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REPORT ON THE COLLECTION OF DATA DURING THE ACOUSTIC-TRAWL AND DAILY EGG PRODUCTION METHODS SURVEY OF COASTAL PELAGIC FISH SPECIES AND KRILL (1704RL) WITHIN THE CALIFORNIA CURRENT ECOSYSTEM, 21 MARCH TO 22 APRIL 2017, CONDUCTED ABOARD FISHERIES SURVEY VESSEL *REUBEN LASKER*

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

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U.S. DEPARTMENT OF COMMERCE
Wilbur L. Ross, Secretary of Commerce

National Oceanic and Atmospheric Administration
Benjamin Friedman, Acting NOAA Administrator

National Marine Fisheries Service
Chris Oliver, Assistant Administrator for Fisheries

I. Introduction

Coastal pelagic fish species (CPS), krill, and their environment within the California Current Ecosystem (CCE) were sampled using multi-frequency echosounders, surface trawls, vertically integrating net tows, a continuous underway fish-egg sampler (CUFES), and conductivity-temperature-depth probes (CTD), and assessed using the Acoustic-Trawl Method (ATM) and Daily Egg Production Method (DEPM) during the Spring CPS Survey (1704RL) aboard the NOAA Fisheries Survey Vessel (FSV) *Reuben Lasker* (hereafter, *Lasker*), 21 March to 22 April 2017. The objectives of the survey were to: 1) acoustically map the distributions and estimate the abundances of CPS, e.g., Pacific sardine (*Sardinops sagax*), Northern anchovy (*Engraulis mordax*), Pacific herring (*Clupea pallasii*), Pacific mackerel (*Scomber japonicus*), and jack mackerel (*Trachurus symmetricus*); and krill (euphausiid spp.); 2) characterize their biotic and abiotic environments, and investigate linkages; and 3) gather information regarding their life history parameters. The survey domain encompassed the anticipated distribution of the central sub-population of anchovy. The modeled distribution of potential sardine habitat, and information recently gathered from other research projects (e.g., CalCOFI samples) or the fishing industry (e.g., sardine bycatch) were used to determine whether the survey domain also encompassed the northern sub-population of sardine.

This report provides an overview of the survey objectives and a summary of the survey equipment, acoustic-system calibration, sampling and analysis methods, and preliminary results. This report does not include estimates of the distributions and biomasses for CPS and krill.

I.1 Scientific Personnel

As elaborated below, the collection and analysis of acoustic data was conducted by the Advanced Survey Technologies Program (AST) at the Southwest Fisheries Science Center (SWFSC); and fish-egg and trawl data, provided by E. Weber and B. Macewicz (both from SWFSC), were collected by the SWFSC Trawl Sampling Group.

Project Leads:

- D. Demer (Chief Scientist, AST Leader)
- K. Stierhoff (Project Leader)

Acoustic Data Collection and Processing:

- K. Stierhoff (Leg I, Chief Scientist)
- D. Palance and S. Mau (Leg II, Acousticians)

Unmanned Aircraft System (UAS) Operations:

- J. Barbaro (Pilot in Command)
- S. Mau and D. Palance (Ground Station Operators)

Echosounder Calibration:

- D. Demer, D. Murfin, J. Renfree, T. Sessions

Trawl Sampling:

- E. Gardner, D. Griffith, M. Human, B. Macewicz, S. Manion, C. Sandvik, C. Tait, L. Vasquez, W. Watson, E. Weber

II. Methods

II.1. Survey region and design

The central sub-population of anchovy occurs in the Southern California Bight (SCB) between Point Conception and northern Baja California (McHugh, 1951), and generally spawns within 60 nmi of the coast during late-winter and spring (Baxter, 1967). Sardine populations typically aggregate offshore of central and southern California to spawn in spring, then migrate north, compress along the coast, and feed in the upwelled regions in summer (Demer *et al.*, 2012; Zwolinski *et al.*, 2012, **Figure II.1**).

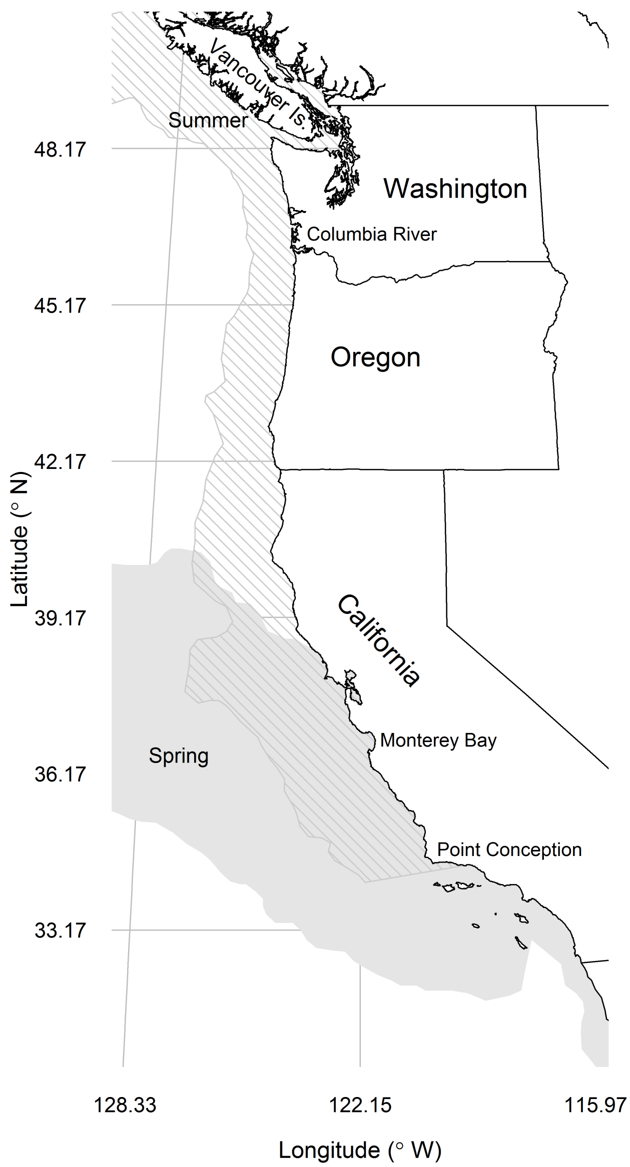


Figure II.1. Conceptual map showing the average seasonal distributions of Pacific sardine habitat during spring and summer along the west coasts of Mexico, the United States, and Canada (Zwolinski *et al.*, 2012). The distribution of potential habitat and catch information from the fishing industry are considered in the sampling design.

During spring 2017, part of the west coast of the United States was surveyed using *Lasker* during the principal spawning seasons of sardine and anchovy. Since the central sub-population of anchovy inhabits southern and central California during the spring, the survey began off San Diego and progressed northward toward San Francisco. Transect positions, lengths, and spaces were adjusted according to the expected distribution of anchovy at the time of the survey. Compulsory transects were nearly perpendicular to the coast with nominal separations of 20 nmi; adaptive transects were placed between compulsory transects to reduce nominal separation to 10 nmi when the survey encountered putative CPS backscatter in echograms, high-density eggs in the CUFES (1 or 0.3 eggs min^{-1} for anchovy or sardine, respectively), or adults in trawls (**Figure II.2**). After initiating adaptive acoustic sampling, the adaptive transect immediately south of the completed compulsory transect was sampled before proceeding northward along the next adaptive and compulsory transects. An adaptive cluster was defined as a minimum of five consecutive transects with 10-nmi spacing. The transect positions also covered much of the potential habitat of sardine at the time of the survey (**Figure II.3**; http://swfscdata.nmfs.noaa.gov/AST/sardineHabitat/habitat.asp).

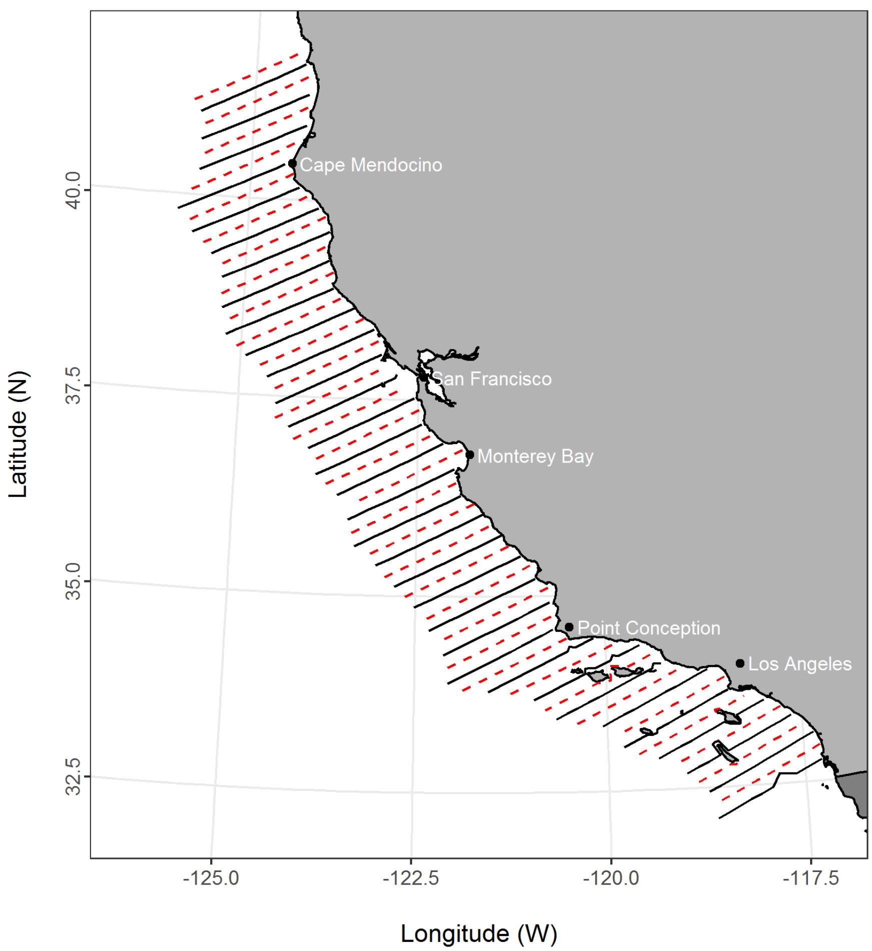


Figure II.2. Planned compulsory (solid, black line) and adaptive (dashed, red line) transect lines.

