https://doi.org/10.25923/1vgs-sf98

NOAA Technical Memorandum NMFS

JULY 2024

DISTRIBUTION, BIOMASS, AND DEMOGRAPHICS OF COASTAL PELAGIC FISHES IN THE CALIFORNIA CURRENT ECOSYSTEM DURING SUMMER 2023 BASED ON ACOUSTIC-TRAWL SAMPLING

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NOAA-TM-NMFS-SWFSC-703

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. 2024. Distribution, biomass, and demographics of coastal pelagic fishes in the California Current Ecosystem during summer 2023 based on acoustic-trawl sampling. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-SWFSC-703. https://doi.org/10.25923/1vgs-sf98

DISTRIBUTION, BIOMASS, AND DEMOGRAPHICS OF COASTAL PELAGIC FISHES IN THE CALIFORNIA CURRENT ECOSYSTEM DURING SUMMER 2023 BASED ON ACOUSTIC-TRAWL SAMPLING

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Executive Summary

This report provides: 1) a detailed description of the acoustic-trawl method (ATM) used by NOAA's Southwest Fisheries Science Center for direct assessments of the dominant coastal pelagic species (CPS; i.e.: Pacific Sardine *Sardinops sagax*, Northern Anchovy *Engraulis mordax*, Pacific Mackerel *Scomber japonicus*, Jack Mackerel *Trachurus symmetricus*, and Pacific Herring *Clupea pallasii*) in the California Current Ecosystem off the west coast of the United States (U.S.) and sometimes portions of Canada and Baja CA, Mexico; and 2) estimates of the biomasses, distributions, and demographics of those CPS encountered in the survey area between 17 July and 3 November 2023.

The core survey region, which was sampled by NOAA ships *Reuben Lasker* (hereafter, *Lasker*) and *Bell M. Shimada* (hereafter, *Shimada*), spanned most of the continental shelf between Cape Flattery, WA and San Diego, CA. Planned transects were oriented approximately perpendicular to the coast, from the shallowest navigable depth (~20 m) to a distance of 35 nmi offshore or, if farther, to the 1,000 ftm (~1830 m) isobath. In the SCB, transects in the core region were extended to approximately 100 nmi. The survey area was initially designed to extend south to Punta Baja off Baja CA and north to Cape Scott off Vancouver Island, Canada, but was necessarily reduced due to a loss of approximately 60% of the 81 sea days allocated aboard *Lasker*. An additional 15 days were executed aboard *Shimada* to sample in the core region north of Cape Mendocino where *Reuben Lasker* did not sample. Portions of the core survey region were also sampled acoustically using three wind-powered uncrewed surface vehicles (Explorer USVs; Saildrone, Inc.), but those data were not included in the biomass estimates because of a temporal offset with data from other vessels.

Because navigation by *Lasker*, *Shimada*, and the USVs in water shallower than ~20 m was deemed inefficient, unsafe, or both, fishing vessels *Long Beach Carnage* and *Lisa Marie* sampled CPS in the nearshore region, along 2.5 to 5 nmi-long transects spaced 5 nmi apart off the mainland coast of the U.S., between San Diego and Cape Flattery, as well as around Santa Cruz and Santa Catalina Islands in the Southern CA Bight. In the nearshore region, the species composition and CPS length distributions were estimated using catches in daytime purse-seine sets by *Long Beach Carnage* or *Lisa Marie* that were 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. Sampling was conducted in core and nearshore regions off Baja CA by IMIPAS (formerly INAPESCA), but the estimates in this report are for U.S. waters only.

The estimated biomass of the northern stock of Northern Anchovy was 11,356 t ($CI_{95\%}$ = 438 - 30,038 t, CV = 72%). In the core region, the biomass was 11,040 t ($CI_{95\%}$ = 369.2 - 29,774 t, CV = 74%), and in the nearshore region, biomass was 315 t ($CI_{95\%}$ = 68.9 - 265 t, CV = 17%), or 2.8% of the total biomass. The northern stock ranged from approximately Cape Flattery to Newport, OR, and the distribution of standard lengths (L_S) ranged from 9 to 16 cm with a mode at 13 cm in the core region and 14 cm in the nearshore region.

The estimated biomass of the central stock of Northern Anchovy was 2,689,200 t ($CI_{95\%}$ = 297,242 - 4,932,949 t, CV = 46%). In the core region, the biomass was 2,447,378 t ($CI_{95\%}$ = 206,171 - 4,740,405 t, CV = 51%), and in the nearshore region, the biomass was 241,822 t ($CI_{95\%}$ = 91,071 - 192,544 t, CV = 11%), or 9% of the total biomass. The central stock ranged from approximately Cape Mendocino to San Diego, and the distribution of L_S ranged from 5 to 15 cm with a mode at 13 cm in the core region and 11 cm in the nearshore region. The estimated biomass of the central stock of Northern Anchovy, which has comprised the majority of CPS biomass since 2015, increased from the 2,235,996 t estimated in summer 2022 (Stierhoff *et al.*, 2023b).

The estimated biomass of the northern stock of Pacific Sardine was 77,252 t ($CI_{95\%}$ = 17,856 - 171,829 t, CV = 47%), all in U.S. waters. In the core region, the biomass was 49,643 t ($CI_{95\%}$ = 3,009 - 132,210 t, CV = 71%), and in the nearshore region, the biomass was 27,610 t ($CI_{95\%}$ = 14,847 - 39,619 t, CV = 23%), or 36% of the total biomass. Within the survey area, the northern stock ranged from approximately Cape Flattery to Newport. The distribution of L_S ranged from 7 to 28 cm with modes at 9 and 19 cm in the core region and at 19 cm in the nearshore region.

The estimated biomass of the southern stock of Pacific Sardine in the surveyed area was 82,132 t ($CI_{95\%}$ = 44,039 - 133,290 t, CV = 23%). In the core region, the biomass was 6,447 t ($CI_{95\%}$ = 646 - 17,940 t, CV = 73%), and in the nearshore region, the biomass was 75,686 t ($CI_{95\%}$ = 43,393 - 115,350 t, CV = 24%), or 92% of the total biomass. Within the survey area, the southern stock ranged from approximately Bodega Bay to San Diego. The distribution of L_S ranged from 8 to 22 cm with a mode at 15 cm in the core region and modes at 6 and 16 cm in the nearshore region. Notably, the survey area did not span the entire distribution of this stock, which extends south of the U.S.-Mexico border.

The estimated biomass of Pacific Mackerel was 7,289 t ($CI_{95\%}$ = 3,305 - 11,394 t, CV = 28%). In the core region, the biomass was 24.9 t ($CI_{95\%}$ = 0.718 - 63.9 t, CV = 70%), and in the nearshore region, the biomass was 7,264 t ($CI_{95\%}$ = 3,304 - 11,330 t, CV = 29%), or 99.7% of the total biomass. Pacific Mackerel were present off northern OR, around Monterey Bay, and in the SCB between Point Conception and Los Angeles. The distribution of fork lengths (L_F) ranged from 8 to 31 cm with modes at 12 cm in the core region and 23 cm in the nearshore region.

The estimated biomass of Jack Mackerel was 159,354 t ($CI_{95\%}$ = 51,323 - 270,757 t, CV = 27%), and in the core region, biomass was 101,159 t ($CI_{95\%}$ = 24,177 - 181,030 t, CV = 40%), and, in the nearshore region, biomass was 58,194 t ($CI_{95\%}$ = 27,146 - 89,726 t, CV = 27%), or 37% of the total biomass. Jack Mackerel were present throughout the survey area, but were most abundant between Cape Mendocino and Fort Bragg and near the northern Channel Islands in the core and nearshore regions. The distribution of L_F ranged from 2 to 52 cm with modes at 10 and 50 cm in the core region. There was no clear length mode in the nearshore region.

The total estimated biomass of Pacific Herring was 106,723 t ($CI_{95\%}$ = 36,364 - 149,772 t, CV = 21%). In the core region, the biomass was 34,627 t ($CI_{95\%}$ = 7,769 - 83,063 t, CV = 60%). In the nearshore region, the biomass was 72,095 t ($CI_{95\%}$ = 28,595 - 66,710 t, CV = 14%), or 68% of the total biomass. Pacific Herring were distributed from approximately Cape Flattery to Cape Mendocino, but were most abundance in the core region between Cape Flattery and Newport, and in the nearshore region between Westport and Newport, and between Cape Blanco and Cape Mendocino. The distribution of L_F ranged from 8 to 23 cm, with modes at 10 cm in the core region and 9 and 15 cm in the nearshore region.

The total estimated biomass of seven stocks of five species within the survey area was 3,133,306 t. Of this, 86% (2,689,200 t) was from the central stock of Northern Anchovy. Proportions of other stocks, in decreasing order, were: Jack Mackerel (5%), Pacific Herring (3.4%), southern stock of Pacific Sardine (3%), northern stock of Pacific Sardine (2.5%), Pacific Mackerel (0.2%), and northern stock of Northern Anchovy (0.4%).

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). 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 50 years ago to survey CPS off the west coast of the United States (U.S.) (Mais, 1974, 1977; Smith, 1978). Following a two-decade hiatus, the ATM was reintroduced in the CCE in spring 2006 to sample the then-abundant Pacific Sardine population (Cutter and Demer, 2008). Since then, this sampling effort has continued and expanded through annual or semi-annual surveys (Demer *et al.*, 2012; Zwolinski *et al.*, 2014). Beginning in 2011, the ATM estimates of Pacific Sardine abundance, age structure, and distribution have been incorporated in the annual assessments of the northern stock (Hill *et al.*, 2017; Kuriyama *et al.*, 2020, 2022a). 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.*, 2022b). Additionally, ATM survey results have yielded estimated abundances, demographics, and distributions of epipelagic and semi-demersal fishes (e.g., Swartzman, 1997; Williams *et al.*, 2013; Zwolinski *et al.*, 2014) and zooplankton (Hewitt and Demer, 2000).

This document, and references herein, describes in detail the ATM as presently used by NOAA's Southwest Fisheries Science Center (SWFSC) to survey the distributions, abundances, and demographics of CPS and their oceanographic environments (e.g., Cutter and Demer, 2008; Demer *et al.*, 2012; Zwolinski *et al.*, 2014). In general terms, the contemporary ATM combines information from satellite-sensed oceanographic conditions, multifrequency echosounders, probe-sampled oceanographic conditions, pumped samples of fish eggs, and trawl-net catches of juvenile and adult CPS. The summer survey area spans the continental shelf and adjacent waters to the 1000 fathom isobath off the west coast of the U.S., is expanded to encompass the potential habitat of the northern stock of Pacific Sardine (**Fig. 1**), and as time permits, further expanded to encompass as much of the potential habitat as possible for other CPS present over the shelf along the west coasts of Canada and Baja CA.

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).

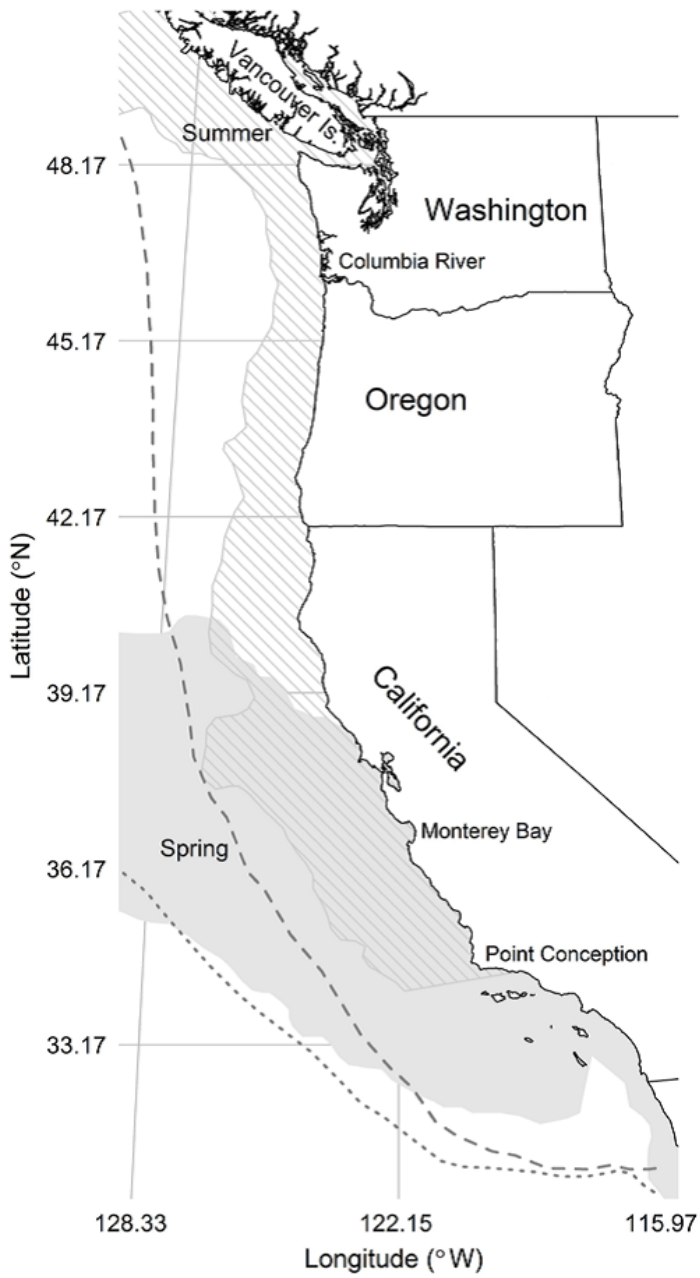

Figure 1: Conceptual spring (shaded region) and summer (hashed region) distributions of potential habitat for the northern stock of Pacific Sardine along the west coasts of Mexico, the United States, and Canada. The dashed and dotted lines represent, respectively, the approximate summer and spring positions 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, abundances, and demographics of CPS, and their abiotic environments in the CCE. Typically, summer surveys are conducted during 50-90 days-at-sea (DAS) between June and October. When they occur, spring surveys are conducted during 25-40 DAS between March and May and 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 2023, the ATM survey, spanning the west coast of the U.S., was conducted by *Lasker* from San Diego to Cape Mendocino, and by *Shimada* between Florence, OR and Cape Flattery. Between Pt. Conception and Cape Flattery, along adaptive transects not sampled by *Lasker* or *Shimada*, three wind-powered uncrewed surface vessels (Explorer USVs; Saildrone, Inc.) conducted acoustic sampling that was not ultimately used for biomass estimation. From San Diego to Cape Flattery, sampling from fishing vessels *Lisa Marie* and *Long Beach Carnage* was used to estimate the biomasses of CPS in the nearshore regions, where sampling by *Lasker*, *Shimada*, and USVs was not possible or safe.

Presented here are: 1) a detailed description of the ATM used to survey CPS in the California Current Ecosystem (CCE) off the west coast of the U.S.; and 2) estimates of the abundances, biomasses, spatial distributions, and demographics of CPS, specifically the northern and southern 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.*, 2024). A complementary survey off Baja CA by IMIPAS used approximately the same sampling protocol. Data from that survey, including biomass estimates for CPS in those core and nearshore regions, are reported elsewhere (Vallarta-Zárate *et al.*, 2023).

The SWFSC's survey was conducted with the approval of the Secretaria de Relaciones Exteriores (SRE, Diplomatic note UAN0995/2023), the Instituto Nacional de Estadística y Geografía (INEGI; Authorization: EG0022023, through official letter 400./91/2023), Unidad de Planeación y Coordinación Estratégica de la Secretaría de Marina (SEMAR; Letter no AI/2301/23), Unidad Coordinadora de Asuntos Internacionales (UCAI) de la Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT; Letter UCAI/01519/2023), Universidad Nacional Autónoma de México (UNAM; Letter ICML/DIR/210/2023), Unidad de Concesiones y Servicios del Instituto Federal de Telecomunicaciones (IFT; Letter IFT/223/UCS/DG-AUSE/3925/2023), and the Comisión Nacional de Acuacultura y Pesca (CONAPESCA; Permit: PPFE/DGPPE.-04052/100523).

2 Methods

2.1 Sampling

2.1.1 Design

The summer 2023 survey was conducted principally using *Lasker* and *Shimada*, but was augmented with nearshore acoustic and purse-seine sampling by two fishing vessels, *Long Beach Carnage* and *Lisa Marie*. Additional acoustic sampling by three USVs did not ultimately produce data used in biomass estimation because of a temporal offset with data from other vessels due to operational challenges by OMAO. The sampling domain between Cape Flattery, WA and San Diego, CA was defined by the conceptual distribution of potential habitat for the northern stock of Pacific Sardine in summer (**Fig. 1**), but also encompassed an unknown portion of 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. It also spanned portions of the Pacific Mackerel, Jack Mackerel, and Pacific 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 (81 days at sea, DAS), the primary objective was to estimate the biomasses, spatial distributions, and demographics of the northern stock of Pacific Sardine and the northern stock of Northern Anchovy, whose expected distributions were encompassed by the survey region. Secondary objectives were to estimate the biomasses, spatial distributions, and demographics of the southern stock of Pacific Sardine, central stock of Northern Anchovy, Pacific Mackerel, Jack Mackerel, Pacific Herring, and Round Herring, since their expected distributions extend beyond the planned 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, where farther, to the 1,000 ftm isobath (**Fig. 2**). Compulsory transects were spaced 10 nmi apart in areas of historic CPS abundance (e.g., between Cape Flattery and Cape Mendocino) 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 north were extended in 5-nmi increments until no CPS were observed in the last 3 nmi of the extension, to a maximum extension of 50 nmi. In most years, transects are sampled in a north-to-south direction. In summer 2023, transects were sampled south-to-north to coordinate sampling with the Northwest Fisheries Science Center's hake survey conducted aboard *Shimada*.

The 81 DAS aboard *Lasker* were divided among three survey legs, and mid-leg personnel transfers were planned to exchange scientists, resulting in six shorter legs (Legs I.1 and I.2; II.1 and II.2; and III.1 and III.2) between each scheduled port call. Leg I.1 and all of Leg II on *Lasker* were canceled due to OMAO staffing and mechanical issues aboard the ship, prompting modifications to the sampling plan. For example, all transects off Baja CA and Vancouver Island were canceled, and Leg I.2 sampling began off San Diego, CA. Compulsory transect spacing was changed to 20 nmi throughout the survey area, and the three USVs (SD-1048, SD-1060, and SD-1096) were directed to sample groups of five adaptive interstitial transects spaced 20-nmi apart using a "leapfrog approach" between Pt. Conception and Cape Flattery (cyan lines, **Fig. 2**). However, due to delays and lost sea days, the time between acoustic sampling from USVs and trawl sampling from *Lasker* and *Shimada* was often greater than 30 d, so CPS backscatter measured from USVs was not used to estimate biomass. Nine days were lost during Leg III due to mechanical issues and weather. To mitigate the loss of sea days aboard *Lasker*, additional sampling was conducted aboard *Shimada* during Leg IV (19 DAS), which sampled the core region between Florence, OR and Cape Flattery.

To estimate the abundances and biomasses of CPS in the nearshore region between Cape Flattery and San Diego, where *Lasker*, *Shimada*, and the USVs could not efficiently or safely navigate or trawl, two fishing vessels conducted acoustic and purse-seine sampling (magenta lines, **Fig. 2**). *Long Beach Carnage* sampled to ~5-m depth along 5-nmi-long transects spaced 5 nmi apart between San Diego and Bodega Bay, and 2.5-nmi-long transects spaced 2.5 nmi apart around Santa Cruz and Santa Catalina Islands in the SCB. *Lisa Marie* sampled transects to ~5-m depth, spaced 5 nmi apart between Bodega Bay and Cape Flattery (**Fig. 2**). Off OR and WA, *Lisa Marie* conducted exploratory acoustic and purse-seine sampling beyond the 5-nmi nearshore region, but those data were excluded prior to estimating biomasses to avoid double-counting of biomass estimated by *Shimada* in the core region.

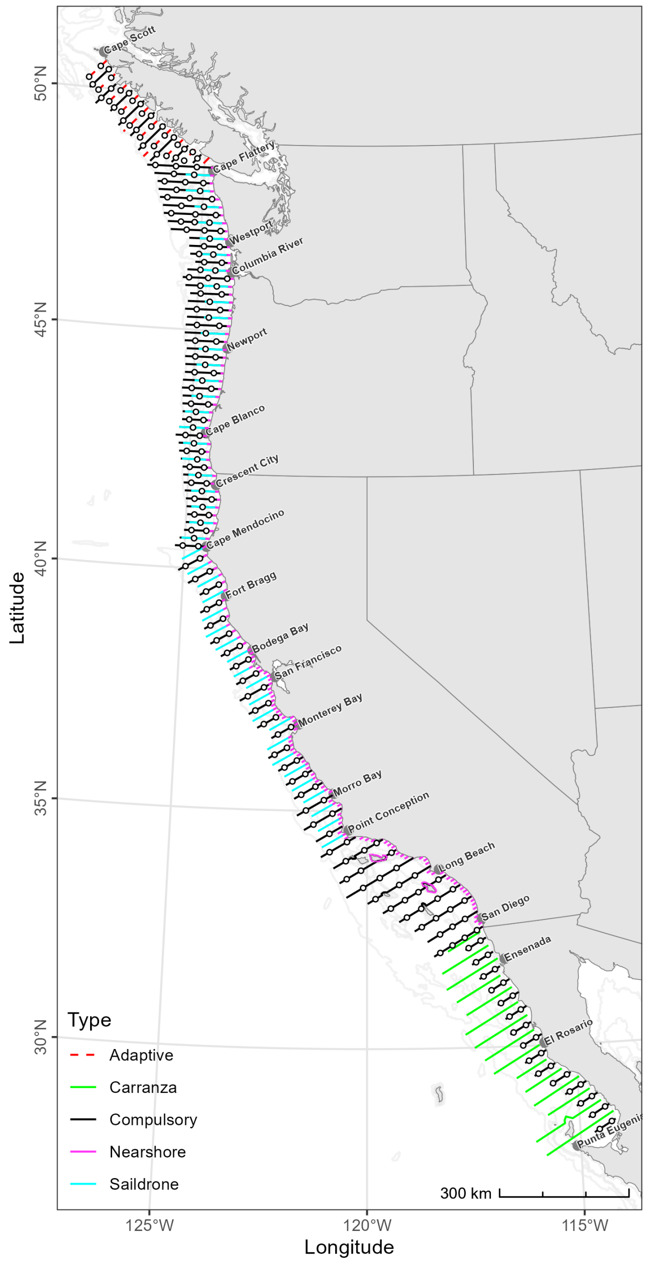

Figure 2: Planned compulsory transects sampled by NOAA Ships *Lasker* and *Shimada* (black lines); adaptive transects to be sampled by FSVs when target CPS are present (dashed red lines); interstitial transects sampled by USVs (cyan lines); and nearshore transects sampled by *Lisa Marie* and *Long Beach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

2.1.2 Acoustic

2.1.2.1 Acoustic equipment

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

2.1.2.1.2 ***Shimada*** Multi-frequency Wide-Bandwidth Transceivers (18-, 38-, 70-, 120-, and 200-kHz Simrad EK80 WBTs; Kongsberg) were configured with split-beam transducers (Simrad ES18-11, ES38B, ES70-7C, ES120-7C, and ES200-7C, respectively; Kongsberg). The transducers were mounted on the bottom of a retractable keel or "centerboard" (**Fig. 4**). 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) 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).

2.1.2.1.3 ***Lisa Marie*** On *Lisa Marie*, multi-frequency Wideband Transceivers (Simrad 38-, 70-, 120-, and 200-kHz Simrad EK80 WBTs; Kongsberg) were connected to the vessel's hull-mounted split-beam transducers (Simrad ES38-7, ES70-7C, ES120-7C and ES200-7C; Kongsberg). The transducers were mounted in a blister on the hull at a water depth of ~4 m (**Fig. 6**).

2.1.2.1.4 ***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. 5**). The transducers were at a water depth of roughly 2 m.

2.1.2.1.5 **USVs** On the three USVs (SD-1048, SD-1060, and SD-1096), 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 (**Fig. 7**).

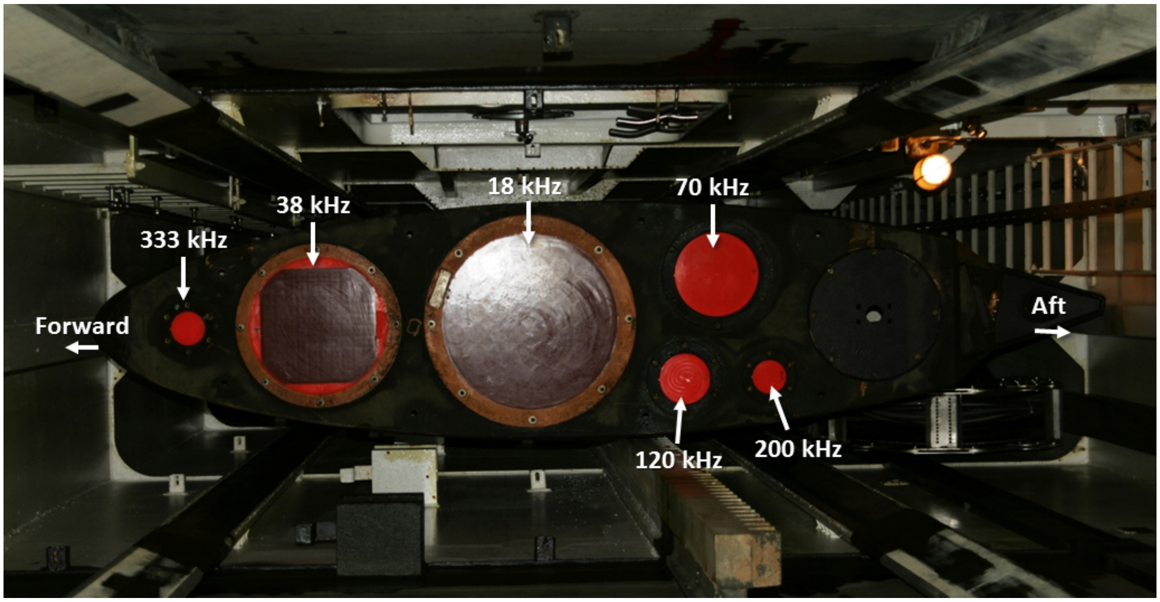

Figure 3: Echosounder transducers mounted on the bottom of the retractable centerboard on *Lasker*. During the survey, the centerboard was extended, typically positioning the transducers ~2 m below the keel at a water depth of ~7 m.

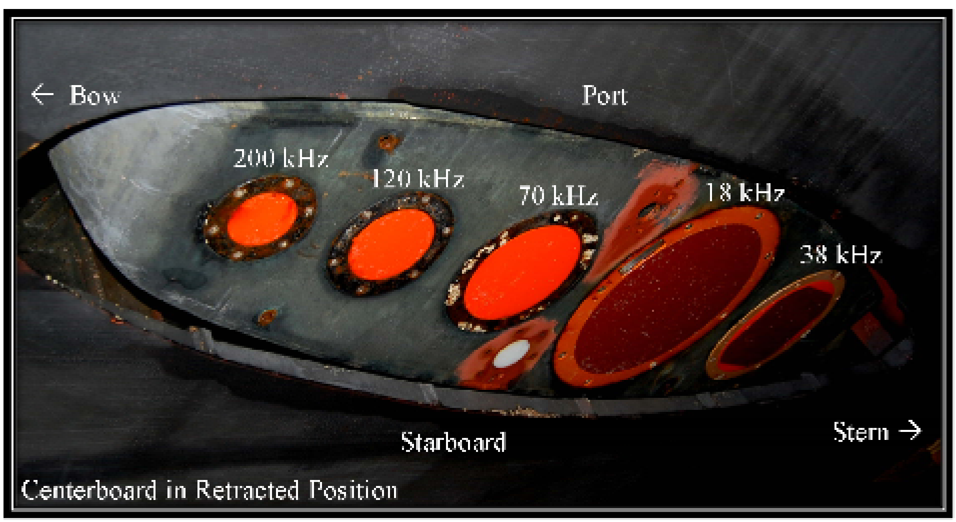

Figure 4: Echosounder transducers mounted on the bottom of the retractable centerboard on *Shimada*. During the survey, the centerboard was extended, typically positioning the transducers ~2 m below the keel at a water depth of ~7 m.

