DISTRIBUTION, BIOMASS, AND DEMOGRAPHICS OF COASTAL PELAGIC FISHES IN THE CALIFORNIA CURRENT ECOSYSTEM DURING SUMMER 2024 BASED ON ACOUSTIC-TRAWL SAMPLING

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Executive Summary

This report provides: 1) a detailed description of the acoustic-trawl method (ATM) used by NOAA's Southwest Fisheries Science Center for direct assessments of the dominant coastal pelagic species (CPS; i.e.: Pacific Sardine *Sardinops sagax*, Northern Anchovy *Engraulis mordax*, Pacific Mackerel *Scomber japonicus*, Jack Mackerel *Trachurus symmetricus*, Pacific Herring *Clupea pallasii*, and Round Herring *Etrumeus acuminatus*) in the California Current Ecosystem off the west coast of the United States (U.S.) and portions of Canada and Baja CA, Mexico; 2) a description of the new multi-function trawl (MFT) system and sea trials conducted during five days at sea (DAS) at the beginning of the survey; and 3) estimates of the biomasses, distributions, and demographics of those CPS encountered in the survey area between 30 June and 30 September 2024.

The core survey region, which was sampled by NOAA ship *Reuben Lasker* (hereafter, *Lasker*), spanned most of the continental shelf between Punta Eugenia, Baja CA, Mexico, CA and Winter Harbour, Vancouver Island, Canada. Planned transects were oriented approximately perpendicular to the coast, from the shallowest navigable depth (~20 m) to a distance of 35 nmi offshore or, if farther, to the 1,000 ftm (~1830 m) isobath. In the SCB, transects in the core region were extended to approximately 100 nmi.

Because navigation by *Lasker* in water shallower than ~20 m was deemed inefficient, unsafe, or both, fishing vessels *Long Beach Carnage* and *Lisa Marie* sampled CPS in the nearshore region, along 2.5 to 5 nmi-long transects spaced 5 to 7 nmi-apart off the mainland coast of the U.S., between San Diego and Cape Flattery, as well as around Santa Cruz and Santa Catalina Islands in the Southern CA Bight. In the nearshore region, and due to sparse purse seine sampling along portions of the coast, the acoustically-sampled CPS were apportioned using the species compositions and length distributions from either daytime purse-seine sets by *Long Beach Carnage* or *Lisa Marie* or nighttime trawl from *Lasker*, whichever was closest in space.

The biomasses (metric tons, t), distributions, and demographics for each species and subpopulation are for the survey area and period, and therefore may not represent their entire population or subpopulation. Sampling was also conducted in the core and nearshore regions off Baja CA by Instituto Mexicano de Investigación en Pesca y Acuacultura Sustentables (IMIPAS, formerly INAPESCA), but the estimates in this report are only derived from data collected by *Lasker*, *Long Beach Carnage*, and *Lisa Marie*.

The estimated biomass of the northern subpopulation of Northern Anchovy was 151 t ($\text{CI}_{95\%}$ = 21 - 289 t, CV = 40%). In the core region, the biomass was 130.3 t ($\text{CI}_{95\%}$ = 13 - 250 t, CV = 46%), and in the nearshore region the biomass was 21 t ($\text{CI}_{95\%}$ = 8 - 40 t, CV = 40%), or 14% of the total biomass. The northern subpopulation was sparsely distributed between Astoria and Cape Flattery, and the distribution of standard lengths (L_S) ranged from 12 to 16 cm with a mode at 15 cm in both regions.

The estimated biomass of the central subpopulation of Northern Anchovy was 682,657 t ($\text{CI}_{95\%}$ = 328,527 - 796,114 t, CV = 17%). In the core region, the biomass was 672,528 t ($\text{CI}_{95\%}$ = 324,181 - 775,324 t, CV = 17%), and in the nearshore region the biomass was 10,129 t ($\text{CI}_{95\%}$ = 4,346 - 20,789 t, CV = 43%), or 1.5% of the total biomass. The central subpopulation ranged from approximately San Diego to San Francisco, and the distribution of L_S ranged from 4 to 15 cm with modes at 6 and 13 cm in the core region and at 8 and 13 cm in the nearshore region. The estimated biomass of the central subpopulation of Northern Anchovy, which has comprised the majority of CPS biomass since 2015, decreased 75% from the 2,689,200 t estimated in summer 2023 (Stierhoff *et al.*, 2024).

The estimated biomass of the northern subpopulation of Pacific Sardine was 77,750 t ($\text{CI}_{95\%}$ = 21,800 - 156,748 t, CV = 45%). In the core region, the biomass was 337 t ($\text{CI}_{95\%}$ = 64 - 892 t, CV = 69%) and in the nearshore region the biomass was 77,412 t ($\text{CI}_{95\%}$ = 21,736 - 155,856 t, CV = 45%), or 99.6% of the total biomass. The northern subpopulation was observed between Pt. Conception and Monterey, and between Astoria and Cape Flattery in the core region, and in the nearshore region was mostly observed between Pt. Conception and San Francisco. The distribution of L_S ranged from 6 to 26 cm with modes at 9 and 17 cm in the core region and at 19 cm in the nearshore region. These results were included in the update assessment used to provide a biomass estimate for harvest specifications of the northern subpopulation of Pacific Sardine during the 2025-2026 fishing year (Allen Akselrud *et al.*, In review).

The estimated biomass of the southern subpopulation of Pacific Sardine in the surveyed area was 47,566 t (CI$_{95\%}$ = 32,397 - 96,235 t, CV = 25%). In the core region, the biomass was 22,136 t (CI$_{95\%}$ = 7,452 - 39,462 t, CV = 38%), and in the nearshore region the biomass was 25,431 t (CI$_{95\%}$ = 24,945 - 56,773 t, CV = 32%), or 53% of the total biomass. The southern subpopulation in this survey was observed off central Baja CA and throughout the SCB, but these results do not include biomass observed in areas surveyed independently by IMIPAS. The distribution of L_S ranged from 6 to 21 cm with modes at 6 and 19 cm in the core region and modes at 9 and 15 cm in the nearshore region.

The estimated biomass of Pacific Mackerel was 11,129 t (CI$_{95\%}$ = 4,950 - 19,241 t, CV = 24%). In the core region, the biomass was 4,740 t (CI$_{95\%}$ = 1,909 - 8,498 t, CV = 36%), and in the nearshore region the biomass was 6,388 t (CI$_{95\%}$ = 3,041 - 10,743 t, CV = 31%), or 57% of the total biomass. Pacific Mackerel were observed in the core and nearshore regions in the SCB, off San Francisco, and off central OR. The distribution of fork lengths (L_F) ranged from 5 to 42 cm with modes at 8, 17, and 37 cm in the core region and 22 and 41 cm in the nearshore region.

The estimated biomass of Jack Mackerel was 618,467 t (CI$_{95\%}$ = 446,095 - 804,715 t, CV = 12%). In the core region, the biomass was 513,181 t (CI$_{95\%}$ = 371,986 - 654,903 t, CV = 14%), and in the nearshore region the biomass was 105,287 t (CI$_{95\%}$ = 74,109 - 149,813 t, CV = 18%), or 17% of the total biomass. Jack Mackerel were observed throughout the survey area, but were most abundant between Cape Mendocino and Cape Scott, Vancouver Island in the core region and between Cape Mendocino and Astoria in the nearshore region. The distribution of L_F ranged from 2 to 52 cm with modes at 4, 12, and 41 cm in the core region and at 4 cm in the nearshore region.

The total estimated biomass of Pacific Herring was 69,923 t (CI$_{95\%}$ = 37,912 - 109,595 t, CV = 21%). In the core region, the biomass was 51,213 t (CI$_{95\%}$ = 27,162 - 83,165 t, CV = 28%), and in the nearshore region the biomass was 18,710 t (CI$_{95\%}$ = 10,751 - 26,429 t, CV = 21%), or 27% of the total biomass. Pacific Herring were observed from approximately Florence, OR to central Vancouver Island in the core region, and between San Francisco and Cape Flattery in the nearshore region. The distribution of L_F ranged from 8 to 25 cm, with modes at 9, 17, and 22 cm in the core region and 9 and 16 cm in the nearshore region.

The total estimated biomass of Round Herring was 1,837 t (CI$_{95\%}$ = 276 - 3,952 t, CV = 42%). In the core region, the biomass was 752 t (CI$_{95\%}$ = 269 - 1,281 t, CV = 34%), and in the nearshore region the biomass was 1,085 t (CI$_{95\%}$ = 8 - 2,671 t, CV = 67%), or 59% of the total biomass. Round Herring were observed between Punta Eugenia to El Rosario off Baja CA, and near San Nicolas Island, Santa Catalina Island, and Long Beach in the SCB. The distribution of L_F ranged from 2 cm, with modes at 16, 23, and 26 cm in the core region; all lengths were 2-4 cm in the nearshore region.

The total estimated biomass of eight populations or subpopulations of six coastal pelagic species within the survey area was 1,509,481 t. Of this, 45% (682,657 t) was from the central subpopulation of Northern Anchovy and 41% (618,467 t) was from Jack Mackerel. Proportions of other subpopulations, in decreasing order, were: northern subpopulation of Pacific Sardine (5.2%), Pacific Herring (4.6%), southern subpopulation of Pacific Sardine (3%), Pacific Mackerel (0.7%), Round Herring (0.1%), and northern subpopulation of Northern Anchovy (0.01%).

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. The term CPS is used here to refer to any of the above-mentioned species, which are a subset of the CPS assemblage listed in the Pacific Fishery Management Council's CPS Fishery Management Plan[1]. 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 some are targets of commercial fisheries.

During summer and fall, the northern subpopulation of Pacific Sardine typically migrates north to feed in the productive coastal upwelling off OR, WA, and Vancouver Island (Zwolinski *et al.*, 2012, and references therein, **Fig. 1**). In synchrony, but separately, the southern subpopulation of Pacific Sardine migrates from Northern Baja CA, Mexico to the Southern CA Bight (SCB) (Smith, 2005). 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 subpopulation of Pacific Sardine typically migrates south to its spawning grounds, generally off Central and Southern CA (Demer *et al.*, 2012) and occasionally off OR and WA (Lo *et al.*, 2011). These migrations vary in extent with population size, fish age and length, and oceanographic conditions (Zwolinski *et al.*, 2012). The transition zone chlorophyll front (TZCF, Polovina *et al.*, 2001) may delineate the offshore and southern limit of both northern subpopulation 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 during spring and early summer in intertidal beach areas (Love, 1996). The northern subpopulation of Northern Anchovy is located off WA and OR and the central subpopulation is located off Central and Southern CA and northern Baja CA. Whether a species migrates or remains in an area depends on its reproductive and feeding behaviors, affinity to certain oceanographic or seabed habitats, and its population size.

Acoustic-trawl method (ATM) surveys, which combine information collected with echosounders and nets, were introduced to the CCE more than 50 years ago to survey CPS off the west coast of the United States (U.S.) (Mais, 1974, 1977; Smith, 1978). Following a two-decade hiatus, the ATM was reintroduced in the CCE in spring 2006 to sample the then-abundant Pacific Sardine population (Cutter and Demer, 2008). Since then, this sampling effort has continued and expanded through annual or semi-annual surveys (Demer *et al.*, 2012; Zwolinski *et al.*, 2014). Beginning in 2011, the ATM estimates of Pacific Sardine abundance, age structure, and distribution have been incorporated in the annual assessments of the northern subpopulation (Hill *et al.*, 2017; Kuriyama *et al.*, 2020, 2022a). ATM estimates are also used in assessments of Pacific Mackerel (Crone *et al.*, 2019; Crone and Hill, 2015) and the central subpopulation of Northern Anchovy (Kuriyama *et al.*, 2022b). Additionally, ATM survey results have yielded estimated abundances, demographics, and distributions of epipelagic and semi-demersal fishes (e.g., Swartzman, 1997; Williams *et al.*, 2013; Zwolinski *et al.*, 2014) and zooplankton (Hewitt and Demer, 2000).

This document, and references herein, describes in detail the ATM as presently used by NOAA's Southwest Fisheries Science Center (SWFSC) to survey the distributions, abundances, biomasses, and demographics 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, multifrequency echosounders, probe-sampled oceanographic conditions, trawl-net catches of juvenile and adult CPS, and sometimes pumped samples of fish eggs. The summer survey area spans the continental shelf and adjacent waters to the 1000-fathom isobath off the west coast of the U.S., is expanded to encompass the potential habitat of the northern subpopulation of Pacific Sardine (**Fig. 1**), and as time permits, further expanded to encompass as much of the potential habitat as possible for other CPS present over the shelf along the west coasts of Canada and Baja CA.

[1] https://www.pcouncil.org/documents/2023/06/coastal-pelagic-species-fishery-management-plan/

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

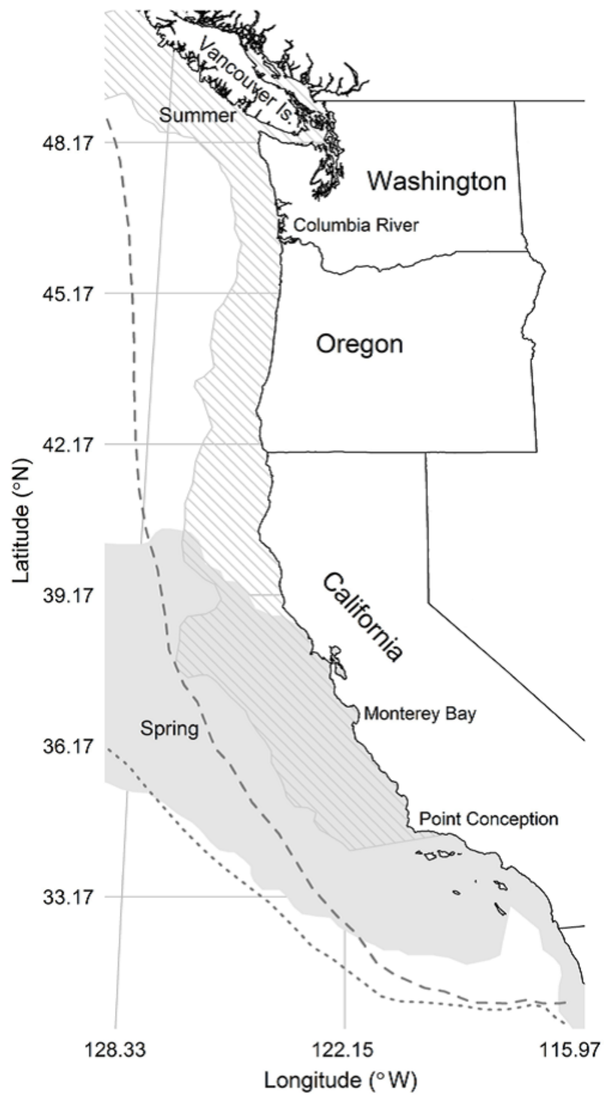

Figure 1: Conceptual spring (shaded region) and summer (hashed region) distributions of potential habitat for the northern subpopulation of Pacific Sardine along the west coasts of Mexico, the United States, and Canada. The dashed and dotted lines represent, respectively, the approximate summer and spring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

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

Animal densities are estimated by dividing the vertically summed area-backscattering coefficients attributed to a species by their average echo intensity, i.e., the mean backscattering cross-section, from animals of that species (e.g., Demer *et al.*, 2012). Transects with similar densities and transect spacings are grouped into post-sampling strata that mimic the natural patchiness of the target species (e.g., Zwolinski *et al.*, 2014). Estimates of abundance are obtained by multiplying the mean densities in the stratum by the respective stratum areas (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, abundances, and demographics of CPS, and their abiotic environments in the CCE. Typically, summer surveys are conducted during 50-90 days-at-sea (DAS) between June and October. In summer, the ATM surveys also include the northern subpopulation of Northern Anchovy and Pacific Herring. When they occur, spring surveys are conducted during 25-40 DAS between March and May and focus primarily on the northern subpopulation of Pacific Sardine and the central subpopulation of Northern Anchovy. During spring and summer, biomasses are also estimated for other CPS (e.g., Pacific Mackerel, Jack Mackerel, and Round Herring) present in the survey area.

In summer 2024, the ATM survey was conducted by *Lasker* from Punta Eugenia, Baja CA, Mexico to Winter Harbour, Vancouver Island, Canada. From San Diego to Cape Flattery, sampling from fishing vessels *Lisa Marie* and *Long Beach Carnage* was used to estimate the biomasses of CPS in the nearshore regions, where sampling by *Lasker* was not possible or safe.

Presented here are: 1) a detailed description of the ATM used to survey CPS in the California Current Ecosystem (CCE) off the west coast of the U.S.; and 2) estimates of the abundances, biomasses, spatial distributions, and demographics of CPS, specifically the northern and southern subpopulations of Pacific Sardine, the central and northern subpopulations of Northern Anchovy, Pacific Mackerel, Jack Mackerel, Pacific Herring, and Round Herring for the core and nearshore survey regions in which they were sampled. A complementary survey off Baja CA by IMIPAS used approximately the same sampling protocol. Data from that survey, including biomass estimates for CPS in those core and nearshore regions, are reported elsewhere (Martínez-Magaña *et al.*, In revision).

The SWFSC's survey was conducted with the approval of the Secretaria de Relaciones Exteriores (SRE, Diplomatic note UAN0731/2024), the Instituto Nacional de Estadística y Geografía (INEGI; Authorization: LIG0032024, through official letter 400./67/2024), Unidad de Planeación y Coordinación Estratégica de la Secretaría de Marina (SEMAR; Letter no DAI-1305-24), Unidad Coordinadora de Asuntos Internacionales (UCAI) de la Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT; Letter UCAI/01210/2024), Universidad Nacional Autónoma de México (UNAM; Letter ICML/DIR/182/2024), Unidad de Concesiones y Servicios del Instituto Federal de Telecomunicaciones (IFT; Letter IFT/223/UCS/01962/2024), and the Comisión Nacional de Acuacultura y Pesca (CONAPESCA; Permit: PPFE/DGPPE.04357-210524).

2 Methods

2.1 Sampling

2.1.1 Design

The summer 2024 survey was conducted principally using *Lasker*, but was augmented with nearshore acoustic and purse-seine sampling by two fishing vessels, *Long Beach Carnage* and *Lisa Marie*. The sampling domain between Punta Eugenia, Baja CA, Mexico and Winter Harbour, Vancouver Island, Canada was defined by the conceptual distribution of potential habitat for the northern subpopulation of Pacific Sardine in summer (**Fig. 1**), but also encompassed an unknown portion of the anticipated distributions of the southern subpopulation of Pacific Sardine, the central and northern subpopulations of Northern Anchovy, Pacific Mackerel, Jack Mackerel, Pacific Herring, and Round Herring populations off the west coasts of the U.S., Mexico, and Canada. East to west, the sampling domain extended from the coast to at least the 1,000 ftm (~1830 m) isobath (**Fig. 2**). Considering the expected distribution of the target species, and the available ship time (85 days at sea, DAS), the primary objective was to estimate the biomasses, spatial distributions, and demographics of the northern subpopulation of Pacific Sardine and the northern and central subpopulations of Northern Anchovy, whose expected distributions were encompassed by the survey region. Secondary objectives were to estimate the biomasses, spatial distributions, and demographics of the southern subpopulation of Pacific Sardine, Pacific Mackerel, Jack Mackerel, Pacific Herring, and Round Herring, since their expected distributions extend beyond the planned survey region.

The planned core region transects were perpendicular to the coast, extending from the shallowest navigable depth (~20 m) to either a distance of 35 nmi or, where farther, to the 1,000 ftm isobath (**Fig. 2**). Compulsory transects were spaced 10 nmi apart in U.S. waters, and 20 nmi apart off Baja CA and Vancouver Is. The length of compulsory transects was shortened to 30 nmi off Baja CA, and adaptive transects, which are sampled only when CPS were observed along compulsory transects, were spaced 20 nmi apart off Vancouver Island. When CPS were observed within the westernmost 3 nmi of a transect, that transect and the next one to the north were extended in 5-nmi increments until no CPS were observed in the last 3 nmi of the extension, to a maximum extension of 50 nmi. In summer 2024, transects were sampled south-to-north to coordinate sampling with the CPS survey conducted by Instituto Mexicano de Investigación en Pesca y Acuacultura Sustentables (IMIPAS, formerly INAPESCA) aboard R/V *Jorge Carranza Fraser*.

To estimate the abundances and biomasses of CPS in the nearshore region between San Diego and Cape Flattery, where *Lasker* could not efficiently or safely navigate or trawl, two fishing vessels were used to conduct acoustic and purse-seine sampling (magenta lines, **Fig. 2**). *Long Beach Carnage* planned to sample as close to shore as possible, typically to the 5-m isobath, along 5-nmi-long transects spaced 5 nmi apart between San Diego and Pacific Grove, CA, and 2.5-nmi-long transects spaced 2.5 nmi apart around Santa Cruz and Santa Catalina Islands in the SCB. *Lisa Marie* planned to sample transects as close to shore as possible, typically to the 5-m isobath, spaced 7 nmi apart between Pacific Grove and Cape Flattery (**Fig. 2**). Off OR, *Lisa Marie* planned to conduct coordinated comparative nighttime purse-seine sampling in the core region where *Lasker* observed backscatter from CPS during the day.

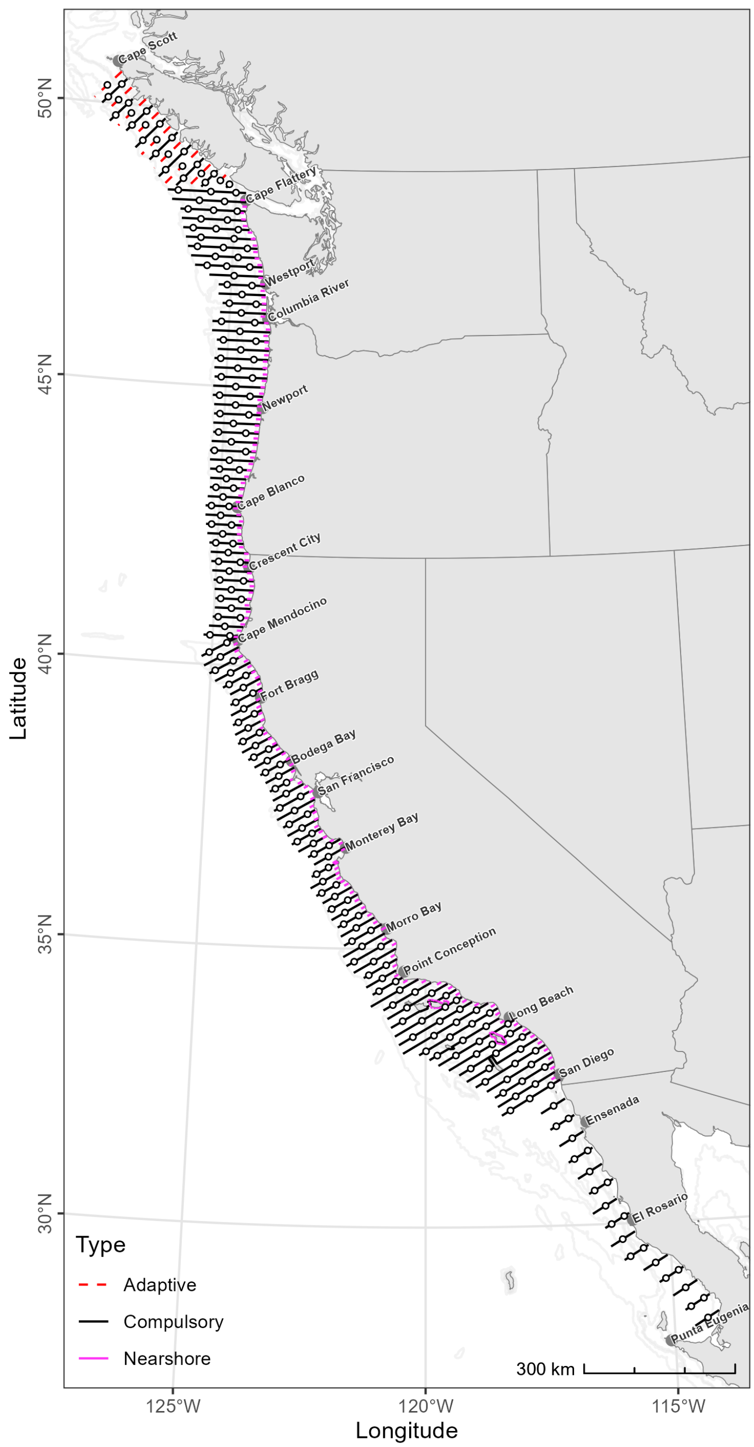

Figure 2: Planned compulsory transects sampled by NOAA Ship *Lasker* (black lines); adaptive transects to be sampled by the FSV when target CPS are present (dashed red lines); and nearshore transects sampled by *Lisa Marie* and *Long Beach Carnage* (magenta lines). White points indicate planned UCTD stations. Isobaths (light gray lines) are 50, 200, 500, and 2,000 m.

2.1.2 Acoustic

2.1.2.1 Acoustic equipment

2.1.2.1.1 *Lasker* Multi-frequency Wide-Bandwidth Transceivers (18-, 38-, 70-, 120-, 200-, and 333-kHz Simrad EK80 WBTs; Kongsberg) were configured with split-beam transducers (Simrad ES18, ES38, ES70-7C, ES120-7C, ES200-7C, and ES333-7C, respectively; Kongsberg). The transducers were mounted on the bottom of a retractable keel or "centerboard" (**Fig. 3**). The keel was retracted (transducers at ~5-m depth) during calibration, and extended to the intermediate position (transducers at ~7-m depth) during the survey. Exceptions were made during shallow water operations, when the keel was retracted; or during times of heavy weather, when the keel was extended (transducers at ~9-m depth) to provide extra stability and reduce the effect of weather-generated noise. In addition, acoustic data were also collected using a multibeam echosounder (Simrad ME70; Kongsberg), multibeam sonar (Simrad MS70; Kongsberg), scanning sonar (Simrad SX90; Kongsberg), acoustic Doppler current profiler and echosounder (Simrad EC150-3C, Kongsberg), and a separate ADCP (Ocean Surveyor OS75; Teledyne RD Instruments). Transducer position and motion were measured at 5 Hz using an inertial motion unit (Applanix POS-MV; Trimble).

2.1.2.1.2 *Long Beach Carnage* On *Long Beach Carnage*, the SWFSC's multi-frequency Wideband Transceivers (38-, 70-, 120-, and 200-kHz Simrad EK80 WBTs; Kongsberg) were configured with the SWFSC's split-beam transducers (Simrad ES38-12, ES70-7C, ES120-7C and ES200-7C; Kongsberg) mounted in a multi-frequency transducer array (MTA4) on the bottom of a retractable pole (**Fig. 4**). The transducers were at a water depth of approximately 2 m.

2.1.2.1.3 *Lisa Marie* On *Lisa Marie*, multi-frequency Wideband Transceivers (38-, 70-, 120-, and 200-kHz Simrad EK80 WBTs; Kongsberg) were connected to the vessel's hull-mounted split-beam transducers (Simrad ES38-7, ES70-7C, ES120-7C and ES200-7C; Kongsberg). The transducers were mounted in a blister on the hull at a water depth of ~4 m (**Fig. 5**).

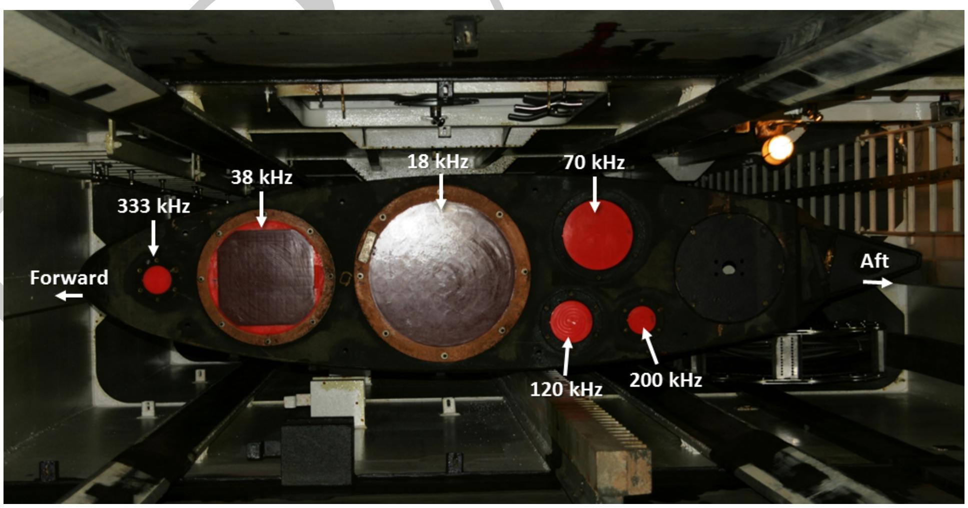

Figure 3: Echosounder transducers mounted on the bottom of the retractable centerboard on *Lasker*. During the survey, the centerboard was typically positioned in the intermediate position, placing the transducers ~2 m below the keel at a water depth of ~7 m.

Figure 4: Transducers (Top-bottom: Simrad ES200-7C, ES120-7C, ES38-12, and ES70-7C, Kongsberg) in a pole-mounted multi-transducer array (MTA4) installed on *Long Beach Carnage*.

Figure 5: Transducers (Simrad ES38-7, ES70-7C, ES120-7C and ES200-7C; Kongsberg, not visible) mounted in a blister on the hull of *Lisa Marie*.

2.1.2.2 Echosounder calibrations

2.1.2.2.1 ***Lasker*** The echosounder systems aboard *Lasker* were calibrated on 20 June while the vessel was docked at 10th Avenue Marine Terminal, San Diego Bay (32.6936 °N, -117.1503 °W) using the standard sphere technique (Demer *et al.*, 2015; Foote *et al.*, 1987). Each WBT was calibrated in both CW (i.e., continuous wave or narrowband mode) and FM mode (i.e., frequency modulation or broadband mode). For both CW and FM modes, the reference target was a 38.1-mm diameter sphere made from tungsten carbide (WC) with 6% cobalt binder material (WC38.1); for FM mode, additional calibrations were conducted for the 120, 200, and 333-kHz echosounders using a 25-mm WC sphere (WC25). Prior to the calibrations, temperature and salinity were measured to a depth of 10 m using a handheld probe (Pro2030, YSI) to estimate sound speeds at the transducer and sphere depths, and the time-averaged sound speed and absorption coefficients for the range between them. The theoretical target strength (TS; dB re 1 m^2) of the sphere was calculated using values for the sphere, sound-pulse, and seawater properties. The sphere was positioned throughout the main lobe of each of the transducer beams using three motorized downriggers, two on the port side of the vessel and one on the starboard side. The calibration parameters for all vessels were derived in Echoview. For each echosounder, the calibrated Equivalent Two-Way Beam Angle (EBA) was derived by compensating the factory-measured EBA by the change in local sound speed (Bodholt, 2002; Demer *et al.*, 2015); when processing the survey transects, the calibrated measures of transducer gain, beamwidths, and EBA were then also compensated by the changes in local sound speed. Calibration results for *Lasker* are presented in **Table 1**, and were used to process the acoustic data used to estimate biomasses. Calibration plots for WBTs in CW and FM mode are presented in **Appendix B.1.1** and **Appendix B.1.2**, respectively.

Table 1: Wide-Bandwidth Transceiver (Simrad EK80 WBT; Kongsberg) information, pre-calibration settings, and post-calibration beam model results (below the horizontal line) estimated from calibration of the echosounders aboard *Lasker* using a WC38.1 standard sphere.

		Frequency (kHz)					
	Units	18	38	70	120	200	333
Model		ES18	ES38-7	ES70-7C	ES120-7C	ES200-7C	ES333-7C
Serial Number		2106	337	233	783	513	124
Transmit Power (p_{et})	W	1000	2000	600	200	90	35
Pulse Duration (τ)	ms	1.024	1.024	1.024	1.024	1.024	1.024
Temperature	C	20.7	20.7	20.7	20.7	20.7	20.7
Salinity	ppt	33.9	33.9	33.9	33.9	33.9	33.9
Sound speed	m s^{-1}	1522.4	1522.4	1522.4	1522.4	1522.4	1522.4
On-axis Gain (G_0)	dB re 1	23.07	25.97	27.33	26.46	26.28	25.81
S_{a} Correction (S_{a}corr)	dB re 1	-0.01	-0.23	-0.07	-0.06	-0.04	-0.11
3-dB Beamwidth Along. ($\alpha_{-3\mathrm{dB}}$)	deg	10.51	6.75	6.75	6.62	6.83	6.87
3-dB Beamwidth Athw. ($\beta_{-3\mathrm{dB}}$)	deg	10.45	6.71	6.76	6.58	6.82	6.79
Angle Offset Along. (α_0)	deg	0.05	0.01	0.01	0.02	0.02	0.03
Angle Offset Athw. (β_0)	deg	-0.03	-0.04	-0.06	-0.02	0.03	0.02
Equivalent Two-way Beam Angle (Ψ)	dB re 1 sr	-16.94	-20.23	-20.22	-20.13	-20.12	-19.59
RMS	db	0.10	0.11	0.14	0.11	0.19	0.46

2.1.2.2.2 ***Long Beach Carnage*** The WBTs aboard *Long Beach Carnage* were calibrated on 16 May, using the standard sphere technique (Demer *et al.*, 2015; Foote *et al.*, 1987), in a tank at the SWFSC (Demer *et al.*, 2015). Calibration results for *Long Beach Carnage* are presented in **Table 2**, and were used to process the acoustic data used to estimate biomasses. Calibration plots for WBTs in CW mode are presented in **Appendix B.3**.

Table 2: Wideband Transceiver (Simrad EK80 WBT; Kongsberg) and transducer information (above horizontal line) and beam model results (below horizontal line) estimated from a tank calibration, using a WC38.1 standard sphere, of the echosounders later installed and used aboard *Long Beach Carnage*.

		Frequency (kHz)			
	Units	38	70	120	200
Model		ES38-12	ES70-7C	ES120-7C	ES200-7C
Serial Number		28075	234	813	616
Transmit Power (p_{et})	W	1000	600	200	90
Pulse Duration (τ)	ms	1.024	1.024	1.024	1.024
Temperature	C	18.9	18.9	18.9	18.9
Salinity	ppt	35.3	35.3	35.3	35.3
Sound speed	m s^{-1}	1518.8	1518.8	1518.8	1518.8
On-axis Gain (G_0)	dB re 1	21.75	27.49	26.44	26.33
S_a Correction ($S_a$corr)	dB re 1	-0.09	-0.07	-0.06	-0.05
3-dB Beamwidth Along. (α_{-3dB})	deg	13.34	6.74	6.65	6.77
3-dB Beamwidth Athw. (β_{-3dB})	deg	13.29	6.83	6.60	6.74
Angle Offset Along. (α_0)	deg	-0.04	-0.03	-0.06	-0.06
Angle Offset Athw. (β_0)	deg	0.05	0.08	-0.00	-0.03
Equivalent Two-way Beam Angle (Ψ)	dB re 1 sr	-15.65	-20.24	-20.14	-20.07
RMS	db	0.10	0.09	0.13	0.26

2.1.2.2.3 ***Lisa Marie*** The WBTs aboard *Lisa Marie* were calibrated prior to the survey on 4 June using the standard sphere technique (Demer *et al.*, 2015; Foote *et al.*, 1987), while the vessel was anchored in Gray's Harbor, WA (46.8885 °N, -124.1319 °W). Due to poor calibration results, a second calibration was conducted in Gig Harbor, WA (47.3344 °N, -122.5817 °W) on 16 September. Results from the post-survey *Lisa Marie* calibration, presented in **Table 3**, were used to process the acoustic data used to estimate biomasses. Calibration plots for WBTs in CW mode are presented in **Appendix B.2**.

