https://doi.org/10.25923/40x3-b146

NOAA Technical Memorandum NMFS

JUNE 2023

DISTRIBUTION, BIOMASS, AND DEMOGRAPHICS OF COASTAL PELAGIC FISHES IN THE CALIFORNIA CURRENT ECOSYSTEM DURING SUMMER 2022 BASED ON ACOUSTIC-TRAWL SAMPLING

Kevin L. Stierhoff[1], Juan P. Zwolinski[1,2], Josiah S. Renfree[1], and David A. Demer[1]

[1] NOAA Fisheries, SWFSC Fisheries Resources Division
8901 La Jolla Shores Drive, La Jolla, California 92037 USA

[2] University of California, Santa Cruz
The Cooperative Institute for Marine, Earth,
and Atmospheric Systems (CIMEAS)
1156 High Street, Santa Cruz, California 95064 USA

NOAA-TM-NMFS-SWFSC-683

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southwest Fisheries Science Center

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Recommended citation

Stierhoff, Kevin L., Juan P. Zwolinski, Josiah S. Renfree, and David A. Demer. 2023. Distribution, biomass, and demographics of coastal pelagic fishes in the California Current Ecosystem during summer 2022 based on acoustic-trawl sampling. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-SWFSC-683. https://doi.org/10.25923/40x3-b146

DISTRIBUTION, BIOMASS, AND DEMOGRAPHICS OF COASTAL PELAGIC FISHES IN THE CALIFORNIA CURRENT ECOSYSTEM DURING SUMMER 2022 BASED ON ACOUSTIC-TRAWL SAMPLING

Kevin L. Stierhoff[1], Juan P. Zwolinski[1,2], Josiah S. Renfree[1], and David A. Demer[1]

[1]Fisheries Resources Division
Southwest Fisheries Science Center (SWFSC)
NOAA-National Marine Fisheries Service
8901 La Jolla Shores Dr.
La Jolla, CA 92037, USA

[2]University of California, Santa Cruz
The Cooperative Institute for Marine, Earth and Atmospheric Systems (CIMEAS)
1156 High St Santa Cruz, CA 95064, USA

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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*, and Pacific Herring *Clupea pallasii* in the California Current Ecosystem off the west coast of the United States (U.S.) and portions of Baja CA, Mexico (MX); and 2) estimates of the biomasses, distributions, and demographics of those CPS encountered in the survey area between 27 June and 30 September 2022.

The core survey region, which was to be sampled by NOAA ship *Reuben Lasker* (hereafter, *Lasker*) and two wind-powered uncrewed surface vehicles (Explorer USVs; Saildrone, Inc.), spanned most of the continental shelf between Cape Flattery, WA and Punta Baja, Baja CA Norte. Planned transects were oriented approximately perpendicular to the coast, from the shallowest navigable depth (~20 m) to either a distance of 35 nmi or to the 1,000 ftm (~1830 m) isobath, whichever is farthest. In the SCB, transects in the core region were extended to approximately 75 nmi. However, after losing roughly half of the scheduled sea days aboard *Lasker*, the plan was modified for chartered fishing vessel *Lisa Marie* to survey *Lasker*'s transects, 20 nmi apart, between Cape Flattery, WA and Cape Mendocino, but extended into the nearshore region to ~5 m depth. Both *Lisa Marie* and *Lasker* sampled in the area between Cape Mendocino and Bodega Bay, and then *Lasker* sampled farther south, ending at Punta Baja. North of Cape Mendocino, where *Lasker* did not sample, species composition and CPS length distributions were estimated from *Lisa Marie*'s daytime purse-seine catches, but adjusted to reflect the associations between Pacific Sardine and Jack Mackerel in this region during summer 2018-2021 (see **Section 3.5.1**). Between Cape Mendocino and Punta Baja, species composition and CPS length distributions were estimated, as usual, by the catches from nighttime surface trawls.

Because sampling by *Lasker* and the USVs in water shallower than ~20 m was deemed inefficient, unsafe, or both, fishing vessel *Long Beach Carnage* sampled CPS in the U.S. nearshore region, along 2.5 to 5 nmi-long transects spaced 5 nmi apart off the mainland coast of the U.S., between Bodega Bay and San Diego, as well as around Santa Cruz and Santa Catalina Islands in the Southern CA Bight. In the nearshore region, the species composition and CPS length distributions were estimated using catches in daytime purse-seine sets by *Long Beach Carnage* or nighttime surface trawls by *Lasker*, whichever was nearest to the acoustically sampled CPS.

The biomasses, distributions, and demographics for each species and stock are for the survey area and period, and therefore may not represent their entire population or stock. Nearshore sampling was not conducted off Baja CA, so nearshore biomass estimates are for U.S. waters only.

The estimated biomass of the northern stock of Northern Anchovy was 16,432 t ($\text{CI}_{95\%}$ = 5,646 - 27,680 t, CV = 34%). In the core region, the biomass was 16,432 t ($\text{CI}_{95\%}$ = 5,646 - 27,680 t, CV = 34%), and in the nearshore region, biomass was 0.0934 t ($\text{CI}_{95\%}$ = 0 - 0.285 t, CV = 94%), or 0.00057% of the total biomass. The estimated nearshore biomass includes uncertainty associated with the assumed nearshore-area (see **Section 3.5.1**). The northern stock ranged from approximately Westport, WA to Cape Blanco, OR, and the distribution of their standard length (L_S) ranged from 10 to 15 cm with a mode at 10 cm in both the core and nearshore regions.

The estimated biomass of the central stock of Northern Anchovy was 2,235,996 t ($\text{CI}_{95\%}$ = 1,248,956 - 3,051,863 t, CV = 20%), of which 6% was observed in Mexican waters. In the core region, the biomass was 2,197,812 t ($\text{CI}_{95\%}$ = 1,231,227 - 3,002,630 t, CV = 21%), and in the nearshore region, the biomass was 38,184 t ($\text{CI}_{95\%}$ = 17,729 - 49,233 t, CV = 21%), or 1.7% of the total biomass. The central stock ranged from approximately Bodega Bay to El Rosario, and the distribution of their L_S ranged from 5 to 16 cm with modes at 9 and 12 cm in the core region and 9 cm in the nearshore region.

The estimated biomass of the northern stock of Pacific Sardine was 69,506 t ($\text{CI}_{95\%}$ = 30,484 - 99,021 t, CV = 21%), all in U.S. waters. In the core region, the biomass was 53,741 t ($\text{CI}_{95\%}$ = 29,672 - 84,749 t, CV = 26%), and in the nearshore region, the biomass was 15,765 t ($\text{CI}_{95\%}$ = 812 - 14,272 t, CV = 23%), or 23% of the total biomass. The nearshore and total biomasses include uncertainties associated with the assumed nearshore-area (see **Section 2.2.5**) and the estimated species proportions from the daytime purse-seine sets (see **Section 3.5.1**), respectively. Within the survey area, the northern stock ranged from approximately Westport, WA to Point Conception. The distribution of L_S ranged from 11 to 27 cm with a mode at 16 cm in the core region and modes at 11 and 14 cm in the nearshore region.

The estimated biomass of the southern stock of Pacific Sardine in the surveyed area was 107,468 t ($CI_{95\%}$ = 47,994 - 178,947 t, CV = 23%), of which 0.9% was observed in Mexican waters. In the core region, the biomass was 40,206 t ($CI_{95\%}$ = 4,741 - 79,328 t, CV = 48%), and in the nearshore region, the biomass was 67,262 t ($CI_{95\%}$ = 43,253 - 99,620 t, CV = 23%), or 63% of the total biomass. Within the survey area, the southern stock ranged from approximately Point Conception to El Rosario. The distribution of L_S ranged from 9 to 21 cm with modes at 13 and 18 cm in the core region and at 12 and 16 cm in the nearshore region. Notably, the survey area may not have spanned the latitudinal distribution of this stock, and no nearshore sampling was conducted in the nearshore region off Baja CA.

The estimated biomass of Pacific Mackerel was 7,968 t ($CI_{95\%}$ = 3,741 - 12,662 t, CV = 22%), of which 27% was observed in Mexican waters. In the core region, the biomass was 5,619 t ($CI_{95\%}$ = 2,851 - 9,108 t, CV = 29%), and in the nearshore region, the biomass was 2,349 t ($CI_{95\%}$ = 890 - 3,553 t, CV = 30%), or 29% of the total biomass. The nearshore and total biomasses include uncertainties associated with the assumed nearshore-area (see **Section 2.2.5**) and the estimated species proportions from the daytime purse-seine sets (see **Section 3.5.1**), respectively. Therefore, it is not advised to use the Pacific Mackerel biomass from this survey for assessment purposes. Pacific Mackerel ranged from approximately Cape Mendocino to El Rosario, but was mostly south of Point Conception and around Santa Cruz and Santa Catalina Islands. The distribution of fork length (L_F) ranged from 8 to 38 cm with modes at 11 and 15 cm in the core region, and at 18 and 27 cm in the nearshore region.

The estimated biomass of Jack Mackerel was 807,090 t ($CI_{95\%}$ = 515,560 - 1,145,812 t, CV = 20%), of which 0.06% was observed in Mexican waters. In the core region, biomass was 799,082 t ($CI_{95\%}$ = 512,231 - 1,132,052 t, CV = 20%), and, in the nearshore region, biomass was 8,009 t ($CI_{95\%}$ = 3,328 - 13,761 t, CV = 35%), or 0.99% of the total biomass. The nearshore and total biomasses include uncertainties associated with the assumed nearshore-area (see **Section 2.2.5**) and the estimated species proportions from the daytime purse-seine sets (see **Section 3.5.1**), respectively. Therefore, it is not advised to use the Jack Mackerel biomass from this survey for assessment purposes. Jack Mackerel were present throughout the survey area from the Columbia River to El Rosario, but were most abundant in the core region between Astoria and Bodega Bay and around Santa Cruz Island in the nearshore region. The distribution of L_F ranged from 3 to 51 cm with modes at 8 and 34 cm in the core region, and at 19 cm in the nearshore region.

The total estimated biomass of Pacific Herring was 50,718 t ($CI_{95\%}$ = 14,461 - 99,700 t, CV = 41%), all in U.S. waters. In the core region, biomass was 47,024 t ($CI_{95\%}$ = 13,306 - 93,207 t, CV = 44%), and was distributed from approximately Cape Flattery to Cape Mendocino, but was most abundant from Cape Flattery to the Columbia River, and between Crescent City and Cape Mendocino. The distribution of L_F ranged from 13 to 17 cm, with modes at 13 and 17 cm. In the nearshore region, biomass was 3,694 t ($CI_{95\%}$ = 1,154 - 6,493 t, CV = 36%), or 7.3% of the total biomass. The distribution of L_F ranged from 13 to 17 cm, and had a mode at 14 cm.

The total estimated biomass of seven stocks of five species within the survey area was 3,295,179 t. Of this 68% (2,235,996 t) was from the central stock of Northern Anchovy. Proportions of other stocks, in decreasing order, were: northern stock of Pacific Sardine (2.1%), Jack Mackerel (24%), southern stock of Pacific Sardine (3%), Pacific Herring (1.5%), northern stock of Northern Anchovy (0.5%), and Pacific Mackerel (0.2%). The biomass of the central stock of Northern Anchovy, which had been growing rapidly since 2015, decreased ~20% from 2,721,689 t estimated in summer 2021 (Stierhoff *et al.*, 2023). Jack Mackerel, which were found mostly north of Cape Mendocino, included an abundance of apparently age-0 fish farther south, suggesting a strong recruitment. Biomass attributed to the southern stock of Pacific Sardine was observed mostly north of the U.S.-Mexico border, and was greater in the nearshore area than in the core area; however, no nearshore sampling was conducted in Mexican waters and the survey area did not span the anticipated distribution of this stock. Even considering the additional uncertainties in the biomass estimates north of Cape Mendocino (see **Sections 2.2.5** and **3.5.1**) there is no indication that the biomasses of the northern stock of Pacific

Sardine have changed significantly since summer 2021. However, due to these same uncertainties, it is not advised to use the biomasses of Jack Mackerel or Pacific Mackerel for assessment purposes.

1 Introduction

In the California Current Ecosystem (CCE), multiple coastal pelagic fish species (CPS; i.e.: Pacific Sardine *Sardinops sagax*, Northern Anchovy *Engraulis mordax*, Jack Mackerel *Trachurus symmetricus*, Pacific Mackerel *Scomber japonicus*, and Pacific Herring *Clupea pallasii*) comprise the bulk of the forage fish assemblage. These populations, which can change by an order of magnitude within a few years, represent important prey for marine mammals, birds, and larger migratory fishes (Field *et al.*, 2001), and some are targets of commercial fisheries.

During summer and fall, the northern stock of Pacific Sardine typically migrates north to feed in the productive coastal upwelling off OR, WA, and Vancouver Island (Zwolinski *et al.*, 2012, and references therein, **Fig. 1**). In synchrony, but separately, the southern stock 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 stock of Pacific Sardine typically migrates south to its spawning grounds, generally off Central and Southern CA (Demer *et al.*, 2012) and occasionally off OR and WA (Lo *et al.*, 2011). These migrations vary in extent with population size; fish age and length; and oceanographic conditions (Zwolinski *et al.*, 2012). For example, the transition zone chlorophyll front [TZCF; Polovina *et al.* (2001)] may delineate the offshore and southern limit of both Pacific Sardine and Pacific Mackerel habitat (e.g., Demer *et al.*, 2012; Zwolinski *et al.*, 2012), and juveniles may have nursery areas in the SCB, downstream of upwelling regions. In contrast, Northern Anchovy spawn predominantly during winter and closer to the coast where seasonal down-welling increases retention of their eggs and larvae (Bakun and Parrish, 1982). Pacific Herring spawn in intertidal beach areas (Love, 1996). The northern stock of Northern Anchovy is located off WA and OR and the central stock is located off Central and Southern CA 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 48 years ago to survey CPS off the west coast of the United States (U.S.) (Mais, 1974, 1977; Smith, 1978). Following a two-decade hiatus, the ATM was reintroduced in the CCE in spring 2006 to sample the then-abundant Pacific Sardine population (Cutter and Demer, 2008). Since then, this sampling effort has continued and expanded through annual or semi-annual surveys (Demer *et al.*, 2012; Zwolinski *et al.*, 2014). Beginning in 2011, the ATM estimates of Pacific Sardine abundance, age structure, and distribution have been incorporated in the annual assessments of the northern stock (Hill *et al.*, 2017). ATM estimates are used in assessments of Pacific Mackerel (Crone *et al.*, 2019; Crone and Hill, 2015) and the central stock of Northern Anchovy (Kuriyama *et al.*, 2022). 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 and abundances of CPS and their oceanographic environments (e.g., Cutter and Demer, 2008; Demer *et al.*, 2012; Zwolinski *et al.*, 2014). In general terms, the contemporary ATM combines information from satellite-sensed oceanographic conditions, multi-frequency echosounders, probe-sampled oceanographic conditions, pumped samples of fish eggs, and trawl-net catches of juvenile and adult CPS. The survey area is initially defined with consideration to the potential habitat of the northern stock of Pacific Sardine for summer surveys (**Fig. 1**) or the central stock of Northern Anchovy for spring surveys, when they occur. The survey area is further expanded to encompass as much of the potential habitat as possible for other CPS present off the West Coast of the U.S. and Baja CA, as time permits.

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

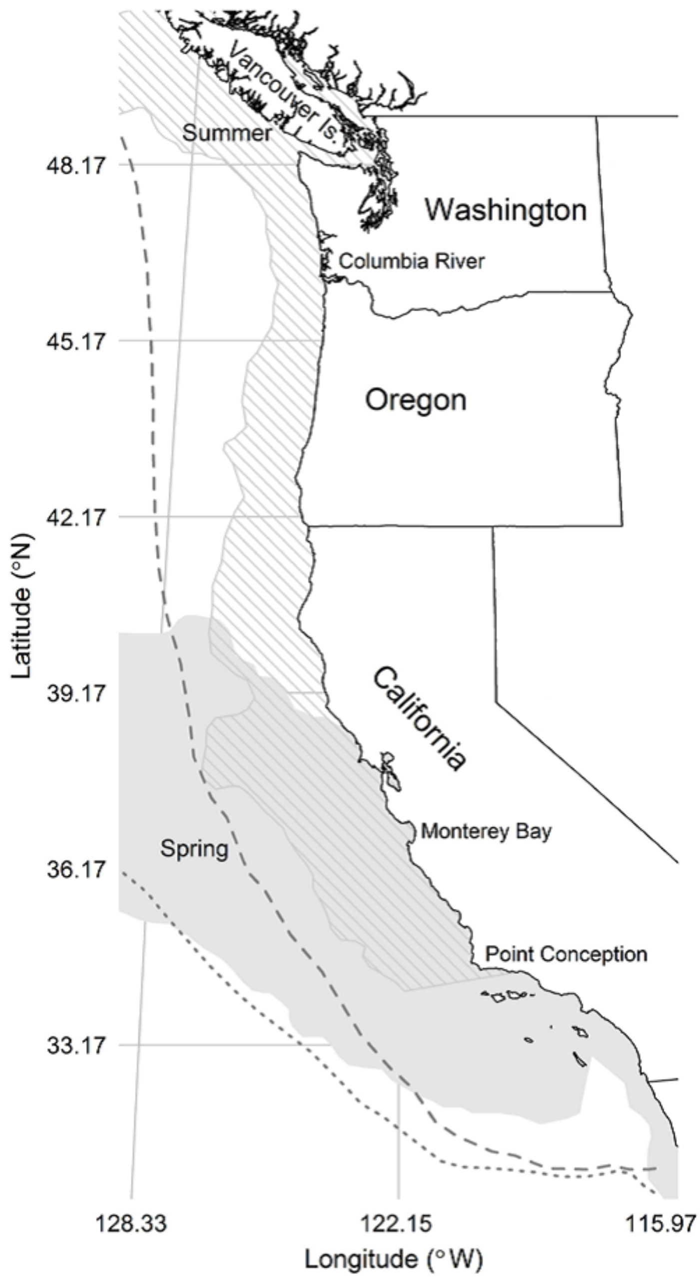

Figure 1: Conceptual spring (shaded region) and summer (hashed region) distributions of potential habitat for the northern stock of Pacific Sardine along the west coasts of Mexico, the United States, and Canada. The dashed and dotted lines represent, respectively, the approximate summer and spring positions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

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

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

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

In summer 2022, the ATM survey, spanning U.S. and Mexican waters, was conducted by fishing vessel *Lisa Marie*, between Cape Flattery and Cape Mendocino, and by *Lasker* from Cape Mendocino to Punta Baja. Between Newport, OR and Bodega Bay, along adaptive transects not sampled by *Lisa Marie* or *Lasker*, two wind-powered uncrewed surface vessels (Explorer USVs; Saildrone, Inc.) conducted acoustic sampling. From Cape Flattery to San Diego, 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 portions of Baja CA; and 2) estimates of the abundances, biomasses, size structures, and distributions of CPS, specifically the northern and southern stocks of Pacific Sardine; the central and northern stocks of Northern Anchovy, Pacific Mackerel, Jack Mackerel, and Pacific Herring for the core and nearshore survey regions in which they were sampled. Additional details about the survey may be found in the survey report (Renfree *et al.*, 2023).

This survey was conducted with the approval of the Secretaria de Relaciones Exteriores (SRE, Diplomatic note UAN0807/2022), the Instituto Nacional de Estadística y Geografía (INEGI; Authorization: EG0022022, through official letters 400./58/2022 and 400./59/2022), Unidad de Planeación y Coordinación Estratégica de la Secretaría de Marina (SEMAR; Letter no AI/1223/22), Unidad Coordinadora de Asuntos Internacionales (UCAI) de la Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT; Letter UCAI/01314/2022), Universidad Nacional Autónoma de México (UNAM; Letter ICML/DIR/127/2022), Unidad de Concesiones y Servicios del Instituto Federal de Telecomunicaciones (IFT; Letter IFT/223/UCS/DG-AUSE/3059/2022), and the Comisión Nacional de Acuacultura y Pesca (CONAPESCA; Permit: PPFE/DGPPE.-05325/120722).

2 Methods

2.1 Sampling

2.1.1 Design

The summer 2022 survey was conducted principally using *Lasker* and *Lisa Marie*, but was augmented with acoustic sampling by two uncrewed surface vehicles (USVs), and nearshore sampling by *Long Beach Carnage*. The sampling domain, or core region, between Cape Flattery, WA and Punta Baja, Baja CA Norte, was defined by the conceptual distribution of potential habitat for the northern stock of Pacific Sardine in summer (**Fig. 1**), but also encompassed the anticipated distributions of the southern stock of Pacific Sardine and the central and northern stocks of Northern Anchovy off the west coasts of the U.S. and portion of Baja CA, Mexico. It also spanned portions of the Pacific Mackerel, Jack Mackerel, Pacific Herring, and Round Herring populations. 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, the acceptable uncertainty in biomass estimates, and the available ship time (75 days at sea, DAS), the principal survey objectives were to estimate the biomasses of the northern and southern stocks of Pacific Sardine and the northern and central stocks of Northern Anchovy in the survey region. Secondary objectives were to estimate the population biomasses of Pacific Mackerel, Jack Mackerel, Pacific Herring, and Round Herring in the survey region.

The core region transects were perpendicular to the coast, extending from the shallowest navigable depth (~20 m) to either a distance of 35 nmi or to the 1,000 ftm isobath, whichever was farthest (**Fig. 2**). Compulsory transects were spaced 10 nmi-apart in areas of historic CPS abundance (e.g., between Cape Flattery and Newport, and between San Francisco and San Diego) and 20-nmi apart elsewhere. When CPS were observed within the westernmost 3 nmi of a transect, that transect and the next one to the south 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. If a transect was extended, the ensuing transect was extended by the same amount.

Leg I on *Lasker* was cancelled for reasons outside of the SWFSC's control, so *Lisa Marie* was directed to sample the transects between Cape Flattery, WA to Bodega Bay, CA using 20-nmi spacing, including the nearshore portions of those transects. Meanwhile USVs (SD-1076 and SD-1077) were directed to sample the interstitial transects, also spaced 20-nmi apart, from Newport, OR to San Francisco (cyan lines, **Fig. 2**). Leg III on *Lasker* was delayed by 16 days for similar reasons, so the remaining four days were used to sample transects spaced 20-nmi apart, from San Diego northward into the Southern California Bight (SCB). During Leg IV on *Lasker*, transects were sampled southward from Monterey, CA to Punta Baja, Baja CA Norte. To progress as far south as possible, the lengths off compulsory transects off Baja CA were shortened to 30-nmi, and adaptive transects were omitted.

To estimate the abundances and biomasses of CPS between Cape Flattery and San Diego, in the nearshore area where *Lasker* and the USVs could not efficiently or safely navigate or trawl, two fishing vessels conducted acoustic and purse-seine sampling (magenta lines, **Fig. 2**). *Lisa Marie* sampled transects to ~5-m depth, spaced 20 nmi apart between Cape Flattery and Bodega Bay. *Long Beach Carnage* sampled 5-nmi-long transects spaced 5 nmi apart between Bodega Bay and San Diego, and 2.5-nmi-long transects spaced 2.5 nmi apart around Santa Cruz and Santa Catalina Islands in the SCB.

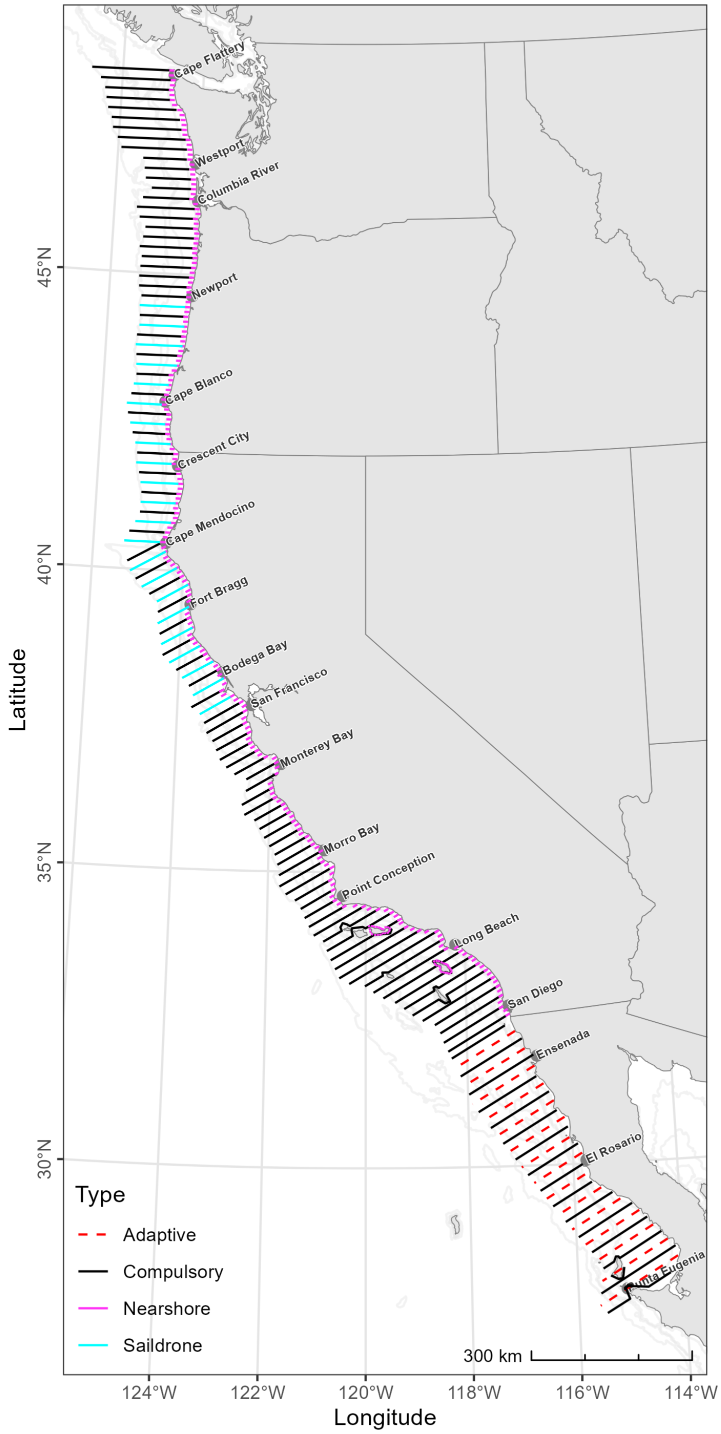

Figure 2: Planned compulsory and adaptive transects sampled by *Lasker* and *Carranza*; interstitial and offshore transects sampled by USVs; and nearshore transects sampled by *Lisa Marie* and *Long Beach Carnage*. Isobaths (light gray lines) are 50, 200, 500, and 2,000 m.

2.1.2 Acoustic

2.1.2.1 Acoustic equipment

2.1.2.1.1 *Lasker* Multi-frequency Wide-Bandwidth Transceivers (18-, 38-, 70-, 120-, 200-, and 333-kHz Simrad EK80 WBTs; Kongsberg) were configured with split-beam transducers (Simrad ES18-11, ES38B, ES70-7C, ES120-7C, ES200-7C, and ES333-7C, respectively; Kongsberg). The transducers were mounted on the bottom of a retractable keel or "centerboard" (**Fig. 3**). The keel was retracted (transducers at ~5-m depth) during calibration, and extended to the intermediate position (transducers at ~7-m depth) during the survey. Exceptions were made during shallow water operations, when the keel was retracted; or during times of heavy weather, when the keel was extended (transducers at ~9-m depth) to provide extra stability and reduce the effect of weather-generated noise. In addition, acoustic data were also collected using a multibeam echosounder (Simrad ME70; Kongsberg), multibeam sonar (Simrad MS70; Kongsberg), scanning sonar (Simrad SX90; Kongsberg), acoustic Doppler current profiler and echosounder (Simrad EC150-3C, Kongsberg), and a separate ADCP (Ocean Surveyor OS75; Teledyne RD Instruments). Transducer position and motion were measured at 5 Hz using an inertial motion unit (Applanix POS-MV; Trimble).

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

2.1.2.1.3 *Long Beach Carnage* On *Long Beach Carnage*, the SWFSC's multi-frequency General Purpose Transceivers (38-, 70-, 120-, and 200-kHz Simrad EK60 GPTs; Kongsberg) were configured with the SWFSC's split-beam transducers (Simrad ES38-12, ES70-7C, ES120-7C and ES200-7C; Kongsberg) mounted in a multi-frequency transducer array (MTA4) on the bottom of a retractable pole (**Fig. 4**). The transducers were at a water depth of roughly 2 m.

2.1.2.1.4 USVs On the two USVs (SD-1076 and SD-1077), miniature Wide-Bandwidth Transceivers (Simrad WBT-Mini; Kongsberg) were configured with gimbaled, keel-mounted, dual-frequency transducers (Simrad ES38-18|200-18C; Kongsberg) containing a split-beam 38-kHz transducer and single-beam 200-kHz transducer with nominally 18° beamwidths. The transducers were at a water depth of ~1.9 m.

