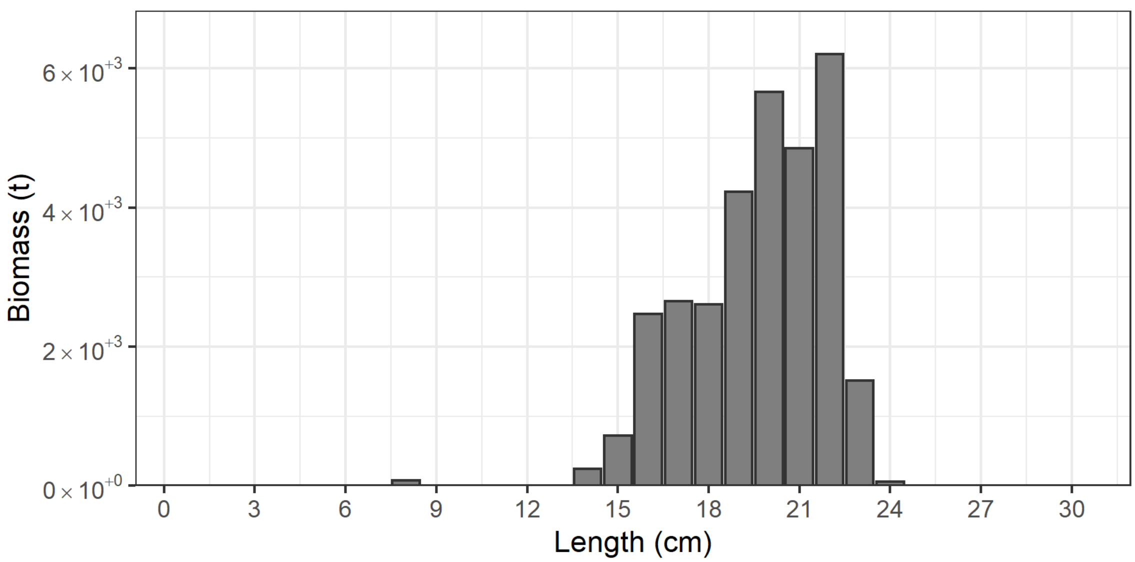


Figure 28: Abundance (n, number of fish) versus L_F (upper panel) and biomass (t) versus L_F (lower panel) for Pacific Herring (*Clupea pallasii*) in the survey region.

4 Discussion

The principal objectives of the 80-day, summer 2016 CCE survey were to survey the northern stock of Pacific Sardine and the northern and central stocks of Northern Anchovy. Then, as possible, estimates were also sought for Pacific Mackerel, Jack Mackerel, Pacific Herring, and the southern stock of Pacific Sardine. *Lasker* surveyed from the northern end of Vancouver Island, BC to San Diego, CA. Between the Strait of Juan de Fuca and Cape Mendocino, the 10-nmi transect spacing allowed the estimation of abundance for all five species of small pelagic fishes 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. Few Pacific Sardine from the southern stock were sampled in the SCB during the survey.

This analysis was conducted during 2020 using methods developed in 2017 for consistency in calculations and reporting of ATM-survey results. Any minor differences between these and previously reported results are explained by differences in target strength models used (i.e., for Northern Anchovy and Pacific Herring), automated and more consistent post-strata definitions, and improved echo classification methods.

4.1 Biomass and abundance of CPS

4.1.1 Northern Anchovy

4.1.1.1 Northern stock The northern stock of Northern Anchovy is north of Cape Mendocino and south of Haida Gwaii, BC [~54 °N; Litz *et al.* (2008)]. In summer 2016, the estimated stock biomass, 6,575 t ($CI_{95\%}$ = 2,479.8 - 11,596 t), was within the range of estimates during subsequent years, which has varied from 1,512 t in 2019 (Stierhoff *et al.*, 2020) to 24,419 t in 2018 (Stierhoff *et al.*, 2019).

4.1.1.2 Central stock The estimated biomass of the central stock of Northern Anchovy, found south of Cape Mendocino, CA was 150,907 t ($CI_{95\%}$ = 32,843 - 317,457 t) in summer 2016, which is similar to summer the 2017 estimate (153,460 t, Zwolinski *et al.*, 2019), but is nearly five-fold less than those observed in 2018 (723,826 t, Stierhoff *et al.*, 2019) and 2019 (769,154 t, Stierhoff *et al.*, 2020). The summer 2016 estimate, presented here, was also not significantly different than the estimate of 151,558 t (CV = 41%) presented in Zwolinski et al. (2017). The length distribution of the stock in summer 2016 had one mode at 11 cm, indicating the presence of only one dominant year-class.

4.1.2 Pacific Sardine

4.1.2.1 Northern stock The summer 2016 survey sampled most of the potential habitat for the northern stock of Pacific Sardine, and likely most of the stock. In summer 2016, the estimated stock biomass was 80,902 t ($CI_{95\%}$ = 10,807 - 142,953 t), which was not significantly different that the estimate of 78,776 t (CV=54%) presented in Hill et al. (2017). Since 2016, biomass has remained relatively low and constant at approximately 25,000-35,000 t between 2017 and 2019 (Stierhoff *et al.*, 2020). Similar to summer 2015, the biomass for Pacific Sardine with lengths less than 15 cm was low, which indicates poor recruitment success. Accordingly, the stock abundance and biomass declined the following year in 2017, and the modal length increased from 17-19 to 21-23 cm.

In recent years, the distribution of the northern stock of Pacific Sardine has been fragmented and its migration has been abbreviated. Despite the recurrent presence of good potential habitat north of Vancouver Island during the summer months (see **Fig.** 2), the stock has not migrated there since 2013 (Stierhoff *et al.*, 2020; Zwolinski *et al.*, 2014).

4.1.2.2 Southern stock A small amount of biomass attributed to the southern stock of Pacific Sardine was observed in an isolated area near the northern Channel Islands off the coast of Los Angeles.

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 32,956 t ($CI_{95\%}$ = 8,987 - 62,808 t) in 2016; the species was distributed between Westport and Cape Blanco in the north and between Big Sur and Pt. Conception in the south. Since 2016, biomass has remained relatively low but constant, ranging from 24,643 t in 2019 (Stierhoff *et al.*, 2020) to 41,139 t in 2017 (Zwolinski *et al.*, 2019), and was broadly distributed off the west coast of the U.S., but predominantly between Westport and Long Beach. Their length distribution had modes at ~15-16 and ~20 cm, which are indicative of two distinct cohorts. A relatively small amount of biomass in size classes approaching the maximum length for Pacific Mackerel probably includes fish from multiple year classes.

4.1.4 Jack Mackerel

The biomass of Jack Mackerel in summer 2016 was 134,989 t ($CI_{95\%}$ = 70,359 - 199,265 t), which was a substantial increase from the 9,000 t estimated in the summer 2013 (Zwolinski *et al.*, 2014), comparable to estimates from summer 2017 (128,313 t, Zwolinski *et al.*, 2019), but considerably lower than that observed in the summers of 2018 (202,471 t, Stierhoff *et al.*, 2019) and 2019 (385,801 t, Stierhoff *et al.*, 2020). Their length distribution had three distinct modes (~12, 28, and 50 cm) indicating the presence of several distinct year classes. Jack Mackerel was the second most abundant species overall. Its biomass was distributed throughout the survey area from Vancouver Island to San Diego, but was most abundant between Cape Flattery and the Columbia River, and around Cape Blanco.

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 Washington, separated by spawning times and locations (DFO, 2017; Stick *et al.*, 2014). The Yaquina Bay and Winchester Bay stocks inhabit waters between Newport and Cape Blanco (ODFW, 2013). The estimated biomass of Pacific Herring off the coast of Vancouver Island, Washington, and Oregon was 68,466 t ($CI_{95\%}$ = 46,829 - 99,009 t). Between 2017 and 2019, biomass of Pacific Herring has varied between 63,418 t in 2017 (Zwolinski *et al.*, 2019) and 267,792 t in 2019 (Stierhoff *et al.*, 2020).