Figure 5: Transducers (Top-bottom: Simrad ES200-7C, ES120-7C, ES38-12, and ES70-7C, Kongsberg) in a pole-mounted multi-transducer array (MTA4) installed on *Long Beach Carnage*.

Figure 6: Transducers mounted in a blister on the hull of *Lisa Marie*.

Figure 7: Transducers mounted on the keel of a Saildrone Explorer uncrewed surface vehicle (USV).

2.1.2.2 Echosounder calibrations

2.1.2.2.1 *Lasker* The echosounder systems aboard *Lasker* were calibrated on 27 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); 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.*, 2024).

Table 1: Wide-Bandwidth Transceiver (Simrad EK80 WBT; Kongsberg) information, pre-calibration settings, and post-calibration beam model results (below the horizontal line) estimated from calibration of the echosounders aboard *Lasker* using a WC38.1 standard sphere. 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	21.8	21.8	21.8	21.8	21.8	21.8
Salinity	ppt	35.0	35.0	35.0	35.0	35.0	35.0
Sound speed	m s^{-1}	1520.8	1520.8	1520.8	1520.8	1520.8	1520.8
On-axis Gain (G_0)	dB re 1	22.93	26.09	27.42	26.51	26.46	25.76
S_a Correction ($S_a$corr)	dB re 1	-0.01	-0.27	-0.07	-0.08	-0.05	-0.34
3-dB Beamwidth Along. (α_{-3dB})	deg	10.75	6.67	6.86	6.55	6.52	6.71
3-dB Beamwidth Athw. (β_{-3dB})	deg	10.71	6.70	6.82	6.69	6.50	6.56
Angle Offset Along. (α_0)	deg	-0.00	0.08	-0.01	0.00	-0.02	0.03
Angle Offset Athw. (β_0)	deg	-0.02	-0.07	-0.04	0.03	0.10	0.01
Equivalent Two-way Beam Angle (Ψ)	dB re 1 sr	-16.94	-20.23	-20.22	-20.13	-20.12	-19.59
RMS	db	0.11	0.13	0.16	0.17	0.24	0.25

2.1.2.2.2 ***Shimada*** The echosounder systems aboard *Shimada* were calibrated by the NWFSC on 9 September after completing the Integrated Ecosystem and Pacific Hake Acoustic-Trawl Survey. The calibration was conducted using the standard sphere technique (Demer *et al.*, 2015; Foote *et al.*, 1987) while the vessel was on anchor near Seattle, WA. Each WBT was calibrated in CW (i.e., continuous wave or narrowband mode) mode. The reference target was a 38.1-mm diameter sphere made from tungsten carbide (WC) with 6% cobalt binder material (WC38.1). 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; Kongsberg; **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 *Shimada* using a WC38.1 standard sphere. Prior to the survey, on-axis gain (G_0), beam angles, angle offsets, and S_A Correction ($S_\mathrm{A}$corr) values from calibration results were entered into the WBT control software (Simrad EK80; Kongsberg).

		Frequency (kHz)				
	Units	18	38	70	120	200
Model		ES18	ES38B	ES70-7C	ES120-7C	ES200-7C
Serial Number		2065	30715	168	573	339
Transmit Power (p_et)	W	1000	2000	750	250	105
Pulse Duration (τ)	ms	1.024	1.024	1.024	1.024	1.024
Temperature	C	13.4	13.4	13.4	13.4	13.4
Salinity	ppt	33.7	33.7	33.7	33.7	33.7
Sound speed	m s^{-1}	1503.3	1503.3	1503.3	1503.3	1503.3
On-axis Gain (G_0)	dB re 1	22.96	26.53	28.10	26.76	28.03
S_a Correction ($S_\mathrm{a}$corr)	dB re 1	-0.10	-0.09	-0.09	-0.14	-0.09
3-dB Beamwidth Along. ($\alpha_{-3\mathrm{dB}}$)	deg	11.72	7.11	6.76	6.38	4.48
3-dB Beamwidth Athw. ($\beta_{-3\mathrm{dB}}$)	deg	11.55	7.16	6.74	7.12	5.05
Angle Offset Along. (α_0)	deg	-0.07	-0.17	-0.06	-0.10	-0.33
Angle Offset Athw. (β_0)	deg	0.16	-0.14	0.06	0.20	0.57
Equivalent Two-way Beam Angle (Ψ)	dB re 1 sr	-17.26	-20.78	-20.64	-20.31	-20.07
RMS	db	0.58	0.11	0.13	0.42	1.13

2.1.2.2.3 ***Lisa Marie*** The WBTs aboard *Lisa Marie* were calibrated on 12 June using the standard sphere technique (Demer *et al.*, 2015; Foote *et al.*, 1987), while the vessel was anchored in Gig Harbor, WA (47.32212 N, 122.57275 W). Calibration results for *Lisa Marie* are presented in **Table 3**.

Table 3: 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. Prior to the survey, on-axis gain (G_0), beam angles, angle offsets, and S_A Correction ($S_\mathrm{A}$corr) values from calibration results were entered into the WBT control software (Simrad EK80; Kongsberg).

		Frequency (kHz)			
	Units	38	70	120	200
Model		ES38-7	ES70-7C	ES120-7C	ES200-7C
Serial Number		448	761	2355	899
Transmit Power (p_et)	W	2000	600	200	90
Pulse Duration (τ)	ms	1.024	1.024	1.024	1.024
Temperature	C	11.7	11.7	11.7	11.7
Salinity	ppt	29.3	29.3	29.3	29.3
Sound speed	m s^{-1}	1488.9	1488.9	1488.9	1488.9
On-axis Gain (G_0)	dB re 1	25.42	27.71	26.57	26.73
S_a Correction ($S_\mathrm{a}$corr)	dB re 1	-0.04	-0.08	-0.07	-0.13
3-dB Beamwidth Along. ($\alpha_{-3\mathrm{dB}}$)	deg	6.71	6.97	6.71	6.38
3-dB Beamwidth Athw. ($\beta_{-3\mathrm{dB}}$)	deg	6.77	6.94	6.72	6.32
Angle Offset Along. (α_0)	deg	-0.08	-0.02	0.03	-0.06
Angle Offset Athw. (β_0)	deg	-0.04	-0.04	-0.02	0.02
Equivalent Two-way Beam Angle (Ψ)	dB re 1 sr	-20.36	-20.47	-20.47	-20.46
RMS	db	0.14	0.17	0.23	0.17

2.1.2.2.4 ***Long Beach Carnage*** The GPTs aboard *Long Beach Carnage* were calibrated on 18 April, using the standard sphere technique (Demer *et al.*, 2015; Foote *et al.*, 1987), in a tank at the SWFSC (Demer *et al.*, 2015). Calibration results for *Long Beach Carnage* are presented in **Table 4**.

Table 4: 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*. Prior to the survey, on-axis gain (G_0), beam angles, angle offsets, and S_A Correction ($S_\mathrm{A}$corr) values from calibration results were entered into the GPT control software (Simrad EK80; Kongsberg).

		Frequency (kHz)			
	Units	38	70	120	200
Model		ES38-12	ES70-7C	ES120-7C	ES200-7C
Serial Number		28075	234	813	616
Transmit Power (p_et)	W	1000	600	200	90
Pulse Duration (τ)	ms	1.024	1.024	1.024	1.024
Temperature	C	18.5	18.5	18.5	18.5
Salinity	ppt	36.0	36.0	36.0	36.0
Sound speed	m s^{-1}	1518.5	1518.5	1518.5	1518.5
On-axis Gain (G_0)	dB re 1	21.79	26.24	26.25	26.63
S_a Correction ($S_\mathrm{a}$corr)	dB re 1	-0.65	-0.32	-0.40	-0.21
3-dB Beamwidth Along. ($\alpha_{-3\mathrm{dB}}$)	deg	12.50	6.74	6.79	6.80
3-dB Beamwidth Athw. ($\beta_{-3\mathrm{dB}}$)	deg	12.61	6.70	6.84	6.83
Angle Offset Along. (α_0)	deg	0.01	0.04	0.17	-0.07
Angle Offset Athw. (β_0)	deg	0.12	0.00	-0.01	0.07
Equivalent Two-way Beam Angle (Ψ)	dB re 1 sr	-15.50	-20.70	-20.70	-20.06
RMS	db	0.04	0.04	0.07	0.08

2.1.2.2.5 USVs The WBTs for the three USVs were calibrated dockside by Saildrone, Inc. using the standard sphere technique (Demer *et al.*, 2015; Foote *et al.*, 1987). The results, processed and derived by the SWFSC using the method described in Renfree et al. (2019), are presented in **Table 5**.

Table 5: 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 three USVs.

		Saildrone (Frequency)					
	Units	1048 (38)	1048 (200)	1060 (38)	1060 (200)	1096 (38)	1096 (200)
Echosounder SN		264028	264028	719362	719362	268636	268636
Transducer SN		126	126	131	131	136	136
Temperature	C	15.9	15.9	17.4	17.4	18.4	18.4
Salinity	ppt	21.9	21.9	23.9	23.9	23.3	23.3
Sound speed	m s^{-1}	1494.3	1494.3	1501.4	1501.4	1503.6	1503.6
Eq. Two-way Beam Angle (Ψ)	dB re 1 sr	-12.4	-11.2	-12.6	-12.0	-12.5	-11.5
On-axis Gain (G_0)	dB re 1	19.10	19.45	19.04	19.44	18.96	19.50
S_{a} Correction (S_{a}corr)	dB re 1	0.04	0.00	-0.04	-0.05	0.03	0.12
3-dB Beamwidth Along. ($\alpha_{-3\mathrm{dB}}$)	deg	18.3	20.6	17.8	19.8	18.1	20.3
3-dB Beamwidth Athw. ($\beta_{-3\mathrm{dB}}$)	deg	18.2	21.5	17.8	18.6	18.2	20.4
Angle Offset Along. (α_0)	deg	0.3	0.2	0.2	0.5	0.0	0.6
Angle Offset Athw. (β_0)	deg	0.1	-0.1	-0.6	-0.3	-0.4	0.1
RMS	dB	0.21	0.50	0.16	0.44	0.20	0.42

2.1.2.3 Data collection

On *Lasker* and *Shimada*, the computer clocks were synchronized with the GPS clock (UTC) using synchronization software (NetTime[1]). The 18-kHz WBTs, operated by a separate PC from the other echosounders, were programmed to track the seabed and output the detected depth to the ship's Scientific Computing System (SCS). The echosounders were controlled by the EK80 Adaptive Logger (EAL[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* and *Shimada*, 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 1-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 in the depths sampled by the surface trawls, 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., 2307RL), 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 `2307RL-CW-D20230801-T125901.raw`.

To minimize acoustic interference, transmit pulses from all echosounders and sonars (e.g., EK80, ME70, MS70, SX90, EC150-3C, and ADCP) were triggered using a synchronization system (Simrad K-Sync; Kongsberg). The K-Sync trigger rate, and thus echosounder ping interval, was modulated by the EAL using the seabed depth measured using the 18-kHz echosounder. During daytime, the ME70, MS70 (*Lasker* only), and SX90 (*Lasker* only) were operated continuously, but only recorded at the discretion of the acoustician during times when CPS were present. During daytime, the ADCP was operated and data were recorded continuously. 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. At nighttime, only the EK80 and EC-150 were operated. Analyses of data from the ADCP, EC-150, ME70, MS70, and SX90 are not presented in this report.

On *Lisa Marie* and *Long Beach Carnage*, the EAL was used to control the EK80 software to modulate the echosounder recording ranges and ping intervals to avoid aliased seabed echoes. When the EAL was not utilized, the EK80 data was recorded to 1000 m and the software was set to use the maximum ping rate. Transmit pulses from the echosounders 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 during daytime, and the data were logged 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. At night, the echosounders were programmed to transmit FM pulses and record backscatter to 100-m range.

2.1.3 Oceanographic

2.1.3.1 Conductivity and temperature versus depth (CTD)

Conductivity and temperature were measured versus depth to 350 m (or to within ~10 m of the seabed if shallower than 350 m) with calibrated sensors on a CTD rosette (Model SBE911+, Seabird) or underway

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

probe [UnderwayCTD (UCTD); Oceanscience] cast from the vessel. One to three casts were planned along each acoustic transect (**Fig. 2**). These data were used to calculate the harmonic mean sound speed (Demer *et al.*, 2015) for estimating ranges to the sound scatterers, and frequency-specific sound absorption coefficients for compensating signal attenuation of the sound pulse between the transducer and scatterers (Simmonds and MacLennan, 2005) (see **Section 2.2.2**).

2.1.3.2 Scientific Computer System

While underway, information about the position and direction (e.g., latitude, longitude, speed, course over ground, and heading), weather (air temperature, humidity, wind speed and direction, and barometric pressure), and sea-surface oceanography (e.g., temperature, salinity, and fluorescence) were measured continuously and logged using the ship's Scientific Computer System (SCS). The data from a subset of these sensors, logged with a standardized format at 1-min resolution, are available on NOAA's ERDDAP data server[3] [4].

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 (i.e., less than 3 d) for most fish species, the egg distributions inferred from CUFES indicated the presence of actively spawning fish, and were used in combination with CPS echoes to select trawl locations.

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 conducted from FSVs sampled fish dispersed in the upper ~15 m of the sea surface. After sunset, schools of CPS and other fish tend to ascend and disperse and are less likely to avoid a trawl net (Mais, 1977). Beginning in the summer of 2023, and when weather conditions were favorable, the trawl net was towed along an arced path so that the net fished outside of the ship's wake (Nøttestad *et al.*, 2015). Daytime purse-seine nets were set nearshore by participating fishing vessels to sample CPS schools where their depth is constrained by the seabed and their vision is obscured by turbidity due to primary production and suspended particulates.

2.1.5.1 Trawl gear Aboard *Lasker* and *Shimada*, a Nordic 264 rope trawl (NET Systems, Bainbridge Island, WA; **Figs. 8a,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. 9**).

2.1.5.2 Purse-seine gear *Lisa Marie* used an approximately 440-m-long and 40-m-deep purse-seine net with 17-mm-wide mesh (A. Blair, pers. comm.). *Long Beach Carnage* used an approximately 200-m-long and 27-m-deep purse-seine net with 17-mm-wide mesh; a small section on the back end of the net had 25-mm-wide mesh (R. Ashley, pers. comm.). Specimens collected by *Lisa Marie* were processed aboard the

[3] http://coastwatch.pfeg.noaa.gov/erddap/tabledap/fsuNoaaShipWTEGnrt.html
[4] http://coastwatch.pfeg.noaa.gov/erddap/tabledap/fsuNoaaShipWTEDnrt.html

vessel by the WA Department of Fish and Wildlife (WDFW; see see **Section 2.1.5.4.2**) and specimens collected aboard *Long Beach Carnage* were processed ashore by the CA Department of Fish and Wildlife (CDFW; see **Section 2.1.5.4.3**)).

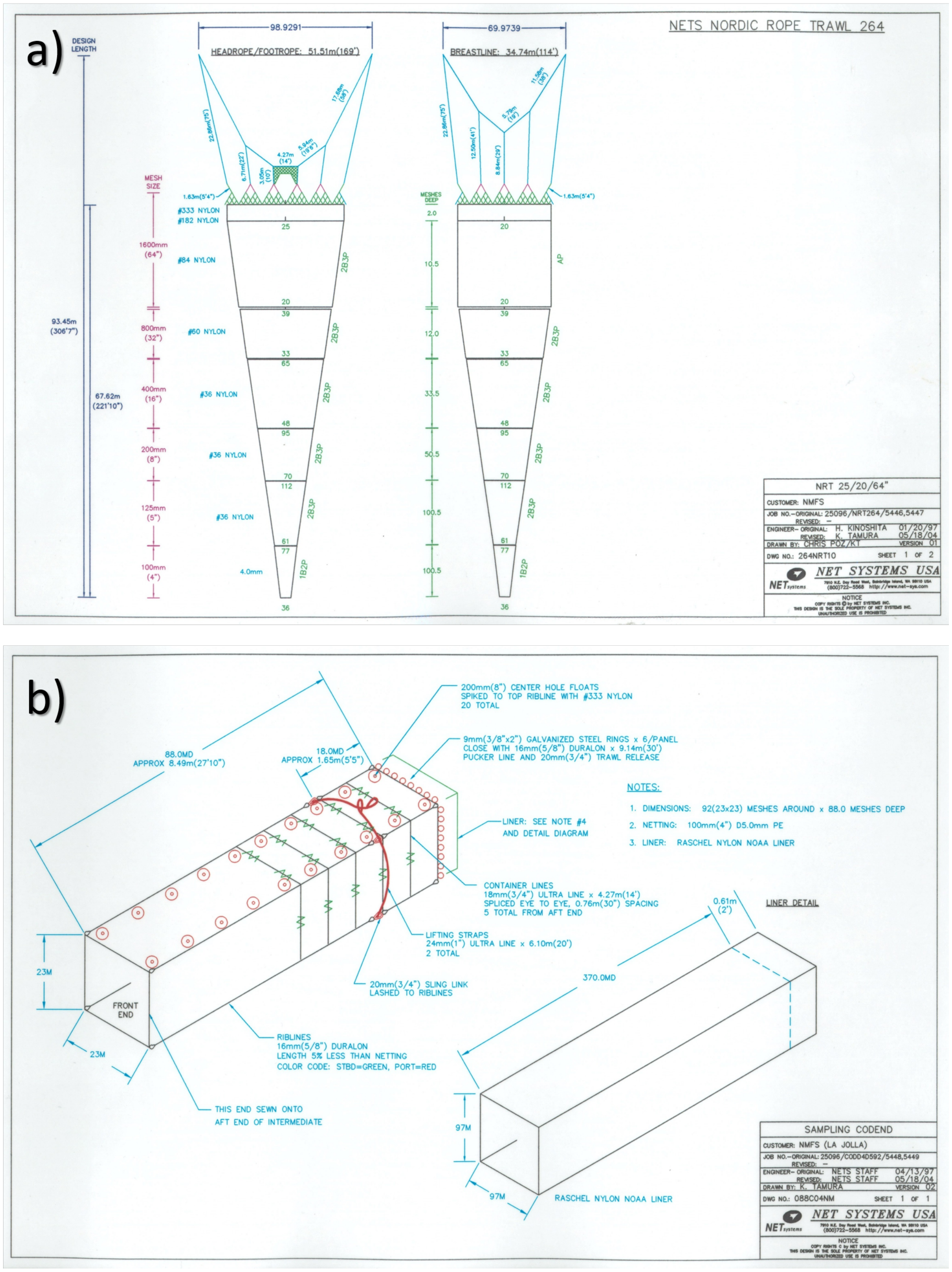

Figure 8: Schematics of the Nordic 264 rope trawl a) net and b) cod-end.

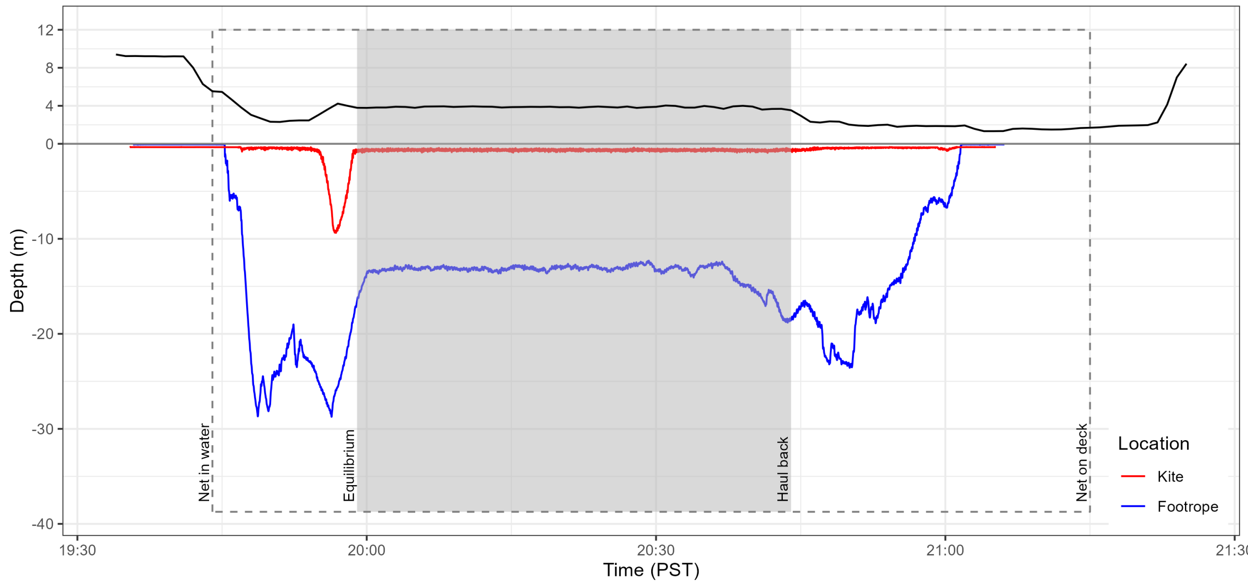

Figure 9: Example depths (m) of the trawl headrope (red line) and footrope (blue line) measured using temperature-depth recorders (TDRs) during the net deployment (dashed box) and when actively fishing (shaded region). The vessel speed over ground (kn, black line) was measured using the ship's GPS.

2.1.5.3 Sampling locations

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

2.1.5.4 Sample processing

2.1.5.4.1 ***Lasker* and *Shimada*** If the total volume of the trawl catch was less than or equal to five 35-l baskets (~175 l), all target species were separated from the catch, sorted by species, weighed, and enumerated. If the volume of the entire catch was more than five baskets, a 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 $P_{w,e} = C_{S,e} / \quad {}_{1}^{s} C_{S,e}$, 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 species. Next, all three dip-net samples were combined and up to 50 specimens of each CPS species were randomly sampled to provide individual measures of weight and length (mm; L_S for Pacific Sardine and Northern Anchovy and L_F for all others), and weight (g) for each set. Otoliths were extracted, macroscopic maturity stage was determined visually, and gonads were collected and preserved from female specimens. For some specimens, fin clips were collected and stored in blotter paper for later genetic analysis.

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 species. Then all dip net samples were combined and as many as 50 specimens of each CPS species present were chosen randomly throughout the sample and frozen for later analysis by CDFW biologists, yielding individual measures of weight (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. (2019). To identify measurement or data-entry errors, length and weight data were graphically compared (**Fig.** 10) to measurements from previous surveys and models of season-specific length-versus-weight from previous surveys (Palance *et al.*, 2019). Outliers were flagged, reviewed, and corrected if errors were identified. Catch data were removed from aborted or unacceptable trawl hauls.

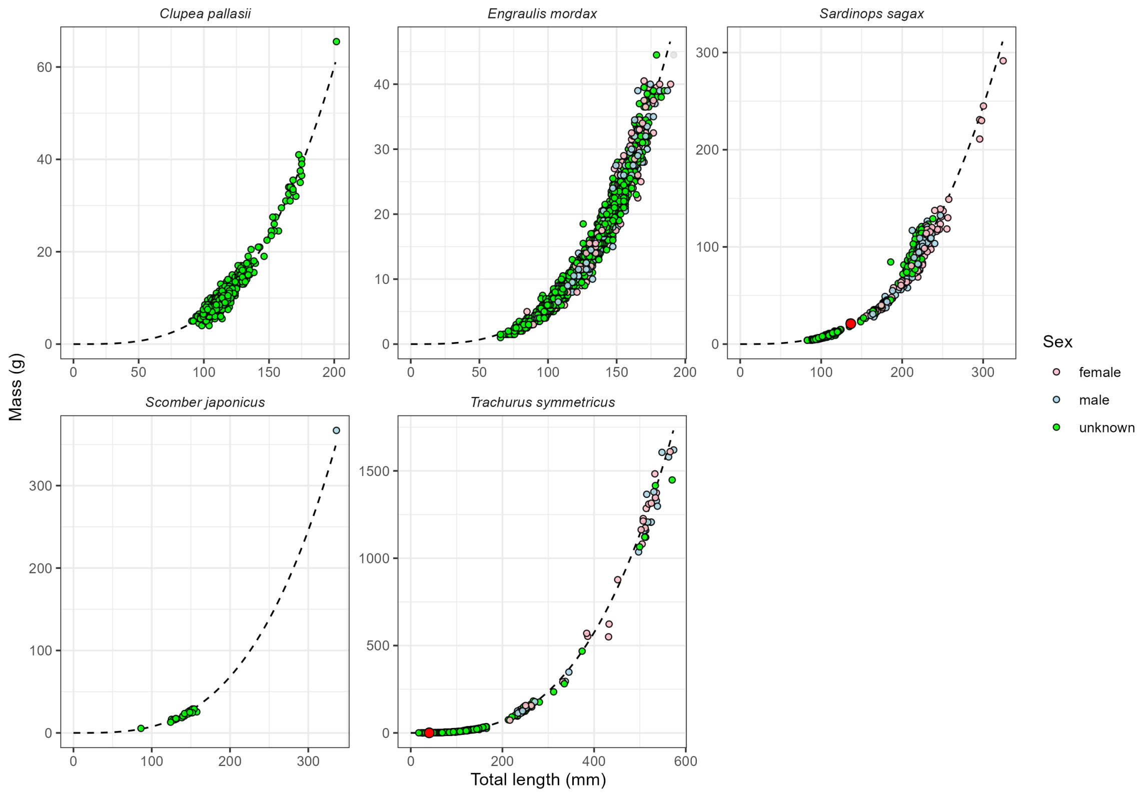

Figure 10: Specimen length versus weight from the current survey (colored points, by sex) compared to those from previous SWFSC surveys during the same season (gray points, all sexes) and models [dashed lines; Palance *et al.* (2019)].

2.2 Data processing

2.2.1 Acoustic and oceanographic data

The calibrated echosounder data from each transect were processed using commercial software (Echoview v13.1; 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 $\geq$ 5 kn were used to estimate CPS densities. Nighttime acoustic data were not used for biomass estimations because they are assumed to be negatively biased due to diel-vertical migration and disaggregation of the target species' schools (Cutter and Demer, 2008).