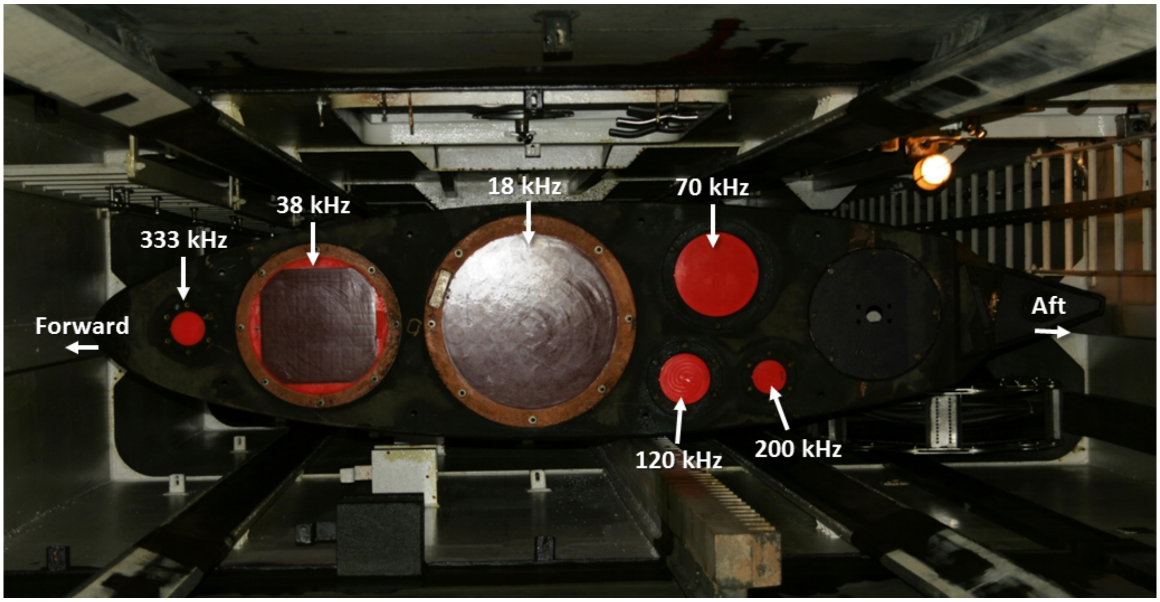

Figure 3: Echosounder transducers mounted on the bottom of the retractable centerboard on *Lasker*. During the survey, the centerboard was extended, typically positioning the transducers ~2 m below the keel at a water depth of ~7 m.

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

2.1.2.2 Echosounder calibrations

2.1.2.2.1 ***Lasker*** The echosounder systems aboard *Lasker* were calibrated on 23 June while the vessel was docked at 10th Avenue Marine Terminal, San Diego Bay (32.6956 °N, -117.15278 °W) using the standard sphere technique (Demer *et al.*, 2015; Foote *et al.*, 1987). Each WBT was calibrated in both CW (i.e., continuous wave or narrowband mode) and FM mode (i.e., frequency modulation or broadband mode). The reference target was a 38.1-mm diameter sphere made from tungsten carbide (WC) with 6% cobalt binder material (WC38.1; *Lasker* sphere #1); for FM mode, additional calibrations were conducted for the 120, 200, and 333-kHz echosounders using a 25-mm WC sphere (WC25). Prior to the calibrations, temperature and salinity were measured to a depth of 10 m using a handheld probe (Pro2030, YSI) to estimate sound speeds at the transducer and sphere depths, and the time-averaged sound speed and absorption coefficients for the range between them. The theoretical target strength (TS; dB re 1 m^2) of the sphere was calculated using values for the sphere, sound-pulse, and seawater properties. The sphere was positioned throughout the main lobe of each of the transducer beams using three motorized downriggers, two on one side of the vessel and one on the other. The WBTs were configured using the calibration results via the control software (Simrad EK80 v21.15.1; Kongsberg; **Table 1**). Calibration results for WBTs in FM mode are presented in the survey report (Renfree *et al.*, 2023).

Table 1: Wide-Bandwidth Transceiver (Simrad EK80 WBT; Kongsberg) information, pre-calibration settings, and post-calibration beam model results (below the horizontal line). Prior to the survey, on-axis gain (G_0), beam angles, angle offsets, and S_A Correction (S_{A}corr) values from calibration results were entered into the WBT control software (Simrad EK80; Kongsberg).

		Frequency (kHz)					
	Units	18	38	70	120	200	333
Model		ES18	ES38-7	ES70-7C	ES120-7C	ES200-7C	ES333-7C
Serial Number		2106	337	233	783	513	124
Transmit Power (p_{et})	W	1000	2000	600	200	90	35
Pulse Duration (τ)	ms	1.024	1.024	1.024	1.024	1.024	1.024
Temperature	C	23.4	23.4	23.4	23.4	23.4	23.4
Salinity	ppt	35.0	35.0	35.0	35.0	35.0	35.0
Sound speed	m s^{-1}	1530.5	1530.5	1530.5	1530.5	1530.5	1530.5
On-axis Gain (G_0)	dB re 1	22.96	26.07	27.24	26.54	26.57	26.40
S_{a} Correction (S_{a}corr)	dB re 1	0.00	-0.37	-0.08	-0.07	-0.05	-0.15
3-dB Beamwidth Along. ($\alpha_{-3\mathrm{dB}}$)	deg	10.29	6.55	6.82	6.59	6.46	6.47
3-dB Beamwidth Athw. ($\beta_{-3\mathrm{dB}}$)	deg	10.47	6.76	6.73	6.54	6.48	6.46
Angle Offset Along. (α_0)	deg	-0.01	0.03	-0.00	-0.00	0.01	-0.00
Angle Offset Athw. (β_0)	deg	-0.02	-0.06	-0.03	-0.01	-0.01	0.01
Equivalent Two-way Beam Angle (Ψ)	dB re 1 sr	-16.90	-20.19	-20.17	-20.09	-20.07	-19.55

2.1.2.2.2 ***Lisa Marie*** The 38- and 200-kHz WBTs aboard *Lisa Marie* were calibrated on 15 June 2022, using the standard sphere technique, while the vessel was anchored in Grays Harbor near Westport, WA (46.9202 N, 124.1090 W). Calibration results for *Lisa Marie* are presented in **Table 2**.

Table 2: Wideband Transceiver (Simrad EK80 WBT; Kongsberg) and transducer information (above horizontal line) and beam model results (below horizontal line) estimated from calibration of the echosounders aboard *Lisa Marie* using a WC38.1 standard sphere.

		Frequency (kHz)	
	Units	38	200
Model		ES38-7	ES200-7C
Serial Number		448	899
Transmit Power (p_{et})	W	1000	90
Pulse Duration (τ)	ms	1.024	1.024
Temperature	C	13.1	13.1
Salinity	ppt	27.5	27.5
Sound speed	m s^{-1}	1491.6	1491.6
On-axis Gain (G_0)	dB re 1	26.76	26.48
S_{a} Correction (S_{a}corr)	dB re 1	-0.05	-0.05
3-dB Beamwidth Along. ($\alpha_{-3\mathrm{dB}}$)	deg	6.49	6.71
3-dB Beamwidth Athw. ($\beta_{-3\mathrm{dB}}$)	deg	6.40	7.25
Angle Offset Along. (α_0)	deg	-0.03	-0.16
Angle Offset Athw. (β_0)	deg	0.00	0.01
Equivalent Two-way Beam Angle (Ψ)	dB re 1 sr	-20.35	-20.46

2.1.2.2.3 ***Long Beach Carnage*** The 38, 70, 120, and 200 kHz EK60 GPTs aboard *Long Beach Carnage* were calibrated on 7 July 2022, using the standard sphere technique, in a tank at the SWFSC (Demer *et al.*, 2015). Calibration results for *Long Beach Carnage* are presented in **Table 3**.

Table 3: General Purpose Transceiver (Simrad EK60 GPT; 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	19.1	19.1	19.1	19.1
Salinity	ppt	35.9	35.9	35.9	35.9
Sound speed	m s^{-1}	1520.1	1520.1	1520.1	1520.1
On-axis Gain (G_0)	dB re 1	21.77	26.21	26.03	26.70
S_{a} Correction (S_{a}corr)	dB re 1	-0.71	-0.29	-0.39	-0.24
3-dB Beamwidth Along. ($\alpha_{-3\mathrm{dB}}$)	deg	12.50	7.08	7.17	6.92
3-dB Beamwidth Athw. ($\beta_{-3\mathrm{dB}}$)	deg	12.49	7.10	7.33	6.96
Angle Offset Along. (α_0)	deg	-0.04	0.04	0.11	-0.05
Angle Offset Athw. (β_0)	deg	0.15	0.03	-0.01	0.02
Equivalent Two-way Beam Angle (Ψ)	dB re 1 sr	-15.64	-20.23	-20.13	-20.06

2.1.2.2.4 USVs For the two USVs, the echosounders were calibrated by Saildrone, Inc., using the standard sphere technique, while dockside. The results, processed and derived by the SWFSC (Renfree *et al.*, 2019), are presented in **Table 4**.

Table 4: Miniature Wideband Transceiver (Simrad-Kongsberg WBT Mini) beam model results estimated from calibrations of echosounders using a WC38.1 standard sphere, of the echosounders aboard the two USVs.

		Saildrone (Frequency)			
	Units	1076 (38)	1076 (200)	1077 (38)	1077 (200)
Echosounder SN		266961-07	266961-08	268632-07	268632-08
Transducer SN		136	136	131	131
Temperature	C	20.2	20.2	20.1	20.1
Salinity	ppt	31.0	31.0	31.1	31.1
Sound speed	m s^{-1}	1517.5	1517.5	1517.5	1517.5
Eq. Two-way Beam Angle (Ψ)	dB re 1 sr	-12.9	-11.7	-12.4	-11.6
On-axis Gain (G_0)	dB re 1	19.18	19.45	18.87	19.00
S_a Correction ($S_\mathrm{a}$corr)	dB re 1	0.08	0.08	0.02	0.09
3-dB Beamwidth Along. ($\alpha_{-3\mathrm{dB}}$)	deg	17.3	19.4	18.2	20.1
3-dB Beamwidth Athw. ($\beta_{-3\mathrm{dB}}$)	deg	17.0	20.2	18.4	19.9
Angle Offset Along. (α_0)	deg	0.1	0.5	0.3	0.2
Angle Offset Athw. (β_0)	deg	-0.5	0.2	-0.6	-0.4
RMS	dB	0.27	0.46	0.32	0.41

2.1.2.3 Data collection

On *Lasker*, the computer clocks were synchronized with the GPS clock (UTC) using synchronization software (NetTime[1]). The 18-kHz WBT, operated by a separate PC from the other echosounders, was programmed to track the seabed and output the detected depth to the ship's Scientific Computing System (SCS). The 38-, 70-, 120-, 200-, and 333-kHz echosounders were controlled by the EK80 Adaptive Logger (EAL[2], Renfree and Demer, 2016). The EAL optimizes the pulse interval based on the seabed depth, while avoiding aliased seabed echoes, and was programmed such that once an hour the echosounders would record three 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}) and target strength (TS; dB re 1 m^2), indexed by time and geographic positions provided by GPS receivers, were logged to 60 m beyond the detected seabed range or to a maximum range of 500, 500, 500, 300, and 150 m for 38, 70, 120, 200, and 333 kHz, respectively, and stored, with a 50-GB maximum file size, in Simrad-EK80 .raw format. At nighttime, echosounders were set to FM mode to improve target strength estimation and species differentiation for CPS near the surface, and logged to 100 m to reduce data volume. For each acoustic instrument, the prefix for the file names is a concatenation of the survey name (e.g., 2207RL), the operational mode (CW or FM), and the logging commencement date and time from the EK80 software. For example, file generated by the EK80 software (v21.15.1) for a WBT operated in CW mode is named `2207RL-CW-D20220801-T125901.raw`.

To minimize acoustic interference, transmit pulses from the EK80, ME70, MS70, SX90, EC150-3C, and ADCP were triggered using a synchronization system (Simrad K-Sync; Kongsberg). The K-Sync trigger rate, and thus echosounder ping interval, was modulated by the EAL (Renfree and Demer, 2016) using the seabed depth measured using the 18-kHz echosounder. During daytime, the ME70, MS70, and SX90 were operated continuously, but only recorded at the discretion of the acoustician during times when CPS were

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

present. During daytime, the ADCP was operated and data were recorded continuously. At nighttime, only the EK80 and ADCP were operated. All other instruments that produce sound within the echosounder bandwidths were secured during daytime survey operations. Exceptions were made during stations (e.g., plankton sampling and fish trawling) or in shallow water when the vessel's command occasionally operated the bridge's 50- and 200-kHz echosounders (Furuno), the Doppler velocity log (SRD-500A; Sperry Marine), or both. Analyses of data from the 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 and ping intervals to avoid aliased seabed echoes. When the EAL was not utilized, the EK80 software recorded to 1000 m and used the maximum ping rate. Transmit pulses from the EK60s and fishing sonars were not synchronized. Therefore, the latter was secured during daytime acoustic transects.

On the USVs, the echosounders were programmed to transmit CW pulses to different ranges, dependent on the seabed depth. For deeper seabed depths, the ping interval was 2 s and the 38 and 200-kHz echosounders recorded to 1000 and 400 m, respectively. For shallower depths, the ping interval was 1 s and both echosounders recorded to 250 m. Once an hour, the echosounders operated in passive mode and recorded data from three pings to obtain estimates of the background noise levels.

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 shallower than 350 m) with calibrated sensors on a CTD rosette (Model SBE911+, Seabird) or underway probe [UnderwayCTD (UCTD); Oceanscience] cast from the vessel. At least one cast was planned along each acoustic transect. These data were used to calculate the harmonic mean sound speed (Demer *et al.*, 2015) for estimating ranges to the sound scatterers, and frequency-specific sound absorption coefficients for compensating signal attenuation of the sound pulse between the transducer and scatterers (Simmonds and MacLennan, 2005) (see **Section 2.2.2**).

2.1.3.2 Scientific Computer System

While underway, information about the position and direction (e.g., latitude, longitude, speed, course over ground, and heading), weather (air temperature, humidity, wind speed and direction, and barometric pressure), and sea-surface oceanography (e.g., temperature, salinity, and fluorescence) were measured continuously and logged using *Lasker*'s Scientific Computer System (SCS). During and after the survey, data from a subset of these sensors, logged with a standardized format at 1-min resolution, are available on the internet via NOAA's ERDDAP data server[3].

2.1.4 Fish-eggs

On *Lasker*, fish eggs were sampled during the day using a continuous underway fish egg sampler (CUFES, Checkley *et al.*, 1997), which collects water and plankton at a rate of ~640 l min^{-1} from an intake at ~3-m depth on the hull of the ship. The particles in the sampled water were sieved by a 505-μm mesh. Pacific Sardine, Northern Anchovy, Jack Mackerel, and Pacific Hake (*Merluccius productus*) eggs were identified to species, counted, and logged. Eggs from other species (e.g., Pacific Mackerel and flatfishes) were also counted and logged as "other fish eggs." Typically, the duration of each CUFES sample was 30 min, corresponding to a distance of 5 nmi at a speed of 10 kn. Because the durations of the early egg stages are short for most fish species, the egg distributions inferred from CUFES indicated the nearby presence of actively spawning fish, and were used in combination with CPS echoes to select trawl locations.

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

2.1.5 Species and Demographics

The net catches provide information about species composition, lengths, weights and ages of CPS sampled acoustically during the day. Nighttime trawls were conducted to sample the fish dispersed near the sea surface, because after sunset, schools of CPS and other fish tend to ascend and disperse and are less likely to avoid a trawl net (Mais, 1977). Daytime purse-seine nets were set nearshore to sample CPS schools where their depth is constrained by the seabed, and their vision is obscured by non-transparent, light-scattering water, due to primary production and suspended particulates. In summer 2022, *Lisa Marie* used daytime purse-seine sets to sample CPS schools nearshore, but also offshore in deeper, clearer water, and with mixed success (see **Section 3.5.1**). For example, fast swimming Jack Mackerel often avoided capture, resulting in unquantified species selectivity.

2.1.5.1 Trawl gear

2.1.5.1.1 ***Lasker*** A Nordic 264 rope trawl (NET Systems, Bainbridge Island, WA; **Figs. 5a,b**), was towed at the surface for 45 min at a speed of 3.5-4.5 kn. The net has a rectangular opening with an area of approximately 300 m^2 (~15-m tall x 20-m wide), a throat with variable-sized mesh and a "marine mammal excluder device" to prevent the capture of large animals, such as dolphins, turtles, or sharks while retaining target species (Dotson *et al.*, 2010), and an 8-mm square-mesh cod-end liner (to retain a large range of animal sizes). The trawl doors were foam-filled and the trawl headrope was lined with floats so the trawl towed at the surface. Temperature-depth recorders (TDRs; RBRduet^3 T.D., RBR) were attached to the kite and footrope to evaluate trawl performance (**Fig. 6**).

2.1.5.2 Purse-seine gear

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

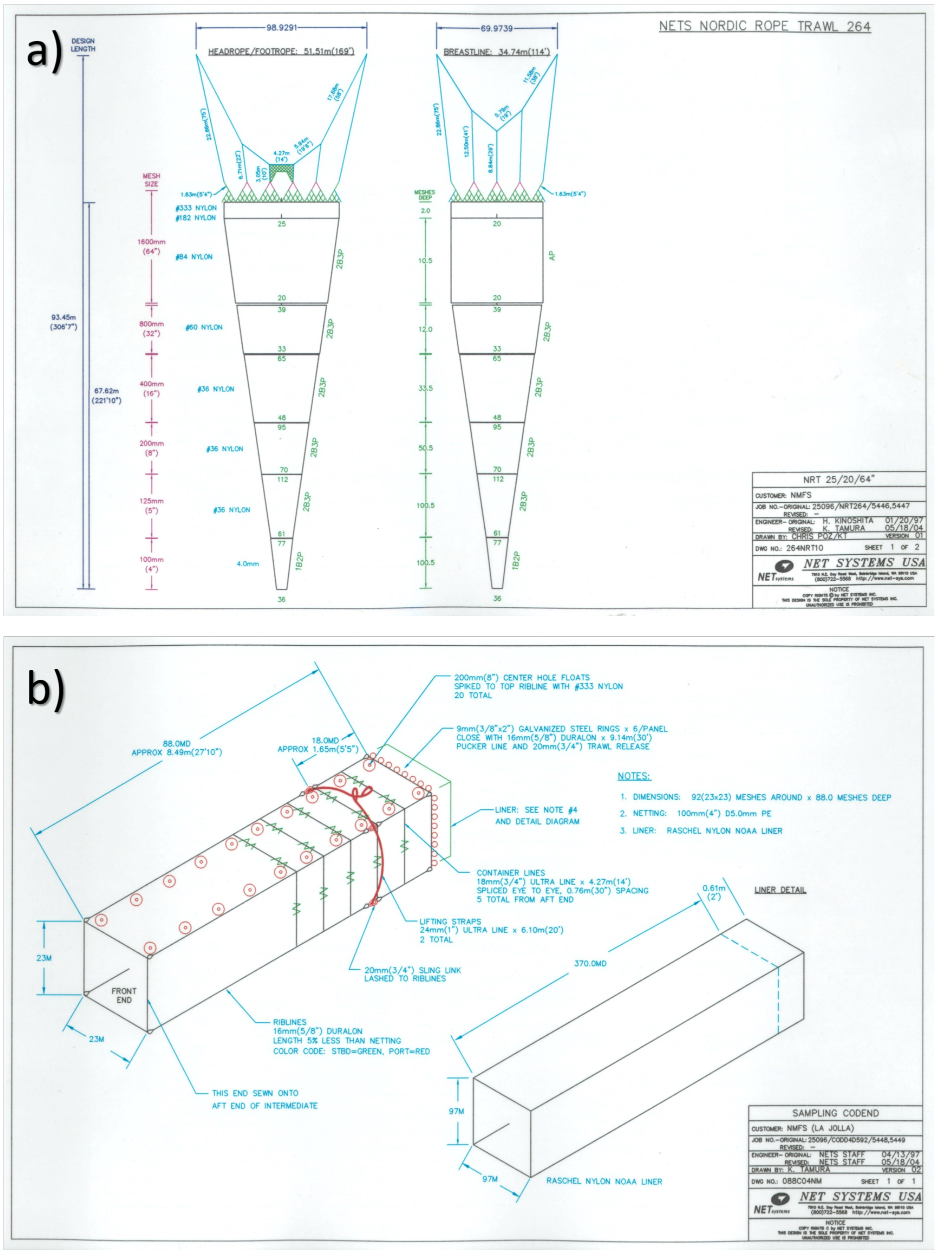

Figure 5: Schematic drawings of the Nordic 264 rope trawl a) net and b) cod-end.

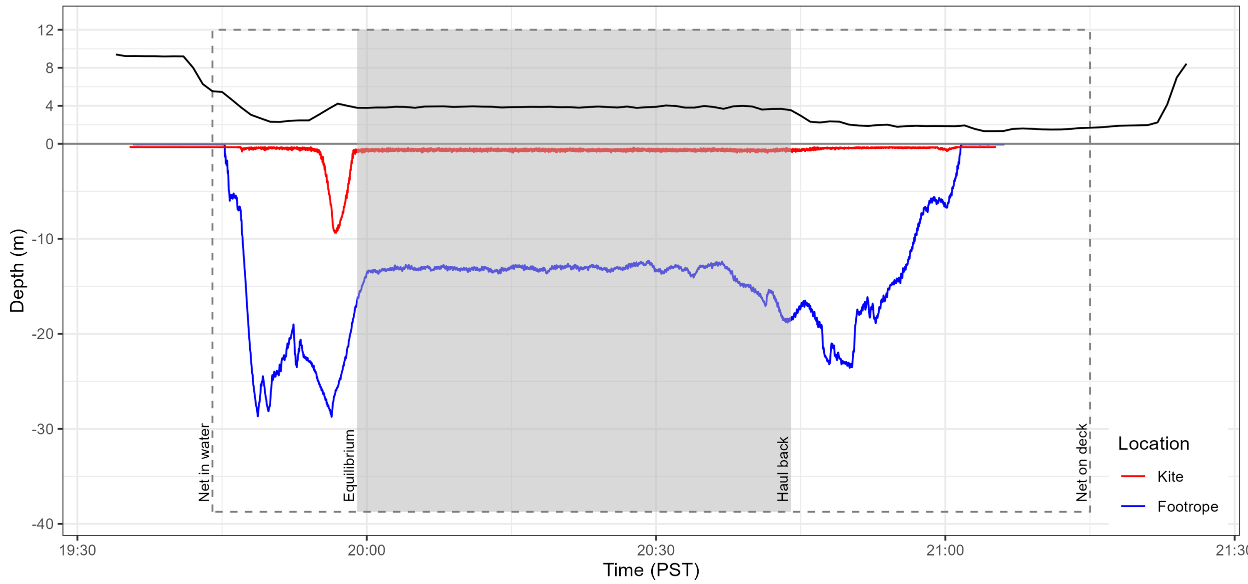

Figure 6: Example depths (m) of the trawl headrope (red line) and footrope (blue line) measured using temperature-depth recorders (TDRs) during the net deployment (dashed box) and when actively fishing (shaded region). The vessel speed over ground (kn, black line) was measured using the ship's GPS.

2.1.5.3 Sampling locations

2.1.5.3.1 ***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 areas where echoes from putative CPS schools were observed earlier that day. Trawl locations were selected using one or more of the following criteria, in descending priority: CPS schools in echograms that day; CPS eggs in CUFES that day; and the trawl locations and catches during the previous night. Each evening, trawl locations were selected by an acoustician, who monitored CPS echoes, and a biologist, who measured the densities of CPS eggs in the CUFES. The locations were provided to the watch officers who charted the proposed trawl sites.

If no CPS echoes or CPS eggs were observed along a transect that day, the trawls were alternately placed nearshore one night and offshore the next night, with consideration given to the seabed depth and the modeled distribution of CPS habitat. Each morning, after the last trawl or 30 min prior to sunrise, *Lasker* resumed sampling at the location where the acoustic sampling stopped the previous day.

2.1.5.3.2 ***Lisa Marie*** **and** ***Long Beach Carnage*** On *Lisa Marie*, as many as three purse-seine sets were conducted each day. For each set, three dip-net samples, were collected, spatially separated as much as possible.

On *Long Beach Carnage*, as many as three purse-seine sets were conducted each day, including evenings. For each set, three dip-net samples were collected, spatially separated as much as possible.

2.1.5.4 Sample processing

2.1.5.4.1 ***Lasker*** If the total volume of the trawl catch was five 35-l baskets (~175 l) or less, all target species were separated from the catch, sorted by species, weighed, and enumerated. If the volume of the entire catch was more than five baskets, a five-basket random subsample that included non-target species was collected, sorted by species, weighed, and enumerated; the remainder of the total catch was weighed.

In these cases, the weight of the entire catch was calculated as the sum of the subsample and remainder weights. The weight of the e-th species in the total catch ($C_{T,e}$) was obtained by summing the catch weight of the respective species in the subsample ($C_{S,e}$) and the corresponding catch in the remainder ($C_{R,e}$), which was calculated as:

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

where $P_{w,e} = C_{S,e}/ \sum_{1}^{s} C_{S,e}$, is the proportion in weight of the e-th species in the subsample. The number of specimens of the e-th species in the total catch ($N_{T,e}$) was estimated by:

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

where $\overline{w}_e$ is the mean weight of the e-th species in the subsample. For Pacific Sardine and Northern Anchovy with 75 specimens or less, individual measurements of standard length (L_S) in mm and weight (w) in g were recorded. For Jack Mackerel, Pacific Mackerel, and Pacific Herring with 50 specimens or less, individual measurements of fork length (L_F) and w were recorded. In addition, sex and maturity were recorded for up to 75 Pacific Sardine and Northern Anchovy and up to 25 Jack and Pacific Mackerel. Ovaries were preserved for up to 10 specimens of each CPS species except Pacific Herring. Fin clips were removed from 50 Pacific Sardine and Northern Anchovy specimens from seven geographic zones (with boundaries at the Columbia River, Cape Mendocino, San Francisco Bay, Point Conception, San Diego, and San Quentin, Baja CA) and preserved in ethanol for genetic analysis. Otoliths were removed from all 50 Pacific Sardine in the subsample; for other CPS species except Pacific Herring, 25 otoliths were removed as equally as possible from the range of sizes present. The combined catches in up to three trawls per night (i.e., trawl cluster) were used to estimate the proportions of species contributing to the nearest samples of acoustic backscatter.

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

2.1.5.4.3 *Long Beach Carnage* For each dip net sample, all specimens were sorted, weighed, and counted to provide a combined weight and count for each, and as many as 20 fish of each CPS species were chosen randomly throughout the sample, and combined for a random sample of 50 fish collected throughout the catch. The fish were frozen for later analysis by CDFW biologists, yielding measures of individual fish and total sample weights (g); length (mm), L_S for Pacific Sardine and Northern Anchovy and L_F for all others; maturity; and otolith-derived ages. No female gonad samples were analyzed.

2.1.5.5 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. (Palance *et al.*, 2019). To identify measurement or data-entry errors, length and weight data were graphically compared (**Fig.** 7) to measurements from previous surveys and models of season-specific length-versus-weight from previous surveys (Palance *et al.*, 2019). Outliers were flagged, reviewed by the trawl team, and corrected if errors were identified; else, catch and specimen data were used as-is. Catch data were removed from aborted trawl hauls, or hauls otherwise deemed unacceptable.

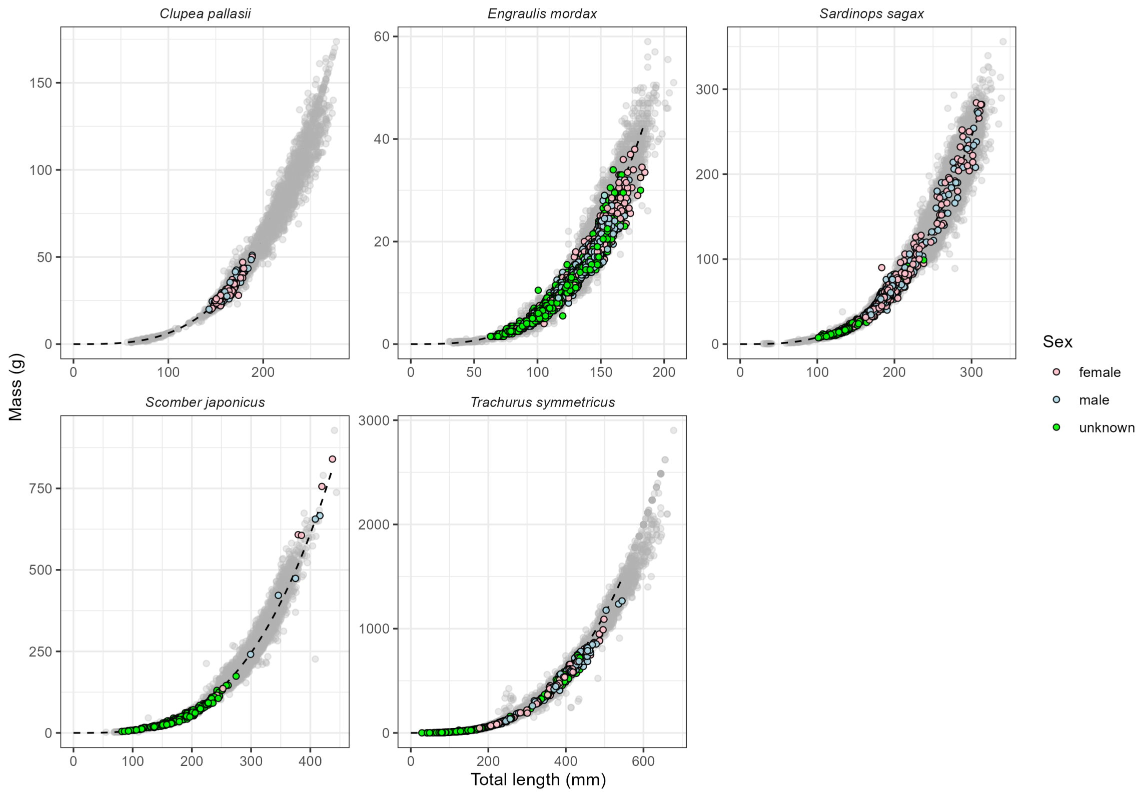

Figure 7: Specimen length versus weight from the current survey (colored points, by sex) compared to those from previous SWFSC surveys during the same season (gray points, all sexes) and models [dashed lines; Palance *et al.* (2019)].