4.2 Ecosystem dynamics: Forage fish community

The acoustic-trawl method (ATM) has been used worldwide to monitor the biomasses and distributions of pelagic and mid-water fish stocks worldwide (e.g., Coetzee *et al.*, 2008; Karp and Walters, 1994; Simmonds *et al.*, 2009). In the CCE, ATM surveys have been used to directly estimate biomasses 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 (Mais, 1974, 1977; Stierhoff *et al.*, 2020). Focused initially, in 2006, on Pacific Sardine (Cutter and Demer, 2008), the SWFSC's ATM surveys of CPS in the CCE have evolved to estimate the biomasses of the five most abundant forage-fish species (Zwolinski *et al.*, 2014): Pacific Sardine, Northern Anchovy, Jack Mackerel, Pacific Mackerel, and Pacific Herring. The proportions of these stocks that are in water too shallow to be sampled by NOAA ships are estimated using extrapolations of samples collected offshore, or samples collected nearshore from fishing vessels and unmanned surface vehicles (USVs). Also, concurrent satellite- and ship-based measures of their biotic and abiotic habitats are used to provide an ecosystem perspective.

Collectively, these annual or bi-annual ATM surveys provide a unique insight into the dynamics of forage fishes in the CCE, including their distributions, abundances, interactions, and environments. For example, results from 2006 through 2013 indicate that Pacific Sardine dominated the CPS assemblage, but their biomass was declining (Demer and Zwolinski, 2012; Zwolinski and Demer, 2012) and their seasonal migration was contracting (Zwolinski *et al.*, 2014). Meanwhile, harvest rates for the declining stock increased (Demer and Zwolinski, 2017), and the total forage-fish biomass decreased to less than 200,000 t in 2014 and 2015 (**Figs. 29, 30**). The U.S. fishery for Pacific Sardine was closed in 2015 (National Marine Fisheries Service, 2015), and there were reports of mass strandings, deaths, and reproductive failures in Brown Pelicans (*Pelecanus occidentalis*[3]), Common Murres (*Uria aalge*), Brandt's Cormorants (*Phalacrocorax penicillatus*), and California sea lions (*Zalophus californianus*[4]) (McClatchie *et al.*, 2016), all of which depend on forage species. Since 2016, the forage-fish biomass has increased, mainly due to resurgences of Jack Mackerel and the now dominant central stock of Northern Anchovy (**Figs. 29, 30**).

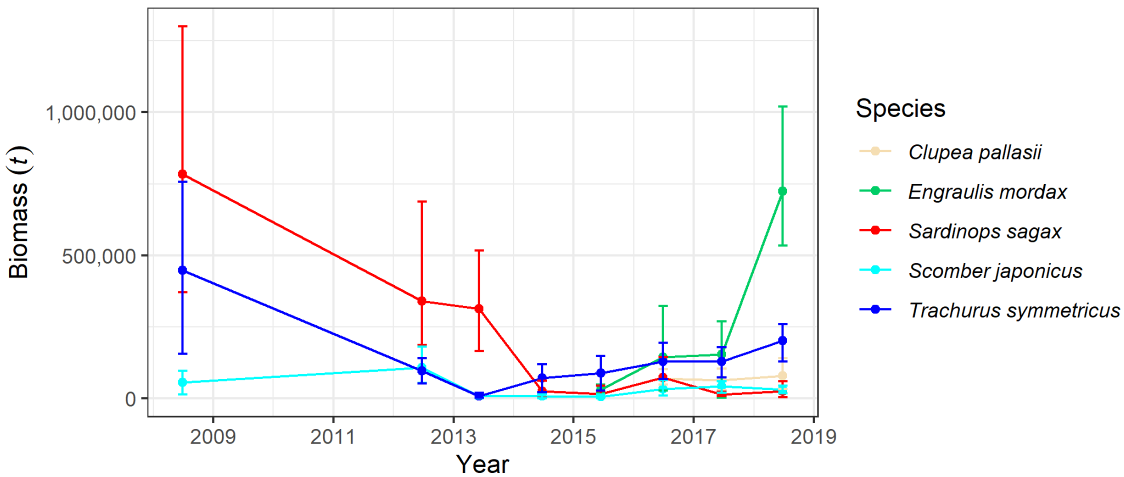


Figure 29: Estimated biomasses (t) of CPS in the CCE since 2008. Error bars are 95% confidence intervals.

[3]https://e360.yale.edu/features/brown_pelicans_a_test_case_for_the_endangered_species_act
[4]https://www.fisheries.noaa.gov/national/marine-life-distress/2013-2017-california-sea-lion-unusual-mortality-event-california

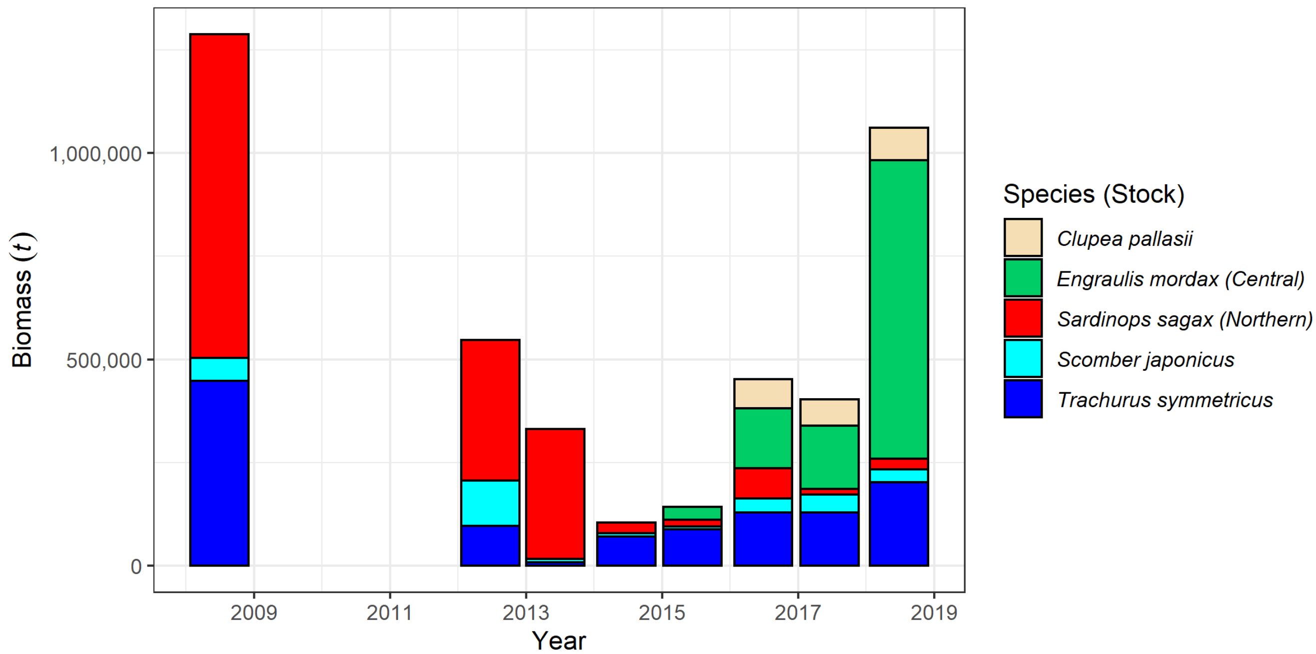


Figure 30: Cumulative biomass (t) for the five most abundant CPS in the CCE during summer. The forage-fish assemblage was dominated by Pacific Sardine prior to 2014 and by the central stock of Northern Anchovy after 2015. During the transition period with minimum forage-fish biomass, the U.S. fishery for Pacific Sardine was closed, NOAA recognized an unusual mortality event for California Sea lions, and multiple species of seabirds experienced reproductive failures.

4.3 Conclusion

The acoustic-trawl method (ATM) has 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; Kuriyama *et al.*, 2020; Mais, 1974, 1977). Since 2006, ATM surveys of CPS have been evolving into more comprehensive ecosystem surveys (Cutter and Demer, 2008; Zwolinski *et al.*, 2014). The survey now provides direct estimates of the five principal species of small pelagic fishes in the CCE.