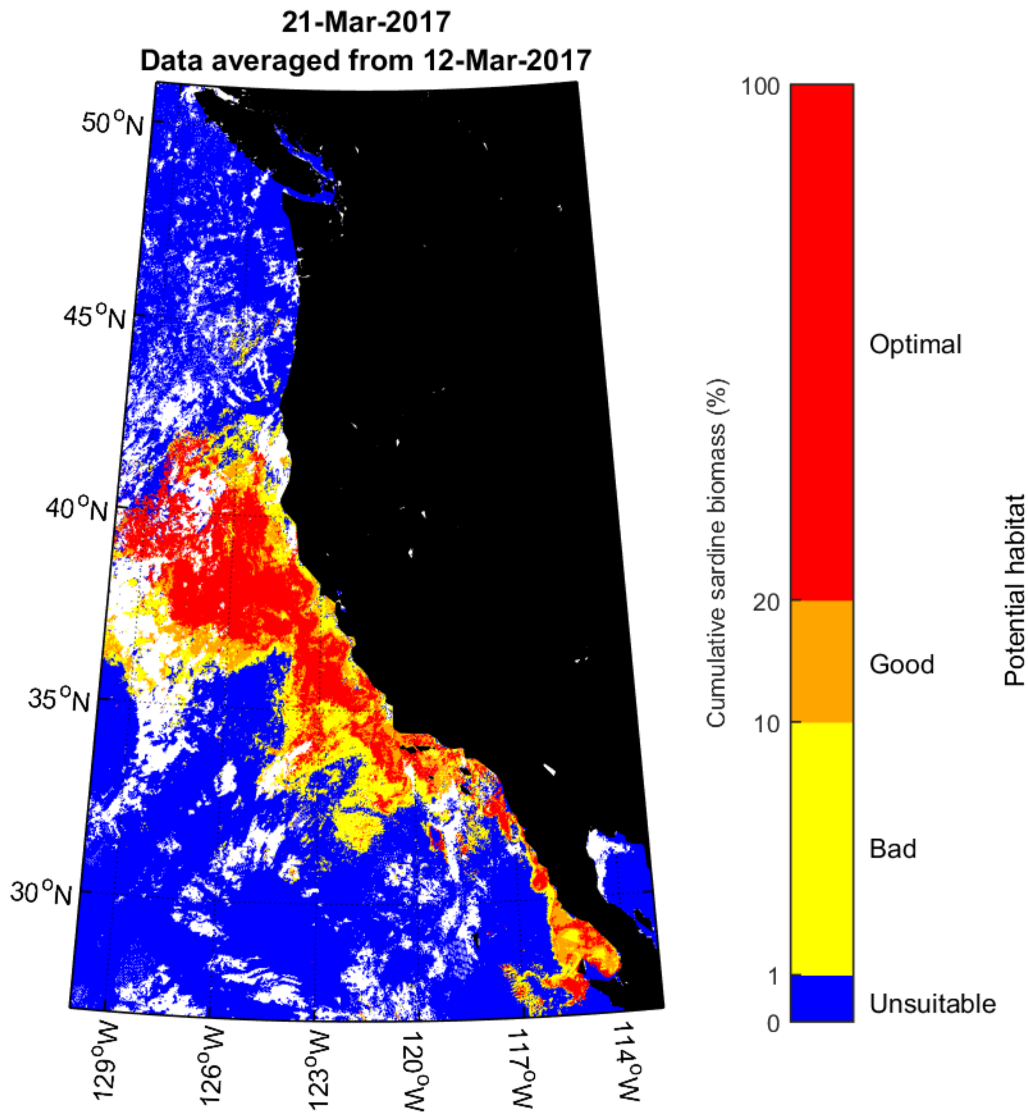


Figure II.3. Distribution of potential habitat for the northern stock of Pacific sardine on 21 March 2017 at the beginning of the Spring CPS Survey.

II.2 Acoustic sampling

II.2.1 Echosounders

Multi-frequency (18, 38, 70, 120, 200, and 333 kHz) General Purpose Transceivers (Simrad EK60 GPTs) and Wideband Transceivers (Simrad EK80 WBTs) were configured with split-beam transducers (Simrad ES18-11, ES38B, ES70-7C, ES120-7C, ES200-7C, and ES333-7C, respectively). The transducers were mounted on the bottom of a retractable keel or "centerboard" (**Figure II.4**). The keel was retracted (~ 5-m depth) during calibration, and extended to the intermediate position (~7-m depth) during the survey. Exceptions were made during shallow water operations, when the keel was retracted to ~ 5-m depth; or during times of heavy weather, when the keel was extended to ~9-m depth to provide extra stability and reduce the effect of weather-generated noise.

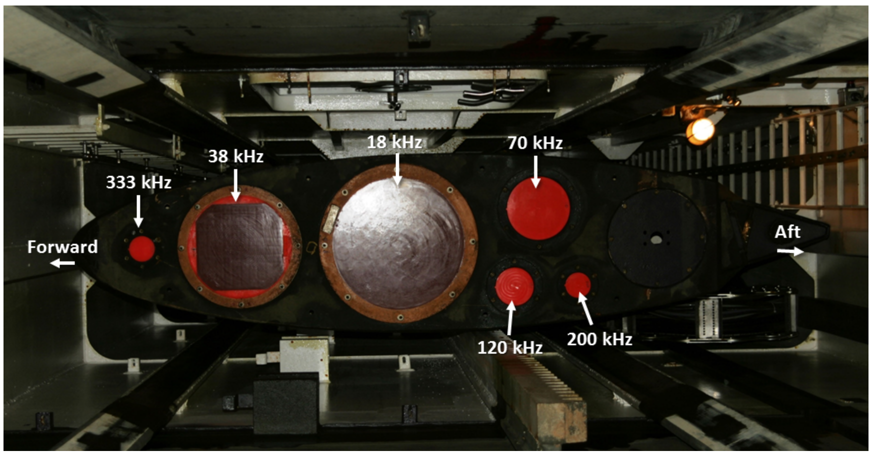


Figure II.4. Transducer locations on the bottom of the centerboard aboard *Lasker*.

II.2.2 Calibration

Prior to calibration, the integrity of the hardware was verified by impedance measurements of each transducer quadrant, individually and connected in parallel, using an Agilent 4294A Precision Impedance Analyzer and custom Matlab software. For each transducer, the magnitude (Z, Ω) and phase (θ, °) of the impedance, conductance (G, mS), susceptance (B, mS), and admittance circles (G vs. B) were plotted for each quadrant and for the quadrants in parallel (**Appendix A**). Also, the resonance frequency and quality factor were measured, and G, B, Z, and θ were measured at both the resonance and operational frequencies.

The echosounders were then calibrated using the standard sphere technique (Demer *et al.*, 2015; Foote *et al.*, 1987). The reference target was a 38.1-mm diameter sphere made from tungsten carbide (WC) with 6% cobalt binder material (Lasker sphere #1).

The GPTs were configured, via the ER60 software, using the parameters in **Appendix B**.

II.2.3. Data collection

The ER60-computer clock was set to GMT and synchronized with the GPS clock using SymmTime (Symmetricon, Inc.) every six hours. Echosounder pulses were transmitted simultaneously at all frequencies, at variable intervals, as controlled by the ER60 Adaptive Logger (EAL, Renfree and Demer, 2016). The EAL optimizes the pulse interval, based on the seabed depth, while minimizing aliased seabed echoes. A custom multiplexer (AST EK-MUX) was used to alternate transmissions from the EK60 and EK80 echosounders. Every 30 min, a custom multiplexer (AST Z-MUX) was used to facilitate measures of ambient noise and the impedances of each echosounder transducer concomitant with measurements of ambient environmental conditions. Acoustic sampling for CPS-density estimation along the pre-determined transects (see **Section II.1**) was limited to daylight hours (approximately between sunrise and sunset).

Measurements of volume backscattering strength (S_{v}; dB re 1 m^3) and target strength (TS; dB re 1 m^2), indexed by time and geographic positions provided by GPS receivers, were logged to 350-m range, and stored in .raw format (50-MB maximum file size; each filename begins with "1704RL_" and ends with the logging commencement date and time) using the GPT- or WBT-control software (Simrad ER60 V2.4.3 and Simrad EK80 V1.10.3, respectively). Changes to the nominal transducer depth (~7 m) are indicated in **Appendix C**.

To minimize acoustic interference, transmit pulses from two multibeam sonars (Simrad ME70 and MS70), an omni-directional sonar (Simrad SX90), and acoustic Doppler current profiler (Teledyne RD Instruments Ocean Surveyor Model OS75) were triggered using a synchronization system (Simrad K-Sync). All other instruments that produce sound within the echosounder bandwidths were secured during 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 (Sperry Marine Model SRD-500A), or both.