Table 3: Wideband Transceiver (Simrad EK80 WBT; Kongsberg) and transducer information (above horizontal line) and beam model results (below horizontal line) estimated from a tank calibration, using a WC38.1 standard sphere, of the echosounders later installed and used aboard *Lisa Marie*.

		Frequency (kHz)			
	Units	38	70	120	200
Model		ES38-7	ES70-7C	ES120-7C	ES200-7C
Serial Number		448	761	2355	899
Transmit Power (p_{et})	W	2000	600	200	90
Pulse Duration (τ)	ms	1.024	1.024	1.024	1.024
Temperature	C	13.3	13.3	13.3	13.3
Salinity	ppt	29.9	29.9	29.9	29.9
Sound speed	m s^{-1}	1495.3	1495.3	1495.3	1495.3
On-axis Gain (G_0)	dB re 1	26.70	27.61	24.05	22.68
S_{a} Correction (S_{a}corr)	dB re 1	-0.04	-0.07	-0.08	-0.22
3-dB Beamwidth Along. ($\alpha_{-3\mathrm{dB}}$)	deg	6.44	6.90	6.85	6.63
3-dB Beamwidth Athw. ($\beta_{-3\mathrm{dB}}$)	deg	6.66	7.01	6.99	6.38
Angle Offset Along. (α_0)	deg	-0.07	-0.19	-0.01	-0.06
Angle Offset Athw. (β_0)	deg	0.09	-0.01	-0.02	0.03
Equivalent Two-way Beam Angle (Ψ)	dB re 1 sr	-20.33	-20.44	-20.45	-20.44
RMS	db	0.14	0.14	0.17	0.37

2.1.2.3 Data collection

On *Lasker*, the computer clocks were synchronized with the GPS clock (UTC) using synchronization software (NetTime[2]). The 18-kHz WBT, operated by a separate PC from the other EK80 WBTs, was programmed to track the seabed and output the detected depth to the ship's Scientific Computing System (SCS). The echosounders were controlled by the EK80 Adaptive Logger (EAL[3], Renfree and Demer, 2016). The EAL optimizes the pulse interval based on the seabed depth, while avoiding aliased seabed echoes, and can be programmed to periodically record pings in passive mode, for obtaining estimates of the background noise level. Acoustic sampling for CPS-density estimation along the pre-determined transects was limited to daylight hours (approximately between sunrise and sunset).

During daytime aboard *Lasker*, measurements of volume backscattering strength (S_v; dB re 1 m^2 m^{-3}), indexed by time and geographic positions provided by GPS receivers, were logged to 60 m beyond the detected seabed range or to a maximum range of 500, 500, 500, 300, and 200 m for 38, 70, 120, 200, and 333 kHz, respectively, and stored, with a 2-GB maximum file size, in Simrad-EK80 .raw format. At nighttime, echosounders were set to FM mode and logged to 100 m to reduce data volume and to improve target strength (TS; dB re 1 m^2) estimation and species differentiation for CPS in the depths sampled by the surface trawls. The prefix for the file names was a concatenation of the survey name (e.g., 2407RL), the operational mode (CW or FM), and the logging commencement date and time from the EK80 software. For example, a file generated by the EK80 software (v23.6.2) for a WBT operated in CW mode is named `2407RL-CW-D20240801-T125901.raw`.

To minimize acoustic interference, transmit pulses from all echosounders and sonars (i.e., EK80, ME70, MS70, SX90, EC150-3C, and ADCP) were triggered using a synchronization system (Simrad K-Sync; Kongsberg). The K-Sync trigger rate, and thus echosounder ping interval, was modulated by the EAL using the seabed depth measured using the 18-kHz echosounder. During both day and night, the ME70, SX90, and ADCP were operated and recorded continuously whenever possible. In 2024, the MS70 was inoperable, so no data were recorded. All other instruments that produce sound within the echosounder bandwidths were secured during daytime survey operations. Exceptions were made during stations (e.g., plankton sampling and fish trawling) or in shallow water when the vessel's command occasionally operated the bridge's 50- and 200-kHz echosounders (Furuno), the Doppler velocity log (SRD-500A; Sperry Marine), or both. Analyses of data from the ADCP, EC-150, ME70, MS70, and SX90 are not presented in this report.

On *Lisa Marie* and *Long Beach Carnage*, the EAL was used to control the EK80 software to modulate the echosounder recording ranges (500, 500, 500, and 300 m for 38, 70, 120, and 200 kHz, respectively) and ping intervals to avoid aliased seabed echoes. When the EAL was not utilized, the EK80 was set to "auto-range" mode to adjust the maximum ping rate and recording range. Transmit pulses from the echosounders and fishing sonars were not synchronized. Therefore, the latter were secured during daytime acoustic transects.

2.1.3 Oceanographic

2.1.3.1 Conductivity and temperature versus depth (CTD)

Conductivity and temperature were measured versus depth to 350 m (or to within ~10 m of the seabed if shallower than 350 m) with calibrated sensors on a CTD rosette (Model SBE911+, Seabird) or underway probe [RapidPro Plus (UCTD); Valeport] cast from the vessel. One to three casts were planned along each acoustic transect (**Fig. 2**). These data were used to calculate the harmonic mean sound speed (Demer *et al.*, 2015) for estimating ranges to the sound scatterers, and frequency-specific sound absorption coefficients for compensating signal attenuation of the sound pulse between the transducer and scatterers (Simmonds and MacLennan, 2005) (see **Section 2.2.2**).

[2] http://timesynctool.com
[3] https://www.fisheries.noaa.gov/west-coast/science-data/ek80-adaptive-logger/

2.1.3.2 Scientific Computer System

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

2.1.4 Species Composition and Demographics

The net catches provide information about the regional species composition, lengths, weights and ages of CPS. After sunset, schools of CPS and other fish tend to ascend and disperse and are less likely to avoid a trawl net (Mais, 1977). Nighttime trawls conducted from *Lasker* sampled fish dispersed in the upper ~20-30 m of the sea surface. Beginning in the summer of 2023, and when weather conditions were favorable, the trawl net was towed along an arced path so that the net fished outside of the ship's wake (Nøttestad *et al.*, 2015). In 2024, a new Multifunction Trawl Net System (MFT; Swan Nets, Seattle, WA; **Figs. 6** and **7**), was used instead of the Nordic 264 (see net specifications in Stierhoff *et al.*, 2024) to trawl at night. Daytime purse-seine nets were set nearshore by *Long Beach Carnage* and *Lisa Marie* to sample CPS schools where their depth is constrained by the seabed and their vision is obscured by turbidity due to primary production and suspended particulates.

2.1.4.1 Trawl gear Aboard *Lasker*, the MFT was towed at the surface for 30 min at a speed of ~3.5 kn. The net has a rectangular opening with an area of approximately 648 m^2 (~18-m tall x 36-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, **Figs. 6** and **7**). The trawl doors (Type 22 VK 4m2; Thyboron) have adjustable attachment points and flaps to modulate the depth of the doors, and the trawl headrope was configured with mesh pockets to allow for the addition of up to ten A4 floats to adjust the depth of the net. Temperature-depth recorders (TDRs; RBRduet^3 T.D., RBR) were attached to the kite and footrope to measure the headrope depth and vertical net opening, and net mensuration sensors (Simrad PxPos sensors; Kongsberg) were installed on the doors to provide real-time measurements of door pitch, roll, depth, and spread for monitoring net performance (**Fig. 8**).

2.1.4.2 Purse-seine gear *Lisa Marie* used an approximately 440-m-long and 40-m-deep purse-seine net with 17-mm-wide mesh (A. Blair, pers. comm.). *Long Beach Carnage* used an approximately 200-m-long and 27-m-deep purse-seine net with 17-mm-wide mesh; a small section on the back end of the net had 25-mm-wide mesh (R. Ashley, pers. comm.). Specimens collected by *Lisa Marie* were processed aboard the vessel by the WA Department of Fish and Wildlife (WDFW; see **Section 2.1.4.4.2**), and specimens collected aboard *Long Beach Carnage* were processed ashore by the CA Department of Fish and Wildlife (CDFW; see **Section 2.1.4.4.3**)).

[4] http://coastwatch.pfeg.noaa.gov/erddap/tabledap/fsuNoaaShipWTEG.html

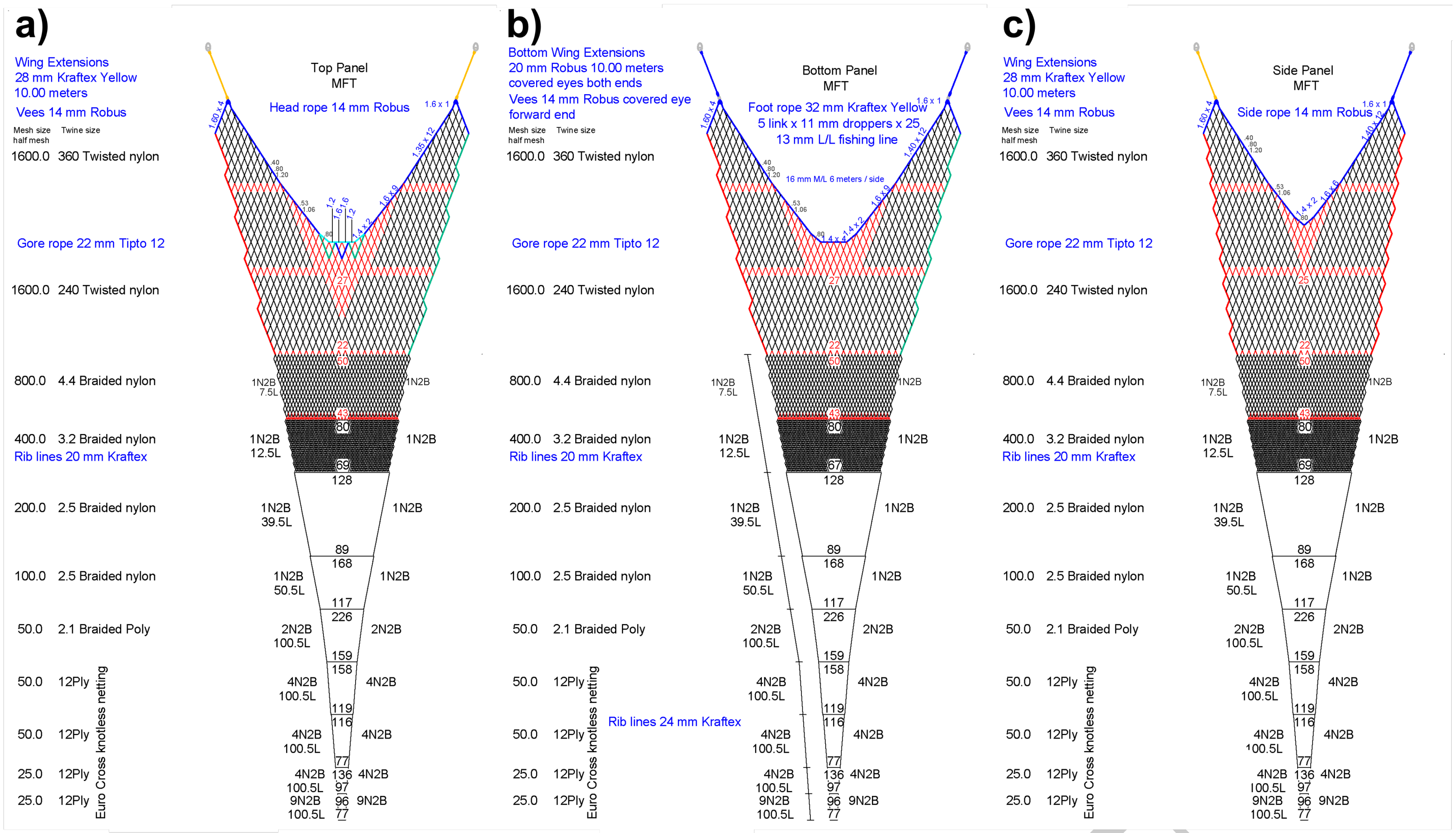

Figure 6: Schematics of the Multifunction Trawl Net System panels as viewed from the a) top, b) bottom, and c) side.

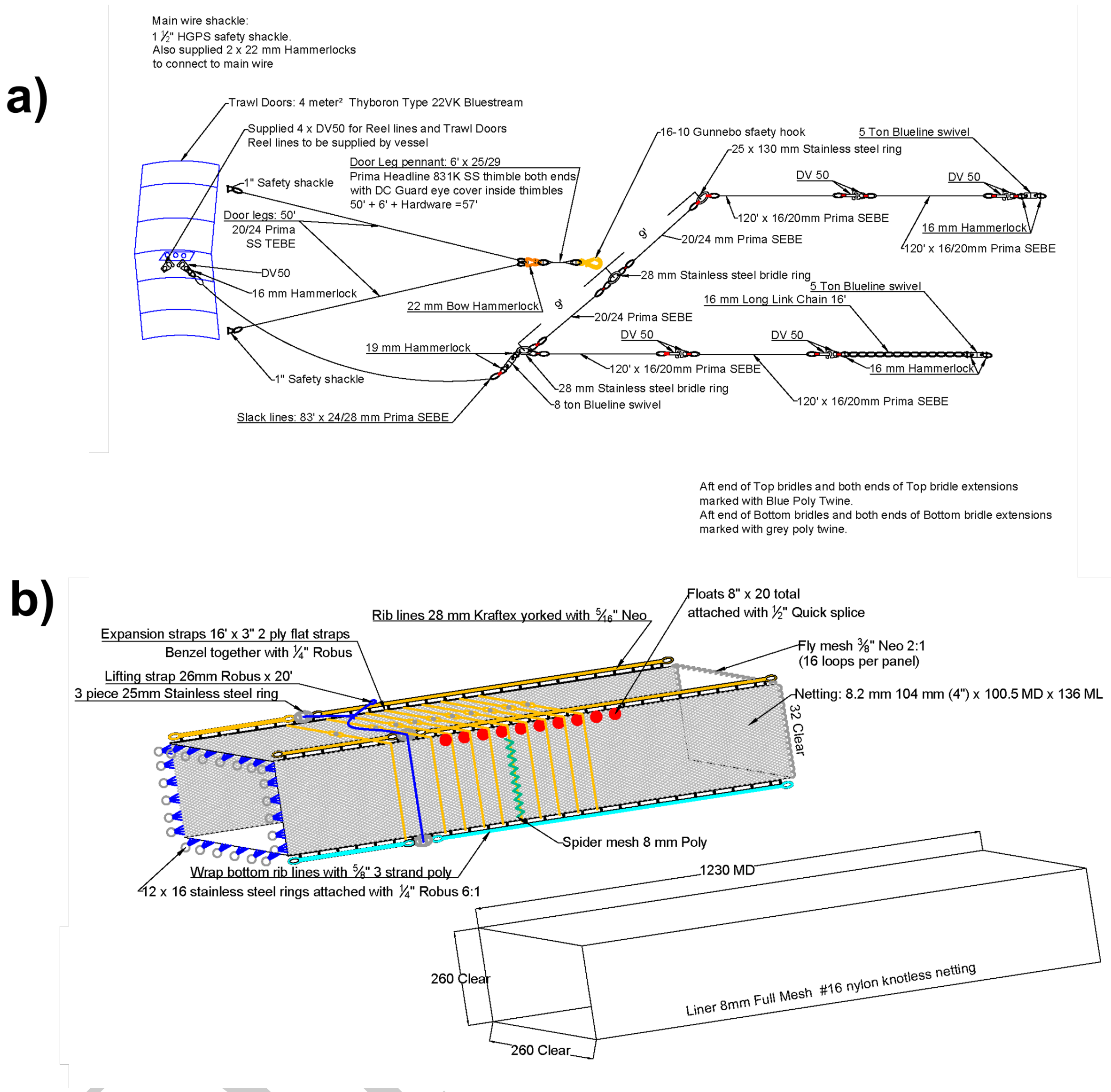

Figure 7: Schematics of the Multifunction Trawl Net System a) rigging and b) cod-end.

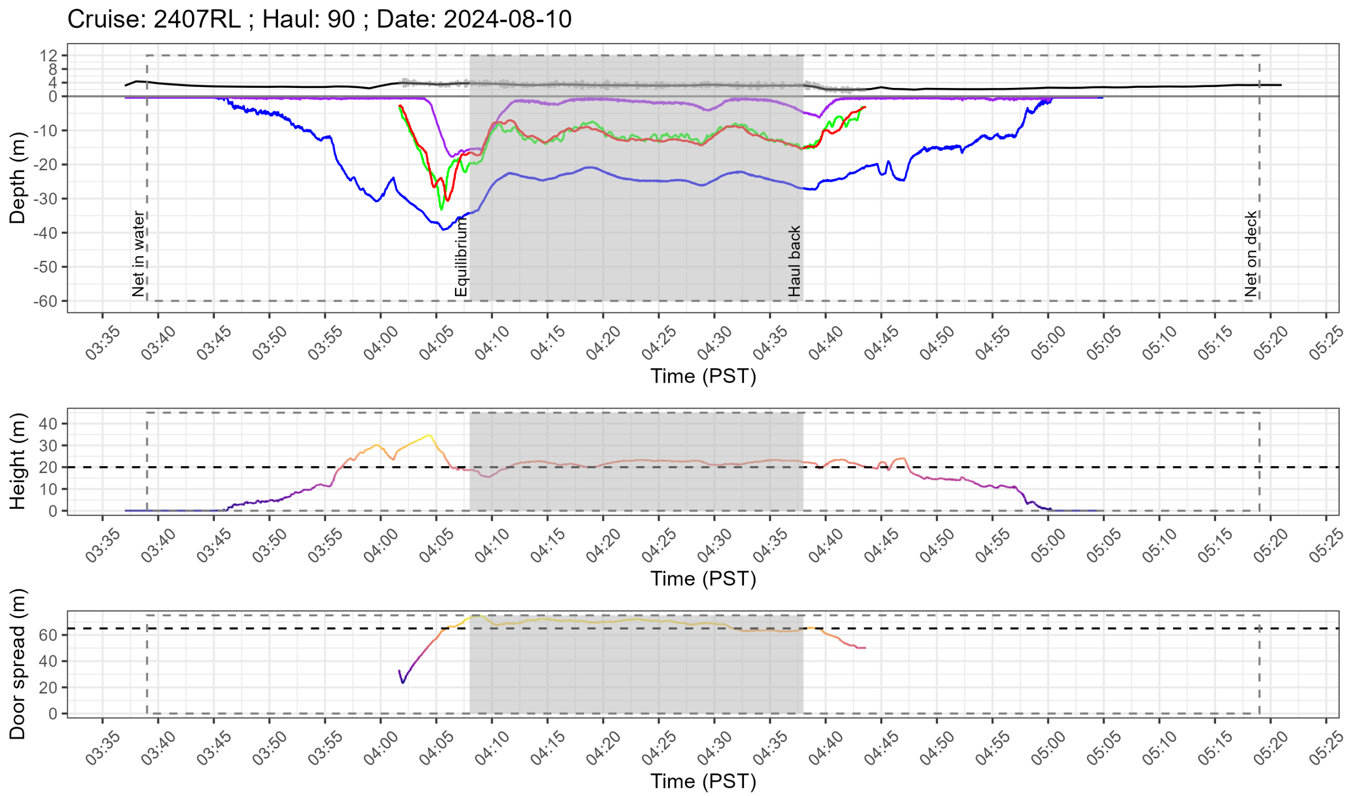

Figure 8: Example plot illustrating net performance during the net deployment (dashed box) and when actively fishing (shaded region) by combining outputs from the SCS, temperature-depth recorders (TDR), and Simrad PxPos sensors. (Top) The vessel speed over ground (kn, black line), measured using the ship's GPS, and depths of the trawl kite (purple line) and footrope (blue line), measured using TDRs, and the port (green line) and starboard doors (red line), measured using the PxPos sensors. (Middle) Height of the net opening measured as the difference between the kite and footrope depths. (Bottom) The spread of the doors measured by the PxPos sensors.

2.1.4.3 Sampling locations

2.1.4.3.1 ***Lasker*** Up to three nighttime (i.e., 30 min after sunset to 30 min before sunrise) surface trawls, typically spaced at least 10-nmi apart, were conducted in locations where putative CPS schools were observed by an acoustician in echograms earlier that day. If no CPS echoes were observed along a transect that day, the trawls were alternately placed nearshore that night and offshore the next night, with consideration given to the seabed depth and the modeled distribution of CPS habitat. The locations were provided to the watch officers who charted the proposed trawl sites. Each morning, after the last trawl or no earlier than 30 min prior to sunrise, *Lasker* resumed sampling at the location where the acoustic sampling stopped the previous day.

2.1.4.3.2 ***Lisa Marie* and *Long Beach Carnage*** On *Lisa Marie* and *Long Beach Carnage*, as many as three purse-seine sets were conducted each day where CPS schools were observed at the surface or in echograms. For each set, three dip-net samples were collected that were spatially separated as much as possible.

2.1.4.4 Sample processing

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

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

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

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

where $\overline{w}_e$ is the mean weight of the e-th species in the subsample. For Pacific Sardine and Northern Anchovy, individual measurements of standard length (L_S, mm) and weight (w, g) were recorded for up to 75 specimens. For Jack Mackerel, Pacific Mackerel, Pacific Herring, and Round Herring, individual measurements of fork length (L_F) and w were recorded for up to 50 specimens. In addition, sex and maturity were recorded for all Pacific Sardine processed for lengths. Ovaries were only preserved for Pacific Sardine that were considered active and spawning. Fin clips were removed from all Pacific Sardine processed for lengths and up to 50 Northern Anchovy per trawl from seven geographic zones (with boundaries at the Columbia River, Cape Mendocino, San Francisco Bay, Point Conception, San Diego, and San Quentin, Baja CA) and preserved in ethanol for genetic analysis. Otoliths were removed from all Pacific Sardine in the subsample; for Northern Anchovy, Pacific Mackerel, and Jack Mackerel, up to 25 otoliths were removed from the available specimens as equally as possible from the range of sizes present. The combined catches in up to three trawls per night (i.e., trawl cluster) were used to estimate the proportions of species contributing to the nearest samples of acoustic backscatter.

2.1.4.4.2 *Lisa Marie* For each dip-net sample, all specimens were sorted, weighed, and counted to provide a combined weight and count for each species. Next, all three dip-net samples were combined and up to 50 specimens of each CPS species were randomly sampled to provide individual measures of weight and length (L_S for Pacific Sardine and Northern Anchovy and L_F for all others) and weight for each set. Otoliths were extracted and macroscopic maturity stage was determined visually for CPS. For Pacific Sardine, tissue samples were collected and stored in ethanol for later genetic analysis.

2.1.4.4.3 *Long Beach Carnage* For each dip-net sample, all specimens were sorted, weighed, and counted to provide a combined weight and count for each species. Then all dip net samples were combined and as many as 50 specimens of each CPS species present were chosen randomly throughout the sample and frozen for later analysis by CDFW biologists, yielding individual measures of weight, length (L_S for Pacific Sardine and Northern Anchovy and L_F for all others), and maturity. No female gonad samples were analyzed. Otoliths were collected but not aged. For some specimens, fin clips were collected in the laboratory from specimens that were frozen at sea, and those samples were stored in ethanol for later genetic analysis.

2.1.4.5 Quality Assurance and Quality Control At sea, trawl data were entered into a database (Microsoft Access). During and following the survey, data were further scrutinized and verified, or corrected. Missing length (L_{miss}) and weight (W_{miss}) measurements were estimated as $W_{miss} = \beta_0 L^{\beta_1}$ and $L_{miss} = (W/\beta_0)^{(1/\beta_1)}$, respectively, where values for β_0 and β_1 are species- and season-specific parameters of the length-versus-weight relationships described in Palance et al. (2019). To identify measurement or data-entry errors, length and weight data were graphically compared (**Fig.** 9) to measurements from previous surveys and models of season-specific length-versus-weight from previous surveys (Palance *et al.*, 2019). Outliers were flagged, reviewed, and corrected if errors were identified. Catch data were removed from aborted trawl hauls.

2.1.4.6 Comparative nighttime trawl and purse seine sampling From 31 August to 6 September, off the coast of central OR, *Lisa Marie* conducted nighttime purse seine sampling in core region areas where *Lasker* conducted nighttime trawling on the same evening (**Fig.** 10). This one-time research effort was not part of operational survey, and data collected during this effort were not used to estimate biomass. Prior to sunset, acousticians aboard *Lasker* provided the crew of *Lisa Marie* up to three planned trawl locations for that evening. Upon completion of each trawl, *Lisa Marie* attempted to set their purse seine as close as possible in space and time to the trawl location. Catches from both vessels were processed in the same manner as those from the main portion of the survey. Species proportions and size distributions were compared to examine similarities and differences between the two net sampling methods used to apportion acoustic backscatter observed in the core survey area.

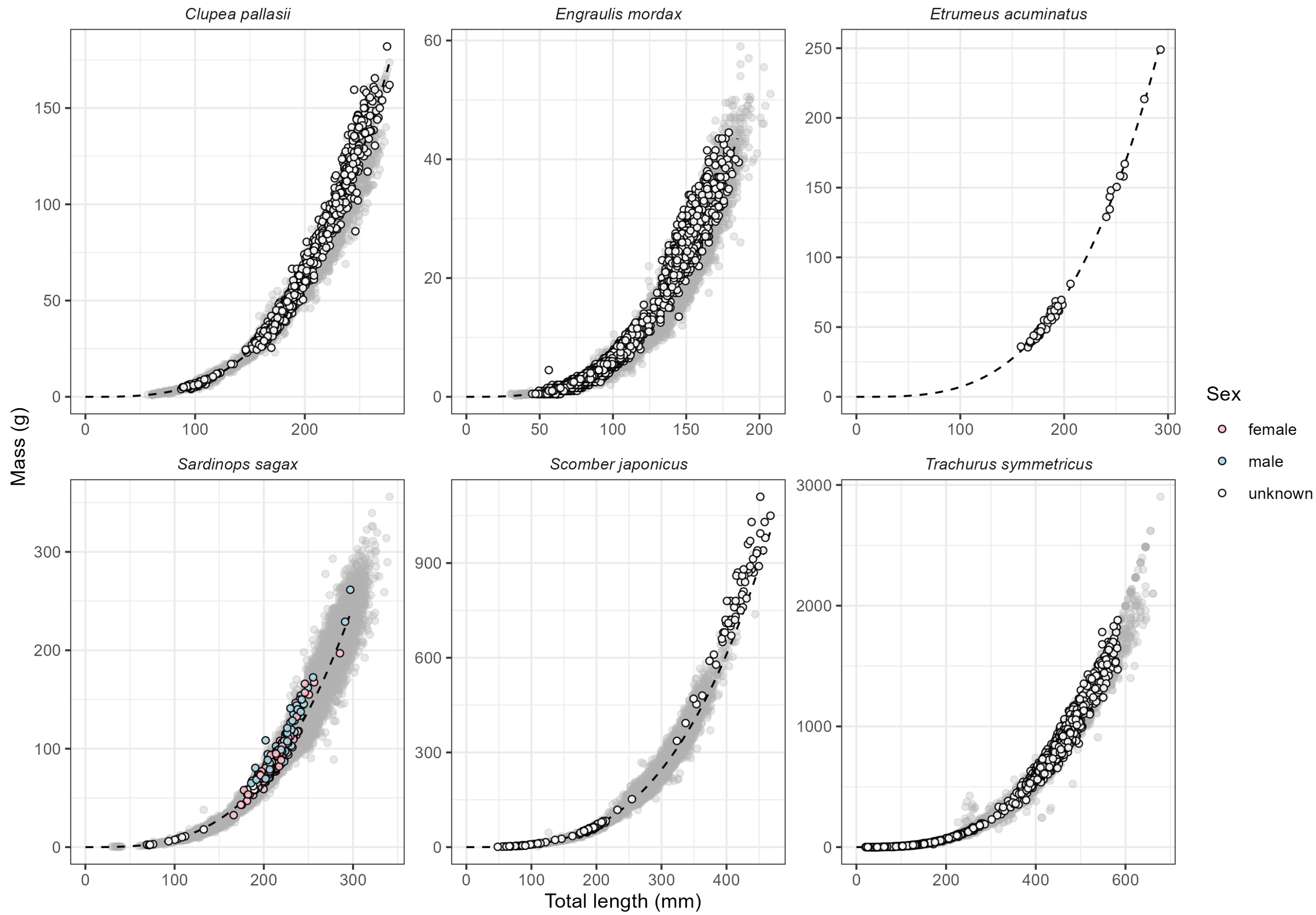

Figure 9: Specimen weight versus length from the current survey (colored points, by sex) compared to those from previous SWFSC surveys during the same season (gray points) and length-weight models from Palance et al. (2019), except for Round Herring, which was fit using data from recent surveys (dashed lines).

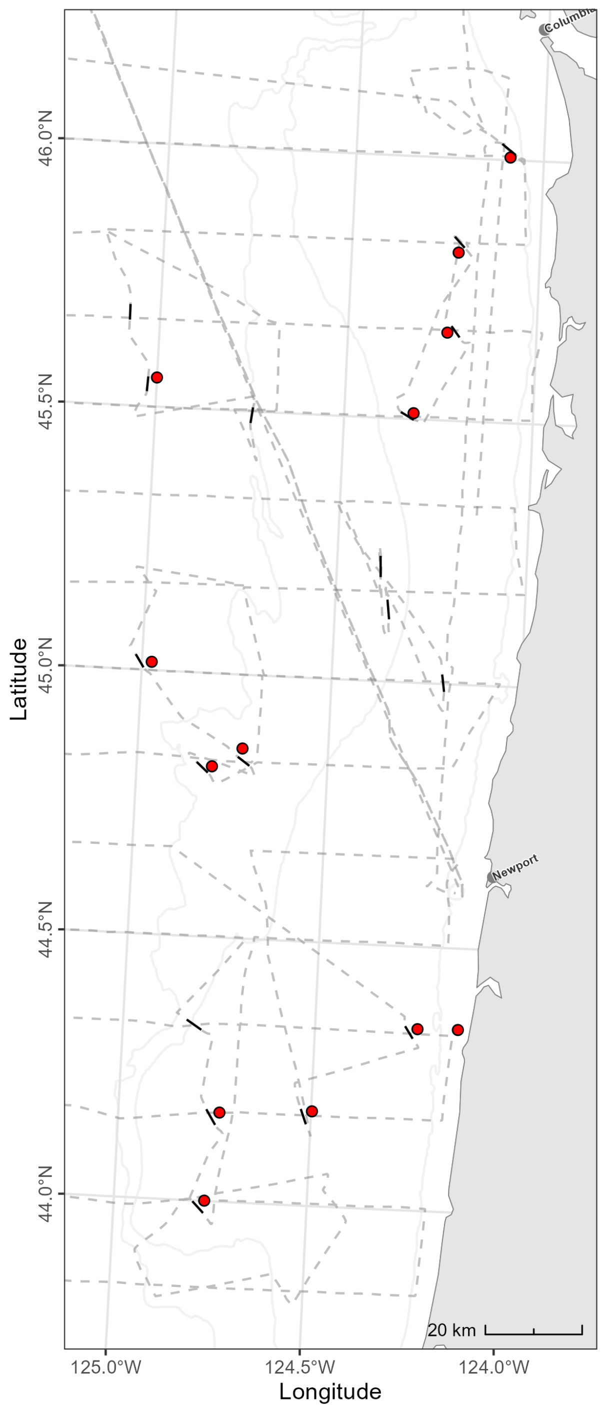

Figure 10: Locations of nighttime trawls (black lines) and purse seine sets (red points) used to compare net sampling methods. The dashed line indicates the path of *Lasker* during daytime acoustic sampling and nighttime trawling.

2.2 Acoustic data processing

2.2.1 Acoustic and oceanographic data

The calibrated echosounder data from each transect were processed using commercial software (Echoview v14.0; Echoview Software Pty Ltd.) and estimates of the sound speed and absorption coefficient calculated with contemporaneous data from CTD probes cast while stationary or underway (UCTD, see **Section 2.1.3.1**). Data collected along the daytime transects at speeds $\geq$ 5 kn were used to estimate CPS densities. Nighttime acoustic data were not used for biomass estimations because they are assumed to be negatively biased due to diel-vertical migration and disaggregation of the target species' schools (Cutter and Demer, 2008).

2.2.2 Sound speed and absorption compensation

CTD casts provide measures of pressure, conductivity, and temperature, from which depth, salinity, and sound speed (c_w, m s^{-1}) are derived. On *Lasker*, the underway CTD probe (RapidPro Plus; Valeport) provided pre-processed data containing temperature and derived measures of depth, salinity, and c_w. On *Lisa Marie*, the CTD probe (SBE19plus; Seabird) provided raw measures of pressure, conductivity, and temperature, for which post-processing software (Seabird SBEDataProcessing) was used to filter the data, derive depth, average into 1-m bins, then derive salinity and c_w for each bin. For both probes, values of depth and c_w for the downcast were defined in transect-specific Echoview Calibration Supplement (ECS) files utilized for the Echoview data processing. The c_w profile is used to estimate ranges to the sound scatterers and 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). Similarly, the average temperature, salinity, and depth, along with the harmonic mean of c_w, were computed over the entire downcast and defined in the ECS file. These averaged values are used by Echoview to calculate absorption coefficients which account for frequency-dependent absorption losses. Lastly, the calibration parameters were updated to compensate for changes in local c_w relative to that at the time of the calibration (Bodholt, 2002):

$$G_0 = G_0^{'} + 20log_{10}\left(\frac{c_w^{'}}{c_w}\right), \tag{3}$$

$$\Psi = \Psi^{'} + 20log_{10}\left(\frac{c_w}{c_w^{'}}\right), \tag{4}$$

$$\alpha_{-3\text{dB}} = \alpha_{-3\text{dB}}^{'} * \left(\frac{c_w}{c_w^{'}}\right), \tag{5}$$

$$\beta_{-3\text{dB}} = \beta_{-3\text{dB}}^{'} * \left(\frac{c_w}{c_w^{'}}\right), \tag{6}$$

where the prime symbol denotes values from the calibration and c_w is at the depth of the transducer. 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**).

The CTD probe used by *Long Beach Carnage* malfunctioned at the beginning of their survey. Therefore, the oceanographic data used for generating the ECS files to process the *Long Beach Carnage* acoustic data was obtained from the nearest *Lasker* underway CTD cast.