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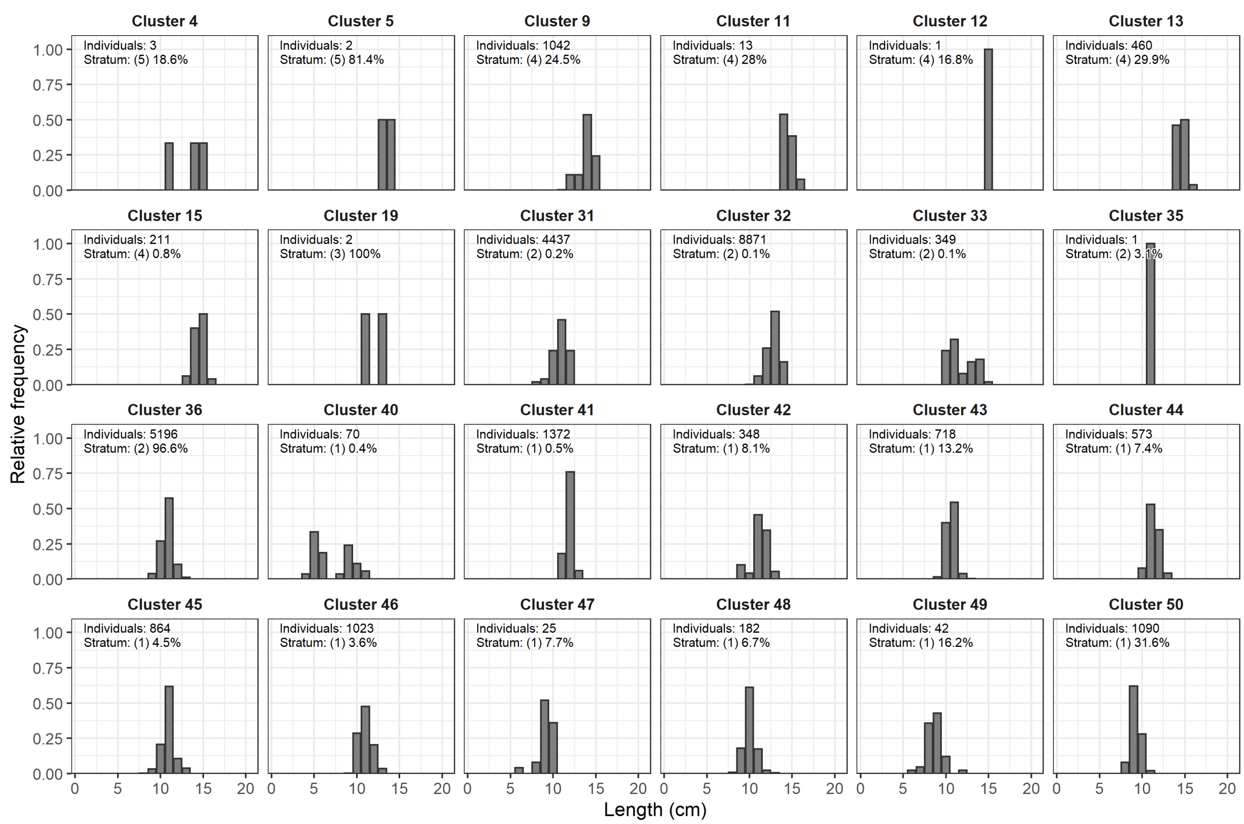
Appendix

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

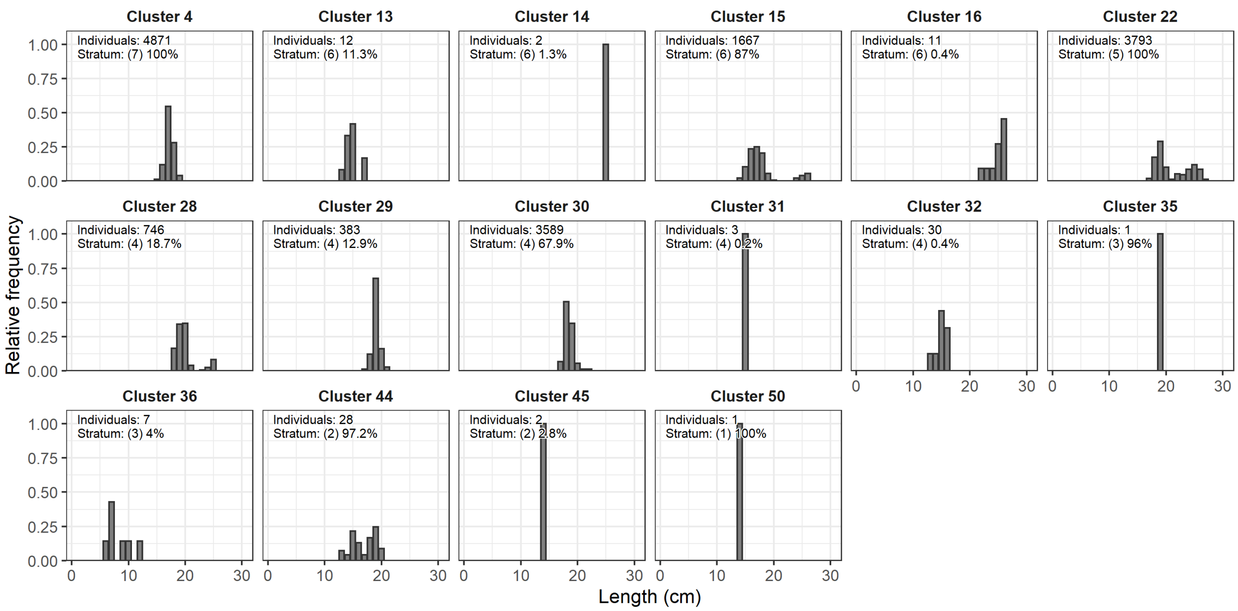
A.1 Northern Anchovy

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. per nighttime trawl cluster, annotated with the number of individuals caught and their percentage contributions to the abundance in each stratum. Stratum contributions to the entire survey are obtained by summing percentages across respective strata.



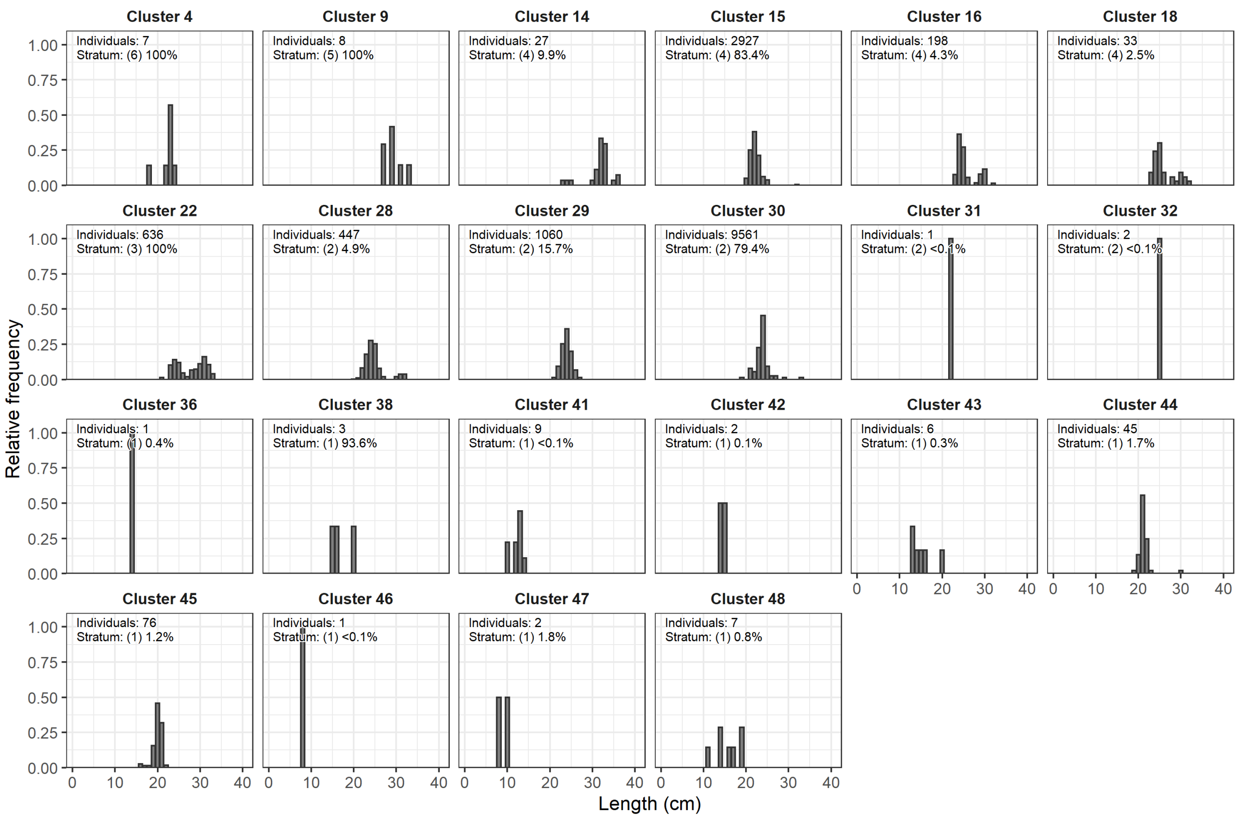
A.2 Pacific Sardine

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. per nighttime trawl cluster, annotated with the number of individuals caught and their percentage contributions to the abundance in each stratum. Stratum contributions to the entire survey are obtained by summing percentages across respective strata.