II.2.4 Data processing

The calibrated echosounder data were processed on a dedicated computer, using commercial software (Echoview V8.0.73.30735, Myriax) and the following procedure:

1. For each transect, the associated data files (.raw format) were loaded into an Echoview (.ev) file. Transducer depths were set to 0 m.
2. In each .ev file, values for the environment were set using Echoview calibration supplement (.ecs) files, including data from the closest CTD or UCTD cast. Since the CPS of interest reside in the upper mixed layer, environment data were averaged over 0- to 70-m depth.
3. For each frequency:
   - Echograms of S_{v} were displayed.
   - "Noise-reduced" echograms (**Figure II.5a**), generated by subtracting in the linear domain simulated background noise from the raw S_{v}, were smoothed by computing the median value in non-overlapping 11-sample by 3-ping cells (**Figure II.5b**).
   - The smoothed, noise-reduced echograms were used to calculate S_{v}-differences using the 38-kHz S_{v} (S_{v38kHz}) as a reference (i.e., S_{v70kHz} - S_{v38kHz}; S_{v120kHz} - S_{v38kHz}; S_{v200kHz} - S_{v38kHz}).
   - A CPS mask (**Figure II.5c**) was created for regions where S_{v}-differences were within the expected ranges for CPS (**Table II.1.**).
   - Data were provisionally ascribed to CPS if their S_{v}-differences (i.e., S_{v70kHz} - S_{v38kHz}; S_{v120kHz} - S_{v38kHz}; S_{v200kHz} - S_{v38kHz}) were within predicted ranges (**Table II.1.**).
   - Data collected when the ship approached or departed a sampling station, typically associated with a ship-speed less than 5 kn, were automatically marked as "bad data."
   - Provisional CPS regions created above were ascribed to CPS schools if the standard deviation of each 11-sample by 3-ping cell was > -50 dB at 120 and 200 kHz.
   - The 38-kHz CPS data with $S_{\mathrm{v}} < -60$ dB (corresponding to a density of approximately three fish per 100 m^3 in the case of 20-cm-long sardine) were set to -999 dB (effectively zero; **Figure II.5d**).
   - An integration-start line was created at a range of 5 m from the transducers. When necessary, this line was manually modified to exclude reverberation due to bubbles.
   - The dead-zone height was estimated using the variance-to-mean ratio (Demer *et al.*, 2009).
   - An integration-stop line was created at 350-m depth or, when shallower, 3 m above the estimated dead-zone height.
   - Between the integration lines, to a maximum of 350 m, volume backscattering coefficients (s_{v}, m^2 m^{-3}) were integrated over 5-m depths and averaged over 100-m distances. The resulting integrated volume backscattering coefficients (s_{A}; m^2 nmi^{-2}), for each transect and frequency, were output to comma-delimited text (.csv) files.

- The s_A values were summed over ranges from the integration start line to the approximate depth of the bottom of the upper mixed layer.
- Data collected during daytime (i.e., not earlier than 30 min before sunrise to not later than 30 min after sunset) were averaged over 2-km distances, and mapped. Nighttime data, assumed to be negatively biased due to diel-vertical migration (DVM) and disaggregation of the target species' schools (Cutter and Demer, 2008; Demer and Hewitt, 1995) were omitted.

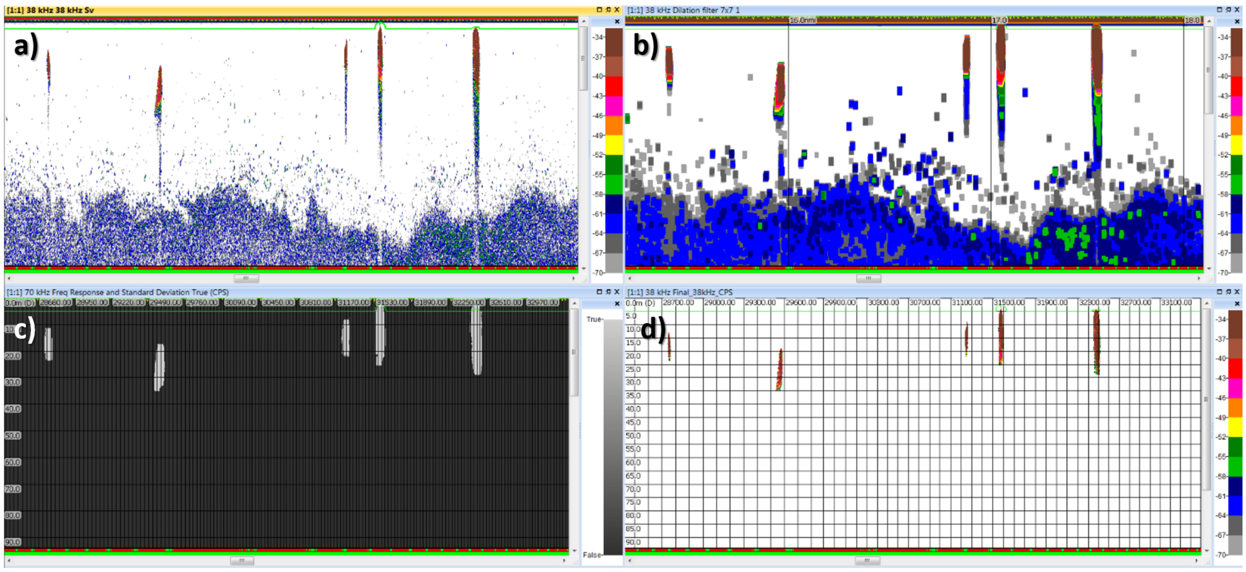


Figure II.5 Synchronized echograms of 38-kHz S_v after a) noise-subtraction, b) median smoothing, c) masking, and d) 38-kHz S_v thresholding at -60 dB (final, CPS-only).

Table II.1. S_v-differences (minimum, maximum; dB) for putative CPS.

$S_{v70kHz} - S_{v38kHz}$	$S_{v120kHz} - S_{v38kHz}$	$S_{v200kHz} - S_{v38kHz}$
-12.85, 9.89	-13.15, 9.37	-13.51, 12.53

II.3. Trawl sampling

During the day, CPS form schools in the upper mixed layer (to 70-m depth in the spring; (Kim and McGowan, 2005)), and much shallower in summer. After sunset, CPS schools tend to ascend and disperse. At that time, with reduced visibility and no schooling behavior, they are less able to avoid a net (Mais, 1974). Therefore, trawl sampling for identifying the species composition and size range of acoustic targets was performed at night.

The net, a Nordic 264 rope trawl (NET Systems; Bainbridge Island, WA), has a square opening of 600 m^2, variable-size mesh in the throat, an 8-mm square-mesh cod end liner (to retain a large range of animal sizes), and a "marine mammal excluder device" to prevent the capture of large animals, such as dolphins, turtles, or sharks. The trawl doors are foam-filled and the trawl headrope is lined with floats so the trawl tows at the surface.

Nighttime trawl sampling was conducted where echoes from CPS schools where observed earlier that day. Trawls were towed at ~ 4 kn for 45 min. The total catch from each trawl was weighed and sorted by species or groups. From the catches with CPS, up to 75 fish were selected randomly for each of the target species. Those were weighed (g) and measured to either their standard length (L_s; mm) for sardine, anchovy, and herring, or fork length (L_f; mm) for jack mackerel and Pacific mackerel. Regional species composition was estimated from the nearest trawl cluster, i.e., the combined catches of up to three trawls per night, separated by ~ 10 nmi.

II.4. Ichthyoplankton and oceanographic sampling

II.4.1 CUFES, CalBOBL, and Pairovet

During the day, fish eggs were collected using CUFES (Checkley *et al.*, 1997), which collects water and plankton at a rate of ~640 l min^{-1} from an intake on the hull of the ship at ~ 3-m depth. The particles in the sampled water were sieved by a 505 μm mesh. All fish eggs were identified to lowest taxa, counted, and logged. Typically, the duration of each CUFES sample was 30 min, corresponding to a distance of 5 nmi at a speed of 10 kn. Because the duration of the initial stages of the egg phase is short for most fish species, the egg distributions inferred from CUFES indicate the nearby presence of actively spawning fish.

CalCOFI Bongo Oblique (CalBOBL, or bongo) nets (71-cm diameter; 505-μm mesh) were used to sample ichthyoplankton and krill at each station. Where there was adequate depth, 300 m of wire was deployed and then retrieved at 20 m min^{-1}, at a nominal wire angle of 45°.

Paired vertical egg tow (Pairovet; formerly CalCOFI vertical egg tow or CalVET, (Smith *et al.*, 1985)) nets (25-cm diameter; 150-μm mesh) were used to sample fish eggs from a depth of 70 m to the sea surface at a rate of 70 m min^{-1} in areas where their densities exceeded a threshold of > 0.3 eggs min^{-1}.

II.4.2. Conductivity and temperature versus depth (CTD)

Day and night, conductivity and temperature versus depth to 350 m were measured with calibrated sensors on a CTD rosette or underway probe (UCTD) cast from the vessel. These data were used to estimate the time-averaged sound speed (Demer, 2004), for estimating ranges to the sound scatterers, and frequency-specific sound absorption coefficients, for compensating the echo signal for attenuation during propagation of the sound pulse from the transducer to the scatterer range and back (Simmonds and MacLennan, 2005). These data also provided indication of the depth of the upper-mixed layer, where most epipelagic CPS reside during the day.

II.5. Unmanned Aircraft System (UAS)

During the day on Leg II, a UAS (Model APH-22, Aerial Imaging Solutions) was opportunistically evaluated for its potential to visually sample near-surface CPS aggregations in the vicinity of the vessel during acoustic transects, and between the eastern-most end of acoustic transects and shore where the vessel could not safely navigate. The UAS was equipped with a 16 megapixel (MP) still camera (Model E-PM2, Olympus) with a 17-mm lens that collected images at a 2-s interval to achieve maximum coverage with *ca.* 20% overlap when flying at a nominal altitude of *ca.* 120 m (400') above sea level (ASL). Maximum flight duration was *ca.* 15 min, which was limited by battery capacity, payload, and prevailing weather conditions (e.g., wind).