2.2.3 Echo classification

Echoes from schooling CPS (**Figs. 11a, d**) were identified using the semi-automated data processing algorithm described below and implemented using Echoview software (v14.0; Echoview Software Pty Ltd). The filters and thresholds were based on a subsample of echoes from randomly selected CPS schools. The aim of the filter criteria is to retain at least 95% of the noise-free backscatter from CPS while rejecting at least 95% of the non-CPS backscatter (**Fig. 11**). Data from *Lasker*, *Lisa Marie*, and *Long Beach Carnage* were processed using the following steps:

1. Match geometry of all S_v variables to the 38-kHz S_v;
2. Remove passive-mode pings;
3. Estimate and subtract background noise using the background noise removal function (De Robertis and Higginbottom, 2007) in Echoview (**Figs. 11b, e**);
4. Average the noise-free S_v echograms using non-overlapping 11-sample by 3-ping bins;
5. Expand the averaged, noise-reduced S_v echograms with a 7 pixel x 7 pixel dilation;
6. For each pixel, compute: $S_{v,200\text{kHz}} - S_{v,38\text{kHz}}$, $S_{v,120\text{kHz}} - S_{v,38\text{kHz}}$, and $S_{v,70\text{kHz}} - S_{v,38\text{kHz}}$;
7. Create a Boolean echogram for S_v differences in the CPS range: $-13.85 < S_{v,70\text{kHz}} - S_{v,38\text{kHz}} < 9.89$ and $-13.5 < S_{v,120\text{kHz}} - S_{v,38\text{kHz}} < 9.37$ and $-13.51 < S_{v,200\text{kHz}} - S_{v,38\text{kHz}} < 12.53$;
8. For 120 and 200 kHz, compute the squared difference between the noise-filtered S_v (Step 3) and averaged S_v (Step 4), average the results using an 11-sample by 3-ping window to derive variance, then compute the square root to derive the 120- and 200-kHz standard deviations ($\sigma_{120\text{kHz}}$ and $\sigma_{200\text{kHz}}$, respectively);
9. Expand the standard deviation echograms with a 7 pixel x 7 pixel dilation;
10. Create a Boolean echogram based on the standard deviations in the CPS range: $\sigma_{120\text{kHz}} >$ -65 dB and $\sigma_{200\text{kHz}} >$ -65 dB. Diffuse backscattering layers have low σ (Zwolinski *et al.*, 2010) whereas fish schools have high σ;
11. Intersect the two Boolean echograms to create an echogram with "TRUE" samples for candidate CPS schools and "FALSE" elsewhere;
12. Mask the noise-reduced echograms using the CPS Boolean echogram (**Figs. 11c, f**);
13. Create an integration-start line 5 m below the transducer (~10 m depth);
14. Create an integration-stop line 3 m above the estimated seabed (Demer *et al.*, 2009a), or to the maximum logging range (e.g., 350 m), whichever is shallowest;
15. Set the minimum S_v threshold to -70 dB (corresponding to a density of approximately three 20-cm-long Pacific Sardine per 100 m^3);
16. Integrate the volume backscattering coefficients (s_V, m^2 m^{-3}) attributed to CPS over 5-m depths and averaged over 100-m distances;
17. Output the resulting nautical area scattering coefficients (s_A; m^2 nmi^{-2}) and associated information from each transect and frequency to comma-delimited text (.csv) files.

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

2.2.4 Removal of non-CPS backscatter

In addition to echoes from target CPS, echoes may also be present from other pelagic fish species (Pacific Saury, *Cololabis saira*), or semi-demersal fish such as Pacific Hake and rockfishes (*Sebastes* spp.). When analyzing the acoustic-survey data, it was therefore necessary to filter "acoustic by-catch," i.e., backscatter not from the target species. To exclude these echoes, echograms were visually examined using R and integration depths were edited to exclude echoes where the seabed was hard and rugose, or where diffuse schools were observed either near the surface or deeper than ~250 m (**Fig. 12**). In areas dominated by Pacific Herring, for example off Vancouver Island, backscatter was integrated to a maximum depth of 75 m.

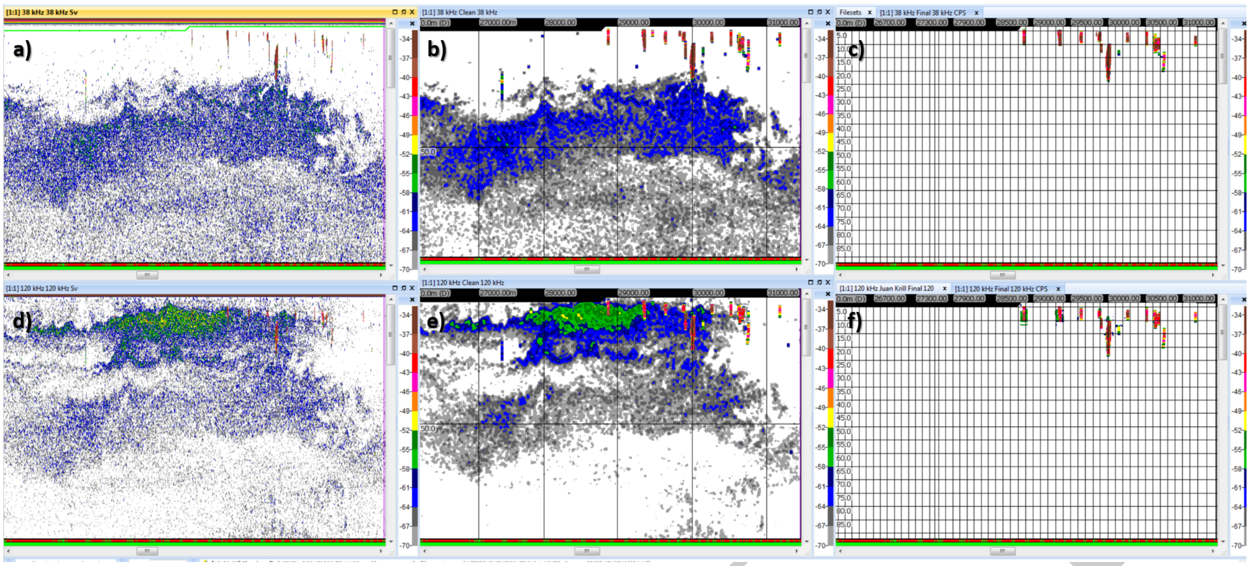

Figure 11: Two examples of echograms depicting CPS schools (red) and plankton aggregations (blue and green) at 38 kHz (top) and 120 kHz (bottom). Example data processing steps include the original echogram (a, d), after noise subtraction and bin-averaging (b, e), and after filtering to retain only putative CPS echoes (c, f).

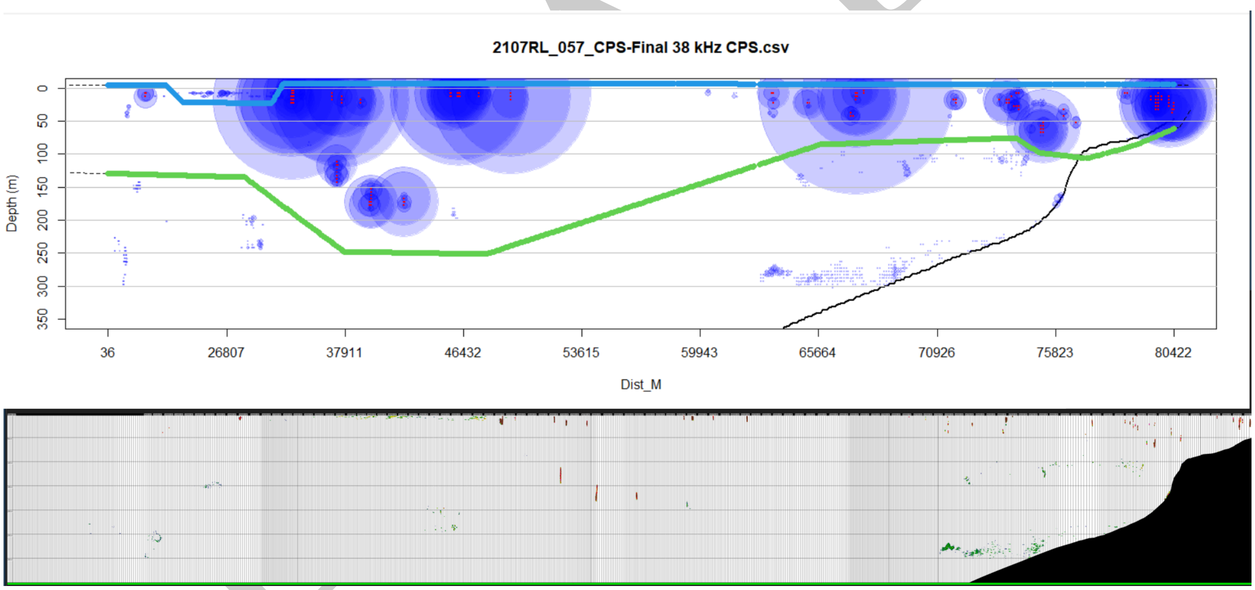

Figure 12: Echoes from fishes with swimbladders (blue points, scaled by backscatter intensity) along an example acoustic transect (top) and the corresponding echogram image (bottom). In this example, the upper (blue) and lower lines (green) indicate boundaries within which echoes were retained. Where the lower boundary was deeper than the seabed (black line), echoes above the seabed were retained. Echoes from deep, bottom-dwelling schools of non-CPS fishes with swimbladders, and from diffuse scatterers near the surface were excluded.

2.2.5 Quality Assurance and Quality Control

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

2.2.6 Echo integral partitioning and acoustic inversion

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

$$\sigma_{bs} = 10^{\frac{m\ \log_{10}(L)+b}{10}}, \tag{7}$$

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:

$$TS = 10\ \log_{10}(\sigma_{bs}) = m\ \log_{10}(L) + b. \tag{8}$$

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:

$$TS_{38\text{kHz}} = -14.90 \times \log_{10}(L_T) - 13.21, \text{ for Pacific Sardine;} \tag{9}$$

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

$$TS_{38\text{kHz}} = -13.87 \times \log_{10}(L_T) - 11.797, \text{ for Northern Anchovy; and} \tag{11}$$

$$TS_{38\text{kHz}} = -15.44 \times \log_{10}(L_T) - 7.75, \text{ for Pacific and Jack Mackerels,} \tag{12}$$

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

Equations (9) and (12) were derived from echosounder measurements of σ_{bs} for in situ fish and measures of L_T and W from concomitant catches of South American Pilchard (*Sardinops ocellatus*) and Horse Mackerel (*Trachurus trachurus*) off South Africa (Barange *et al.*, 1996). Because mackerels have similar TS (Peña, 2008), Equation (12) is used for both Pacific and Jack Mackerels. For Pacific Herring and Round Herring, Equation (10) was derived from that of Thomas et al. (2002) measured at 120 kHz with the following modifications: 1) the intercept used here was calculated as the average intercept of Thomas et al.'s spring and fall regressions; 2) the intercept was compensated for swimbladder compression after Zhao et al. (2008) using the average depth for Pacific Herring of 44 m; and 3) the intercept was increased by 2.98 dB to account for the change of frequency from 120 to 38 kHz (Saunders *et al.*, 2012). For Northern Anchovy, Equation (11) was derived from that of Kang et al. (2009), after compensation of the swimbladder volume (Ona, 2003; Zhao *et al.*, 2008) for the average depth of Northern Anchovy observed in summer 2016 (19 m, Zwolinski *et al.*, 2017).

To calculate $TS_{38\text{kHz}}$, L_T was estimated from measurements of L_S or L_F using linear relationships between length and weight derived from specimens collected in the CCE (Palance *et al.*, 2019): for Pacific Sardine, $L_T = 0.3574 + 1.149 L_S$; for Northern Anchovy, $L_T = 0.2056 + 1.1646 L_S$; for Pacific Mackerel, $L_T = 0.2994 + 1.092 L_F$; for Jack Mackerel $L_T = 0.7295 + 1.078 L_F$; and for Pacific Herring $L_T = -0.105 + 1.2 L_F$.

Since a conversion does not exist for Round Herring, the equation for Pacific Herring was used to estimate L_T, when present.

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 proportion of acoustic backscatter for the e-th species in the a-th trawl (P_{ae}) is:

$$P_{ae} = \frac{N_{ae} \times \overline{w}_{ae} \times \overline{\sigma}_{bs,ae}}{\sum_{e=1}^{s_a}(N_{ae} \times \overline{w}_{ae} \times \overline{\sigma}_{bs,ae})}, \tag{13}$$

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

$$\overline{\sigma}_{bs,ae} = \frac{\sum_{i=1}^{n_{ae}} 10^{(TS_i/10)}}{n_{ae}}, \tag{14}$$

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:

$$\overline{\sigma}_{bs,ge} = \frac{\sum_{a=1}^{h_g} N_{ae} \times \overline{w}_{ae} \times \overline{\sigma}_{bs,ae}}{\sum_{a=1}^{s_g} N_{ae} \times \overline{w}_{ae}}, \tag{15}$$

where:

$$\overline{w}_{ge} = \frac{\sum_{a=1}^{h_g} N_{ae} \times \overline{w}_{ae}}{\sum_{a=1}^{h_g} N_{ae}}, \tag{16}$$

and the proportion (P_{ge}) is;

$$P_{ge} = \frac{N_{ge} \times \overline{w}_{ge} \times \overline{\sigma}_{bs,ae}}{\sum_{e=1}^{s}(N_{ge} \times \overline{w}_{ge} \times \overline{\sigma}_{bs,ge})}. \tag{17}$$

2.2.7 Trawl clustering and species proportion

Nighttime trawl and daytime purse seine samples were used to apportion backscatter in the core and nearshore areas, respectively. Trawls that occurred on the same night were assigned to a trawl cluster. Biomass densities (ρ; t nmi^{-2}) 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 or purse seine nearest in space. Acoustic transects were post-stratified to account for spatial heterogeneity in sampling effort and biomass density in a similar way to that performed for Pacific Sardine (PFMC, 2018; Zwolinski *et al.*, 2016).

For a generic 100-m long acoustic interval, the vertically summed area-backscattering coefficient for species e was computed as: $s_{A,e} = s_{A,cps} \times P_{ge}$, where $s_{A,cps}$ is the vertically summed area-backscattering coefficient for all CPS and P_{ge} (Equation (17)) is the proportion of acoustic backscatter from species e in the nearest trawl cluster or purse seine (**Fig. 13**). Then, $s_{A,e}$ was used to estimate the biomass density ($\rho_{w,e}$) (MacLennan *et al.*, 2002; Simmonds and MacLennan, 2005) for every 100-m interval:

$$\rho_{w,e} = \frac{s_{A,e}}{4\pi\overline{\sigma}_{bs,e}}. \tag{18}$$

In 2024, purse seine sampling was sparse in some areas where CPS backscatter was observed, so the nearest purse seine or trawl cluster were used to apportion backscatter, whichever was closest in space (**Fig. 13, b**).

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 or purse seine.

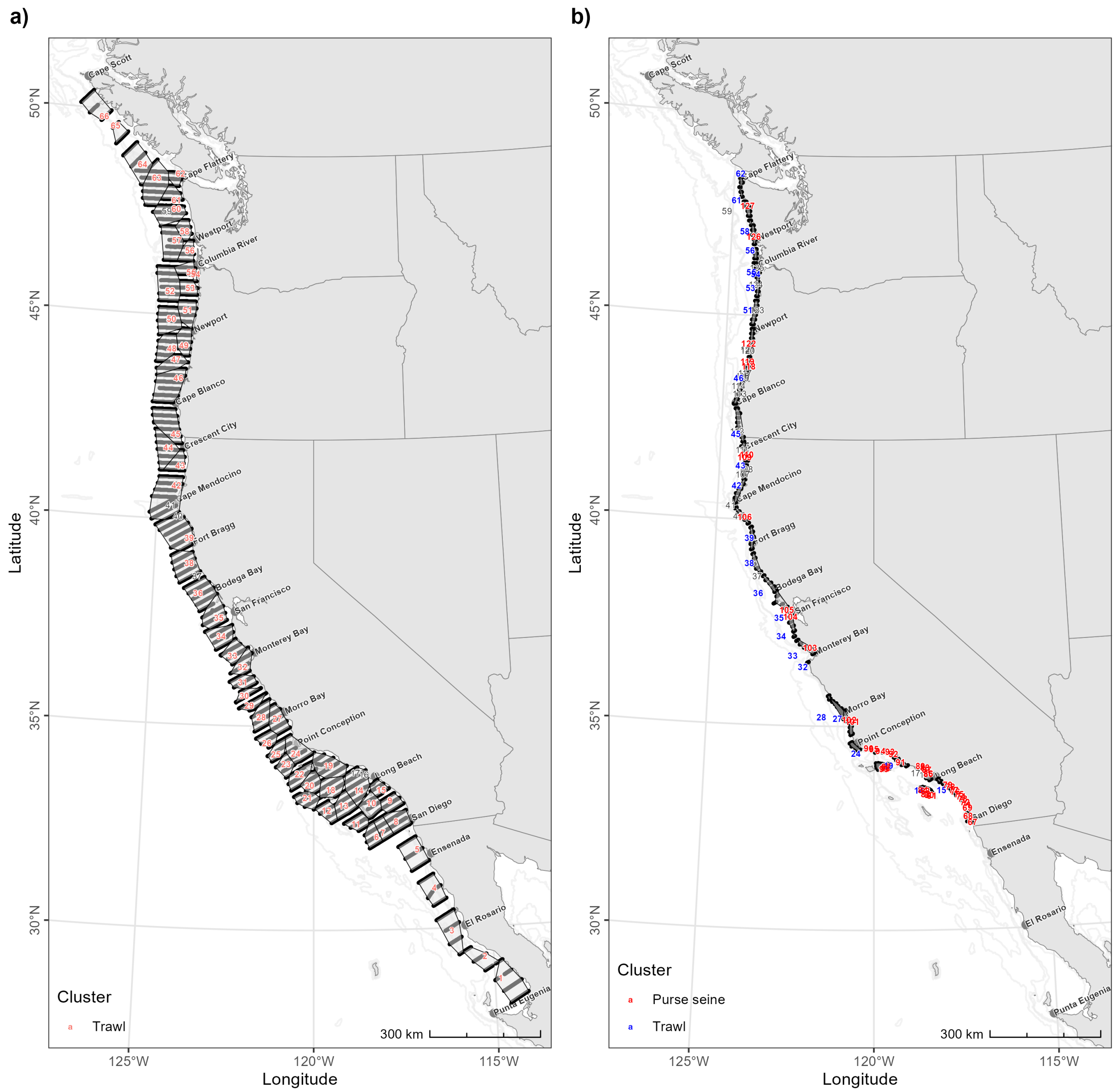

Figure 13: Polygons enclosing 100 m-long acoustic transect intervals sampled by a) *Lasker* in the core region and b) *Long Beach Carnage* and *Lisa Marie* in the nearshore region relative to the nearest trawl cluster or purse-seine set used to apportion acoustic backscatter. The colored numbers inside each polygon indicate the sample number and gear type. Dark gray numbers indicate trawl clusters or purse-seine sets with no CPS present in the catch.

2.3 Data analysis

2.3.1 Post-stratification

The transects were the sampling units (Simmonds and Fryer, 1996). Because most species do not generally span the entire survey area (Demer and Zwolinski, 2017; Zwolinski *et al.*, 2014), the sampling domain was post-stratified for each species and subpopulation (PFMC, 2018; Zwolinski *et al.*, 2016). Strata were defined by uniform transect spacing (i.e., sampling intensity) and either the presence (i.e., positive densities and potentially structural zeros) or absence (i.e., real zeros) of biomass for each species. Each stratum has: 1) at least three transects, with approximately equal spacing, 2) fewer than three consecutive transects with zero-biomass density, and 3) bounding transects with zero-biomass density (**Fig. 14**). This approach tracks 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 subpopulations at Cape Mendocino (40.8 °N). For Pacific Sardine, the northern subpopulation biomass present in the survey area (Felix-Uraga *et al.*, 2004; Felix-Uraga *et al.*, 2005; Garcia-Morales *et al.*, 2012; Hill *et al.*, 2014) was separated using the revised model of Pacific Sardine potential habitat (Zwolinski and Demer, 2024) during the survey (**Fig. 15**), with all other Pacific Sardine biomass considered to belong to the southern subpopulation. This separation is further supported by different distributions of L_S and a break in the distribution of Pacific Sardine biomass, which, in this survey, coincided geographically with Pt. Conception (34.7 °N, **Fig. 14**).

2.3.2 Analysis of deep backscatter in the nearshore region

In some areas, substantial backscatter was observed deeper than the upper mixed layer (approximately 30-m deep) in the nearshore region. In those areas, the purse-seine catches sampled using a 27-m deep net contained mostly Pacific Sardine, which typically reside above the thermocline (J. Zwolinski, unpublished data), but also Northern Anchovy. Therefore, the CPS backscatter shallower than 30 m was apportioned using the length and species composition of all CPS in the nearest purse seine sample or trawl cluster and used to estimate biomass. **The backscatter attributed to Northern Anchovy deeper than 30 m has not yet been used to estimate biomass, but will be done prior to publication.**

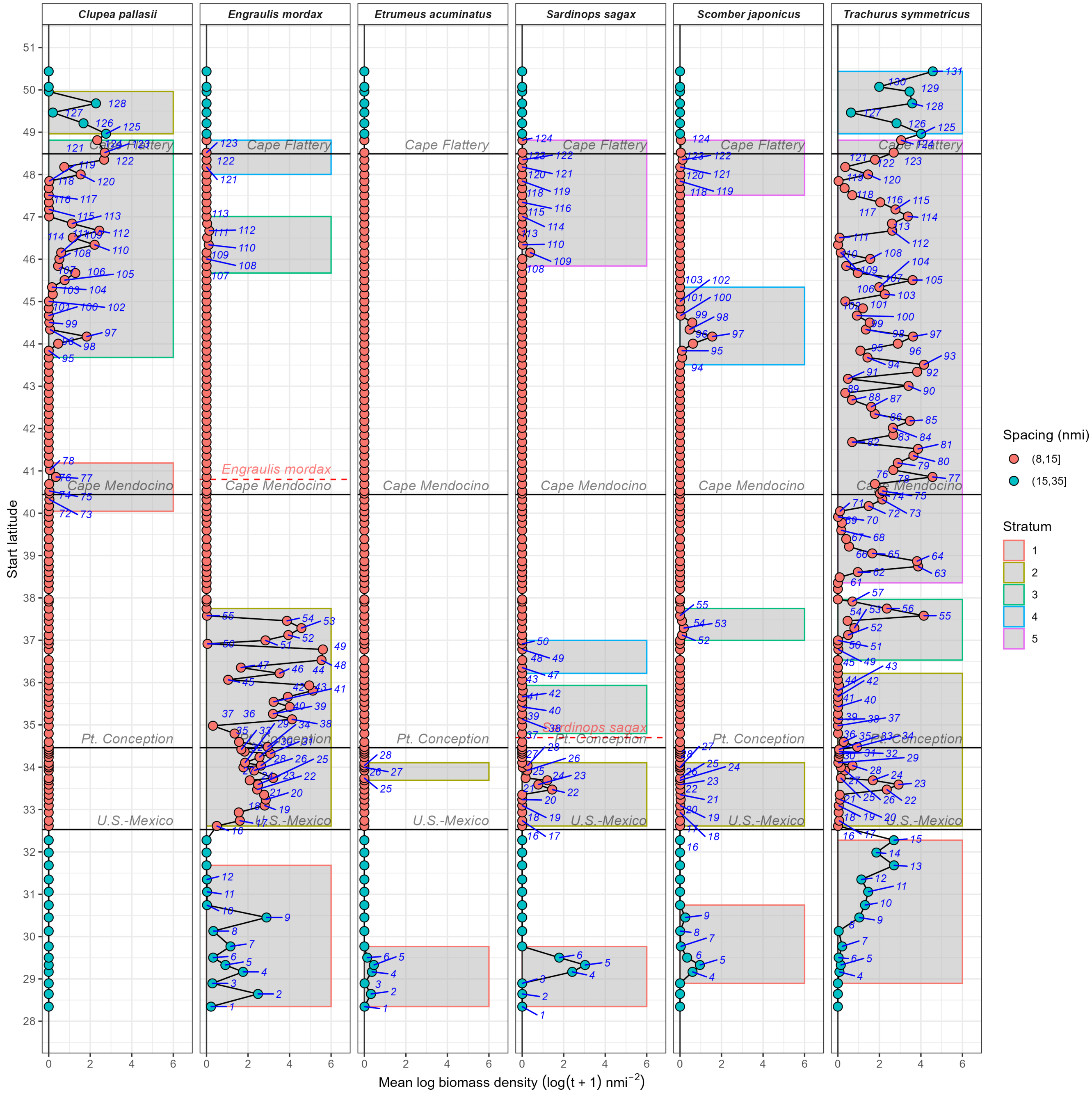

Figure 14: Log-transformed biomass density + 1 ($(t\,\text{nmi}^{-2})$) by transect versus latitude (easternmost portion of each transect) and strata (shaded regions; outline indicates stratum number) used to estimate biomass and abundance for each species in the core region surveyed by *Lasker*. Data labels (blue numbers) correspond to transects with positive biomass ($\log_e(t+1) > 0$). Transect spacing (nmi; point color), and subpopulation breaks for Northern Anchovy and Pacific Sardine (red dashed lines and text) are indicated.

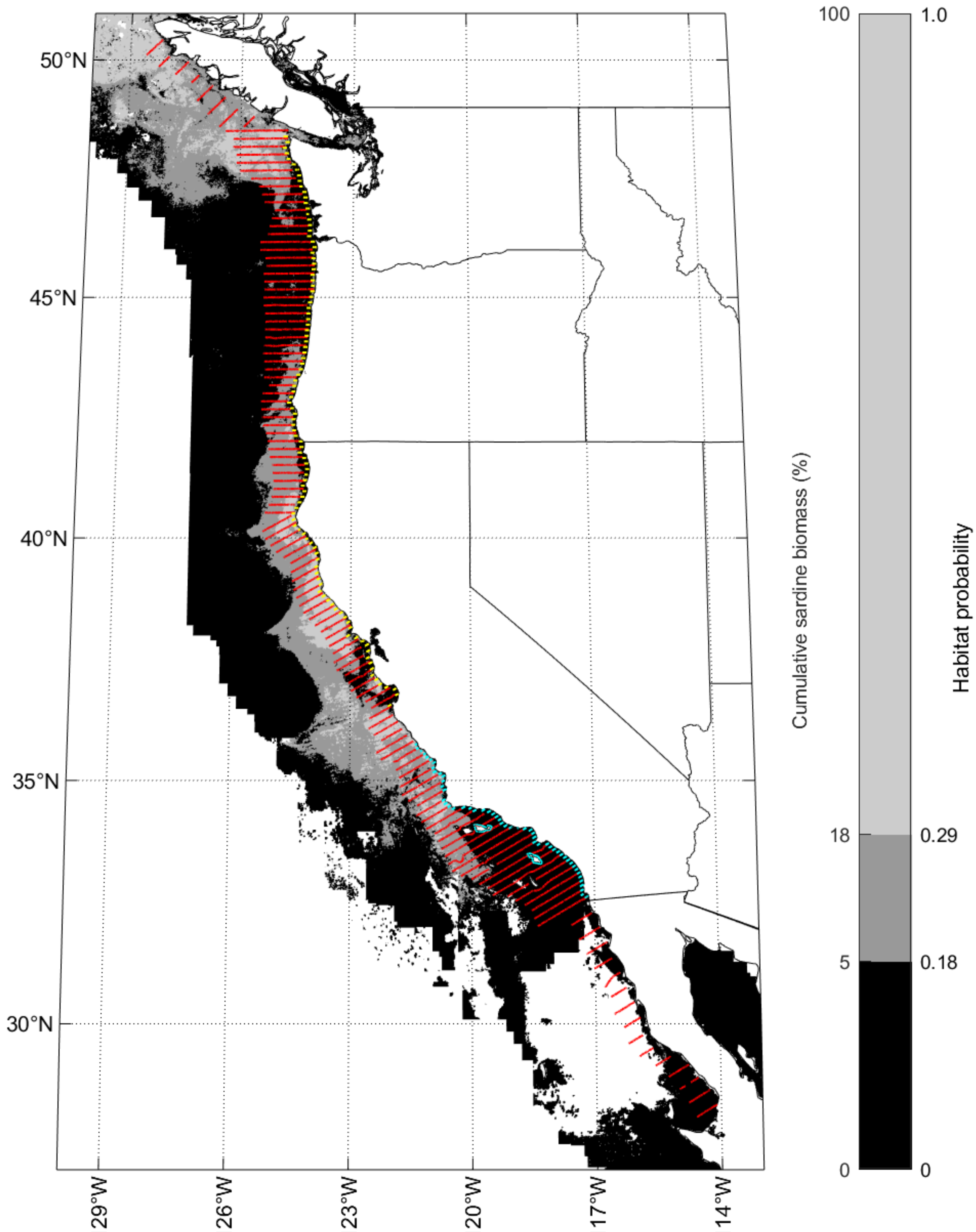

Figure 15: Summary of all core- and nearshore-region transects, in relation to the potential habitat for the northern subpopulation of Pacific Sardine, as sampled by *Lasker* (red), *Long Beach Carnage* (cyan), and *Lisa Marie* (yellow). The habitat is temporally aggregated using an average of the habitat centered ±2° around each vessel during the survey. Areas in white correspond to no available data (e.g., when cloud coverage prevented satellite-sensed observations).

2.3.3 Biomass and sampling precision estimation

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

$$\hat{B} = A \times \hat{D}, \tag{19}$$

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

$$\hat{D} = \frac{\sum_{l=1}^{k} \overline{\rho}_{w,l} c_l}{\sum_{l=1}^{k} c_l}, \tag{20}$$

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 asymptotically unbiased estimates of variance.

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

2.3.4 Abundance- and biomass-at-length estimation

The numerical densities by length class (**Section 2.2.7**) were averaged for each stratum in a similar way for that used for biomass (Equation (20)), and multiplied by the stratum area to obtain abundance per length class.

2.3.5 Percent biomass per cluster contribution

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

$$\frac{\Sigma_{i=1}^{l} \overline{\rho}_{ci}}{\Sigma_{c=1}^{C} \Sigma_{i=1}^{l} \overline{\rho}_{ci}}, \tag{21}$$

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

3 Results

3.1 Sampling effort and allocation

At the beginning of Leg 1, five days at sea (DAS) were allocated for drills, training, additional sea trials with the multi-function trawl (MFT) net system, and underway echosounder calibrations (see below).

The core region of the summer 2024 survey spanned the continental shelf from the Punta Eugenia, Baja California, Mexico to Cape Scott, Vancouver Island, between 24 June and 30 September 2024, and included most of the potential habitat for the northern subpopulation of Pacific Sardine at the time of the survey[5]. In this region, *Lasker* (75 DAS) sampled 131 east-west transects totaling 5,664 nmi (**Fig. 17**). Catches from a total of 173 nighttime surface trawls were combined into 66 trawl clusters. In the core region, one to five post-survey strata were defined by their transect spacing and the densities of biomass attributed to each species.

The nearshore region spanned an area from 5-m depth to approximately 5 nmi from the continental coast, or 2.5 nmi from the Santa Cruz and Santa Catalina Islands, between San Diego and Cape Flattery. *Long Beach Carnage* (16 DAS) surveyed from approximately San Diego to Ragged Point along the Big Sur coast, and around the Santa Cruz and Santa Catalina Islands, with 93 east-west transects totaling 283 nmi and 36 purse-seine sets (**Fig. 18**). *Lisa Marie* (24 DAS) surveyed from approximately Pacific Grove, CA to Cape Flattery, WA with 106 east-west transects totaling 371 nmi and 25 purse-seine sets (**Fig. 19**). In the nearshore region, one to thirteen post-survey strata were defined by their transect spacing and the densities of biomass attributed to each species.

Biomasses and abundances were estimated for each species and subpopulation in both the core and nearshore survey regions. The total biomass for each subpopulation within the survey region was estimated as the sum of its biomasses in the core and nearshore regions.

Leg I

Multi-Function Trawl (MFT) Net Testing

Leg I aboard *Lasker* departed from 10th Avenue Marine Terminal in San Diego, CA at 19:30 (all times UTC) on June 25, 2024. The first day consisted of drills, shipboard Operational Readiness Training (ORT), and equipment setup. Prior to sailing, the ship underwent a refit of its entire network to a new Fortinet solution, as part of OMAO's Ocean Data Lake initiative. The next five days (26-30 June) were spent testing the new Multi-Function Trawl (MFT) net and familiarizing personnel with its operations. On 27 June, the Cetacean Health and Life History Program from SWFSC's Marine Mammal and Turtle Division (MMTD) rendezvoused with *Lasker* outside San Diego Bay to conduct drone footage of the MFT during operations. On 29 June, Greg Shaughnessey (Ocean Gold Seafood, Inc.) and Seamus Melly (Swan Nets) departed *Lasker* via a small boat. On 30 June, another small-boat transfer was conducted to swap personnel for the remainder of Leg 1. During the transfer, *Lasker* conducted a calibration of the EC150-3C ADCP at 32.602 N, 117.287 W following the protocols as prescribed by Kongsberg, which involved the ship moving in multiple clockwise and counterclockwise circles. After completing a successful calibration, *Lasker* then transited to 32.542 N / 117.184 W and dropped anchor in approximately 30-m of water. Once anchored, calibrations of the EC150-3C echosounder and ME70 multibeam sonar were conducted. Upon completion of the calibrations, and after the small boat had returned, *Lasker* pulled up anchor and began its transit south to Baja California, Mexico, where it would begin the ATM survey.

ATM survey

On the morning of 2 July, *Lasker* commenced acoustic sampling on Transect 001 in Sebastián Vizcaíno Bay to officially begin the 2024 survey. Acoustic and trawl sampling in Baja California, MX proceeded northward along the 20-nmi-spaced transects. On 7 July, *Lasker* completed the last transect in Mexico, Transect 027C. Between 7-16 July, *Lasker* continued sampling in the SCB. Due to the long transect lines in the SCB, regional sampling was conducted to ensure adequate biological sampling in both the inshore and offshore regions.

[5] https://coastwatch.pfeg.noaa.gov/erddap/griddap/sardine_habitat_modis.html

On 16 July, *Lasker* completed the final sampling of Leg I off Huntington Beach, CA. In total, Leg I sampled all transects from Transects 001 to 040. At 05:00 on 17 July, after completing a single trawl for the final evening, *Lasker* began its transit back to San Diego, CA, arriving at 10th Avenue Marine Terminal at 14:50.

Nearshore

On 8 July, *Long Beach Carnage* was mobilized with EK80 echosounders at Point Loma Sportfishing in San Diego, CA. From 9 to 18 July, *Long Beach Carnage* sampled nearshore transects 1 to 36, between San Diego and Point Conception, including around Santa Catalina Island.

Leg II

Leg II aboard *Lasker* departed on Monday, 22 July at 21:30 from 10th Avenue Marine Terminal in San Diego. At around 13:00 on 23 July, *Lasker* resumed acoustic sampling along the nearshore portion of Transect 041 off Huntington Beach. At ~13:00 on 31 July, a lander containing a WBAT and Aural-M2 was recovered off Point Conception, and at ~14:00 a new lander was deployed in the same area (34.439 N / 120.548 W). On 6 August, *Lasker* transited to Santa Cruz, CA to find calm seas and improved visibility for troubleshooting problems with the X-band radar; ET Trevathan successfully replaced the brushes in the radar antenna motor and the survey resumed the following day with minimal impact to sampling. At ~06:00 on 12 August, acoustic sampling was completed along Transect 075 off Bodega Bay, CA, and at 14:30 *Lasker* arrived at Pier 76 in San Francisco, CA to conclude Leg II.