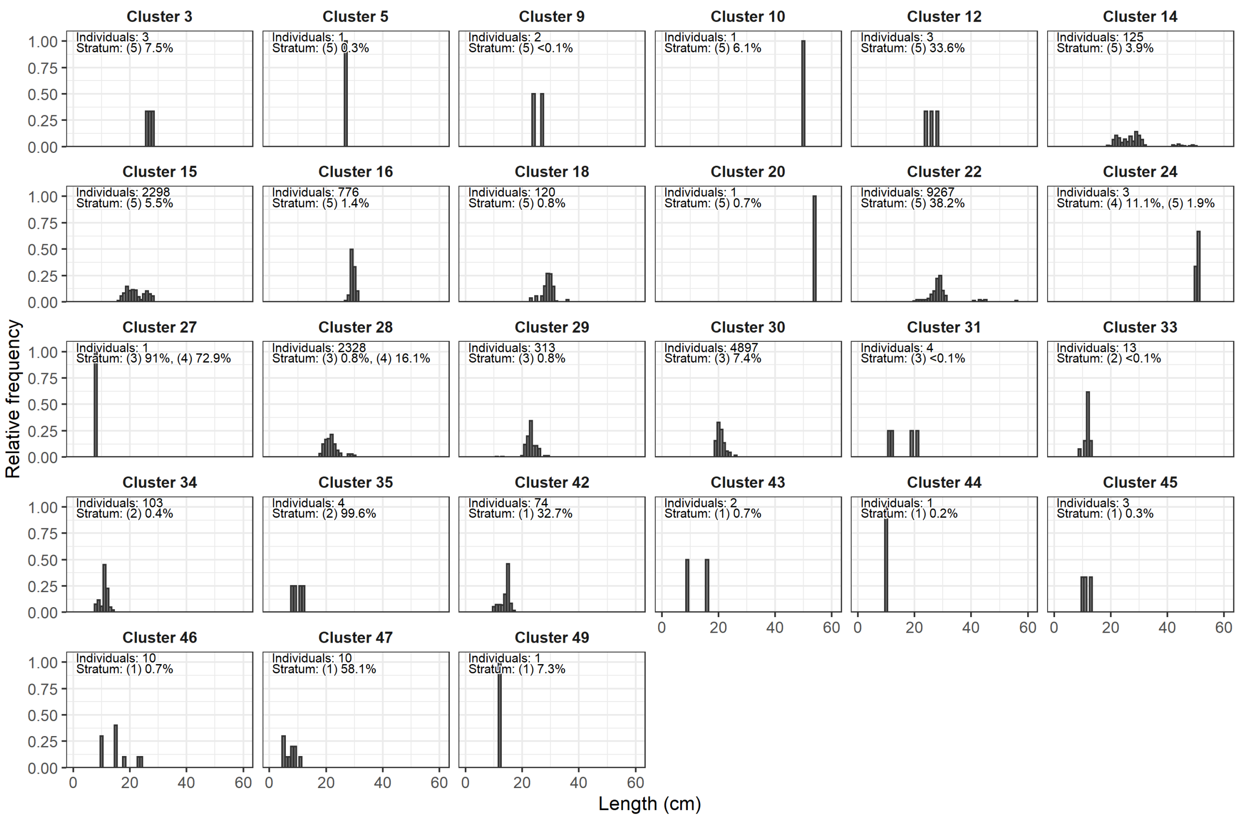
A.3 Pacific Mackerel

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. per nighttime trawl cluster, annotated with the number of individuals caught and their percentage contributions to the abundance in each stratum. Stratum contributions to the entire survey are obtained by summing percentages across respective strata.



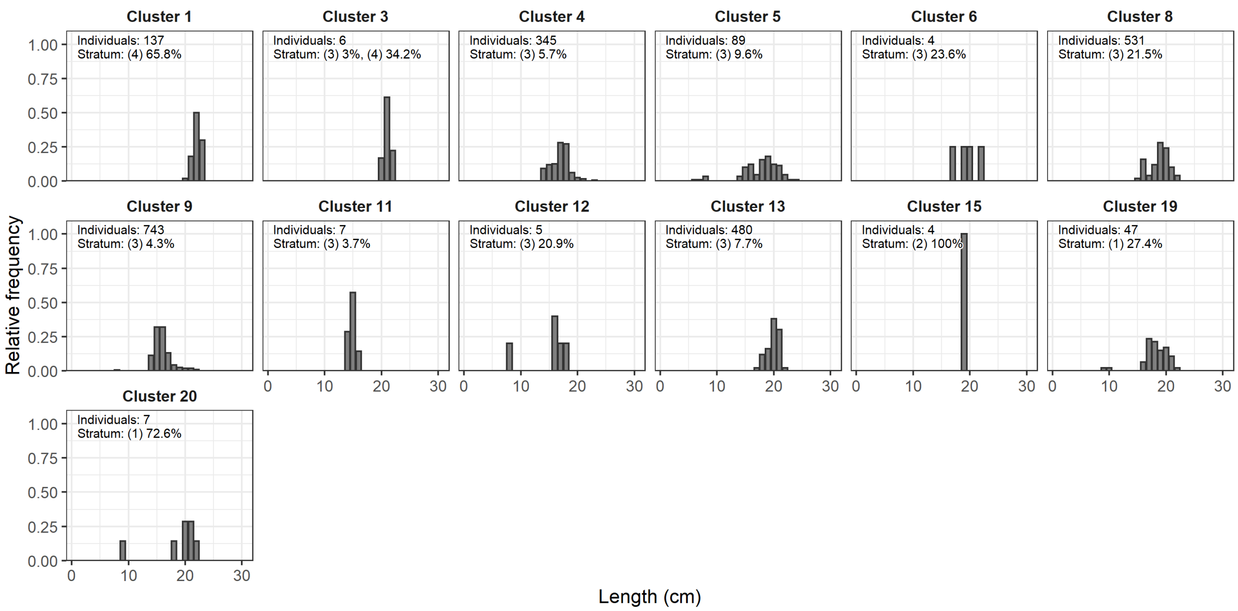
A.4 Jack Mackerel

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. per nighttime trawl cluster, annotated with the number of individuals caught and their percentage contributions to the abundance in each stratum. Stratum contributions to the entire survey are obtained by summing percentages across respective strata.



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. per nighttime trawl cluster, annotated with the number of individuals caught and their percentage contributions to the abundance in each stratum. Stratum contributions to the entire survey are obtained by summing percentages across respective strata.



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 ship did not sample, the survey data was 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. 31**). 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).