2.2 Data processing

2.2.1 Acoustic and oceanographic data

The calibrated echosounder data from each transect were processed using commercial software (Echoview v12.1; Echoview Software Pty Ltd.) and estimates of the sound speed and absorption coefficient calculated with contemporaneous data from CTD probes cast while stationary or underway (UCTD, see **Section 2.1.3.1**). Data collected along the daytime transects at speeds ≥ 5 kn were used to estimate CPS densities. Nighttime acoustic data were 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 calculation

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

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

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

2.2.3 Echo classification

Echoes from schooling CPS and plankton (**Figs. 8a,d**) were identified using a semi-automated data processing algorithm implemented using Echoview software (v12.1; 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. 8**). Data from *Lasker* 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. 8b,e**);
4. Average the noise-free S_v echograms using non-overlapping 11-sample by 3-ping bins;
5. Expand the averaged, noise-reduced S_v echograms with a 7 pixel x 7 pixel dilation;
6. For each pixel, compute: $S_{v,200\text{kHz}} - S_{v,38\text{kHz}}$, $S_{v,120\text{kHz}} - S_{v,38\text{kHz}}$, and $S_{v,70\text{kHz}} - S_{v,38\text{kHz}}$;
7. Create a Boolean echogram for S_v differences in the CPS range: $-13.85 < S_{v,70\text{kHz}} - S_{v,38\text{kHz}} < 9.89$ and $-13.5 < S_{v,120\text{kHz}} - S_{v,38\text{kHz}} < 9.37$ and $-13.51 < S_{v,200\text{kHz}} - S_{v,38\text{kHz}} < 12.53$;
8. Compute the 120- and 200-kHz Variance-to-Mean Ratios ($VMR_{120\text{kHz}}$ and $VMR_{200\text{kHz}}$, respectively, Demer *et al.*, 2009a) using the difference between noise-filtered S_v (Step 3) and averaged S_v (Step 4);
9. Expand the $VMR_{120\text{kHz}}$ and $VMR_{200\text{kHz}}$ echograms with a 7 pixel x 7 pixel dilation;
10. Create a Boolean echogram based on the VMRs in the CPS range: $VMR_{120\text{kHz}} >$ -65 dB and $VMR_{200\text{kHz}} >$ -65 dB. Diffuse backscattering layers have low VMR (Zwolinski *et al.*, 2010) whereas fish schools have high VMR (Demer *et al.*, 2009a);
11. Intersect the two Boolean echograms to create an echogram with "TRUE" samples for candidate CPS schools and "FALSE" elsewhere;
12. Mask the noise-reduced echograms using the CPS Boolean echogram (**Figs. 8c,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 -60 dB (corresponding to a density of approximately three 20-cm-long Pacific Sardine per 100 m^3);
16. Integrate the volume backscattering coefficients (s_V, m^2 m^{-3}) attributed to CPS over 5-m depths and averaged over 100-m distances;
17. Output the resulting nautical area scattering coefficients (s_A; m^2 nmi^{-2}) and associated information from each transect and frequency to comma-delimited text (.csv) files.

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

1. Match geometry of the $S_{v,200\text{kHz}}$ to the $S_{v,38\text{kHz}}$;
2. Remove passive-mode pings;
3. Perform Steps 3-5 from *Lasker* processing;

4. For each pixel, compute: $S_{v,200\text{kHz}} - S_{v,38\text{kHz}}$;
5. Create a Boolean echogram for S_v differences in the CPS range: $-13.51 < S_{v,200\text{kHz}} - S_{v,38\text{kHz}} < 12.53$
6. Perform Steps 8-9 from *Lasker* processing;
7. Create a Boolean echogram mask using $VMR >$ -57 dB;
8. Performs Steps 11-17 from *Lasker* processing.

When necessary, the start and stop integration lines were manually edited to exclude reverberation due to bubbles, to include the entirety of shallow CPS aggregations, or to exclude seabed echoes. Also, echoes from putative rockfish schools were excluded based on their aggregation shapes and proximity to the rocky seabed.

2.2.4 Removal of non-CPS backscatter

In addition to echoes from target CPS, echoes may also be present from other pelagic fish species (Pacific Saury, *Cololabis saira*), or semi-demersal fish such as Pacific Hake and rockfishes (*Sebastes* spp.). When analyzing the acoustic-survey data, it was therefore necessary to filter "acoustic by-catch," i.e., backscatter not from the target species. To exclude echoes from mid-water, demersal, and benthic fishes, echograms were visually examined to exclude fish echoes where the seabed was hard and rugose, or where diffuse schools are observed offshore either near the surface or deeper than ~250 m (**Fig. 9**). In areas dominated by Pacific Herring, for example off Vancouver Island, backscatter was integrated to a maximum depth of 75 m.

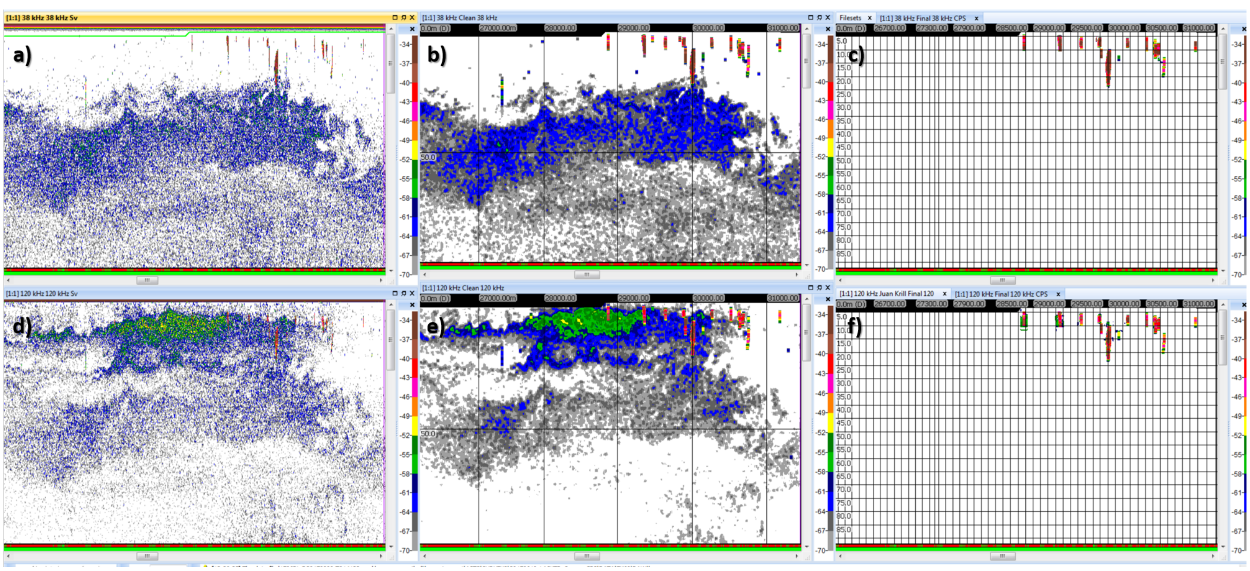

Figure 8: Two examples of echograms depicting CPS schools (red) and plankton aggregations (blue and green) at 38 kHz (top) and 120 kHz (bottom). Example data processing steps include the original echogram (a, d), after noise subtraction and bin-averaging (b, e), and after filtering to retain only putative CPS echoes (c, f).

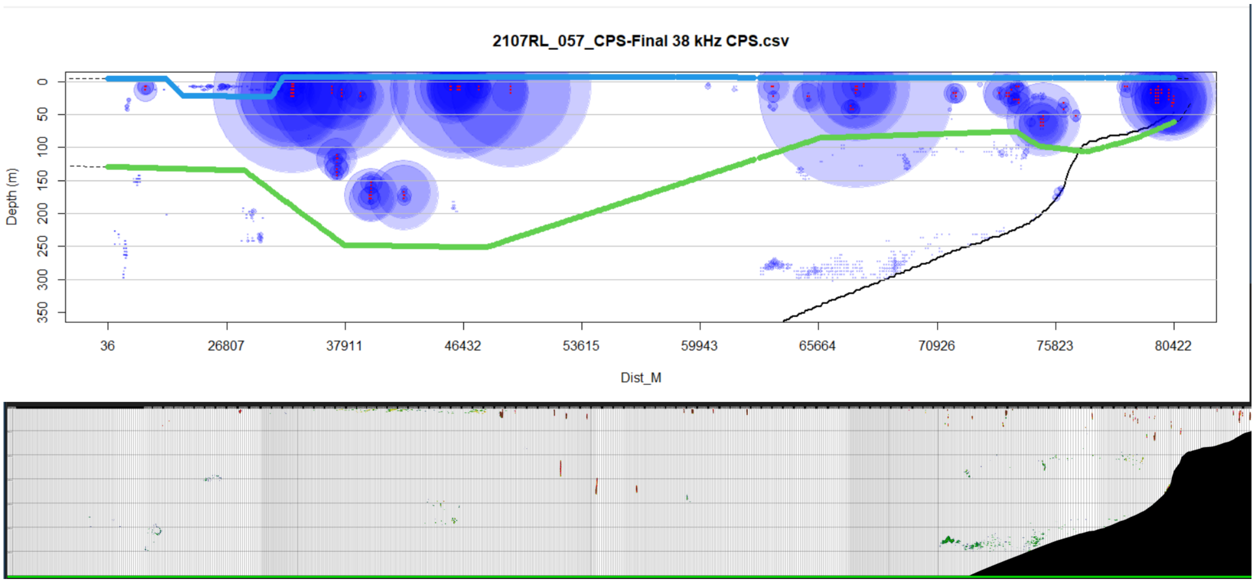

Figure 9: Echoes from fishes with swimbladders (blue points, scaled by backscatter intensity) along an example acoustic transect (top) and the corresponding echogram image (bottom). In this example, the upper (blue) and lower lines (green) indicate boundaries within which echoes were retained. When the lower boundary is deeper than the seabed (black line), echoes above the seabed are retained. Echoes from deep, bottom-dwelling schools of non-CPS fishes with swimbladders, and from diffuse scatterers near the surface were excluded. The proximity of the echoes to the seabed was also used to define the lower limit for vertical integration.

2.2.5 Extraction of nearshore backscatter

In summer 2022, between Cape Flattery and Bodega Bay, *Lisa Marie* sampled along acoustic transects to a depth of ~5 m. Because there was not a separate nearshore survey in this area, as there was between 2016 and 2021, acoustic intervals in water shallower than the 20-m isobath were assigned to nearshore strata, else to core strata, and biomasses were estimated as usual. The 20-m isobath roughly corresponds to the shallowest depth in which *Lasker* can safely navigate, so this nearshore area roughly approximates those from previous surveys. However, a study of inter-annual variation in nearshore biomasses should use a standardized area across years.

2.2.6 Quality Assurance and Quality Control

The largest 38-kHz integrated backscattering coefficients (s_A, m^2 nmi^{-2}) were graphically examined to identify potential errors in the integrated data (e.g., when a portion of the seabed was accidentally integrated, not shown). If found, errors were corrected and data were re-integrated prior to use for biomass estimation.

2.2.7 Echo integral partitioning and acoustic inversion

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

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

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

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

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

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

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

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

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

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

Equations (6) and (9) were derived from echosounder measurements of σ_{bs} for in situ fish and measures of L_T and W from concomitant catches of South American Pilchard (*Sardinops ocellatus*) and Horse Mackerel (*Trachurus trachurus*) off South Africa (Barange *et al.*, 1996). Because mackerels have similar TS (Peña, 2008), Equation (9) is used for both Pacific and Jack Mackerels. For Pacific Herring and Round Herring, Equation (7) was derived from that of Thomas et al. (2002) measured at 120 kHz with the following modifications: 1) the intercept used here was calculated as the average intercept of Thomas et al.'s spring and fall regressions; 2) the intercept was compensated for swimbladder compression after Zhao et al. (2008) using the average depth for Pacific Herring of 44 m; 3) the intercept was increased by 2.98 dB to account for the change of frequency from 120 to 38 kHz (Saunders *et al.*, 2012). For Northern Anchovy, Equation (8) was derived from that of Kang et al. (2009), after compensation of the swimbladder volume (Ona, 2003; Zhao *et al.*, 2008) for the average depth of Northern Anchovy observed in summer 2016 (19 m, Zwolinski *et al.*, 2017).

To calculate $TS_{38\mathrm{kHz}}$, L_T was estimated from measurements of L_S or L_F using linear relationships between length and weight derived from specimens collected in the CCE (Palance *et al.*, 2019): for Pacific Sardine, $L_T = 0.3574 + 1.149 L_S$; for Northern Anchovy, $L_T = 0.2056 + 1.1646 L_S$; for Pacific Mackerel, $L_T = 0.2994 + 1.092 L_F$; for Jack Mackerel $L_T = 0.7295 + 1.078 L_F$; and for Pacific Herring $L_T = -0.105 + 1.2 L_F$. Since a conversion does not exist for Round Herring, the equation for Pacific Herring was used to estimate L_T.

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

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

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

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

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

The trawls within a cluster were combined to reduce sampling variability (see **Section 2.2.8**), and the number of individuals caught from the e-th species in a cluster g (N_{ge}) was obtained by summing the catches across the h trawls in the cluster: $N_{ge} = \sum_{a=1}^{h_g} N_{ae}$. The backscattering cross-section for species e in the g-th cluster with a trawls is then given by:

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

where:

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

and the proportion (P_{ge}) is;

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

2.2.8 Trawl clustering and species proportion

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

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

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

See **Section 3.5.1** and **Fig. 13** for a description of the method used for this survey to estimate species proportions and Jack Mackerel lengths in the area between Cape Flattery and Cape Mendocino. The biomass densities were converted to numerical densities using: $\rho_{n,e} = \rho_{w,e}/\overline{w}_e$, where $\overline{w}_e$ is the corresponding mean weight. Also, for each acoustic interval, the biomass or numeric densities are partitioned into length classes according to the species' length distribution in the respective trawl cluster.

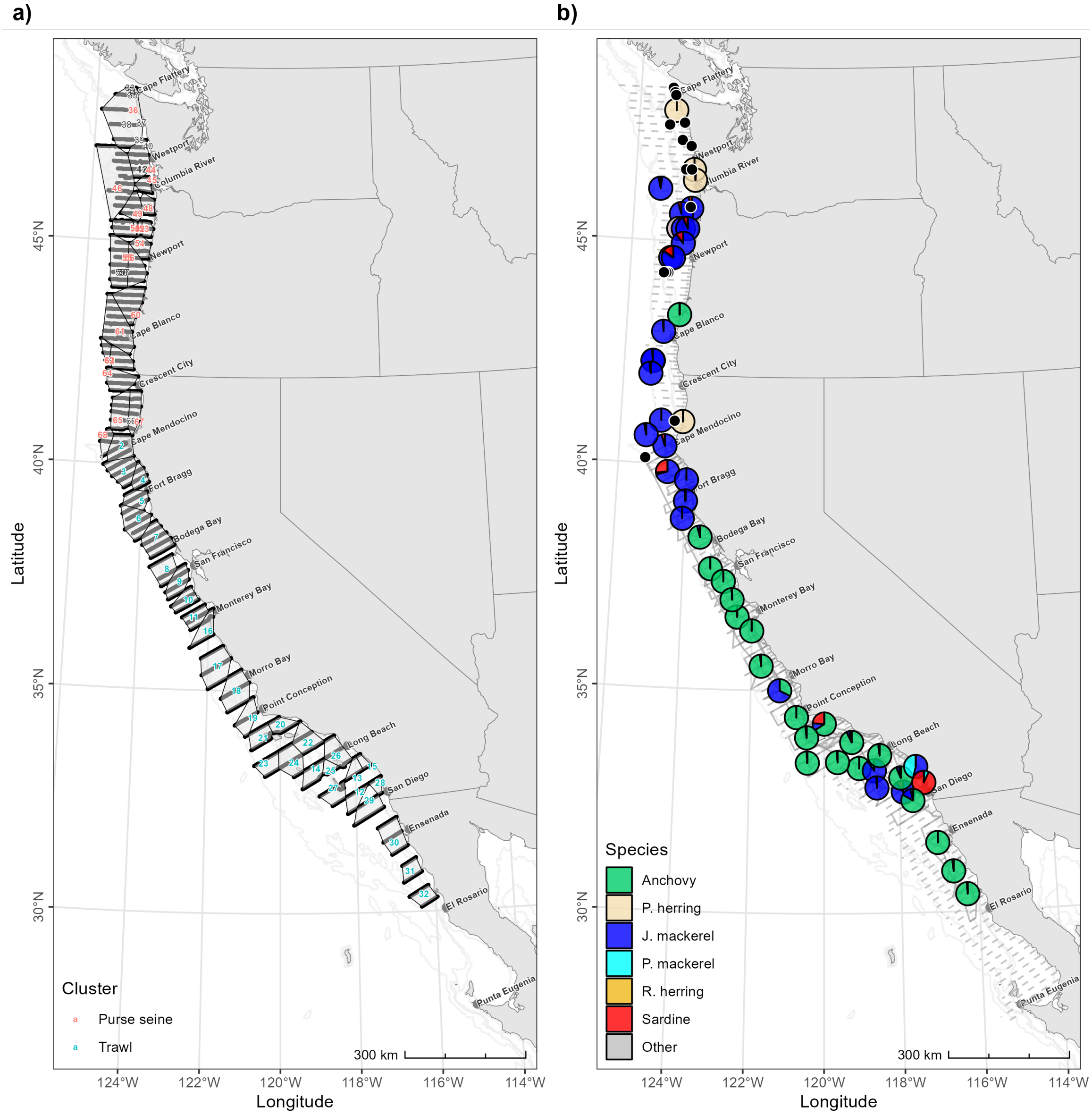

Figure 10: a) Polygons enclosing 100-m acoustic intervals from *Lasker*, *Lisa Marie*, and USVs assigned to catches from each trawl cluster or purse-seine set, and b) the acoustic proportions of CPS in catches from trawl clusters or purse-seine sets. See **Section 3.5.1** and **Fig. 13** for a description of the method used for this survey to estimate species proportions and Jack Mackerel lengths in the area between Cape Flattery and Cape Mendocino. The numbers inside each polygon in panel a) are the cluster or purse-seine numbers, which are located at the average latitude and longitude of all trawls in that cluster or each individual purse-seine set. Black points in panel b) 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 sampling units (Simmonds and Fryer, 1996). Because each species does not generally span the entire survey area (Demer and Zwolinski, 2017; Zwolinski *et al.*, 2014), the sampling domain was stratified for each species and stock. Strata were defined by uniform transect spacing (sampling intensity) and either presences (positive densities and potentially structural zeros) or absences (real zeros) of species biomass. Each stratum has: 1) at least three transects, with approximately equal spacing, 2) fewer than three consecutive transects with zero-biomass density, and 3) bounding transects with zero-biomass density (**Fig. 11**). This approach tracks stock patchiness and creates statistically-independent, stationary, post-sampling strata (Johannesson and Mitson, 1983; Simmonds *et al.*, 1992). For Northern Anchovy, we define the separation between the northern and central stock at Cape Mendocino (40.5 °N). For Pacific Sardine, the northern and southern stocks present in the survey area (Felix-Uraga *et al.*, 2004; Felix-Uraga *et al.*, 2005; Garcia-Morales *et al.*, 2012; Hill *et al.*, 2014) were separated using the revised model of Pacific Sardine potential habitat (Zwolinski and Demer, In prep.) during the survey (**Fig. 12**). 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 Big Sur (36.2 °N, **Fig. 11**).

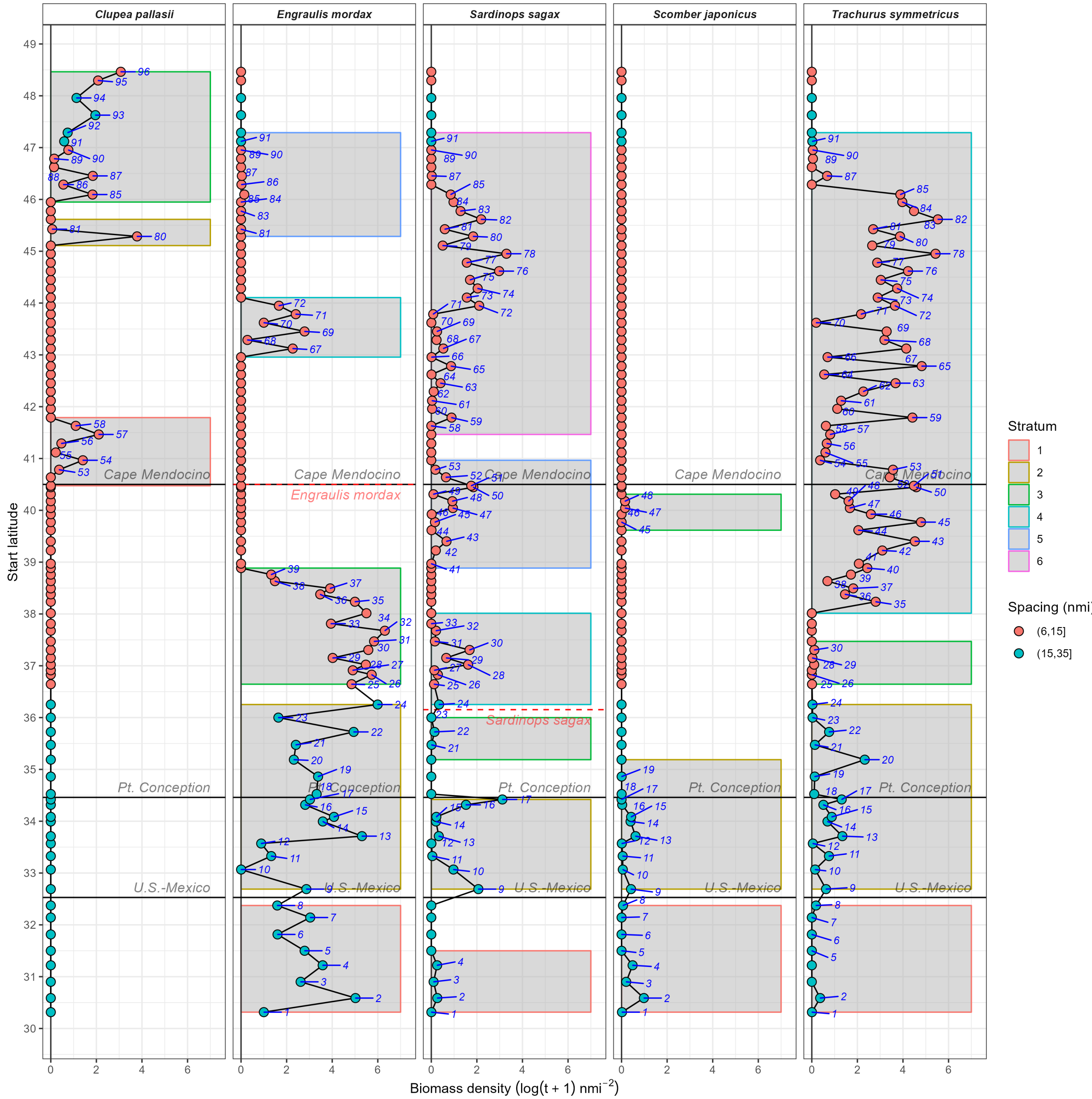

Figure 11: Biomass density ($\log_{10}(t\,\mathrm{nmi}^2 + 1)$) versus latitude (easternmost portion of each transect) and strata used to estimate biomass and abundance (shaded regions; outline indicates stratum number) for each species in the core survey region. Data labels (blue numbers) correspond to transects with positive biomass ($\log_{10}(t+1) > 0.01$). Transect spacing (nmi; point color), and stock breaks for Northern Anchovy and Pacific Sardine (red dashed lines and text) are indicated.

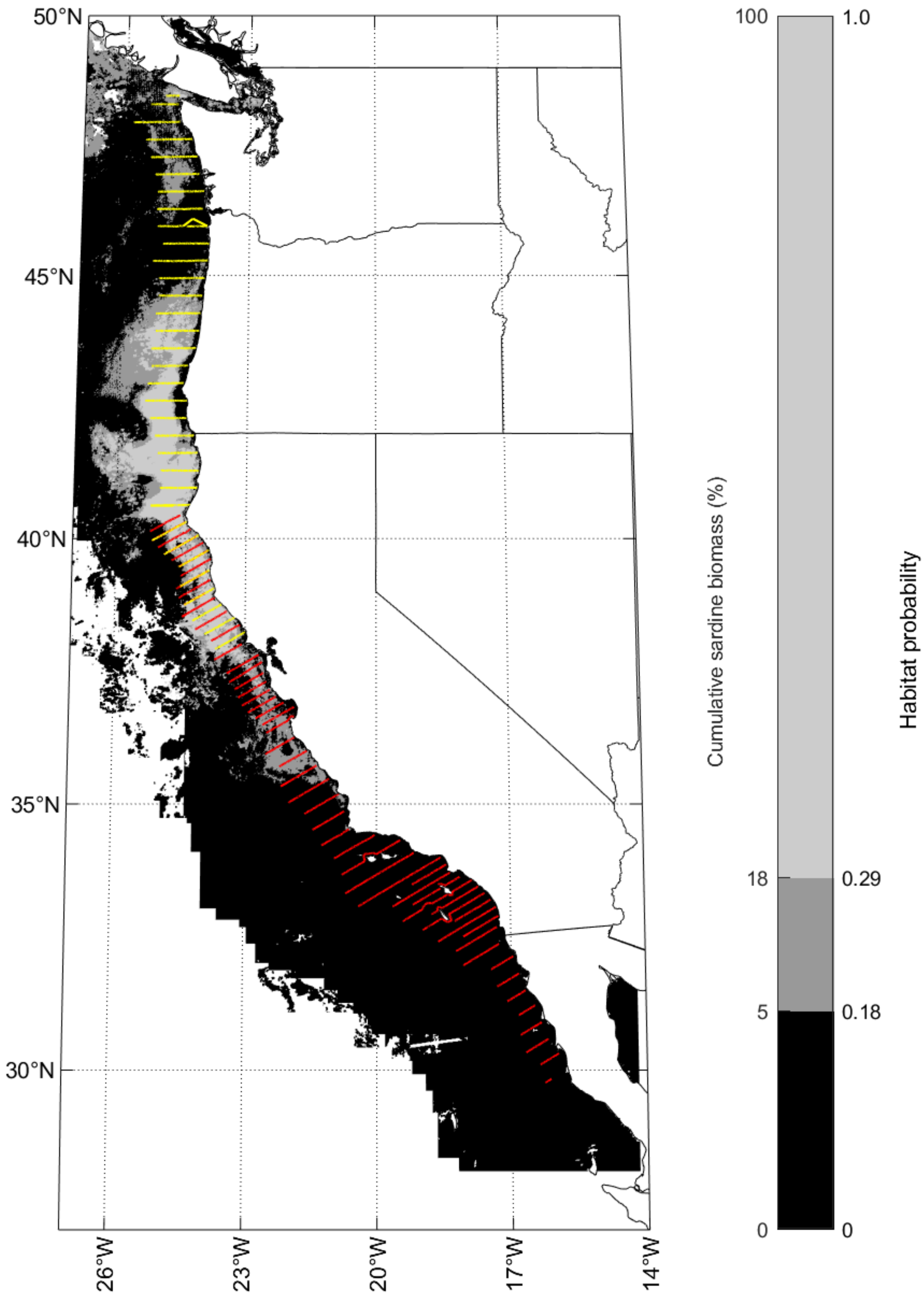

Figure 12: Summary of all transects sampled throughout the survey by *Lasker* (red) and *Lisa Marie* (yellow) in relation to the probability thresholds of the revised model of potential habitat for the northern stock of Pacific Sardine (Zwolinski and Demer, In prep.). The shaded regions with probabilities higher than 0.29 and 0.18 contained 82% and 95% of all spring northern stock Pacific Sardine spawning stock biomass, respectively. The habitat-model output is averaged in areas, ±2° latitude and longitude, centered around the daytime location of each vessel throughout the survey. Areas without data (white), occurred in the analysis domain where and when clouds prevented satellite-sensed observations.

2.3.2 Biomass and sampling precision estimation

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

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

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

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

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

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

2.3.3 Abundance- and biomass-at-length estimation

The numerical densities by length class (**Section 2.2.8**) were averaged for each stratum in a similar way for that used for biomass (Equation (17)), and multiplied by the stratum area to obtain abundance per length class.

2.3.4 Percent biomass per cluster contribution

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

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

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

3 Results

3.1 Sampling effort and allocation

The summer 2022 survey spanned the area from Cape Flattery and El Rosario between 27 June and 30 September 2022, and included most of the potential habitat for the northern stock of Pacific Sardine at the time of the survey[4]. In the core survey region that spanned this area (**Fig. 15**), *Lasker* (40 days at sea, DAS), *Lisa Marie* (26 DAS), and the two USVs (108 mission days) sampled 96 east-west transects totaling 4,264 nmi. Catches from a total of 86 nighttime surface trawls and 41 purse-seine sets from *Lisa Marie* were combined into 73 trawl clusters. In the core area, one to six post-survey strata were defined by their transect spacing and the densities of echoes attributed to each species.

The nearshore region spanned an area from approximately Cape Flattery to San Diego, including around Santa Cruz and Santa Catalina Islands. *Lisa Marie* (26 DAS) surveyed from approximately Cape Flattery, WA to Stewarts Point, CA with 24 east-west transects totaling **18 nmi** and 41 purse-seine sets. *Long Beach Carnage* (22 DAS) surveyed from approximately Stewarts Point to San Diego, and around the Santa Cruz and Santa Catalina Islands, with 129 east-west transects totaling 511 nmi and 53 purse-seine sets (**Fig. 17**). In the nearshore area, one to fourteen post-survey strata were defined by their transect spacing and the biomass densities.