Nearshore

From 22 to 25 July, *Long Beach Carnage* sampled nearshore transects 37 to 48, between Point Conception and Morro Bay, including around Santa Cruz Island. Then, from 2 to 3 August, *Long Beach Carnage* sampled nearshore transects 49 to 54. On 3 August, *Long Beach Carnage* docked in Monterey, CA, where the acoustic equipment was demobilized for transport back to San Diego, CA.

Leg III

Leg III aboard *Lasker* departed at 19:30 on Saturday, 17 August from Pier 96 in San Francisco, CA. The first day consisted of drills and shipboard ORT activities, followed by two nighttime trawls in the vicinity of Bodega Canyon. Acoustic sampling then resumed at sunrise on 18 August along Transect 076. On 28 and 29 August, inclement weather precluded trawl sampling. Moreover, on the evening of 28 August, *Lasker* was requested by the U.S. Coast Guard to watch over the distressed sailboat *Sundance* until the following morning. On 31 August, *Lasker* commenced regional sampling, in part to obtain both inshore and offshore trawls to enable comparative biosampling with *Lisa Marie*. On 6 September, *Lasker* completed partial acoustic sampling of Transect 124, just outside the mouth of the Columbia River, then conducted a final trawl just north of Tillamook Head. *Lasker* then returned to MOC-P in Newport, OR at 23:00 on 7 September to conclude Leg III.

Nearshore

From 7 to 25 August, *Lisa Marie* sampled nearshore transects 66 to 151, between Monterey, CA and the WA/OR border, returning to port in Westport, WA on 26 August. Then, from 31 August to 6 September, *Lisa Marie* conducted comparative purse seine sets in close proximity, in both space and time, to *Lasker* nighttime trawls. Finally, from 7 to 11 September, *Lisa Marie* sampled nearshore transects 152 to 171, between the WA/OR border and Cape Flattery, WA, to conclude the nearshore survey.

Leg IV

Leg IV aboard *Lasker* departed from MOC-P in Newport, OR at 16:30 on 13 September after a one-day delay awaiting arrival of an augmenting steward. The first day included drills followed by transiting to and beginning sampling on Transect 124, which had been partially sampled during Leg III. *Lasker* then continued sampling northward, entering Canadian waters on 21 September to conduct transects off Vancouver Island. Due to time and weather constraints, sampling off Vancouver Island was only conducted on compulsory transects, spaced 20-nmi apart. On 23 September, after acoustically sampling and conducting trawls on Transect 149, *Lasker* transited to the northernmost transect (Transect 155) off Vancouver Island and resumed sampling from north to south. This decision was made due to an impending weather system, and would optimize sampling effort before *Lasker* would need to vacate the region. On 24 September, *Lasker* completed its final transect of the survey, Transect 151, and conducted one last trawl, before transiting to Newport, OR, where *Lasker* arrived at ~17:00 on 26 September.

3.2 Acoustic backscatter

Acoustic backscatter ascribed to CPS was observed throughout the latitudinal range of the core survey area (**Fig. 17a**), but was greatest between San Diego and San Francisco. Acoustic backscatter was present from the shore to the shelf break, but was generally greater closer to shore. Zero-biomass intervals were observed at the offshore end of each transect in the core region. Greater than 90% of the biomass for each species was apportioned using catch data from trawl clusters conducted within ~25 nmi (**Fig. 16**).

Acoustic backscatter ascribed to CPS was also observed throughout the nearshore survey area, but was most prevalent along mainland and Channel Island transects sampled by *Long Beach Carnage* between San Diego and Ragged Point (**Fig. 18a**), and along transects sampled by *Lisa Marie* between Santa Cruz and San Francisco, and north of Cape Mendocino (**Fig. 19a**).

3.3 Trawl catch

Trawl catches from *Lasker* were composed of mostly Northern Anchovy between Punta Eugenia and San Francisco, and Jack Mackerel farther north (**Fig. 17b**). Pacific Herring were also prevalent in trawl catches between Newport and Cape Flattery. Some Pacific Sardine and Pacific Mackerel were present in trawl clusters offshore in the SCB and close to shore between Newport and Astoria, OR off the Columbia River. Overall, the 173 trawls captured a combined 26,142 kg of CPS (13,806 kg of Northern Anchovy, 8,170 kg of Jack Mackerel, 3,208 kg of Pacific Herring, 324 kg of Pacific Sardine, 624 kg of Pacific Mackerel, and 8.92 kg of Round Herring).

3.4 Purse-seine catch

3.4.1 *Long Beach Carnage*

Purse-seine catches from *Long Beach Carnage* in the nearshore region were composed mostly of Pacific Sardine and Pacific Mackerel (**Fig. 18b**). In general, Pacific Mackerel were more prevalent in samples collected along the mainland coast south of Los Angeles, CA and around Santa Catalina Island. Relatively few Jack Mackerel, Northern Anchovy, and Round Herring were collected in purse-seine samples collected by *Long Beach Carnage* (**Fig. 18b**). Overall, dip-net samples from 36 seines totaled 148 kg of CPS (71.9 kg of Pacific Sardine, 62 kg of Pacific Mackerel, 1.4 kg of Northern Anchovy, 12 kg of Jack Mackerel, and 0.7 kg of Round Herring).

3.4.2 *Lisa Marie*

Purse seine catches from *Lisa Marie* in the nearshore were composed mostly of Pacific Herring, except a few catches of Pacific Sardine between Monterey and San Francisco and a few catches of Jack Mackerel and Pacific Mackerel between Cape Blanco and Newport (**Fig. 19b**). Purse seine sampling between Monterey and Cape Mendocino was sparse due to few CPS targets, the presence or marine mammals that did not permit the deployment of the purse seine gear, or both. Many of the purse seine sets north of Cape Mendocino contained no CPS (**Fig. 19b**). Overall, the dip-net samples from 25 purse-seine sets totaled 44.6 kg of CPS (18.9 kg of Jack Mackerel, 10 kg of Pacific Mackerel, 8.22 kg of Pacific Sardine, 7.27 kg of Pacific Herring, and 0.166 kg of Northern Anchovy).

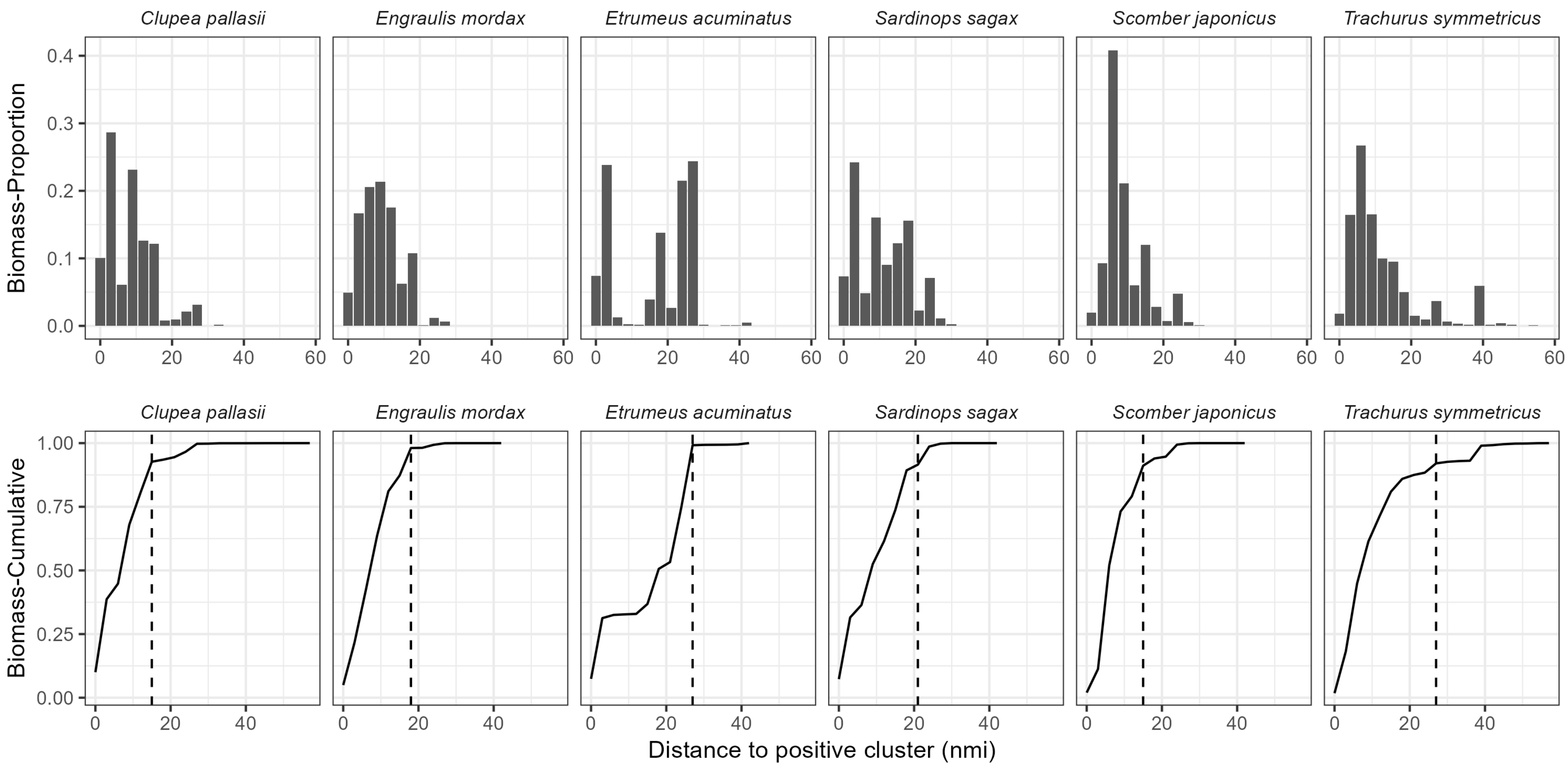

Figure 16: Proportion (top) and cumulative proportion (bottom) of biomass of each CPS species versus distance to the nearest positive trawl cluster sampled by *Lasker*. Dashed vertical lines (bottom) represent the cluster distance where cumulative biomass equals 90%. Note: these results are not separated by subpopulation.

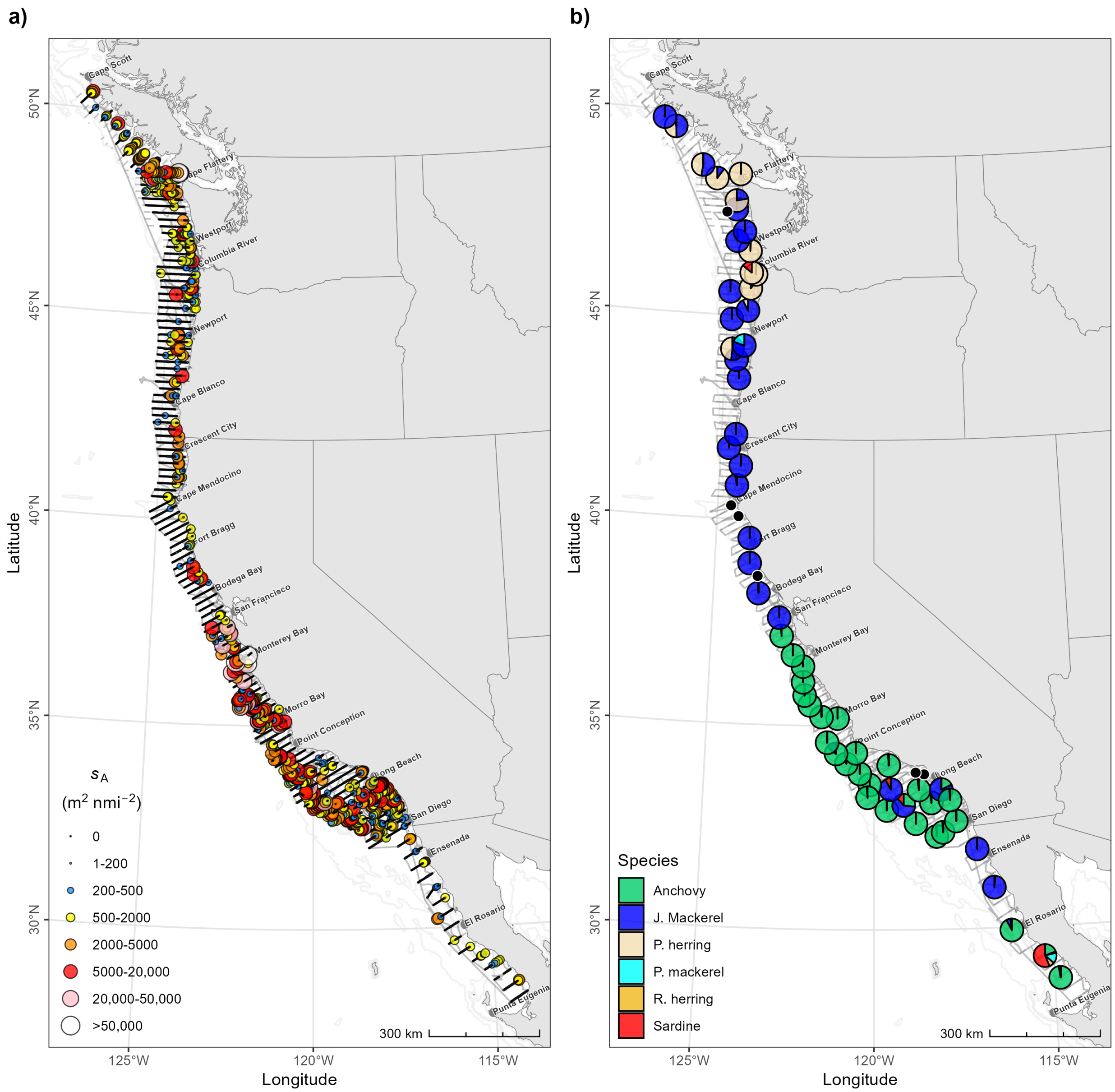

Figure 17: Spatial distributions of: a) 38-kHz vertically integrated backscattering coefficients (s_A, m^2 nmi^{-2}; averaged over 2000-m distance intervals) ascribed to CPS and b) proportion of acoustic backscatter from CPS in trawl clusters sampled by *Lasker*.

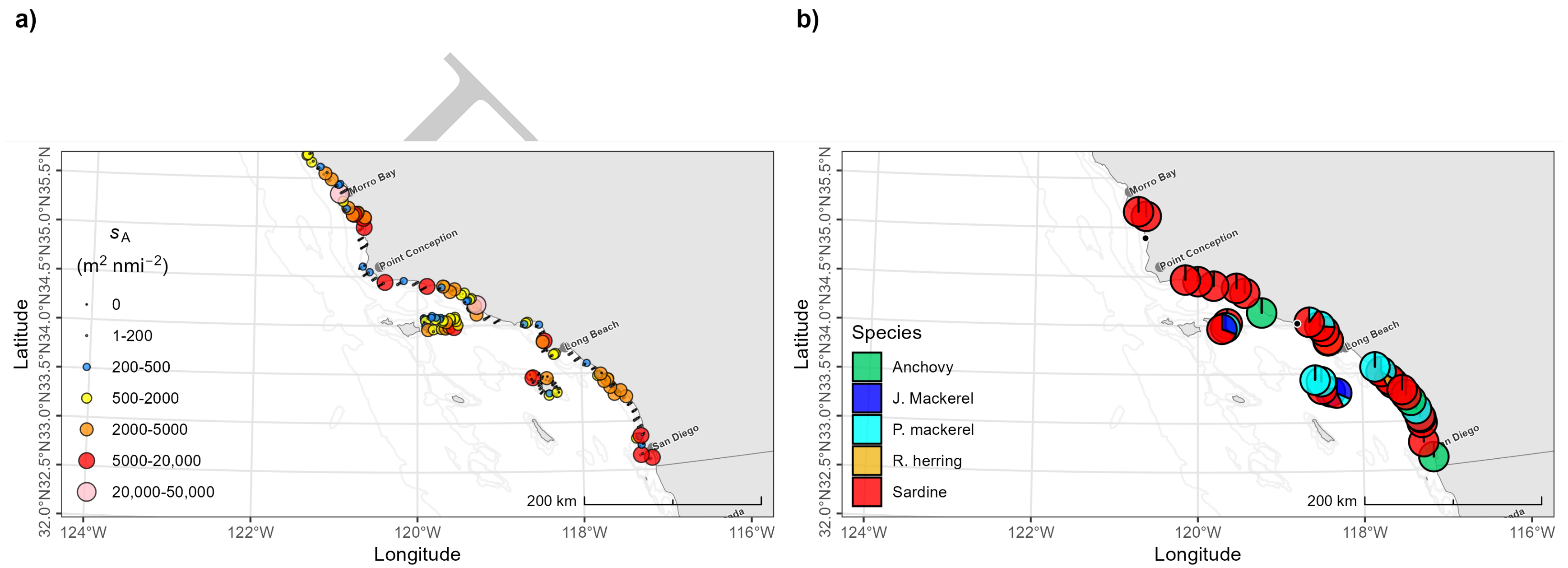

Figure 18: Nearshore transects sampled by *Long Beach Carnage* overlaid with the distributions of: a) 38-kHz integrated backscattering coefficients (s_A, m^2 nmi^{-2}; averaged over 2000-m distance intervals) ascribed to CPS; and b) the proportions of acoustic backscatter from CPS in each purse-seine catch. Black points indicate purse-seine sets with no CPS present. Species with low catch weights may not be visible at this scale.

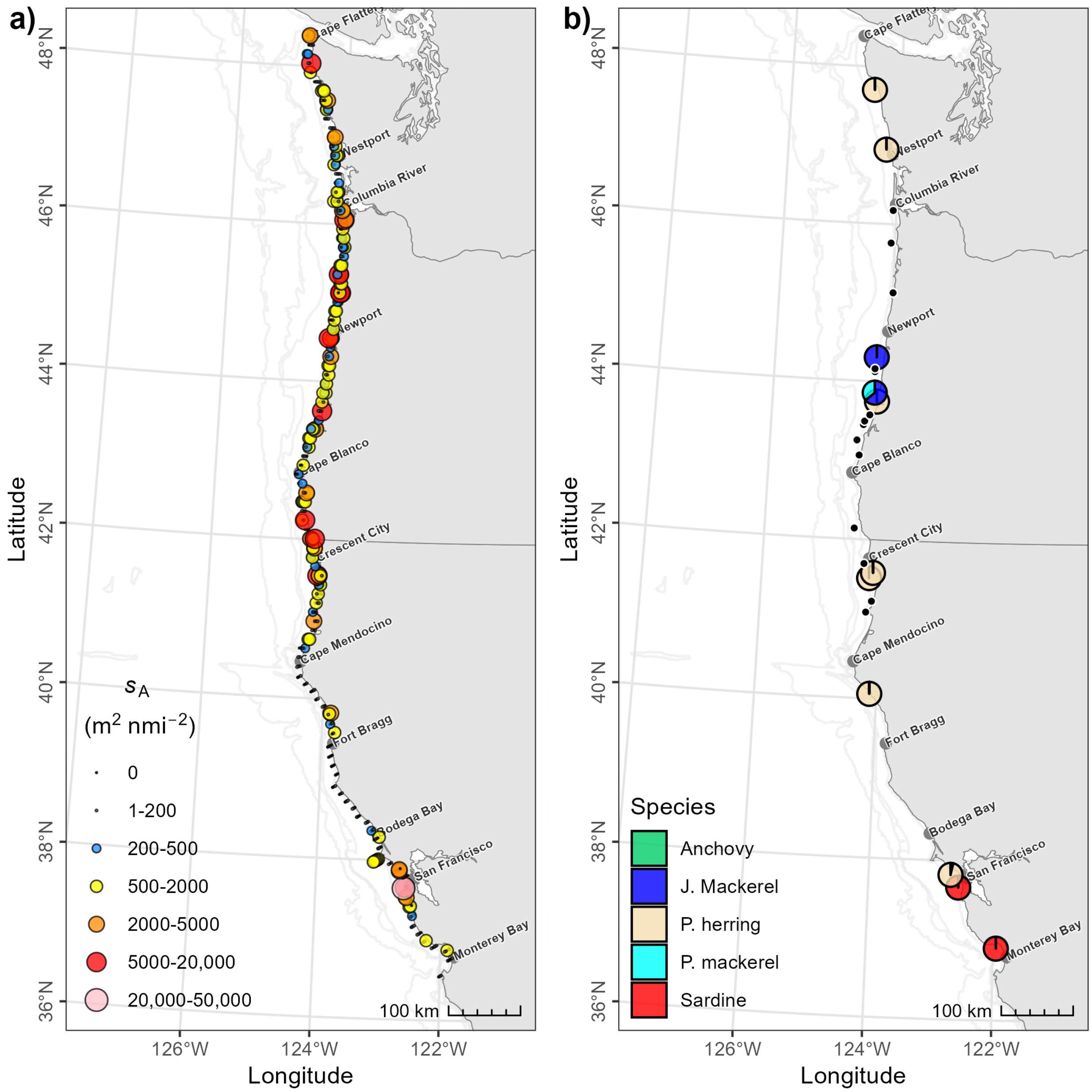

Figure 19: Nearshore survey transects sampled by *Lisa Marie* overlaid with the distributions of: a) 38-kHz vertically integrated backscattering coefficients (s_A, m^2 nmi^{-2}; averaged over 2000-m distance intervals) ascribed to CPS; and b) the proportion of acoustic backscatter from CPS in each purse-seine catch. Black points indicate purse-seine sets with no CPS present. Species with low catch weights may not be visible at this scale.

3.5 Biomass distribution and demographics

The biomasses, distributions, and demographics for each species and subpopulation are for the survey area and period and therefore may not represent the entire population. All biomass estimates are in metric tons (t).

3.5.1 Northern Anchovy

3.5.1.1 Northern subpopulation

The total estimated biomass of the northern subpopulation of Northern Anchovy was 151 t ($\mathrm{CI}_{95\%}$ = 21.4 - 289 t, CV = 40%; **Table 4**). In the core region, biomass was 130 t ($\mathrm{CI}_{95\%}$ = 12.9 - 250 t, CV = 46%; **Table 4**). L_S ranged from 12 to 16 cm with a mode at 15 cm (**Table 5**, **Fig. 21**). In the nearshore region, biomass was 21 t ($\mathrm{CI}_{95\%}$ = 8.42 - 39.6 t, CV = 40%; **Table 4**), comprising 14% of the total biomass. Lengths in the nearshore region had a single mode at 15 cm (**Table 5**; **Fig. 21**). In both the core and nearshore regions, the subpopulation was sparsely distributed between Astoria and Cape Flattery (**Fig. 20a, b**).

Table 4: Biomass estimates (metric tons, t) and their precisions (upper and lower 95% confidence intervals, $\mathrm{CI}_{95\%}$; and coefficients of variation, CVs) for the northern subpopulation of Northern Anchovy (*Engraulis mordax*) in the core and nearshore survey regions. Stratum areas are nmi^2.

Stratum					Trawl		Biomass			
Region	Number	Area	Transects	Distance	Clusters	Individuals	$\hat{B}$	$\mathrm{CI}_{L,95\%}$	$\mathrm{CI}_{U,95\%}$	CV
Core	3	4,165	9	416	2	76	129	12	249	46
	4	2,622	5	250	1	2	1	0	2	80
	All	6,787	14	666	3	78	130	13	250	46
Nearshore	11	234	10	35	2	76	21	8	39	40
	12	66	4	10	1	2	0	0	1	72
	All	300	14	46	3	78	21	8	40	40
All	**-**	**7,086**	**28**	**712**	**6**	**155**	**151**	**21**	**289**	**40**

Table 5: Abundance estimates versus standard length (L_S, cm) for the northern subpopulation of Northern Anchovy (*Engraulis mordax*) in the core and nearshore survey regions.

	Region	
L_S	Core	Nearshore
1	0	0
2	0	0
3	0	0
4	0	0
5	0	0
6	0	0
7	0	0
8	0	0
9	0	0
10	0	0
11	0	0
12	22,961	5,393
13	105,636	13,402
14	578,725	56,063
15	2,602,509	461,165
16	248,025	24,027
17	0	0
18	0	0
19	0	0
20	0	0

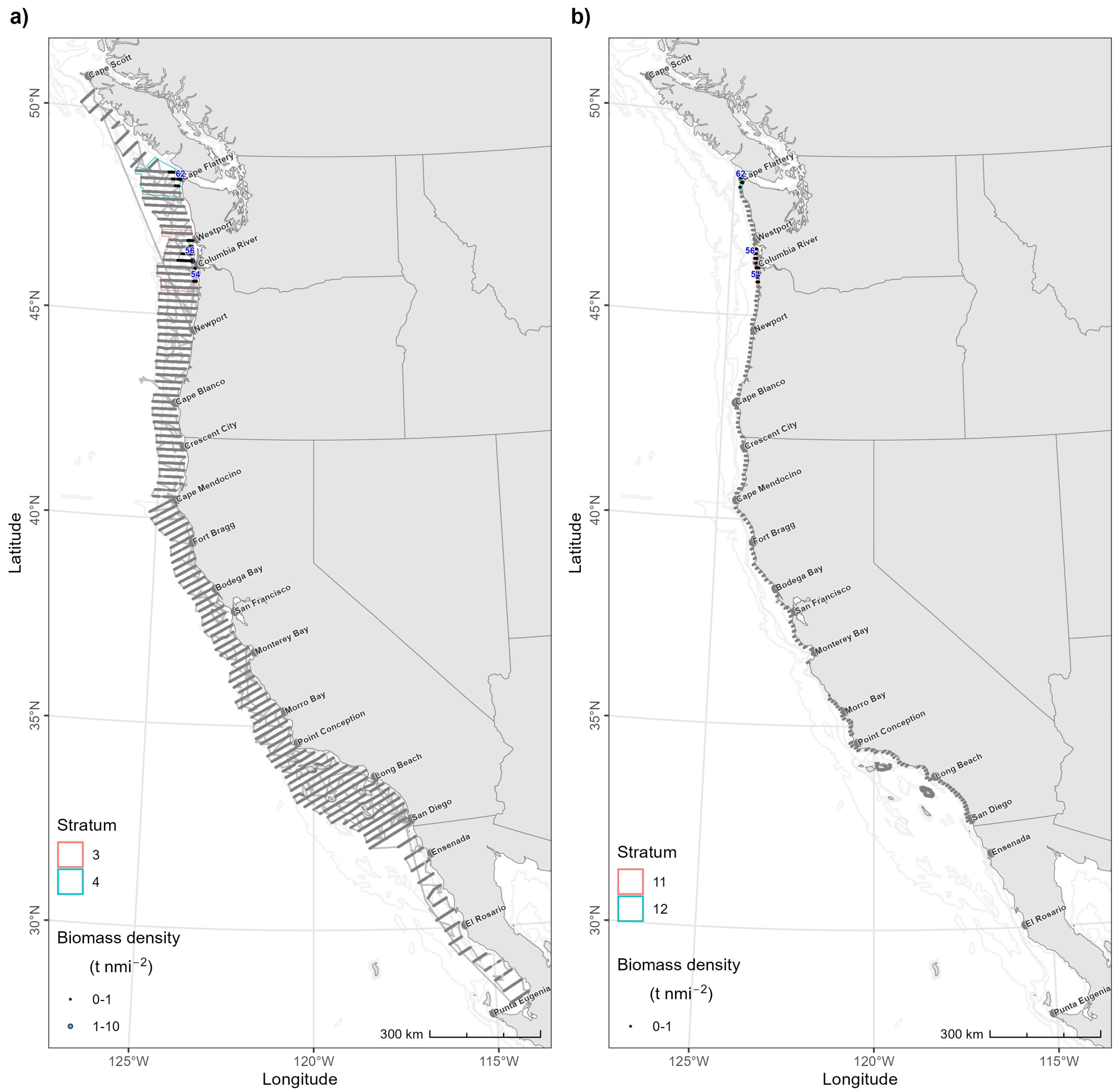

Figure 20: Biomass densities (colored points) of the northern subpopulation of Northern Anchovy (*Engraulis mordax*), per stratum, in the a) core and b) nearshore survey regions. Overlaid are the locations of trawl clusters (blue numbers) or purse seine samples (red numbers) with at least one Northern Anchovy in each stratum (colored polygons). Thick gray lines represent acoustic transects.

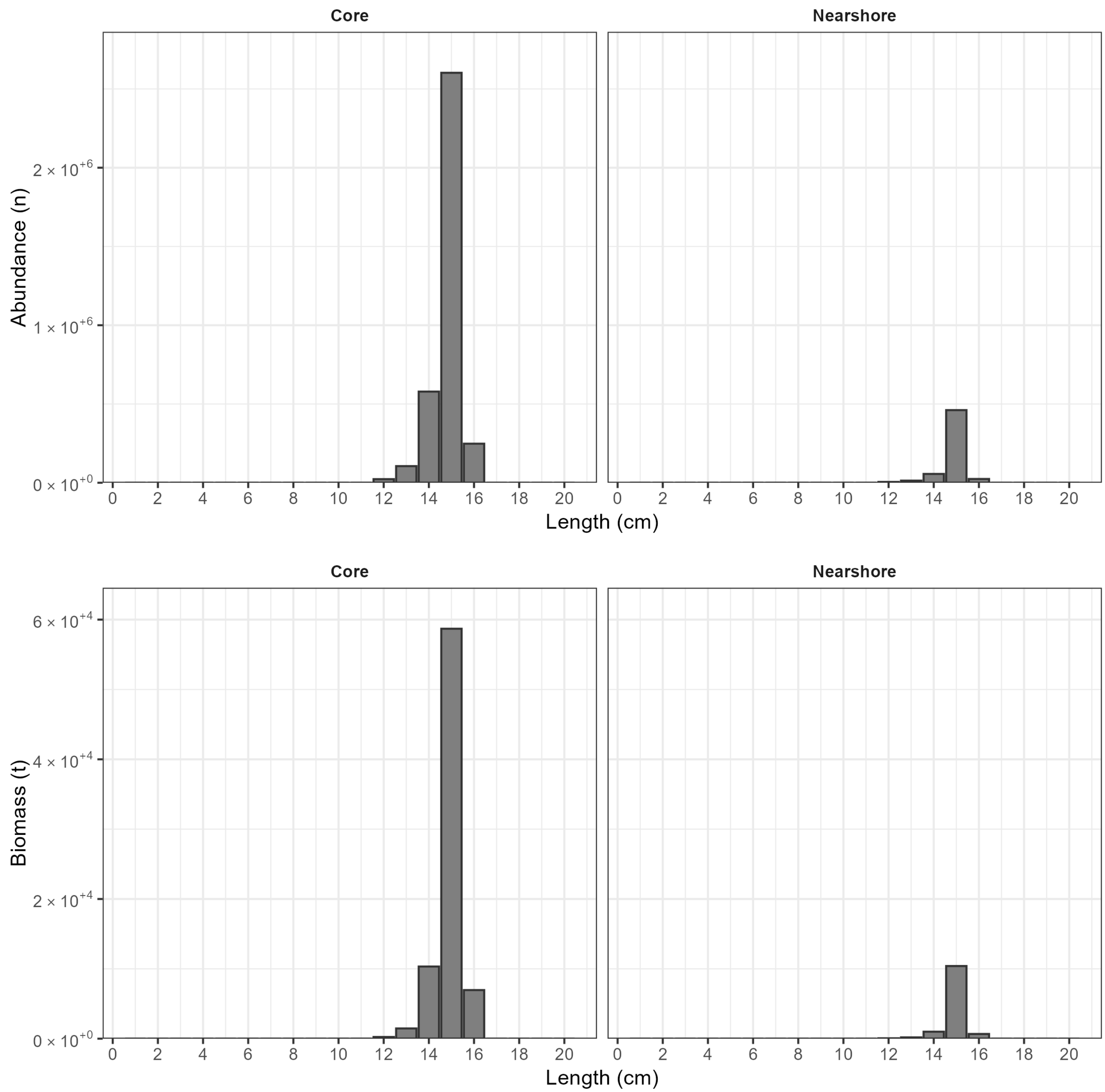

Figure 21: Abundance estimates versus standard length (L_S, upper panels) and biomass (t) versus L_S (lower panels) for the northern subpopulation of Northern Anchovy (*Engraulis mordax*) in the core and nearshore survey regions. Abundance and biomass in the nearshore region is negligible relative to the core region and not visible at this scale.

3.5.1.2 Central subpopulation

The total estimated biomass of the central subpopulation of Northern Anchovy was 682,657 t ($CI_{95\%}$ = 328,527 - 796,114 t, CV = 17%; **Table 6**). In the core region, biomass was 672,528 t ($CI_{95\%}$ = 324,181 - 775,324 t, CV = 17%; **Table 6**). The subpopulation was distributed throughout most of the survey area from San Diego to San Francisco, but was most abundant north of Pt. Conception (**Fig. 22a**). L_S ranged from 4 to 15 cm with a modes at 6 and 13 cm (**Table 7**, **Fig. 23**). In the nearshore region, biomass was 10,129 t ($CI_{95\%}$ = 4,346 - 20,789 t, CV = 43%; **Table 6**), comprising 1.5% of the total biomass. The biomass was sparsely distributed between Long Beach and Bodega Bay, but was greatest near Morro Bay (**Fig. 22b**). The nearshore length distribution had two modes at 8 and 13 cm (**Table 7**, **Fig. 23**).

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

Stratum					Trawl		Biomass			
Region	Number	Area	Transects	Distance	Clusters	Individuals	$\hat{B}$	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Core	1	6,589	13	331	4	5,707	21,488	3,622	45,753	51
	2	23,175	41	2,313	26	1,170,284	651,040	301,156	753,944	18
	All	29,763	54	2,644	30	1,175,991	672,528	324,181	775,324	17
Nearshore	1	43	3	9	1	50	1	0	2	81
	2	62	4	13	1	1,141	5	0	10	50
	3	96	5	21	1	50	1,653	8	4,051	69
	4	84	5	22	1	4	1,093	56	2,901	76
	5	139	9	31	2	407,918	6,397	1,537	16,303	64
	6	28	7	14	1	1,006	726	305	1,173	30
	7	13	4	8	1	3	0	0	0	70
	8	12	4	9	1	3	0	0	0	58
	9	107	5	17	2	13,900	53	0	105	52
	10	229	8	37	1	9	200	35	432	52
	All	814	54	180	11	424,084	10,129	4,346	20,789	43
All	**-**	**30,577**	**108**	**2,825**	**41**	**1,600,074**	**682,657**	**328,527**	**796,114**	**17**

Table 7: Abundance estimates versus standard length (L_S, cm) for the central subpopulation of Northern Anchovy (*Engraulis mordax*) in the core and nearshore survey regions.