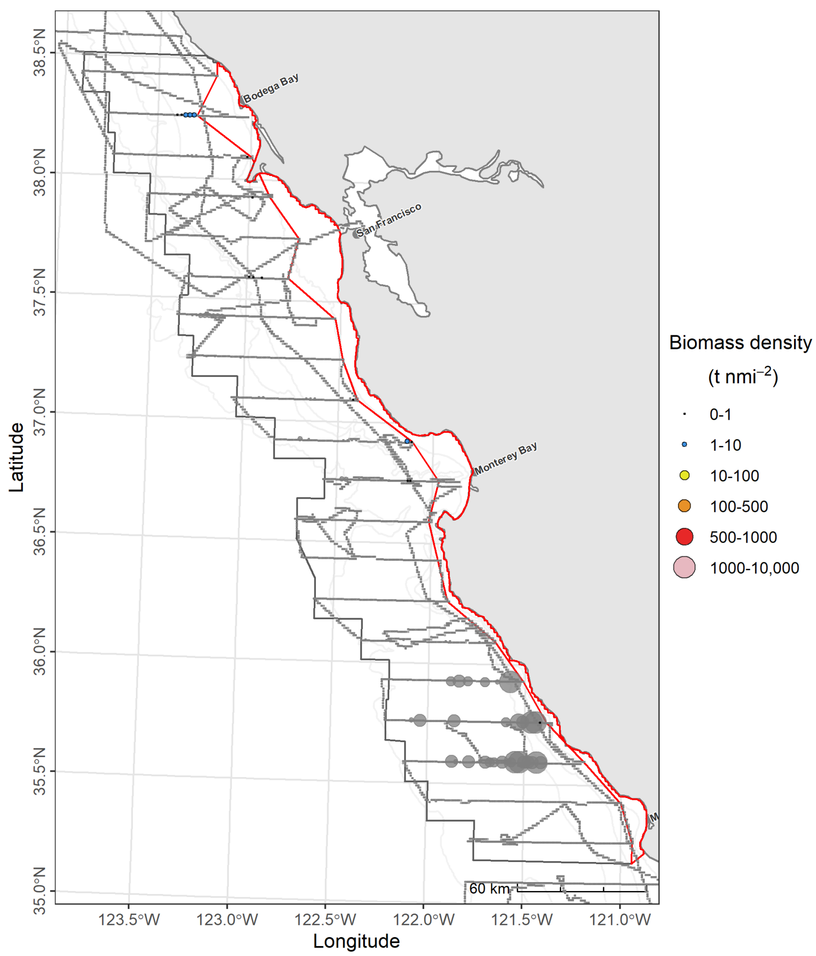


Figure 31: Example biomass densities of the central stock of Northern Anchovy (*Engraulis mordax*) in stratum 2 throughout the offshore survey region (gray points); the subset of biomass densities used to extrapolate biomass into the unsampled nearshore waters (colored points); and the corresponding 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 an estimated 1,880 t ($CI_{95\%}$ = 484 - 3,983 t, CV = 51%; **Table 16**, **Fig. 32**).

Table 16: 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*) in the unsampled, nearshore waters. Stratum areas are nmi^2.

Species		Stratum				Trawl		Biomass			
Name	Stock	Number	Area	Transects	Distance	Clusters	Individuals	$\hat{B}$	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Engraulis mordax	Northern	3	176	6	31	1	2	0	0	0	63
		4	904	15	170	5	1,727	1,880	484	3,983	51
		5	228	6	24	2	5	0	0	0	39
		All	1,308	27	225	8	1,734	1,880	484	3,983	51

B.3.1.2 Central stock Extrapolation of the central stock of Northern Anchovy biomass into the unsampled, nearshore waters amounts to an estimated 274 t ($CI_{95\%}$ = 56.7 - 635 t, CV = 53%; **Table 17**, **Fig. 33**).

Table 17: 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*) in the unsampled, nearshore waters. Stratum areas are nmi^2.

Species		Stratum				Trawl		Biomass			
Name	Stock	Number	Area	Transects	Distance	Clusters	Individuals	$\hat{B}$	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Engraulis mordax	Central	1	931	20	132	9	4,710	32	0	47	42
		2	1,014	19	154	5	18,854	243	38	618	60
		All	1,945	39	286	14	23,564	274	57	635	53

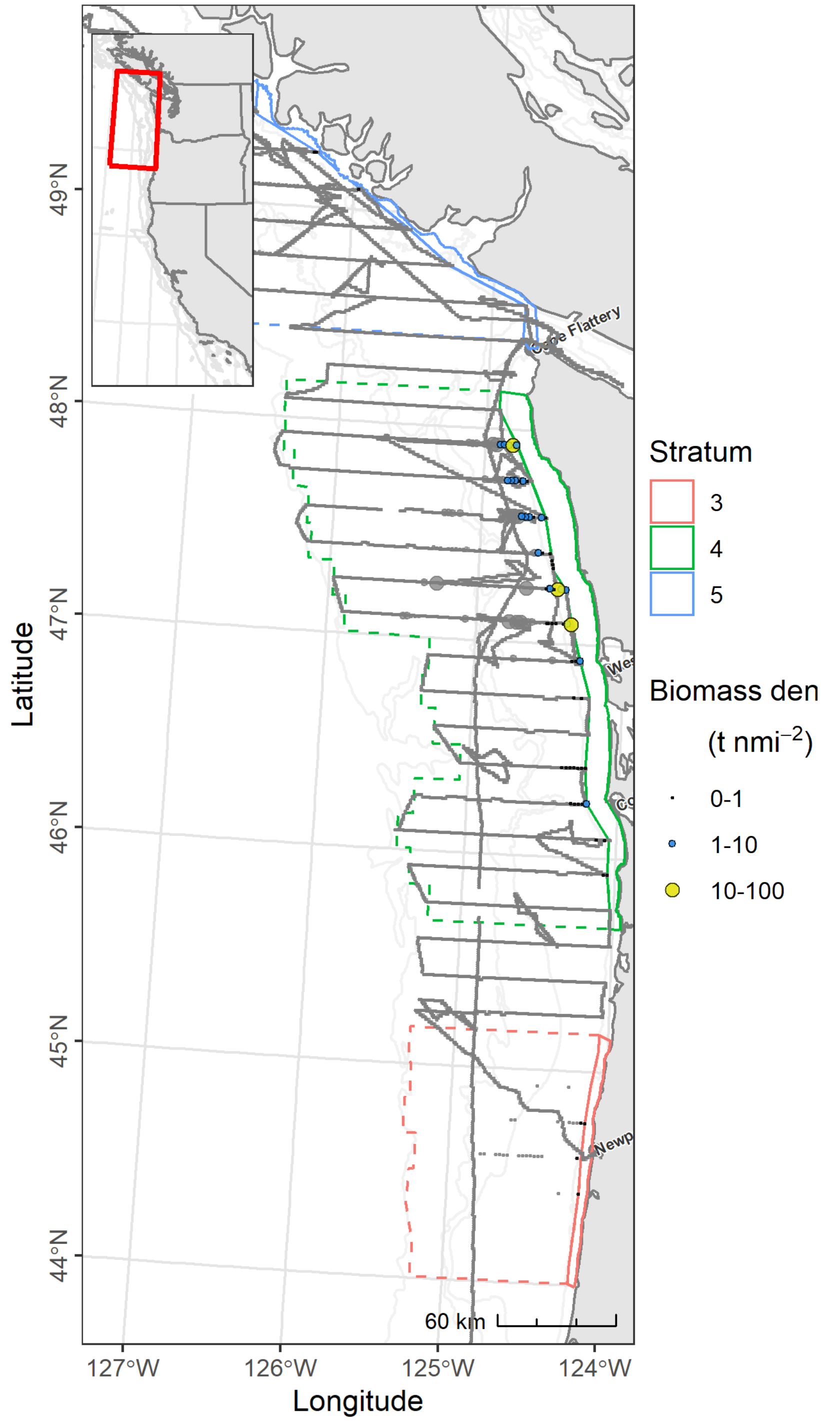


Figure 32: Biomass densities of the northern stock of Northern Anchovy (*Engraulis mordax*), per strata, throughout the survey region (gray points) and the subset of biomass densities used to extrapolate biomass into the unsampled nearshore waters (colored points), and the corresponding offshore (dashed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