2.2.2 Sound speed and absorption calculation

Pressure measured in CTD casts was used to derive depths averaged in 1-m 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:

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

where Δr is the depth of increment i (Seabird, 2013). Measurements of seawater temperature (t_w, °C), salinity (s_w, psu), depth, pH, and $\bar{c}_w$ are also used to calculate the mean absorption coefficients ($\overline{\alpha}_a$, dB m^{-1}) over species-specific portion of the profile, using equations in Francois and Garrison (1982), Ainslie and McColm (1998), and Doonan et al. (2003). Both $\bar{c}_w$ 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 (**Figs. 11a, d**) were identified using a semi-automated data processing algorithm implemented using Echoview software (v13.1; 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. 11**). Data from *Lasker*, *Shimada*, *Lisa Marie*, and *Long Beach Carnage* were processed using the following steps:

1. Match geometry of all S_v variables to the 38-kHz S_v;
2. Remove passive-mode pings;
3. Estimate and subtract background noise using the background noise removal function (De Robertis and Higginbottom, 2007) in Echoview (**Figs. 11b, e**);
4. Average the noise-free S_v echograms using non-overlapping 11-sample by 3-ping bins;
5. Expand the averaged, noise-reduced S_v echograms with a 7 pixel x 7 pixel dilation;
6. For each pixel, compute: $S_{v,200\text{kHz}} - S_{v,38\text{kHz}}$, $S_{v,120\text{kHz}} - S_{v,38\text{kHz}}$, and $S_{v,70\text{kHz}} - S_{v,38\text{kHz}}$;
7. Create a Boolean echogram for S_v differences in the CPS range: $-13.85 < S_{v,70\text{kHz}} - S_{v,38\text{kHz}} < 9.89$ and $-13.5 < S_{v,120\text{kHz}} - S_{v,38\text{kHz}} < 9.37$ and $-13.51 < S_{v,200\text{kHz}} - S_{v,38\text{kHz}} < 12.53$;
8. For 120 and 200 kHz, compute the squared difference between the noise-filtered S_v (Step 3) and averaged S_v (Step 4), average the results using an 11-sample by 3-ping window to derive variance, then compute the square root to derive the 120- and 200-kHz standard deviations ($\sigma_{120\text{kHz}}$ and $\sigma_{200\text{kHz}}$, respectively);
9. Expand the standard deviation echograms with a 7 pixel x 7 pixel dilation;
10. Create a Boolean echogram based on the standard deviations in the CPS range: $\sigma_{120\text{kHz}} >$ -65 dB and $\sigma_{200\text{kHz}} >$ -65 dB. Diffuse backscattering layers have low σ (Zwolinski *et al.*, 2010) whereas fish schools have high σ;
11. Intersect the two Boolean echograms to create an echogram with "TRUE" samples for candidate CPS schools and "FALSE" elsewhere;
12. Mask the noise-reduced echograms using the CPS Boolean echogram (**Figs. 11c, f**);
13. Create an integration-start line 5 m below the transducer (~10 m depth);
14. Create an integration-stop line 3 m above the estimated seabed (Demer *et al.*, 2009a), or to the maximum logging range (e.g., 350 m), whichever is shallowest;
15. Set the minimum S_v threshold to -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 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 for 200 kHz;
7. Create a Boolean echogram mask using $\sigma_{200\text{kHz}} >$ -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, include the entirety of shallow CPS aggregations, and exclude seabed echoes.

2.2.4 Removal of non-CPS backscatter

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

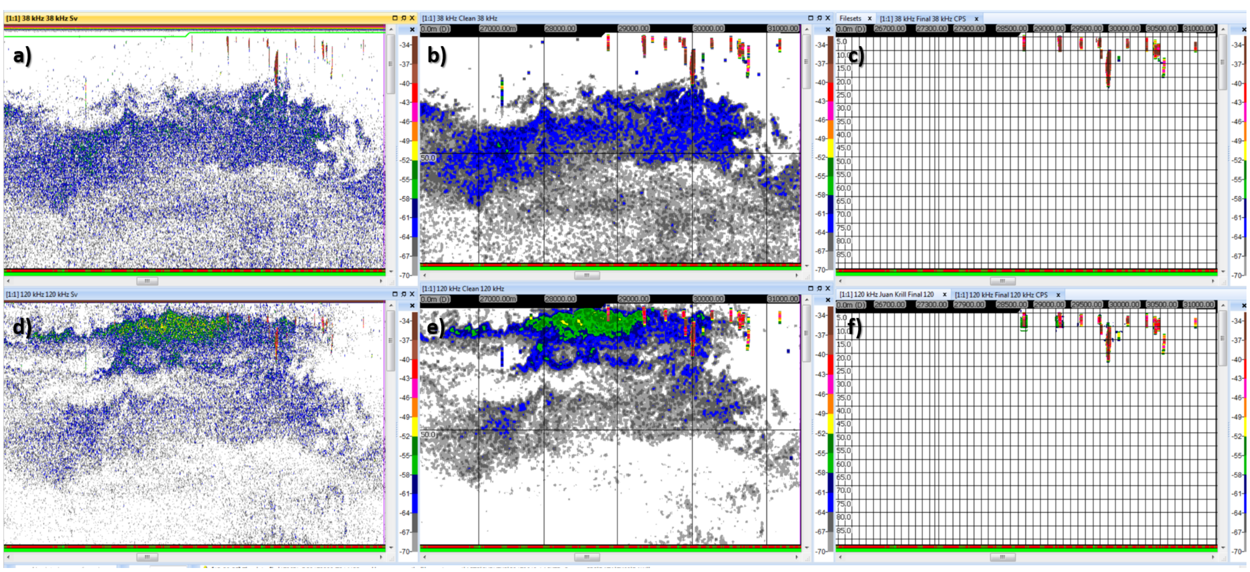

Figure 11: Two examples of echograms depicting CPS schools (red) and plankton aggregations (blue and green) at 38 kHz (top) and 120 kHz (bottom). Example data processing steps include the original echogram (a, d), after noise subtraction and bin-averaging (b, e), and after filtering to retain only putative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

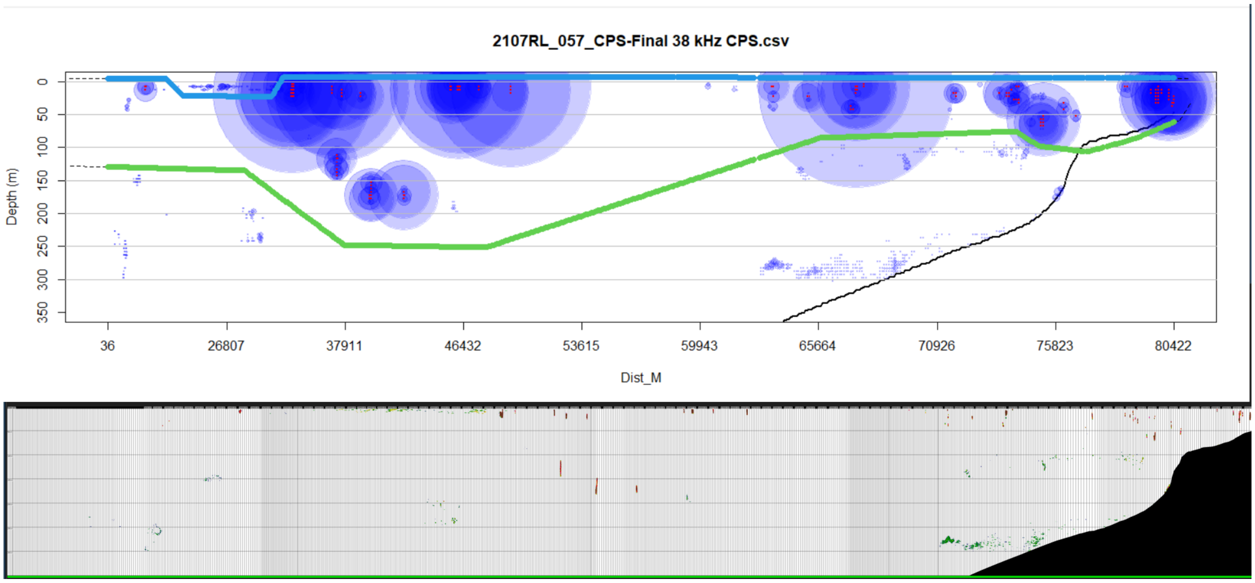

Figure 12: Echoes from fishes with swimbladders (blue points, scaled by backscatter intensity) along an example acoustic transect (top) and the corresponding echogram image (bottom). In this example, the upper (blue) and lower lines (green) indicate boundaries within which echoes were retained. Where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

2.2.5 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.

2.2.6 Echo integral partitioning and acoustic inversion

For fishes with swimbladders, the acoustic backscattering cross-section of an individual (σ_{bs}, m^2) depends on many factors but mostly on the acoustic wavelength and the swimbladder size and orientation relative to the incident sound pulse. For echosounder sampling conducted in this survey, σ_{bs} is a function of the dorsal-surface area of the swimbladder and was approximated by a function of fish length (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 $TS_{38\text{kHz}}$, were used in this analysis:

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

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

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

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

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

Equations (6) and (9) were derived from echosounder measurements of σ_{bs} 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 $TS_{38\text{kHz}}$, L_T was estimated from measurements of L_S or L_F using linear relationships between length and weight derived from specimens collected in the CCE (Palance *et al.*, 2019): for Pacific Sardine, $L_T = 0.3574 + 1.149L_S$; for Northern Anchovy, $L_T = 0.2056 + 1.1646L_S$; for Pacific Mackerel, $L_T = 0.2994 + 1.092L_F$; for Jack Mackerel $L_T = 0.7295 + 1.078L_F$; and for Pacific Herring $L_T = -0.105 + 1.2L_F$. Since a conversion does not exist for Round Herring, the equation for Pacific Herring was used to estimate L_T, when present.

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

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

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

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

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

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

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

where:

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

and the proportion (P_{ge}) is;

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

2.2.7 Trawl clustering and species 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. Acoustic transects were post-stratified to account for spatial heterogeneity in sampling effort and biomass density in a similar way to that performed for Pacific Sardine (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. 13**):

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

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

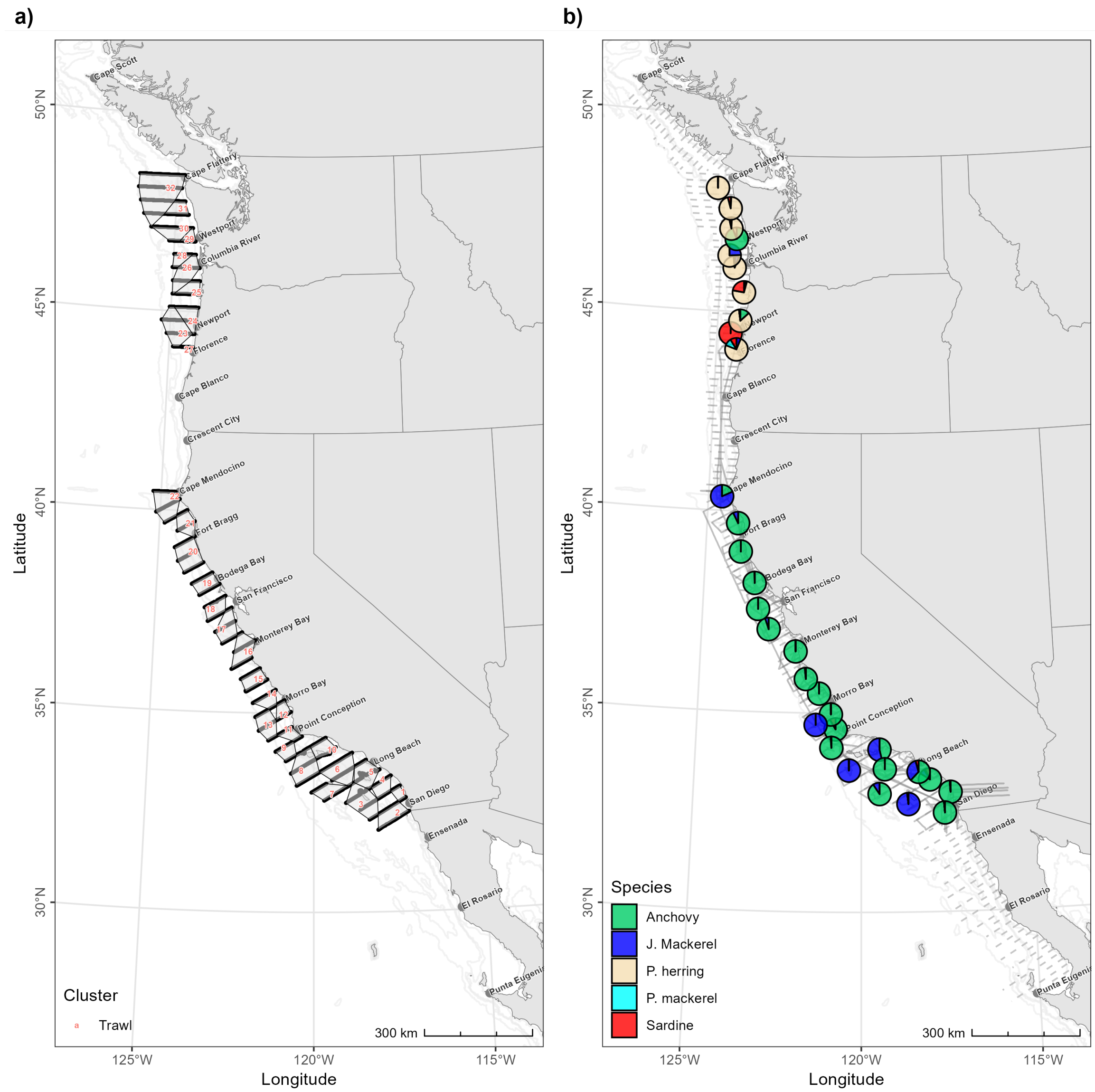

Figure 13: a) Polygons enclosing 100-m acoustic intervals from *Lasker* and *Shimada* assigned to catches from each trawl cluster, and b) the acoustic proportions of CPS in catches from trawl clusters. The numbers inside each polygon in panel a) are the cluster numbers, which are located at the average latitude and longitude of all trawls in that cluster. Black points in panel b) indicate trawl clusters with no CPS present in the catch. No Round Herring or "other" CPS were collected in trawl samples. Dashed gray lines in panel b) indicate planned acoustic transects, and the solid gray lines indicate the paths of *Lasker* and *Shimada*.

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 the presence (positive densities and potentially structural zeros) or absence (real zeros) of biomass for each species. Each stratum has: 1) at least three transects, with approximately equal spacing, 2) fewer than three consecutive transects with zero-biomass density, and 3) bounding transects with zero-biomass density (**Fig. 14**). This approach tracks 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 (40.8 °N). For Pacific Sardine, the northern stock present in the survey area (Felix-Uraga *et al.*, 2004; Felix-Uraga *et al.*, 2005; Garcia-Morales *et al.*, 2012; Hill *et al.*, 2014) was separated using the revised model of Pacific Sardine potential habitat (Zwolinski and Demer, 2023) during the survey (**Figs. 15** and **16**), with all other Pacific Sardine considered to be southern stock. 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 Bodega Bay (38.3 °N, **Fig. 14**).

2.3.2 Analysis of deep backscatter in the nearshore region

In summer 2023, the majority of backscatter observed in the nearshore region of the SCB was deeper than the thermocline, which was approximately 30-m deep (**Fig. 17**). In the same area, the purse-seine catches sampled using a 27-m deep net contained mostly Pacific Sardine, which typically reside above the thermocline (J. Zwolinski, unpublished data), but also Northern Anchovy. Therefore, the CPS backscatter shallower than 30 m was apportioned using the length and species composition of all CPS in the nearest purse seine sample; and the CPS backscatter deeper than 30 m was assumed to be Northern Anchovy with lengths corresponding to the nearest purse-seine catch with Northern Anchovy.

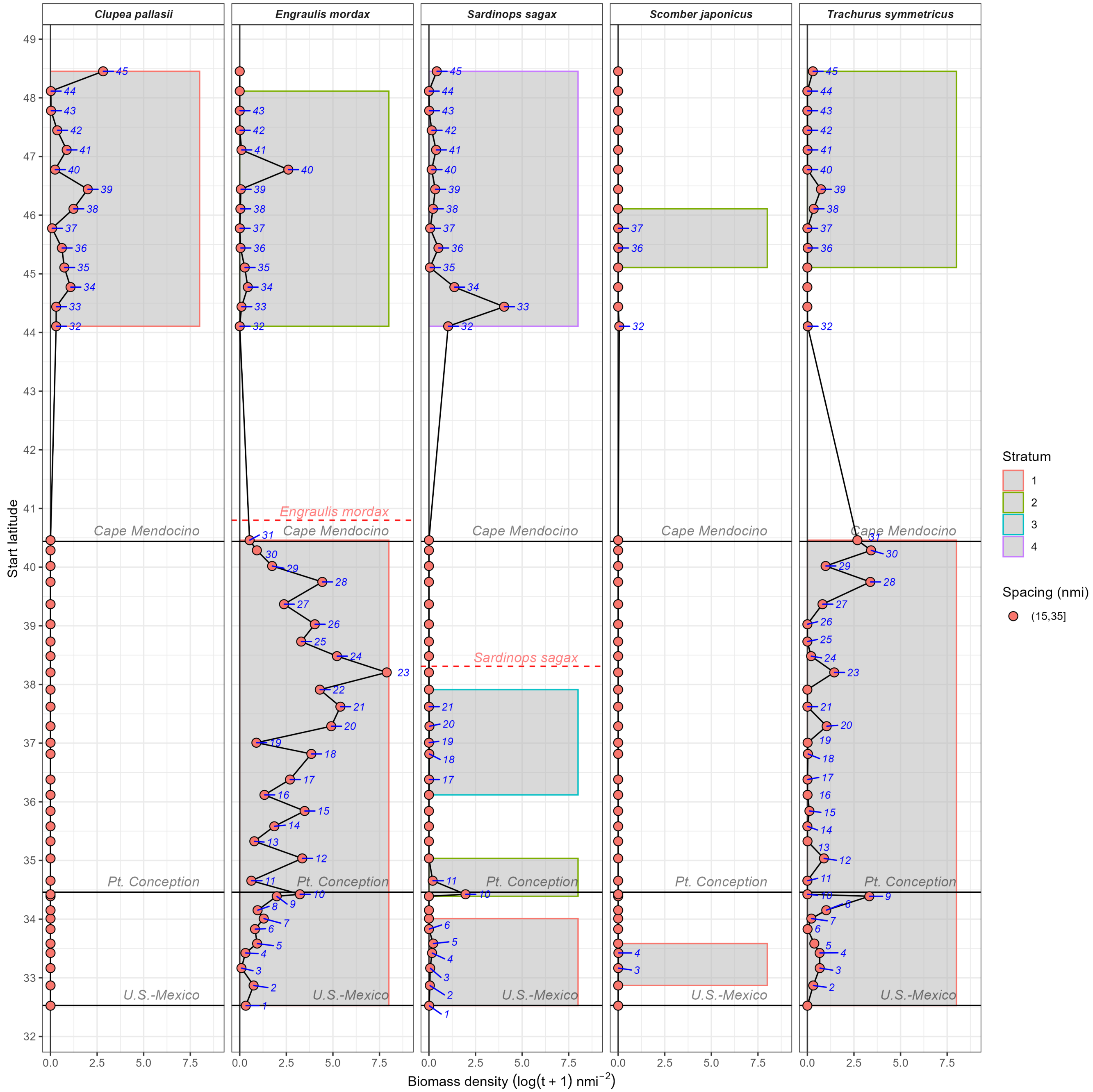

Figure 14: Biomass density ($\log_{10}(t\,\mathrm{nmi}^2 + 1)$) versus latitude (easternmost portion of each transect) and strata (shaded regions; outline indicates stratum number) used to estimate biomass and abundance for each species in the core survey region. Data labels (blue numbers) correspond 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.

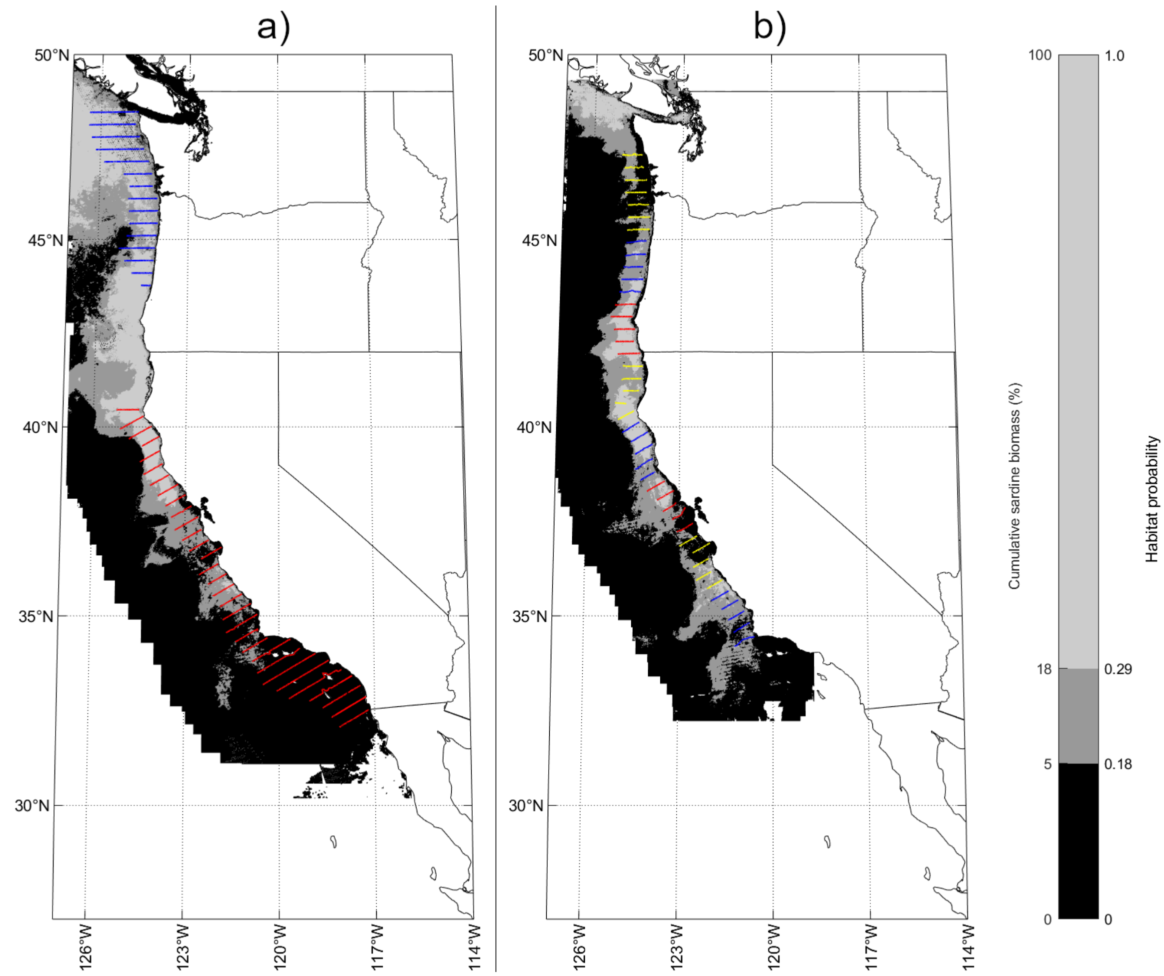

Figure 15: Summary of all core-region transects, in relation to the potential habitat for the northern stock of Pacific Sardine, as sampled by a) *Lasker* (red) and *Shimada* (blue); and b) Saildrone USVs SD-1048 (red), SD-1060 (blue), and SD-1096 (yellow). The habitat is temporally aggregated using an average of the habitat centered $\pm 2°$ around each vessel during the survey. Areas in white correspond to no available data (e.g., when cloud coverage prevented satellite-sensed observations).

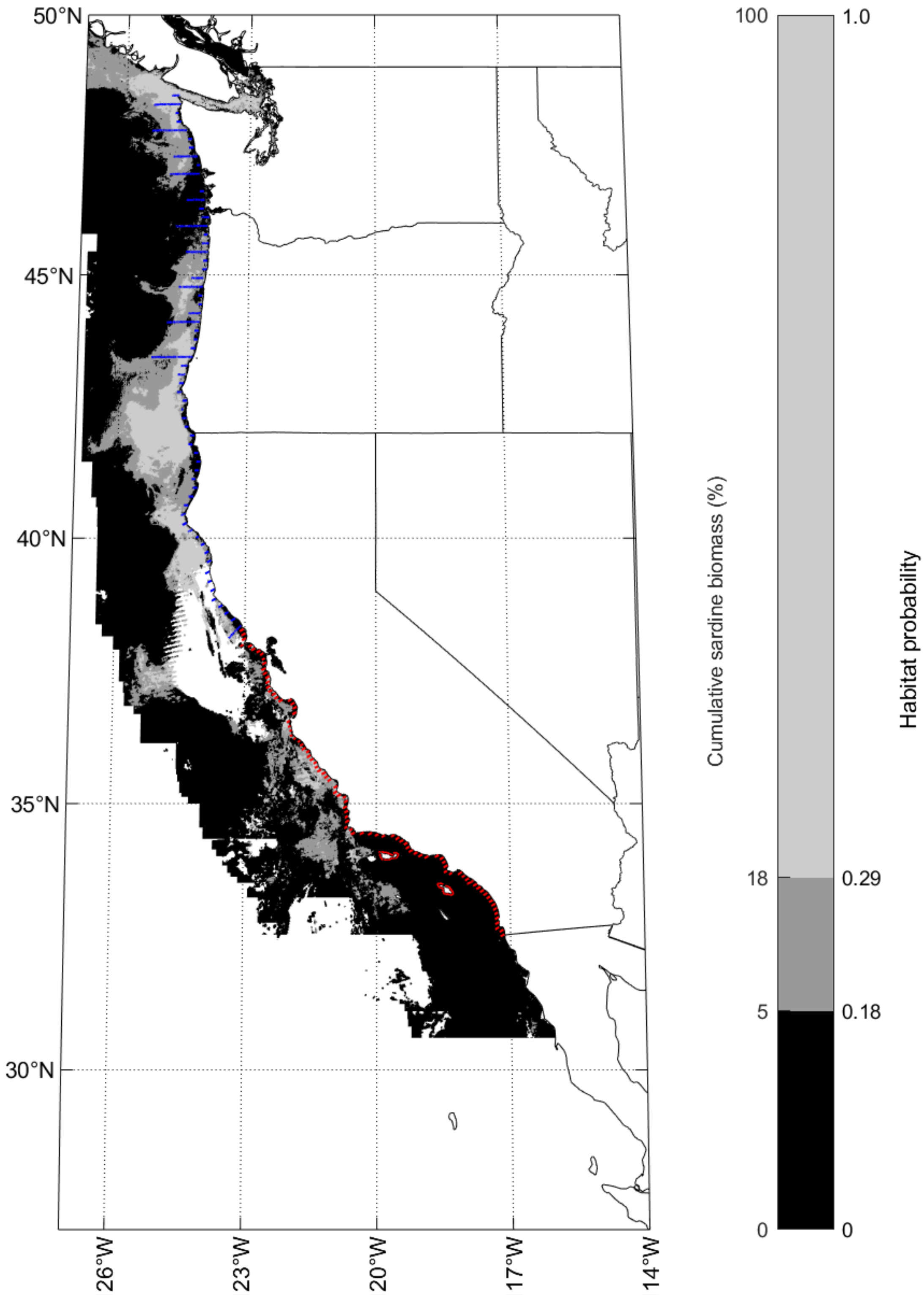

Figure 16: Summary of all nearshore-region transects sampled by *Long Beach Carnage* (red) and *Lisa Marie* (blue), in relation to the potential habitat for the northern stock of Pacific Sardine. The habitat is temporally aggregated using an average of the habitat centered ±2° around each vessel during the survey. Areas in white correspond to no available data (e.g., when cloud coverage prevented satellite-sensed observations).