	Region	
L_S	Core	Nearshore
1	0	0
2	0	0
3	0	0
4	3,478,968,165	0
5	26,563,299,958	471,279
6	29,397,268,939	836,349
7	16,706,663,971	177,893,990
8	13,706,470,608	502,963,366
9	11,325,721,224	310,150,738
10	4,332,841,460	37,421,841
11	488,438,229	7,882,421
12	4,258,087,239	83,544,364
13	6,751,538,741	105,267,807
14	2,764,899,619	17,613,120
15	302,619,290	66,556
16	0	0
17	0	0
18	0	0
19	0	0
20	0	0

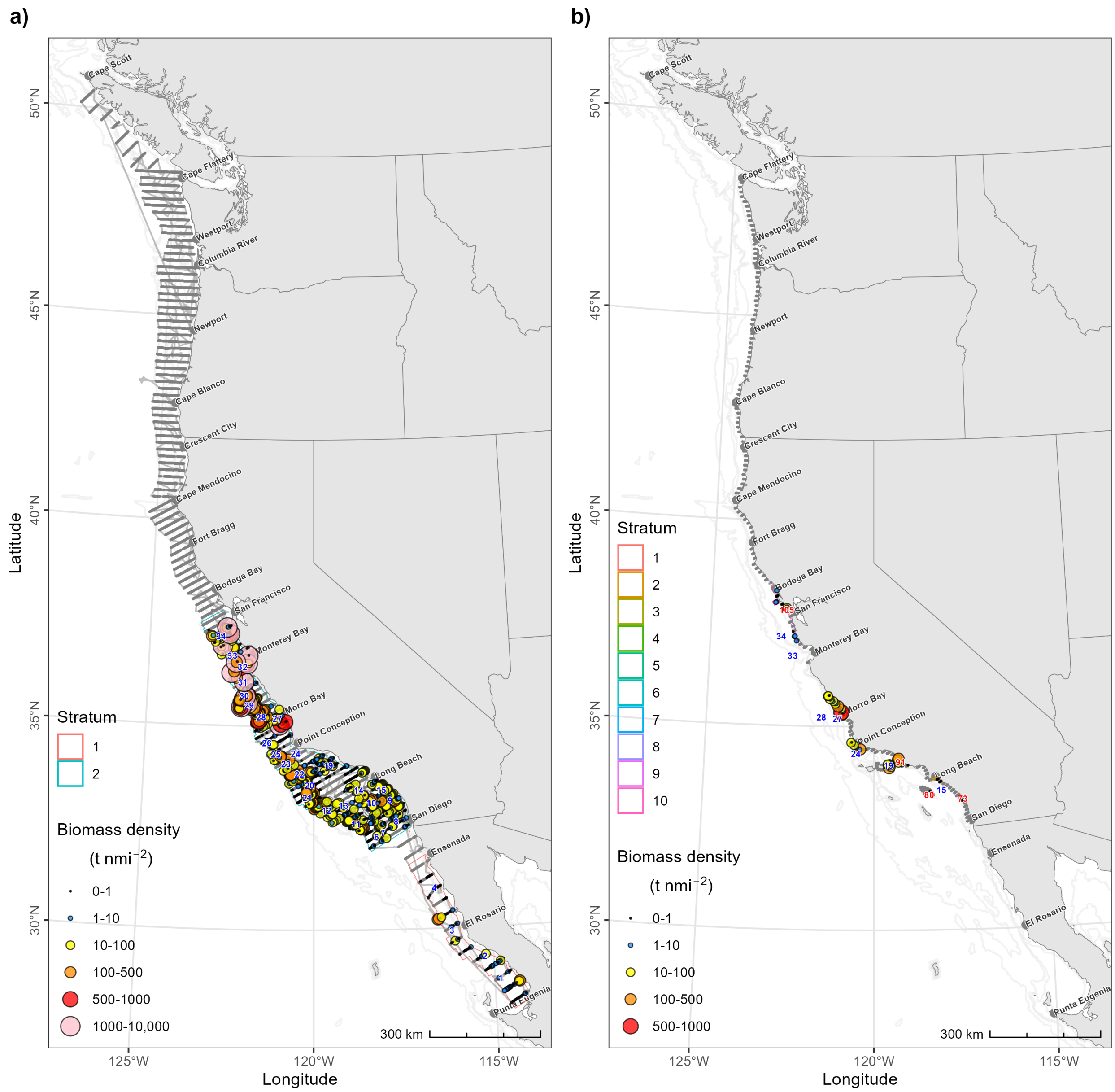

Figure 22: Biomass densities (colored points) of central subpopulation of Northern Anchovy (*Engraulis mordax*), per stratum, in the a) core and b) nearshore survey regions. Overlaid are the locations of trawl clusters (blue numbers) or purse seine samples (red numbers) with at least one Northern Anchovy in each stratum (colored polygons). Thick gray lines represent acoustic transects.

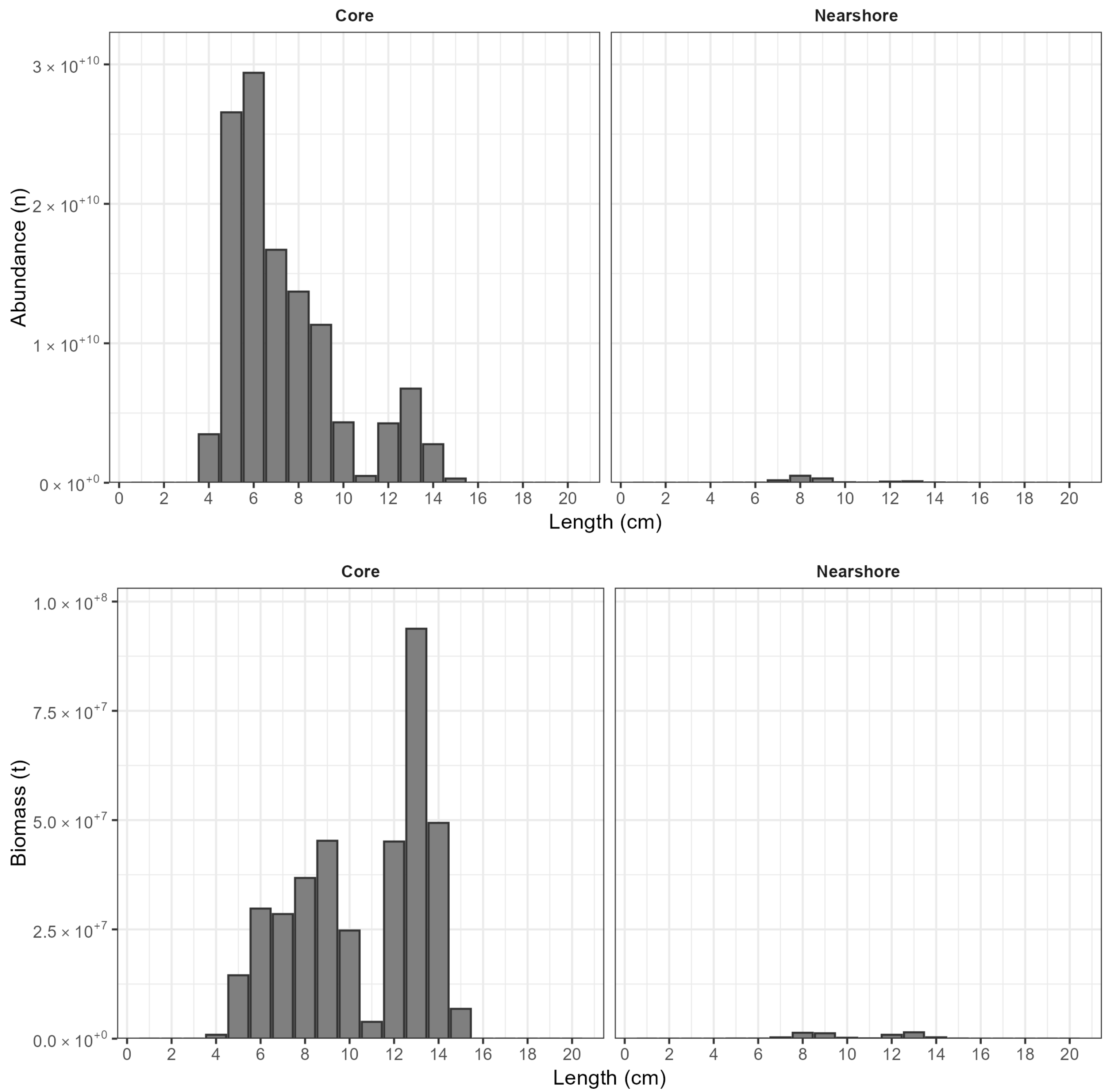

Figure 23: Abundance estimates versus standard length (L_S, upper panels) and biomass (t) versus L_S (lower panels) for the central subpopulation of Northern Anchovy (*Engraulis mordax*) in the core and nearshore survey regions.

3.5.2 Pacific Sardine

3.5.2.1 Northern subpopulation

The total estimated biomass of the northern subpopulation of Pacific Sardine was 77,750 t ($CI_{95\%}$ = 21,800 - 156,748 t, CV = 45%; **Table 8**). In the core region, biomass was 337 t ($CI_{95\%}$ = 63.8 - 892 t, CV = 69%; **Table 8**), and was observed between Pt. Conception and Monterey, and between Astoria and Cape Flattery (**Fig. 24a**). L_S ranged from 6 to 26 cm with modes at 9 and 17 cm (**Table 9**, **Fig. 25**). In the nearshore region, biomass was 77,412 t ($CI_{95\%}$ = 21,736 - 155,856 t, CV = 45%; **Table 8**), comprising 99.6% of the total biomass. Biomass was distributed between Pt. Conception and San Francisco (**Fig. 24b**). Lengths in the nearshore region had a mode at 18 cm (**Table 9**, **Fig. 25**).

Table 8: Biomass estimates (metric tons, t) and their precisions (upper and lower 95% confidence intervals, $CI_{95\%}$; and coefficients of variation, CVs) for the northern subpopulation of Pacific Sardine (*Sardinops sagax*) in the core and nearshore survey regions. Stratum areas are nmi^2.

Stratum					Trawl		Biomass			
Region	Number	Area	Transects	Distance	Clusters	Individuals	$\hat{B}$	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Core	3	3,877	9	392	3	61	20	5	43	51
	4	1,885	6	203	1	1	3	0	6	60
	5	8,768	18	861	4	570	314	42	865	74
	All	14,530	33	1,456	8	632	337	64	892	69
Nearshore	1	238	14	53	4	149	34,060	5,601	48,627	32
	2	317	12	49	3	101	43,223	4,787	126,693	76
	3	84	3	13	1	549	129	0	270	81
	4	103	4	16	1	1	0	0	1	84
	5	66	4	10	1	1	0	0	1	72
	All	808	37	141	10	801	77,412	21,736	155,856	45
All	**-**	**15,338**	**70**	**1,597**	**18**	**1,433**	**77,750**	**21,800**	**156,748**	**45**

Table 9: Abundance estimates versus standard length (L_S, cm) for the northern subpopulation of Pacific Sardine (*Sardinops sagax*) in the core and nearshore survey regions.

	Region	
L_S	Core	Nearshore
1	0	0
2	0	0
3	0	0
4	0	0
5	0	0
6	176,856	0
7	0	0
8	939,546	0
9	1,436,154	39,182
10	246,485	36,785
11	0	0
12	0	0
13	0	0
14	0	0
15	133,054	64,746
16	443,513	24,429,835
17	1,163,996	90,857,323
18	399,162	241,979,800
19	185,665	351,316,915
20	576,567	104,338,818
21	487,864	3,657,680
22	177,405	86,328
23	0	0
24	0	0
25	93,025	0
26	46,513	0
27	0	0
28	0	0
29	0	0
30	0	0

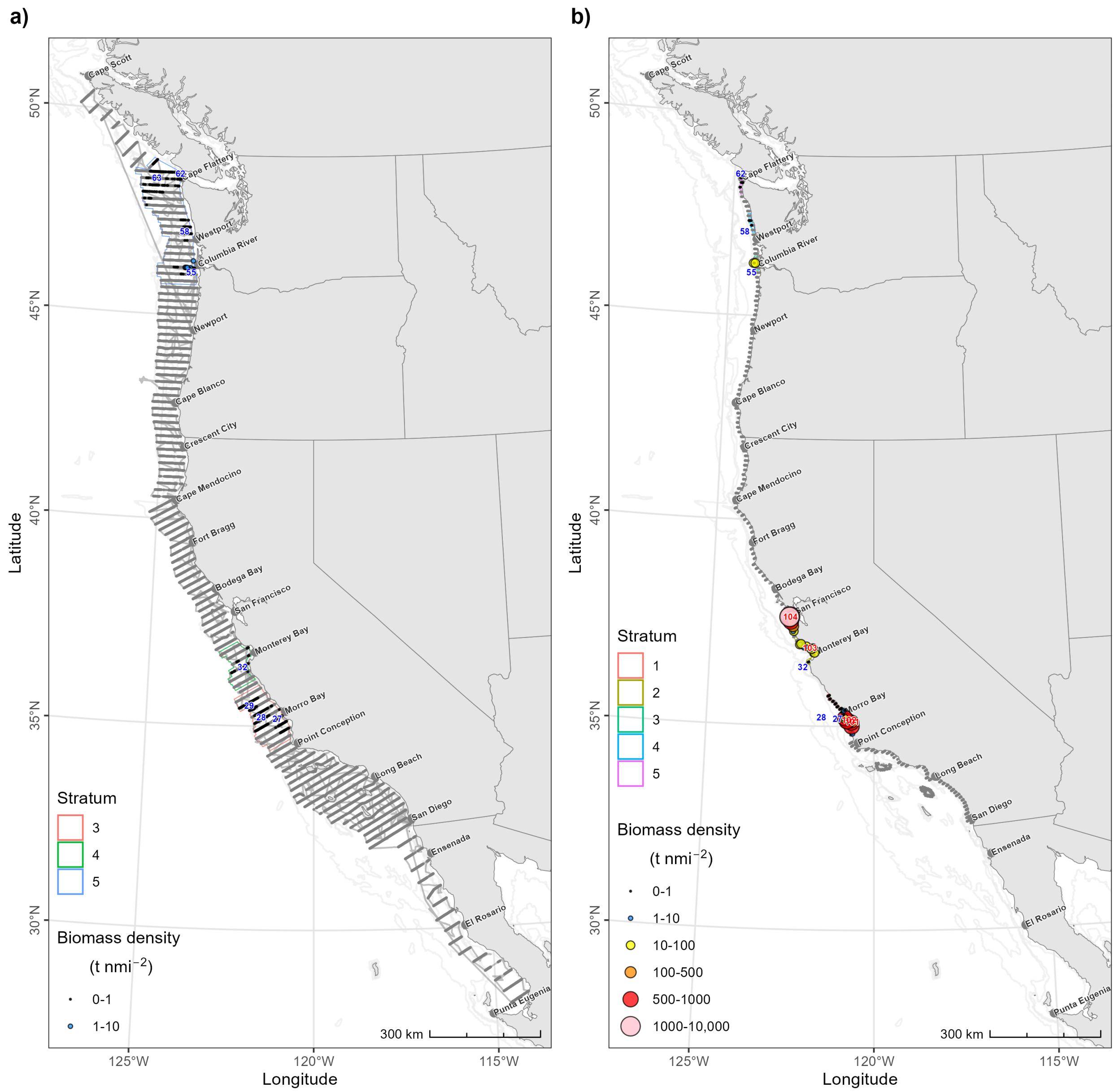

Figure 24: Biomass densities (colored points) of the northern subpopulation of Pacific Sardine (*Sardinops sagax*), per stratum, in the a) core and b) nearshore survey regions. Overlaid are the locations of trawl clusters (blue numbers) or purse seine samples (red numbers) with at least one Pacific Sardine in each stratum (colored polygons). Thick gray lines represent acoustic transects.

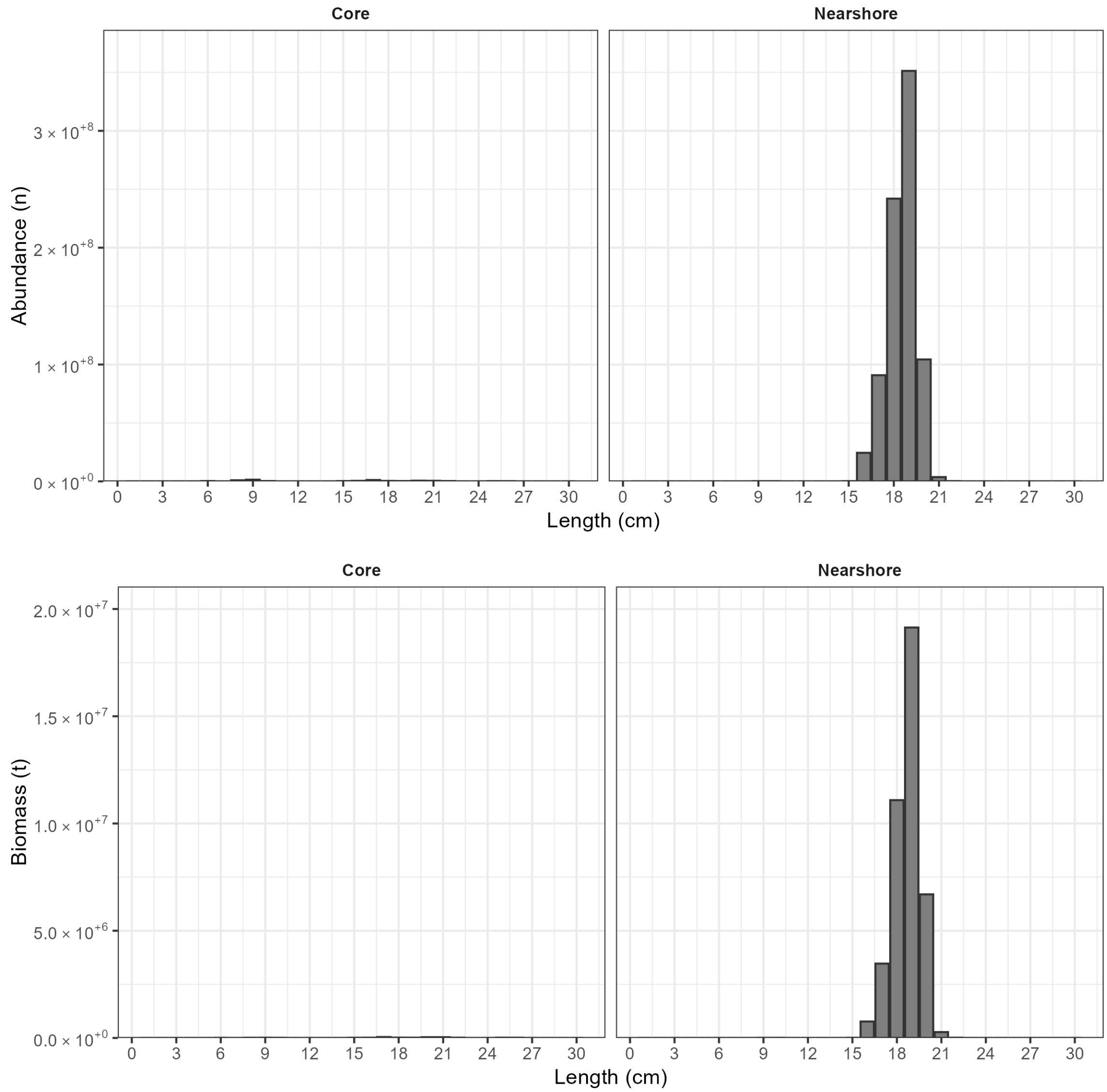

Figure 25: Estimated abundance (upper panel) and biomass (lower panel) versus standard length (L_S, cm) for the northern subpopulation of Pacific Sardine (*Sardinops sagax*) in the core and nearshore survey regions. Note: the abundance and biomass in the core region are difficult to see at this scale.

3.5.2.2 Southern subpopulation

The total estimated biomass of the southern subpopulation of Pacific Sardine was 47,566 t ($CI_{95\%}$ = 32,397 - 96,235 t, CV = 25%; **Table 10**). In the core region, biomass was 22,136 t ($CI_{95\%}$ = 7,452 - 39,462 t, CV = 38%; **Table 10**), and was distributed between Punta Eugenia and El Rosario off Baja CA and between San Diego and Long Beach in the SCB (**Fig. 26a**). L_S ranged from 6 to 21 cm with modes at 6 and 19 cm (**Table 11**, **Fig. 27**). In the nearshore region, biomass was 25,431 t ($CI_{95\%}$ = 24,945 - 56,773 t, CV = 32%; **Table 10**), comprising 53% of the total biomass. The nearshore biomass was distributed along the mainland coast from San Diego to Pt. Conception and around Santa Cruz and Santa Catalina Islands. Lengths in the nearshore region had modes at 9 and 15 cm (**Table 11**, **Fig. 27**).

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

Stratum					Trawl		Biomass			
Region	Number	Area	Transects	Distance	Clusters	Individuals	$\hat{B}$	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Core	1	3,510	7	171	2	2,260	14,638	9	32,293	53
	2	12,116	14	1,184	7	594	7,498	1,836	16,031	49
	All	15,627	21	1,355	9	2,854	22,136	7,452	39,462	38
Nearshore	6	624	35	134	22	875	22,184	22,271	53,091	36
	7	46	10	19	3	150	1,576	557	3,151	43
	8	29	7	14	2	100	1,546	212	2,916	47
	9	70	18	39	5	152	124	34	233	42
	All	769	70	206	30	1,277	25,431	24,945	56,773	32
All	**-**	**16,395**	**91**	**1,561**	**39**	**4,131**	**47,566**	**32,397**	**96,235**	**25**

Table 11: Abundance estimates versus standard length (L_S, cm) for the southern subpopulation of Pacific Sardine (*Sardinops sagax*) in the core and nearshore survey regions.

	Region	
L_S	Core	Nearshore
1	0	0
2	0	0
3	0	0
4	0	0
5	0	0
6	1,949,012	0
7	697,778	0
8	0	12,809,336
9	0	48,179,307
10	0	5,353,256
11	223,301	0
12	0	0
13	0	61,908,237
14	24,706	311,968,687
15	0	380,212,596
16	28,107,192	132,164,790
17	58,557,886	34,242,368
18	78,936,923	7,597,772
19	82,724,185	1,031,500
20	35,346,376	158,427
21	4,557,478	23,146
22	0	0
23	0	0
24	0	0
25	0	0
26	0	0
27	0	0
28	0	0
29	0	0
30	0	0

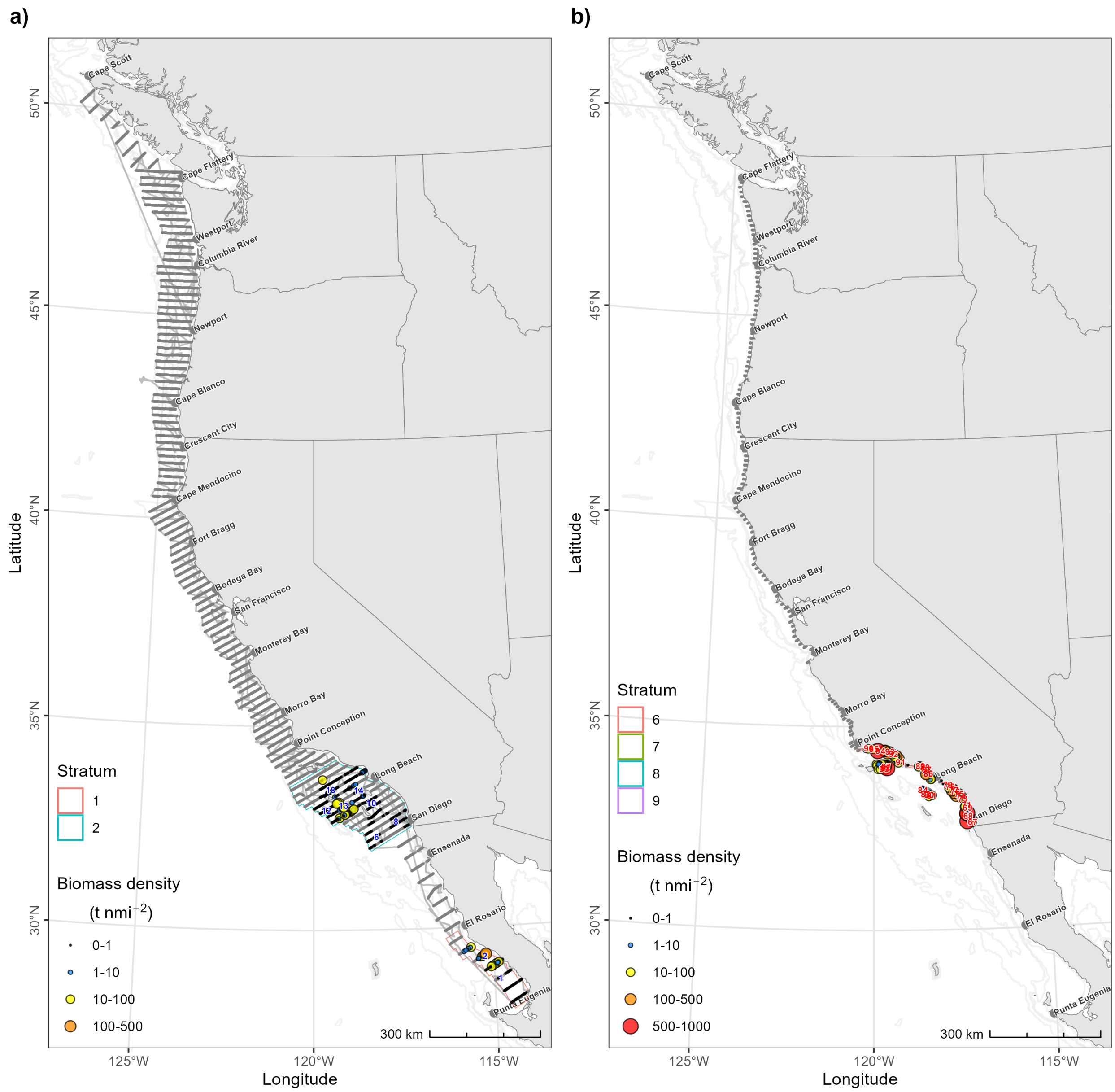

Figure 26: Biomass densities (colored points) of the southern subpopulation of Pacific Sardine (*Sardinops sagax*), per stratum, in the a) core and b) nearshore survey regions. Overlaid are the locations of trawl clusters (blue numbers) or purse seine samples (red numbers) with at least one Pacific Sardine in each stratum (colored polygons). Thick gray lines represent acoustic transects.

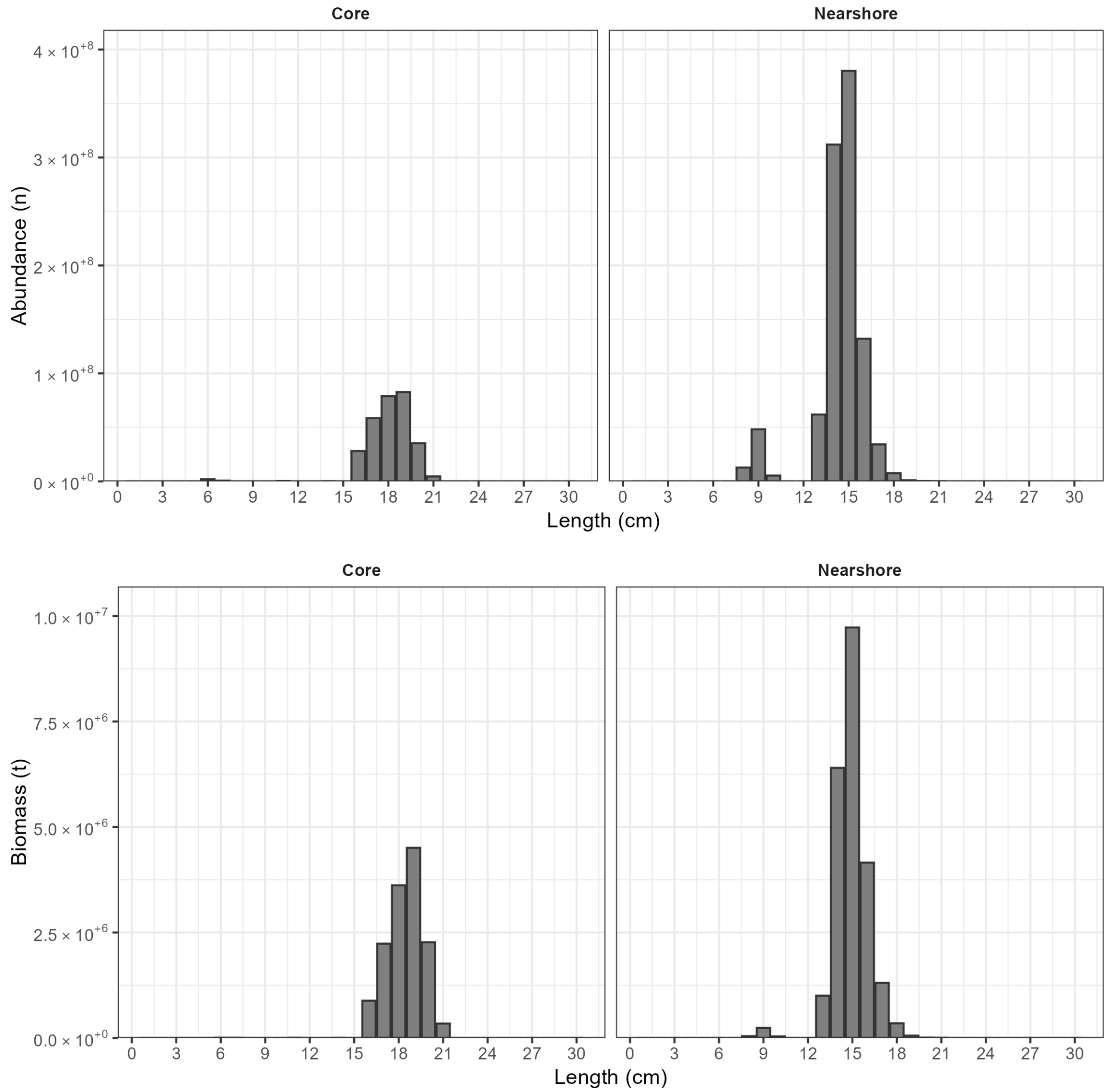

Figure 27: Estimated abundance (upper panels) and biomass (lower panels) versus standard length (L_S, cm) for the southern subpopulation of Pacific Sardine (*Sardinops sagax*) in the core and nearshore survey regions.

3.5.3 Pacific Mackerel

The total estimated biomass of Pacific Mackerel was 11,129 t ($CI_{95\%}$ = 4,950 - 19,241 t, CV = 24%; **Table 12**). In the core region, biomass was 4,740 t ($CI_{95\%}$ = 1,909 - 8,498 t, CV = 36%) and was mostly located in the SCB and off central OR (**Fig. 28a**). The distribution of L_F ranged from 5 to 42 cm with modes at 8, 17, and 37 cm (**Table 13**, not visible in **Fig. 29**). In the nearshore region, biomass was 6,388 t ($CI_{95\%}$ = 3,041 - 10,743 t, CV = 31%; **Table 12**, **Fig. 28b**), comprising 57.4% of the total biomass, and was mostly present in along the mainland coast in the SCB and around Santa Cruz and Santa Catalina Islands. Lengths in the nearshore region had modes at 22 and 41 cm.

Table 12: Biomass estimates (metric tons, t) and their precisions (upper and lower 95% confidence intervals, $CI_{95\%}$; and coefficients of variation, CVs) for Pacific Mackerel (*Scomber japonicus*) in nearshore survey region. Stratum areas are nmi^2.

Stratum					Trawl		Biomass			
Region	Number	Area	Transects	Distance	Clusters	Individuals	$\hat{B}$	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Core	1	3,892	8	186	2	226	1,419	402	2,754	43
	2	12,116	14	1,184	8	49	101	57	157	26
	3	2,066	6	210	1	1	134	32	246	47
	4	5,658	12	573	4	725	2,960	458	6,391	55
	5	4,225	8	412	1	26	126	24	265	53
	All	27,957	48	2,565	16	1,027	4,740	1,909	8,498	36
Nearshore	1	218	14	49	8	160	1,999	194	5,097	68
	2	63	4	14	3	74	555	5	1,223	63
	3	198	9	43	4	7	520	209	850	32
	4	46	10	19	2	53	484	34	1,362	85
	5	20	5	10	1	3	11	2	23	51
	6	87	21	45	6	159	1,657	127	4,146	63
	7	88	4	14	1	1	0	0	0	84
	8	77	4	12	1	11	1,163	0	2,629	60
	All	796	71	206	25	468	6,388	3,041	10,743	31
All	**-**	**28,753**	**119**	**2,771**	**41**	**1,495**	**11,129**	**4,950**	**19,241**	**24**

Table 13: Abundance estimates versus fork length (L_F, cm) for Pacific Mackerel (*Scomber japonicus*) in the core and nearshore survey regions.