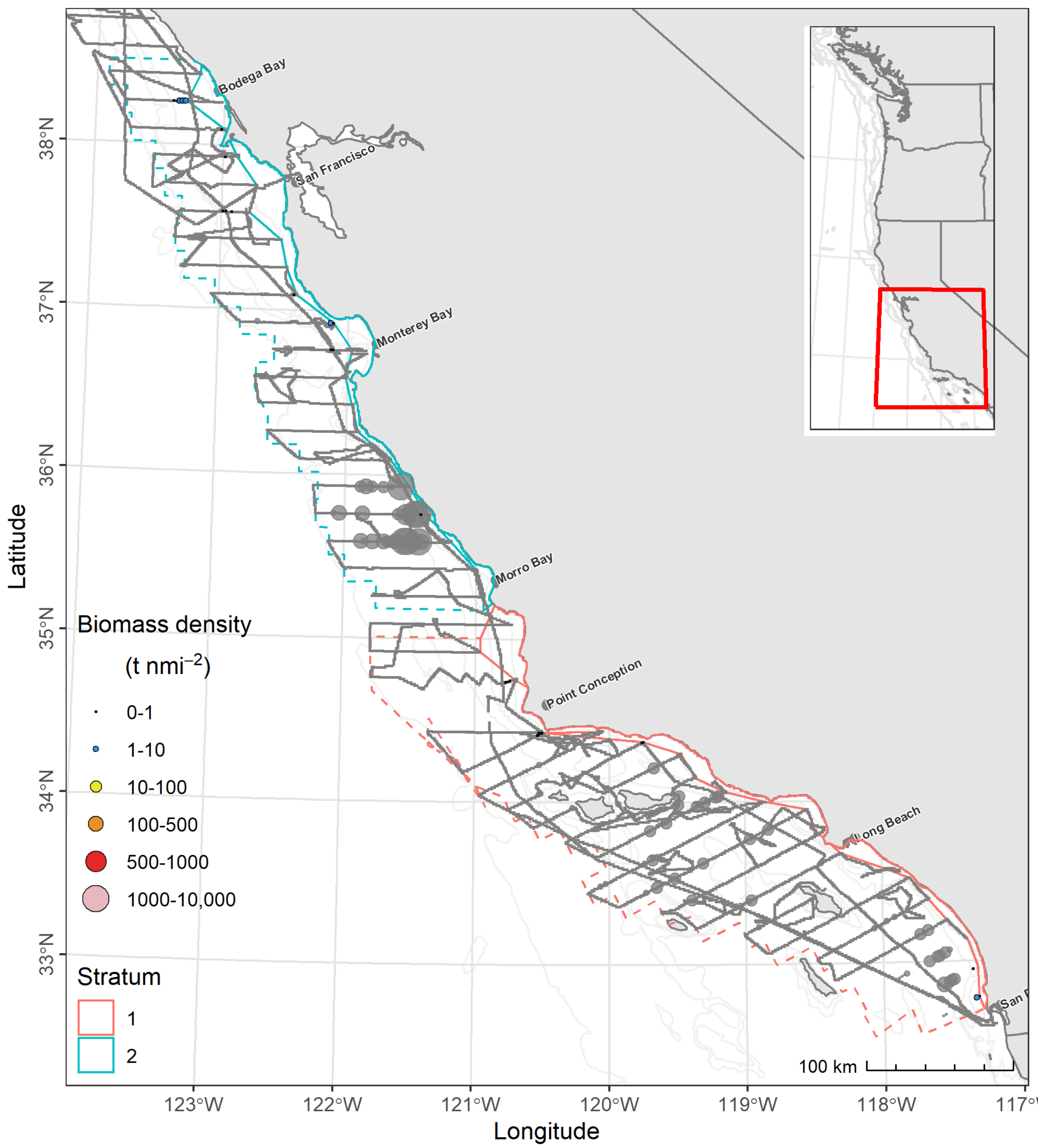


Figure 33: Biomass densities of the central stock of Northern Anchovy (*Engraulis mordax*), per strata, throughout the survey region (gray points) and the subset of biomass densities used to extrapolate biomass into the unsampled nearshore waters (colored points), and the corresponding offshore (dashed 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 an estimated 1,403 t ($CI_{95\%}$ = 774 - 3,094 t, CV = 42%; **Table 18**, **Fig. 34**).

Table 18: 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*) in the unsampled, nearshore waters. Stratum areas are nmi^2.

Species		Stratum				Trawl		Biomass			
Name	Stock	Number	Area	Transects	Distance	Clusters	Individuals	$\hat{B}$	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Sardinops sagax	Northern	3	168	7	27	2	8	0	0	0	93
		4	1,049	20	150	4	4,005	239	3	802	80
		5	569	9	79	1	3,793	544	0	1,658	78
		6	619	13	125	4	1,692	590	9	1,578	68
		7	166	5	15	1	4,871	30	0	47	55
		All	2,571	54	396	12	14,369	1,403	774	3,094	42

B.3.2.2 Southern stock Extrapolation of the southern stock of Pacific Sardine biomass into the unsampled, nearshore waters amounts to an estimated 0.0709 t ($CI_{95\%}$ = 0 - 0.207 t, CV = 82%; **Table 19**, **Fig. 35**).

Table 19: 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 southern stock of Pacific Sardine (*Sardinops sagax*) in the unsampled, nearshore waters. Stratum areas are nmi^2.

Species		Stratum				Trawl		Biomass			
Name	Stock	Number	Area	Transects	Distance	Clusters	Individuals	$\hat{B}$	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Sardinops sagax	Southern	1	64	3	12	1	1	0	0	0	82
		2	202	5	27	1	2	0	0	0	-
		All	266	8	39	2	3	0	0	0	82

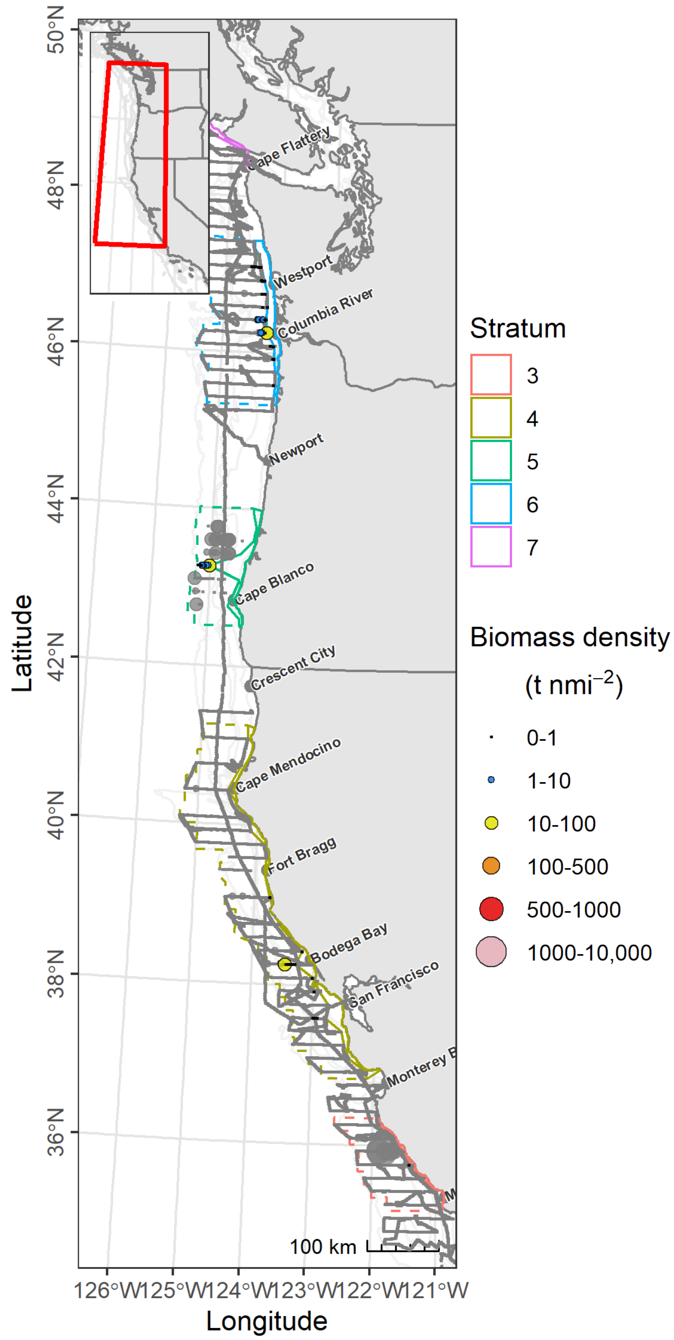


Figure 34: Biomass densities of the northern stock of Pacific Sardine (*Sardinops sagax*), per strata, throughout the survey region (gray points) and the subset of biomass densities used to extrapolate biomass into the unsampled nearshore waters (colored points), and the corresponding offshore (dashed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