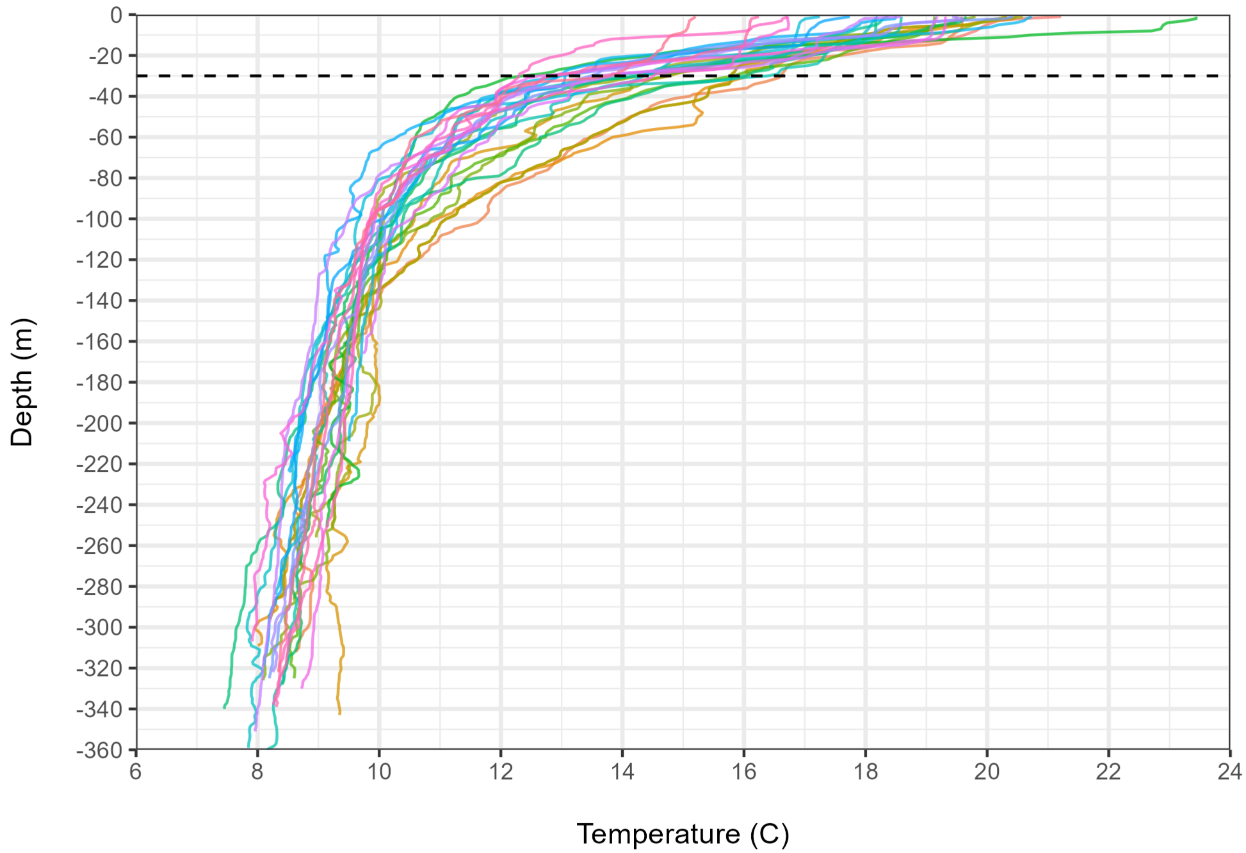

Figure 17: Temperature versus depth for UCTD casts conducted in the SCB during summer 2023. The dashed horizontal line indicates the average estimated depth of the thermocline throughout the SCB.

2.3.3 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}):

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

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

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

2.3.4 Abundance- and biomass-at-length estimation

The numerical densities by length class (**Section 2.2.7**) were averaged for each stratum in a similar way for that used for biomass (Equation (17)), and multiplied by the stratum area to obtain abundance per length class.

2.3.5 Percent biomass per cluster contribution

The percent contribution of each cluster to the estimated abundance in a stratum (**Appendix 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 core region of the summer 2023 survey spanned the continental shelf from the U.S.-Mexico border to Cape Mendocino and from Florence to Cape Flattery between 17 July and 04 November 2023, and included most of the potential habitat for the northern stock of Pacific Sardine at the time of the survey[5]. In this region (**Fig. 19**), *Lasker* (37 days at sea, DAS) and *Shimada* (15 DAS) sampled 45 east-west transects totaling 2,295 nmi. Catches from a total of 81 nighttime surface trawls were combined into 32 trawl clusters. In the core region, one to four post-survey strata were defined by their transect spacing and the densities of biomass attributed to each species.

The nearshore region spanned an area from 5-m depth to approximately 5 nmi from the continental coast, or 2.5 nmi from the Santa Cruz and Santa Catalina Islands, between Cape Flattery and San Diego. *Lisa Marie* (19 DAS) surveyed from approximately Cape Flattery, WA to Bodega Bay with 63 east-west transects totaling 287 nmi and 52 purse-seine sets. *Long Beach Carnage* (21 DAS) surveyed from approximately Bodega Bay to San Diego, and around the Santa Cruz and Santa Catalina Islands, with 130 east-west transects totaling 508 nmi and 56 purse-seine sets (**Fig. 21**). In the nearshore region, one to ten post-survey strata were defined by their transect spacing and the densities of biomass attributed to each species.

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

Leg I

I.1

Leg I.1 on *Lasker* was canceled due to OMAO staffing shortages and a seawater leak.

I.2

On 17 July, after a 14-d delay, *Lasker* departed from the 10th Avenue Marine Terminal in San Diego, CA at ~2000 (all times GMT). Prior to the transit, a calibration of the Simrad EC150-3C ADCP was conducted northwest of the sea buoy outside San Diego Bay (32.6598 N, 117.3833 W). Due to the departure delays, sampling off Baja California was cancelled. The survey commenced on 18 July along transect 033 off Imperial Beach, CA. On the evening of 22 July, a scientist and member of the deck crew were embarked using *Lasker*'s small boat at Dana Point Harbor. On 29 July, *Lasker* ceased acoustic sampling after completing the nearshore portion of transect 57 off Morro Bay, CA. At ~1300 on 30 July, *Lasker* arrived at Pier 30/32 in San Francisco, CA, completing Leg I.

Nearshore

From 8 to 18 July, *Long Beach Carnage* sampled nearshore transects 1 to 38, between San Diego and Point Conception, CA, including around Santa Catalina and Santa Cruz Islands.

From 22 to 25 July, *Lisa Marie* conducted purse-seine sets to compare catches with nighttime and daytime trawls, between Point Conception and Monterey Bay.

From 21 to 30 July, two USVs (SD-1060 and SD-1096) sampled transects 52 to 70, from Point Conception to Half Moon Bay.

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

Leg II

Leg II on *Lasker* was canceled due to OMAO staffing shortages and cases of COVID-19.

Nearshore

From 7 to 16 August, *Long Beach Carnage* sampled nearshore transects 39 to 90, from Point Conception to Bodega Bay, CA.

From 6 to 8 August, *Lisa Marie* conducted purse-seine sets for comparative catch analyses between Point Conception, CA and San Luis Obispo, CA. Then, from 11 August to 2 September, *Lisa Marie* sampled nearshore transects 91 to 216, from Bodega Bay, CA to Cape Flattery, WA.

From 10 to 29 August, three USVs sampled transects 72 to 100, from Half Moon Bay, CA to Crescent City, CA.

Leg III

III.1

At ~2030 on 5 September, *Lasker* departed from 10th Avenue Marine Terminal, San Diego. At ~2100 UTC on 6 September, an acoustic lander was deployed at 34.43877 N, 120.54697 W, near Point Conception. At ~1400 on 7 September, acoustic sampling resumed along transect 57 off Morro Bay, CA. At ~0100 on 11 September, after completing acoustic transect 67, a scientist was embarked via a small boat transfer near Moss Landing, CA. On 12 September, after a crack was discovered in a freshwater anti-roll tank, an emergency trip was planned to Pier 30/32 in San Francisco, CA, with evening trawling operations en-route. However, while in transit to the first trawl location on transect 77, the S-Band RADAR unexpectedly stopped turning. As a result, the ship abandoned the planned trawls on transects 079 and 77 and began the emergency transit to San Francisco, CA. The ship moored alongside pier 30/32 at ~1400 on 13 September. On 13 and 14 September, the ship's engineers patched the crack in the anti-roll tank, and the ship's Electronics Technician worked with RADAR technicians to fix the S-Band RADAR. At ~1430 on 15 September, the ship departed San Francisco, resumed daytime acoustic sampling on transect 81, then trawled that evening on transects 77 and 79. At ~0700 on 17 September, after finishing acoustic sampling on transect 89 and conducting one nighttime trawl, *Lasker* transited to San Francisco for a mid-leg crew transfer on 18 September.

III.2

At ~1800 on 21 September, *Lasker* departed from Pier 30/32 in San Francisco. On 21 September, a passive acoustic buoy, part of SWFSC's ADRIFT acoustic monitoring project, was safely recovered after its previously scheduled retrieval vessel experienced mechanical problems. During the transit, the leak in *Lasker*'s anti-roll tank reemerged, but the decision was made to continue the survey. At ~1815 on 22 September, *Lasker* resumed acoustic sampling along transect 091 off Petrolia, CA. On 22 September, transects 91 and 93 were sampled acoustically and two trawls conducted that evening. With a leaking anti-roll tank and unworkable weather conditions in the forecast, it was decided to cease survey operations on 23 September and return to Newport. At 1700 on 24 September, *Lasker* returned to the MOC-P Pier in Newport to end Leg III and conclude the 2023 Summer CCE survey aboard *Lasker*. On 24 and 25 September, survey equipment was demobilized and transferred ashore, awaiting mobilization of *Shimada* for Leg IV.

Nearshore

From 5 to 30 September, the three USVs sampled their final transects of the survey, 102 to 134, from Crescent City, CA to Santiago, WA.

Leg IV

IV.1

Due to inclement weather on 10 and 11 October, Leg IV.1 on *Shimada* was delayed by two days. At ~1900 on 12 October, *Shimada* departed from Newport and commenced acoustic sampling near Waldport along transect 117. Transects 121, 123, 125, and 127 were shortened to 40-nmi lengths due to weather conditions. At ~1100 on 16 October, after completing nighttime trawling, *Shimada* transited south to transect 115 to be closer to Newport in case weather conditions deteriorated. On 16 October, after completing the third trawl near Astoria, OR, the crew discovered that the main body of the trawl net was damaged. Due to the high sea state, the trawl net was not replaced while underway. At ~2100 on 17 October, during favorable bar conditions, *Shimada* arrived at the MOC-P pier in Newport, OR to complete Leg IV.1. The damaged trawl net was replace with a spare net between Legs IV.1 and IV.2.

IV.2

At ~1945 on 26 October, *Shimada* departed from the MOC-P pier in Newport and, due to poor weather conditions, commenced acoustic sampling nearby on transects 113 and 115 off Florence. Between 28 October and 2 November, *Shimada* sampled transects 129 to 141 between Astoria and Cape Flattery. At ~1800 on 3 November, *Shimada* arrived at Anacortes, WA to complete the 2023 survey.

3.2 Acoustic backscatter

Acoustic backscatter ascribed to CPS was observed throughout the latitudinal range of the core survey area (**Fig. 19a**), but was greatest between Fort Bragg and Monterey. Acoustic backscatter was present from the shore to the shelf break, but was generally greater closer to shore. Zero-biomass intervals were observed at the offshore end of each transect in the core region. Greater than 90% of the biomass for each species was apportioned using catch data from trawl clusters conducted within 30 nmi, except Jack Mackerel, which was within ~40 nmi (**Fig. 18**).

Acoustic backscatter ascribed to CPS was also observed throughout the nearshore survey area (**Figs. 20a** and **21a**), but was most prevalent in transects sampled by *Lisa Marie* between Cape Flattery and Crescent City and near Bodega Bay (**Fig. 20a**) and along mainland transects sampled by *Long Beach Carnage* between Bodega Bay and Santa Barbara (**Fig. 21a**).

3.3 Egg densities and distributions

In 2023, CUFES sampling was only conducted from *Lasker* between San Diego and Cape Mendocino. Northern Anchovy eggs were predominant in samples collected close to shore in the SCB and samples offshore between Santa Barbara and Cape Mendocino (**Fig. 19b**). Some Jack Mackerel eggs were present off Morro Bay and around the northern Channel Islands (**Fig. 19b**). Pacific Sardine eggs were present in samples collected in the SCB, around Santa Catalina and San Clemente Islands (**Fig. 19b**).

3.4 Trawl catch

Trawl catches from *Lasker* and *Shimada* were comprised of mostly Pacific Herring between Florence and Cape Flattery, and Northern Anchovy farther south (**Fig. 19c**). Pacific Sardine were also present in trawl clusters off the coasts of WA and OR, and in trawl clusters south of Long Beach, CA in the SCB. Jack Mackerel were present throughout the survey area, but were most abundant off the Columbia River and offshore between Cape Mendocino and San Diego (**Fig. 19c**). Few Pacific Mackerel were collected between Newport and the Columbia River (**Fig. 19c**; but not visible at this scale). Overall, the 81 trawls captured a combined 3,791 kg of CPS (3,524 kg of Northern Anchovy, 99 kg of Pacific Sardine, 98.9 kg of Pacific Herring, 68.4 kg of Jack Mackerel, and 0.863 kg of Pacific Mackerel).

3.5 Purse-seine catch

3.5.1 *Lisa Marie*

North of Cape Blanco, Pacific Herring and Pacific Sardine were predominant, by weight, in the purse-seine samples (**Fig. 20b**). Some purse-seine sets were located offshore in the core region; however, nearshore biomasses were estimated using only the purse-seine samples collected within the predetermined nearshore region (i.e., within 5-nmi from shore ; **Fig. 20b**). Pacific Herring and Jack Mackerel were predominant between Cape Blanco and Fort Bragg, and Northern Anchovy comprised most of the purse-seine catch south of Fort Bragg. Notably, no Pacific Sardine were captured in purse-seine samples between Cape Blanco and Cape Mendocino where neither *Lasker* nor *Shimada* conducted trawl sampling. Overall, the dip-net samples from 52 purse-seine sets totaled 328 kg of CPS (185 kg of Jack Mackerel, 93.1 kg of Pacific Sardine, 38.5 kg of Pacific Herring, and 11.6 kg of Northern Anchovy; no Pacific Mackerel were caught).

3.5.2 *Long Beach Carnage*

Northern Anchovy and Pacific Sardine were predominant, by weight, in purse-seine samples collected by *Long Beach Carnage* in the nearshore region (**Fig. 21b**). In general, Northern Anchovy were more abundant north of Pt. Conception and Pacific Sardine were more abundant to the south (**Fig. 21b**). Pacific Mackerel were collected in several purse-seine samples along the mainland coast in the SCB. Few Jack Mackerel were collected in purse-seine samples collected by *Long Beach Carnage* (**Fig. 21b**). Overall, dip-net samples from 56 seines totaled 170 kg of CPS (103 kg of Pacific Sardine, 56.1 kg of Pacific Mackerel, 10 kg of Northern Anchovy, and 0.96 kg of Jack Mackerel; no Pacific Herring were caught).

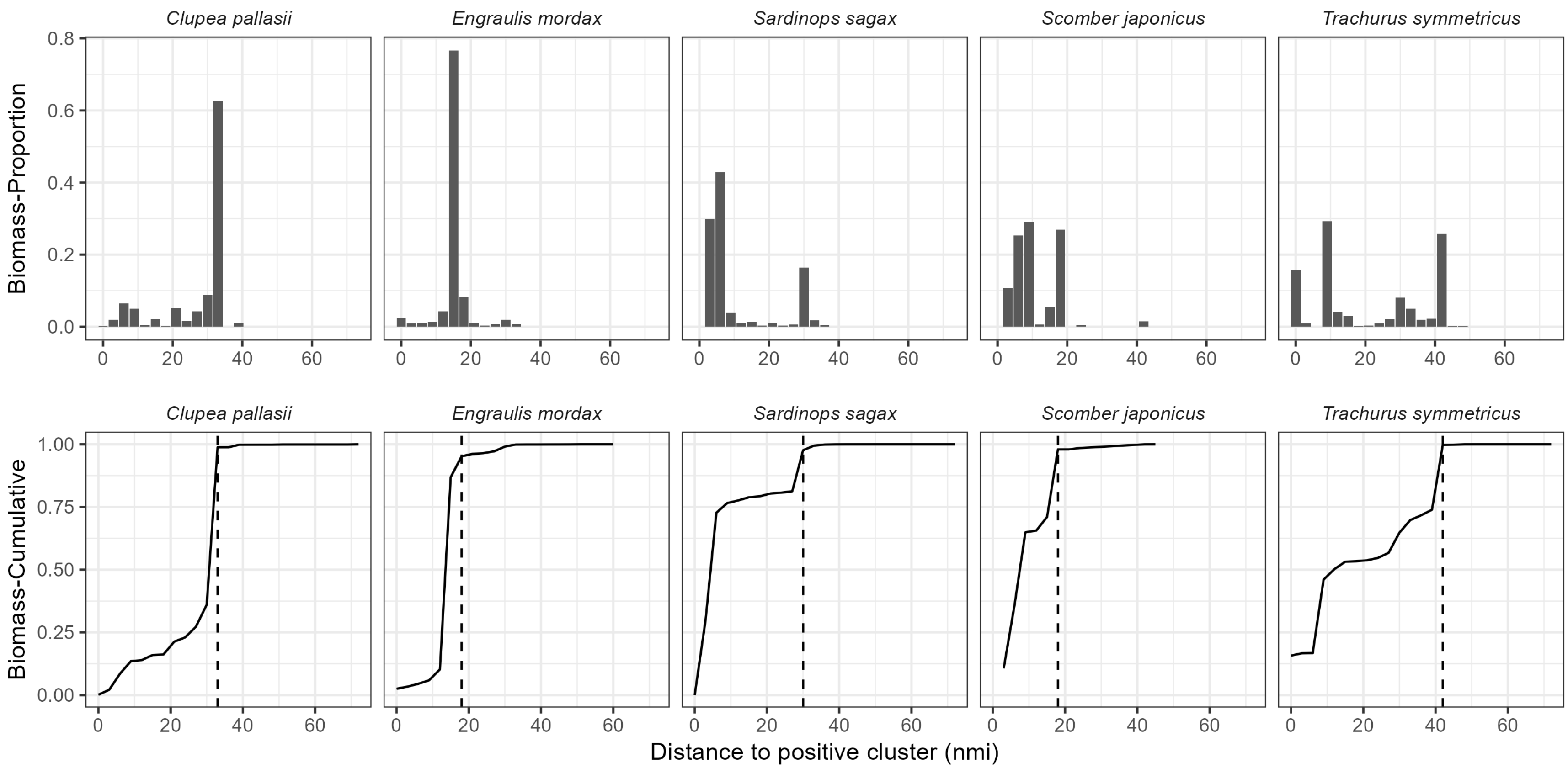

Figure 18: Proportion (top) and cumulative proportion (bottom) of biomass of each CPS species versus distance to the nearest positive trawl cluster. Dashed vertical lines (bottom) represent the cluster distance where cumulative biomass equals 90%. Note: these results area not separated by stock.

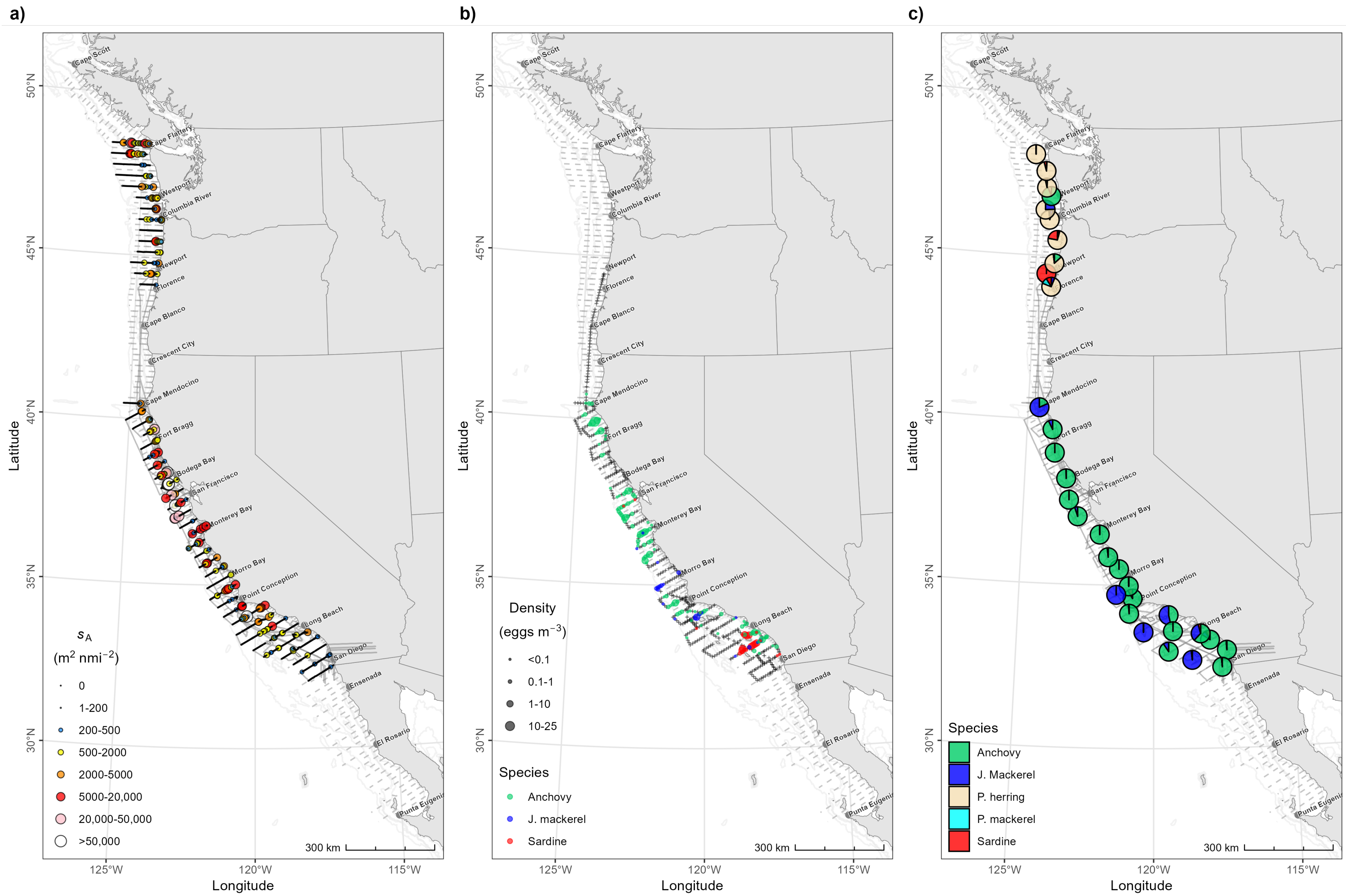

Figure 19: Spatial distributions of: a) 38-kHz integrated backscattering coefficients (s_A, m^2 nmi^{-2}; averaged over 2000-m distance intervals) ascribed to CPS; b) CUFES egg density (eggs m^{-3}) for Northern Anchovy, Pacific Sardine, and Jack Mackerel; and c) acoustic proportions of CPS in trawl clusters.

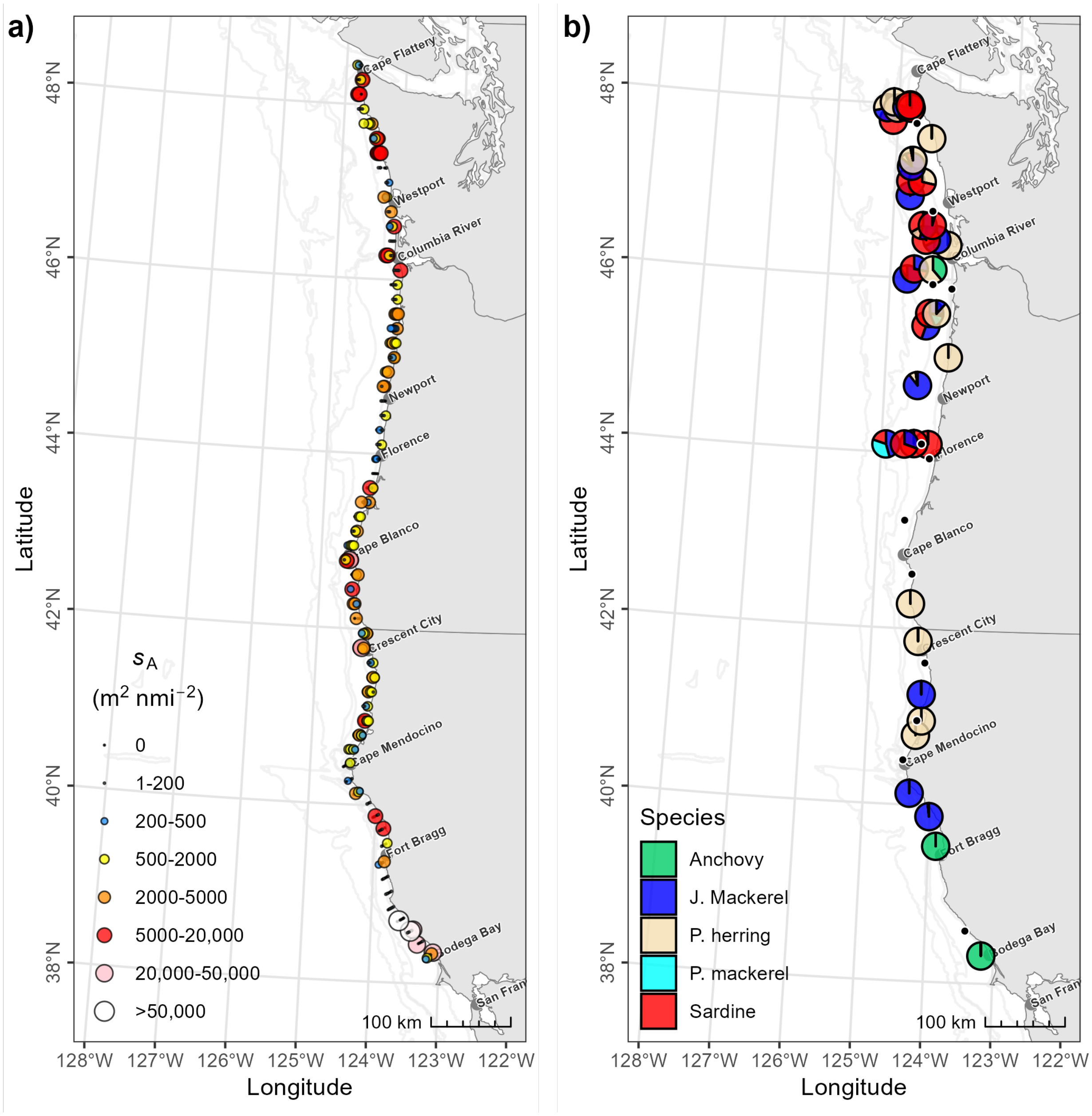

Figure 20: Nearshore survey transects sampled by *Lisa Marie* overlaid with the distributions of: a) 38-kHz integrated backscattering coefficients (s_A, m^2 nmi^{-2}; averaged over 2000-m distance intervals) ascribed to CPS; and b) the proportions, by weight, of CPS in each purse-seine catch. Black points indicate purse-seine sets with no CPS present. Species with low catch weights may not be visible at this scale. Note, acoustic backscatter and purse-seine catches beyond the 5-nmi boundary of the planned nearshore transects were not used to estimate biomasses in either the core or nearshore regions.