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

Leg I

Leg I on *Lasker* was canceled. Therefore, *Lisa Marie* was directed to sample the 20-nmi-spaced compulsory Transects, 178 to 143, between Cape Flattery and Port Orford, OR, but extending them shoreward to ~5 m depth. Two USVs (SD-1076 and SD-1077) sampled Transects 170 to 160, between Copalis Beach, WA to Tillamook Bay, OR, from 9 to 22 July.

Leg II

On 21 July, *Lasker* departed from the 10th Avenue Marine Terminal in San Diego, CA at ~1745 (all times GMT). Prior to the transit north, a calibration of the Simrad-Kongsberg EC150-3C ADCP-echosounder was attempted northwest of the sea buoy outside San Diego Bay (32.6598 N, 117.3833 W), but was not completed, due to GPS data-format incompatibilities. Throughout the northward transit, daytime sampling was conducted with CUFES, EK80s, ME70, MS70 and SX90 while personnel continued to troubleshoot GPS issues and test equipment. On 25 July, *Lasker* arrived at the waypoint offshore of Cape Mendocino, CA at ~1930 and conducted one tow before initiating acoustic sampling on transect 129 at sunrise. After encountering CPS echoes on the first transect, adaptive sampling was initiated. On 26 July, Simrad-Kongsberg representative David Barbee resolved the issues with GPS-attitude data inputs to the EK80s. ADCP calibrations were successfully completed on 27 July, taking advantage of good weather conditions, close proximity to the intended trawl locations, and the last two hours of daylight. On 29 July, after completing transect 119, *Lasker* ceased adaptive sampling. Small boat operations were conducted near Point Arena on 30 July at ~0230 to embark two scientists and one crew member. On 4 August, *Lasker* completed transect 103 off Monterey, CA, ceased acoustic sampling, and transited to Point Conception, CA to recover an acoustic lander. The lander was recovered on 5 August at ~1400 before *Lasker* continued south to San Diego. On 6 August, *Lasker* arrived at the 10th Avenue Marine Terminal in San Diego, CA at ~1400 to complete Leg II.

Meanwhile, *Lisa Marie* sampled core-region Transects 141 to 114, between Cape Sebastian, OR to Bodega Bay, CA, from 21 July to 1 August. On 2 August, on its transit north, *Lisa Marie* resampled Transect 133, which she had previously sampled during Leg II, but without recording EK80 data. On 3 August, *Lisa Marie* returned to Westport, WA to conclude its portion of the 2022 Summer CCE survey.

The two USVs (SD-1076 and SD-1077) sampled core-region Transects 158 to 146, between Neskowin, OR to Bandon, OR, from 23 July to 13 August.

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

Long Beach Carnage sampled nearshore Transects 227 to 186, between Bodega Bay, CA to Morro Bay, CA, from 30 July to 5 August.

Between Cape Flattery and Cape Mendocino, *Lisa Marie* and the two USVs sampled alternating transects with a two- to 27-day lag between the two platforms. Between Cape Mendocino and Bodega Bay, *Lasker* and *Lisa Marie* sampled the same transects with a lag of less than two days. To estimate biomass in the overlapping area, only data from *Lasker* was used.

Leg III

All but four days on Leg III were lost, so the remaining time was used for CPS reconnaissance in the SCB. At ~1400 on 26 August, after a 16-day delay, *Lasker* departed from the 10th Avenue Marine Terminal Pier in San Diego, CA. At ~1930 on 26 August, acoustic sampling was conducted along transect 72. A total of five transects were completed in the SCB. On 29 August, acoustic sampling ceased after the completion of transect 78 off Long Beach, CA. On 30 August, after completing a compass calibration outside of the San Diego sea buoy, *Lasker* arrived at the 10th Avenue Marine Terminal in San Diego, CA at ~1900 to complete Leg III.

The two USVs (SD-1076 and SD-1077) sampled core-region Transects 144 to 122, between Cape Blanco, OR to Beaver Point, CA, from 9 to 31 August. *Long Beach Carnage* sampled nearshore Transects 185 to 138, between Point Buchon, CA to the U.S.-Mexico border, and the Santa Cruz and Santa Catalina Islands, from 20 August to 8 September.

Leg IV

At ~1615 on 9 September, *Lasker* departed from 10th Avenue Marine Terminal in San Diego, CA. At ~1430 on 12 September, *Lasker* resumed acoustic sampling along transect 103 off Monterey, CA. At ~0330 on 16 September, an acoustic lander was deployed at 34.438635 N, 120.54667 W. The lander, consisting of an autonomous echosounder (WBAT; Simrad-Kongsberg) and passive-acoustic recorder (AURAL-M2; Multi-Electronique), is part of an ongoing project to utilize stationary platforms for monitoring the ecosystem off Point Conception, CA, and stocks of CPS that migrate past there. At 0330 on 17 September, scientists Dayv Lowry and Daniel Hernandez Cruz embarked via small craft in Santa Barbara Harbor, CA. At 0330 on 24 September, scientist Brittany Schwarzkopf disembarked and *Lasker's* XO embarked via small craft in Mission Bay, CA. At 0200 on 29 September, acoustic sampling ceased at sunset along transect 54 off Punta Baja, Baja California. At 0700 on 30 September, *Lasker* arrived at the 10th Avenue Marine Terminal in San Diego, CA to conclude the 2022 Summer CCE survey.

3.2 Acoustic backscatter

Acoustic backscatter ascribed to CPS was observed throughout the latitudinal range of the core survey area (**Fig. 15a**) and was present nearshore to the shelf break. Zero-biomass intervals were observed at the offshore end of each transect in the core region. The majority (greater than 90%) of the biomass for each species was apportioned using catch data from trawl clusters conducted within 30 nmi (**Fig. 14**).

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

3.3 Egg densities and distributions

Jack Mackerel eggs were predominant in CUFES samples collected north of Monterey, but were most abundant between Cape Mendocino and Fort Bragg (**Fig. 15b**). Northern Anchovy eggs were predominant in positive samples collected between Monterey and El Rosario (**Fig. 15b**). Some Pacific Sardine eggs were present in samples collected offshore between San Francisco and Half Moon Bay, CA and in a few samples throughout the SCB (**Fig. 15b**).

3.4 Trawl catch

Trawl catches from *Lasker* were comprised of mostly Jack Mackerel between Cape Mendocino and Point Arena, CA, and Northern Anchovy farther south (**Fig. 15c**). Pacific Herring were present in several trawl clusters off the coast of WA and OR. Pacific Sardine were caught in relatively small numbers between Cape Mendocino and Fort Bragg (**Fig. 15c**). Relatively few Pacific Mackerel and Pacific Herring were collected (**Fig. 15c**). Overall, the 86 trawls and 41 purse-seine sets captured a combined 7,360 kg of CPS (6,887 kg of Northern Anchovy, 213 kg of Pacific Sardine, 22.2 kg of Pacific Mackerel, 217 kg of Jack Mackerel, and 20.2 kg of Pacific Herring).

3.5 Purse-seine catch

3.5.1 *Lisa Marie*

North of the Columbia River, Pacific Herring were predominant, by weight, in the purse-seine samples (**Fig. 13e**). Between the Columbia River and Cape Mendocino, Pacific Sardine were predominant (**Fig. 13e**). On numerous occasions, however, Jack Mackerel were reportedly schooling with Pacific Sardine, but eluded capture, thereby biasing the species composition in those samples (K. Hinton, pers. comm.). Therefore, for the region between Astoria and Cape Mendocino, the acoustic proportions of Pacific Sardine in nighttime trawl clusters from *Lasker* between 2018 and 2021 (**Fig. 13a-c**) were used to create a generalized additive model (GAM) describing their acoustic proportion versus latitude (**Fig. 13d**). In 2022, this model was used to estimate the acoustic proportion of Pacific Sardine in purse-seine clusters that contained Pacific Sardine (**Fig. 13f**), and the complement acoustic proportion was assumed to be Jack Mackerel based on the association between Jack Mackerel and Pacific Sardine in the summer 2021 nighttime trawl catches (**Fig. 13f**). No adjustment was made to acoustic proportions in 2022 purse-seine clusters if no Pacific Sardine were present. Other species (e.g., Pacific Herring, Pacific Mackerel, saury, and smelt) that could have contributed to the CPS backscatter in this area were also observed or suspected to be avoiding the net (K. Hinton, pers. comm.), but those species comprised a small fraction (always <5%, <1.4% on average, and mostly <1%) of the acoustic proportions in clusters that contained both Pacific Sardine and Jack Mackerel in 2021. The Jack Mackerel lengths in this region are those from the summer 2021 nighttime trawl clusters nearest to the CPS backscatter observed in summer 2022. The purse-seine was only deployed when schools were observed, so purse-seine sampling was sparse along portions of the WA and OR coast. Overall, the 41 seines captured a combined 58.3 kg of CPS (37.5 kg of Pacific Sardine, 12.1 kg of Jack Mackerel, 4.75 kg of Pacific Herring, t of Pacific Mackerel, and 3.9 kg of Northern Anchovy).

3.5.2 *Long Beach Carnage*

Northern Anchovy were predominant, by weight, in purse-seine samples collected by *Long Beach Carnage* nearshore off central CA between Cape Mendocino and Monterey (**Fig. 17b**). Pacific Sardine were predominant between Big Sur and San Diego (**Fig. 17b**). Some Pacific Mackerel were collected between Oceanside, CA and San Diego and around Santa Cruz and Santa Catalina Islands. Jack Mackerel were collected between Big Sur and Morro Bay, and off San Diego (**Fig. 17b**). Overall, dip net samples from 53 seines totaled 151 kg of CPS (87 kg of Pacific Sardine, 46 kg of Pacific Mackerel, kg of Jack Mackerel, and 10 kg of Northern Anchovy; and no Pacific Herring).

3.5.3 Combined catch

In some areas, purse-seine sets were sparse (**Figs. 16b** and **17b**). To estimate biomass in the nearshore region, acoustic intervals were assigned the species proportions from the nearest purse-seine set or trawl cluster, whichever was closest (**Fig. 18b**).

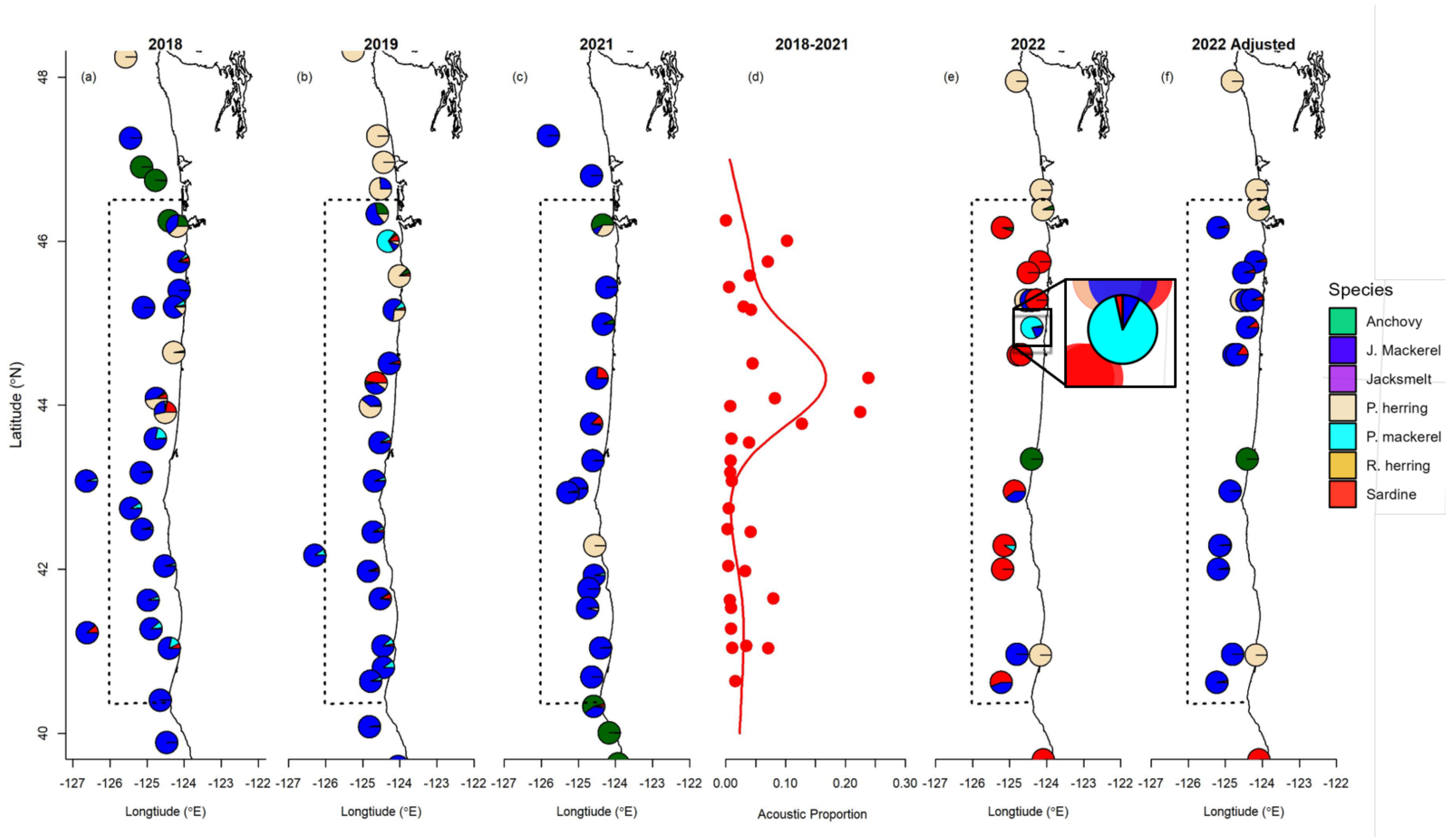

Figure 13: Maps of species proportions in *Lasker*'s nighttime trawl-catch clusters during summer a) 2018, b) 2019, and c) 2021 depicting an analysis region between the Columbia River and Cape Mendocino (dashed line); d) a model of the acoustic proportions of Pacific Sardine versus latitude in *Lasker*'s nighttime trawl-catch clusters between 2018 and 2021; e) species proportions in *Lisa Marie*'s summer 2022 purse-seine catches (the inset shows the presence of Pacific Sardine that are not visible in the full image); and f) the species proportions used in the estimation of summer 2022 CPS biomasses north of Cape Mendocino, replacing *Lisa Marie*'s catches containing Pacific Sardine, in the analysis region, with the modeled proportion of Pacific Sardine, with its complement assigned to Jack Mackerel.

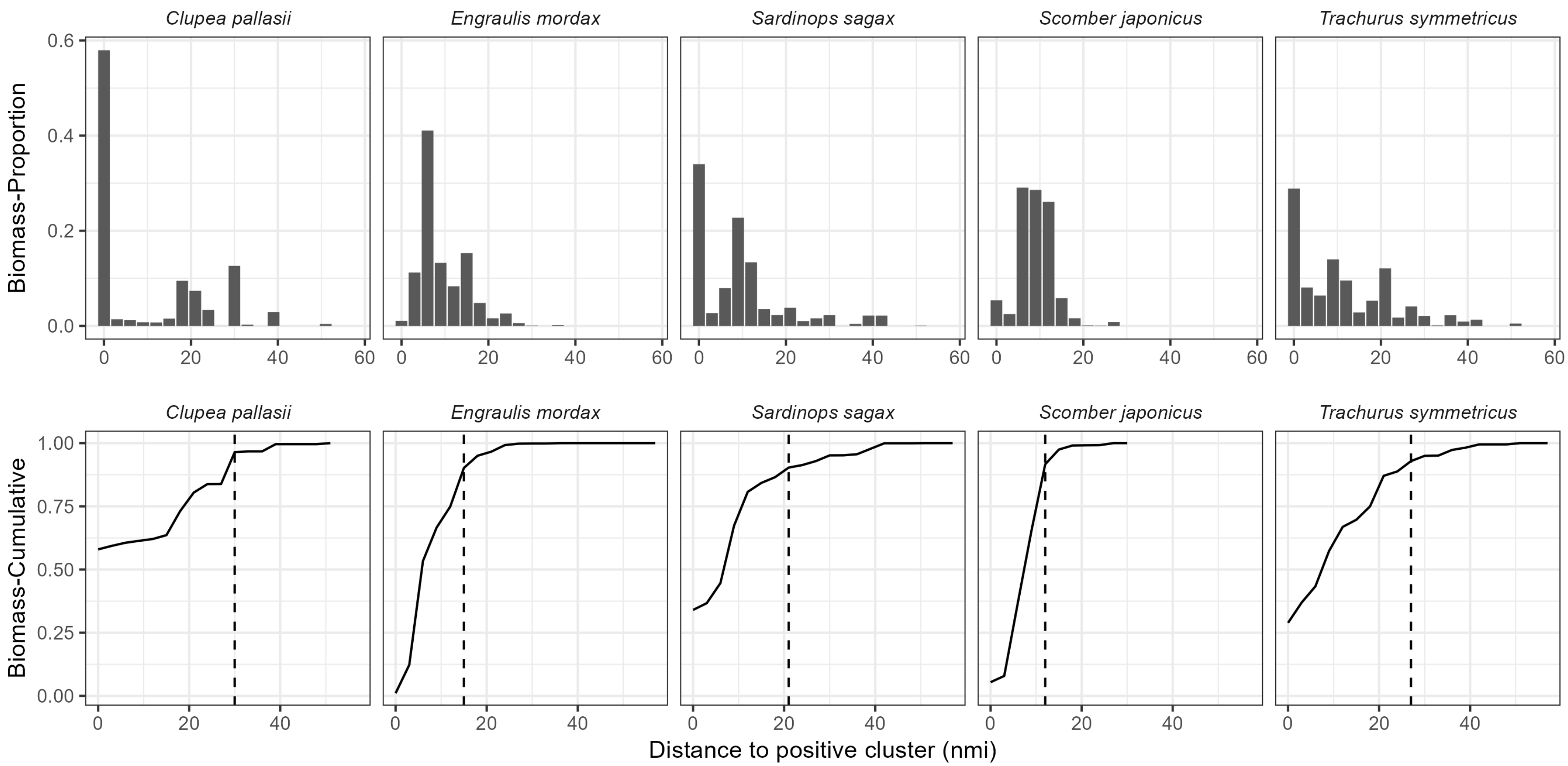

Figure 14: Proportion (top) and cumulative proportion (bottom) of biomass versus distance to the nearest positive trawl cluster. Dashed vertical lines (bottom) represent the cluster distance where cumulative biomass equals 90%.

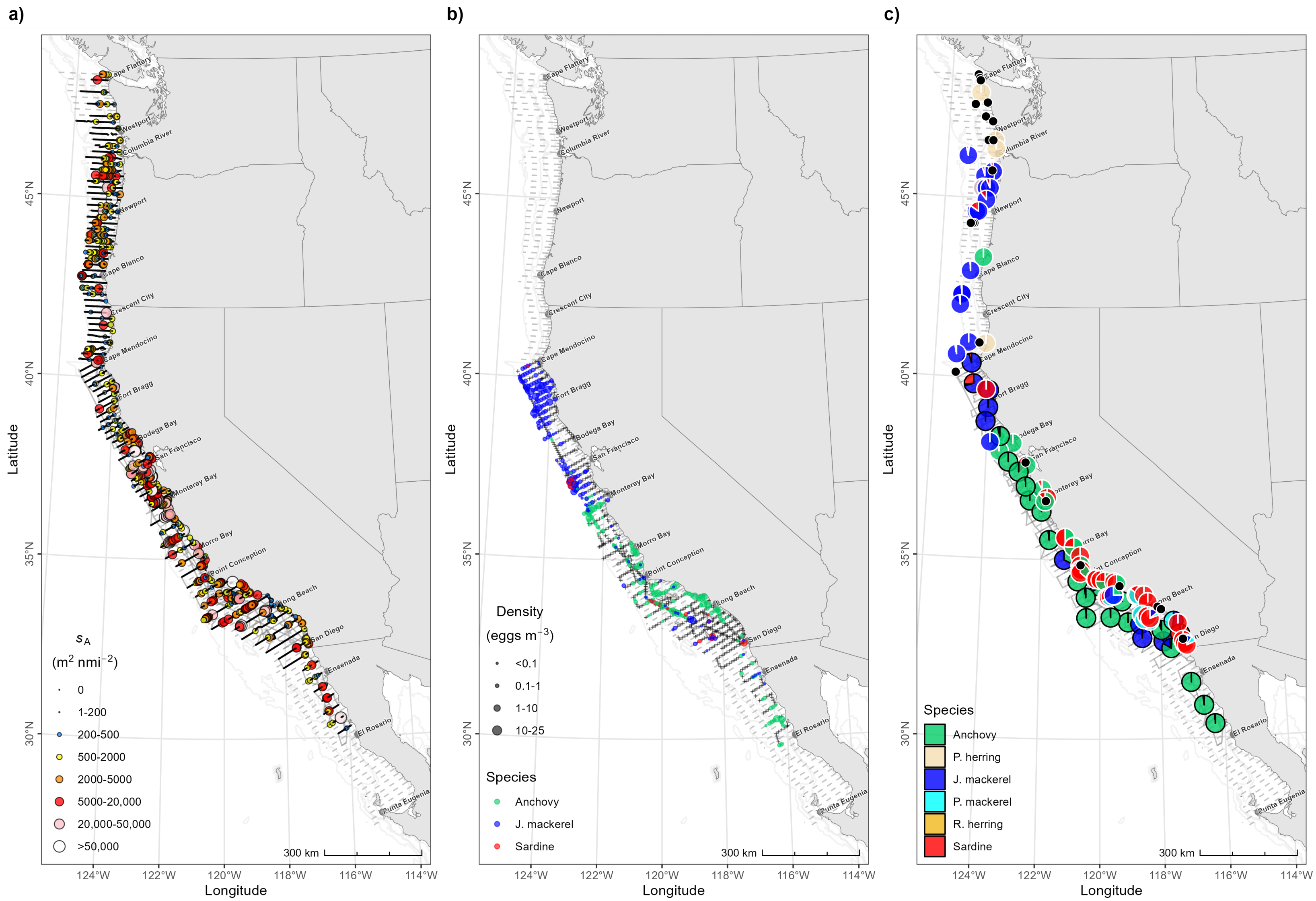

Figure 15: Spatial distributions of: a) 38-kHz integrated backscattering coefficients (s_A, m^2 nmi^{-2}; averaged over 2000-m distance intervals) ascribed to CPS; b) CUFES egg density (eggs m^{-3}) for Northern Anchovy, Pacific Sardine, and Jack Mackerel; and c) acoustic proportions of CPS in trawl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

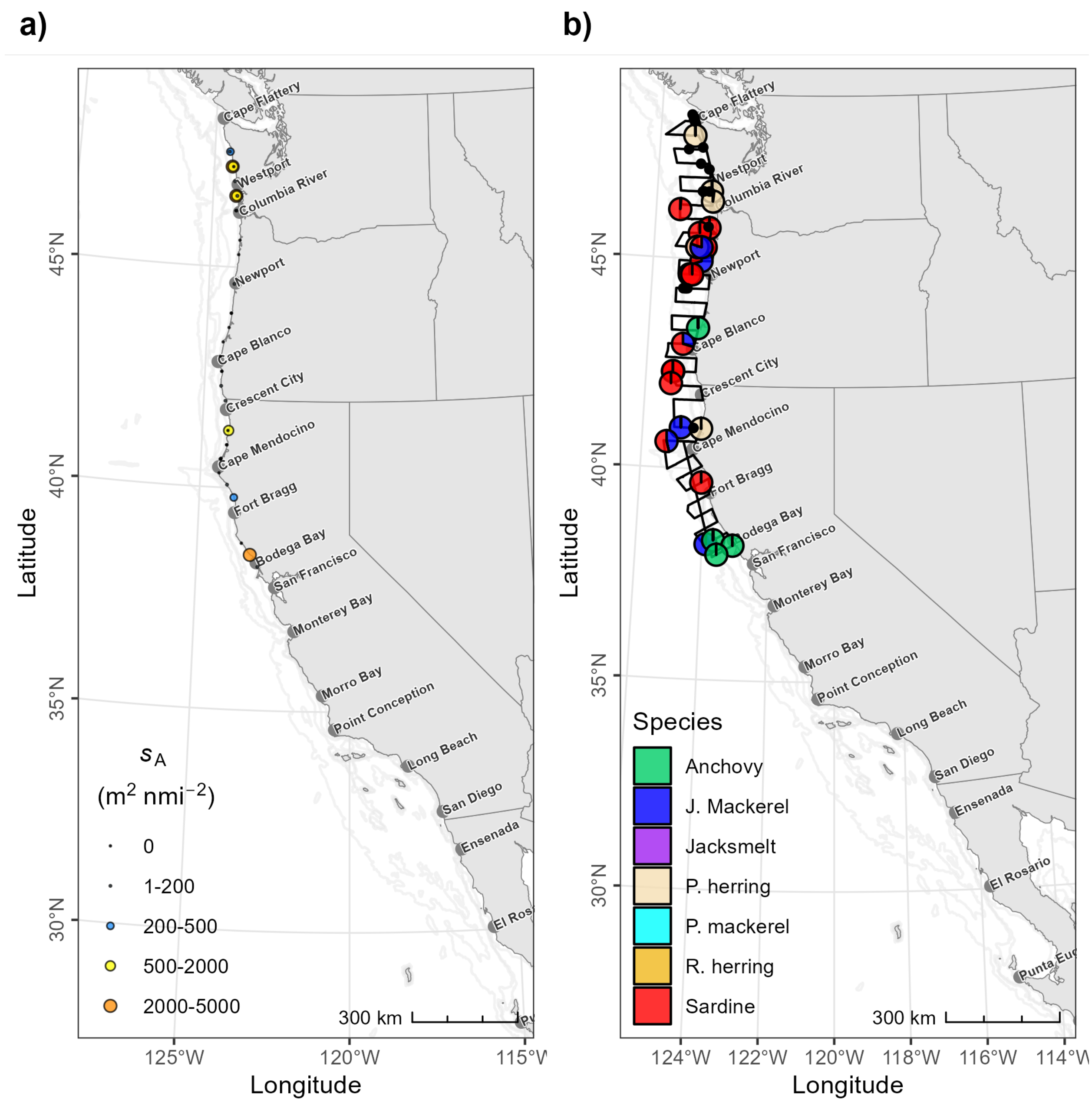

Figure 16: Nearshore survey transects sampled by *Lisa Marie* overlaid with the distributions of: a) 38-kHz integrated backscattering coefficients (s_A, m^2 nmi^{-2}; averaged over 2000-m distance intervals) ascribed to CPS; and b) the proportions, by weight, of CPS in each purse-seine catch. Species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

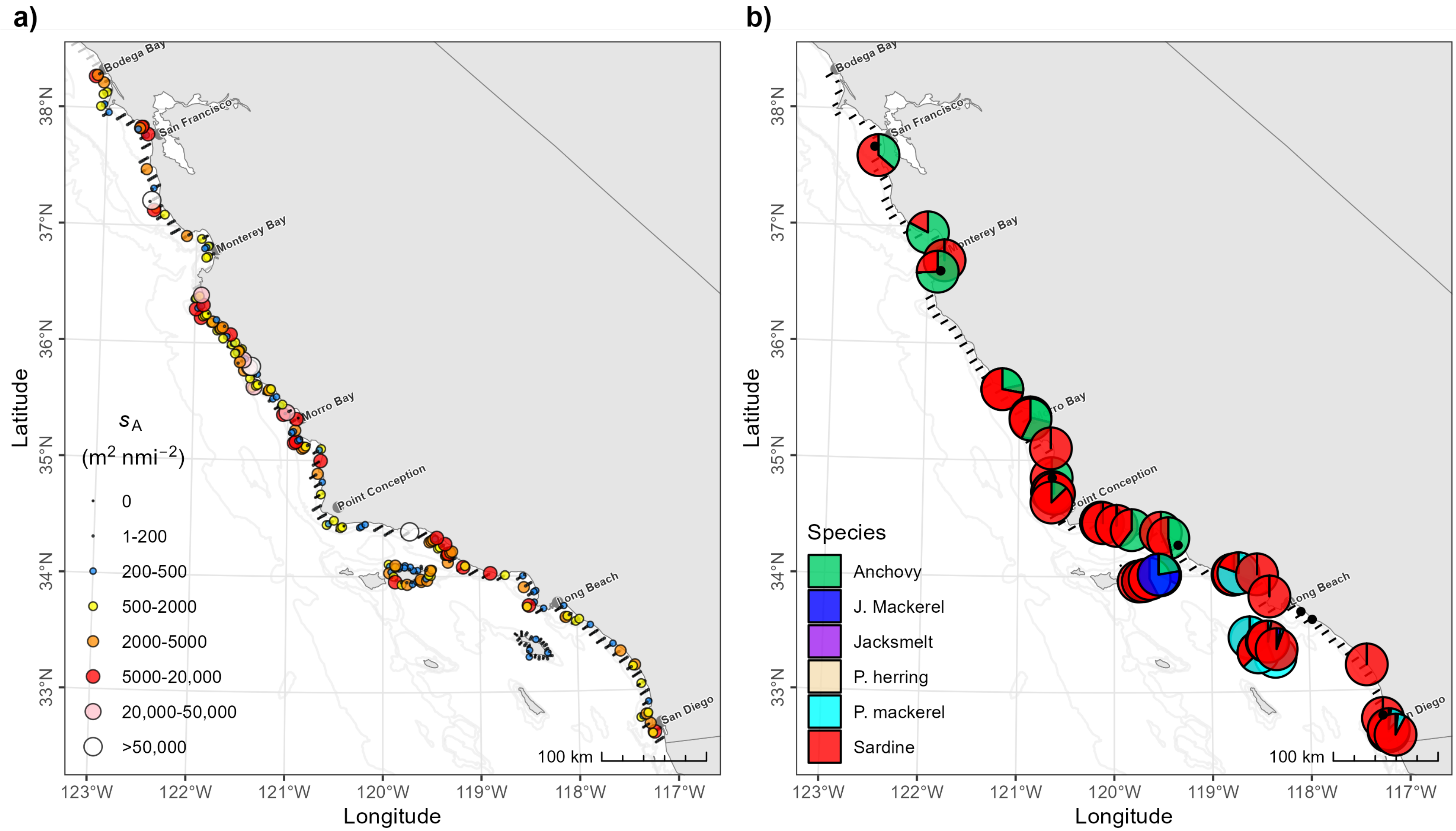

Figure 17: Nearshore transects sampled by *Long Beach Carnage* overlaid with the distributions of: a) 38-kHz integrated backscattering coefficients (s_A, m^2 nmi^{-2}; averaged over 2000-m distance intervals) ascribed to CPS; and b) the proportions, by weight, of CPS in each purse-seine catch. Species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