	Region	
L_F	Core	Nearshore
1	0	0
2	0	0
3	0	0
4	0	0
5	1,212,890	0
6	2,007,606	0
7	809,350	0
8	3,103,554	0
9	1,879,798	0
10	2,017,041	0
11	798,068	0
12	0	79,260
13	535,829	0
14	535,829	87,141
15	43,250	0
16	2,712,311	1,183,698
17	7,077,287	4,003,534
18	6,725,598	4,932,977
19	3,199,571	3,030,871
20	707,958	4,582,440
21	353,979	6,025,952
22	0	12,430,208
23	353,979	7,910,461
24	0	4,906,703
25	0	957,313
26	0	201,396
27	0	154,019
28	0	365
29	478,010	179
30	0	12,209
31	13,761	12,209
32	462,395	0
33	108,416	0
34	108,416	0
35	93,007	0
36	633,511	0
37	958,761	146,567
38	876,489	0
39	739,741	586,269
40	554,964	0
41	480,556	586,269
42	325,249	146,567
43	0	146,567
44	0	0
45	0	0
46	0	0
47	0	0

Table 13: Abundance estimates versus fork length (L_F, cm) for Pacific Mackerel (*Scomber japonicus*) in the core and nearshore survey regions. *(continued)*

L_F	Core	Nearshore
48	0	0
49	0	0
50	0	0

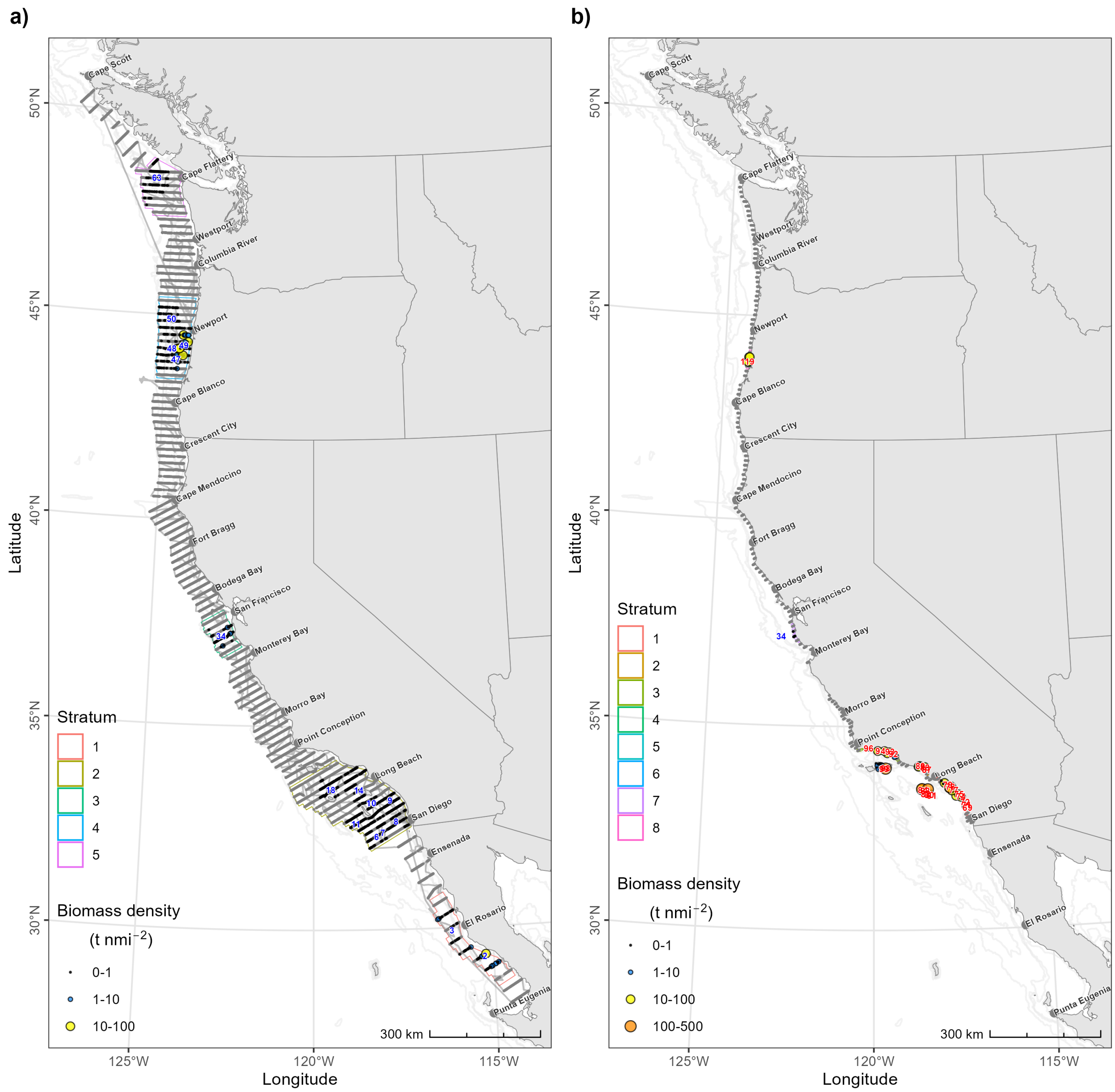

Figure 28: Biomass densities (colored points) of Pacific Mackerel (*Scomber japonicus*), per stratum, in the a) core and b) nearshore survey regions. Overlaid are the locations of trawl clusters (blue numbers) or purse seine samples (red numbers) with at least one Pacific Mackerel in each stratum (colored polygons). Thick gray lines represent acoustic transects.

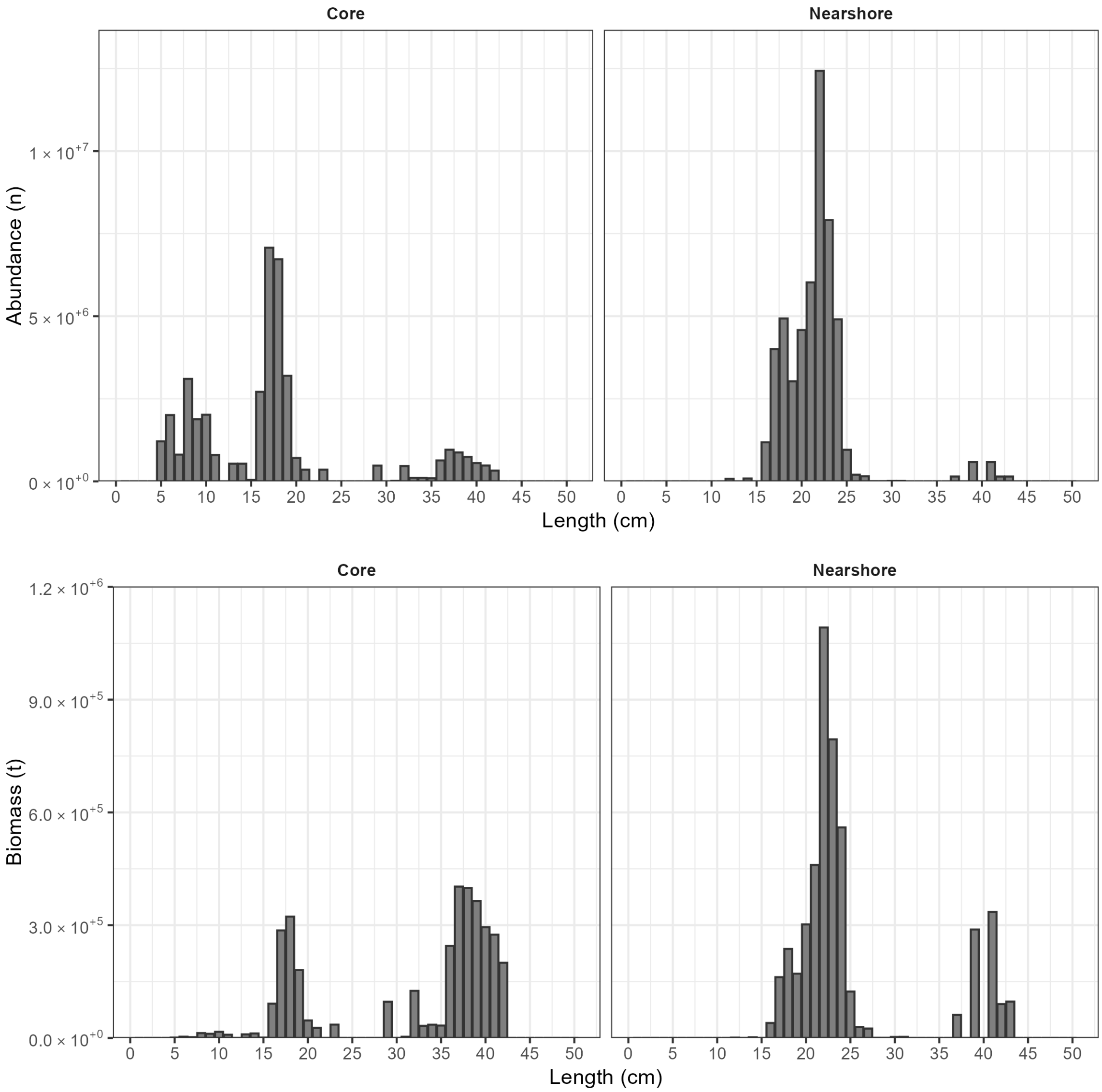

Figure 29: Estimated abundance (upper panels) and biomass (lower panels) versus fork length (L_F, cm) for Pacific Mackerel (*Scomber japonicus*) in the core and nearshore survey regions.

3.5.4 Jack Mackerel

The total estimated biomass of Jack Mackerel was 618,467 t ($CI_{95\%}$ = 446,095 - 804,715 t, CV = 12%; **Table 14**). In the core region, the biomass was 513,181 t ($CI_{95\%}$ = 371,986 - 654,903 t, CV = 14%; **Table 14**), was distributed throughout the entire survey area, but was greatest between Cape Mendocino and Cape Scott off Vancouver Island (**Fig. 30a**). L_F ranged from 2 to 52 cm, with modes at 4, 12 and 41 cm. (**Table 15**, **Fig. 31**). In the nearshore region, the biomass was 105,287 t ($CI_{95\%}$ = 74,109 - 149,813 t, CV = 18%; **Table 14**), comprising 17% of the total biomass. Biomass was present throughout the nearshore survey area, but was greatest between Cape Mendocino and Astoria (**Fig. 30b**). Lengths in the nearshore region had a mode at 4 cm and a broad distribution between 31 and 53 cm (**Table 15**, **Fig. 31**).

Table 14: Biomass estimates (metric tons, t) and their precisions (upper and lower 95% confidence intervals, $CI_{95\%}$; and coefficients of variation, CVs) for Jack Mackerel (*Trachurus symmetricus*) in the core and nearshore survey regions. Stratum areas are nmi^2.

Stratum					Trawl		Biomass			
Region	Number	Area	Transects	Distance	Clusters	Individuals	$\hat{B}$	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Core	1	6,626	13	329	4	110	25,740	10,867	50,606	39
	2	19,858	31	1,969	21	4,605	32,711	9,141	78,918	55
	3	3,577	11	370	4	129	27,337	1,277	73,597	77
	4	3,131	7	160	3	4,162	115,637	45,667	203,304	34
	5	26,854	65	2,706	22	9,517	311,756	197,805	404,073	17
	All	60,046	127	5,534	52	18,524	513,181	371,986	654,903	14
Nearshore	1	103	7	23	2	1,668	350	19	881	66
	2	85	4	18	1	5	233	0	532	59
	3	66	3	15	1	2	4	0	8	85
	4	139	9	31	2	34	0	0	1	52
	5	93	20	40	3	66	743	322	1,317	35
	6	36	10	21	2	93	117	9	268	57
	7	107	5	17	2	124	0	0	1	84
	8	404	19	64	4	18	2,827	79	9,598	97
	9	246	11	38	2	95	10,583	4,096	18,862	37
	10	721	36	116	6	532	84,576	55,771	127,490	21
	11	119	5	18	1	2	1	0	2	63
	12	103	4	16	1	86	167	0	549	84
	13	94	5	15	1	130	5,686	0	14,521	76
	All	2,316	138	431	28	2,854	105,287	74,109	149,813	18
All	**-**	**62,363**	**265**	**5,965**	**80**	**21,378**	**618,467**	**446,095**	**804,715**	**12**

Table 15: Abundance estimates versus fork length (L_F, cm) for Jack Mackerel (*Trachurus symmetricus*) in the core and nearshore survey regions.

	Region	
L_F	Core	Nearshore
1	0	0
2	23,933,952	2,757
3	71,177,015	9,126
4	755,021,061	139,401,883
5	169,222,975	117,299,218
6	10,484,804	6,319
7	5,259,126	0
8	74,035,658	0
9	154,934,468	141,463
10	351,215,975	303,154
11	419,287,876	653,739
12	424,366,401	483,057
13	167,320,990	1,645,809
14	66,702,393	3,701,752
15	64,705,419	2,404,350
16	22,663,462	3,174,525
17	7,858,248	4,688,196
18	1,617,567	3,197,557
19	8,391,546	1,751,565
20	7,507,343	4,822,860
21	5,751,430	92,312
22	542,386	179,010
23	57,992,358	59,611
24	25,291,625	2,262,563
25	2,958,222	724,070
26	251,754	368,339
27	23,237,241	2,222,822
28	15,616,717	0
29	32,603,217	0
30	1,734,957	355
31	1,755,096	724,248
32	25,073,898	19,259,019
33	25,071,186	3,810,854
34	3,330,523	18,482,229
35	8,697,111	8,318,883
36	9,216,688	6,783,220
37	25,638,280	10,344,953
38	34,913,194	7,650,385
39	56,491,472	6,178,465
40	39,727,723	5,900,212
41	50,219,019	6,243,577
42	43,836,188	7,717,154
43	34,338,786	8,266,198
44	27,567,594	3,868,869
45	24,575,437	4,430,356
46	15,153,937	5,520,863
47	57,514,039	12,441,429

Table 15: Abundance estimates versus fork length (L_F, cm) for Jack Mackerel (*Trachurus symmetricus*) in the core and nearshore survey regions. *(continued)*

L_F	Core	Nearshore
48	9,239,800	899,951
49	8,887,462	1,874,664
50	12,164,802	1,481,434
51	10,211,546	1,994,677
52	7,142,771	1,068,132
53	0	0
54	0	0
55	0	0
56	0	0
57	0	0
58	0	0
59	0	0
60	0	0

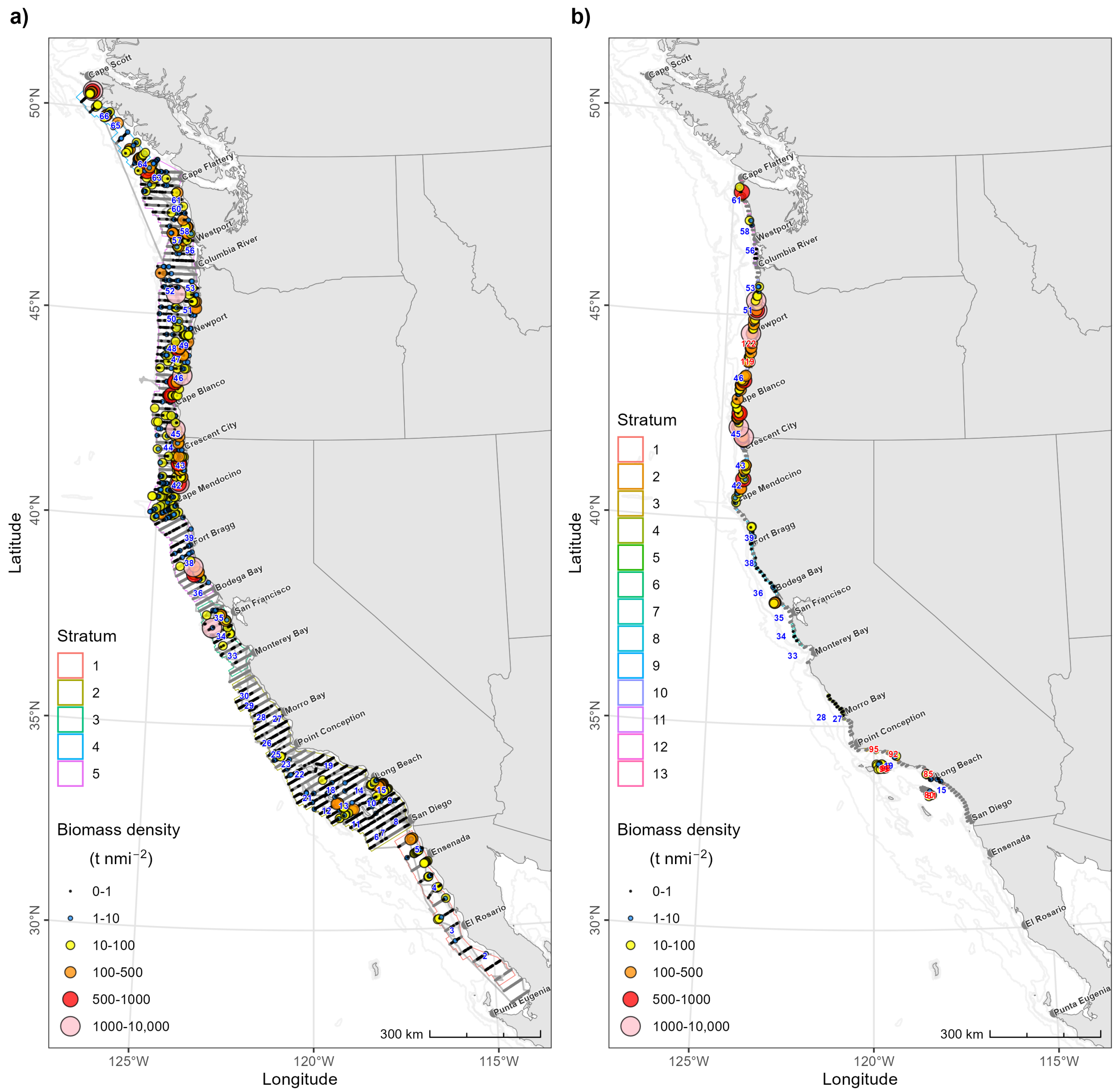

Figure 30: Biomass densities (colored points) of Jack Mackerel (*Trachurus symmetricus*), per stratum, in the a) core and b) nearshore survey regions. Overlaid are the locations of trawl clusters (blue numbers) or purse seine samples (red numbers) with at least one Jack Mackerel in each stratum (colored polygons). Thick gray lines represent acoustic transects.

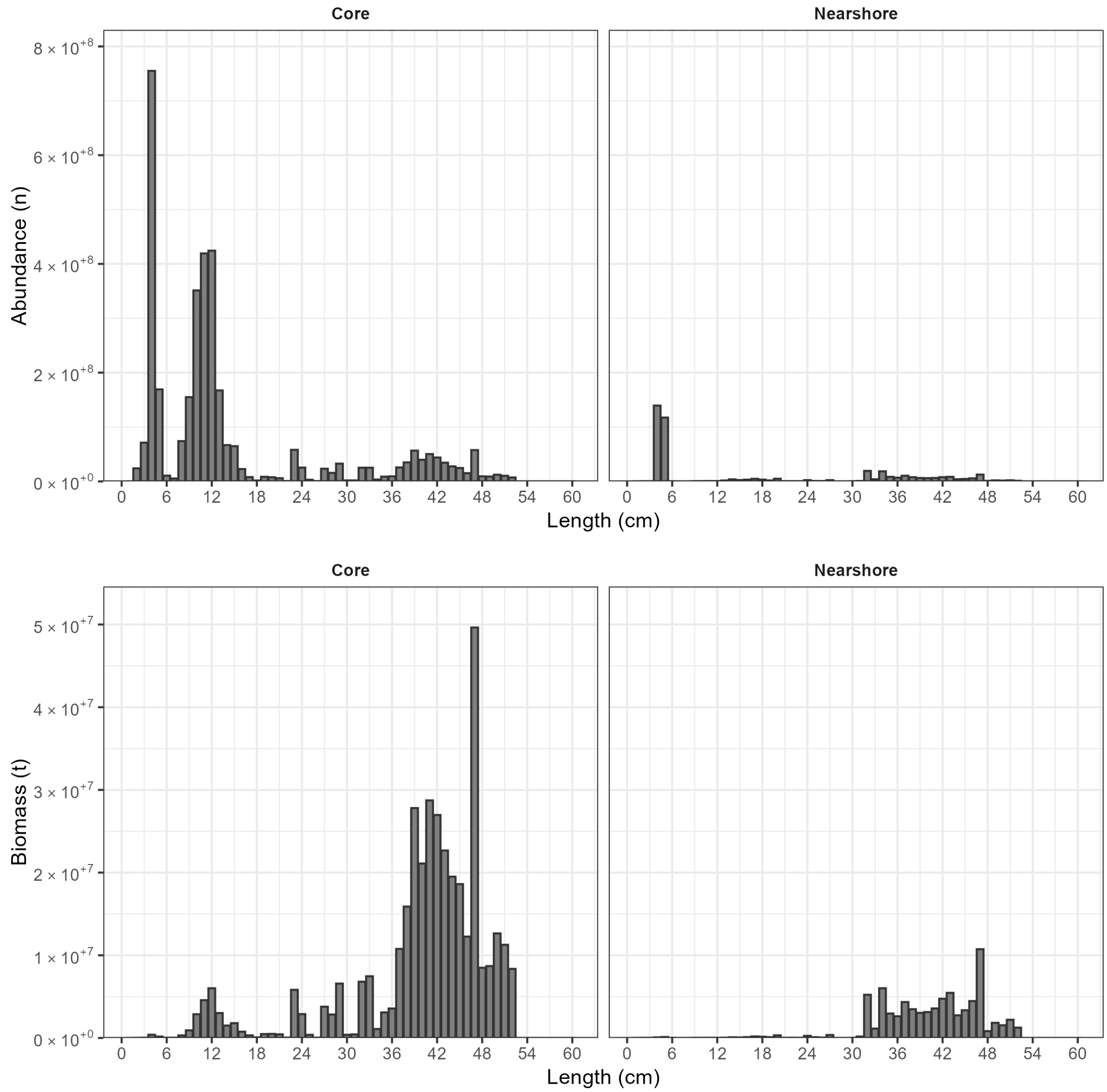

Figure 31: Estimated abundance (upper panel) and biomass (lower panel) versus fork length (L_F, cm) for Jack Mackerel (*Trachurus symmetricus*) in the core and nearshore survey regions.

3.5.5 Pacific Herring

The total estimated biomass of Pacific Herring was 69,923 t ($CI_{95\%}$ = 37,912 - 109,595 t, CV = 21%; **Table 16**). In the core region, biomass was 51,213 t ($CI_{95\%}$ = 27,162 - 83,165 t, CV = 28%; **Table 16**). It was distributed from approximately Florence, OR to central Vancouver Island (**Fig. 32a**). L_F in the core region ranged from 8 to 25 cm, with modes at 9, 17, and 22 cm (**Table 17**, **Fig. 33**). In the nearshore region, biomass was 18,710 t ($CI_{95\%}$ = 10,751 - 26,429 t, CV = 21%; **Table 16**, **Fig. 32b**), or 27% of the total biomass. It was distributed from San Francisco to Cape Flattery (**Fig. 33**), but was most abundant north of Newport. Lengths in the nearshore region had modes at 9 and 16 cm (**Table 17**, **Fig. 33**).

Table 16: Biomass estimates (metric tons, t) and their precisions (upper and lower 95% confidence intervals, $CI_{95\%}$; and coefficients of variation, CVs) for Pacific Herring (*Clupea pallasii*) in the core and nearshore survey regions. Stratum areas are nmi^2.

Stratum					Trawl		Biomass			
Region	Number	Area	Transects	Distance	Clusters	Individuals	$\hat{B}$	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Core	1	3,322	9	332	1	8	222	51	516	59
	2	2,303	5	117	2	6,421	13,502	2,628	27,739	49
	3	15,070	31	1,501	13	36,660	37,488	15,670	68,242	35
	All	20,695	45	1,950	15	43,090	51,213	27,162	83,165	28
Nearshore	1	229	8	37	1	50	1,396	243	3,023	52
	2	258	13	41	2	58	78	36	133	32
	3	185	7	26	2	64	2,750	763	5,809	48
	4	101	5	17	1	40	1,000	6	2,631	69
	5	748	33	117	10	12,599	13,487	6,681	20,158	26
	All	1,522	66	236	16	12,811	18,710	10,751	26,429	21
All	**-**	**22,217**	**111**	**2,186**	**31**	**55,901**	**69,923**	**37,912**	**109,595**	**21**

Table 17: Abundance estimates versus fork length (L_F, cm) for Pacific Herring (*Clupea pallasii*) in the core and nearshore survey regions.

	Region	
L_F	Core	Nearshore
1	0	0
2	0	0
3	0	0
4	0	0
5	0	0
6	0	0
7	0	0
8	1,584,716	63,364,468
9	28,518,246	261,278,619
10	14,978,221	102,704,054
11	2,016,982	28,339,478
12	1,066,837	2,446,814
13	1,164,137	28,542,559
14	16,972,117	22,455,572
15	48,741,708	62,342,061
16	86,462,915	87,039,115
17	95,556,277	57,440,741
18	69,820,583	29,353,199
19	54,885,772	9,052,087
20	59,896,602	16,737,694
21	64,088,437	6,825,091
22	96,570,411	2,384,637
23	41,216,831	1,055,924
24	12,171,198	0
25	843,822	0
26	0	0
27	0	0
28	0	0
29	0	0
30	0	0

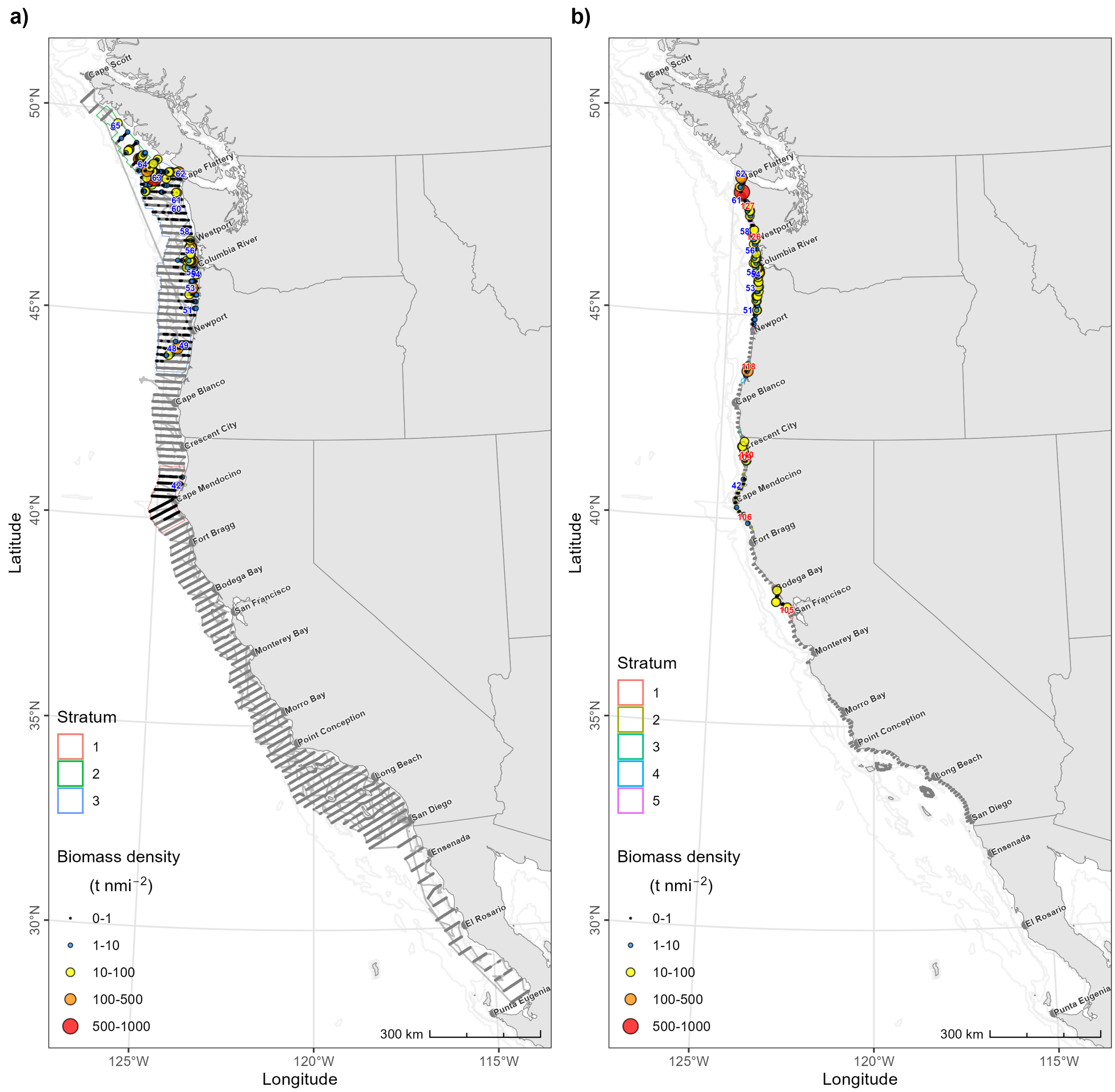

Figure 32: Biomass densities (colored points) of Pacific Herring (*Clupea pallasii*), per stratum, in the a) core and b) nearshore survey regions. Overlaid are the locations of trawl clusters (blue numbers) or purse seine samples (red numbers) with at least one Pacific Herring in each stratum (colored polygons). Thick gray lines represent acoustic transects.

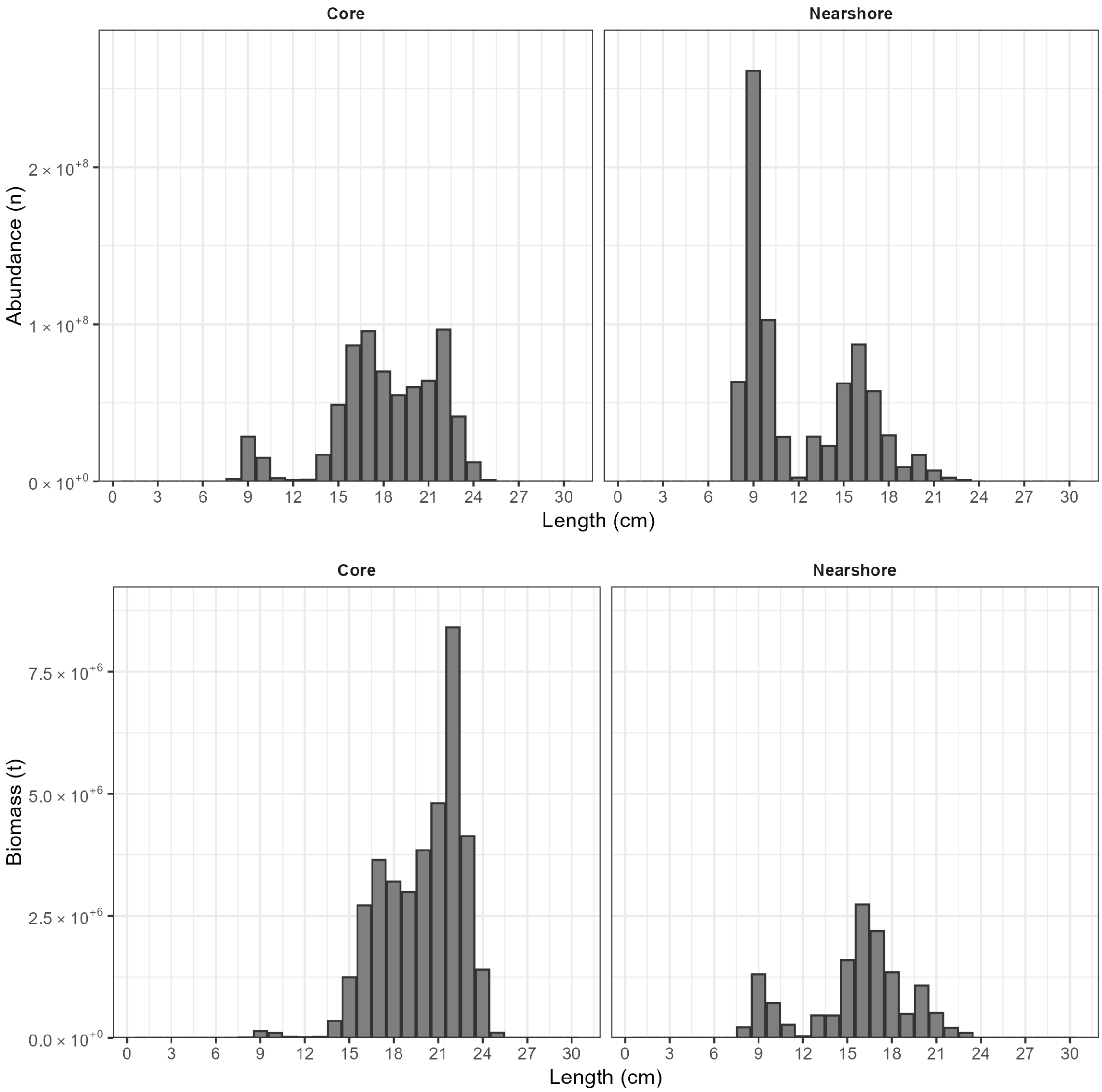

Figure 33: Estimated abundance (upper panel) and biomass (lower panel) versus fork length (L_F, cm) for Pacific Herring (*Clupea pallasii*) in the core and nearshore survey regions.

3.5.6 Round Herring

The total estimated biomass of Round Herring was 1,837 t ($CI_{95\%}$ = 276 - 3,952 t, CV = 42%, **Table 18**), and was located between Punta Eugenia and El Rosario off Baja CA and along a few transects north of San Nicolas Island in the SCB (**Fig. 34a**). L_F ranged from 14 to 26 cm with modes at 16, 23, and 26 cm (**Table 19**, **Fig. 35**). In the nearshore region, biomass was 1,085 t ($CI_{95\%}$ = 7.53 - 2,671 t, CV = 67%; **Table 18**, **Fig. 34b**), or 59% of the total biomass. It was distributed along the mainland coast near Long Beach and off the southern shore of Santa Catalina Island (**Fig. 35**). All lengths in the nearshore region were 2-4 cm. (**Table 19**, **Fig. 35**).

Table 18: Biomass estimates (metric tons, t) and their precisions (upper and lower 95% confidence intervals, $CI_{95\%}$; and coefficients of variation, CVs) for Round Herring (*Etrumeus acuminatus*) in the core and nearshore survey regions. Stratum areas are nmi^2.

Stratum					Trawl		Biomass			
Region	Number	Area	Transects	Distance	Clusters	Individuals	$\hat{B}$	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Core	1	3,510	7	171	2	140	751	268	1,281	34
	2	5,598	6	549	1	1	1	0	2	55
	All	9,109	13	720	3	141	752	269	1,281	34
Nearshore	1	70	5	16	1	7	1,080	3	2,670	67
	2	13	4	8	1	4	5	0	13	70
	3	12	4	9	1	4	0	0	0	58
	All	95	13	33	2	15	1,085	8	2,671	67
All	**-**	**9,203**	**26**	**754**	**5**	**156**	**1,837**	**276**	**3,952**	**42**

Table 19: Abundance estimates versus fork length (L_F, cm) for Round Herring (*Etrumeus acuminatus*) in the core region. No Round Herring were caught in the nearshore region.