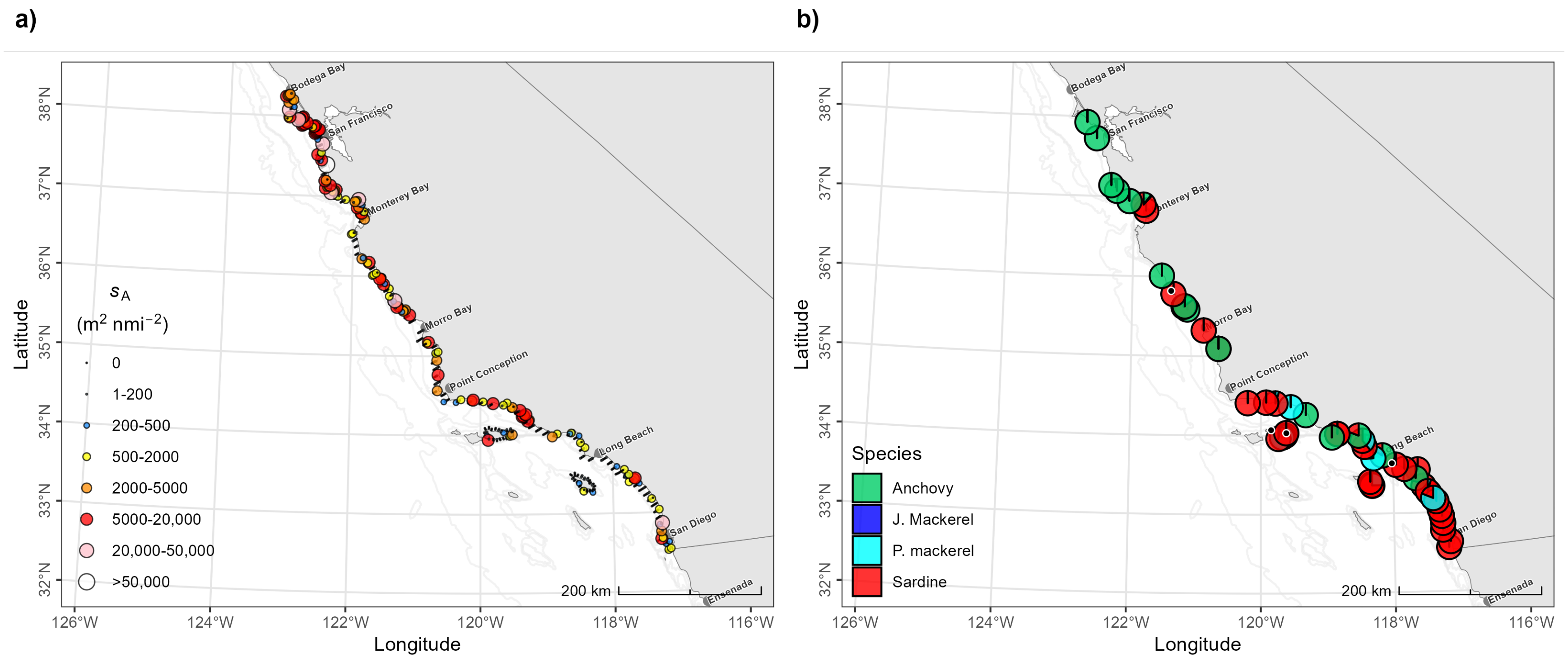

Figure 21: Nearshore transects sampled by *Long Beach Carnage* overlaid with the distributions of: a) 38-kHz integrated backscattering coefficients (s_A, m^2 nmi^{-2}; averaged over 2000-m distance intervals) ascribed to CPS; and b) the proportions, by weight, of CPS in each purse-seine catch. Black points indicate purse-seine sets with no CPS present. Species with low catch weights may not be visible at this scale.

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.

3.6.1 Northern Anchovy

3.6.1.1 Northern stock

The total estimated biomass of the northern stock of Northern Anchovy was 11,356 t ($CI_{95\%}$ = 438 - 30,038 t, CV = 72%; **Table 6**). In the core region, biomass was 11,040 t ($CI_{95\%}$ = 369 - 29,774 t, CV = 74%; **Table 6**); the stock was sparsely distributed throughout the region from Cape Flattery to Newport (**Fig. 22a**). L_S ranged from 9 to 16 cm with a mode at 13 cm (**Table 7**, **Fig. 23**). In the nearshore region, biomass was 315 t ($CI_{95\%}$ = 68.9 - 265 t, CV = 17%; **Table 6**), comprising 2.8% of the total biomass, and was located near the entrance to the Columbia River (**Fig. 22b**). Lengths in the nearshore region had a single mode at ~14 cm (**Table 7**; **Fig. 23**).

Table 6: Biomass estimates (metric tons, t) and their precisions (upper and lower 95% confidence intervals, $CI_{95\%}$; and coefficients of variation, CVs) for the 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	2	12,321	13	619	6	10,370	11,040	369	29,774	74
	All	12,321	13	619	6	10,370	11,040	369	29,774	74
Nearshore	8	69	3	14	2	2	315	69	265	17
	All	69	3	14	2	2	315	69	265	17
All	**-**	**12,390**	**16**	**633**	**8**	**10,372**	**11,356**	**438**	**30,038**	**72**

Table 7: Abundance estimates 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	74,309	0
10	25,896,404	0
11	56,269,664	0
12	99,225,218	0
13	253,421,391	0
14	54,668,577	2,831,866
15	14,052,368	2,544,279
16	860,321	0
17	0	0
18	0	0
19	0	0
20	0	0

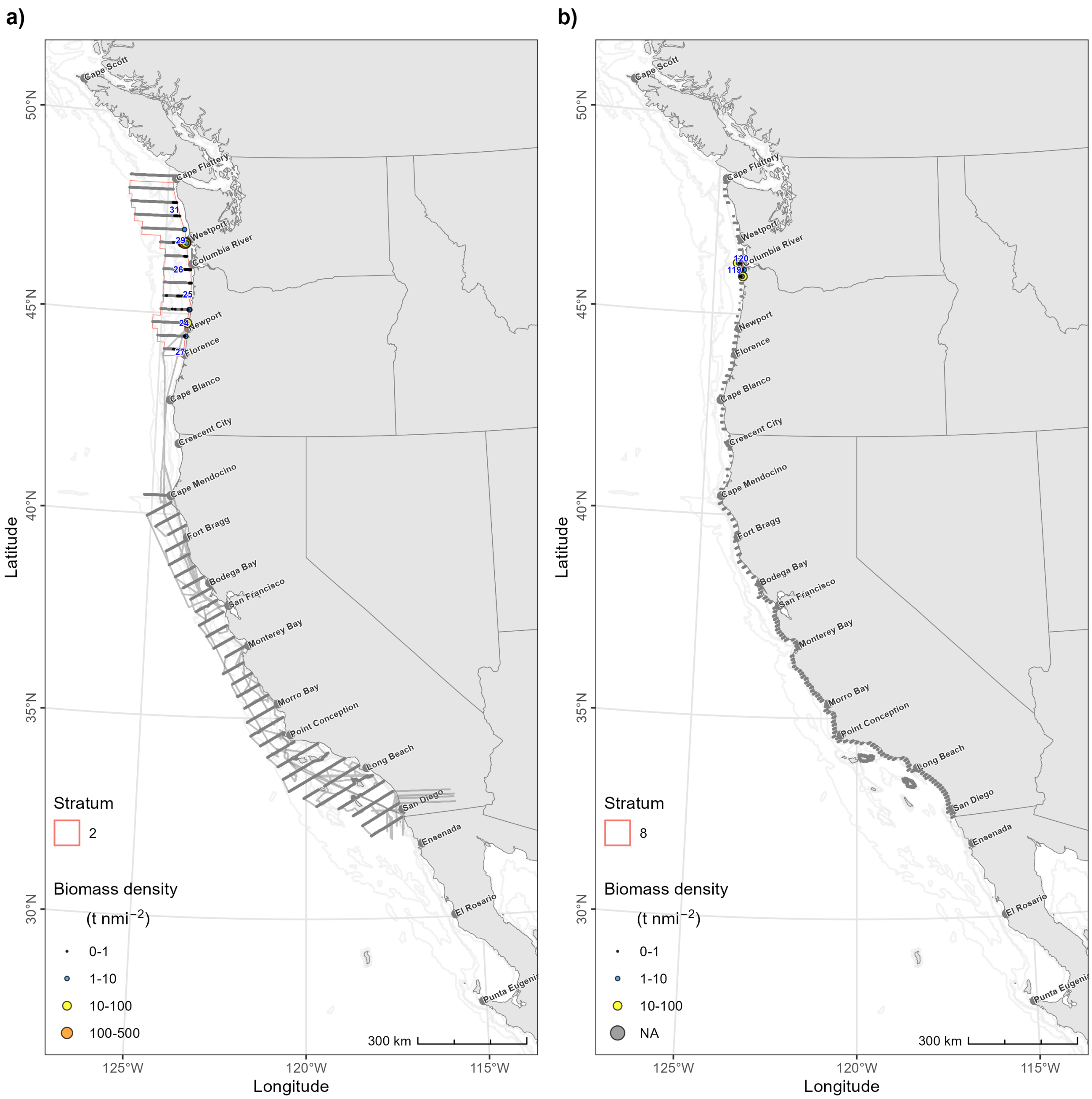

Figure 22: Biomass densities (colored points) of the northern stock of Northern Anchovy (*Engraulis mordax*), per stratum, in the a) core and b) nearshore survey regions. Overlaid are the locations of trawl clusters with at least one Northern Anchovy (blue numbers) in each stratum (colored polygons).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

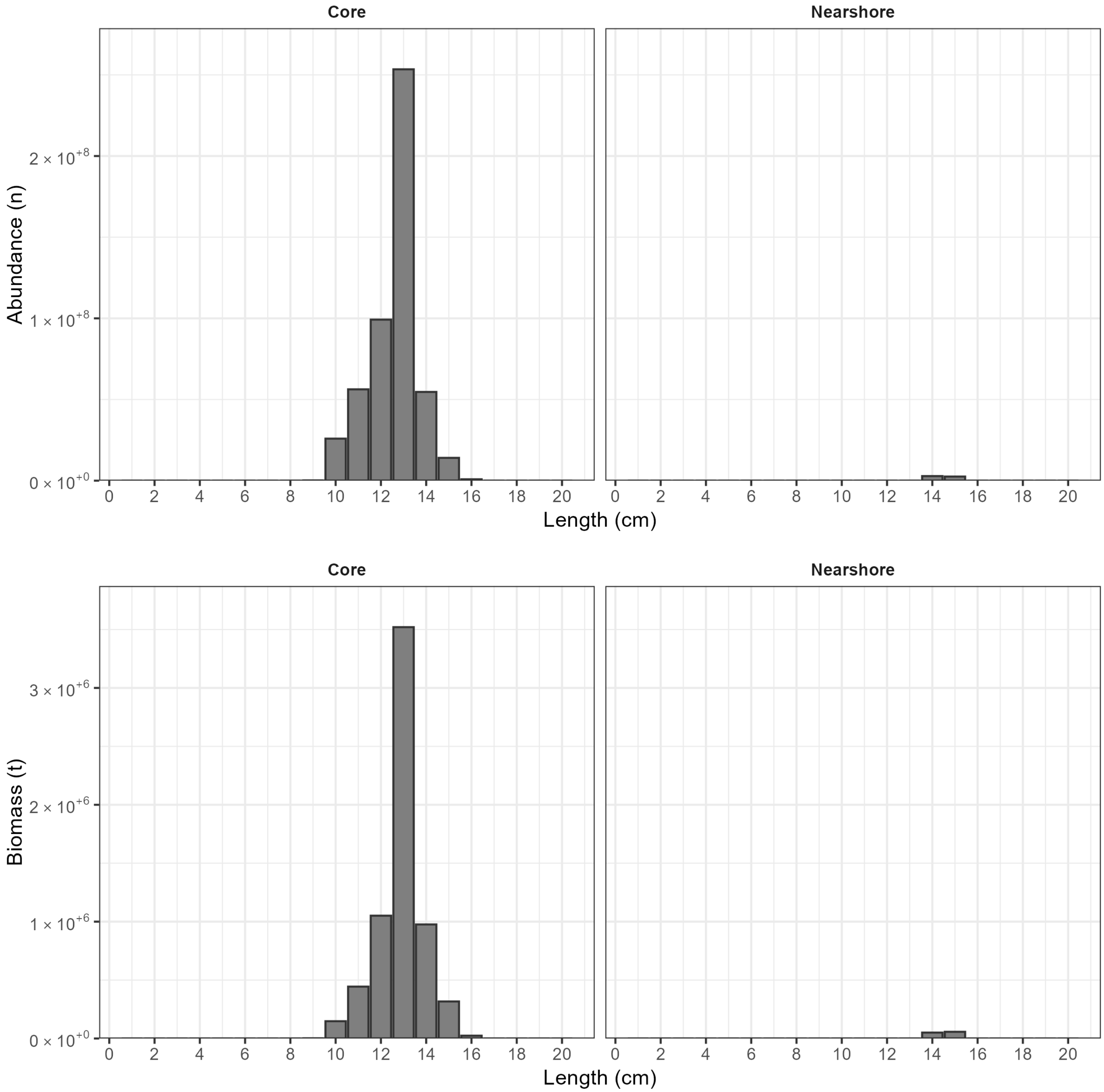

Figure 23: Abundance estimates versus standard length (L_S, upper panels) and biomass (t) versus L_S (lower panels) for the northern stock of Northern Anchovy (*Engraulis mordax*) in the core and nearshore survey regions. Abundance and biomass in the nearshore region is negligible relative to the core 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 2,689,200 t ($CI_{95\%}$ = 297,242 - 4,932,949 t, CV = 46%; **Table 8**). In the core region, biomass was 2,447,378 t ($CI_{95\%}$ = 206,171 - 4,740,405 t, CV = 51%; **Table 8**); the stock was distributed throughout most of the survey area from Cape Mendocino to San Diego (**Fig. 24a**). L_S ranged from 5 to 15 cm with a mode 13 cm (**Table 9**, **Fig. 25**). In the nearshore region, biomass was 241,822 t ($CI_{95\%}$ = 91,071 - 192,544 t, CV = 11%; **Table 8**), comprising 9% of the total biomass, and was distributed between Fort Bragg and Los Angeles, CA (**Fig. 24b**). The nearshore length distribution had a single mode at 11 cm (**Table 9**, **Fig. 25**).

Table 8: Biomass estimates (metric tons, t) and their precisions (upper and lower 95% confidence intervals, $CI_{95\%}$; and coefficients of variation, CVs) for the 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	29,857	31	1,609	19	199,166	2,447,378	206,171	4,740,405	51
	All	29,857	31	1,609	19	199,166	2,447,378	206,171	4,740,405	51
Nearshore	1	78	4	23	1	50	466	0	1,372	84
	2	210	11	55	3	142	10,622	565	21,073	49
	3	130	8	37	1	50	1,829	57	3,898	56
	4	54	5	24	2	100	12,005	553	2,403	4
	5	108	9	35	1	50	11,176	1,746	10,208	19
	6	336	22	108	7	350	100,554	39,565	86,768	12
	7	217	9	48	2	100	105,170	15,684	103,840	21
	All	1,132	68	330	16	842	241,822	91,071	192,544	11
All	**-**	**30,989**	**99**	**1,938**	**35**	**200,008**	**2,689,200**	**297,242**	**4,932,949**	**46**

Table 9: Abundance estimates 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	53,780,028	0
6	604,851,821	1,597,037
7	1,493,069,387	35,723,831
8	1,059,022,314	270,790,060
9	832,033,496	729,989,266
10	1,766,549,404	692,346,069
11	6,969,215,091	1,897,841,180
12	19,297,780,328	2,697,575,124
13	55,232,985,675	1,710,154,843
14	19,357,108,843	359,176,849
15	1,353,314,656	809,490
16	0	0
17	0	0
18	0	0
19	0	0
20	0	0

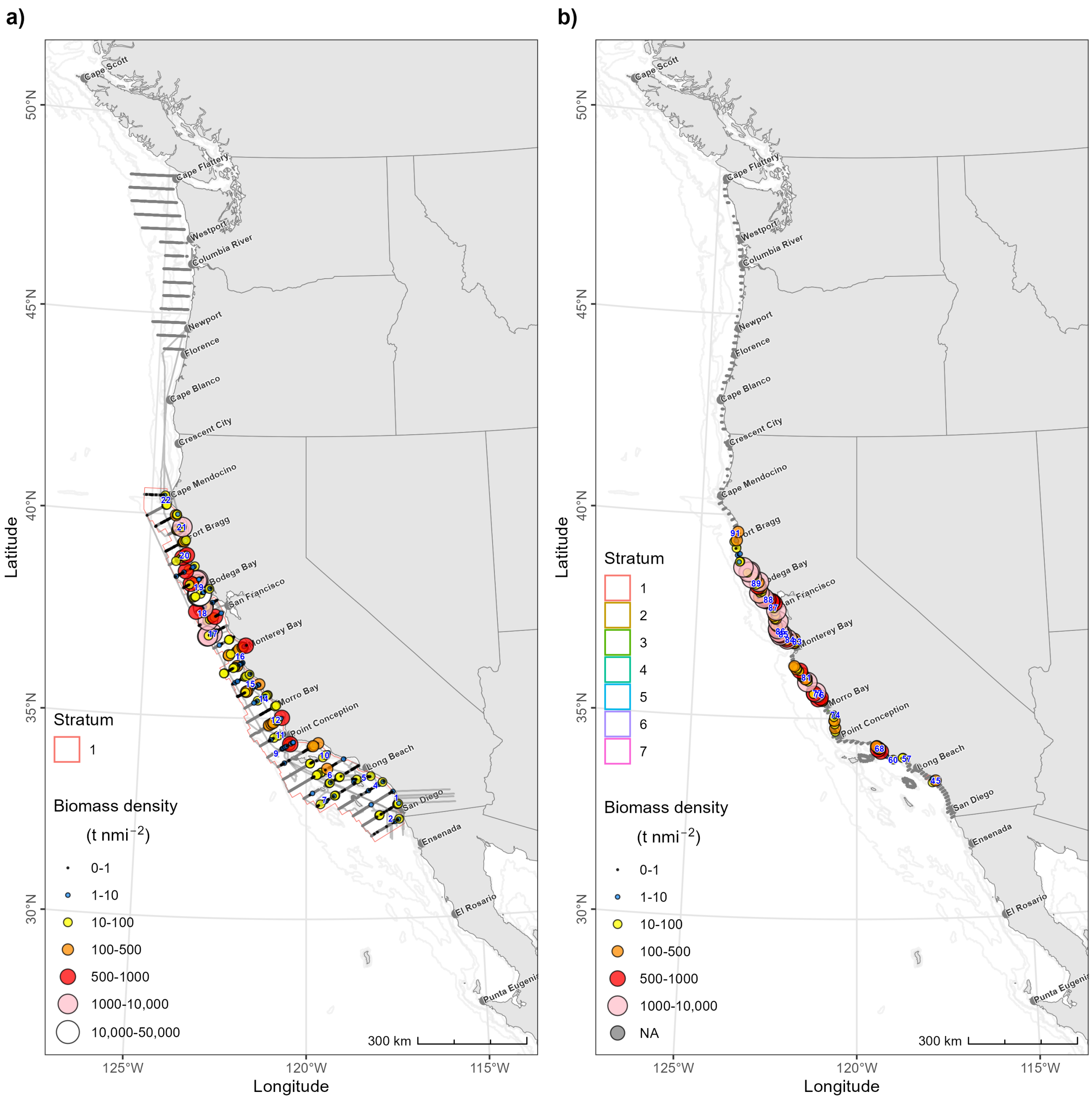

Figure 24: Biomass densities (colored points) of central stock of Northern Anchovy (*Engraulis mordax*), per stratum, in the a) core and b) nearshore survey regions. Overlaid are the locations of trawl clusters with at least one Northern Anchovy (blue numbers) in each stratum (colored polygons). Thick gray lines represent acoustic transects.

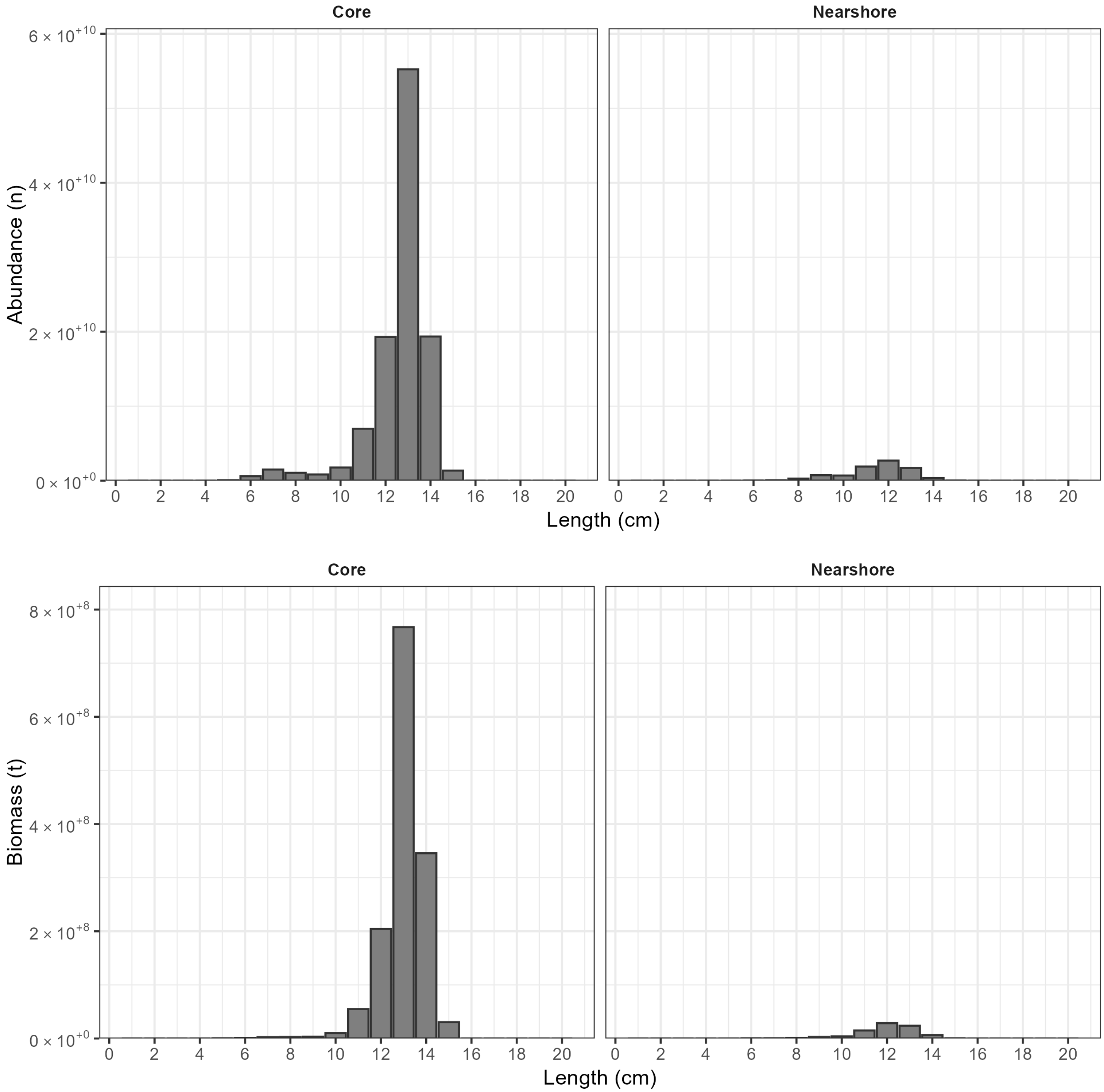

Figure 25: Abundance estimates versus standard length (L_S, upper panels) and biomass (t) versus L_S (lower panels) for the central stock of Northern Anchovy (*Engraulis mordax*) in the core and nearshore survey regions.

3.6.2 Pacific Sardine

3.6.2.1 Northern stock

The total estimated biomass of the northern stock of Pacific Sardine was 77,252 t ($CI_{95\%}$ = 17,856 - 171,829 t, CV = 47%; **Table 10**). In the core region, biomass was 49,643 t ($CI_{95\%}$ = 3,009 - 132,210 t, CV = 71%; **Table 10**), was distributed from Cape Flattery to Newport, but was most abundant between around Newport (**Fig. 26a**). L_S ranged from 7 to 28 cm with modes at 9 and 19 cm (**Table 11**, **Fig. 27**). In the nearshore region, biomass was 27,610 t ($CI_{95\%}$ = 14,847 - 39,619 t, CV = 23%; **Table 10**), comprising 36% of the total biomass. It was distributed mostly north of the Columbia River and between Newport and Cape Blanco (**Fig. 26b**). Lengths in the nearshore region had a mode at 19 cm (**Table 11**, **Fig. 27**).