III. Results

III.1. EK60 echosounder calibration

The EK60s were calibrated on 13 March 2017 (~23:00 GMT) while the vessel was docked at 10th Avenue Marine Terminal, San Diego Bay (32.6956 °N, -117.15278 °W, **Figure III.1**). Thermosalinograph (Seabird Model SBE38) measurements of sea-surface temperature (t_{w} = 16.5 °C) and salinity (s_{w} = 31.4 psu) were input to the GPT-control software, which derived estimates of sound speed (c_{w} = 1507.8 m s^{-1}) and absorption coefficients. Varying with tide, the seabed was 4 to 9 m beneath the transducers. The calibration sphere was positioned 5 to 8 m below the transducers.

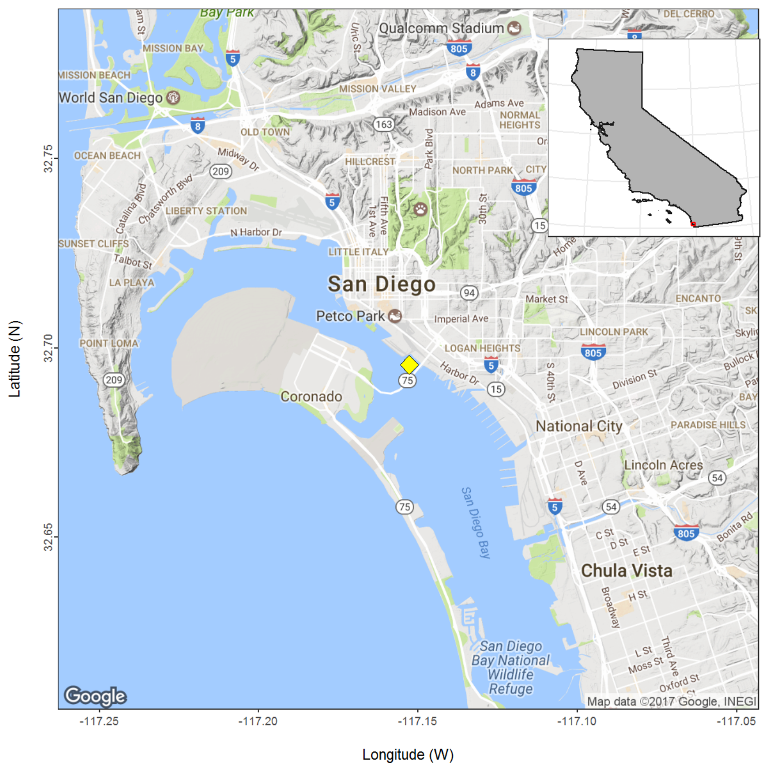


Figure III.1. Map of the calibration location (yellow diamond) near 10th Avenue Marine Terminal, San Diego Bay.

Measurements of beam-uncompensated sphere target strength (TS_{u}, dB re 1 m^2) and the beam model are plotted in **Figure III.2**, beam-compensated sphere target strength (TS_{c}, dB re 1 m^2) measurements are plotted in **Figure III.3**, and nautical area scattering coefficients (s_{A}, m^2 nmi^{-2}) are plotted in **Figure III.4**. GPT information, configuration settings, and beam model results following calibration are presented in **Appendix B**.

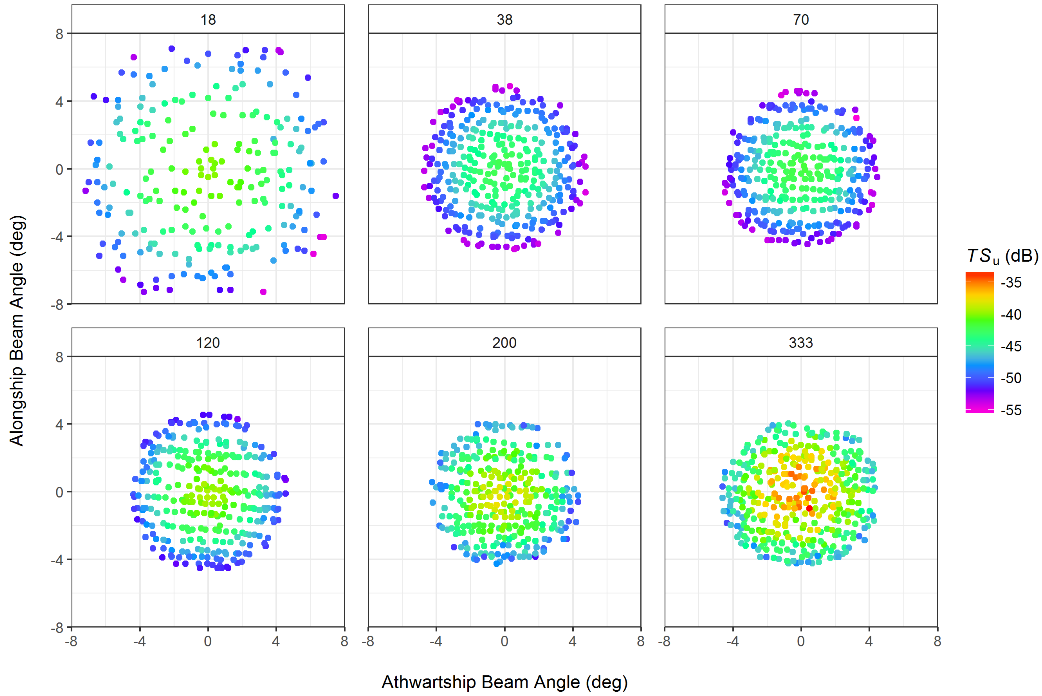


Figure III.2. Beam-uncompensated sphere target strength (TS_{u}, dB re 1 m^2) measurements of a 38.1-mm diameter sphere made from tungsten carbide (WC) with 6% cobalt binder material, at multiple EK60 frequencies (18, 38, 70, 120, 200, and 333 kHz).

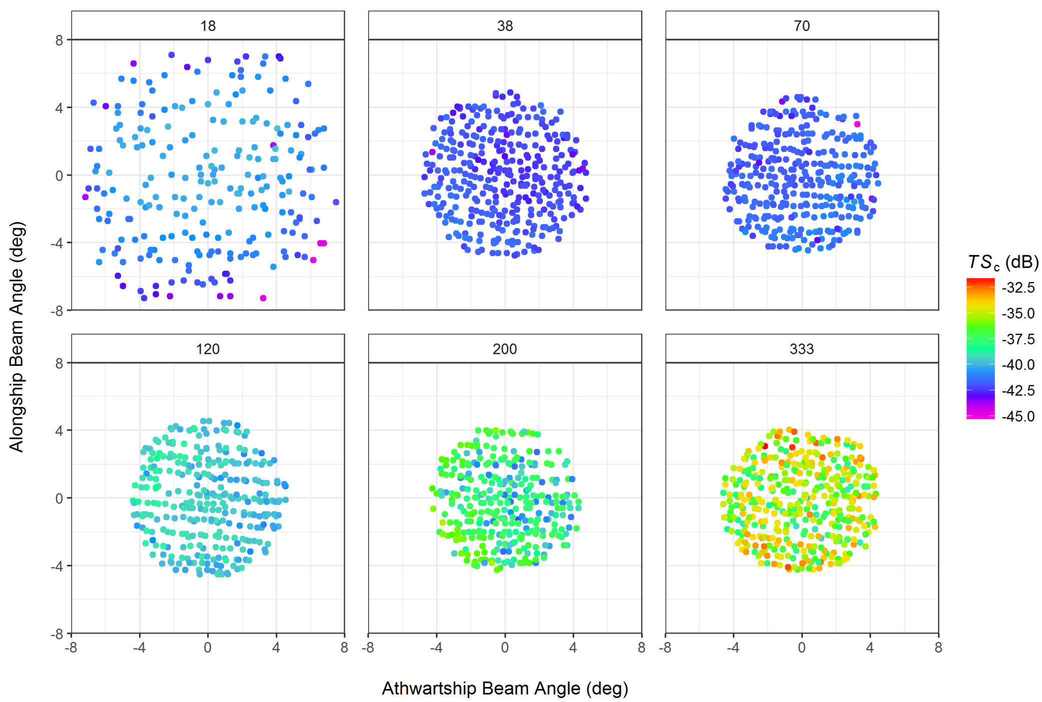


Figure III.3. Beam-compensated sphere target strength (TS_{c}, dB re 1 m^2) measurements of a 38.1-mm diameter sphere made from tungsten carbide (WC) with 6% cobalt binder material, at multiple EK60 frequencies (18, 38, 70, 120, 200, and 333 kHz).

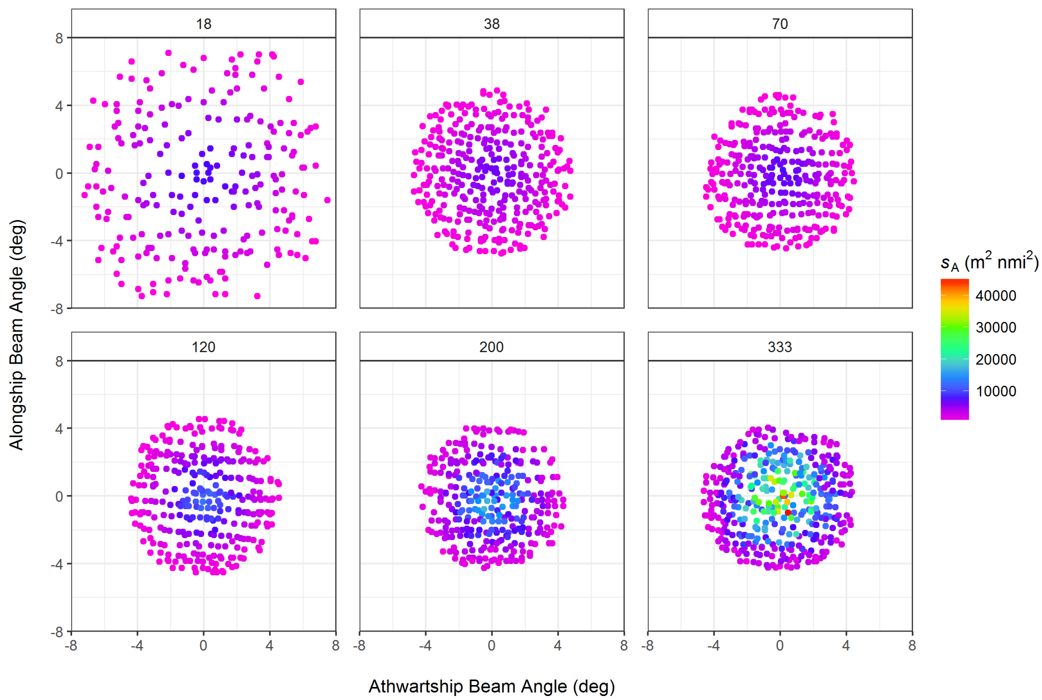


Figure III.4. Nautical area scattering coefficient (s_{A}, $\mathrm{m}^2\ \mathrm{nmi}^{-2}$) measurements of a 38.1-mm diameter sphere made from tungsten carbide (WC) with 6% cobalt binder material, at multiple EK60 frequencies (18, 38, 70, 120, 200, and 333 kHz).