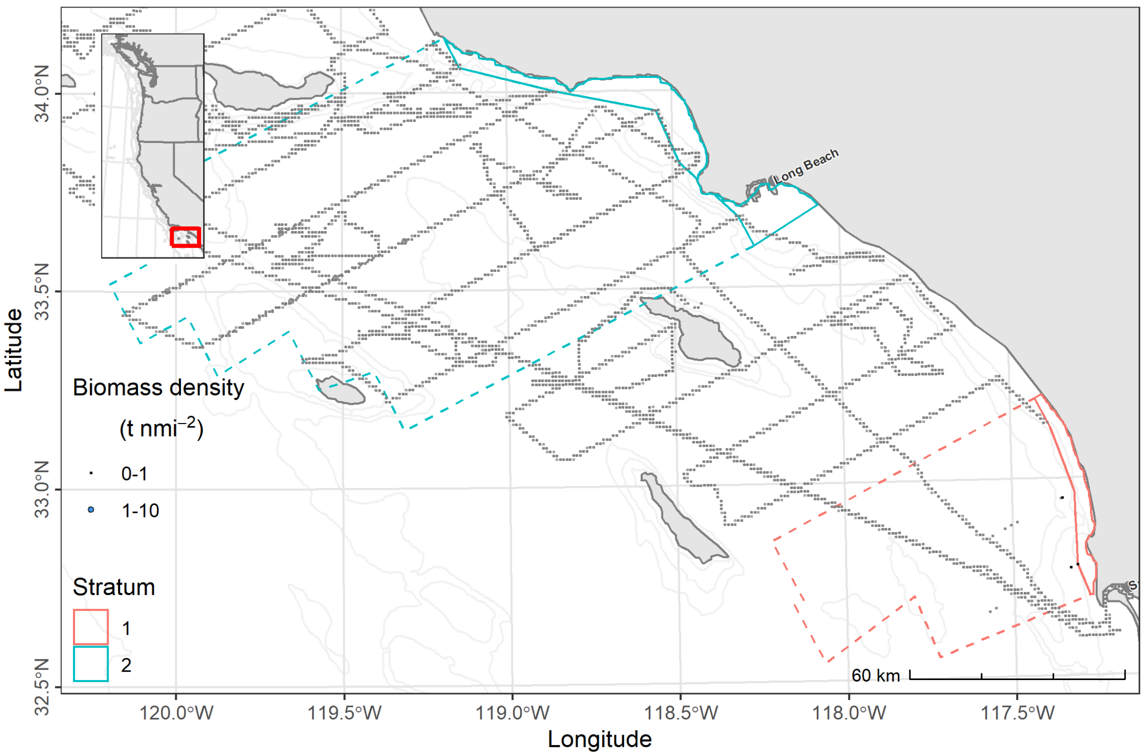


Figure 35: Biomass densities of the southern stock of Pacific Sardine (*Sardinops sagax*), per strata, throughout the survey region (gray points) and the subset of biomass densities used to extrapolate biomass into the unsampled nearshore waters (colored points), and the corresponding offshore (dashed polygon) and nearshore (solid polygon) strata.

B.3.3 Pacific Mackerel

Extrapolation of the Pacific Mackerel biomass into the unsampled, nearshore waters amounts to an estimated 3,102 t ($CI_{95\%}$ = 1,665 - 7,799 t, CV = 51%; **Table 20**, **Fig. 36**).

Table 20: 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*) in the unsampled, nearshore waters. Stratum areas are nmi^2.

Species		Stratum				Trawl		Biomass			
Name	Stock	Number	Area	Transects	Distance	Clusters	Individuals	$\hat{B}$	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Scomber japonicus	All	1	930	25	155	8	106	6	5	22	67
		2	1,049	20	150	4	10,624	1,178	14	3,946	80
		3	569	9	79	1	636	172	0	526	78
		4	602	16	114	4	3,185	1,718	403	4,913	71
		5	286	4	55	1	8	27	0	62	57
		6	166	5	15	1	7	0	0	0	55
		All	3,602	79	568	19	14,566	3,102	1,665	7,799	51

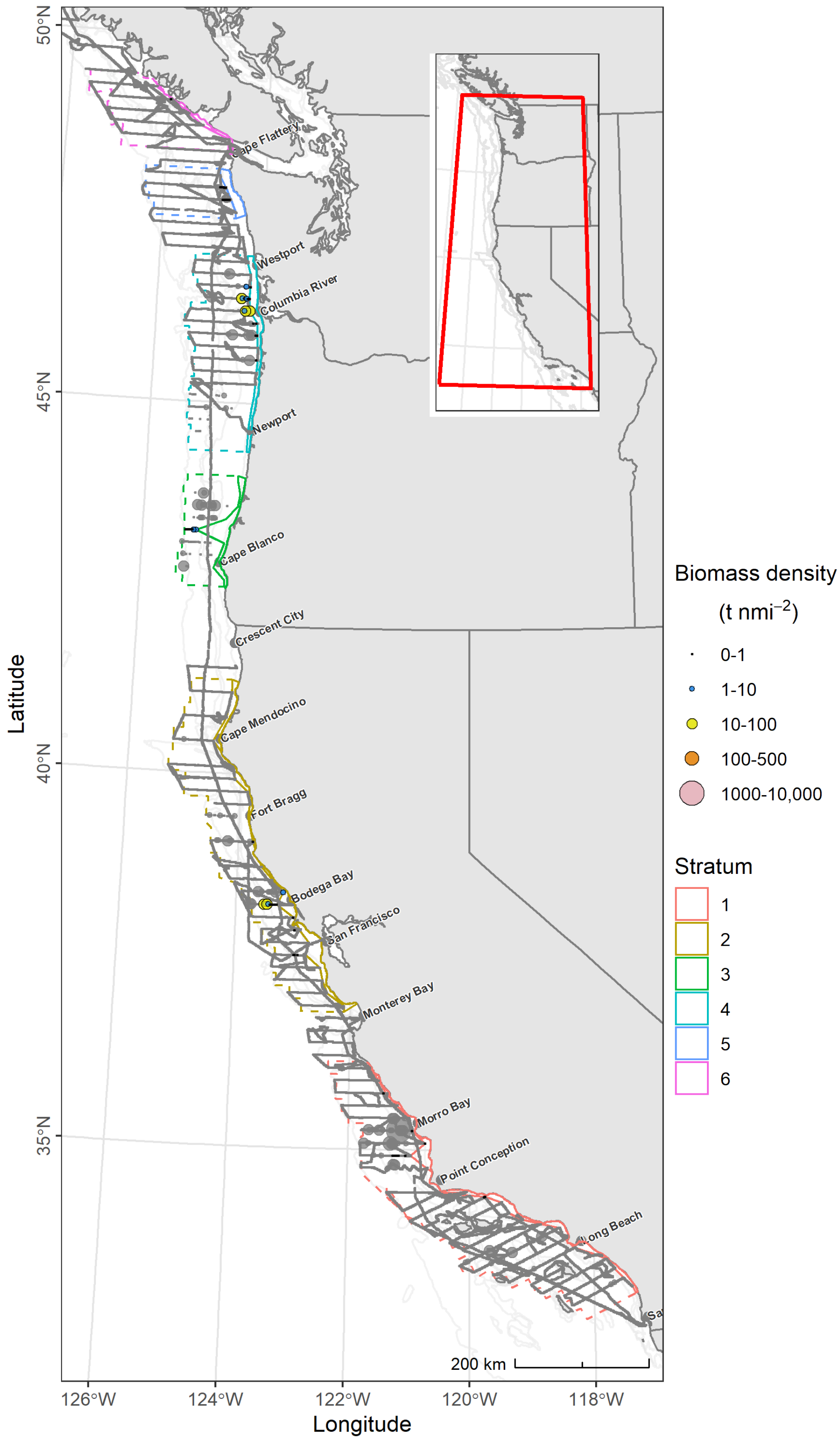


Figure 36: Biomass densities of Pacific Mackerel (*Scomber japonicus*), per strata, throughout the survey region (gray points) and the subset of biomass densities used to extrapolate biomass into the unsampled nearshore waters (colored points), and the corresponding offshore (dashed polygon) and nearshore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

B.3.4 Jack Mackerel

Extrapolation of the Jack Mackerel biomass into the unsampled, nearshore waters amounts to an estimated 30,558 t ($CI_{95\%}$ = 7,942 - 77,932 t, CV = 61%, **Table 21**, **Fig. 37**).

Table 21: 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*) in the unsampled, nearshore waters. Stratum areas are nmi^2.

