https://doi.org/10.7289/V5/TM-SWFSC-593

NOAA Technical Memorandum NMFS

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REPORT ON THE COLLECTION OF DATA DURING THE SUMMER 2017 CALIFORNIA CURRENT ECOSYSTEM SURVEY (1706RL), 19 JUNE TO 11 AUGUST 2017, CONDUCTED ABOARD FISHERIES SURVEY VESSEL *REUBEN LASKER*

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NOAA-TM-NMFS-SWFSC-593

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) during the Summer 2017 California Current Ecosystem Survey (1706RL) aboard the NOAA Fisheries Survey Vessel (FSV) *Reuben Lasker* (hereafter, *Lasker*; **Figure I.1**), 19 June to 11 August 2017.

The objectives of the survey were to: 1) acoustically map the distributions and estimate the abundances of CPS, including Pacific sardine (*Sardinops sagax*), Northern anchovy (*Engraulis mordax*), Pacific herring (*Clupea pallasii*), Pacific chub 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 northern subpopulation of sardine, and the northern and central subpopulations of Northern anchovy off the west coasts of the U.S. and Canada, from approximately San Diego, CA to the north end of Vancouver Island, British Columbia. The sampling domain was constrained by the modeled distribution of potential sardine habitat (Zwolinski *et al.*, 2011), information gathered from other concurrent research projects (e.g., CalCOFI samples) or the fishing industry (e.g., sardine bycatch or anchovy catch), and the number of days available to the survey.

Sampling from *Lasker* was augmented with echosounder and sonar sampling from Fishing Vessel (FV) *Lisa Marie* (**Figure I.1**) in nearshore areas off Washington and Oregon. In the same region, *Lasker* coordinated with the fishing industry's aerial-photographic sampling.

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 or krill or results of the industry's nearshore sampling from *Lisa Marie* and aircraft.

Figure I.1 FSV *Lasker* and FV *Lisa Marie* (inset) used to conduct the survey.

I.1 Scientific Personnel

The collection and analysis of acoustic data was conducted by the SWFSC. Acousticians were exchanged at approximately the midpoint of each survey leg (first and second halves denoted by suffix, -1 and -2). The trawl personnel remained aboard for at least one leg. One SWFSC acoustician embarked *Lisa Marie* for nine days. Two industry fishermen embarked *Lasker* at the beginning of Leg I-2 and remained aboard for five days.

Project Lead:

- D. Demer (Chief Scientist)
- G. Cutter (Survey Coordinator)

Acoustic Calibration, Data Collection, and Processing:

FSV *Lasker*

- Pre-Leg 1 calibration: D. Demer, D. Murfin, J. Renfree, and T. Sessions
- Leg I-1: D. Palance and J. Zwolinski
- Leg I-2: T. Sessions
- Leg II-1: D. Palance
- Leg II-2: G. Cutter

FV *Lisa Marie*

- Pre-survey calibration: J. Renfree
- S. Mau

Trawl Sampling:

- Leg I: D. Chargualaf, E. Gardner, A. Hays, A. Klemmedson (Volunteer), S. Manion (Cruise Leader), N. Osborn (Volunteer), B. Overcash, and D. White (Teacher at Sea)

- Leg II: P. Biondo, D. Chambers (Teacher at Sea), P. Dionne, D. Griffith (Cruise Leader), A. Grodt (Volunteer), S. Manion, N. Rosen, A. Thompson, and L. Vasquez

Industry observers:

- Leg I-2: A. Blair and G. Shaughnessy

II. Methods

II.1. Survey region and design

During spring, sardine typically aggregate offshore of central and southern California to spawn (Demer *et al.*, 2012). During summer, if the stock is large enough, adults will migrate north, compress along the coast, and feed in the upwelled regions (**Figure II.1**).