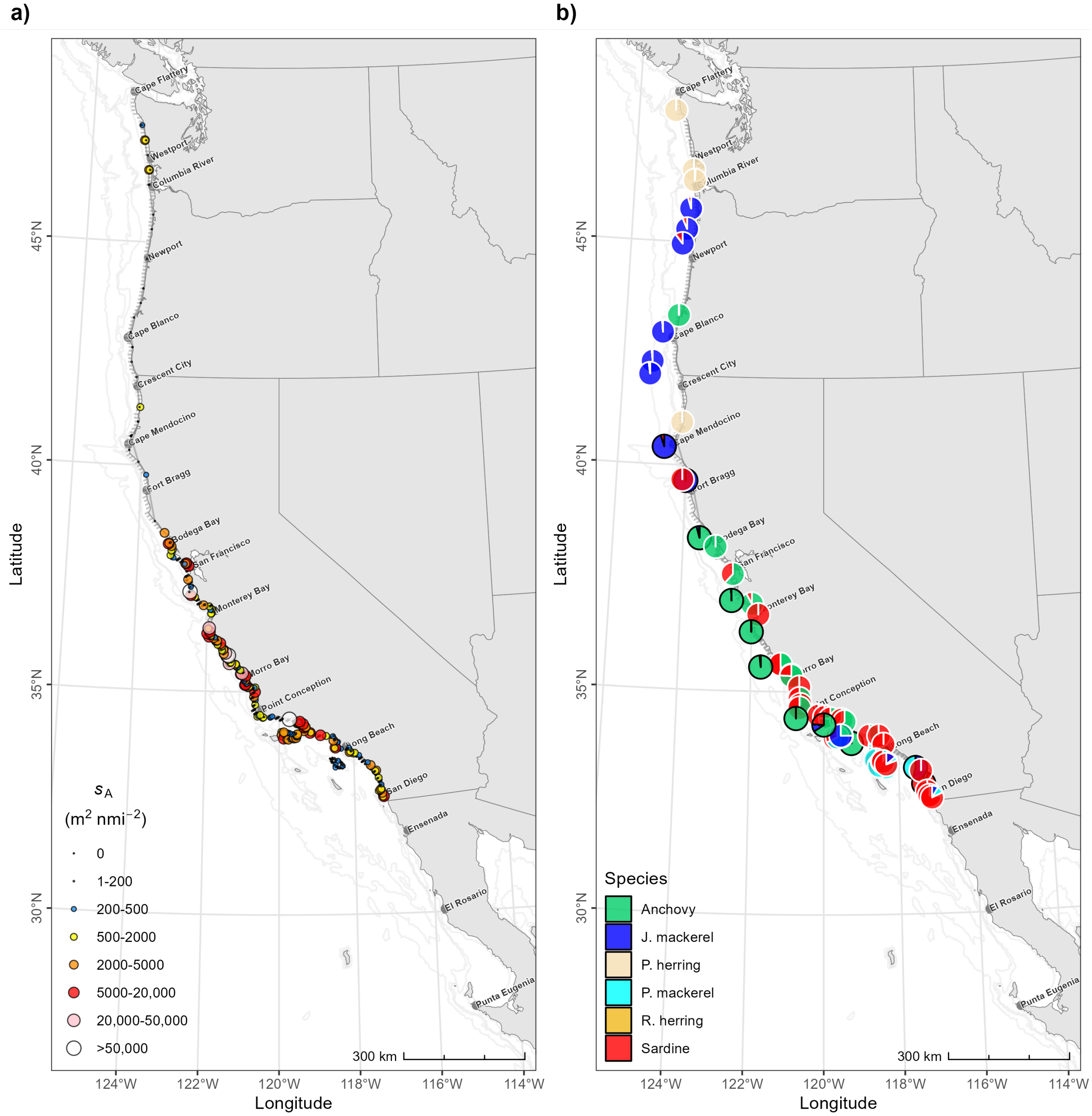

Figure 18: Spatial distributions of: a) 38-kHz integrated backscattering coefficients (s_A, m^2 nmi^{-2}; averaged over 2000-m distance intervals) ascribed to CPS from nearshore sampling; and b) acoustic proportions of CPS in trawl clusters (black outline) and purse-seine sets (white outline).

3.6 Biomass distribution and demographics

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

3.6.1 Northern Anchovy

3.6.1.1 Northern stock

The total estimated biomass of the northern stock of Northern Anchovy was 16,432 t ($CI_{95\%}$ = 5,646 - 27,680 t, CV = 34%; **Table 5**). In the core region, biomass was 16,432 t ($CI_{95\%}$ = 5,646 - 27,680 t, CV = 34%; **Table 5**); the stock was distributed throughout the survey area from approximately Westport to Cape Blanco (**Fig. 19a**). L_S ranged from 10 to 15 cm with modes at 10 and 13 cm (**Table 6**, **Fig. 20**). In the nearshore region, biomass was 0.0934 t ($CI_{95\%}$ = 0 - 0.285 t, CV = 94%; **Table 5**), comprising 0.00057% of the total biomass, and was located near the entrance to the Columbia River (**Fig. 19b**). L_S had a single mode at ~13 cm (**Table 6**; not visible in **Fig. 20**).

Table 5: Biomass estimates (metric tons, t) and their precisions (upper and lower 95% confidence intervals, $CI_{95\%}$; and coefficients of variation, CVs) for the northern stock of Northern Anchovy (*Engraulis mordax*) in the core and nearshore survey regions. Stratum areas are nmi^2.

Stratum					Trawl		Biomass			
Region	Number	Area	Transects	Distance	Clusters	Individuals	$\hat{B}$	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Core	4	3,287	8	352	1	1	16,321	5,556	27,583	35
	5	6,558	13	659	2	9	111	2	319	76
	All	9,844	21	1,011	3	10	16,432	5,646	27,680	34
Nearshore	10	43	2	4	1	7	0	0	0	94
	All	43	2	4	1	7	0	0	0	94
All	**-**	**9,887**	**23**	**1,014**	**4**	**17**	**16,432**	**5,646**	**27,680**	**34**

Table 6: Abundance versus standard length (L_S, cm) for the northern stock of Northern Anchovy (*Engraulis mordax*) in the core and nearshore survey regions.

	Region	
L_S	Core	Nearshore
1	0	0
2	0	0
3	0	0
4	0	0
5	0	0
6	0	0
7	0	0
8	0	0
9	0	0
10	1,704,924,599	0
11	0	0
12	0	0
13	2,091,901	2,070
14	1,568,926	1,553
15	428,218	0
16	0	0
17	0	0
18	0	0
19	0	0
20	0	0

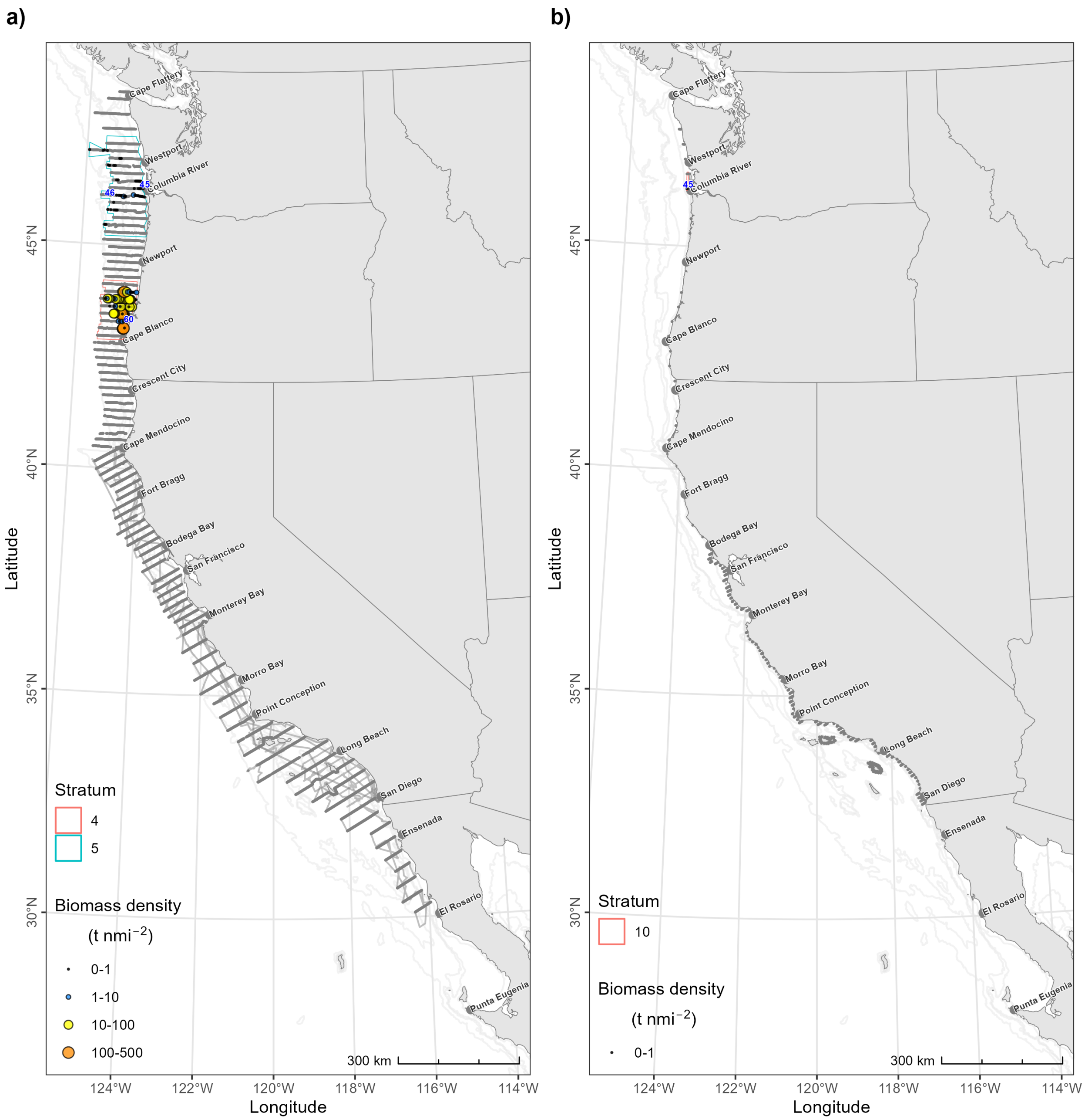

Figure 19: Biomass densities (colored points) of the northern stock of Northern Anchovy (*Engraulis mordax*), per stratum, in the a) core and b) nearshore survey regions. Overlaid are the locations of trawl clusters with at least one Northern Anchovy (blue numbers) in each stratum (colored polygons).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

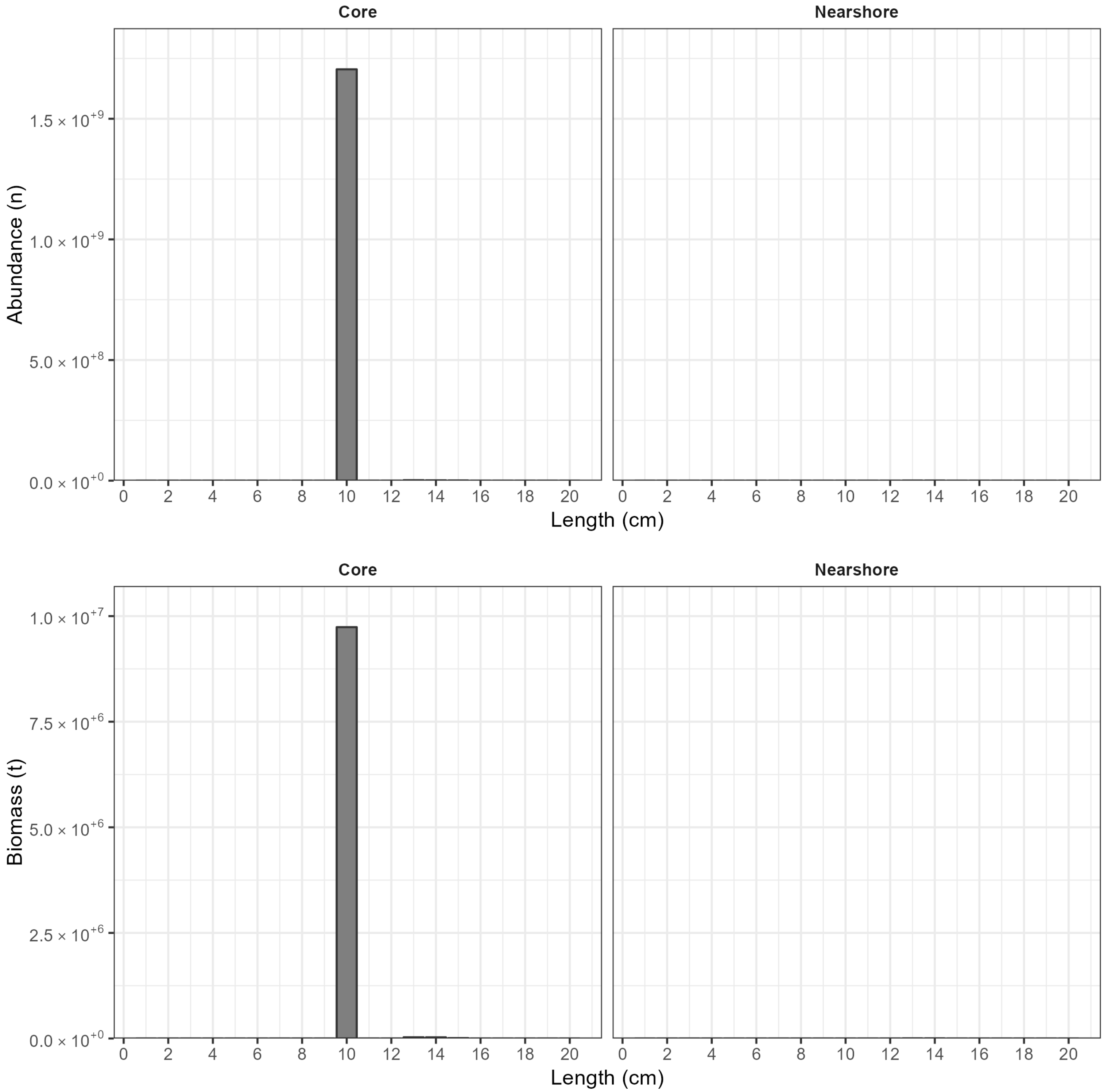

Figure 20: Abundance versus standard length (L_S, upper panels) and biomass (t) versus L_S (lower panels) for the northern stock of Northern Anchovy (*Engraulis mordax*) in the core and nearshore survey regions. This plot correctly shows the abundances and biomasses in the core region, which is based on one specimen resulting in the mode at 10 cm (see Cluster 60 in **Appendix A.1**). Abundance and biomass in the nearshore region is negligible relative to the core region and not visible at this scale.

3.6.1.2 Central stock

The total estimated biomass of the central stock of Northern Anchovy was 2,235,996 t ($CI_{95\%}$ = 1,248,956 - 3,051,863 t, CV = 20%; **Table 7**), of which 6% was observed in Mexican waters. In the core region, biomass was 2,197,812 t ($CI_{95\%}$ = 1,231,227 - 3,002,630 t, CV = 21%; **Table 7**); the stock was distributed throughout most of the survey area from Bodega Bay to El Rosario (**Fig. 21a**). L_S ranged from 5 to 16 cm with modes at 9 and 12 cm (**Table 8**, **Fig. 22**). In the nearshore region, biomass was 38,184 t ($CI_{95\%}$ = 17,729 - 49,233 t, CV = 21%; **Table 7**), comprising 1.7% of the total biomass, and was distributed between Bodega Bay and Los Angeles, CA (**Fig. 21b**). The nearshore length distribution had a single mode at 11 cm (**Table 8**, **Fig. 22**).

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

Stratum					Trawl		Biomass			
Region	Number	Area	Transects	Distance	Clusters	Individuals	$\hat{B}$	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Core	1	4,744	8	237	4	149,276	141,459	32,781	328,023	56
	2	19,805	16	1,020	15	148,855	1,030,667	336,141	1,637,019	34
	3	6,319	16	600	6	197,764	1,025,686	572,423	1,545,177	26
	All	30,867	40	1,857	23	495,895	2,197,812	1,231,227	3,002,630	21
Nearshore	1	46	5	7	1	7	0	0	0	28
	2	142	11	37	5	925	7,872	2,632	13,536	37
	3	279	28	60	9	95,212	24,435	6,546	32,490	28
	4	293	21	66	4	55,065	5,023	1,589	10,124	46
	5	99	2	4	1	462	529	0	1,088	73
	6	99	10	19	2	54	38	11	79	49
	7	99	2	4	1	462	3	0	5	73
	8	85	2	4	1	8,416	53	0	108	74
	9	8	3	1	2	11,729	232	2	551	86
	All	1,149	84	203	24	172,334	38,184	17,729	49,233	21
All	**-**	**32,017**	**124**	**2,060**	**47**	**668,229**	**2,235,996**	**1,248,956**	**3,051,863**	**20**

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

	Region	
L_S	Core	Nearshore
1	0	0
2	0	0
3	0	0
4	0	0
5	667,895	0
6	296,968,038	4,728,472
7	3,554,272,853	39,943,859
8	12,432,116,940	51,948,230
9	29,065,634,300	79,734,397
10	25,632,382,890	166,702,066
11	11,650,326,085	893,956,011
12	30,509,134,701	860,733,228
13	26,142,957,433	250,610,771
14	9,673,296,890	56,452,414
15	715,539,669	257,977
16	136,425,482	125,663
17	0	0
18	0	0
19	0	0
20	0	0

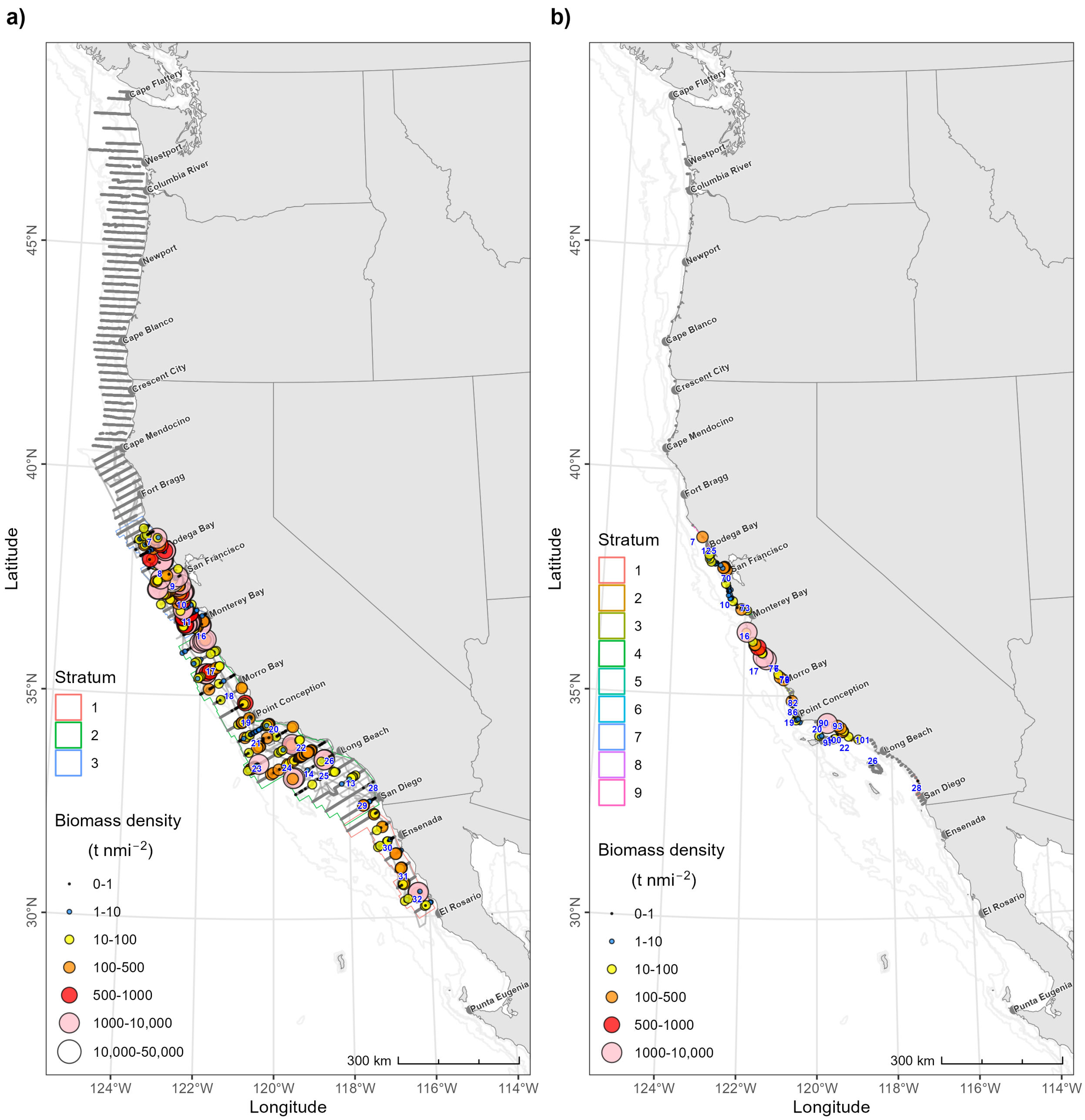

Figure 21: Biomass densities (colored points) of central stock of Northern Anchovy (*Engraulis mordax*), per stratum, in the a) core and b) nearshore survey regions. Overlaid are the locations of trawl clusters with at least one Northern Anchovy (blue numbers) in each stratum (colored polygons). Thick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

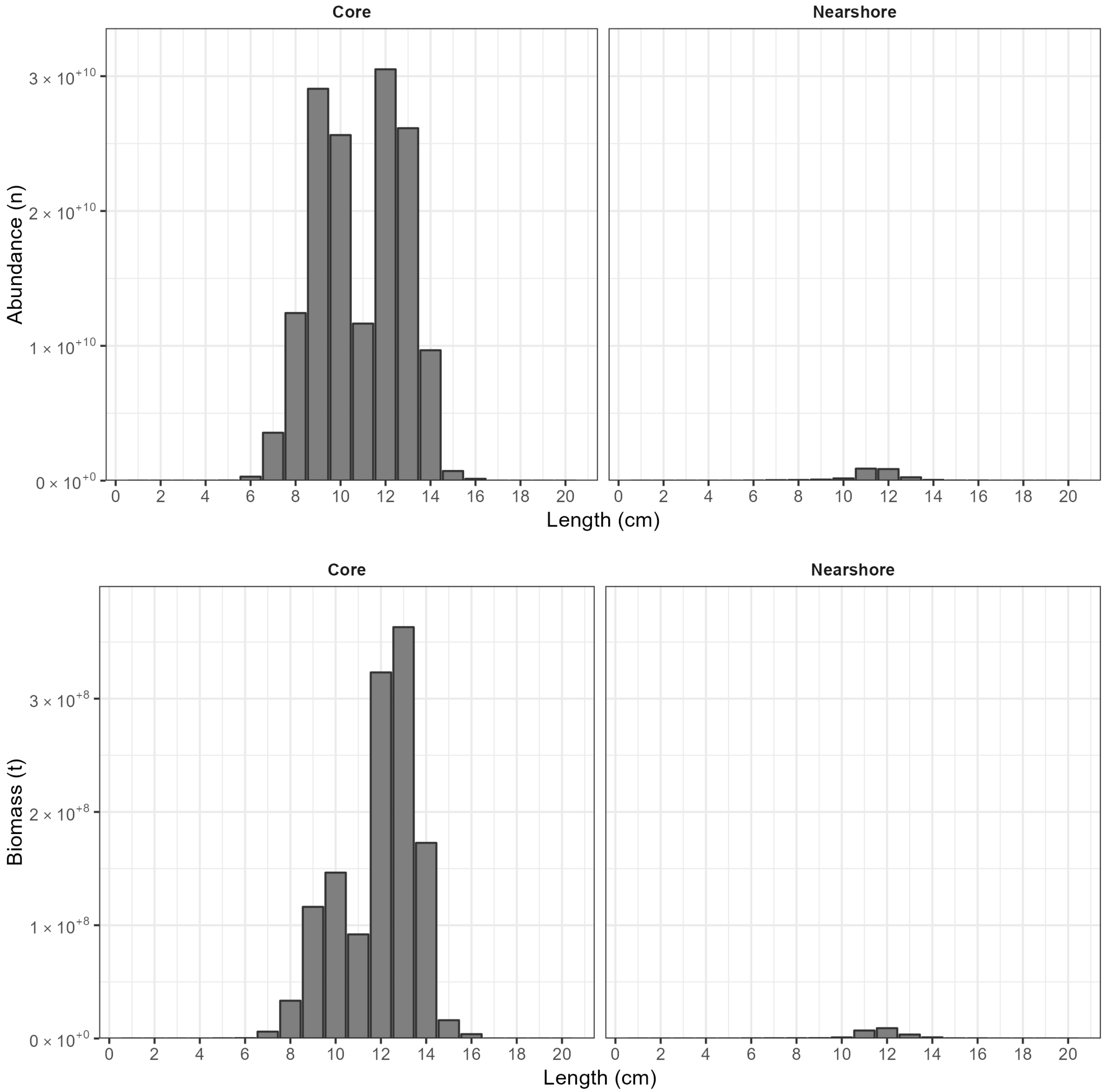

Figure 22: Abundance versus standard length (L_S, upper panels) and biomass (t) versus L_S (lower panels) for the central stock of Northern Anchovy (*Engraulis mordax*) in the core and nearshore survey regions.

3.6.2 Pacific Sardine

3.6.2.1 Northern stock

The total estimated biomass of the northern stock of Pacific Sardine was 69,506 t ($CI_{95\%}$ = 30,484 - 99,021 t, CV = 21%; **Table 9**). In the core region, biomass was 53,741 t ($CI_{95\%}$ = 29,672 - 84,749 t, CV = 26%; **Table 9**), was distributed from Westport to Point Conception, but was most abundant between the Columbia River and Newport (**Fig. 23a**). L_S ranged from 11 to 27 cm with a mode at 16 cm (**Table 10**, **Fig. 24**). In the nearshore region, biomass was 15,765 t ($CI_{95\%}$ = 812 - 14,272 t, CV = 23%; **Table 9**), comprising 23% of the total biomass. It was distributed mostly between San Francisco and Point Conception, with some present near Crescent City (**Fig. 23b**). L_S had two modes at 11 and 15 cm (**Table 10**, **Fig. 24**).

Table 9: Biomass estimates (metric tons, t) and their precisions (upper and lower 95% confidence intervals, $CI_{95\%}$; and coefficients of variation, CVs) for the northern stock of 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	4	4,985	11	410	4	401	4,838	1,145	9,466	45
	5	5,665	15	570	5	179	5,956	2,024	10,094	36
	6	16,113	36	1,672	13	1,056	42,946	20,342	72,916	32
	All	26,764	62	2,651	22	1,636	53,741	29,672	84,749	26
Nearshore	1	297	22	62	5	423	15,764	811	14,270	23
	2	9	3	2	2	52	0	0	1	61
	3	9	3	1	3	20	1	0	2	51
	All	315	28	65	10	495	15,765	812	14,272	23
All	**-**	**27,078**	**90**	**2,716**	**32**	**2,130**	**69,506**	**30,484**	**99,021**	**21**

Table 10: Abundance versus standard length (L_S, cm) for the northern stock of Pacific Sardine (*Sardinops sagax*) in the core and nearshore survey regions.