III.2. Data collection

III.2.1. Acoustic and trawl sampling

The survey spanned an area from approximately San Diego to San Francisco (**Figure III.5**), with 27 east-west transects totaling 1828 nmi, and 64 Nordic trawls.

Leg I departed from 10th Avenue Marine Terminal on 22 March 2017 at *ca.* 16:00 (all times GMT). After conducting trials with the dynamic positioning system, *Lasker* transited to *ca.* 32.8°N (off Mission Beach, San Diego) to conduct side station sampling. Acoustic sampling commenced at *ca.* 23:00 along compulsory transect 0 (along the U.S.-Mexico International Border); planned transects were 60-nmi long and spaced 20-nmi apart. Adaptive transects (spaced 10 nmi-apart) were initiated off Del Mar after CPS backscatter was observed and anchovy eggs were present in the CUFES. Adaptive acoustic sampling continued through compulsory transect 3 (near Dana Point), after which acoustic sampling was conducted only along compulsory transects (spaced 20-nmi apart) for the remainder of Leg I. Training exercises by the U.S. Navy required some acoustic transects to be truncated (e.g., compulsory transect 0, the southernmost transect) and others to be sampled in several smaller segments and out of sequence to achieve full coverage (e.g., compulsory transects 5 and 6). Compulsory transects 4 and 5 were extended to 100 nmi offshore to establish the offshore extent of anchovy eggs, which were very dense at the ends of the planned acoustic transects near San Nicolas, Island. On 4 April, the trawl net was badly damaged and was replaced with a spare net in the lee of Point Conception near Santa Barbara. Acoustic sampling ceased at *ca.* 19:00 on 6 April after completing compulsory transect 11 (near Morro Bay). Trawl sampling was conducted that evening before transiting north to San Francisco. *Lasker* arrived at the sea buoy off San Francisco on 7 April at *ca.* 15:00, and returned to Pier 15 (near the Exploratorium) at *ca.* 17:00.

Leg II departed from Pier 15 in San Francisco on 11 April at *ca.* 16:30 and arrived at the offshore end of compulsory transect 12 at *ca.* 09:00 on 12 April. After conducting two trawls, acoustic sampling resumed at sunrise. Some CPS backscatter was observed in echograms and jack mackerel eggs were present in the CUFES along the inshore portion of compulsory transect 12. Acoustic sampling continued along *ca.* 80-nmi transects spaced 20-nmi apart for all of Leg II. Heavy seas (3 m) and strong winds (35 kn sustained) prevented UCTD deployments and trawling on 14 April, and the ship was slowed to 8 kn to minimize bubble-induced noise during acoustic sampling until conditions improved mid-morning on 15 April. UCTD deployments were also suspended from 19:00 on 16 April to 01:00 on 17 April due to more unsafe weather conditions. The 5-nmi inshore portion of adaptive transects 17 and 18 (near Monterey Bay) and an additional 2 nmi perpendicular to and north of the inshore endpoints were completed on 17 and 18 April to determine whether CPS were present in areas where the habitat model indicated favorable conditions. Anchovy eggs were abundant in the CUFES along each of those short transects but no CPS were caught in trawls conducted in the same areas. On 19 April, the rib line of the trawl was damaged and required replacement; a modified Nordic trawl net with multiple cod-ends in the net body was used for the remainder of Leg II with the extra cod-ends left open. Acoustic sampling ceased at *ca.* 01:00 on 22 April after completing compulsory transect 21 (near Point Reyes). Along this transect, sardine eggs were present in the CUFES and CPS backscatter was present in echograms. The catch of one trawl in the area contained two sardine. *Lasker* arrived at Pier 30/32 in San Francisco at *ca.* 18:30 on 22 April.

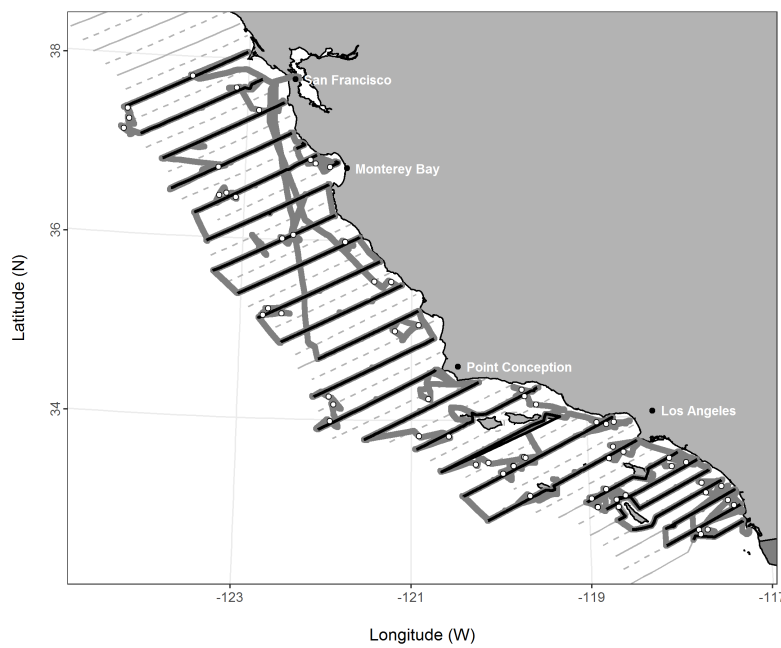


Figure III.5. Cruise track of *Lasker* (bold gray line), east-west acoustic transects (black lines), and locations of surface trawls (white points) superimposed on the proposed transects (light gray lines).

III.2.2 Ichthyoplankton and oceanographic sampling

A total of 26, 79, 131 CTD, bongo, and Pairovet samples were collected throughout the survey, respectively. In addition, 82 UCTD samples and 2970 CUFES samples were collected underway. The locations of CTD and UCTD stations are shown in Figure **III.6** and **Appendix D**.

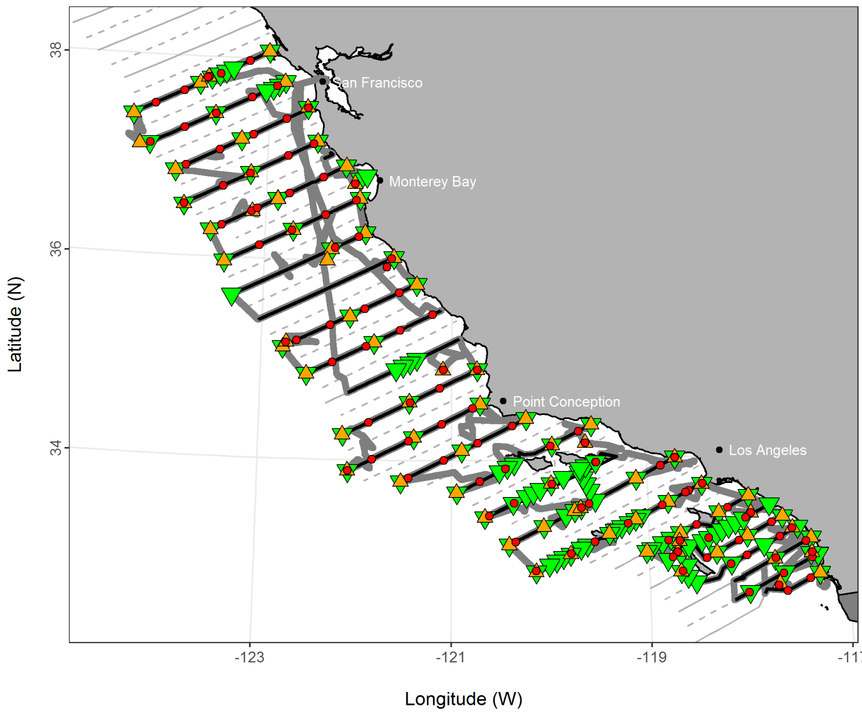


Figure III.6. CTD and UCTD locations (red circles) and plankton net samples (bongo net in orange triangles; Pairovet net in green triangles) relative to the vessel track (bold gray line), acoustic transects (black lines), and proposed transects (light gray lines).

III.2.3 Unmanned Aircraft System (UAS)

A total of five flights were conducted between Big Sur and Moss Beach. Flight duration ranged from 3.95 to 11.45 min; flight distances ranged from 0.03 to 1.63 nmi. One flight was conducted directly over the vessel to simulate flights used to observe CPS schools in the vicinity of the ship during acoustic transects (**Figure III.7**). Several other flights were conducted from the ship's work boat between the end of planned acoustic transects and shore (**Figure III.8**). Ultimately, few flights were attempted due to strong winds and high seas that prevented deployment of the ship's work boat, safe operation of the UAS, or both. These were the first UAS flights conducted aboard *Lasker* and the first conducted by AST during acoustic-trawl surveys.