Table 10: Biomass estimates (metric tons, t) and their precisions (upper and lower 95% confidence intervals, $CI_{95\%}$; and coefficients of variation, CVs) for the 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	13,641	14	686	9	1,380	49,643	3,009	132,210	71
	All	13,641	14	686	9	1,380	49,643	3,009	132,210	71
Nearshore	1	57	3	16	3	150	12,596	7,068	23,393	32
	2	103	6	26	2	52	1,871	836	2,930	29
	3	143	5	16	3	82	9,618	2,026	17,728	49
	4	59	2	11	1	50	3,525	1,406	6,216	49
	All	362	16	69	8	334	27,610	14,847	39,619	23
All	**-**	**14,004**	**30**	**755**	**17**	**1,714**	**77,252**	**17,856**	**171,829**	**47**

Table 11: Abundance estimates 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	1,746,850	0
8	43,251,593	0
9	46,971,529	0
10	5,916,249	0
11	0	0
12	0	0
13	0	0
14	488,898	222,794
15	323,974	0
16	19,216,683	0
17	26,698,300	2,433,858
18	187,160,759	69,562,244
19	265,266,627	173,934,075
20	74,422,019	36,410,862
21	8,687,447	4,057,049
22	488,898	2,028,525
23	0	2,839,935
24	0	2,434,230
25	0	5,060,967
26	1,655,431	1,034,204
27	0	1,217,115
28	244,449	811,410
29	0	0
30	0	0

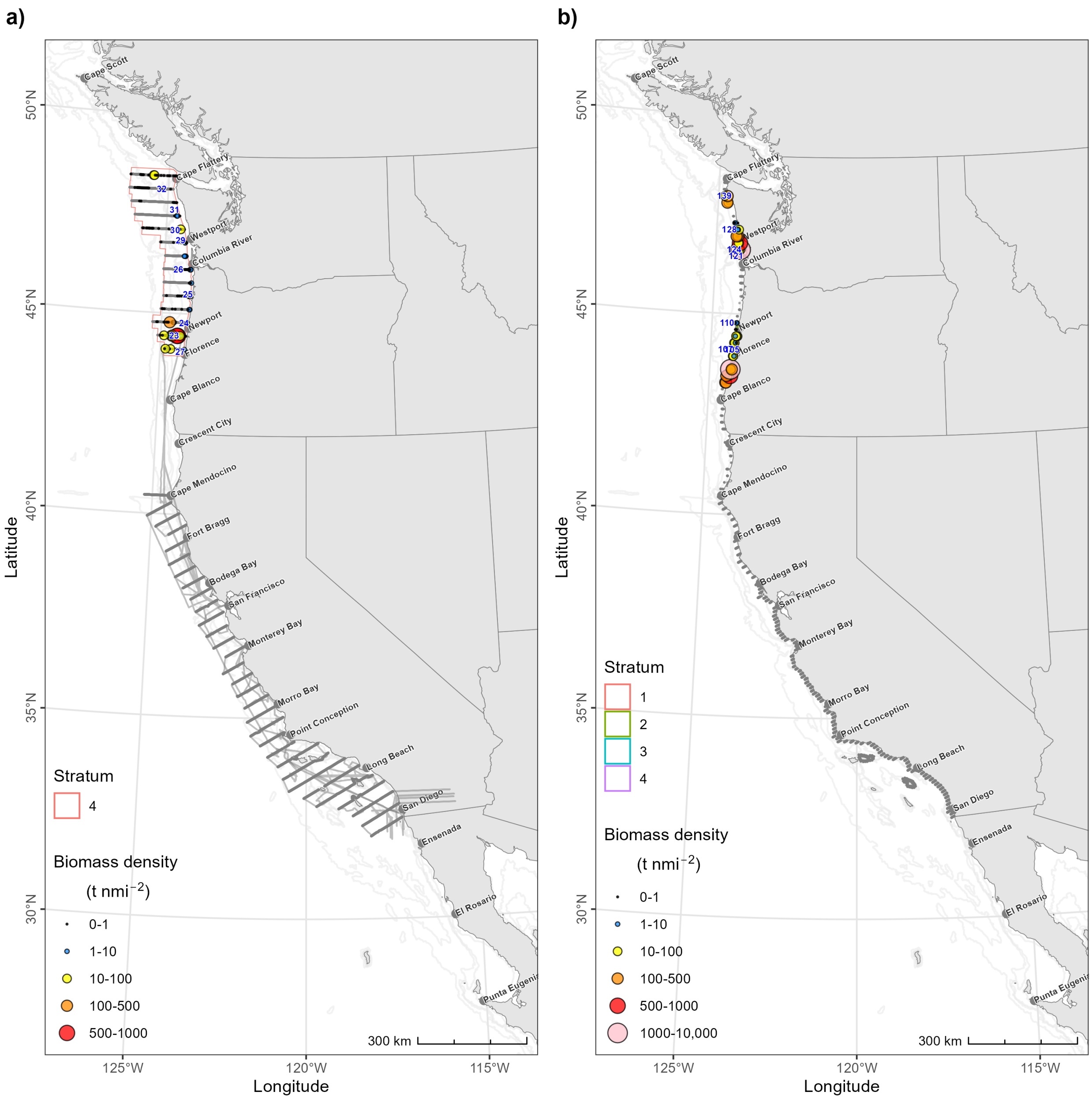

Figure 26: Biomass densities (colored points) of the northern stock of Pacific Sardine (*Sardinops sagax*), per stratum, in the a) core and b) nearshore survey regions. Overlaid are the locations of trawl clusters with at least one Pacific Sardine (blue numbers) in each stratum (colored polygons). Thick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

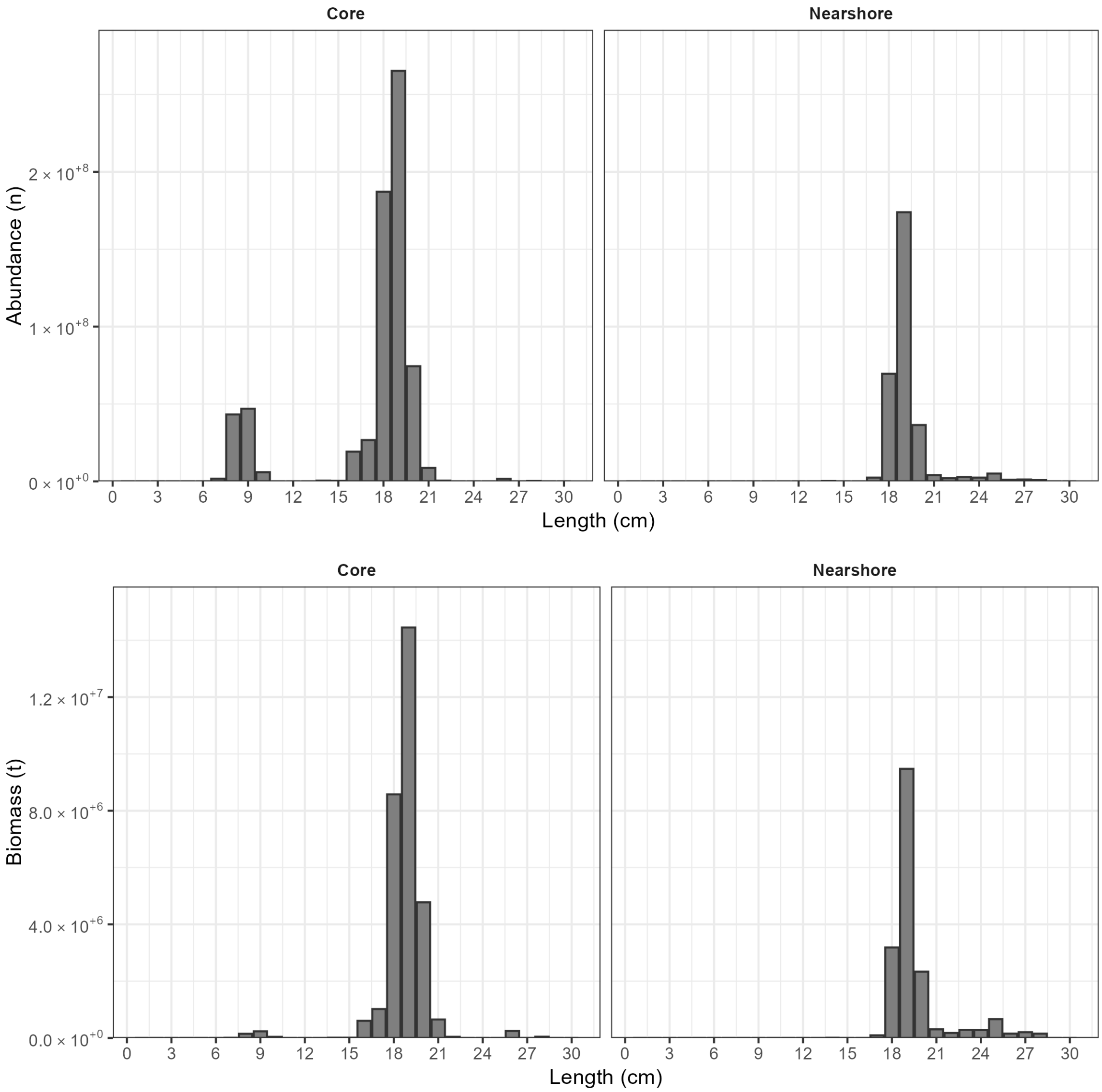

Figure 27: Estimated abundance (upper panel) and biomass (lower panel) versus standard length (L_S, cm) for the northern stock of Pacific Sardine (*Sardinops sagax*) in the core and nearshore survey regions.

3.6.2.2 Southern stock

The total estimated biomass of the southern stock of Pacific Sardine was 82,132 t ($CI_{95\%}$ = 44,039 - 133,290 t, CV = 23%; **Table 12**). In the core region, biomass was 6,447 t ($CI_{95\%}$ = 646 - 17,940 t, CV = 73%; **Table 12**), and was sparsely distributed between Bodega Bay and San Diego (**Fig. 28a**). L_S ranged from 8 to 22 cm with a mode at 15 cm (**Table 13**, **Fig. 29**). In the nearshore region, biomass was 75,686 t ($CI_{95\%}$ = 43,393 - 115,350 t, CV = 24%; **Table 12**), comprising 92% of the total biomass. The nearshore biomass was also distributed between San Francisco and San Diego, but was greatest along the central CA coast between Santa Cruz, CA and Los Angeles, between Long Beach and San Diego, and around Santa Cruz and Santa Catalina Islands. The nearshore length distribution ranged from 6 to 19 cm and had modes at 6 and 16 cm (**Table 13**, **Fig. 29**).

Table 12: 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	10,823	7	573	5	105	1,060	287	2,157	45
	2	4,105	4	225	1	56	5,354	0	16,739	88
	3	4,761	7	254	2	8	33	4	67	50
	All	19,689	18	1,052	8	169	6,447	646	17,940	73
Nearshore	5	450	28	141	21	980	14,943	3,622	33,876	56
	6	301	18	85	6	243	20,163	4,806	42,373	50
	7	81	7	33	2	100	13,396	1,554	32,947	62
	8	384	26	121	7	152	24,309	7,264	48,197	42
	9	91	20	40	5	150	2,373	229	5,375	59
	10	92	20	41	4	199	501	116	970	45
	All	1,398	119	461	45	1,824	75,686	43,393	115,350	24
All	**-**	**21,087**	**137**	**1,513**	**53**	**1,993**	**82,132**	**44,039**	**133,290**	**23**

Table 13: Abundance estimates 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	513,424,434
7	0	47,955,308
8	195,088	29,249,007
9	790,585	2,214,639
10	4,269,945	7,143,031
11	586,853	3,535,105
12	1,140,803	12,799,125
13	12,779,070	25,303,672
14	51,116,278	88,745,404
15	54,441,414	416,081,711
16	20,684,119	456,426,517
17	5,169,494	317,521,460
18	3,999,377	135,672,528
19	2,803,993	10,517,286
20	976,689	211,654
21	145,089	128,468
22	1,082,841	0
23	0	64,234
24	0	0
25	0	0
26	0	0
27	0	0
28	0	0
29	0	0
30	0	0

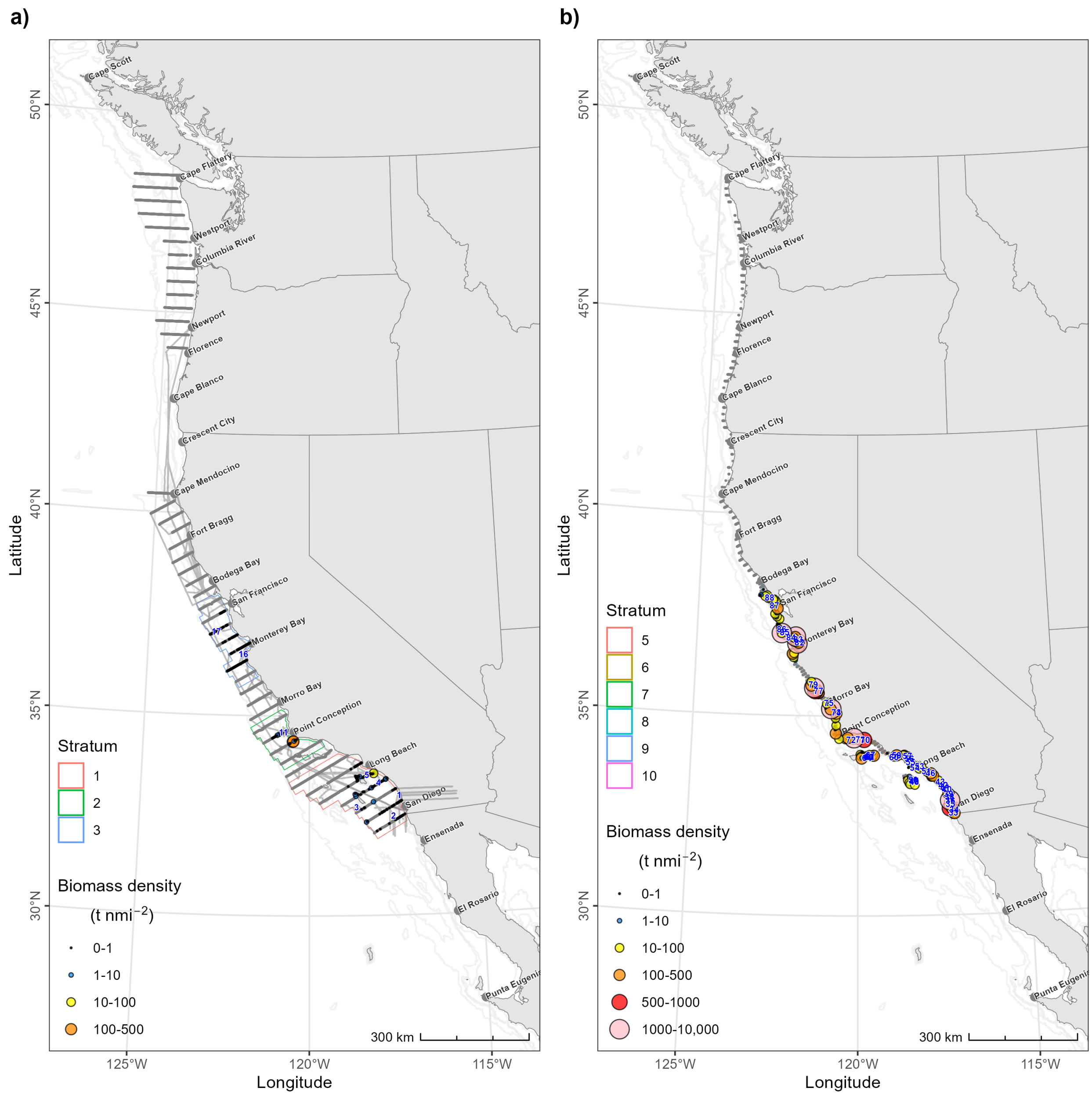

Figure 28: Biomass densities (colored points) of the southern stock of Pacific Sardine (*Sardinops sagax*), per stratum, in the a) core and b) nearshore survey regions. Overlaid are the locations of trawl clusters with at least one Pacific Sardine (blue numbers) in each stratum (colored polygons). Thick gray lines represent acoustic transects.

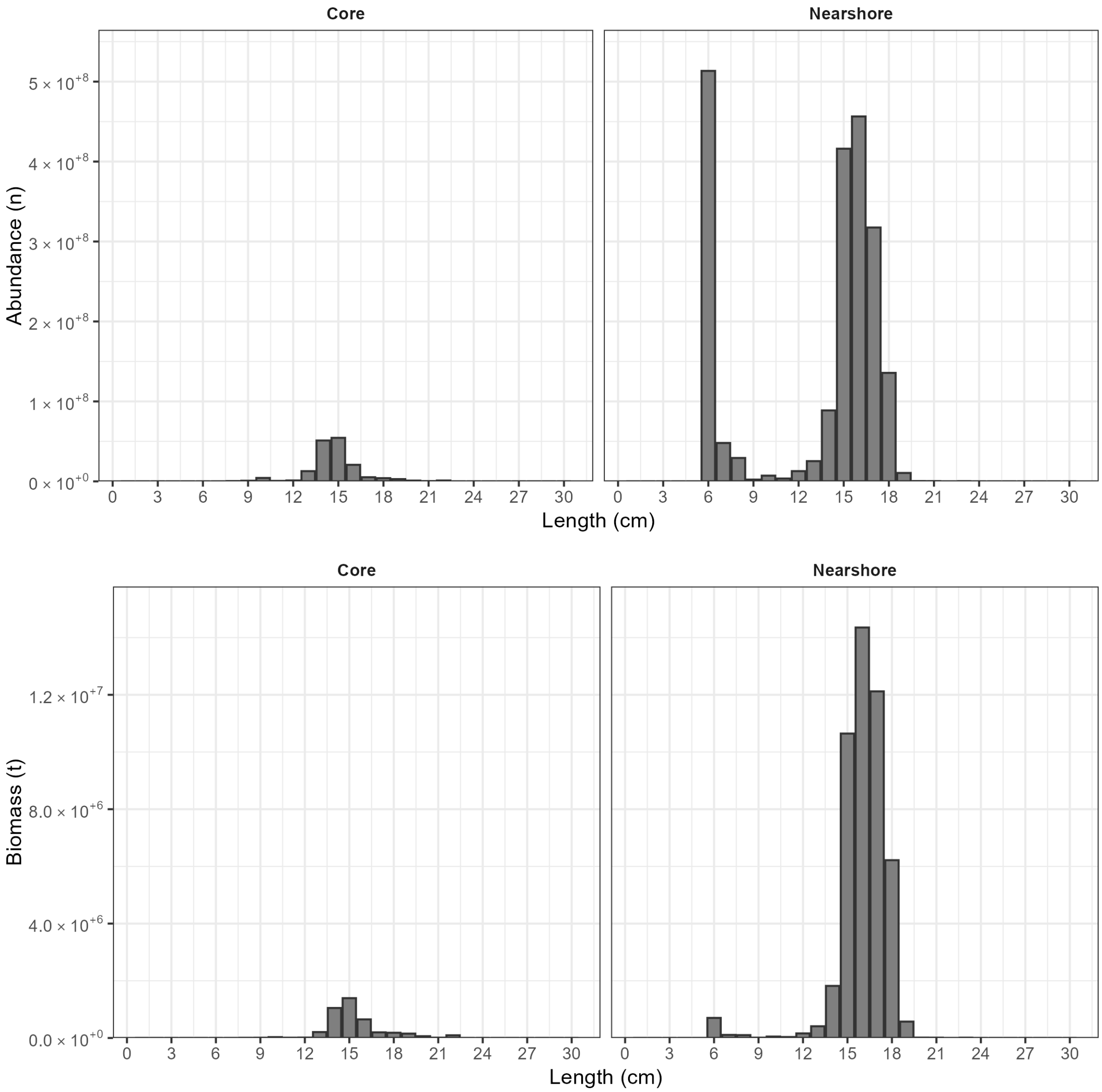

Figure 29: Estimated abundance (upper panels) and biomass (lower panels) versus standard length (L_S, cm) for the southern stock of Pacific Sardine (*Sardinops sagax*) in the core and nearshore survey regions.

3.6.3 Pacific Mackerel

The total estimated biomass of Pacific Mackerel was 7,289 t ($CI_{95\%}$ = 3,305 - 11,394 t, CV = 28%; **Table 14**). In the core region, biomass was 24.9 t ($CI_{95\%}$ = 0.718 - 63.9 t, CV = 70%) and was only present off northern OR (**Fig. 30a**). The distribution of L_F ranged from 8 to 31 cm with a mode at 12 cm (**Table 15**, not visible in **Fig. 31**). In the nearshore region, biomass was 7,264 t ($CI_{95\%}$ = 3,304 - 11,330 t, CV = 29%; **Table 14**, **Fig. 30b**), comprising 99.7% of the total biomass. It was distributed mostly between Point Conception and Los Angeles, but was also present in Monterey Bay and around Santa Cruz and Santa Catalina Islands. Lengths in the nearshore region had a single mode at 23 cm.

Table 14: 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	5,911	4	339	1	3	22	0	64	79
	2	3,243	4	169	1	1	3	0	8	74
	All	9,154	8	508	2	4	25	1	64	70
Nearshore	1	163	11	56	7	86	420	134	747	38
	2	85	4	23	1	1	59	0	106	43
	3	127	9	43	5	118	294	92	531	40
	4	114	6	28	2	58	4,353	1,074	7,691	42
	5	53	4	20	1	3	1,138	0	2,792	64
	6	91	10	19	4	108	808	34	2,276	85
	7	91	6	12	4	108	16	0	38	63
	8	92	10	20	3	24	164	1	414	68
	9	92	8	17	2	18	13	2	24	47
	All	907	68	238	23	524	7,264	3,304	11,330	29
All	**-**	**10,061**	**76**	**746**	**25**	**528**	**7,289**	**3,305**	**11,394**	**28**

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

	Region	
L_F	Core	Nearshore
1	0	0
2	0	0
3	0	0
4	0	0
5	0	0
6	0	0
7	0	0
8	152,305	0
9	0	0
10	0	0
11	0	0
12	160,649	0
13	0	0
14	0	0
15	0	1,446,550
16	0	0
17	0	0
18	0	1,517,385
19	0	1,342,553
20	0	1,450,024
21	0	2,203,514
22	0	8,795,421
23	0	13,871,334
24	0	10,629,250
25	0	7,146,041
26	0	2,447,747
27	0	1,616,674
28	0	635,716
29	0	0
30	0	131,210
31	67,014	248
32	0	745
33	0	248
34	0	248
35	0	248
36	0	248
37	0	0
38	0	0
39	0	0
40	0	0

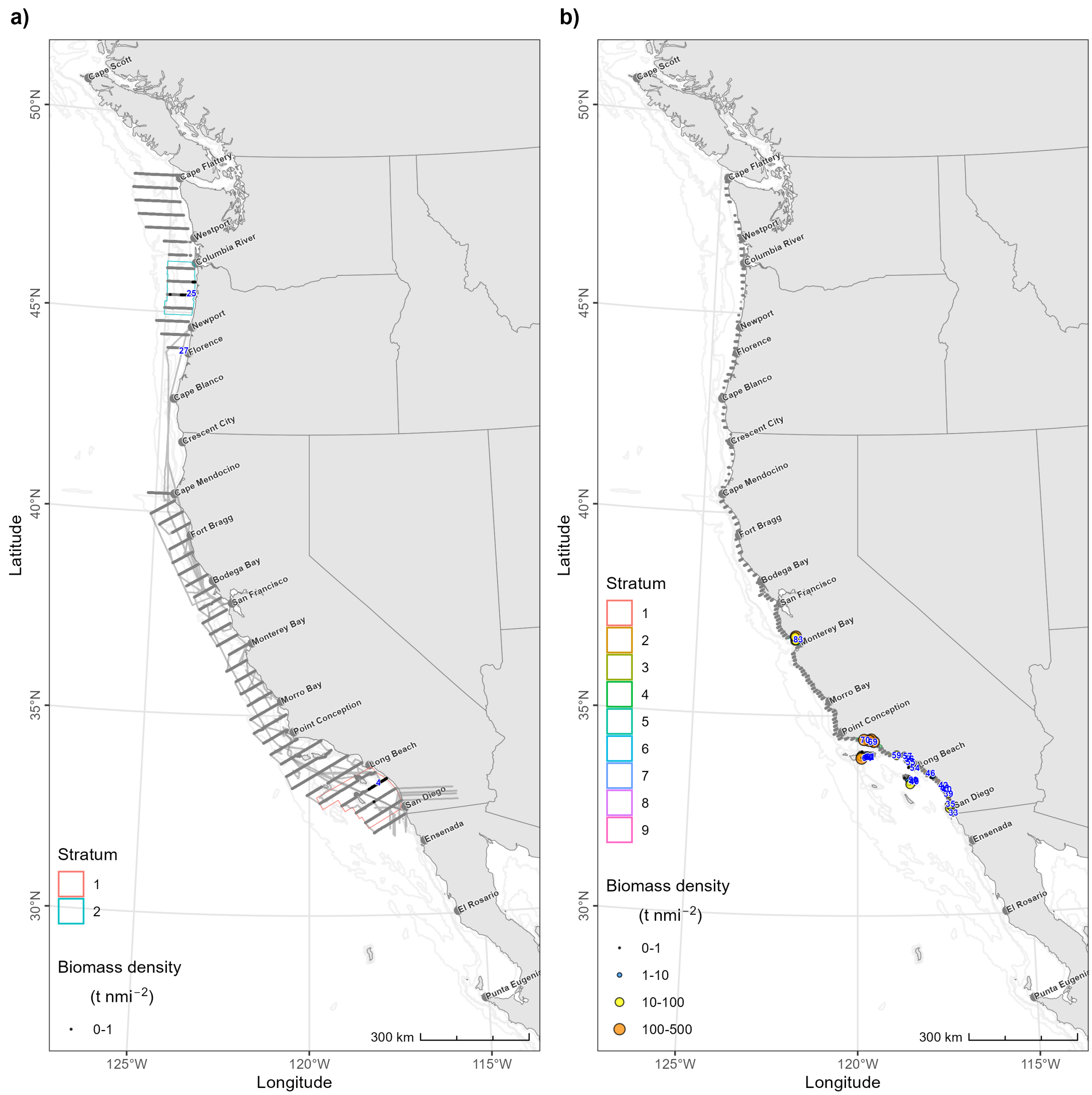

Figure 30: Biomass densities (colored points) of Pacific Mackerel (*Scomber japonicus*), per stratum, in the a) core and b) nearshore survey regions. Overlaid are the locations of trawl clusters with at least one Pacific Mackerel (blue numbers) in each stratum (colored polygons). Thick gray lines represent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

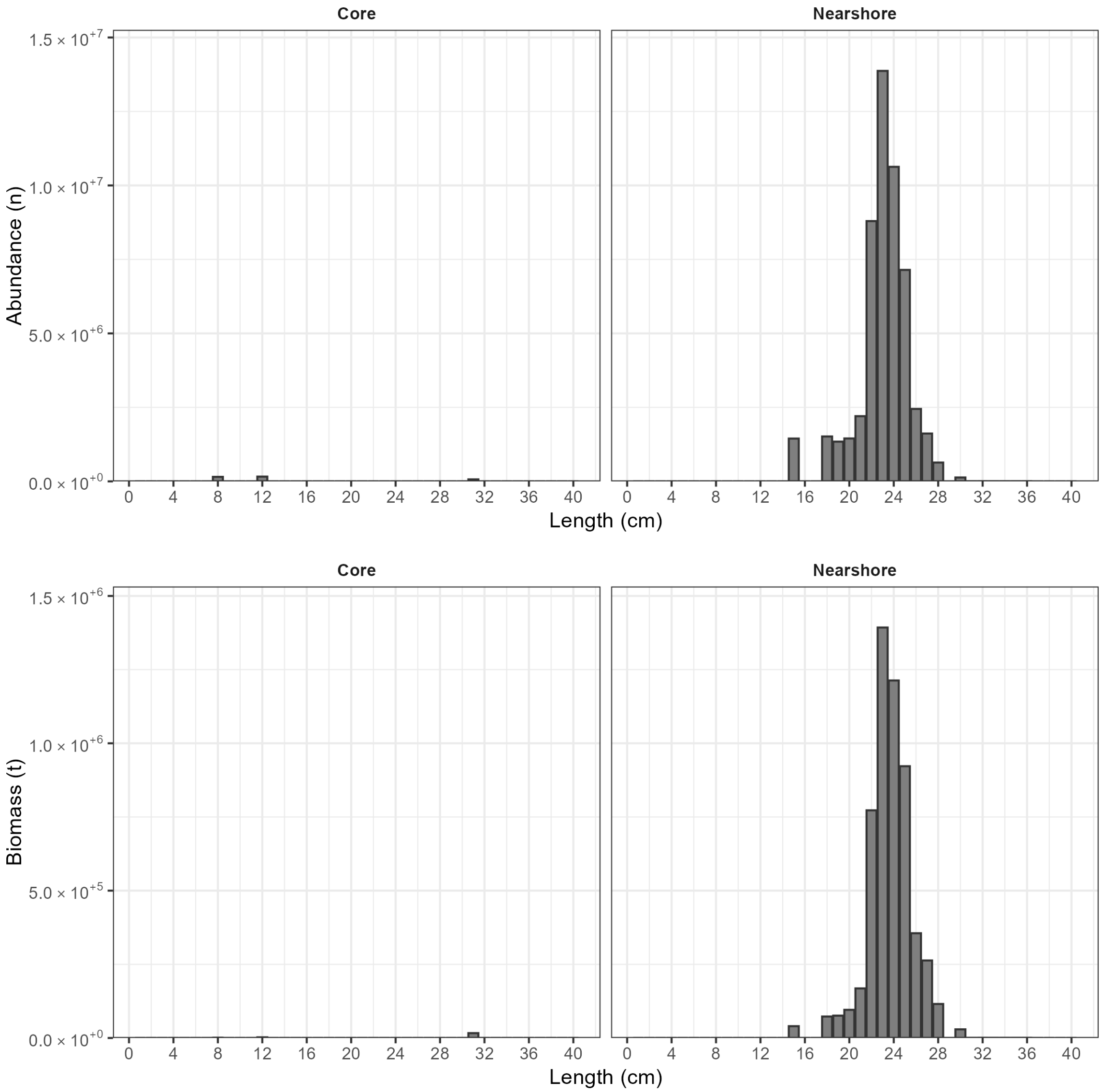

Figure 31: Estimated abundance (upper panels) and biomass (lower panels) versus fork length (L_F, cm) for Pacific Mackerel (*Scomber japonicus*) in the core and nearshore survey regions.