	Region	
L_S	Core	Nearshore
1	0	0
2	0	0
3	0	0
4	0	0
5	0	0
6	0	0
7	0	0
8	0	0
9	0	0
10	0	1,924,590
11	318,297	1,511,625
12	444,361	413,140
13	636,594	619,448
14	13,944,275	3,850,443
15	105,679,270	3,607,983
16	268,105,820	1,026,615
17	219,040,205	20,715
18	47,775,938	4,864
19	13,509,188	3,188
20	20,696,254	1,063
21	10,463,389	1,063
22	11,311,389	0
23	20,900,885	0
24	16,335,566	0
25	13,274,355	0
26	7,290,532	0
27	4,915,285	0
28	0	0
29	0	0
30	0	0

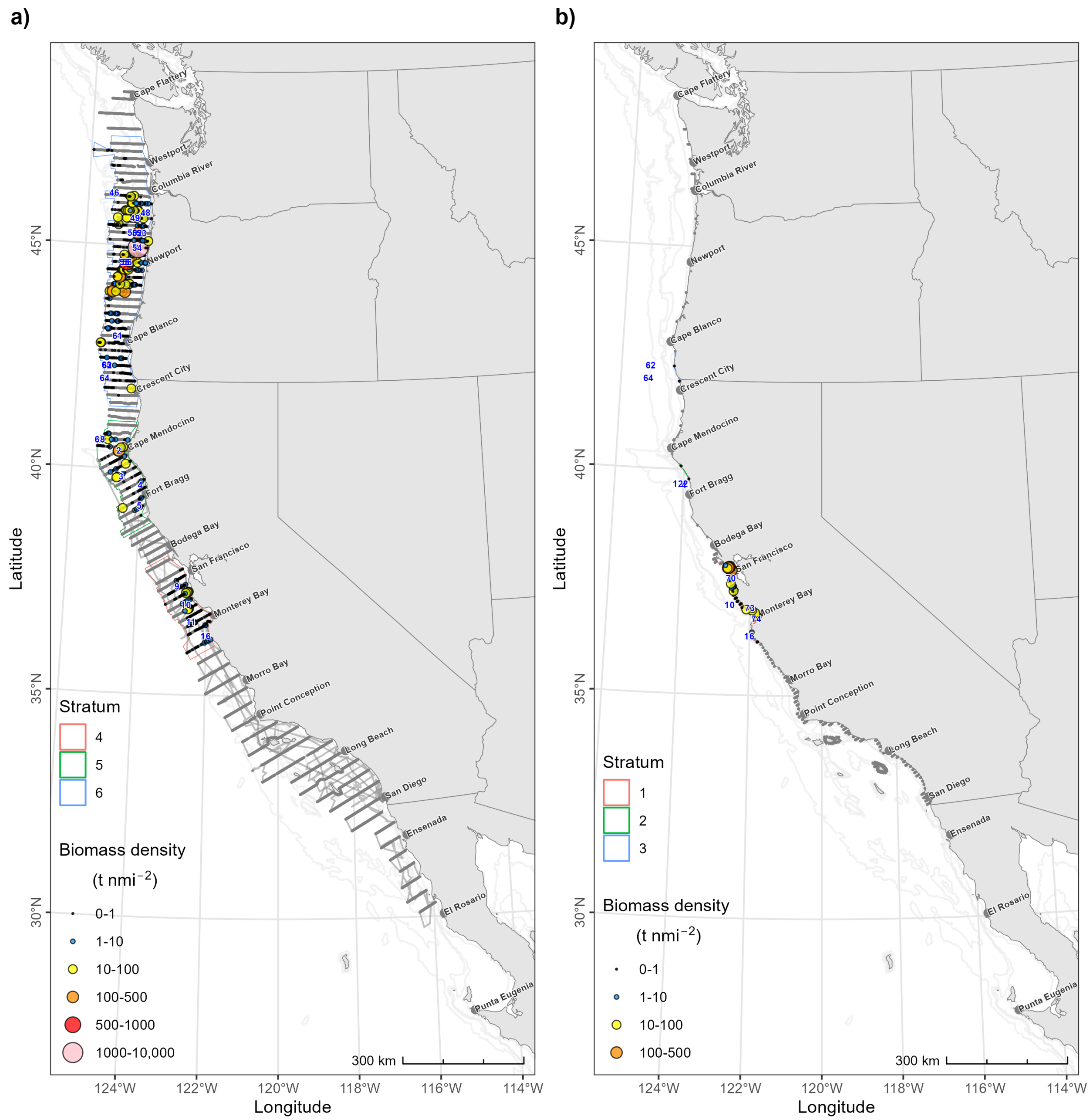

Figure 23: Biomass densities (colored points) of the northern stock of Pacific Sardine (*Sardinops sagax*), per stratum, in the a) core and b) nearshore survey regions. Overlaid are the locations of trawl clusters with at least one Pacific Sardine (blue numbers) in each stratum (colored polygons). Thick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

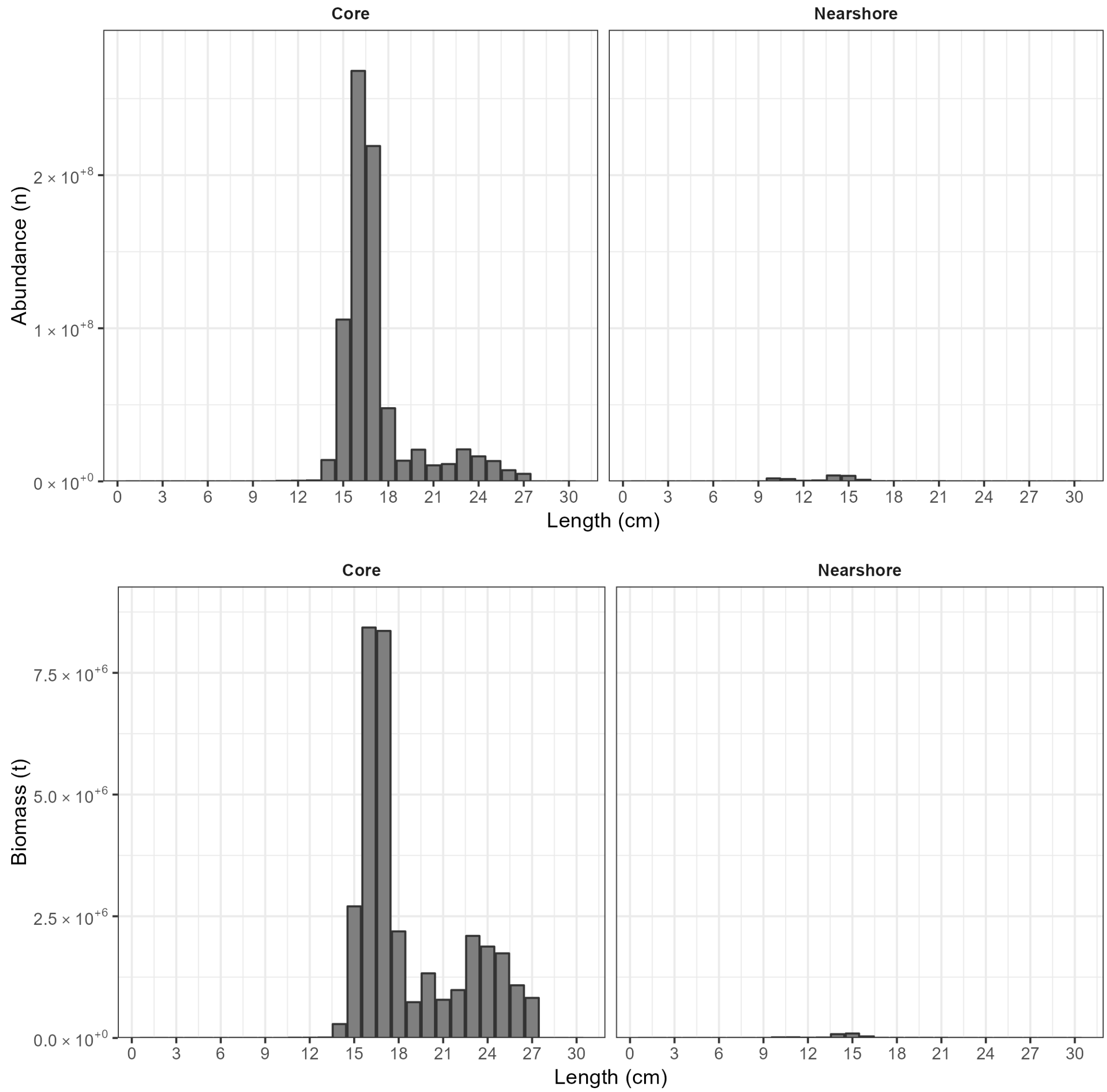

Figure 24: Estimated abundance (upper panel) and biomass (lower panel) versus standard length (L_S, cm) for the northern stock of Pacific Sardine (*Sardinops sagax*) in the core and nearshore survey regions.

3.6.2.2 Southern stock

The total estimated biomass of the southern stock of Pacific Sardine was 107,468 t ($CI_{95\%}$ = 47,994 - 178,947 t, CV = 23%; **Table 11**), of which 0.9% was observed in Mexican waters. In the core region, biomass was 40,206 t ($CI_{95\%}$ = 4,741 - 79,328 t, CV = 48%; **Table 11**), and was distributed from approximately San Francisco to El Rosario (**Fig. 25a**). L_S ranged from 9 to 21 cm with two modes, at 13 and 18 cm (**Table 12**, **Fig. 26**). In the nearshore region, biomass was 67,262 t ($CI_{95\%}$ = 43,253 - 99,620 t, CV = 23%; **Table 11**), comprising 63% of the total biomass. The nearshore biomass was distributed between Point Conception and San Diego, but was greatest near Santa Barbara, San Diego, and around Santa Cruz Island. The L_S in the nearshore region ranged from 10 to 21 cm and had modes at 12 and 16 cm (**Table 12**, **Fig. 26**).

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

Stratum					Trawl		Biomass			
Region	Number	Area	Transects	Distance	Clusters	Individuals	$\hat{B}$	$CI_{L,95\%}$	$CI_{U,95\%}$	CV
Core	1	2,611	5	131	2	200	376	68	674	40
	2	13,960	9	730	10	3,770	39,668	4,085	78,502	49
	3	3,555	4	177	1	2	161	7	425	75
	All	20,127	18	1,037	13	3,972	40,206	4,741	79,328	48
Nearshore	4	126	10	25	6	3,864	6,095	8,568	27,070	76
	5	491	45	114	20	713	51,182	19,167	70,237	28
	6	99	10	19	5	293	7,268	2,873	13,701	40
	7	99	7	15	6	343	1,958	765	3,855	43
	8	85	7	14	3	150	352	7	917	73
	9	85	9	19	5	214	408	79	870	50
	All	984	88	204	37	5,578	67,262	43,253	99,620	23
All	**-**	**21,111**	**106**	**1,241**	**50**	**9,549**	**107,468**	**47,994**	**178,947**	**23**

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

	Region	
L_S	Core	Nearshore
1	0	0
2	0	0
3	0	0
4	0	0
5	0	0
6	0	0
7	0	0
8	0	0
9	2,070,865	0
10	4,439,182	8,383,644
11	54,646,303	158,236,963
12	52,549,062	275,597,032
13	306,314,473	62,485,385
14	121,021,559	181,015,402
15	11,453,420	348,793,820
16	11,453,420	446,726,568
17	120,610,666	335,727,403
18	195,066,323	49,621,103
19	34,484,274	3,238,436
20	111,371	1,305,083
21	5,726,710	1,338,380
22	0	0
23	0	0
24	0	0
25	0	0
26	0	0
27	0	0
28	0	0
29	0	0
30	0	0

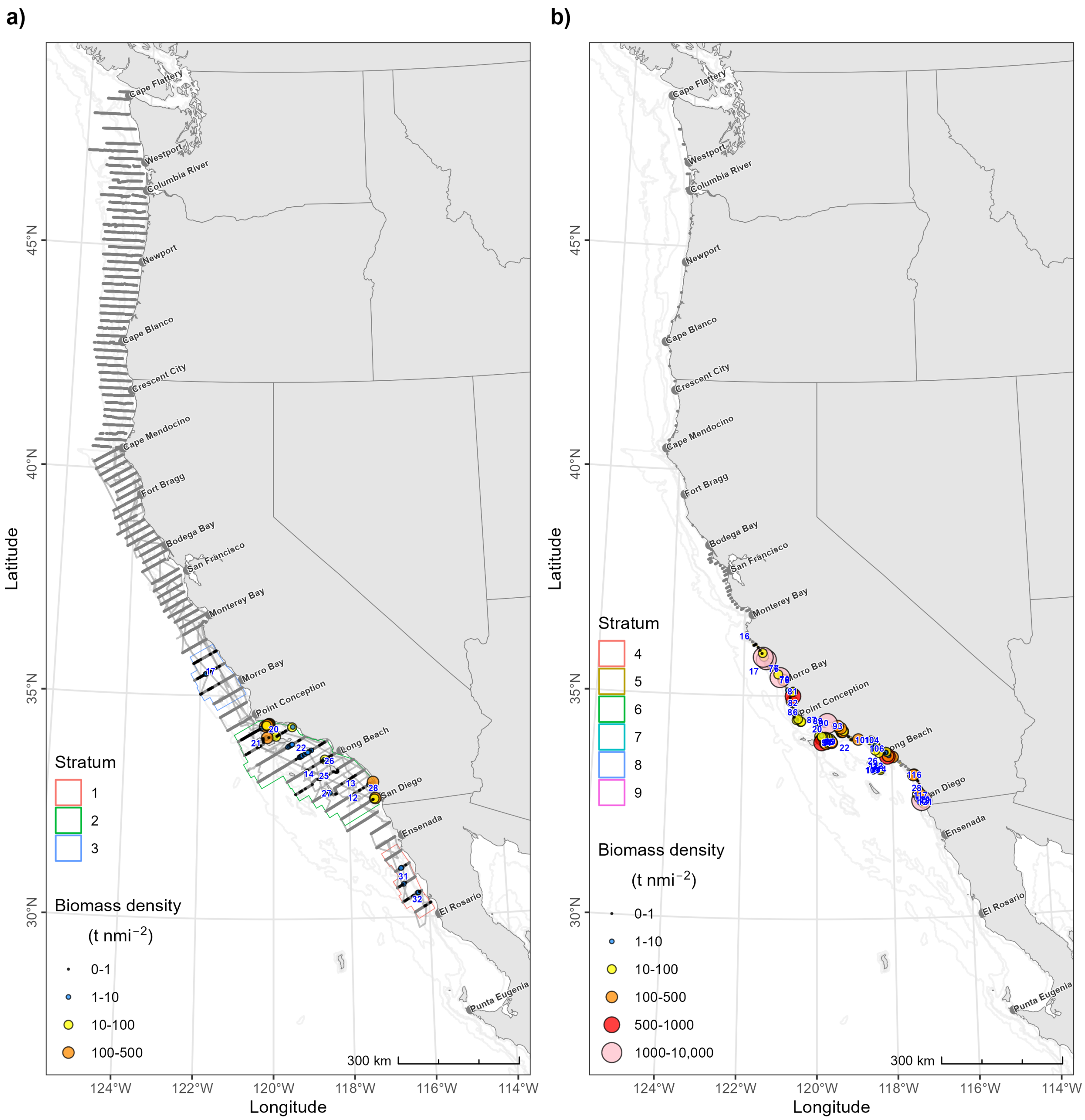

Figure 25: Biomass densities (colored points) of the southern stock of Pacific Sardine (*Sardinops sagax*), per stratum, in the a) core and b) nearshore survey regions. Overlaid are the locations of trawl clusters with at least one Pacific Sardine (blue numbers) in each stratum (colored polygons). Thick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

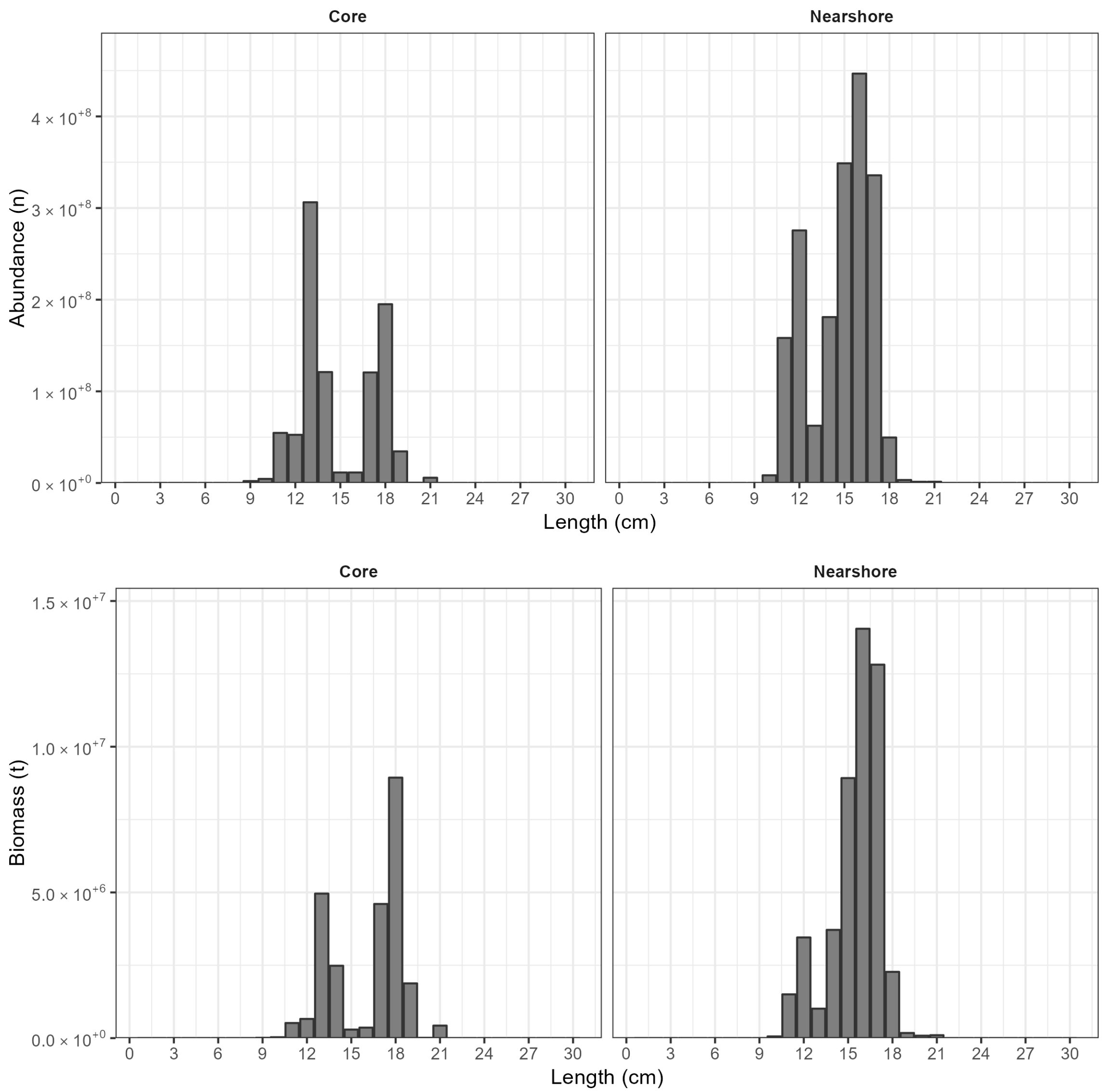

Figure 26: Estimated abundance (upper panels) and biomass (lower panels) versus standard length (L_S, cm) for the southern stock of Pacific Sardine (*Sardinops sagax*) in the core and nearshore survey regions.

3.6.3 Pacific Mackerel

The total estimated biomass of Pacific Mackerel was 7,968 t ($CI_{95\%}$ = 3,741 - 12,662 t, CV = 22%; **Table 13**), of which 27% was observed in Mexican waters. In the core region, biomass was 5,619 t ($CI_{95\%}$ = 2,851 - 9,108 t, CV = 29%) and was distributed from approximately Cape Mendocino to El Rosario, but was primarily located south of Point Conception (**Fig. 27a**). The distribution of L_F ranged from 8 to 38 cm with two modes at 11 and 15 cm (**Table 14**, **Fig. 28**). In the nearshore region, biomass was 2,349 t ($CI_{95\%}$ = 890 - 3,553 t, CV = 30%; **Table 13**, **Fig. 27b**), comprising 29% of the total biomass. It was distributed from Point Conception to San Diego, but was most abundant around Santa Cruz and Santa Catalina Islands. The distribution of L_F ranged from 8 to 35 cm and had modes at 18, 27, and 29 cm. The nearshore and total biomasses include uncertainties associated with the assumed nearshore-area (see **Section 2.2.5**) and the estimated species proportions from the daytime purse-seine sets (see **Section 3.5.1**), respectively. Therefore, it is not advised to use the Pacific Mackerel biomass from this survey for assessment purposes.

Table 13: 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	4,744	8	237	4	197	1,495	159	3,577	61
	2	16,400	12	851	10	122	3,981	1,772	6,926	34
	3	2,327	6	232	1	2	144	0	288	55
	All	23,470	26	1,321	14	321	5,619	2,851	9,108	29
Nearshore	1	185	17	40	5	61	328	17	505	41
	2	75	6	21	2	10	50	0	107	56
	3	37	3	11	1	4	0	0	0	49
	4	99	20	39	5	71	1,802	525	3,216	39
	5	85	19	39	9	142	168	51	325	41
	All	481	65	149	21	288	2,349	890	3,553	30
All	**-**	**23,950**	**91**	**1,470**	**35**	**610**	**7,968**	**3,741**	**12,662**	**22**

Table 14: Abundance versus fork length (L_F, cm) for Pacific Mackerel (*Scomber japonicus*) in the core and nearshore survey regions.

	Region	
L_F	Core	Nearshore
1	0	0
2	0	0
3	0	0
4	0	0
5	0	0
6	0	0
7	0	0
8	41,652,930	161,497
9	35,946,448	322,994
10	25,256,609	0
11	77,660,304	646,051
12	35,867,089	322,994
13	4,933,957	62
14	9,969,569	607
15	16,472,665	1,523,075
16	8,636,305	5,467,389
17	5,295,350	5,797,579
18	6,909,912	7,201,154
19	2,968,101	1,145,259
20	1,677,292	165,231
21	2,633,347	94,314
22	1,210,878	107,018
23	948,000	28,320
24	215,911	196,712
25	107,943	393,425
26	0	575,014
27	136,551	1,522,636
28	0	693,934
29	0	1,009,929
30	0	30,972
31	152,226	331,481
32	0	46,458
33	0	15,486
34	0	15,486
35	0	46,458
36	0	0
37	0	0
38	152,226	0
39	0	0
40	0	0

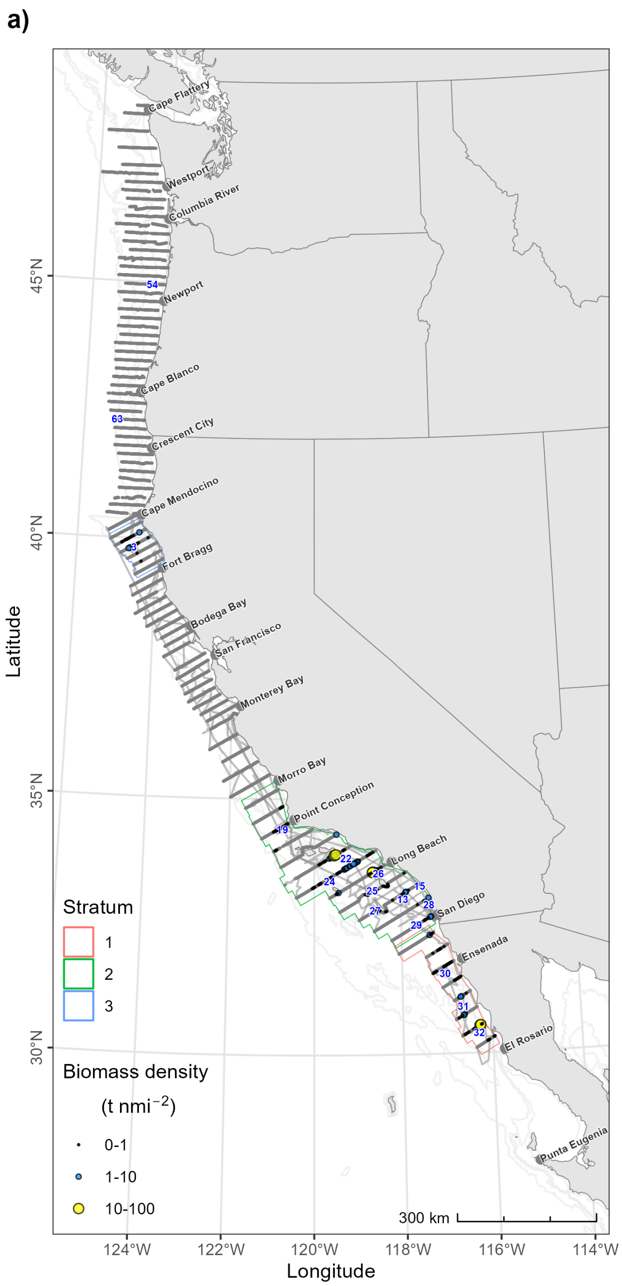

Figure 27: Biomass densities (colored points) of Pacific Mackerel (*Scomber japonicus*), per stratum, in the a) core and b) nearshore survey regions. Overlaid are the locations of trawl clusters with at least one Pacific Mackerel (blue numbers) in each stratum (colored polygons). Thick gray lines represent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

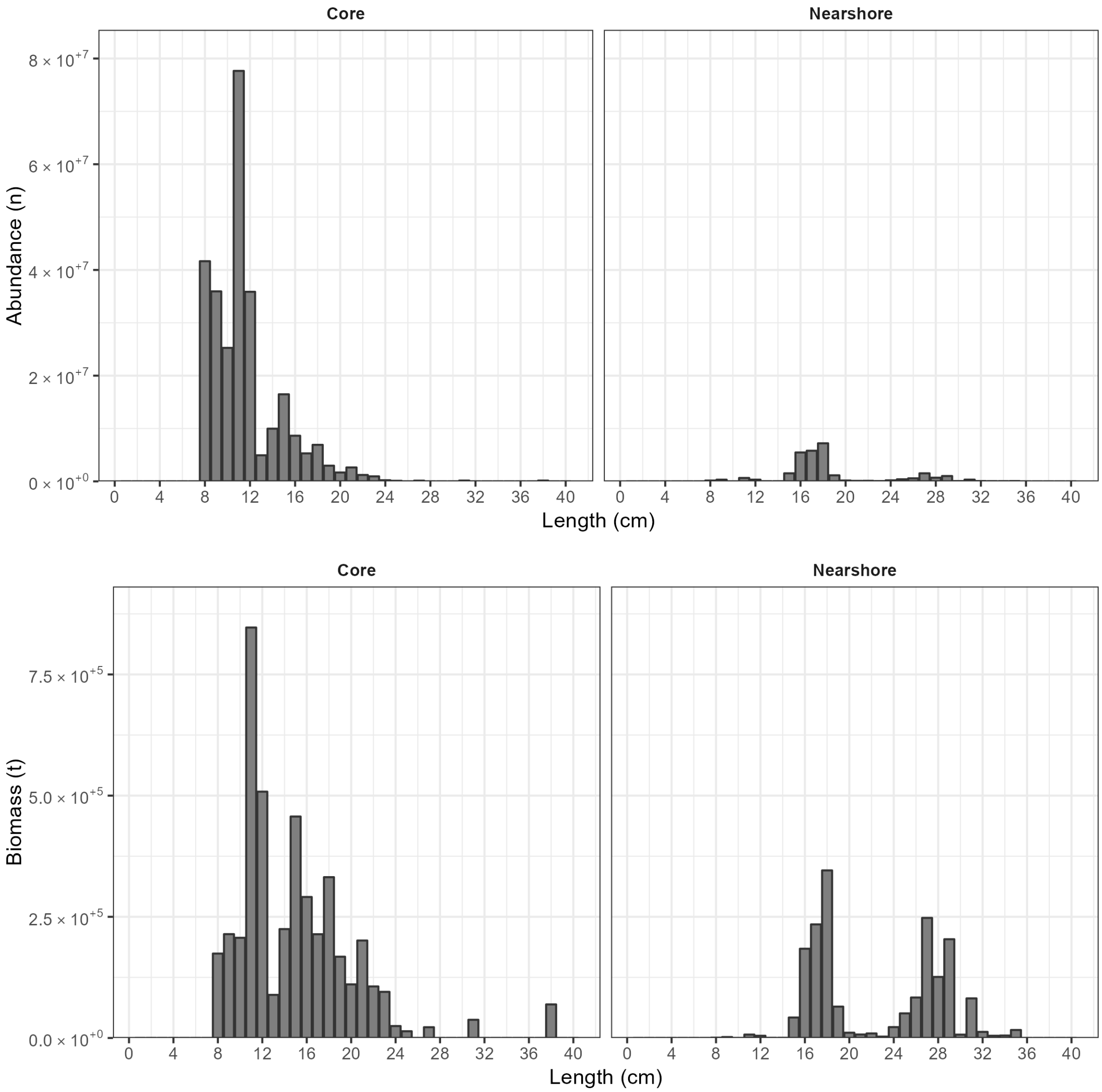

Figure 28: Estimated abundance (upper panels) and biomass (lower panels) versus fork length (L_F, cm) for Pacific Mackerel (*Scomber japonicus*) in the core and nearshore survey regions.

3.6.4 Jack Mackerel

The total estimated biomass of Jack Mackerel was 807,090 t ($CI_{95\%}$ = 515,560 - 1,145,812 t, CV = 20%; **Table 15**), of which 0.06% was observed in Mexican waters. In the core region, the biomass was 799,082 t ($CI_{95\%}$ = 512,231 - 1,132,052 t, CV = 20%; **Table 15**). It was distributed throughout the survey area from the Columbia River to El Rosario, but were most abundant between Astoria and Bodega Bay. (**Fig. 29a**). L_F ranged from 3 to 51 cm, with modes at 8 and 34 cm. (**Table 16**, **Fig. 30**). In the nearshore region, the biomass was 8,009 t ($CI_{95\%}$ = 3,328 - 13,761 t, CV = 35%; **Table 15**), comprising 0.99% of the total biomass. It was distributed from Point Conception to San Diego, but was most abundant near Long Beach and around Santa Cruz Island (**Fig. 29b**), and had a length mode at 19 cm (**Table 16**, **Fig. 30**). A small amount of biomass was present in the nearshore region near Fort Bragg. The nearshore and total biomasses include uncertainties associated with the assumed nearshore-area (see **Section 2.2.5**) and the estimated species proportions from the daytime purse-seine sets (see **Section 3.5.1**), respectively. Therefore, it is not advised to use the Jack Mackerel biomass from this survey for assessment purposes.