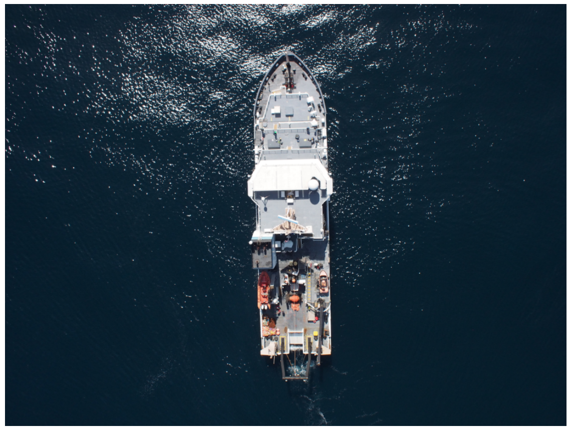


Figure III.7. An overhead view of *Lasker* from the UAS during one of the offshore flights.

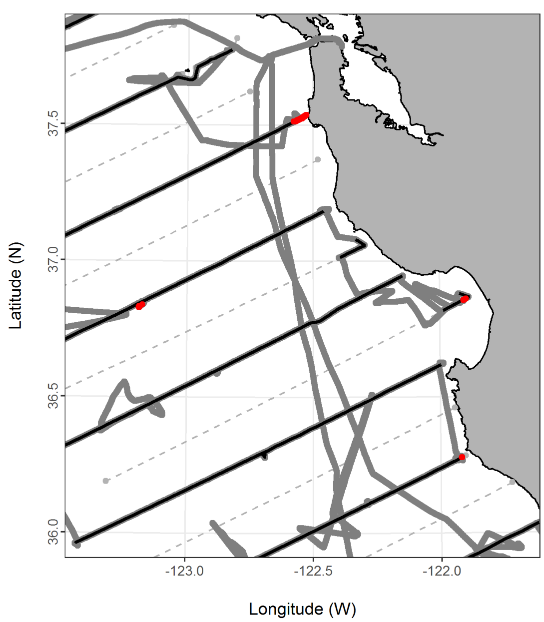


Figure III.8. Cruise track of *Lasker* (bold gray line), east-west acoustic transects (black lines), and UAS flight paths (red lines) superimposed on the proposed transects (light gray lines).

III.3. Distribution of CPS

Anchovy eggs were most abundant in the CUFES samples in the SCB, south of the Channel Islands around San Nicolas and San Clemente Islands (**Figure III.7a**). The maximum density of anchovy eggs (420 eggs m^{-3}) south of Santa Rosa Island was the highest density ever observed for any CPS in the CUFES (E. Weber, pers. comm.). Jack mackerel eggs were most abundant in the offshore portion of transects conducted along the central CA coast between Point Conception and Monterey (**Figure III.7b**). The few sardine eggs observed in the CUFES were south of Santa Rosa Island in the SCB, off Morro Bay, and off Point Reyes near San Francisco (**Figure III.7c**).

The majority of acoustic backscatter ascribed to CPS was observed in the SCB, south of the Channel Island in the vicinity of San Nicolas Island (**Figure III.7d**), and coincident with the greatest concentrations of anchovy eggs in the CUFES. To a lesser extent, acoustic backscatter ascribed to CPS was observed along the offshore portions of acoustic transects conducted between Point Conception and Monterey (**Figure III.7d**) coincident with the greatest concentrations of jack mackerel eggs.

Anchovy comprised the greatest proportion of catch in trawl samples south of Point Conception (**Figure III.7e**). Jack mackerel were predominantly found in trawls conducted between Point Conception and Monterey (**Figure III.7e**). The few sardine caught were collected offshore between Big Sur and San Francisco. Overall, the 64 trawls captured a combined 755.2 kg of CPS (0.6 kg sardine, 730.8 kg anchovy, and 23.3 kg jack mackerel; **Appendix E**).

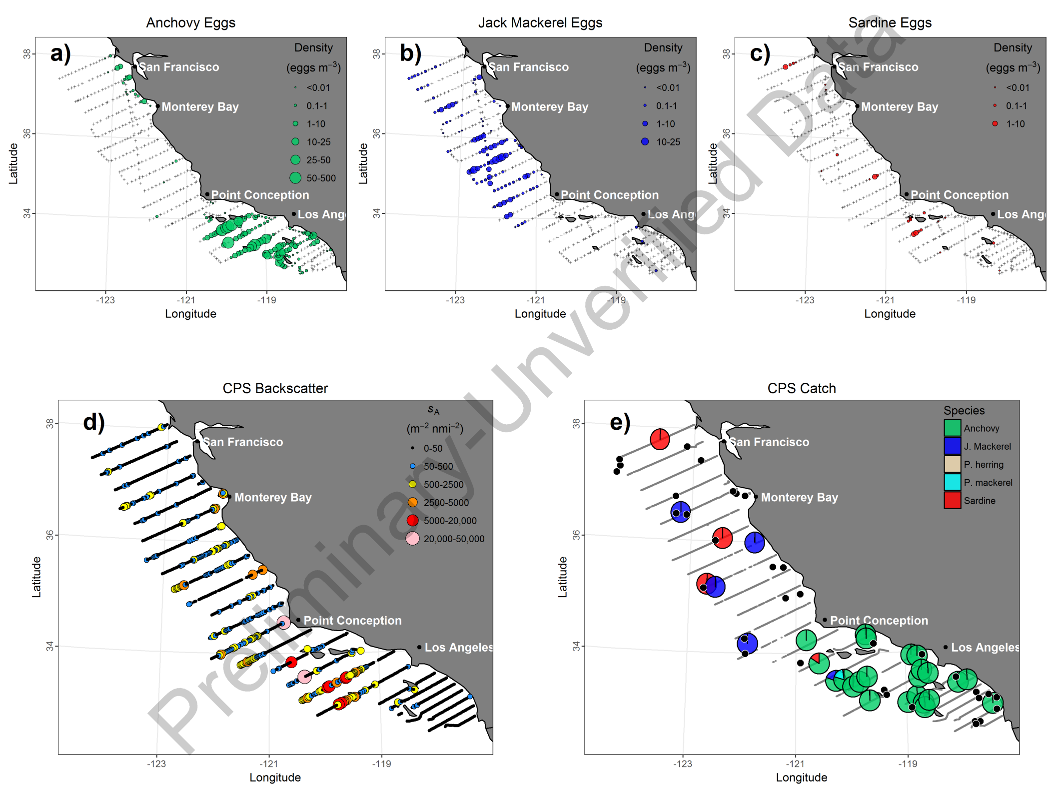


Figure III.9. Survey transects performed aboard *Lasker* overlaid with (a-c) anchovy-, jack mackerel-, and sardine-egg densities (eggs m^{-3}) from the CUFES; (d) the distribution of 38-kHz integrated backscattering coefficients (s_A, m^2 nmi^{-2}; averaged over 2000-m distance intervals and from 70 to 5-m deep) ascribed to CPS; and (e) proportions of CPS species in trawl clusters (black points indicate trawls with no CPS).

IV. Problems and Suggestions

The Nordic trawl was damaged twice and required replacement, once during Leg I and Leg II, which resulted in the loss of approximately two survey days. To minimize risk to the trawl gear and deck crew, we recommend trawling down-swell whenever possible. Poor weather conditions limited opportunities to deploy the UAS and battery endurance limited the amount of imagery collected between the inner most portions of acoustic transects and shore. Also, few potential CPS targets were present on which to deploy the UAS. Future attempts to survey CPS using a UAS would likely be more successful during summer when better weather conditions prevail. Electrical noise persisted primarily in the 120 kHz and 200 kHz EK60 echosounders and across all EK80 echosounders. Measurements were made with all echosounders in passive mode to help isolate noise sources, which appeared to be generated by either power sources to the echosounders or EK-Mux system or grounding of the echosounders and transducer cable shielding to the ship's hull. Additional work is required to identify and eliminate the source(s) of noise to maximize the quality of acoustic data collected. Finally, the full suite of echosounders and sonars aboard Lasker generate nearly 1 TB of data per day when operating simultaneously, which poses significant challenges to the storage and archiving of critical data collected during surveys. A high-capacity, centralized, data storage and transfer system is necessary to ensure that data are stored securely during surveys and transferred to archives at the SWFSC or elsewhere afterward.

V. Disposition of Data

Archived on the SWFSC data server are approximately 64.4 GB of raw EK60 data, 4.89 TB of raw EK80 data, 577 GB of raw ME70 data, 929 GB of raw MS70 data, and 1.16 TB of raw SX90 data. For more information, contact: David Demer (Southwest Fisheries Science Center, 8901 La Jolla Shores Drive, La Jolla, California, 92037, U.S.A.; phone: 858-546-5603; email: david.demer@noaa.gov).