	Region	
L_F	Core	Nearshore
1	0	0
2	0	13,311,216
3	0	0
4	0	13,311,216
5	0	0
6	0	0
7	0	0
8	0	0
9	0	0
10	0	0
11	0	0
12	0	0
13	0	0
14	183,247	0
15	2,250,785	0
16	3,577,325	0
17	2,565,461	0
18	746,701	0
19	183,247	0
20	0	0
21	0	0
22	887,687	0
23	887,687	0
24	0	0
25	221,922	0
26	221,922	0
27	0	0
28	0	0
29	0	0
30	0	0

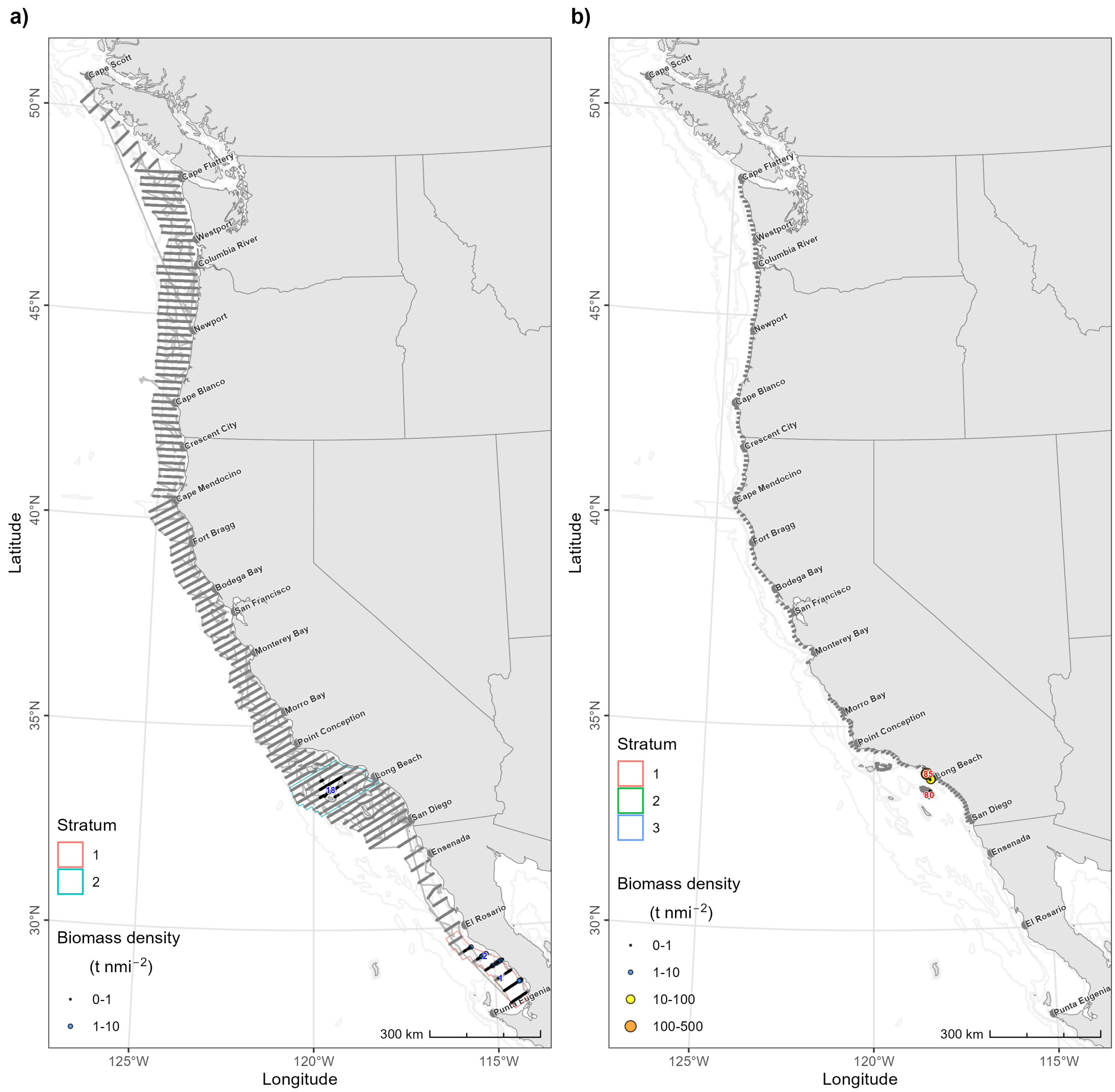

Figure 34: Biomass densities (colored points) of Round Herring (*Etrumeus acuminatus*), per stratum, in the a) core and b) nearshore survey regions. Overlaid are the locations of trawl clusters (blue numbers) or purse seine samples (red numbers) with at least one Round Herring in each stratum (colored polygons). Thick gray lines represent acoustic transects.

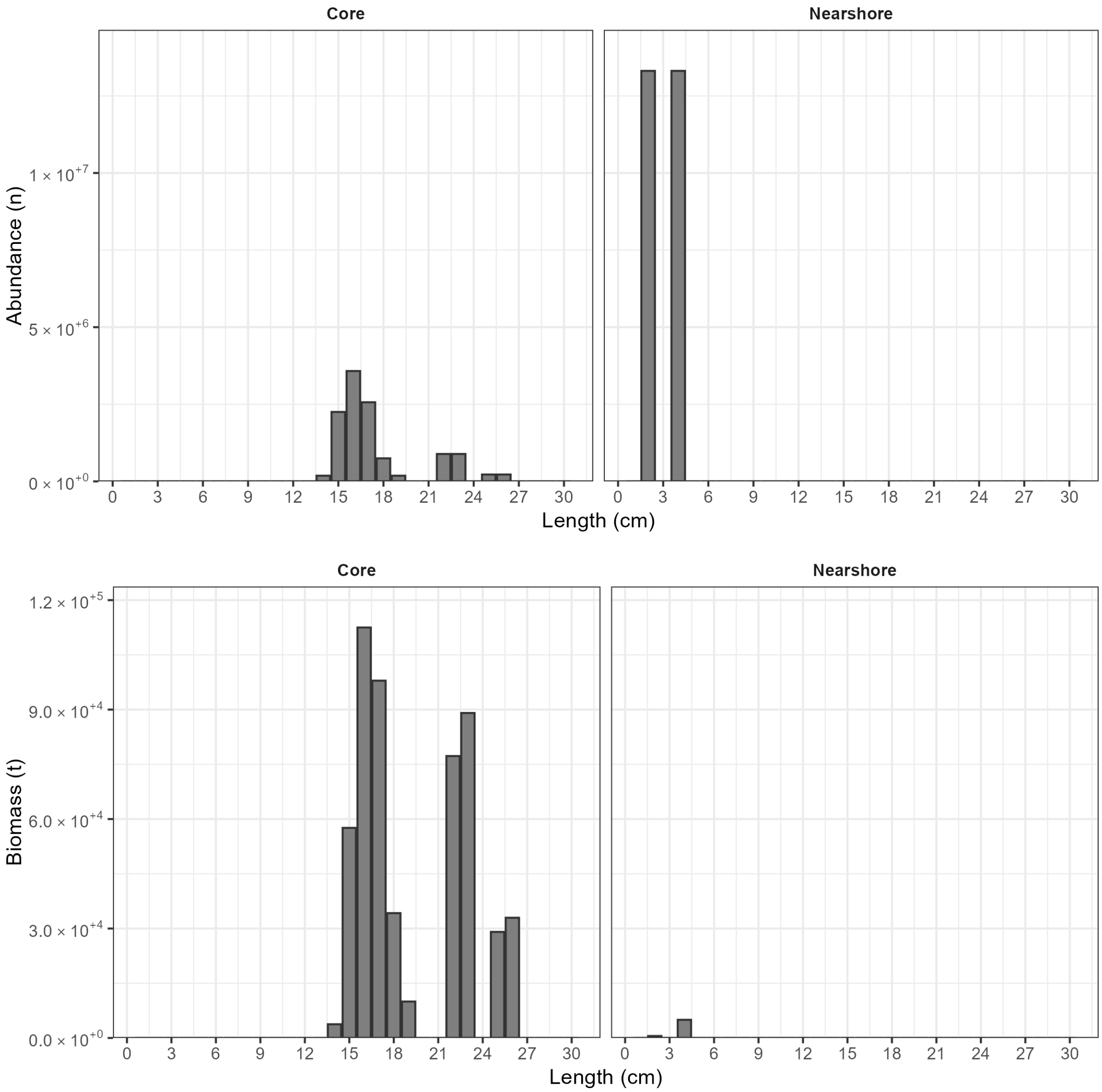

Figure 35: Estimated abundance (upper panel) and biomass (lower panel) versus fork length (L_F, cm) for Round Herring (*Etrumeus acuminatus*) in the core survey region. No Round Herring were caught in the nearshore region.

3.6 Comparative nighttime trawl and purse seine sampling

Lisa Marie conducted thirteen nighttime purse seine sets in close proximity to the eighteen trawl locations sampled by *Lasker*. In general, the species composition in catches from nighttime seine samples were visually similar to those in individual trawl hauls (**Fig. 36**) and trawl clusters (**Fig. 37**). One notable exception was the two nearshore locations in the northern part of the area where purse seines collected Pacific Sardine but none were captured in the trawl net. Several of the purse seine samples contained no CPS, but those were farther offshore and nearby trawls contained Jack Mackerel and Pacific Mackerel.

Similar to species composition, the number and length distributions of CPS specimens were similar between purse seine and trawl samples **Fig. 38**). No Pacific Sardine were captured in the trawls, and no Northern Anchovy were collected in the purse seine samples; however, only one Northern Anchovy was collected in the trawls.

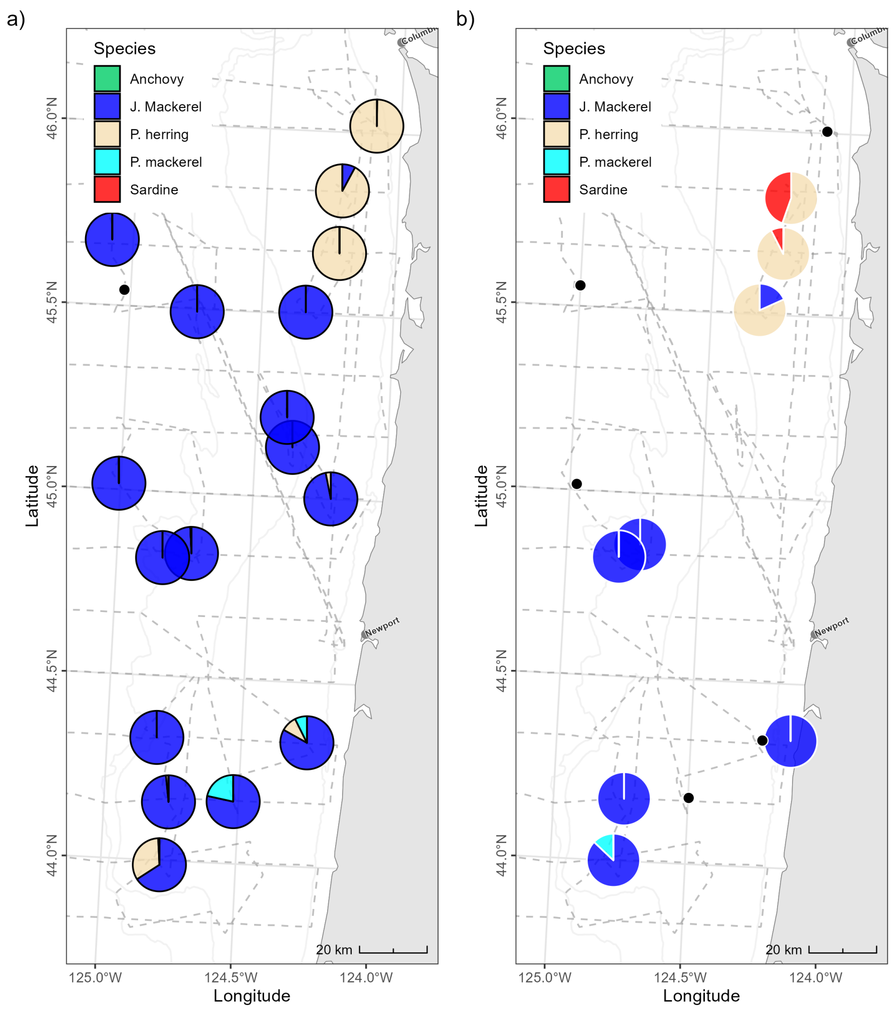

Figure 36: The proportion of CPS (by weight) in nighttime a) trawls and b) purse seines. Black points indicate trawl or purse seine samples where no CPS were collected.

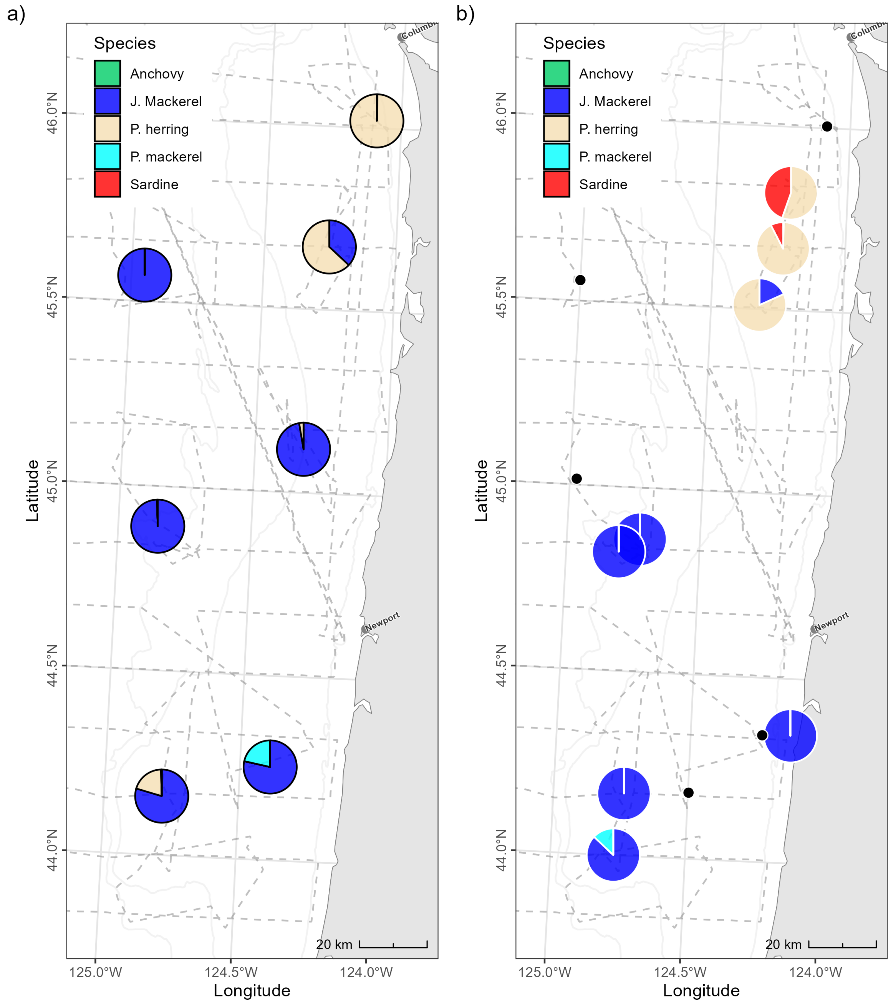

Figure 37: The proportion of CPS (by weight) in nighttime a) trawl clusters and b) purse seines. Black points indicate trawl clusters or purse seine samples where no CPS were collected.

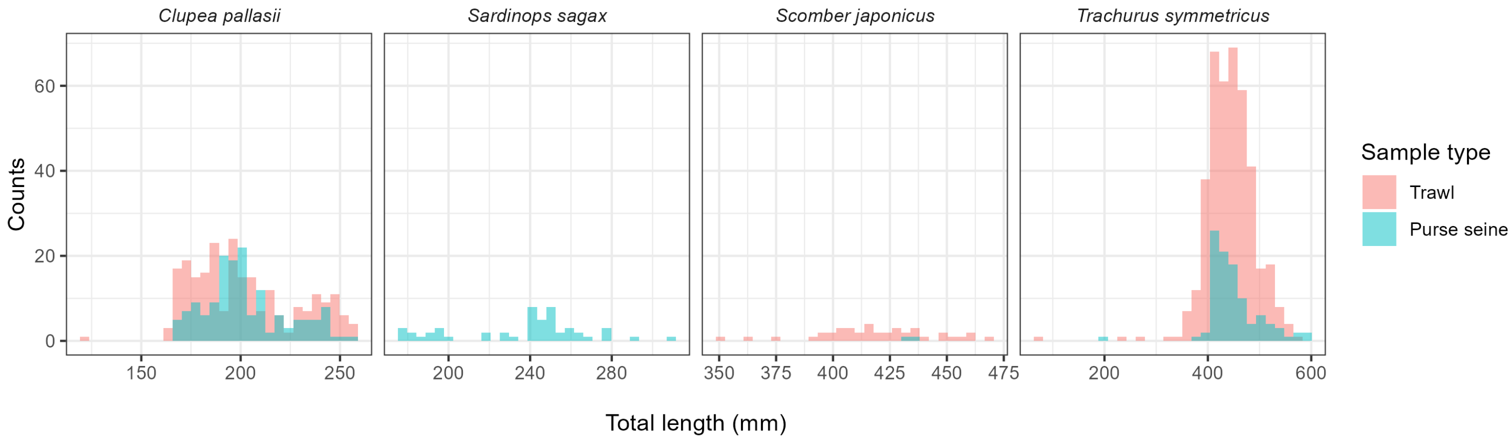

Figure 38: Length distributions for CPS in nighttime purse seine samples by *Lisa Marie* and in trawl samples collected by *Lasker*. Note: only one Northern Anchovy (L_t = 177 mm) was collected in the trawls but is not presented here.

4 Discussion

The primary objective of the ATM surveys is to estimate the biomasses, distributions, and demographics of CPS within the survey area at the time of the survey. With the benefit of favorable weather conditions and minimal delays related to mechanical failures, staffing shortages, and other logistical challenges, nearly all of the originally allocated 85 sea days aboard *Lasker* were successfully executed, and the sampling of the core and nearshore regions in coordination with F/Vs *Long Beach Carnage* and *Lisa Marie* was accomplished with minimal temporal and spatial separation, all of which were testament to the planning, preparation, and skill of all parties involved. The summer 2024 survey area spanned the expected distribution of the northern subpopulation of Pacific Sardine and northern subpopulation of Northern Anchovy in U.S. waters, but also portions of the expected distribution of the southern subpopulation of Pacific Sardine, central subpopulation of Northern Anchovy, Pacific Mackerel, Jack Mackerel, Pacific Herring, and Round Herring.

Due to sparse sampling by *Lisa Marie* in the nearshore region, due in part to the general lack of schools to target but also to the presence of marine mammals that precluded setting their net, the nearest trawl cluster or purse-seine set was used to apportion backscatter in the nearshore region to minimize bias in the biomass estimates. The comparison of nighttime trawl and purse-seine samples yielded remarkably similar results in terms of both species and size composition. This is in contrast to purse-seine samples collected offshore by *Lisa Marie* during daytime in 2022, where Jack Mackerel were reportedly schooling with Pacific Sardine but eluded capture, thereby biasing the species composition in those samples (Stierhoff *et al.*, 2023b), and provides support for using nighttime purse-seine catches to apportion backscatter observed farther offshore if necessary.

4.1 Biomass and abundance

4.1.1 Northern Anchovy

4.1.1.1 Northern subpopulation The estimated biomass of the northern subpopulation of Northern Anchovy in the survey region north of Astoria was 151 t ($CI_{95\%}$ = 21 - 289 t) in summer 2024. The northern subpopulation biomass has comprised a small fraction (0 to 5.4%) of the total CPS biomass in the CCE since at least 2015 (Stierhoff *et al.*, 2021a), and was lower than the 8,030.6 t observed in summer 2023 (Stierhoff *et al.*, 2024).

4.1.1.2 Central subpopulation The estimated biomass of the central subpopulation of Northern Anchovy in the survey region was 682,657 t ($CI_{95\%}$ = 328,527 - 796,114 t), making up 45% of the total CPS biomass in summer 2024, and has comprised a substantial portion of the CPS biomass in the CCE since approximately 2016. The biomass in 2024 decreased 75% from the 2,689,200 t estimated in summer 2023 (Stierhoff *et al.*, 2024). Additional scrutiny of the 2023 survey data identified one acoustic transect near San Francisco with a significant CPS backscatter density that greatly increased both the point estimate and the confidence intervals (see **Fig. 40a**). For example, removing that transect reduced the 2023 biomass estimate by ~56%, which would have resulted in a more gradual decrease in the biomass of the central subpopulation of Northern Anchovy over the past three survey years. The decrease in biomass in 2024 may also be due in part to the decreased northern extent of the distribution, which typically extends to Cape Mendocino but ended near San Francisco this year. We will continue exploring additional explanations for the apparent decline in biomass observed since 2022.

4.1.2 Pacific Sardine

4.1.2.1 Northern subpopulation The southern extent of northern subpopulation Pacific Sardine habitat was Pt. Conception, based on the potential habitat model (Zwolinski and Demer, 2024) and corroborated by both the geographic separation of biomass density north and south of Point Conception (**Fig. 14**) and visual differences in length compositions (**Fig. 39**). The estimated biomass of 77,750 t ($CI_{95\%}$ = 21,800

- 156,748 t) in the survey region was virtually unchanged from the 77,252 t estimated in summer 2023 (Stierhoff *et al.*, 2024). However, unlike in past years, nearly all of the biomass attributed to the northern subpopulation was observed in the nearshore region near Pt. Conception and between Santa Cruz and San Francisco. These results were included in the update assessment used to provide a biomass estimate for harvest specifications of the northern subpopulation of Pacific Sardine during the 2025-2026 fishing year (Allen Akselrud *et al.*, In review). Since 2014, the ATM biomass of the northern subpopulation of Pacific Sardine has remained less than the 150,000 t rebuilding target adopted by the Pacific Fishery Management Council in 2020[6] (**Figs. 40**).

4.1.2.2 Southern subpopulation The estimated biomass of the southern subpopulation of Pacific Sardine was 47,566 t ($CI_{95\%}$ = 32,397 - 96,235 t), of which 25,431 t (53%) occurred in the nearshore region in the SCB. The southern subpopulation was first observed in U.S. waters by the SWFSC's ATM surveys in 2016 (323 t, Stierhoff *et al.*, 2021b). Since then, the southern subpopulation biomass in U.S. waters has persisted. The biomass estimated in 2024 (48,984 t) is within the range of biomasses from 14,890 t estimated in summer 2019 (Stierhoff *et al.*, 2020) to 196,609 t in summer 2021 (Stierhoff *et al.*, 2023a). In 2017, the summer survey did not extend into the SCB (Zwolinski *et al.*, 2019), and no summer survey was conducted in 2020 due to the COVID-19 pandemic. In 2024, Mexico conducted a contemporaneous survey of CPS, including the nearshore region, but those results are reported elsewhere (Martínez-Magaña *et al.*, In revision).

4.1.3 Pacific Mackerel

In summer 2024, the estimated biomass of Pacific Mackerel in the survey region was 11,129 t ($CI_{95\%}$ = 4,950 - 19,241 t), which is within the range of recent estimates (7,289 - 42,423) between 2016 and 2023.

4.1.4 Jack Mackerel

In summer 2024, the estimated biomass of Jack Mackerel in the survey region was 618,467 t ($CI_{95\%}$ = 446,095 - 804,715 t), which was a significant (390%) increase from the 159,354 t estimated in summer 2023 (Stierhoff *et al.*, 2023a). However, the 2023 survey suffered from a substantial loss of sea days and sampling effort, with the estimated biomass (159,354 t, Stierhoff *et al.*, 2024) being the lowest since 2017 (Zwolinski *et al.*, 2019). In 2024, the estimate is more similar to the estimates from 2021 and 2022, and comprised 41% of the total CPS biomass.

4.1.5 Pacific Herring

In summer 2024, the estimated biomass of Pacific Herring in the survey region was 69,923 t ($CI_{95\%}$ = 37,912 - 109,595 t), which was a 35% decrease from the 106,723 t estimated in summer 2023 (Stierhoff *et al.*, 2024), but similar to estimates from 2021 and 2022 (67,920 t and 50,718 t, respectively).

4.1.6 Round Herring

In summer 2024, the estimated biomass of Round Herring in U.S. and Mexican waters north of Punta Eugenia was 1,837 t ($CI_{95\%}$ = 276 - 3,952 t). While this is the first time that Round Herring biomass has been estimated in U.S. waters, specimens have been encountered in low numbers during past surveys (unpublished data).

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

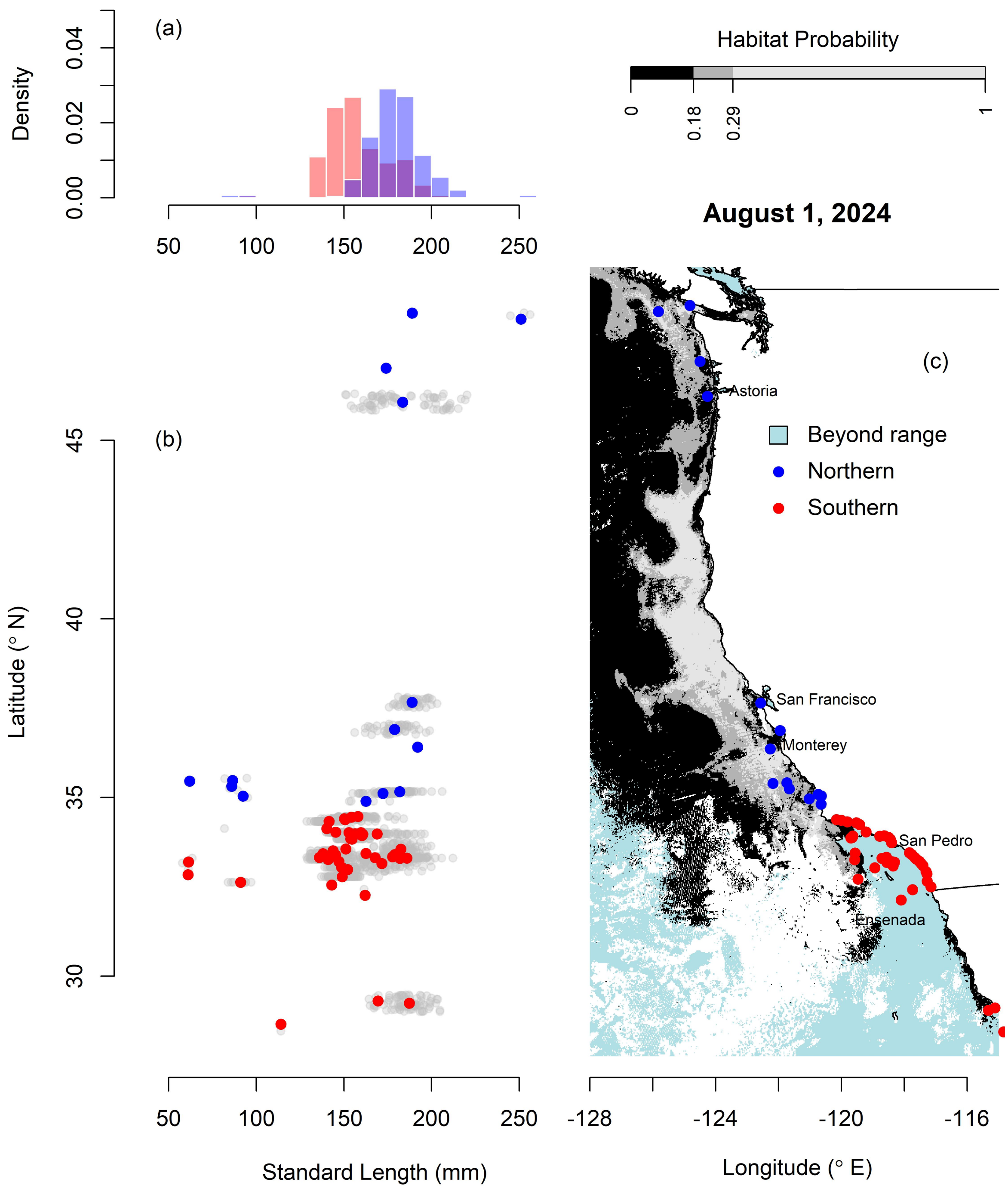

Figure 39: Summary of lengths for Pacific Sardine sampled during the summer 2024 survey: a) relative length distribution of individuals classified as northern (blue) and southern (red) subpopulations (NSP and SSP, respectively); b) individual length measurements (grey points) and mean lengths (blue and red points for NSP and SSP, respectively) for each trawl cluster versus latitude; and c) locations of trawls clusters with Pacific Sardine assigned to each subpopulation (blue and red points) based on the predicted potential habitat for the NSP (Zwolinski and Demer, 2024) at the midpoint of the survey (August 1, 2024).

4.2 Ecosystem dynamics: Forage fish community

The acoustic-trawl method (ATM) has been used to monitor the biomasses and distributions of pelagic and mid-water fish stocks worldwide (e.g., Coetzee *et al.*, 2008; Karp and Walters, 1994; Simmonds *et al.*, 2009). In 2006, the SWFSC's ATM survey in the CCE focused on Pacific Sardine (Cutter and Demer, 2008), but evolved to assess the five most abundant CPS (Zwolinski *et al.*, 2014): Pacific Sardine, Northern Anchovy, Jack Mackerel, Pacific Mackerel, and Pacific Herring. In the CCE, ATM surveys have been used to directly assess Pacific Hake (Edwards *et al.*, 2018; JTC, 2014); rockfishes (Demer, 2012a, 2012b, 2012c; Starr *et al.*, 1996); Pacific Herring (Thomas and Thorne, 2003); northern subpopulation of Pacific Sardine (Hill *et al.*, 2017; Kuriyama *et al.*, 2020, 2022a); northern (Mais, 1974, 1977) and central subpopulations (Kuriyama *et al.*, 2022b) of Northern Anchovy; and Pacific Mackerel (Crone *et al.*, 2019; Crone and Hill, 2015). The proportions of these subpopulations that are in water too shallow to be sampled by NOAA ships are estimated using samples collected from fishing vessels. 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 subpopulation increased (Demer and Zwolinski, 2017), and the total forage-fish biomass decreased to less than 200,000 t in 2014 and 2015 (**Figs. 40a,b**). 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*[7]), Common Murres (*Uria aalge*), Brandt's Cormorants (*Phalacrocorax penicillatus*), and California sea lions (*Zalophus californianus*[8]) (McClatchie *et al.*, 2016), all of which depend on forage species. The National Marine Fisheries Service deemed the subpopulation 'overfished' in 2019.

The biomass of the central subpopulation of Northern Anchovy, which had been growing rapidly since 2015, decreased from the estimate in 2023 (Stierhoff *et al.*, 2024). After re-examination of the 2023 survey data, a single acoustic transect near San Francisco was identified as having significant influence on both the biomass point estimate and confidence intervals. In any case, the biomass of the central subpopulation of Northern Anchovy appears to have declined recently. Meanwhile, the northern and southern subpopulations of Pacific Sardine, delineated at Point Conception, were observed mostly in the nearshore region, with very little biomass north of San Francisco. Comparatively, in 2023, the subpopulations of Pacific Sardine were delineated at Bodega Bay, with the northern subpopulation observed predominantly off Washington and central Oregon (Stierhoff *et al.*, 2024). However, because the change in distribution largely follows the geographical change in potential habitat, there is no indication that the biomasses of the northern or southern subpopulations of Pacific Sardine have changed significantly since summer 2023.

The survey-estimated CPS biomasses since 2008 were dominated by northern subpopulation Pacific Sardine until 2013, Jack Mackerel in 2014 and 2015, and then central subpopulation of Northern Anchovy since 2015, when it was resurgent. The latter subpopulation grew to ~2.75 million metric tons by 2021 (Stierhoff *et al.*, 2023a), and has hovered around ~2.5 million metric tons before decreasing recently. Meanwhile, the biomass of Pacific Mackerel remained the lowest in the assemblage, and the biomass of Jack Mackerel trended up from 2017 through 2022. In 2023, the delayed and smaller survey in the northern area created uncertainty about the decrease in Jack Mackerel biomass (**Fig. 40**), perhaps corroborated by the 2024 being between the 2021 and 2022 biomasses (**Fig. 40b**). In 2024, the biomass of Jack Mackerel was roughly equal to the biomass of the central subpopulation of Northern Anchovy, with each contributing to 41% and 45% of the total CPS biomass, respectively. The biomasses of northern and southern subpopulations of Pacific Sardine are calculated separately based on oceanographic habitat (Zwolinski and Demer, 2024). The southern subpopulation of Pacific Sardine has been present in U.S. waters since at least 2015, located mostly nearshore, south of Monterey Bay; the biomass of the northern subpopulation has been fluctuating below 100,000 t mostly off Oregon and Washington.

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

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

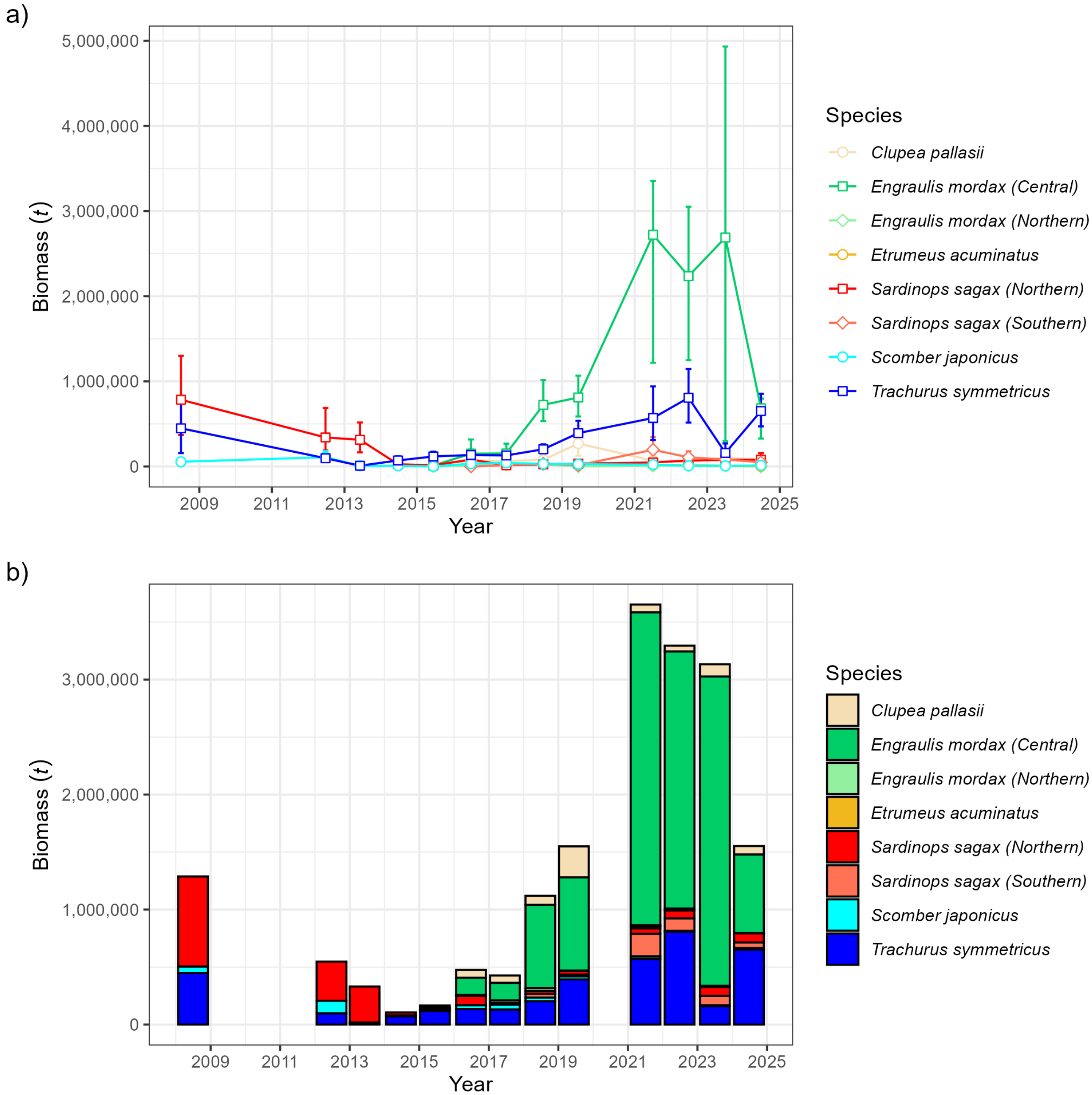

Figure 40: a) Estimated and b) cumulative estimated biomasses (t) of the eight most abundant CPS populations or subpopulations of six species in the CCE during summer since 2008. Surveys typically span the area between Cape Flattery and San Diego, but in some years also include Vancouver Island, Canada (2015-2019, 2024) and portions of Baja CA (2021-2022, 2024).