Table 15: 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	4,744	8	237	3	16	465	3	1,034	57
	2	19,805	16	1,020	18	1,478	25,551	12,637	39,938	27
	3	2,504	7	256	2	4	94	12	185	49
	4	24,712	59	2,539	11	333	772,972	488,717	1,104,653	21
	All	51,764	90	4,052	32	1,831	799,082	512,231	1,132,052	20
Nearshore	1	185	17	40	6	16	318	55	467	34
	2	85	2	4	1	1	5,589	0	0	0
	3	85	3	6	1	28	1,835	0	160	2
	5	85	2	4	2	20	55	0	2	1
	6	71	5	19	1	10	20	0	76	102
	7	37	3	11	1	81	1	0	1	16
	8	66	10	17	2	34	36	1	8	6
	9	69	6	15	1	3	0	0	0	12
	10	99	7	13	2	45	4	1,317	11,409	64,364
	11	99	12	24	4	120	0	604	3,165	769,833
	12	8	3	1	1	68	24	0	58	87
	13	3	2	0	1	146	75	0	105	40
	14	9	3	1	1	1	52	1	97	51
	All	900	75	155	21	573	8,009	3,328	13,761	35
All	**-**	**52,664**	**165**	**4,207**	**53**	**2,404**	**807,090**	**515,560**	**1,145,812**	**20**

Table 16: Abundance versus fork length (L_F, cm) for Jack Mackerel (*Trachurus symmetricus*) in the core and nearshore survey regions.

	Region	
L_F	Core	Nearshore
1	0	0
2	0	0
3	241,794	0
4	1,419,851	0
5	629,808	0
6	86,626,388	9,501
7	413,381,593	2,696,403
8	561,261,791	602,429
9	297,229,109	252,294
10	116,464,804	108,161
11	116,535,707	1,333,800
12	161,670,180	5,154,860
13	30,428,028	5,290,971
14	39,476,650	3,717,705
15	24,562,868	16,354,113
16	29,829,944	11,423,912
17	10,578,404	19,428,435
18	11,748,959	20,718,304
19	18,663,528	38,024,306
20	12,779,069	5,405,898
21	8,948,724	314,591
22	5,960,163	543,747
23	13,276,594	816,105
24	3,864,777	813,187
25	2,233,347	271,022
26	0	0
27	8,614,274	2,372
28	15,158,763	2,667
29	18,108,237	2,805
30	24,446,401	10,388
31	51,218,487	6,277
32	51,901,530	13,830
33	96,540,428	24,229
34	215,042,403	27,179
35	160,101,796	39,669
36	187,761,602	55,110
37	148,046,781	30,005
38	45,002,461	26,162
39	36,409,165	30,295
40	7,764,248	8,287
41	17,836,083	4,482
42	13,856,657	2,667
43	4,961,080	0
44	3,917,073	1,704
45	6,795,860	0
46	260,788	0
47	260,788	0

Table 16: Abundance versus fork length (L_F, cm) for Jack Mackerel (*Trachurus symmetricus*) in the core and nearshore survey regions. *(continued)*

L_F	Core	Nearshore
48	4,166,132	0
49	3,027,970	0
50	1,538,823	0
51	139,570,655	0
52	0	0
53	0	0
54	0	0
55	0	0
56	0	0
57	0	0
58	0	0
59	0	0
60	0	0

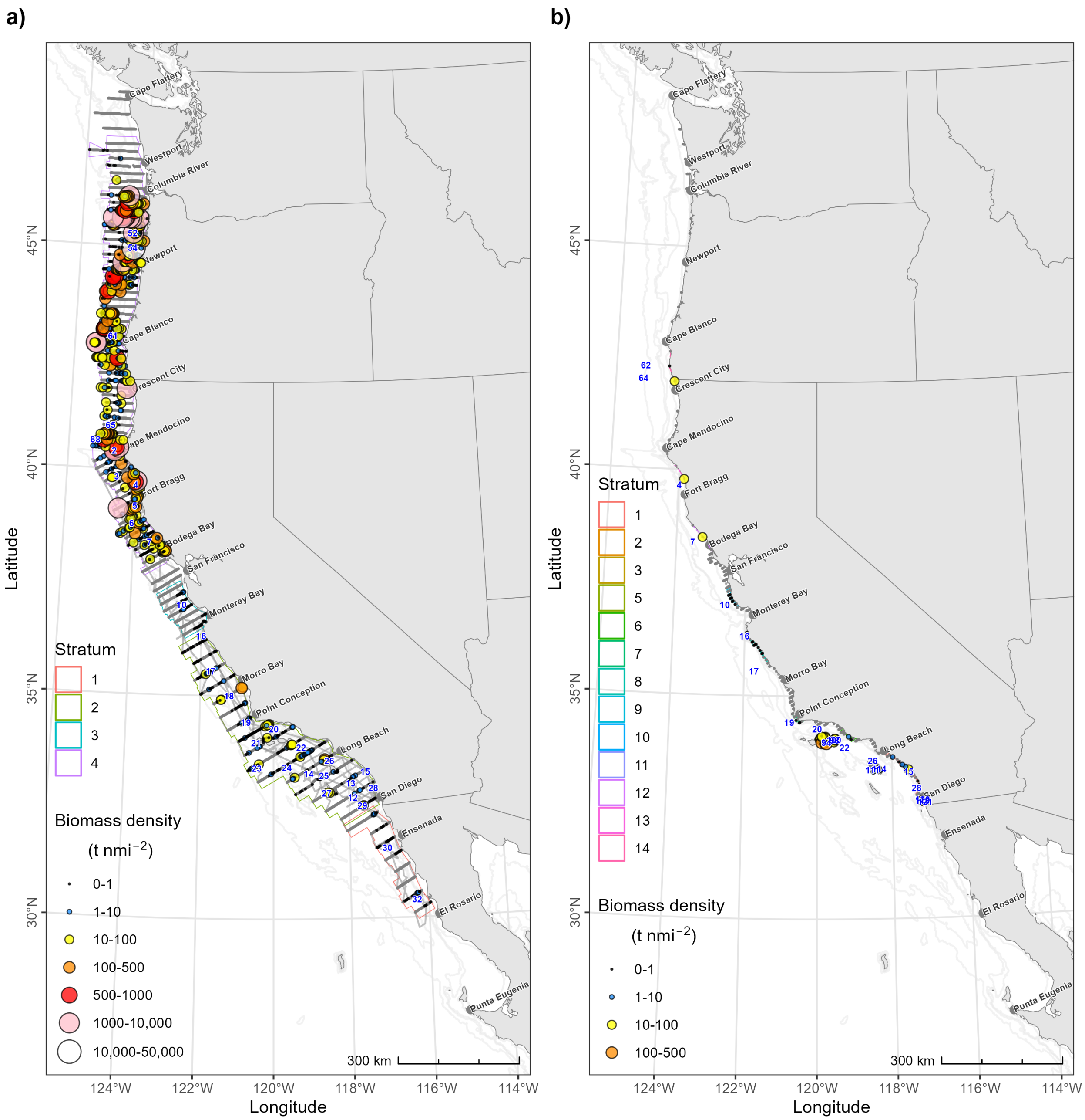

Figure 29: Biomass densities (colored points) of Jack Mackerel (*Trachurus symmetricus*), per stratum, in the a) core and b) nearshore survey regions. Overlaid are the locations of trawl clusters with at least one Jack Mackerel (blue numbers) in each stratum (colored polygons). Thick gray lines represent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

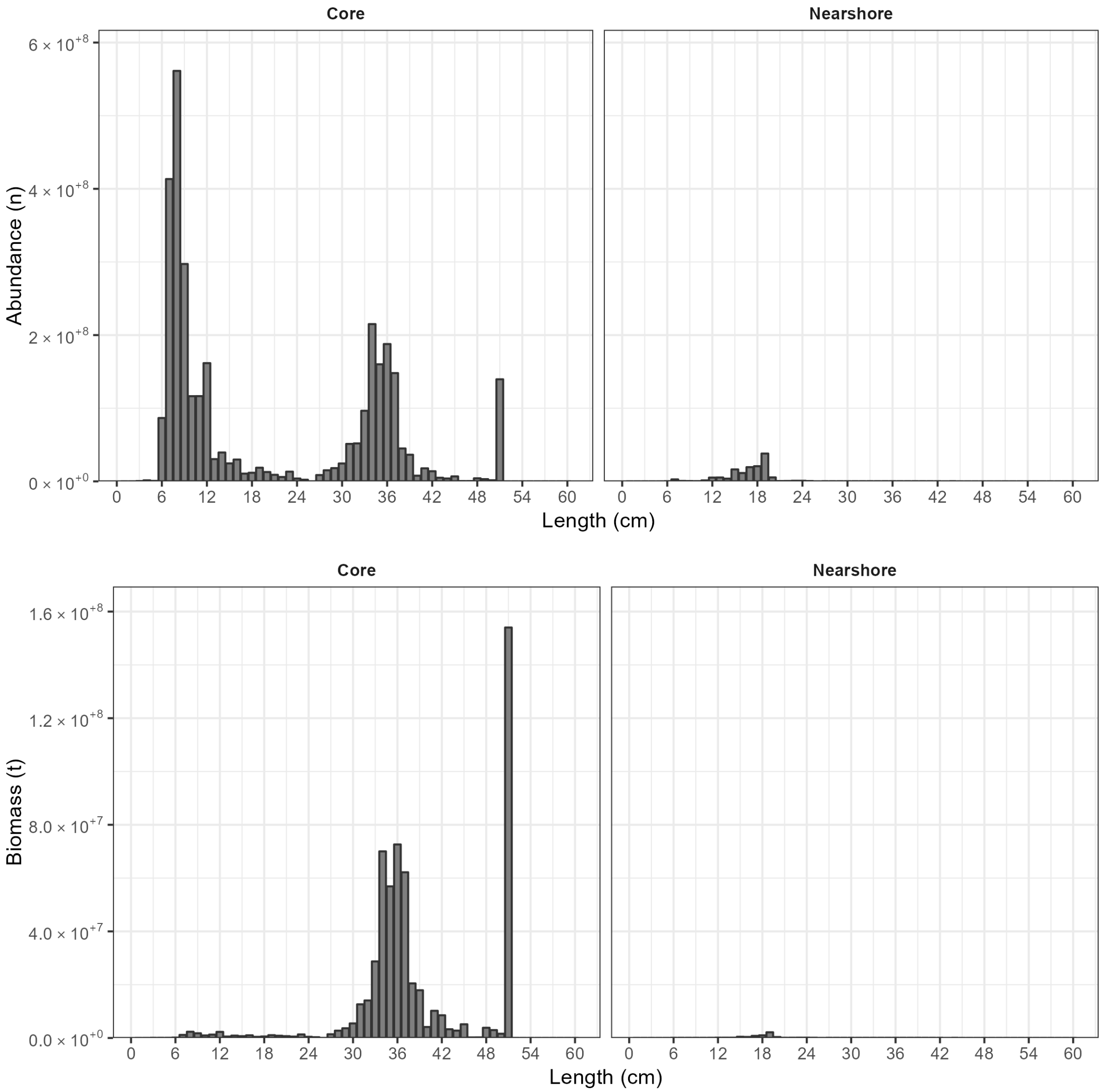

Figure 30: Estimated abundance (upper panel) and biomass (lower panel) versus fork length (L_F, cm) for Jack Mackerel (*Trachurus symmetricus*) in the core and nearshore survey regions.

3.6.5 Pacific Herring

The total estimated biomass of Pacific Herring was 50,718 t ($CI_{95\%}$ = 14,461 - 99,700 t, CV = 41%; **Table 17**). In the core region, biomass was 47,024 t ($CI_{95\%}$ = 13,306 - 93,207 t, CV = 44%; **Table 17**). It was distributed from approximately Cape Flattery to Cape Mendocino, but was most abundant from Cape Flattery to the Columbia River, and between Crescent City and Cape Mendocino (**Fig. 31a**). L_F ranged from 13 to 17 cm, with modes at 13 and 17 cm (**Table 18**, **Fig. 32**). In the nearshore region, biomass was 3,694 t ($CI_{95\%}$ = 1,154 - 6,493 t, CV = 36%; **Table 17**, **Fig. 31b**), or 7.3% of the total biomass. It was distributed from Cape Flattery to Cape Mendocino (**Fig. 32**), and the distribution of L_F ranged from 13 to 17 cm and had a mode at 14 cm (**Table 18**, **Fig. 32**).

Table 17: 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	3,308	9	351	1	6	5,130	1,206	10,319	48
	2	2,087	4	227	1	1	23,177	0	70,776	85
	3	6,911	13	562	3	699	18,717	6,630	26,433	26
	All	12,305	26	1,140	5	706	47,024	13,306	93,207	44
Nearshore	1	27	5	3	1	6	163	2	357	60
	2	146	5	9	3	699	3,531	916	6,295	37
	All	172	10	13	4	705	3,694	1,154	6,493	36
All	**-**	**12,478**	**36**	**1,153**	**9**	**1,411**	**50,718**	**14,461**	**99,700**	**41**

Table 18: Abundance versus fork length (L_F, cm) for Pacific Herring (*Clupea pallasii*) in the core and nearshore survey regions.

	Region	
L_F	Core	Nearshore
1	0	0
2	0	0
3	0	0
4	0	0
5	0	0
6	0	0
7	0	0
8	0	0
9	0	0
10	0	0
11	0	0
12	0	0
13	37,385,309	10,751,591
14	201,859,877	48,768,596
15	284,781,511	37,138,321
16	115,944,703	15,045,190
17	481,156,110	1,429,211
18	0	0
19	0	0
20	0	0
21	0	0
22	0	0
23	0	0
24	0	0
25	0	0
26	0	0
27	0	0
28	0	0
29	0	0
30	0	0

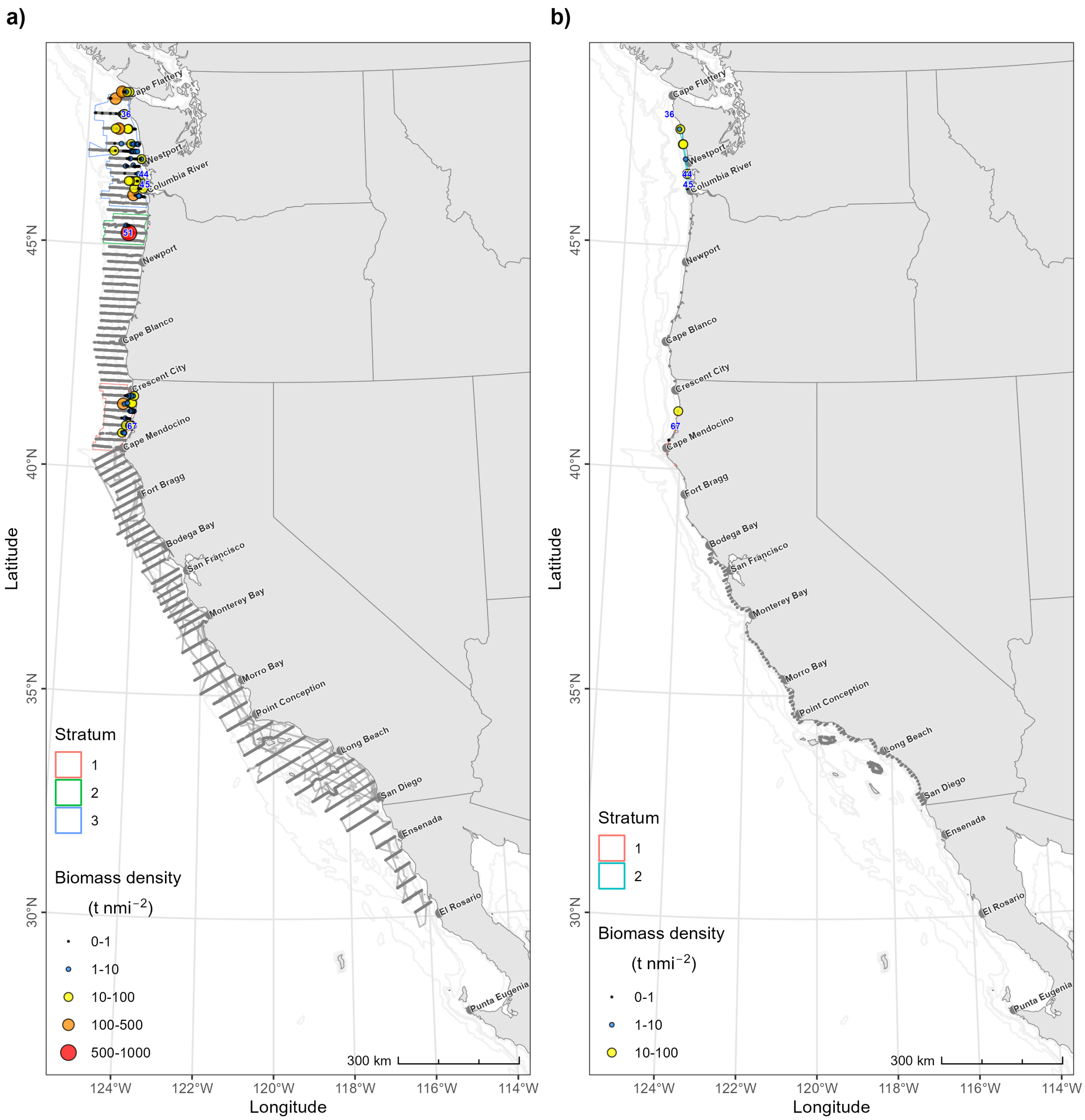

Figure 31: Biomass densities (colored points) of Pacific Herring (*Clupea pallasii*), per stratum, in the a) core and b) nearshore survey regions. Overlaid are the locations of trawl clusters with at least one Pacific Herring (blue numbers) in each stratum (colored polygons). Thick gray lines represent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

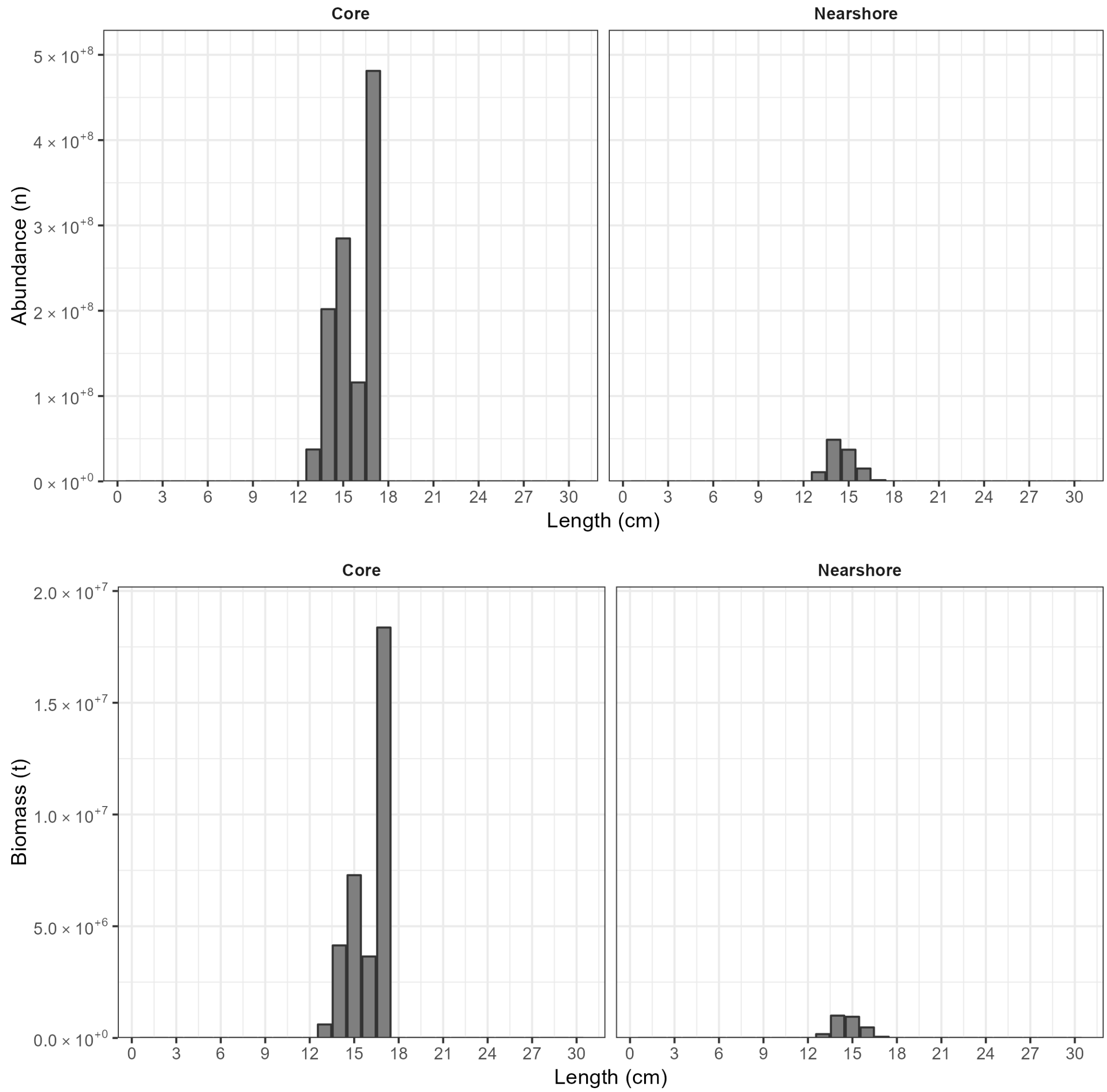

Figure 32: Estimated abundance (upper panel) and biomass (lower panel) versus fork length (L_F, cm) for Pacific Herring (*Clupea pallasii*) in the core and nearshore survey regions.

4 Discussion

The principal objectives of the 75-day, summer 2022 CCE Survey were to estimate the biomasses and distributions of the northern and southern stocks of Pacific Sardine and the northern and central stocks of Northern Anchovy. Secondary objectives were to produce estimates for Pacific Mackerel, Jack Mackerel, and Pacific Herring within the survey area at the time of the survey.

Despite inclement weather conditions, mechanical limitations, staffing issues, and logistical challenges related to the COVID-19 pandemic, and the loss of nearly half of the allocated sea days aboard *Lasker*, the core region was surveyed by *Lisa Marie* and two USVs from Cape Flattery to Bodega Bay, and by *Lasker* between Cape Mendocino and El Rosario off Baja CA. Following the cancellation of Leg 1, the decision was made to forgo sampling off Vancouver Island to maximize the likelihood of surveying all of the transects in U.S. waters. To mitigate the loss of acoustic sampling effort north of Cape Mendocino, the decision was made to have *Lisa Marie* and two USVs acoustically sample along *Lasker*'s compulsory transects in tandem, and daytime purse-seine sampling was conducted by *Lisa Marie* to provide information about the distribution, species composition, and length distribution of CPS. This approach deviated from the standard ATM surveys, which created additional challenges and uncertainty (see **Section 3.5.1** and **Fig. 13**). For example, net avoidance by fast-swimming species, such as Jack Mackerel, required a novel method to adjust species proportions in that region to minimize uncertainty in the biomass estimates. For this reason, it is not advised to use the biomasses of Jack Mackerel or Pacific Mackerel for assessment purposes.

4.1 Biomass and abundance

4.1.1 Northern Anchovy

4.1.1.1 Northern stock The estimated biomass of the northern stock of Northern Anchovy in the survey region north of Cape Mendocino was 16,432 t ($CI_{95\%}$ = 5,646 - 27,680 t) in summer 2022. The northern stock biomass has comprised a small fraction (0.1 to 5.4%) of the total biomass in the ATM surveys conducted in the CCE since at least 2015 (Stierhoff *et al.*, 2021a).

4.1.1.2 Central stock The estimated biomass of the central stock of Northern Anchovy in the survey region was 2,235,996 t ($CI_{95\%}$ = 1,248,956 - 3,051,863 t) and comprised 68% of the total CPS biomass in summer 2022. The biomass represents a ~20% decrease from the 2,721,689 t estimated in summer 2021 (Stierhoff *et al.*, 2023). In summer 2022, 6% of the central stock Northern Anchovy biomass was observed in Mexican waters. In 2015, the ATM survey documented a large recruitment to the central stock of Northern Anchovy, and since 2018, the central stock of Northern Anchovy has been the dominant forage fish species in the survey area (**Figs. 35a,b**).

4.1.2 Pacific Sardine

4.1.2.1 Northern stock The boundary between the northern and southern stocks of Pacific Sardine was Big Sur, based foremost on associations with potential habitat but corroborated by the distributions of biomass density north and south of Point Conception, and differences in length distribution (**Fig. 33**). The estimated biomass of 69,506 t ($CI_{95\%}$ = 30,484 - 99,021 t) in the survey region was a 46% increase in biomass compared to the 47,721 t estimated in summer 2021 (Stierhoff *et al.*, 2023). Since 2014, the ATM biomass of the northern stock of Pacific Sardine has remained less than the 150,000 t rebuilding target adopted by the Pacific Fishery Management Council in 2020[5] (**Figs. 35a,b**).

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

4.1.2.2 Southern stock

The estimated biomass of the southern stock of Pacific Sardine in the survey region was 107,468 t ($CI_{95\%}$ = 47,994 - 178,947 t). In summer 2022, 106,930 t (core stratum 2 and all nearshore strata; 99% of the total biomass) of southern stock biomass was observed in U.S. waters, and the remaining 376 t (stratum 1; 0.9% of the total biomass) was observed off Baja CA. Of the portion in U.S. waters in summer 2022, 67,262 t (63%) occurred in the nearshore region. Notably, the survey area may not have spanned the latitudinal distribution of this stock, and no nearshore sampling was conducted in the nearshore region off Baja CA.

The southern stock was first observed in U.S. waters by the SWFSC's ATM surveys in 2016 (323 t, Stierhoff *et al.*, 2021b). Since then, the southern stock biomass in U.S. waters has been increasing, from 33,093 t in summer 2018 (Stierhoff *et al.*, 2021b) to 107,468 t in summer 2022. In summer 2017, the summer survey did not extend into the SCB (Zwolinski *et al.*, 2019), and no summer survey was conducted in 2020 due to COVID-19.

4.1.3 Pacific Mackerel

In summer 2022, the estimated biomass of Pacific Mackerel in the survey region was 7,968 t ($CI_{95\%}$ = 3,741 - 12,662 t), which is lower than recent estimates (21,998 - 42,423 between 2016 and 2021, and the lowest biomass observed since 2015 (1,224 t, Stierhoff *et al.*, 2021a).

4.1.4 Jack Mackerel

In summer 2022, the estimated biomass of Jack Mackerel in the survey region, south of Cape Flattery, was 807,090 t ($CI_{95\%}$ = 515,560 - 1,145,812 t), which is 1.4-fold higher than 569,793 t estimated in summer 2021 (Stierhoff *et al.*, 2023). In summer 2022, Jack Mackerel was the second most abundant CPS overall, and comprised 24% of the total CPS biomass (**Figs. 35a,b**).

4.1.5 Pacific Herring

In summer 2022, the estimated biomass of Pacific Herring in U.S. waters south of Cape Flattery, was 50,718 t ($CI_{95\%}$ = 14,461 - 99,700 t), which was 75% of the 67,920 t estimated in summer 2021 (Stierhoff *et al.*, 2023).

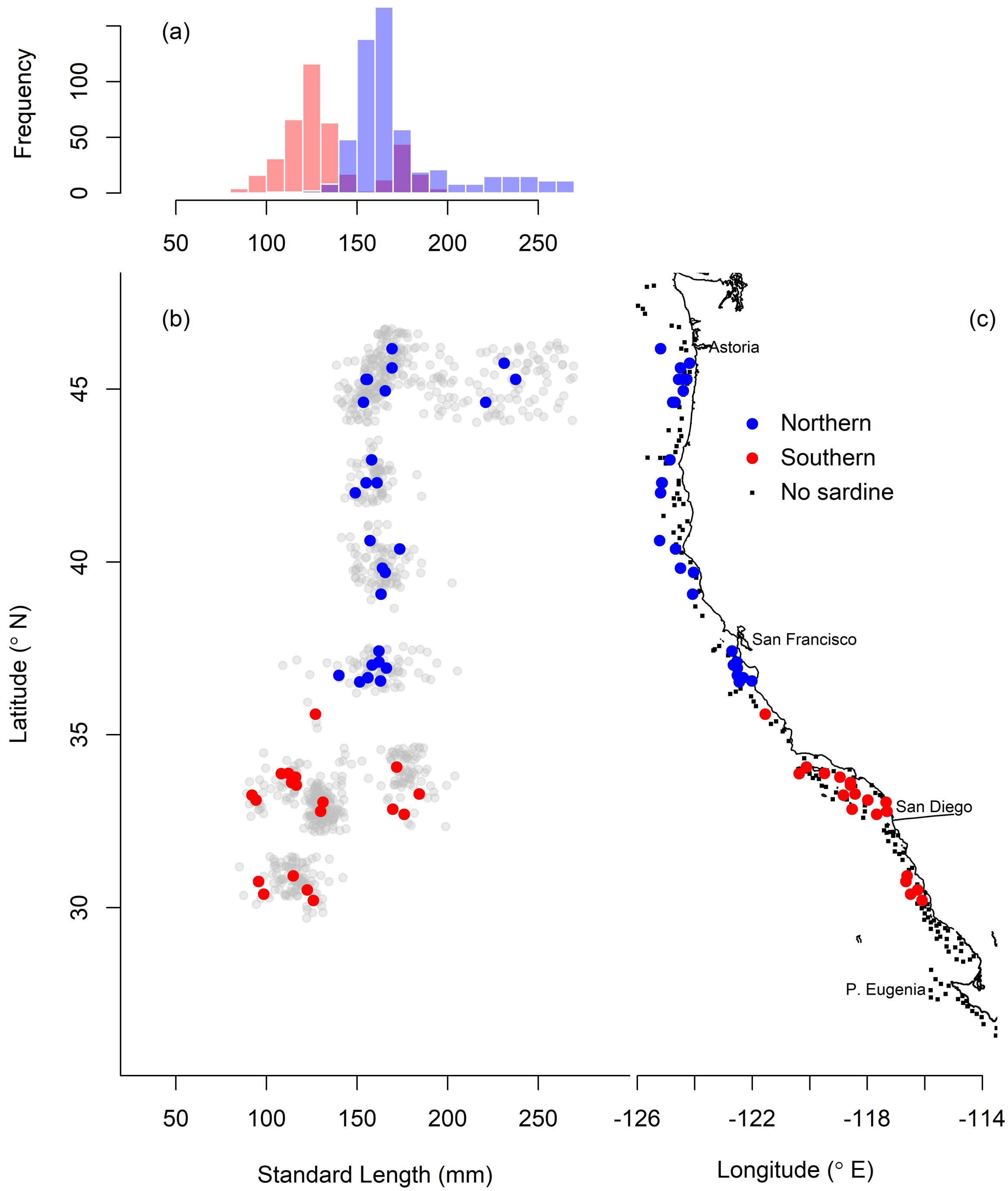

Figure 33: Differentiation of northern (blue) and southern (red) stocks of Pacific Sardine by: a) length distributions; b) individual (grey points) and catch-mean (colored points) lengths at the latitudes of their respective trawls; and c) geographic locations of trawls catches with (colored points) and without (black points) Pacific Sardine.