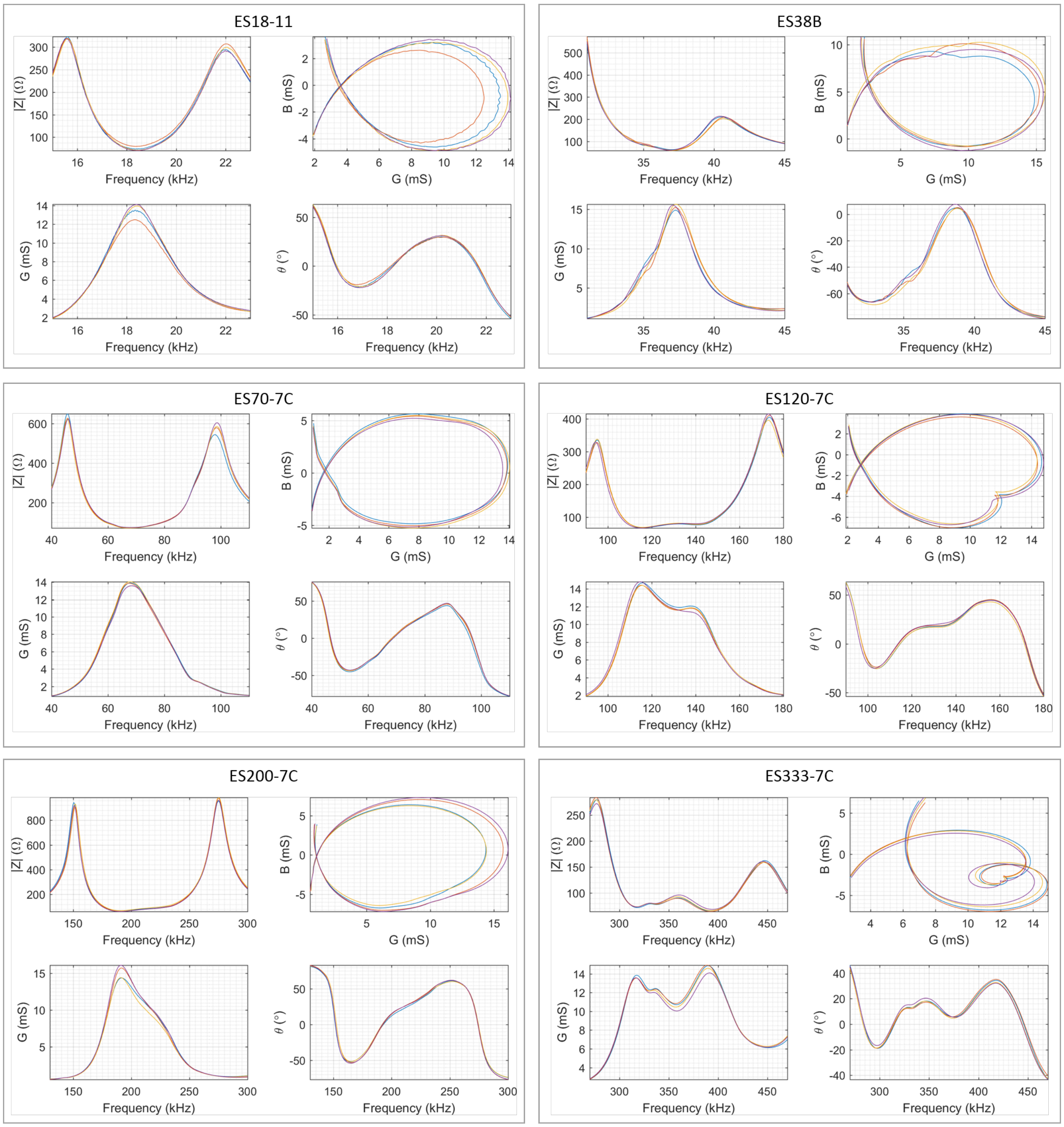
VI. Acknowledgements

We thank the crew members of *Lasker* and the scientists and technicians that participated in the sampling operations at sea. Critical reviews by E. Weber and G. Dinardo improved this report.

Appendices

Appendix A. Echosounder transducer impedance measurements

The magnitude of impedance ($|Z|$, Ω), phase (θ, $^\circ$), and conductance (G, S) versus frequency, and susceptance (B, S) versus G (admittance circle), for each quadrant (various colors) of the Simrad ES18-11, ES38B, ES70-7C, ES120-7C, ES200-7C, and ES333-7C transducers.



Appendix B. Echosounder settings and calibration results

Simrad EK60 general purpose transceiver (GPT) information, settings (above the line), and beam model results following calibration (below the line). Prior to the survey, on-axis gain (G_0) and S_a Correction ($S_a$corr) values were entered into the GPT-control software (Simrad ER60). Beam angles and offsets were set to their factory specifications.

Frequency (f, kHz)	Units	18	38	70	120	200	333
Model		ES18-11	ES38B	ES70-7C	ES120-7C	ES200-7C	ES333-7C
Serial Number		2116	31296	233	783	513	124
Transmit Power (p_{et})	W	2000	2000	750	250	110	40
Pulse Duration (τ)	ms	1.024	1.024	1.024	1.024	1.024	1.024
On-axis Gain (G_0)	dB re 1	21.38	24.9	27.07	26.64	26.95	25.33
S_a Correction ($S_a$corr)	dB re 1	-0.74	-0.74	-0.43	-0.36	-0.32	-0.4
Bandwidth (W_f)	Hz	1570	2430	2860	3030	3090	3110
Sample Interval	m	0.193	0.193	0.193	0.193	0.193	0.193
Eq. Two-way Beam Angle (Ψ)	dB re 1 sr	-17.3	-20.6	-20.4	-20.3	-20.4	-19.8
Absorption Coefficient (α_f)	dB km^{-1}	2	7.7	20.8	40.4	61.9	88.3
Angle Sensitivity Along. (Λ_α)	Elec.°/Geom.°	13.9	21.9	23	23	23	23
Angle Sensitivity Athw. (Λ_β)	Elec.°/Geom.°	13.9	21.9	23	23	23	23
3-dB Beamwidth Along. (α_{-3dB})	deg	12.11	6.88	6.49	6.49	6.08	5.97
3-dB Beamwidth Athw. (β_{-3dB})	deg	11.81	6.95	6.5	6.51	6.22	6.55
Angle Offset Along. (α_0)	deg	-0.12	0.06	0.06	-0.02	-0.02	-0.06
Angle Offset Athw. (β_0)	deg	-0.09	0.02	-0.05	0.05	0.1	-0.04
Theoretical TS (TS_{theory})	dB re 1 m^2	-42.56	-42.4	-42.3	-39.5	-39.2	-36.62
Ambient Noise	dB re 1 W	-999	-999	-999	-999	-999	-999
On-axis Gain (G_0)	dB re 1	22.74	24.99	27.4	26.64	27.16	25.66
S_a Correction ($S_a$corr)	dB re 1	-0.66	-0.72	-0.38	-0.43	-0.32	-0.26
RMS	dB	0.3	0.17	0.21	0.23	0.65	0.78
3-dB Beamwidth Along. (α_{-3dB})	deg	10.62	7.03	6.5	6.44	6.58	6.42
3-dB Beamwidth Athw. (β_{-3dB})	deg	10.74	7.03	6.49	6.48	6.56	6.66
Angle Offset Along. (α_0)	deg	-0.08	0.06	0.05	-0.03	-0.05	-0.06
Angle Offset Athw. (β_0)	deg	-0.23	-0.03	-0.06	0	-0.01	-0.06

Appendix C. Centerboard positions

Transducer depths, associate with the centerboard position (retracted ~5-m, intermediate ~7-m, extended ~9-m) during the Spring CPS Survey aboard *Lasker*.

Date/Time	Position	Latitude	Longitude
04/07/2017 14:48	Retracted (5 m)	37.7203	-122.6672
04/22/2017 15:39	Retracted (5 m)	37.7608	-122.6477

Appendix D. CTD and UCTD sample summary

Times and locations of conductivity and temperature versus depth measurements while on station (CTD) and underway (UCTD).

Date/Time	Event	Latitude	Longitude
03/21/2017 23:47	UCTD Cast	32.7228	-117.3890
03/22/2017 01:11	UCTD Cast	32.6092	-117.6275
03/22/2017 05:54	CTD Cast	32.6695	-117.7102
03/22/2017 18:23	UCTD Cast	32.9452	-117.7277
03/22/2017 20:12	UCTD Cast	33.1000	-117.4163
03/22/2017 23:55	UCTD Cast	32.9313	-117.3602
03/23/2017 01:51	UCTD Cast	32.7867	-117.6547
03/23/2017 08:11	CTD Cast	32.9837	-117.3583
03/23/2017 08:13	CTD Cast	32.9830	-117.3585
03/23/2017 17:57	UCTD Cast	32.6117	-118.0120
03/24/2017 04:23	CTD Cast	33.2367	-117.5492
03/24/2017 14:49	UCTD Cast	33.1568	-117.6758
03/24/2017 17:00	UCTD Cast	32.9877	-118.0163
03/24/2017 18:18	UCTD Cast	32.9045	-118.1833
03/24/2017 22:32	UCTD Cast	32.8558	-118.6685
03/25/2017 05:56	CTD Cast	33.0495	-118.7117
03/25/2017 14:25	UCTD Cast	32.9762	-118.4228
03/25/2017 17:08	UCTD Cast	33.1407	-118.0892
03/25/2017 20:07	UCTD Cast	33.3053	-117.7545
03/26/2017 04:52	CTD Cast	33.4105	-117.9598
03/26/2017 14:09	UCTD Cast	33.4738	-118.1913
03/26/2017 18:10	UCTD Cast	33.3137	-118.5143
03/26/2017 22:04	UCTD Cast	33.1707	-118.8028
03/27/2017 05:40	CTD Cast	33.1598	-118.6898
03/27/2017 14:07	UCTD Cast	32.9977	-118.7635
03/27/2017 16:56	UCTD Cast	33.1767	-118.3947
03/27/2017 20:04	UCTD Cast	33.3630	-118.0137
03/28/2017 02:07	CTD Cast	33.7265	-118.4397
03/28/2017 14:36	UCTD Cast	33.6607	-118.5795
03/28/2017 14:47	UCTD Cast	33.6450	-118.6118
03/28/2017 17:13	UCTD Cast	33.5233	-118.8547
03/28/2017 21:14	UCTD Cast	33.3490	-119.2048
03/29/2017 00:29	UCTD Cast	33.1768	-119.5487
03/29/2017 02:39	CTD Cast	33.0577	-119.7892
03/29/2017 17:37	UCTD Cast	32.8937	-120.1468
03/29/2017 20:56	UCTD Cast	33.1842	-120.3507
03/30/2017 02:35	CTD Cast	33.5187	-119.6777
03/30/2017 14:53	UCTD Cast	33.5577	-119.6002
03/30/2017 20:46	CTD Cast	33.9723	-119.5262
03/30/2017 20:56	UCTD Cast	33.9727	-119.5220
03/31/2017 02:07	CTD Cast	33.9985	-118.7090
03/31/2017 14:41	UCTD Cast	33.9242	-118.8593
04/01/2017 14:05	UCTD Cast	33.4477	-120.6173
04/01/2017 15:56	UCTD Cast	33.5735	-120.3618
04/01/2017 19:46	UCTD Cast	33.7637	-119.9768
04/02/2017 05:14	CTD Cast	34.1700	-119.6252
04/02/2017 14:34	UCTD Cast	34.2867	-119.6937
04/02/2017 17:11	UCTD Cast	34.1450	-119.9867