Species		Stratum				Trawl		Biomass			
Name	Stock	Number	Area	Transects	Distance	Clusters	Individuals	$\hat{B}$	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Trachurus symmetricus	All	1	546	15	83	5	90	0	0	0	-
		2	396	10	54	2	17	2	0	5	60
		3	668	13	105	4	5,215	396	7	1,046	67
		4	475	6	35	2	4	528	184	1,145	45
		5	2,411	45	352	11	12,600	29,632	6,679	76,823	63
		All	4,496	89	629	22	17,926	30,558	7,942	77,932	61

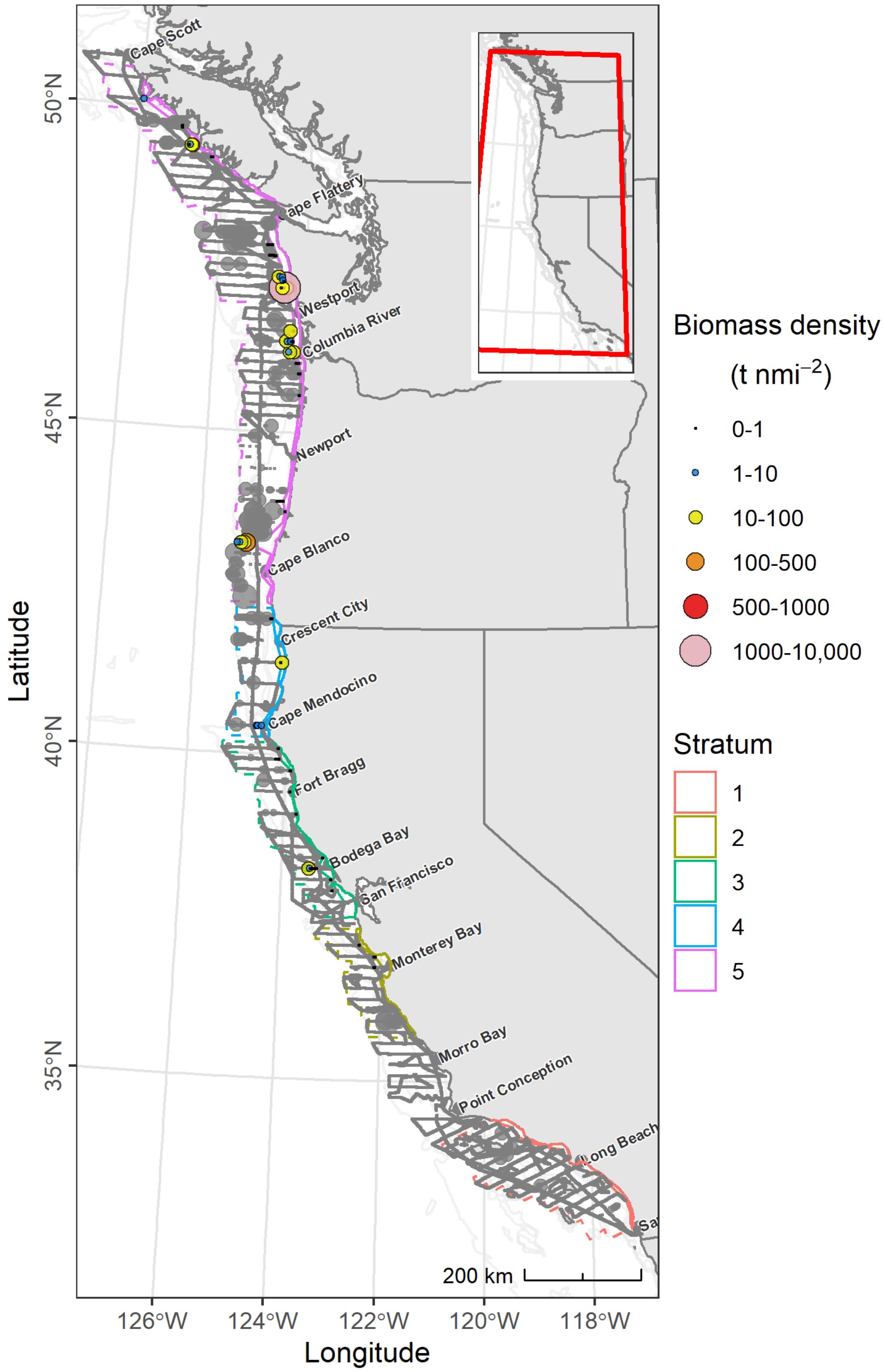


Figure 37: Biomass densities of Jack Mackerel (*Trachurus symmetricus*), per strata, throughout the survey region (gray points) and the subset of biomass densities used to extrapolate biomass into the unsampled nearshore waters (colored points), and the corresponding offshore (dashed polygon) and nearshore (solid polygon) strata.

B.3.5 Pacific Herring

Extrapolation of the Pacific Herring biomass into the unsampled, nearshore waters amounted to an estimated 11,091 t ($CI_{95\%}$ = 3,057 - 22,900 t, CV = 48%; **Table 22**, **Fig. 38**).

Table 22: 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*) in the unsampled, nearshore waters. Stratum areas are nmi^2.

Species		Stratum				Trawl		Biomass			
Name	Stock	Number	Area	Transects	Distance	Clusters	Individuals	$\hat{B}$	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Clupea pallasii	All	1	268	9	51	2	54	4	1	7	40
		2	299	6	54	1	4	1	0	3	60
		3	889	17	157	9	2,208	9,887	1,975	21,838	54
		4	343	4	14	2	143	1,198	91	2,137	43
		All	1,799	36	276	13	2,409	11,091	3,057	22,900	48

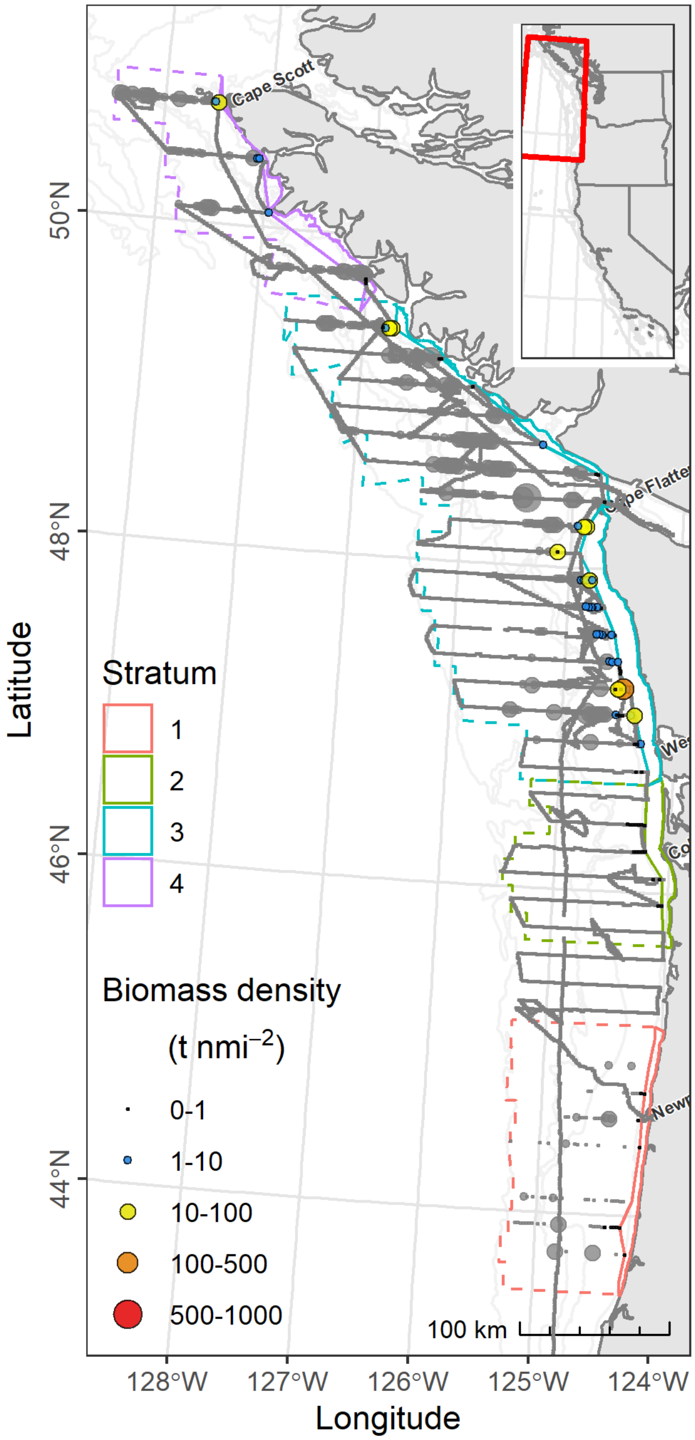


Figure 38: Biomass densities of Pacific Herring (*Clupea pallasii*), per strata, throughout the survey region (gray points) and the subset of biomass densities used to extrapolate biomass into the unsampled nearshore waters (colored points), and the corresponding offshore (dashed polygon) and nearshore (solid polygon) strata.