4.2 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 stock of Pacific Sardine (Hill *et al.*, 2017); northern (Mais, 1974, 1977) and central stocks (Kuriyama *et al.*, 2022) of Northern Anchovy; and Pacific Mackerel (Crone *et al.*, 2019; Crone and Hill, 2015). The proportions of these stocks that are in water too shallow to be sampled by NOAA ships are estimated using samples collected from fishing vessels and USVs. Also, concurrent satellite- and ship-based measures of their biotic and abiotic habitats are used to provide an ecosystem perspective.

Collectively, these annual or bi-annual ATM surveys provide a unique insight into the dynamics of forage fishes in the CCE, including their distributions, abundances, interactions, and environments. For example, results from 2006 through 2013 indicate that Pacific Sardine dominated the CPS assemblage, but their biomass was declining (Demer and Zwolinski, 2012; Zwolinski and Demer, 2012) and their seasonal migration was contracting (Zwolinski *et al.*, 2014). Meanwhile, harvest rates for the declining stock increased (Demer and Zwolinski, 2017), and the total forage-fish biomass decreased to less than 200,000 t in 2014 and 2015 (**Figs. 35a,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*[6]), Common Murres (*Uria aalge*), Brandt's Cormorants (*Phalacrocorax penicillatus*), and California sea lions (*Zalophus californianus*[7]) (McClatchie *et al.*, 2016), all of which depend on forage species. The National Marine Fisheries Service deemed the stock 'overfished' in 2019.

The biomass of the central stock of Northern Anchovy, which had been growing rapidly since 2015, decreased ~20% from the 2,721,689 t estimated in summer 2021 (Stierhoff *et al.*, 2023). Jack Mackerel, which were found mostly north of Cape Mendocino, included an abundance of apparently age-0 fish farther south, suggesting a strong recruitment. The southern stock of Pacific Sardine was found mostly north of the U.S.-Mexico border and nearshore, although nearshore waters in Mexico were not sampled. Even considering the additional uncertainties in the biomass estimates north of Cape Mendocino (see **Section 2.2.5**, **Section 3.5.1**, and **Fig. 13**) there is no indication that the biomasses of the northern stock of Pacific Sardine and the northern stock of Northern Anchovy have changed significantly since summer 2021.

The survey time series of estimated CPS biomasses from summer 2008 to 2022 shows that the forage fish assemblage in the CCE was dominated by the northern stock of Pacific Sardine until 2013 and a low biomass of Jack Mackerel in 2014 and 2015 (**Figs. 35a,b**). Since 2016, the forage-fish biomass has increased, mainly due to resurgences of Jack Mackerel and the now dominant central stock of Northern Anchovy (**Figs. 35a,b**), whose biomass primarily (1,025,686 t, or 47% of the total estimate biomass) occurred in U.S. waters. In 2022, as it was a half century ago (Mais, 1974, 1977), the CPS assemblage is now mostly composed of Northern Anchovy and to a lesser extent Jack Mackerel. Between the summers of 2018 and 2021, the biomass of the southern stock of Pacific Sardine in U.S. waters has increased from 33,093 to 106,930 t.

Since the resurgence of the central stock of Northern Anchovy, beginning in 2015, there has been consistency in the regional distributions of the three dominant species: Northern Anchovy, Jack Mackerel and Pacific Herring (**Fig. 34**). Pacific Herring are caught mostly north of central Washington. Lower biomasses of northern stock Pacific Sardine and northern stock Northern Anchovy are resident off Oregon and Northern California. Jack mackerel are caught between central Washington and Cape Mendocino, often along with fewer northern stock Pacific Sardine in recent years. Central stock Northern Anchovy are caught south of Cape Mendocino and, with the exception of summer 2021, mostly south of Bodega Bay. The smaller northern stock is resident from central Washington to northern California. The summer 2022 distribution

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

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

of Northern Anchovy appears to have shifted south, better aligning with its distributions during 2015-2019. In contrast to earlier surveys in the time series, the southern stock of Pacific sardine has been persistently present during summer surveys in U.S. waters, mostly in the Southern California Bight (**Fig. 34**).

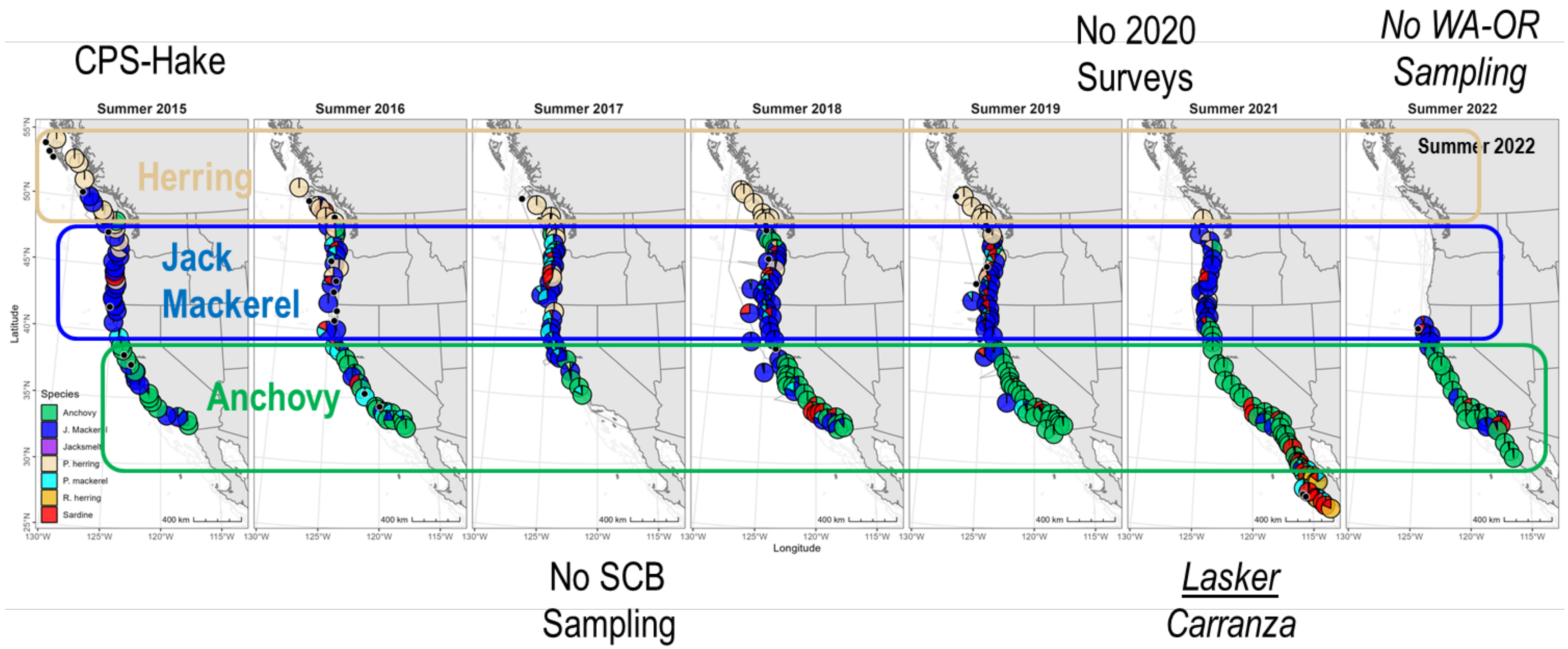

Figure 34: Distributions of species proportions in *Lasker*'s nighttime trawl catches, summer 2015 through 2022. In 2015, the integrated CPS-hake survey sample northward of Vancouver Island. In 2017, there was no sampling in the SCB. In 2020, there was no survey due to the COVID-19 pandemic. In 2021, through a collaboration with Mexico, the CPS survey extended farther south into Baja California. In 2022, there was no nighttime trawl sampling north of Cape Mendocino, California.

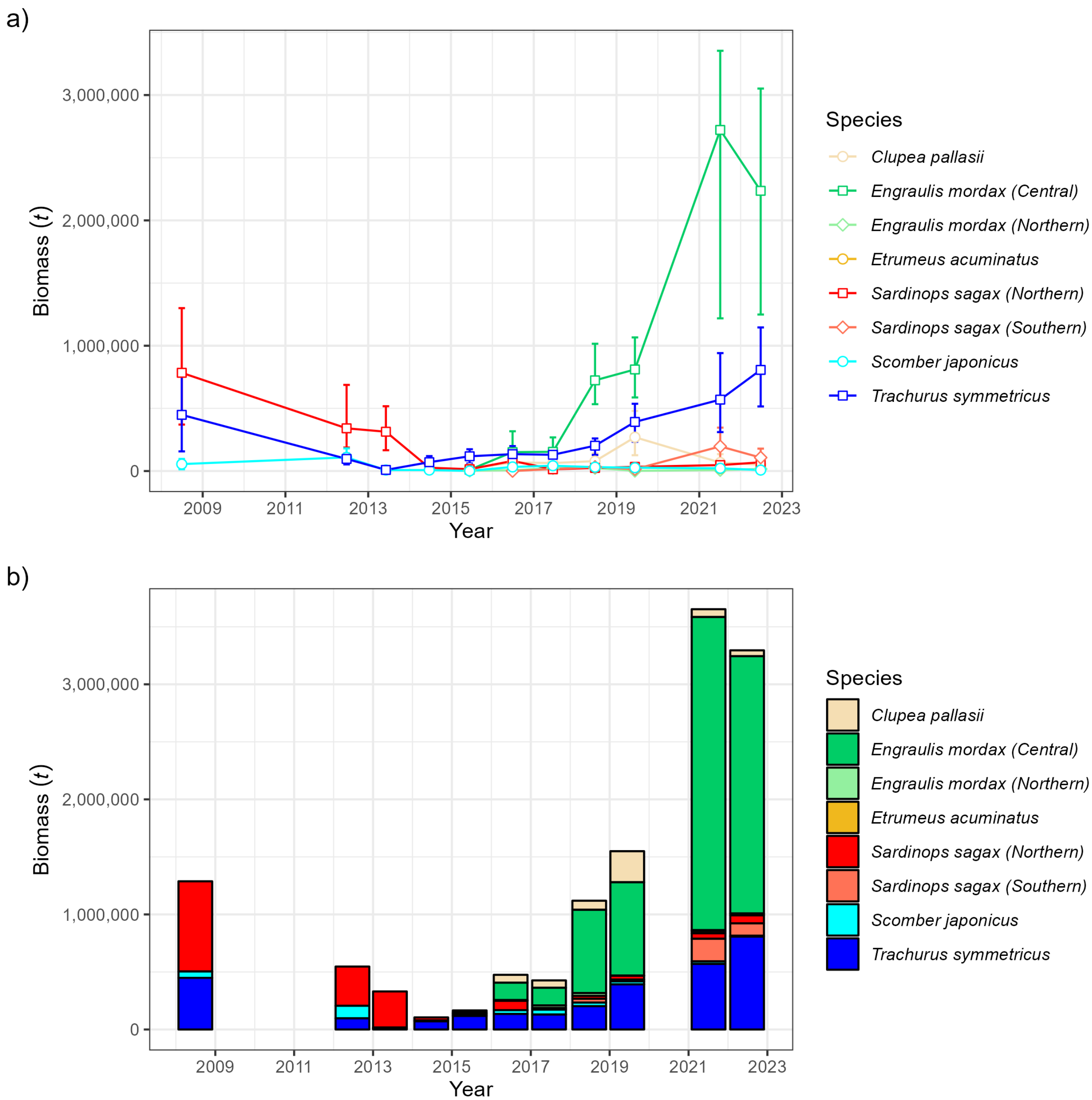

Figure 35: a) Estimated and b) cumulative estimated biomasses (t) of the eight most abundant CPS stocks of six species in the CCE during summer since 2008. Surveys typically span the area between Cape Flattery and San Diego, but in some years also include Vancouver Island, Canada (2015-2019) and portions of Baja CA (2021-2022).

Acknowledgements

The authors greatly appreciate that the ATM surveys require an enormous effort by multiple groups of people, particularly the SWFSC's Advanced Survey Technologies group (Alice Beittel, Scott Mau, David Murfin, and Steve Sessions); CalCOFI and Ship Operations group (Noelle Bowlin, Nicolas Concha Saiz, Anne Freire, Emily Gardner, Amy Hays, Megan Human, Bryan Overcash, Andrew Thompson, Lanora Vasquez de Mercado, Bill Watson, and Ed Weber); Life History Group (Brad Erisman, Kelsey James, Brittany Schwartzkopf, Owyn Snodgrass, and Jon Walker); Stock Assessment (Peter Kuriyama); and their volunteers (Rachel Backman, Shannon Dolan, Morgan Illman, Dayv Lowry, Dan Palance, Kamran Walsh, and Jake Wood). We also thank biologists Daniel Hernandez Cruz and Selene del Carmen Morales Gutierrez (INAPESCA), the officers and crew of *Lasker*, and the SWFSC's Fisheries Resources Division administrative staff. The authors acknowledge that the methods used are the culmination of more than a half century of development efforts from numerous researchers from around the globe. We thank Capts. Rick Blair (*Lisa Marie*) and Rich Ashley and Tom Brinton (*Long Beach Carnage*), along with all the F/V crew members, for their coordination and cooperation during the nearshore sampling, and to Joel van Noord (CWPA) and Kristen Hinton and Patrick Biondo (WDFW) for leading the at-sea processing of purse seine specimens. We thank Diane Pleschner-Steele (CWPA) for contracting the *Long Beach Carnage* to conduct the nearshore survey off central CA and in the SCB, and Greg Shaughnessy (Ocean Gold Seafoods) for contracting the *Lisa Marie* to conduct the nearshore survey of WA, OR, and northern CA. We thank Kelly Kloos, Trevor Stocking, Diego Aceituno, Dane McDermott, Kyle Mooers, Jax Mikkelsen, Leeanne Laughlin, Chelsea Protasio, and Michelle Horeczko (CDFW) for their efforts to coordinate with and process samples from *Long Beach Carnage.* Finally, reviews by Will Satterthwaite and Annie Yau improved this report.

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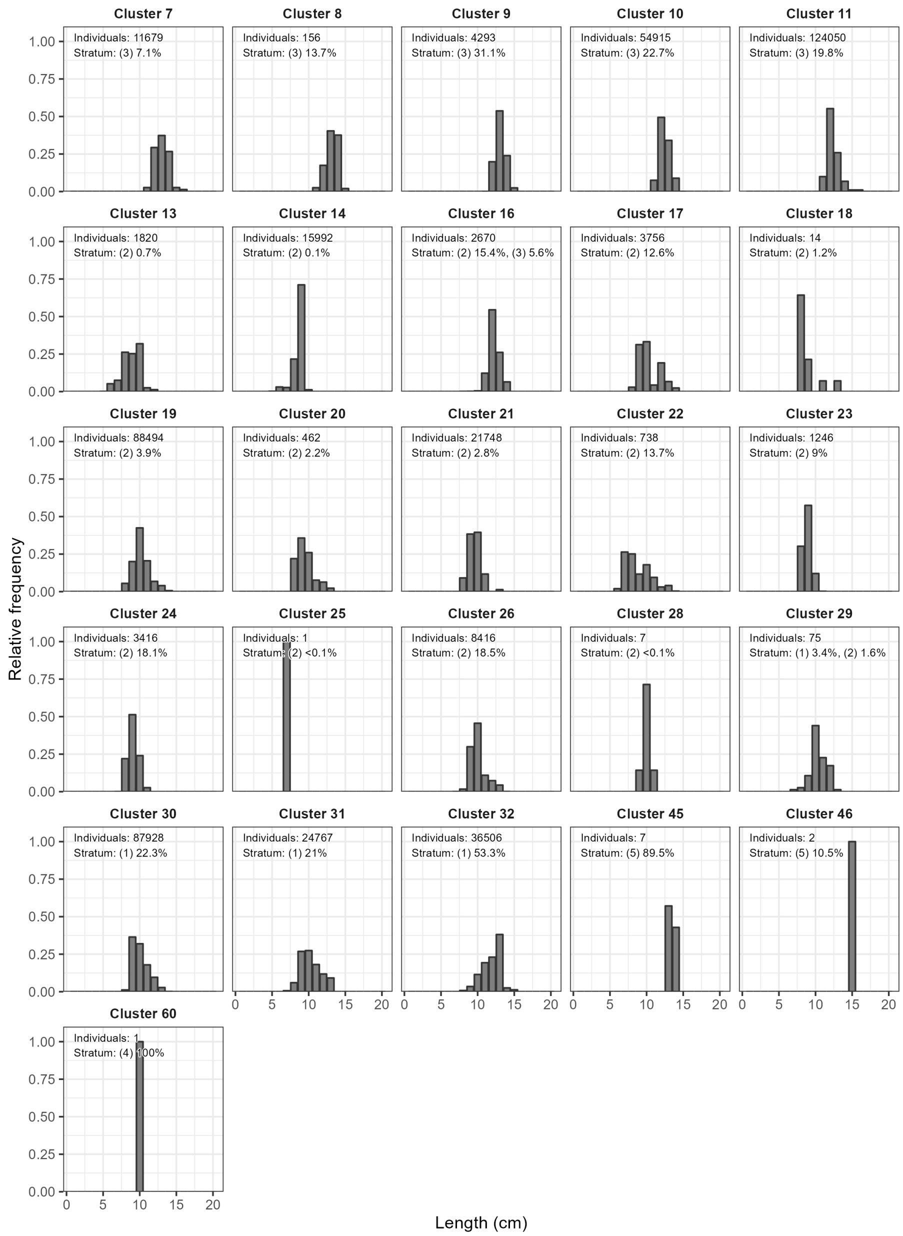
Appendix

A Length distributions and percent biomass by cluster

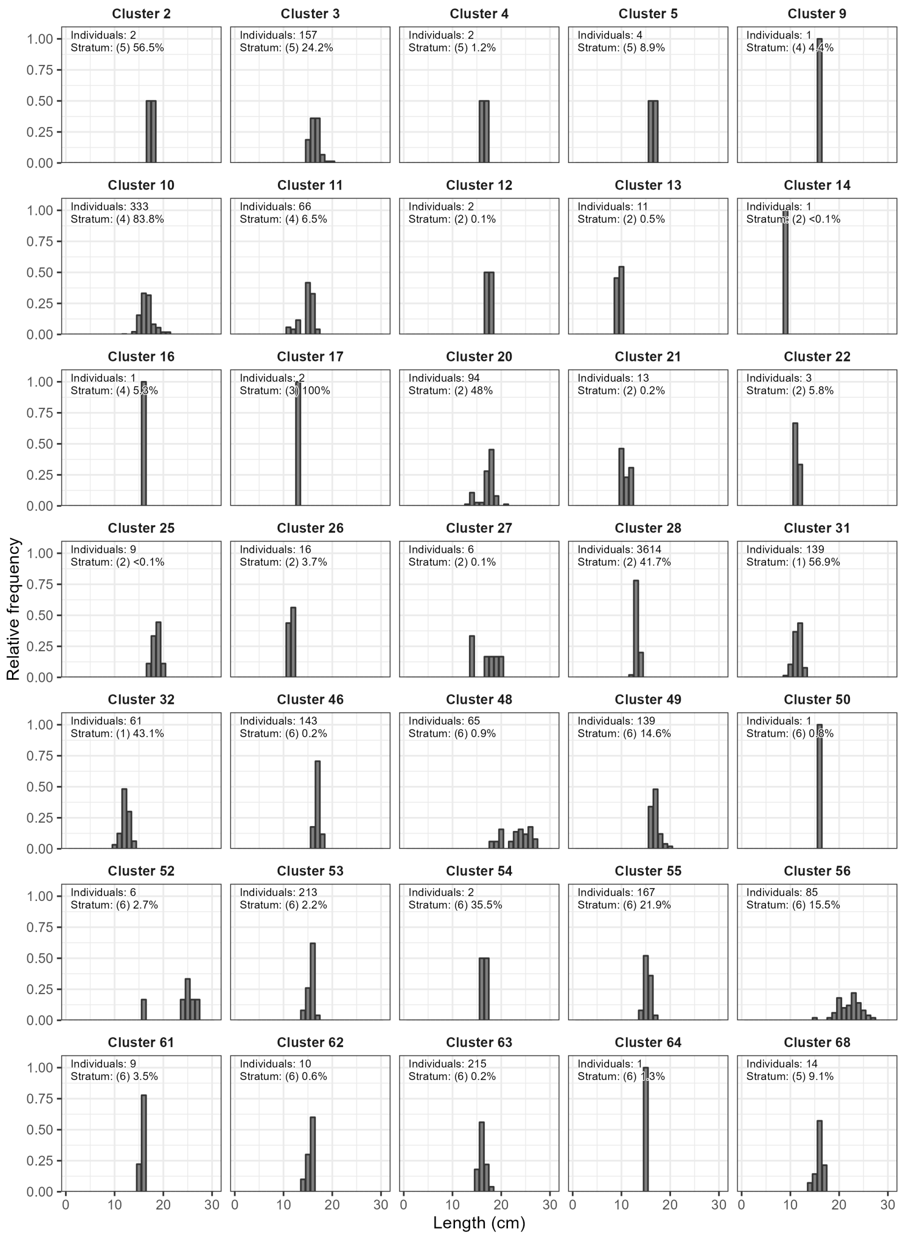
A.1 Northern Anchovy

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



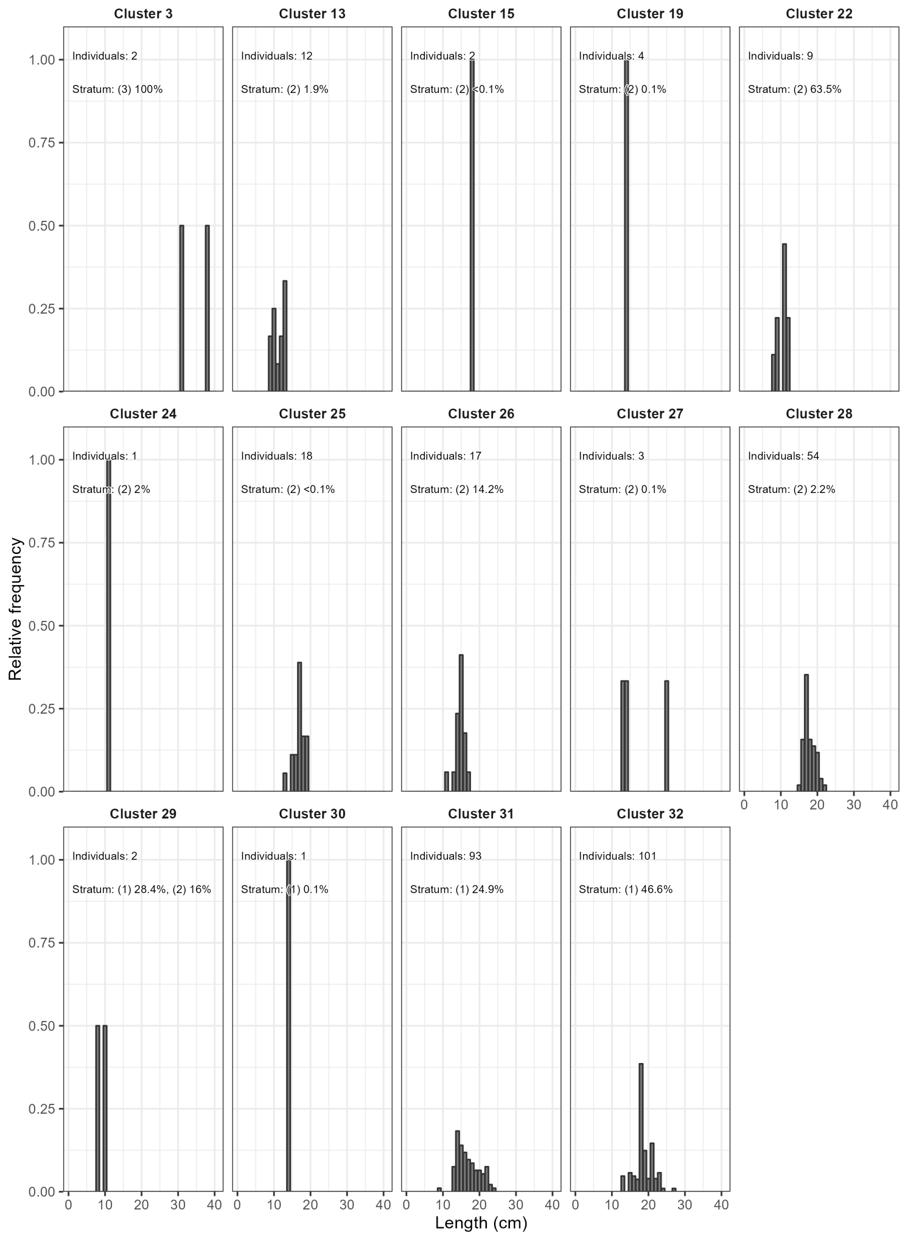
A.2 Pacific Sardine

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



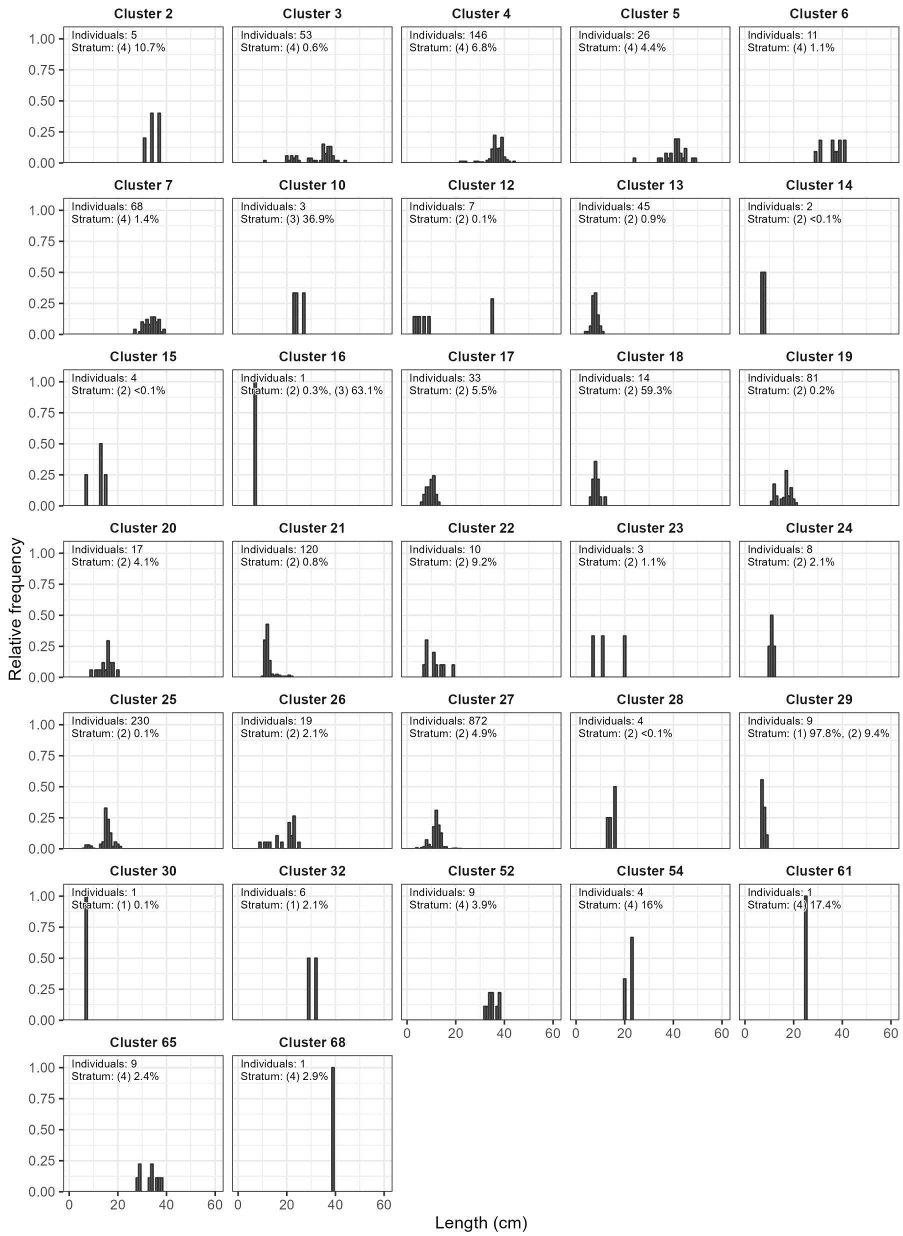
A.3 Pacific Mackerel

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



A.4 Jack Mackerel

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



A.5 Pacific Herring

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