04/02/2017 23:10	UCTD Cast	33.9190	-120.4500
04/03/2017 00:48	UCTD Cast	33.7910	-120.7113
04/03/2017 14:35	UCTD Cast	33.8280	-121.4465
04/03/2017 16:40	UCTD Cast	34.0050	-121.0828
04/03/2017 19:41	UCTD Cast	34.1763	-120.7320
04/03/2017 21:41	UCTD Cast	34.3493	-120.3767
04/04/2017 02:32	CTD Cast	34.5268	-120.7857
04/04/2017 21:05	UCTD Cast	34.3662	-121.1043
04/04/2017 23:45	UCTD Cast	34.1968	-121.4467
04/05/2017 01:49	UCTD Cast	34.0103	-121.8210
04/05/2017 03:24	CTD Cast	33.8913	-122.0682
04/05/2017 16:49	UCTD Cast	34.3788	-121.8600
04/05/2017 20:01	UCTD Cast	34.5825	-121.4333
04/05/2017 21:43	UCTD Cast	34.7297	-121.1245
04/05/2017 23:56	CTD Cast	34.9120	-120.7355
04/06/2017 06:29	CTD Cast	34.9145	-121.0908
04/12/2017 14:05	UCTD Cast	35.4660	-121.2048
04/12/2017 16:01	UCTD Cast	35.3078	-121.5452
04/12/2017 19:06	UCTD Cast	35.1423	-121.8993
04/12/2017 21:05	UCTD Cast	34.9783	-122.2512
04/13/2017 03:40	CTD Cast	35.1657	-122.7415
04/13/2017 14:00	UCTD Cast	35.1880	-122.6328
04/13/2017 15:54	UCTD Cast	35.3510	-122.2803
04/13/2017 18:51	UCTD Cast	35.5175	-121.9207
04/13/2017 20:42	UCTD Cast	35.6855	-121.5558
04/14/2017 01:23	UCTD Cast	36.0250	-121.6427
04/14/2017 05:34	CTD Cast	35.9418	-121.6925
04/15/2017 17:51	UCTD Cast	36.1250	-122.2472
04/15/2017 19:16	UCTD Cast	36.2392	-121.9985
04/16/2017 01:19	UCTD Cast	36.6037	-122.0287
04/16/2017 14:02	UCTD Cast	36.4523	-122.3588
04/16/2017 17:02	UCTD Cast	36.2893	-122.7138
04/16/2017 18:56	UCTD Cast	36.1308	-123.0582
04/17/2017 01:06	UCTD Cast	36.3198	-123.4693
04/17/2017 02:56	CTD Cast	36.4683	-123.1528
04/17/2017 13:58	UCTD Cast	36.4983	-123.0937
04/17/2017 16:55	UCTD Cast	36.6603	-122.7507
04/17/2017 18:58	UCTD Cast	36.8310	-122.3897
04/18/2017 04:59	CTD Cast	36.7700	-122.0493
04/18/2017 16:49	UCTD Cast	37.1615	-122.5043
04/18/2017 18:20	UCTD Cast	37.0357	-122.7772
04/18/2017 22:27	UCTD Cast	36.8463	-123.1838
04/19/2017 00:07	UCTD Cast	36.7118	-123.4712
04/19/2017 02:28	CTD Cast	36.5162	-123.8863
04/19/2017 14:54	UCTD Cast	36.9025	-123.8858
04/19/2017 19:23	UCTD Cast	37.0720	-123.5227
04/19/2017 22:31	UCTD Cast	37.2375	-123.1675
04/20/2017 00:35	UCTD Cast	37.4035	-122.8102
04/20/2017 03:05	CTD Cast	37.5208	-122.5762
04/20/2017 14:48	UCTD Cast	37.7323	-122.9222
04/20/2017 17:40	UCTD Cast	37.6087	-123.1947
04/20/2017 21:00	UCTD Cast	37.4320	-123.5808
04/20/2017 22:52	UCTD Cast	37.2792	-123.9195
04/21/2017 01:00	CTD Cast	37.1122	-124.2850

04/21/2017 15:27	UCTD Cast	37.5100	-124.2470
04/21/2017 17:04	UCTD Cast	37.6495	-123.9430
04/21/2017 20:40	UCTD Cast	37.8305	-123.5478
04/21/2017 23:08	UCTD Cast	37.9723	-123.2335
04/22/2017 05:47	CTD Cast	37.7972	-123.6767
04/22/2017 06:41	CTD Cast	37.7895	-123.6952

Appendix E. Trawl sample summary

Date, time, and location at the start of trawling (i.e., at net equilibrium), and biomasses (kg) of CPS species collected in each trawl. The duration of each trawl set was nominally 45 min.

Trawl	Date/Time	Lat (N)	Lon (W)	Anchovy	Sardine	P. mackerel	J. mackerel	All CPS
1	03/21/2017 20:27	32.699	-117.786					
2	03/22/2017 00:50	32.694	-117.690					
3	03/22/2017 03:34	32.649	-117.768					
4	03/22/2017 20:59	33.106	-117.369					
5	03/22/2017 22:44	33.011	-117.445	0.04				0.04
6	03/23/2017 01:54	32.901	-117.380					
7	03/23/2017 19:00	33.173	-117.510					
8	03/23/2017 22:57	33.222	-117.731					
9	03/24/2017 01:40	33.111	-117.688					
10	03/24/2017 20:19	32.995	-118.673	9.28				9.28
11	03/24/2017 23:45	33.076	-118.692	0.57				0.57
12	03/25/2017 02:38	33.123	-118.591	0.07				0.07
13	03/25/2017 19:24	33.423	-118.054	2.20				2.20
14	03/25/2017 22:44	33.458	-117.890	0.04				0.04
15	03/26/2017 02:10	33.517	-118.086					
16	03/26/2017 19:58	33.199	-118.806	65.86				65.86
17	03/27/2017 00:35	33.097	-118.971	10.62				10.62
18	03/27/2017 03:26	33.000	-118.904					
19	03/27/2017 21:19	33.668	-118.710	0.16				0.16
20	03/28/2017 00:18	33.542	-118.759	1.82				1.82
21	03/28/2017 03:54	33.606	-118.594	0.13				0.13
22	03/28/2017 21:00	33.145	-119.661	3.43				3.43
23	03/29/2017 00:50	33.327	-119.396					
24	03/29/2017 01:58	33.237	-119.355					
25	03/29/2017 21:24	33.398	-119.961	618.76				618.76
26	03/30/2017 01:01	33.482	-119.840	2.80				2.80
27	03/30/2017 03:59	33.572	-119.704	2.85				2.85
28	03/30/2017 19:37	33.943	-118.691					
29	03/31/2017 00:11	33.947	-118.890	0.04				0.04
30	03/31/2017 02:32	33.924	-118.780	0.74				0.74
31	03/31/2017 23:00	33.525	-120.123	2.84	0.08	0.64		3.56
32	04/01/2017 01:29	33.505	-120.270	0.40			0.10	0.50
33	04/01/2017 19:32	34.164	-119.573					
34	04/01/2017 23:02	34.258	-119.706	3.61				3.61
35	04/02/2017 01:32	34.331	-119.717	4.08				4.08
36	04/02/2017 21:15	33.820	-120.575	0.40	0.08			0.48
37	04/03/2017 00:23	33.826	-120.915					
38	04/03/2017 21:02	34.237	-120.807	0.04				0.04
39	04/04/2017 21:35	33.983	-121.933					
40	04/05/2017 01:10	34.169	-121.891				0.16	0.16
41	04/05/2017 03:59	34.256	-121.951					
42	04/05/2017 20:32	34.991	-121.194					
43	04/06/2017 01:45	35.061	-120.919					
44	04/12/2017 01:00	35.546	-121.437					
45	04/12/2017 03:38	35.541	-121.240					
46	04/12/2017 21:09	35.150	-122.733					
47	04/12/2017 23:16	35.173	-122.516				11.01	11.01
48	04/13/2017 02:37	35.225	-122.674		0.08			0.08

49	04/13/2017 19:46	35.984	-121.787		9.96	9.96
50	04/15/2017 21:29	36.052	-122.401	0.07		0.07
51	04/16/2017 00:43	36.004	-122.534			
52	04/16/2017 20:35	36.453	-123.100			
53	04/16/2017 22:48	36.494	-123.217		2.06	2.06
54	04/17/2017 01:10	36.466	-123.301			
55	04/17/2017 19:22	36.816	-121.984			
56	04/17/2017 11:02	36.852	-122.159			
57	04/18/2017 01:17	36.891	-122.219			
58	04/18/2017 22:57	36.780	-123.323			
59	04/19/2017 21:50	37.430	-122.859			
60	04/20/2017 01:28	37.671	-123.141			
61	04/20/2017 19:38	37.158	-124.490			
62	04/20/2017 23:36	37.275	-124.429			
63	04/21/2017 02:59	37.384	-124.453			
64	04/21/2017 23:34	37.780	-123.683	0.25		0.25

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