3.6.4 Jack Mackerel

The total estimated biomass of Jack Mackerel was 159,354 t ($CI_{95\%}$ = 51,323 - 270,757 t, CV = 27%; **Table 16**). In the core region, the biomass was 101,159 t ($CI_{95\%}$ = 24,177 - 181,030 t, CV = 40%; **Table 16**). It was distributed throughout the survey area south of Cape Mendocino, but was also sparsely distributed between Cape Flattery and Newport. Jack Mackerel were most abundant between Cape Mendocino and Fort Bragg and near the northern Channel Islands in the SCB (**Fig. 32a**). L_F ranged from 2 to 52 cm, with modes at 10 and 50 cm. (**Table 17**, **Fig. 33**). In the nearshore region, the biomass was 58,194 t ($CI_{95\%}$ = 27,146 - 89,726 t, CV = 27%; **Table 16**), comprising 37% of the total biomass. It was present throughout the nearshore survey area, but was most abundant near Cape Flattery and between Cape Mendocino and Fort Bragg (**Fig. 32b**). Lengths in the nearshore region had no clear mode (**Table 17**, **Fig. 33**).

Table 16: Biomass estimates (metric tons, t) and their precisions (upper and lower 95% confidence intervals, $CI_{95\%}$; and coefficients of variation, CVs) for 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	29,857	31	1,609	19	2,727	99,590	23,050	179,645	41
	2	11,219	11	565	8	46	1,569	42	2,946	46
	All	41,076	42	2,174	27	2,773	101,159	24,177	181,030	40
Nearshore	1	42	3	15	1	7	0	0	1	84
	2	78	4	23	1	1	76	0	223	84
	3	32	3	13	1	3	0	0	1	83
	4	91	8	16	1	4	213	3	540	71
	5	92	5	10	2	6	6	0	14	64
	6	92	3	6	1	5	0	0	0	83
	7	133	6	30	2	31	21,552	4,459	42,434	45
	8	27	2	8	1	18	1,658	103	2,974	61
	9	55	3	13	1	2	495	189	831	30
	10	67	3	12	1	7	34,194	4,146	60,509	36
	All	707	40	146	11	84	58,194	27,146	89,726	27
All	**-**	**41,783**	**82**	**2,320**	**38**	**2,857**	**159,354**	**51,323**	**270,757**	**27**

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

	Region	
L_F	Core	Nearshore
1	0	0
2	531,943	0
3	1,738,677,369	0
4	1,743,024,822	0
5	6,979,964	0
6	34,927,902	0
7	171,217,296	0
8	341,271,311	0
9	210,725,511	0
10	17,625,748	0
11	1,945,939,993	0
12	20,791,087	6,205
13	25,944,479	274,469
14	111,300,992	632
15	4,577,712	1,126,495
16	0	1,125,863
17	0	2,251,292
18	0	1,661
19	91,680,324	415
20	531,943	794,270
21	6,383,317	0
22	10,106,919	0
23	4,787,488	0
24	3,723,602	0
25	531,943	0
26	0	0
27	0	0
28	244,041	0
29	0	0
30	325,778	0
31	2,083,476	0
32	0	0
33	0	0
34	916,795	17,572,051
35	916,795	528,431
36	0	8,722,935
37	0	18,100,482
38	0	176,144
39	488,081	672,259
40	0	336,129
41	916,795	10,211,280
42	0	9,202,892
43	0	336,129
44	0	0
45	3,667,180	727,709
46	8,251,155	727,709
47	4,583,975	1,455,418

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

L_F	Core	Nearshore
48	6,417,565	0
49	916,795	1,063,839
50	0	1,455,418
51	8,253,620	4,366,255
52	3,668,413	727,709
53	0	2,183,128
54	0	0
55	0	0
56	0	0
57	0	0
58	0	0
59	0	0
60	0	0

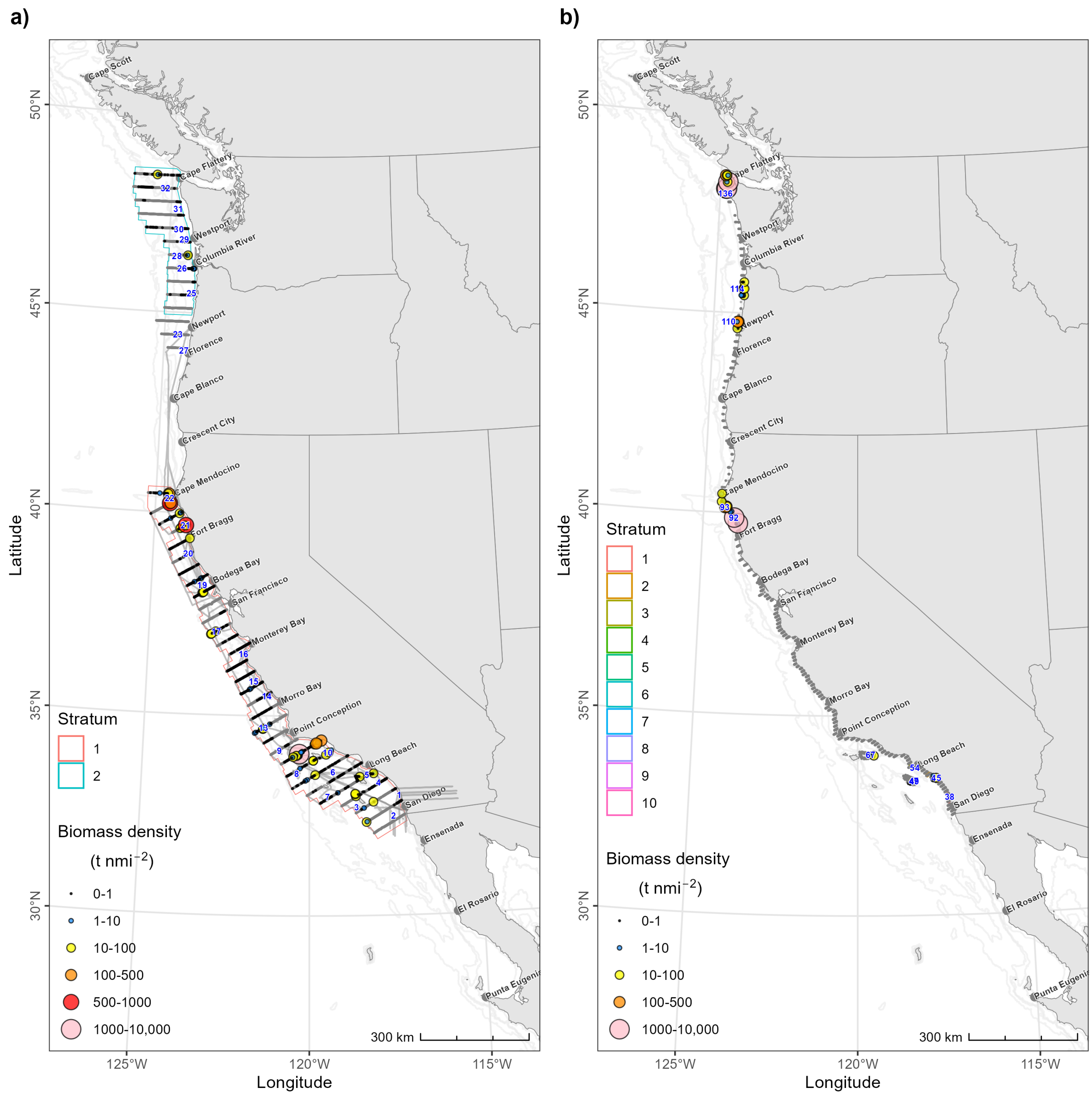

Figure 32: Biomass densities (colored points) of Jack Mackerel (*Trachurus symmetricus*), per stratum, in the a) core and b) nearshore survey regions. Overlaid are the locations of trawl clusters with at least one Jack Mackerel (blue numbers) in each stratum (colored polygons). Thick gray lines represent acoustic transects.

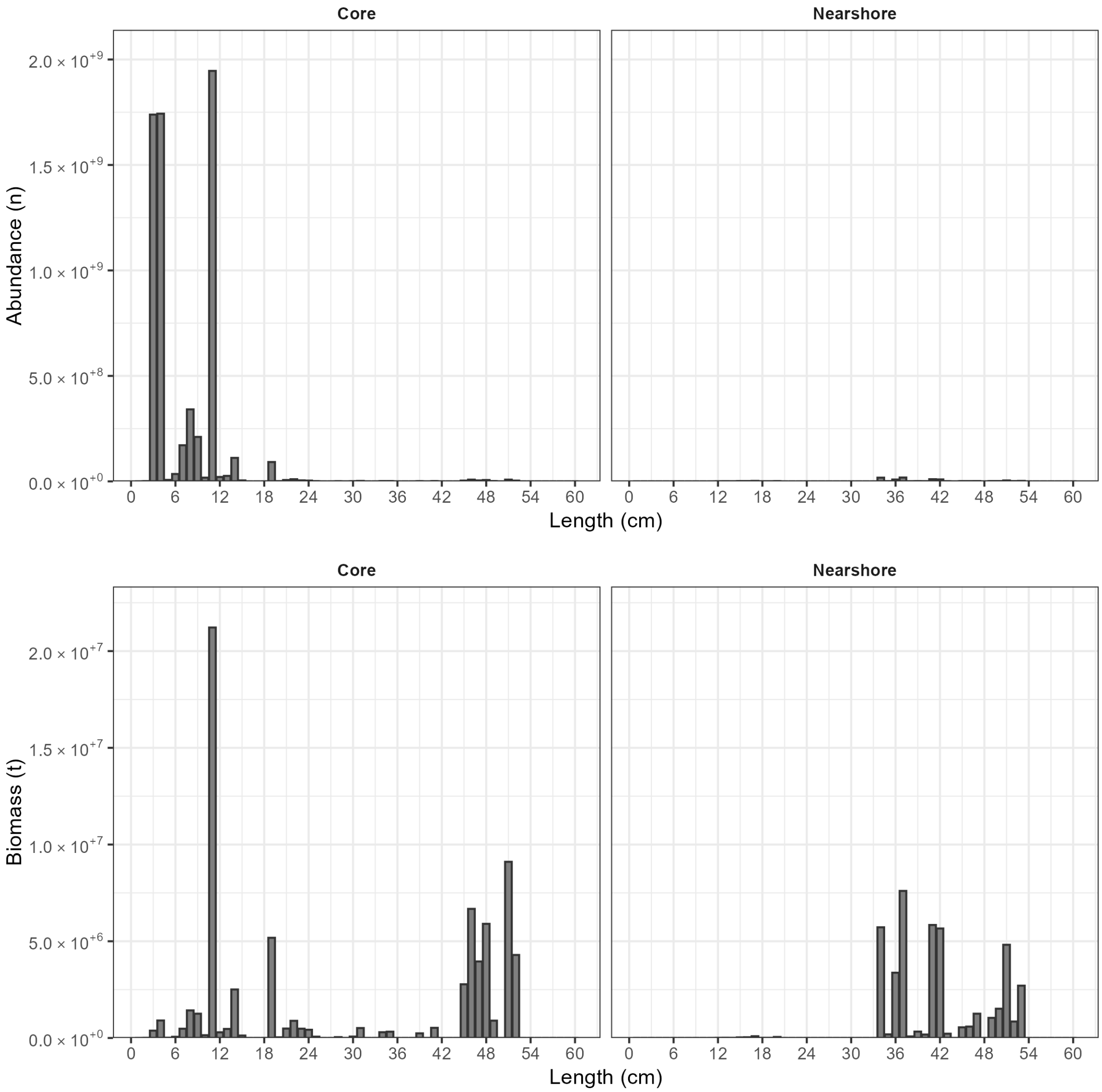

Figure 33: Estimated abundance (upper panel) and biomass (lower panel) versus fork length (L_F, cm) for Jack Mackerel (*Trachurus symmetricus*) in the core and nearshore survey regions.

3.6.5 Pacific Herring

The total estimated biomass of Pacific Herring was 106,723 t ($CI_{95\%}$ = 36,364 - 149,772 t, CV = 21%; **Table 18**). In the core region, biomass was 34,627 t ($CI_{95\%}$ = 7,769 - 83,063 t, CV = 60%; **Table 18**). It was distributed from approximately Cape Flattery to Newport, but was most abundant near Cape Flattery and the mouth of the Columbia River (**Fig. 34a**). L_F in the core region ranged from 8 to 18 cm, with a mode at 10 cm (**Table 19**, **Fig. 35**). In the nearshore region, biomass was 72,095 t ($CI_{95\%}$ = 28,595 - 66,710 t, CV = 14%; **Table 18**, **Fig. 34b**), or 68% of the total biomass. It was distributed from Cape Flattery to Cape Mendocino (**Fig. 35**), but was most abundant between Westport and Newport and between Cape Blanco and Cape Mendocino. Lengths in the nearshore range from 8 to 23 cm and had modes at 9 and 15 cm (**Table 19**, **Fig. 35**).

Table 18: Biomass estimates (metric tons, t) and their precisions (upper and lower 95% confidence intervals, $CI_{95\%}$; and coefficients of variation, CVs) for 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	13,641	14	686	10	10,279	34,627	7,769	83,063	60
	All	13,641	14	686	10	10,279	34,627	7,769	83,063	60
Nearshore	1	169	4	20	2	62	8,163	836	8,542	25
	2	247	10	45	2	95	39,986	8,370	43,916	22
	3	210	10	44	5	163	16,444	5,737	17,294	17
	4	44	2	7	1	6	283	225	278	7
	5	113	3	14	1	50	7,219	3,090	12,042	30
	All	784	29	130	11	376	72,095	28,595	66,710	14
All	**-**	**14,425**	**43**	**817**	**21**	**10,655**	**106,723**	**36,364**	**149,772**	**21**

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

	Region	
L_F	Core	Nearshore
1	0	0
2	0	0
3	0	0
4	0	0
5	0	0
6	0	0
7	0	0
8	59,367,961	455,281,478
9	632,769,036	916,461,175
10	1,587,588,695	528,768,556
11	612,583,989	148,018,397
12	75,452,630	16,076,336
13	49,914,279	44,718,522
14	60,574,359	60,489,324
15	49,394,843	310,832,314
16	31,381,120	240,665,921
17	0	51,410,867
18	347,991	9,964,262
19	0	13,272,869
20	0	10,783,960
21	0	11,683,422
22	0	3,050,106
23	0	558,321
24	0	0
25	0	0
26	0	0
27	0	0
28	0	0
29	0	0
30	0	0

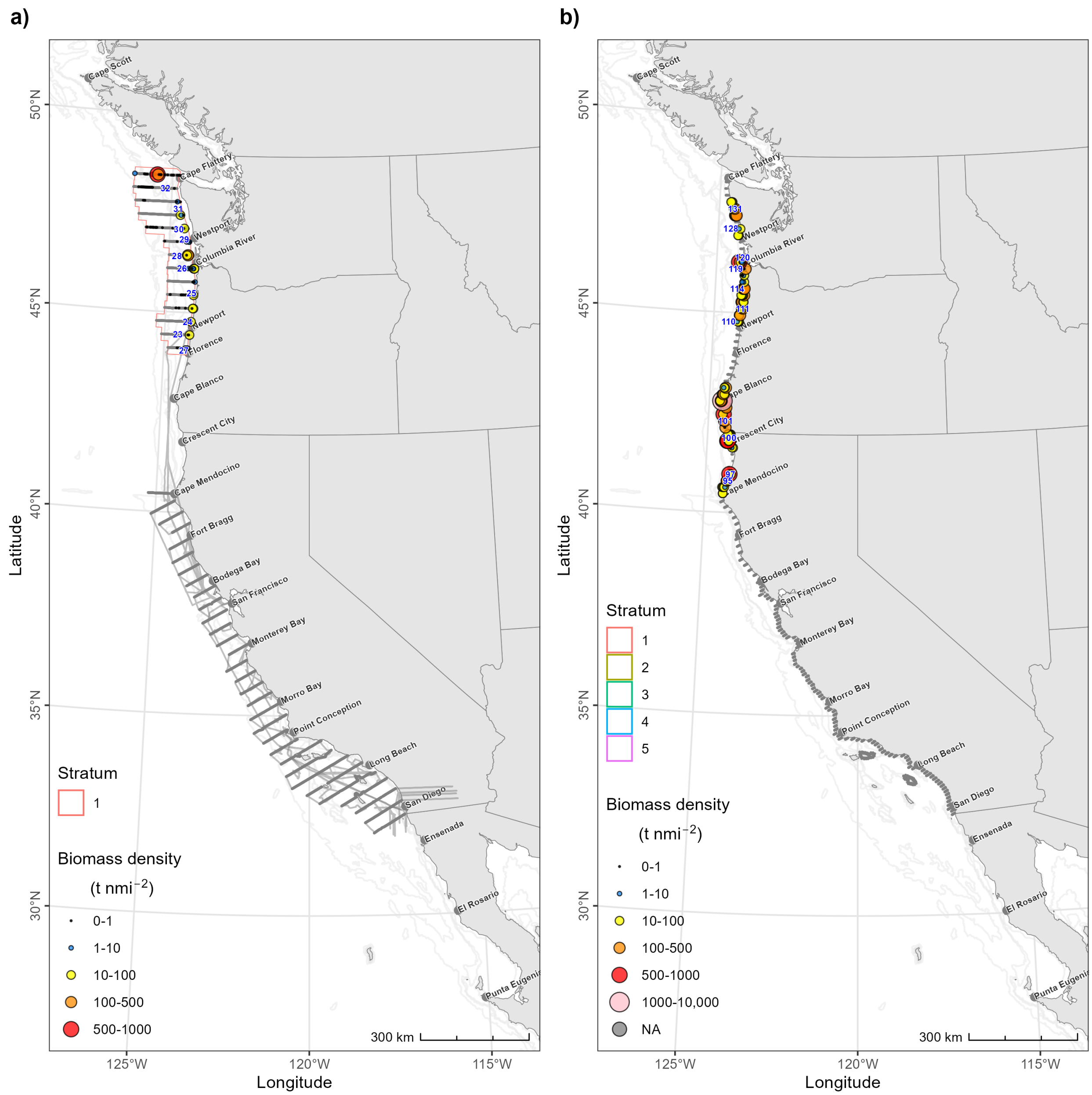

Figure 34: Biomass densities (colored points) of Pacific Herring (*Clupea pallasii*), per stratum, in the a) core and b) nearshore survey regions. Overlaid are the locations of trawl clusters with at least one Pacific Herring (blue numbers) in each stratum (colored polygons). Thick gray lines represent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

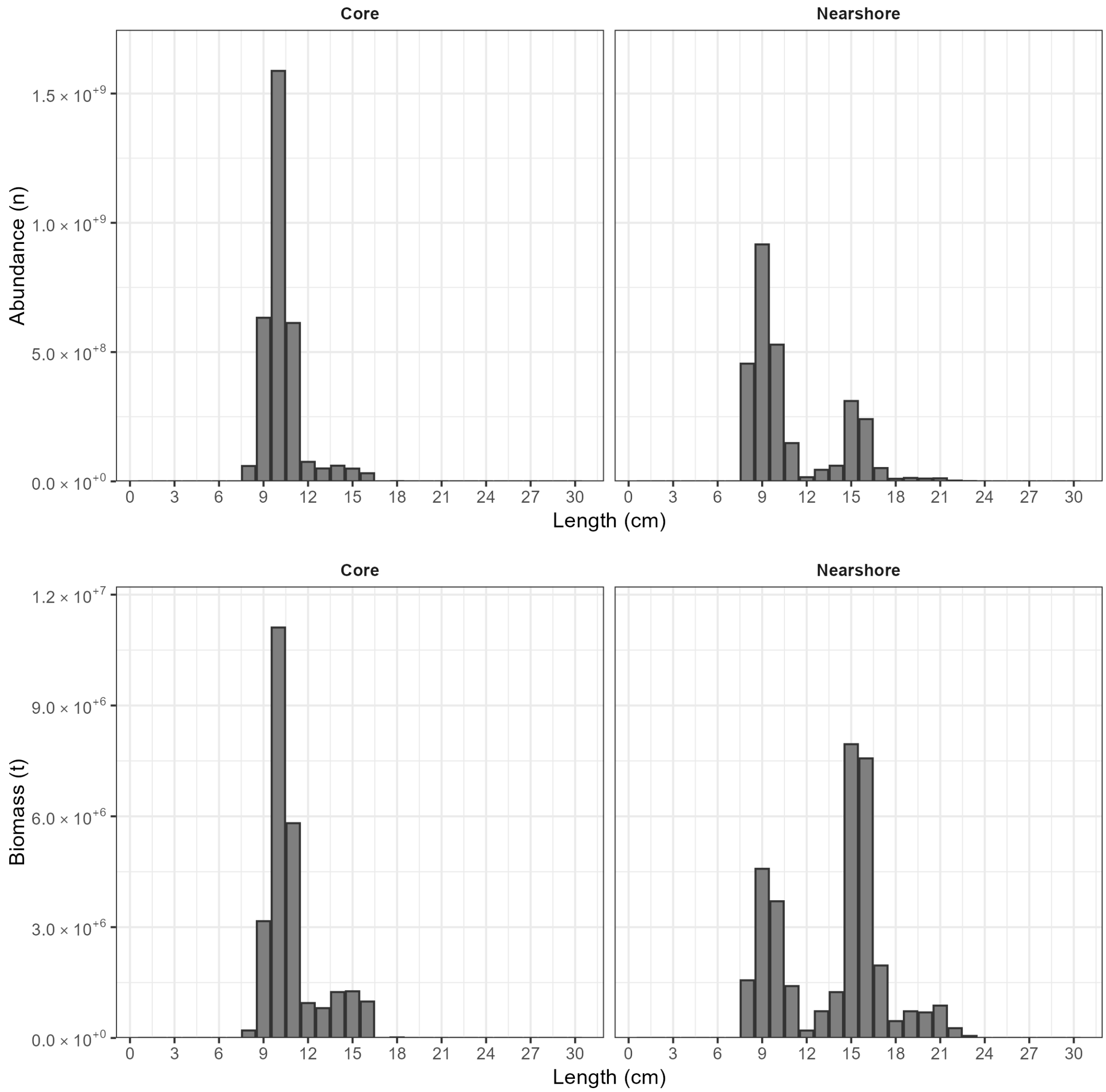

Figure 35: Estimated abundance (upper panel) and biomass (lower panel) versus fork length (L_F, cm) for Pacific Herring (*Clupea pallasii*) in the core and nearshore survey regions.

4 Discussion

The primary objective of the ATM surveys is to estimate the biomasses, distributions, and demographics of CPS within the survey area at the time of the survey. The summer 2023 survey spanned the expected distribution of the northern stock of Pacific Sardine and northern stock of Northern Anchovy in U.S. waters, but also portions of the expected distribution of the southern stock of Pacific Sardine, central stock of Northern Anchovy, Pacific Mackerel, Jack Mackerel, and Pacific Herring.

Despite inclement weather conditions, mechanical limitations, staffing issues, logistical challenges related to the COVID-19 pandemic, and the loss of nearly 60% of the originally allocated 81 sea days aboard *Lasker*, the core region was surveyed by *Lasker* and *Shimada* between Cape Flattery and the U.S.-Mexico border, with a gap in coverage between Cape Mendocino and Cape Blanco. Following the cancellation of Leg 1.1, sampling was cancelled off Vancouver Island and Baja CA 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, additional sea days aboard *Shimada* provided acoustic and net sampling north of Cape Mendocino, and spanning the anticipated distribution of the northern stock of Pacific Sardine. The significant loss of sea days protracted the survey period and reduced the synopticity of sampling from the various sampling platforms, which deviated from the standard ATM surveys, created additional analytical challenges, and added potential uncertainty to the biomass estimates. Due to delays and lost sea days, the time between acoustic sampling from USVs and trawl sampling from *Lasker* and *Shimada* was often greater than 30 d, so CPS backscatter measured from USVs was not used to estimate biomass.

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 11,356 t ($CI_{95\%}$ = 438.1 - 30,038 t) in summer 2023. The northern stock biomass has comprised a small fraction (0.1 to 5.4%) of the total biomass 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 2,689,200 t ($CI_{95\%}$ = 297,242 - 4,932,949 t) and comprised 86% of the total CPS biomass in summer 2023. The biomass represents a ~20% increase from the 2,235,996 t estimated in summer 2022 (Stierhoff *et al.*, 2023b). In summer 2023, the biomass of Northern Anchovy below the thermocline (>30 m depth) was 84,896 t, which was 35% of the biomass in the nearshore region, and 3.2% of the biomass in the core and nearshore regions combined. 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. 37a,b**).

4.1.2 Pacific Sardine

4.1.2.1 Northern stock The southern extent of northern stock Pacific Sardine habitat was Bodega Bay, based foremost on associations with potential habitat but corroborated by the geographic separation of biomass density north and south of Point Conception, and differences in demographics, growth, and lengths-at-age (**Fig. 36**). The estimated biomass of 77,252 t ($CI_{95\%}$ = 17,856 - 171,829 t) in the survey region was a 11% increase in biomass compared to the 69,506 t estimated in summer 2022 (Stierhoff *et al.*, 2023b). Northern stock Pacific Sardine were sampled near the US-Canada border, but Fisheries and Oceans Canada (DFO) and fishers reported that no Pacific Sardine were observed north of the border at the time of the survey (L. Flostrand, pers. comm.). 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[6] (**Figs. 37a,b**). The biomass estimates from 2022 and 2023 have higher CVs than prior year estimates because of modifications to survey design due to the loss of sea days during each of those two field seasons.

4.1.2.2 Southern stock The estimated biomass of the southern stock of Pacific Sardine was 82,132 t ($CI_{95\%}$ = 44,039 - 133,290 t), of which 75,686 t (92%) occurred in the nearshore region off southern and central CA. Using the species proportions and lengths from purse-seine catches to apportion backscatter deeper than 30 m resulted in a biomass estimate of 207,320 t in the nearshore region and a total biomass of 213,768 t.

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 82,132 t in summer 2023. 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. The biomass estimated in 2023 is the largest in the time series, which goes back to 2016. In 2023, Mexico conducted a contemporaneous survey of CPS, including the nearshore region (Vallarta-Zárate *et al.*, 2023).

4.1.3 Pacific Mackerel

In summer 2023, the estimated biomass of Pacific Mackerel in the survey region was 7,289 t ($CI_{95\%}$ = 3,305 - 11,394 t), which is within the range of recent estimates (7,968 - 42,423) between 2016 and 2022.

4.1.4 Jack Mackerel

In summer 2023, the estimated biomass of Jack Mackerel in the survey region, south of Cape Flattery, was 159,354 t ($CI_{95\%}$ = 51,323 - 270,757 t), which is 80% lower than 807,090 t estimated in summer 2022 (Stierhoff *et al.*, 2023a). Fisheries and Oceans Canada (DFO) reported unusually high numbers of Jack Mackerel off Vancouver Island in 2022, which were not reported in 2023 (L. Flostrand, pers. comm.).