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Appendix

A Scientific Personnel

The collection and analysis of the survey data were conducted by members of 1-NOAA, 2-IMIPAS, 3-UCSC/CIMEAS, 5-OAI, 5-RAY Fellow, 6-volunteer, 7-OSU, 8-Cal Maritime, 9-WDFW, and 10-CWPA. For each leg, * denotes the Cruise Leader, and + the Acoustic and Trawl Leads. The survey on *Lasker* was divided into four legs; operational readiness training (ORT) and MFT gear trials were conducted during the first five days of Leg 1, with some personnel transferred ashore via small boat transfer.

Chief Scientist:

- J. Renfree[1]

Acoustic Data Collection and Processing:

- MFT Trials: J. Renfree[1*+] and D. Murfin[1]
- Leg I: J. Renfree[1*+] and M. Vasquez Ortiz[2]
- Leg II: K. Stierhoff[1+] and A. Beittel[1]
- Leg III: S. Mau[1+] and A. White [1]
- Leg IV: J. Zwolinski[3*+] and S. Sessions[1]

Trawl Sampling:

- MFT Trials: K. James[1+], D. Hernandez Cruz[2], B. Overcash[1], Z. Skelton[3], B. Schwartzkopf[1], and M. Vasquez Ortiz[2]
- Leg I: K. James[1+], D. Hernandez Cruz[2], P. Kuriyama[1], B. Overcash[1], and Z. Skelton[4]
- Leg II: T. Davies[7], A. Johannsen[8], A. Ostrowski[1], L. Sartori[8], and B. Schwartzkopf[1*+]
- Leg III: T. Davies[7], A. Malilay[1,5], S. Mitchell[6], Z. Skelton[4], and O. Snodgrass[1*+]
- Leg IV: A. Billings[1], S. Dionson[1,5], M. Liotta[1], B. Overcash[1], and R. Wildermuth[1]

Purse-seine Sampling:

- *Lisa Marie*
  - Z. Calef[9] and K. Hinton[9]
- *Long Beach Carnage*
  - J. van Noord[10]

Echosounder Calibrations:

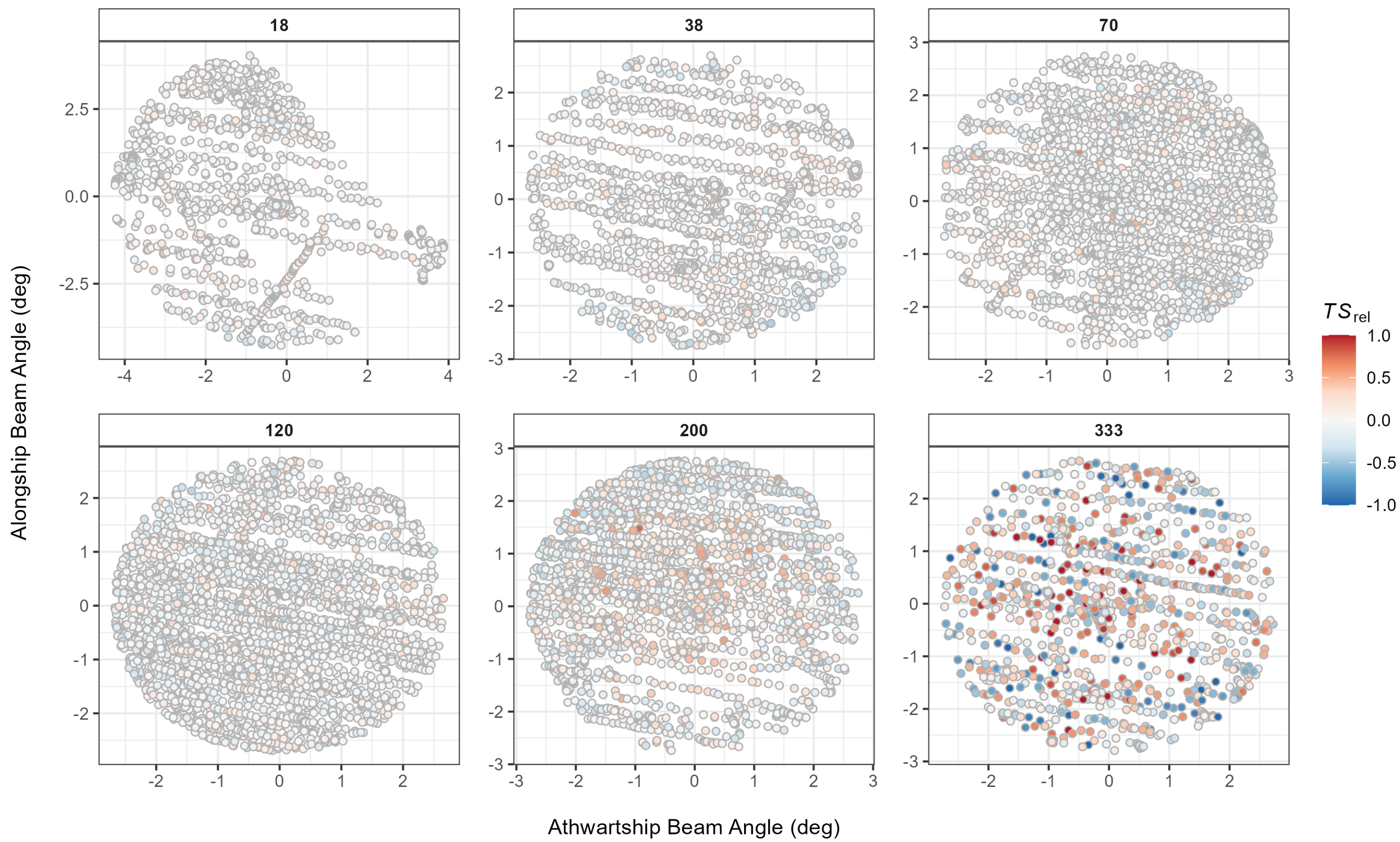
- *Reuben Lasker*
  - A. Beittel[1], D. Murfin[1], J. Renfree[1], and S. Sessions[1]
- *Long Beach Carnage*
  - J. Renfree[1] and S. Sessions[1]
- *Lisa Marie*
  - D. Murfin[1] and J. Renfree[1]

B Calibration plots

B.1 *Reuben Lasker*

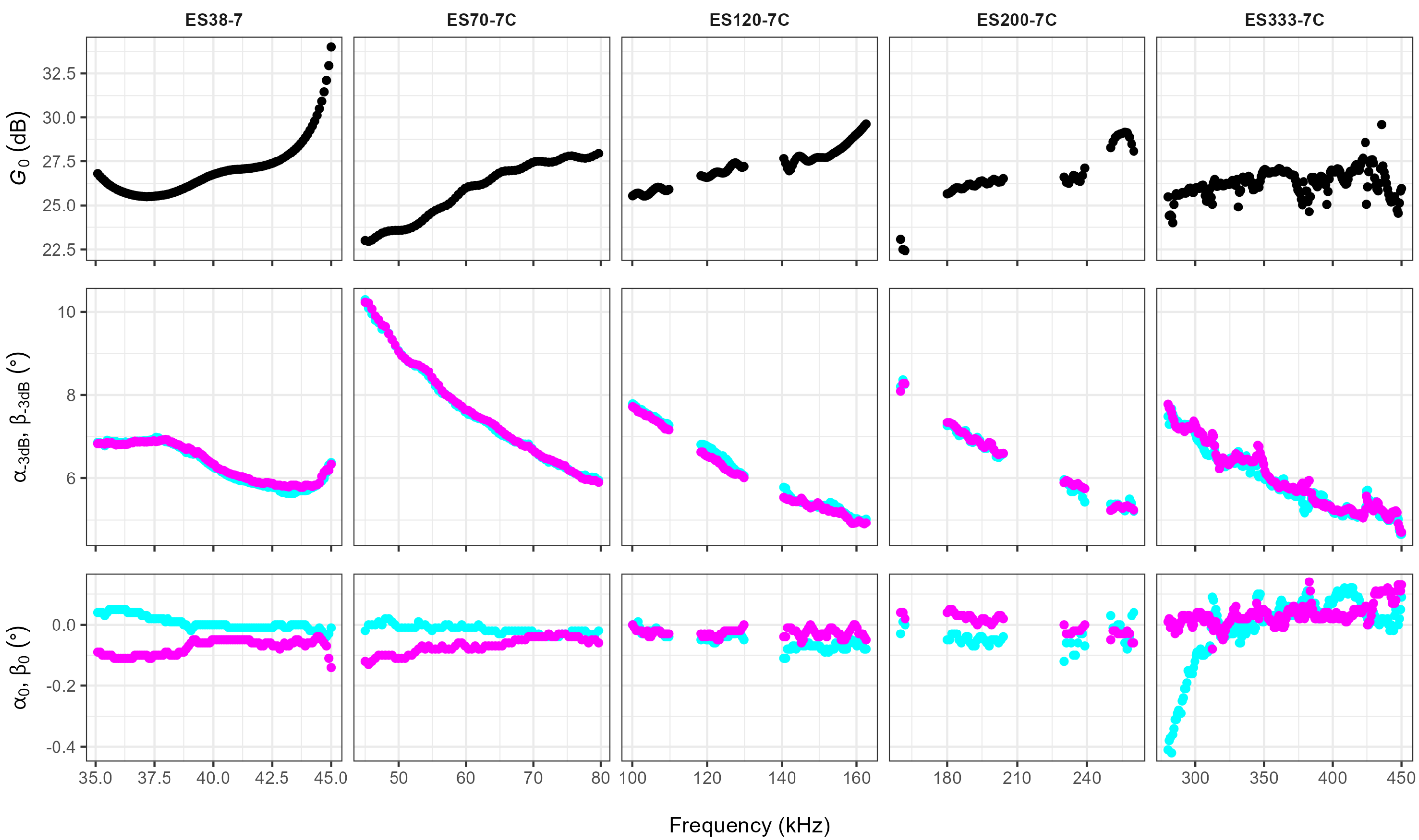
B.1.1 CW Mode

Relative beam-compensated target strength (TS_{rel}, dB re 1 m^2) measurements of a WC38.1 sphere at 18, 38, 70, 120, 200, and 333 kHz for echosounders aboard *Lasker*. TS_{rel} is calculated as the difference between the beam-compensated target strength (TS_c) and the theoretical target strength (TS_{theory}).



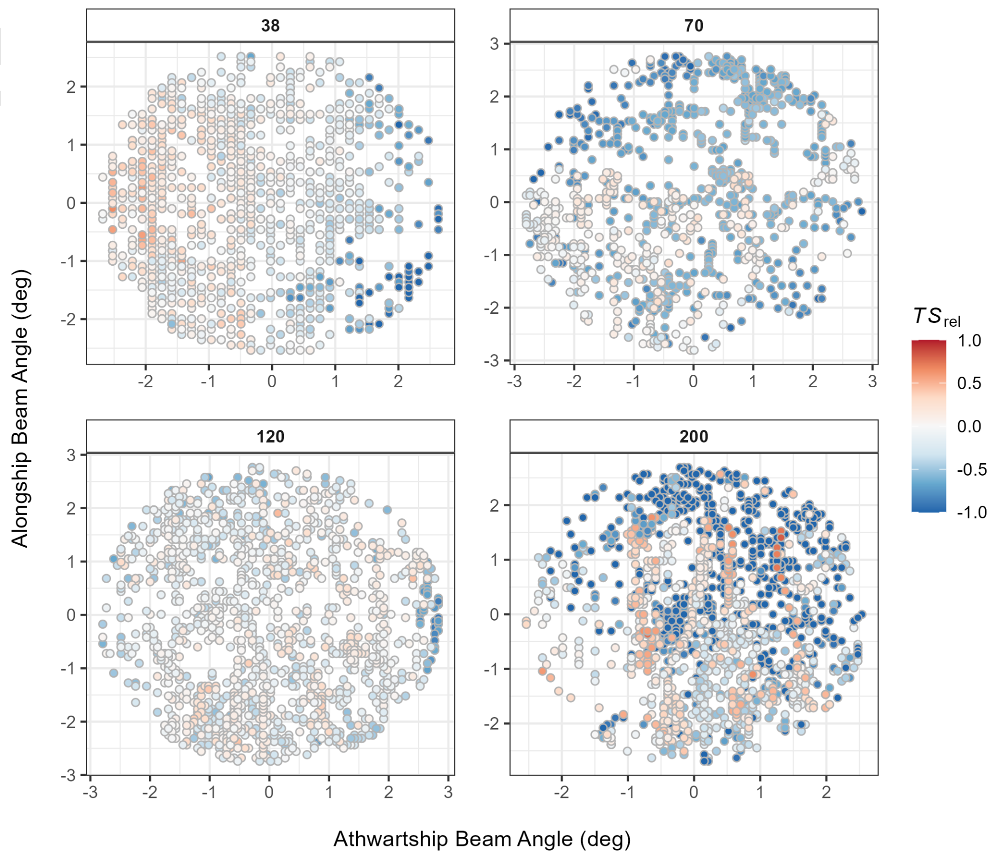
B.1.2 FM Mode

Measurements of on-axis gain (G_0, dB); alongship ($\alpha_{-3\mathrm{dB}}$, cyan) and athwartship ($\beta_{-3\mathrm{dB}}$, magenta) beamwidths (deg); and alongship (α_0, cyan) and athwartship (β_0, magenta) offset angles (deg) measured during calibrations of EK80 wideband transceivers aboard *Lasker* (WBT; 38, 70, 120, 200, and 333 kHz) in frequency modulation (FM, or broadband) mode.



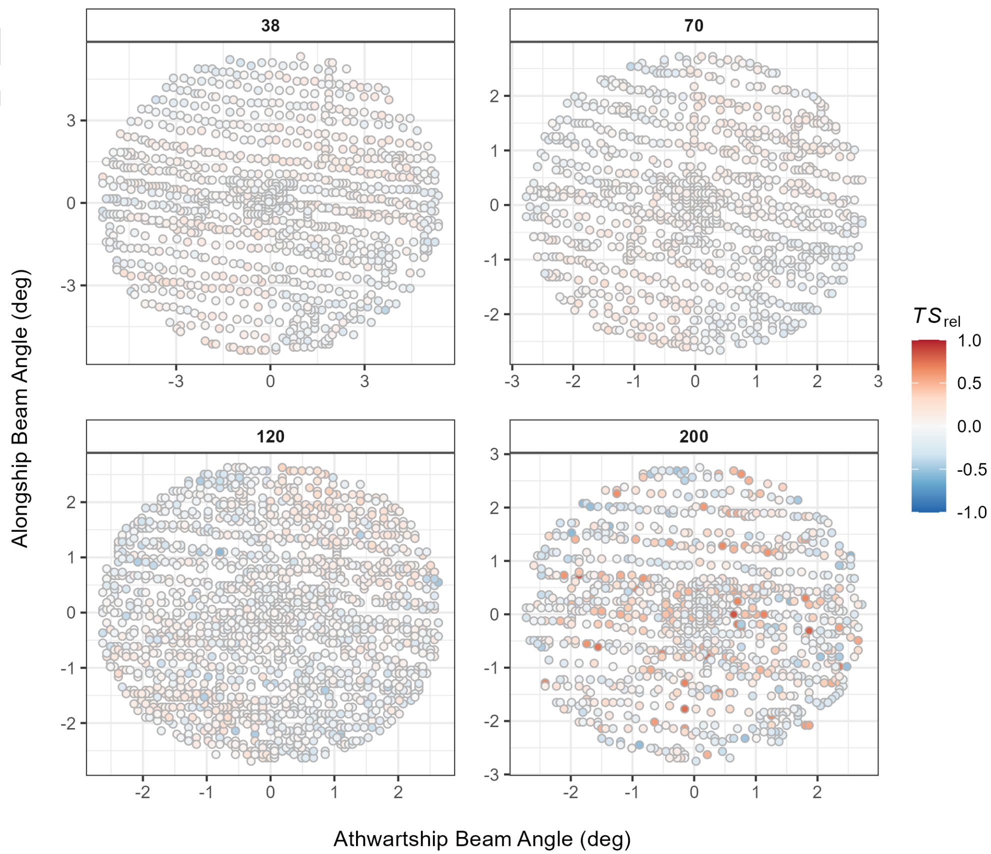
B.2 *Lisa Marie*

Relative beam-compensated target strength (TS_{rel}, dB re 1 m^2) measurements of a WC38.1 sphere at 38, 70, 120, and 200 kHz for echosounders aboard *Lisa Marie*. TS_{rel} is calculated as the difference between the beam-compensated target strength (TS_c) and the theoretical target strength (TS_{theory}). The results shown here are for the post-survey calibration conducted in Gig Harbor, WA.



B.3 *Long Beach Carnage*

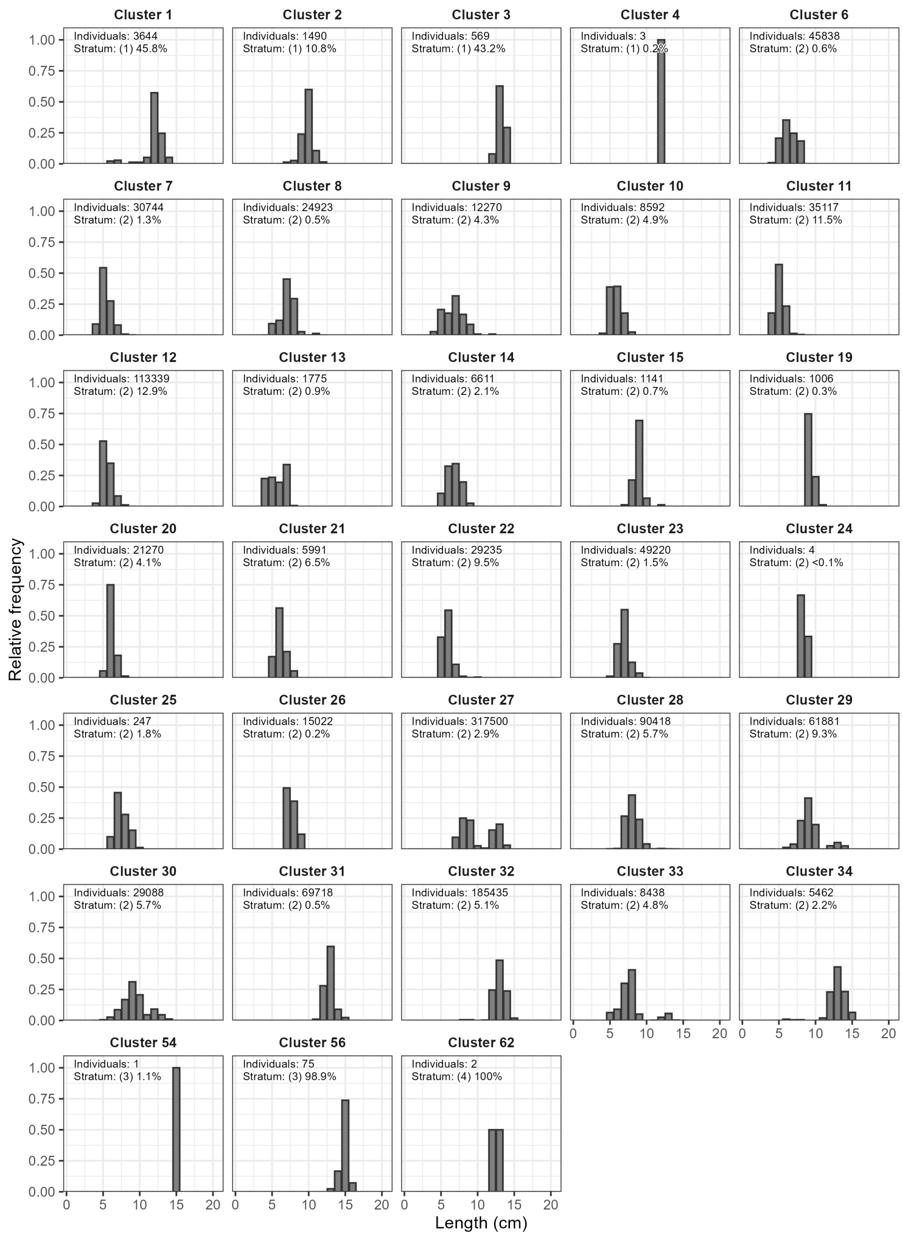
Relative beam-compensated target strength (TS_{rel}, dB re 1 m^2) measurements of a WC38.1 sphere at 38, 70, 120, and 200 kHz for echosounders aboard *Long Beach Carnage*. TS_{rel} is calculated as the difference between the beam-compensated target strength (TS_c) and the theoretical target strength (TS_{theory}).



C Length distributions and percent biomass by cluster

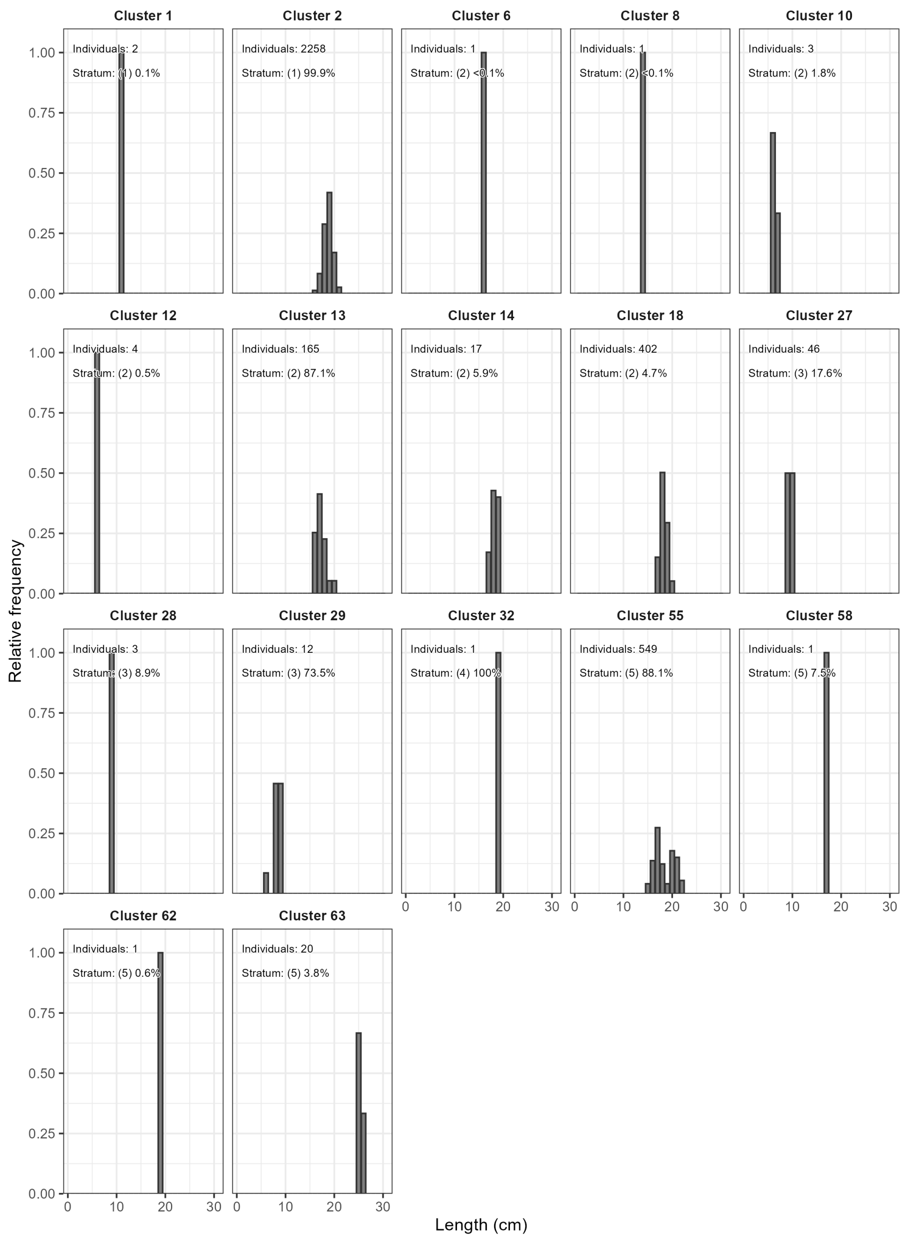
C.1 Northern Anchovy

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.



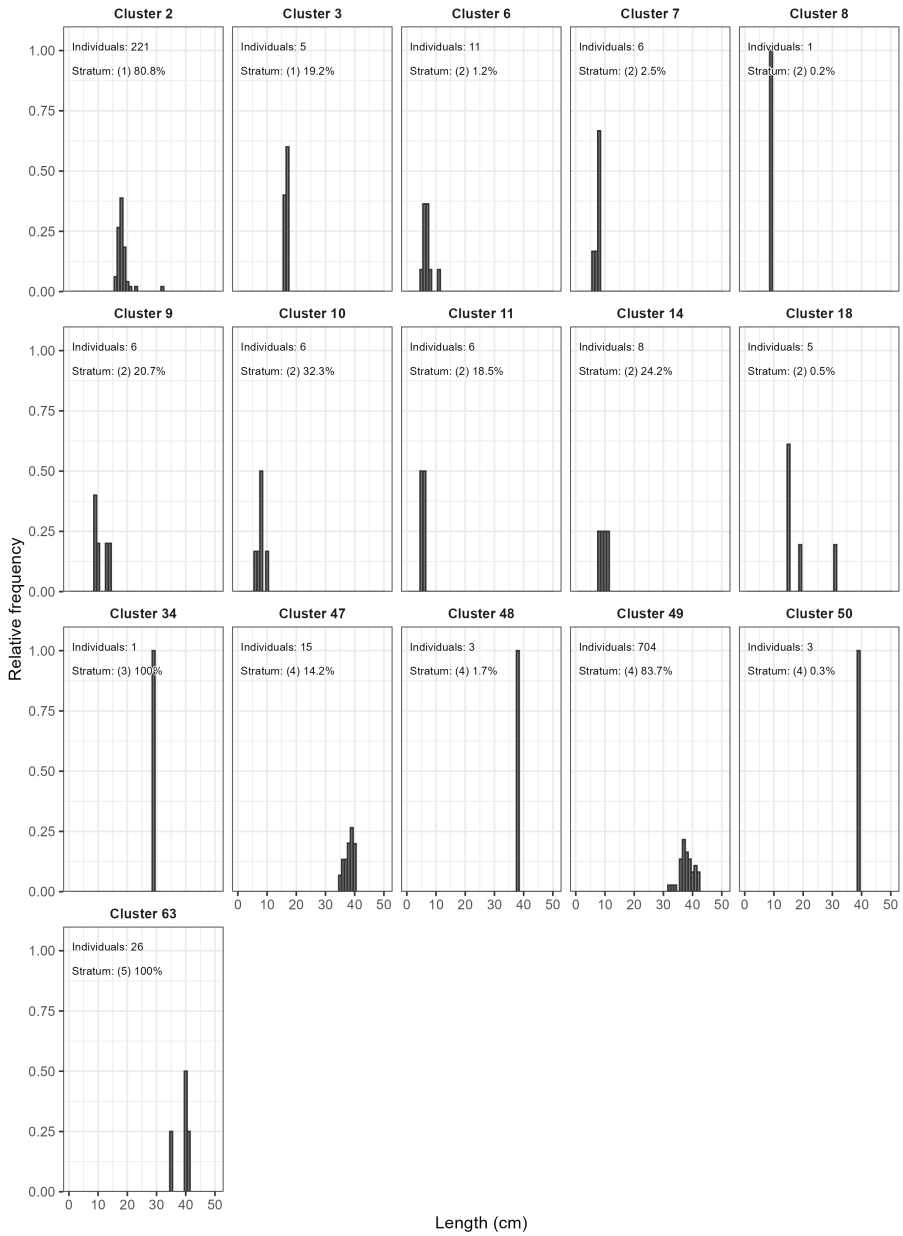
C.2 Pacific Sardine

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. The southern subpopulation are comprised of stratum 1 and 2, while the northern subpopulation are stratum 3, 4, and 5.



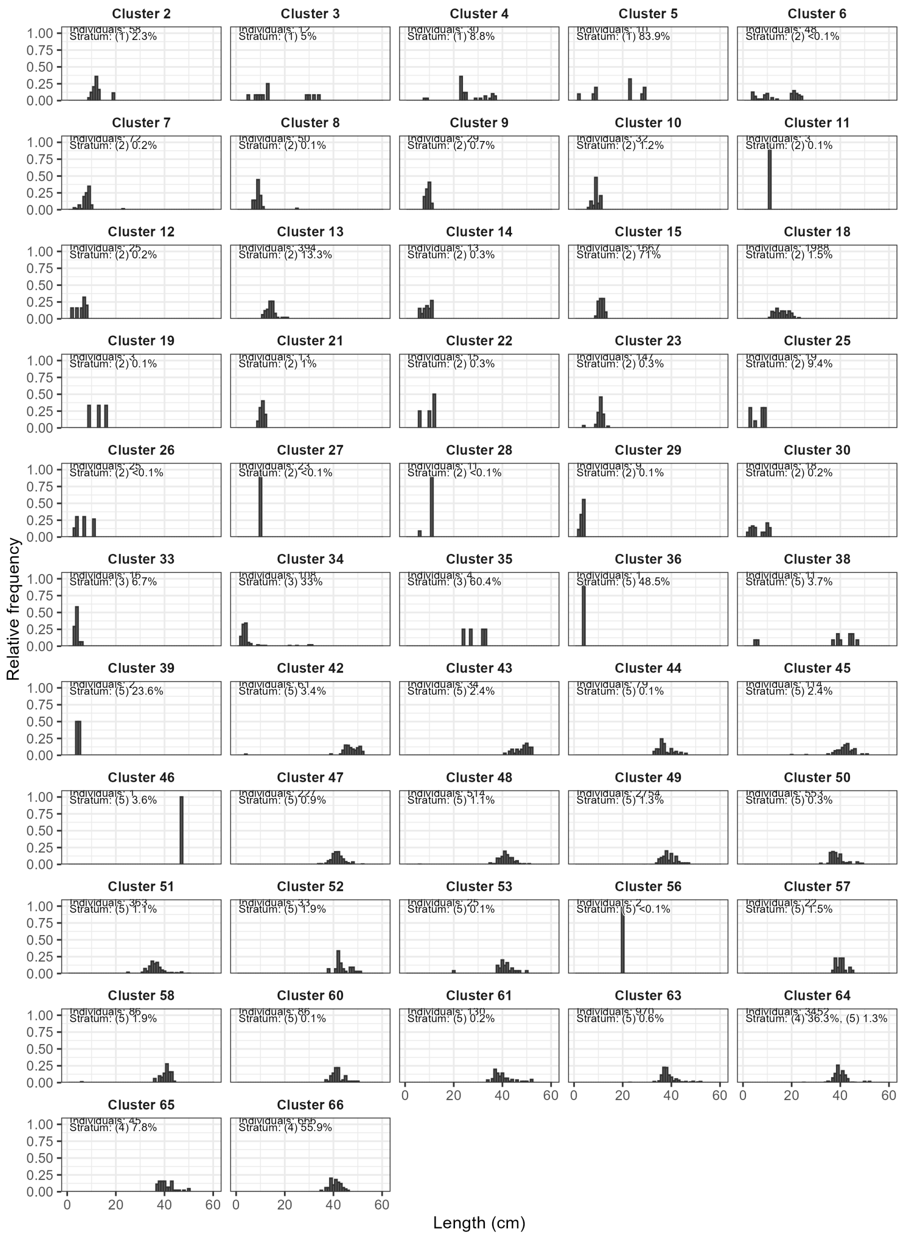
C.3 Pacific Mackerel

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.



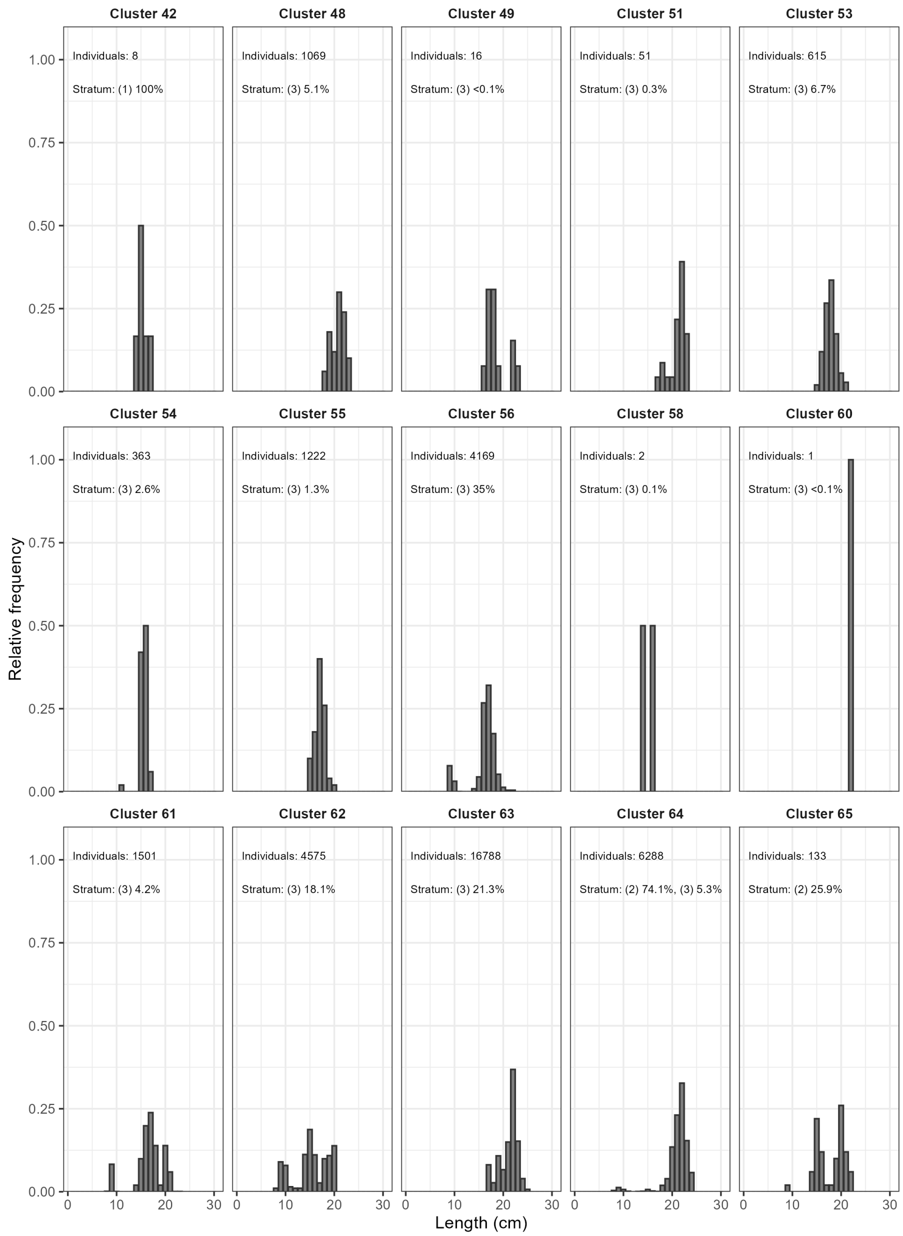
C.4 Jack Mackerel

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.



C.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.



C.6 Round Herring

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