4.1.5 Pacific Herring

In summer 2023, the estimated biomass of Pacific Herring in U.S. waters south of Cape Flattery, was 106,723 t ($CI_{95\%}$ = 36,364 - 149,772 t), which was a 110% increase from the 50,718 t estimated in summer 2022 (Stierhoff *et al.*, 2023b), which was largely due to the increase of biomass in the nearshore region from 3,694 t to 72,095 t over the same period.

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

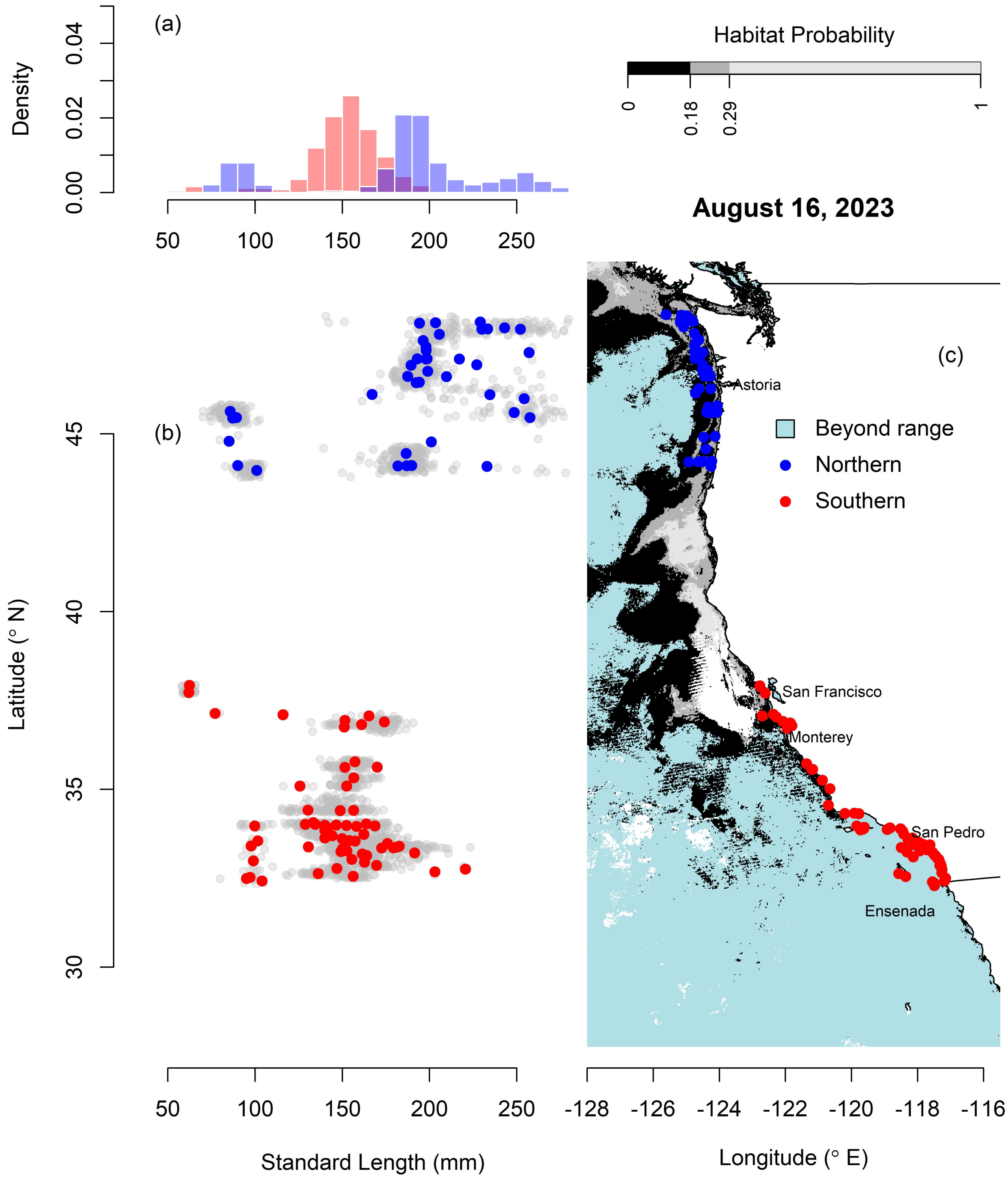

Figure 36: Differentiation of northern (blue) and southern (red) stocks of Pacific Sardine by: a) length distributions; b) individual (grey points) and catch-mean (colored points) lengths at the latitudes of their respective trawls; and c) geographic locations of trawls catches with Pacific Sardine (colored points) in relation to modeled potential habitat for the northern stock of Pacific Sardine (Zwolinski and Demer, 2023) at the midpoint of the survey (August 16, 2023).

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; Kuriyama *et al.*, 2020, 2022a); northern (Mais, 1974, 1977) and central stocks (Kuriyama *et al.*, 2022b) 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. 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. 37a,b**). The U.S. fishery for Pacific Sardine was closed in 2015 (National Marine Fisheries Service, 2015), and there were reports of mass strandings, deaths, and reproductive failures in Brown Pelicans (*Pelecanus occidentalis*[7]), Common Murres (*Uria aalge*), Brandt's Cormorants (*Phalacrocorax penicillatus*), and California sea lions (*Zalophus californianus*[8]) (McClatchie *et al.*, 2016), all of which depend on forage species. The National Marine Fisheries Service deemed the stock 'overfished' in 2019.

The biomass of the central stock of Northern Anchovy, which had been growing rapidly since 2015, increased from the 2,235,996 t estimated in summer 2022 (Stierhoff *et al.*, 2023b). The southern stock of Pacific Sardine in U.S. waters was mostly in the nearshore region. 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 2022.

The survey-estimated CPS biomasses since 2008 were dominated by northern stock Pacific Sardine until 2013, Jack Mackerel in 2014 and 2015, and then central stock of Northern Anchovy since 2015, when it was resurgent. The latter stock grew to ~2.75 million tons by 2021 (Stierhoff *et al.*, 2023a), and has hovered around ~2.5 million t since. Meanwhile, the biomass of Pacific Mackerel remained the lowest in the assemblage, and the biomass of Jack Mackerel trended up from 2017 through 2022. In 2023, the delayed and smaller survey in the northern area created uncertainty about the decrease in Jack Mackerel in 2023. The biomasses of northern and southern stocks of Pacific Sardine are calculated separately based on oceanographic habitat, spatial separation, and demographic structure (Zwolinski and Demer, 2023). The southern stock of Pacific Sardine has been present in U.S. waters since at least 2015, located mostly nearshore, south of Monterey Bay; the biomass of the northern stock has been fluctuating below 100,000 t mostly off Oregon and Washington.

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

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

a)

b)

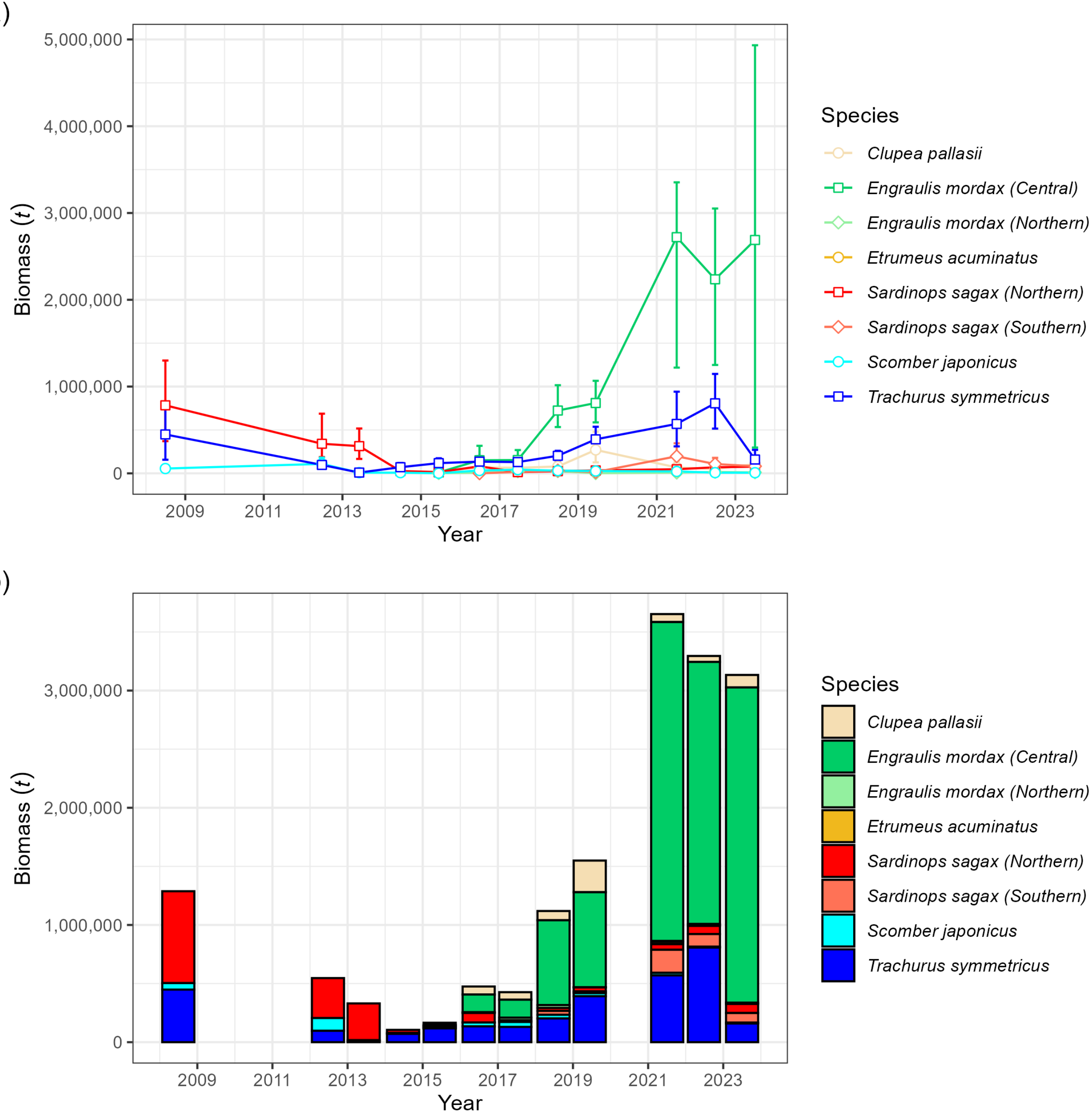

Figure 37: a) Estimated and b) cumulative estimated biomasses (t) of the eight most abundant CPS stocks of six species in the CCE during summer since 2008. Surveys typically span the area between Cape Flattery and San Diego, but in some years also include Vancouver Island, Canada (2015-2019) and portions 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 (Tiffany Bachtel, Noelle Bowlin, Nicolas Concha-Saiz, Emily Gardner, Amy Hays, Megan Human, Drikus Kuyper, Bryan Overcash, Andrew Thompson, Lanora Vasquez de Mercado, and Bill Watson); Life History Group (Brad Erisman, Kelsey James, Brittany Schwartzkopf, Zach Skelton, and Owyn Snodgrass); Stock Assessment (Peter Kuriyama); and their volunteers (Genevieve Angle , Enrique Arce-Larreta, Blane Bellerud, Olivia Boisen, Sarah Callahan, Selene del Carmen Morales Gutierrez, Matthew Dunlap, Johnathan Evanilla, Kassadi Holloway, Morgan Illman, Bill Lind, Gary Longo, Madelyn Macaskill, Violeta Maynez, Solomon Mitchell, Dan Palance, and Emily Ruhl). We also thank the officers and crew of *Lasker* and *Shimada*, 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 (WDFW) for leading the at-sea processing of purse-seine specimens. We thank Jennifer Topping (WDFW) for the ageing of biological samples from *Lisa Marie*. We thank Mark Fina for contracting the *Long Beach Carnage* to conduct the nearshore survey off central CA and in the SCB. Andy Blair [President, West Coast Pelagic Conservation Group (WCPCG)], Mike Okoniewski (Secretary, WCPCG), and Greg Shaughnessy (Vice President of WCPCG and Chief Operating Officer of Ocean Gold Seafoods) were integral in the permitting and planning for the nearshore sampling conducted by *Lisa Marie* off WA, OR, and northern CA. We thank Sandy Diaz, Christian Juico, Leeanne Laughlin, Heather Lee, Dane McDermott, Trung Nguyen, and Chelsea Protasio (CDFW) for their efforts to coordinate with and process samples from *Long Beach Carnage*, and Dianna Porzio for coordinating the biological sampling and organizing, validating, and disseminating the resulting data. Finally, we thank Alicia Billings, Rebecca Thomas, John Pohl, and the entire NWFSC's Fisheries Engineering and Acoustic Technologies (FEAT) team for providing CTD and calibration data from their 2023 Pacific Hake survey. A critical review by Caitlin Allen Akselrud and Annie Yau improved this report.

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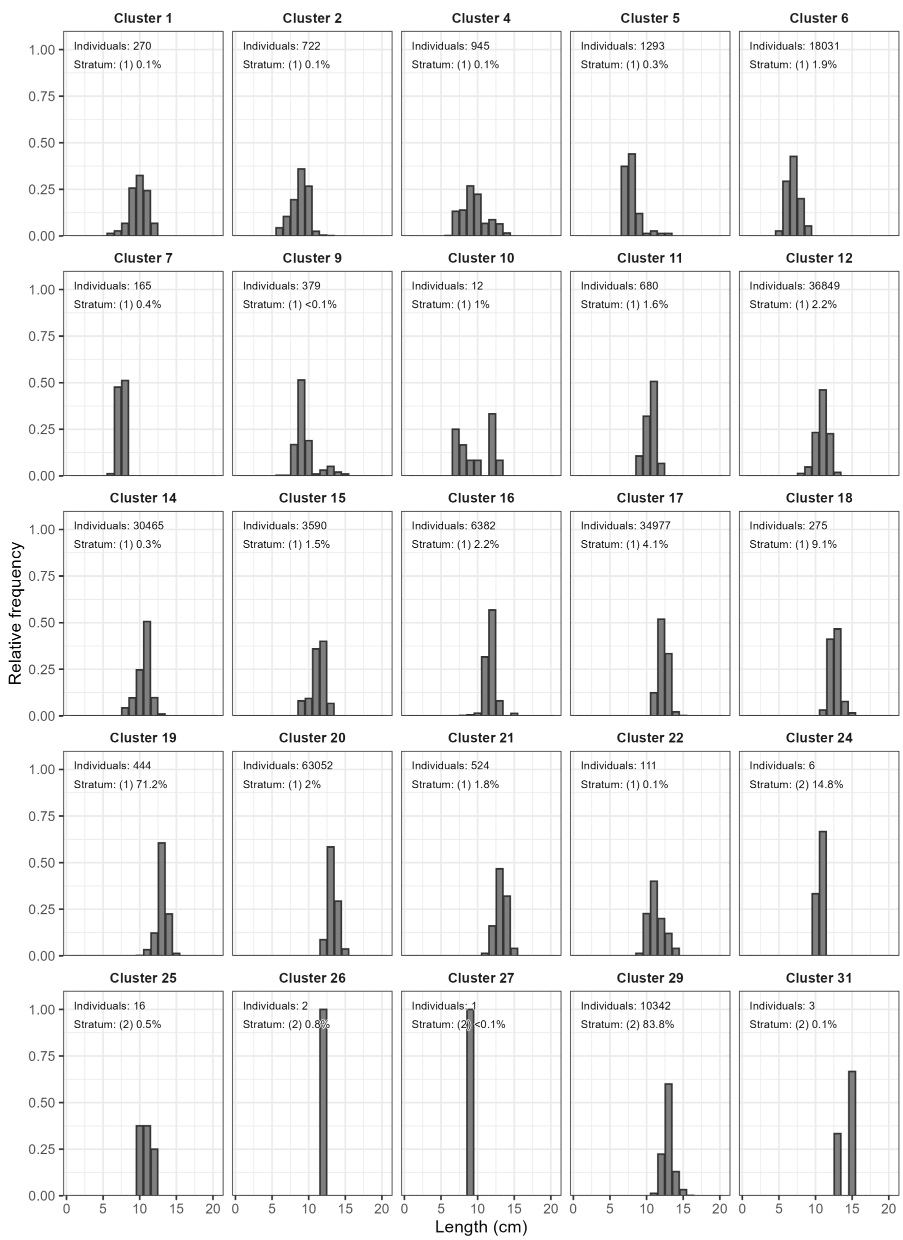
Appendix

A Length distributions and percent biomass by cluster

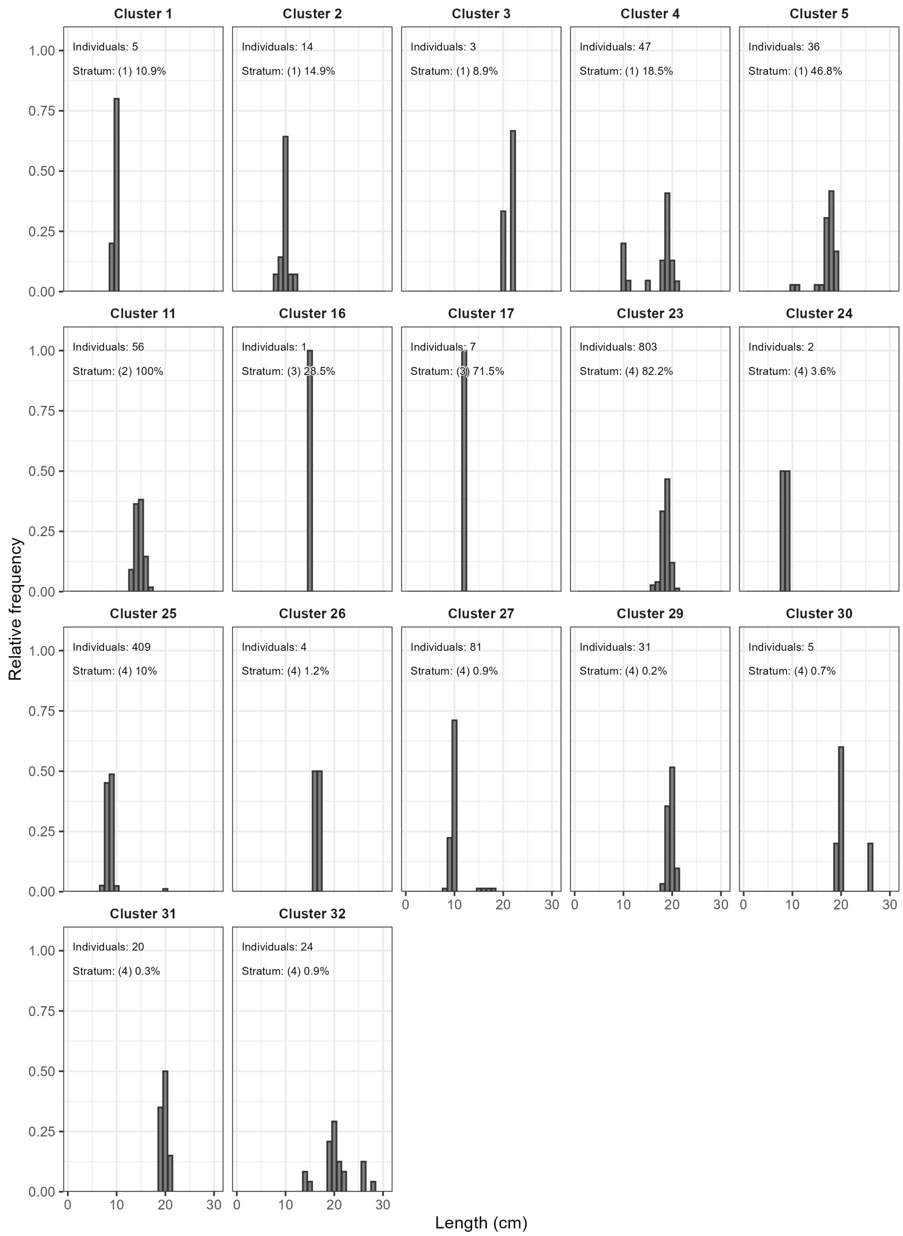
A.1 Northern Anchovy

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.



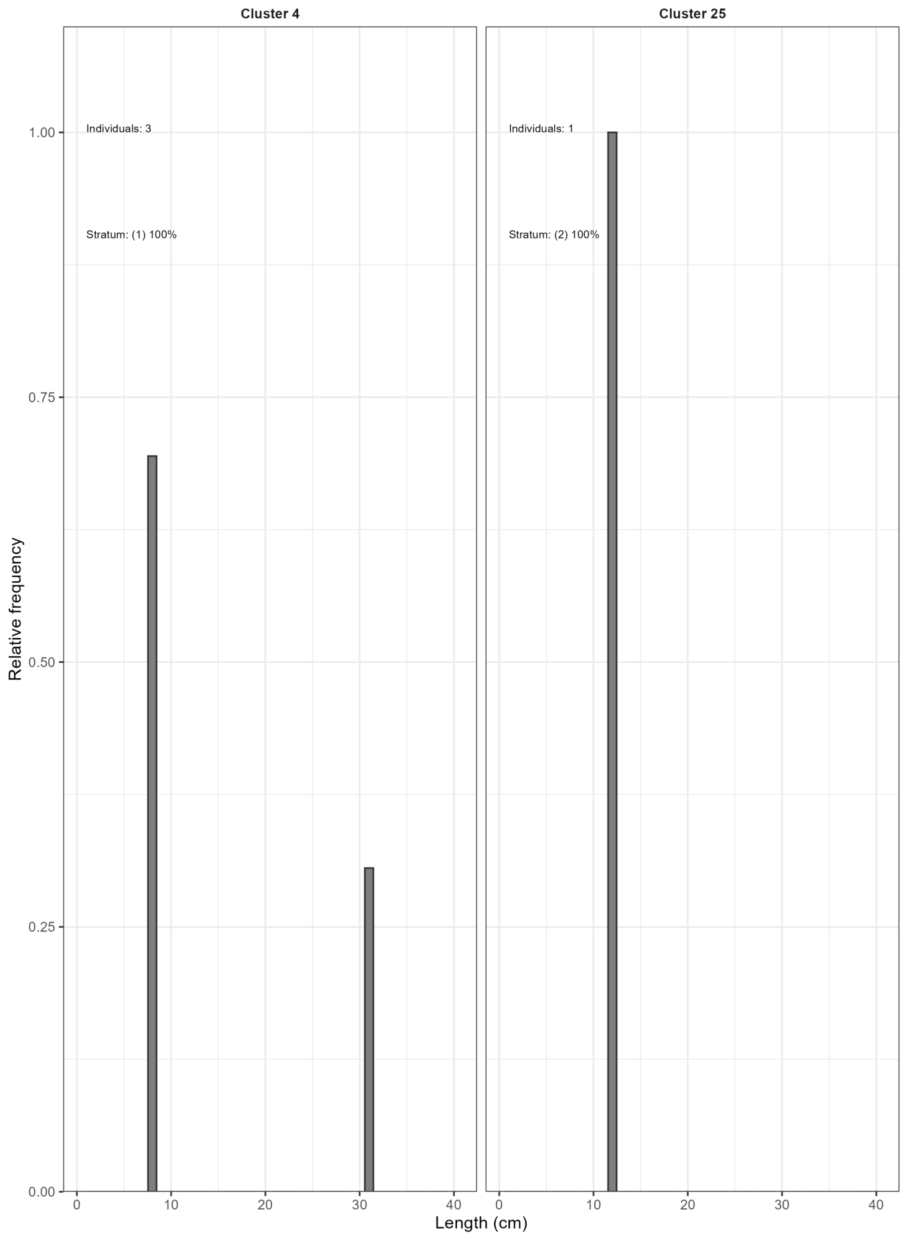
A.2 Pacific Sardine

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.



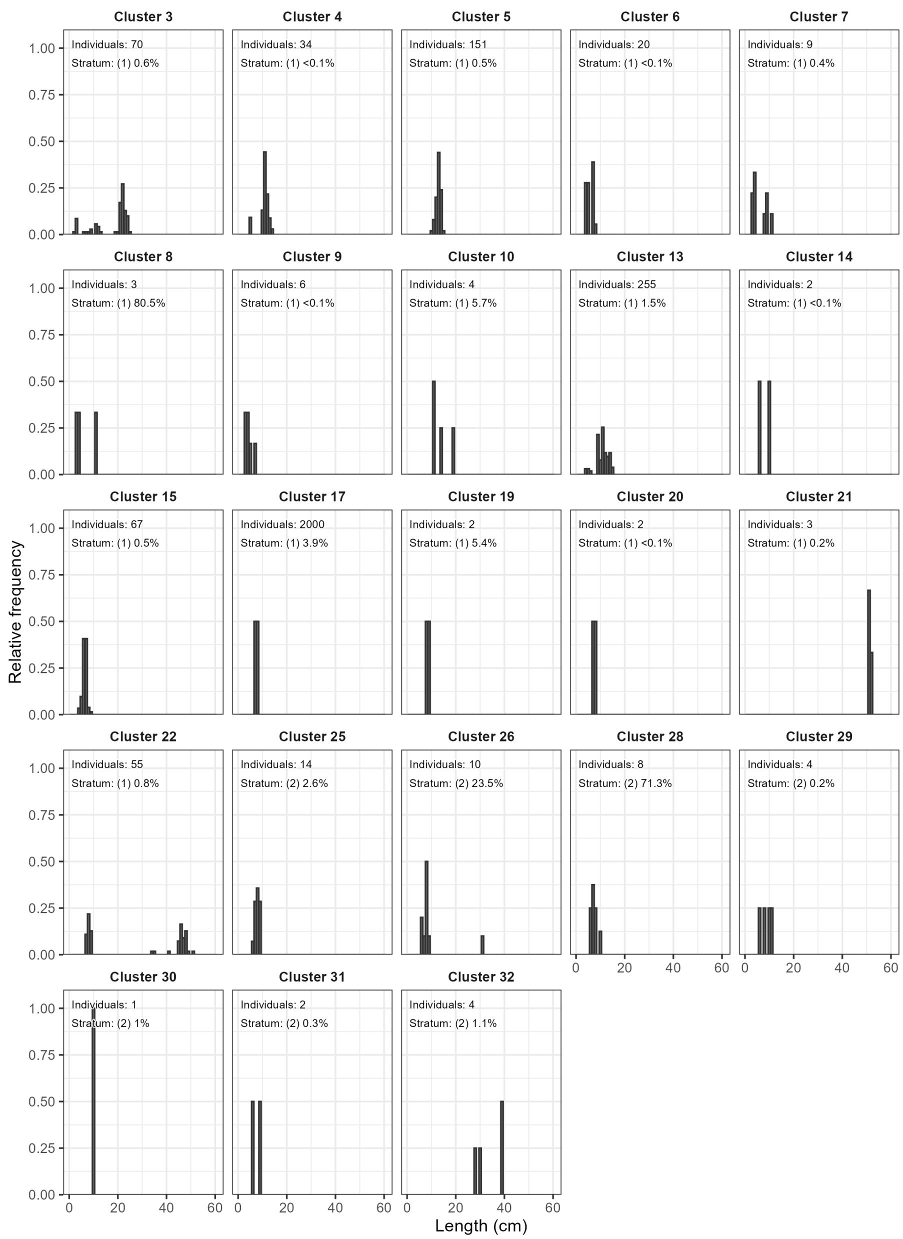
A.3 Pacific Mackerel

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.