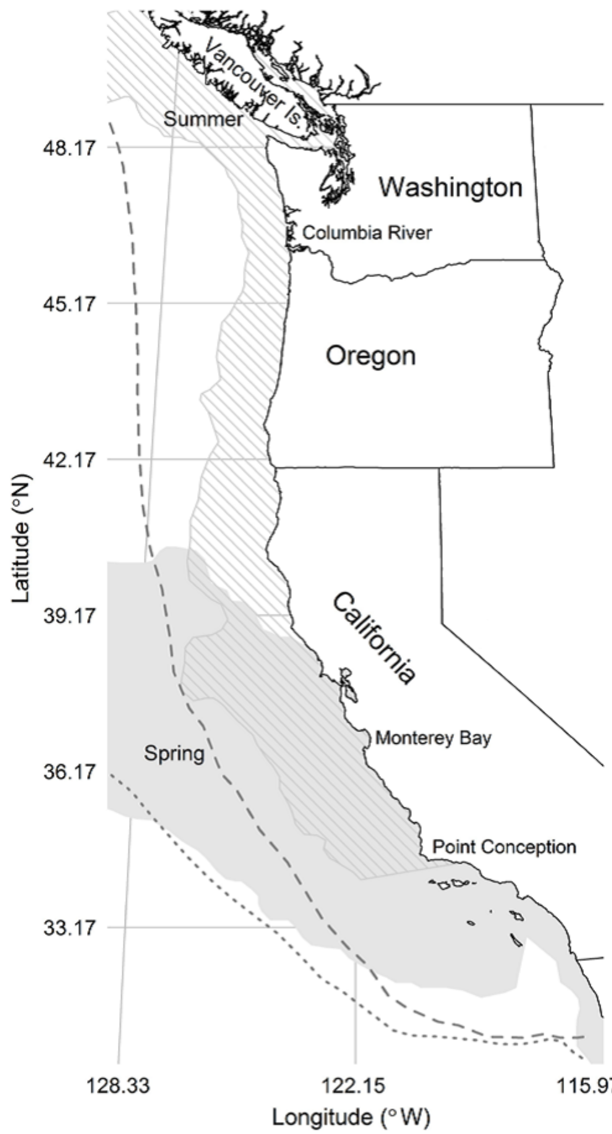


Figure II.1. Conceptual map showing the average spring and summer distributions of the northern subpopulation of Pacific sardine potential habitat during spring and summer along the west coasts of Mexico, the United States, and Canada (Zwolinski *et al.*, 2014).

During summer 2017, the west coasts of the United States and Vancouver Island, Canada, were surveyed using *Lasker* during the feeding seasons of sardine and anchovy. The survey departed from San Diego, transited to the northern end of Vancouver Island and sampled southward. Compulsory transects were nearly perpendicular to the coast with nominal separations of 20 nmi in most areas and with nominal separations of 10 nmi in areas where CPS were observed acoustically, in trawl catches, or both (**Figure II.2**).

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). Transect positions, lengths, and spaces were adjusted according to the expected distributions of sardine and anchovy at the time of the survey.

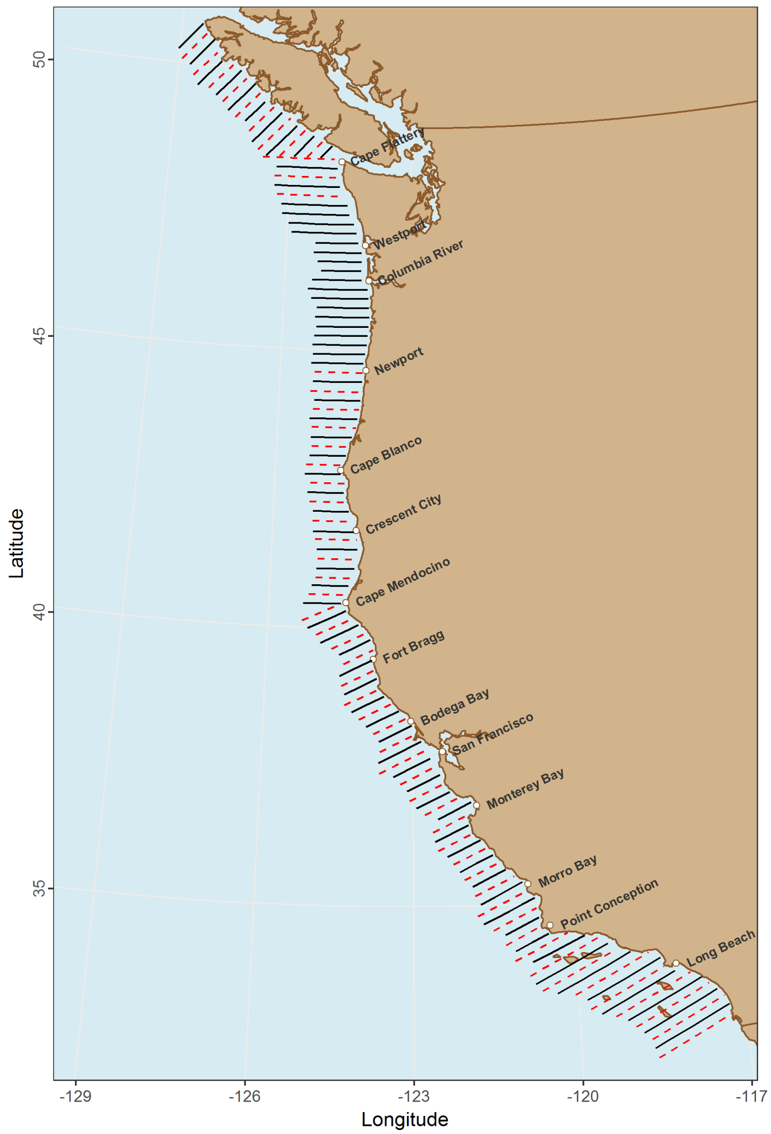


Figure II.2. Planned compulsory (solid black lines) and adaptive (dashed red lines) transect lines.

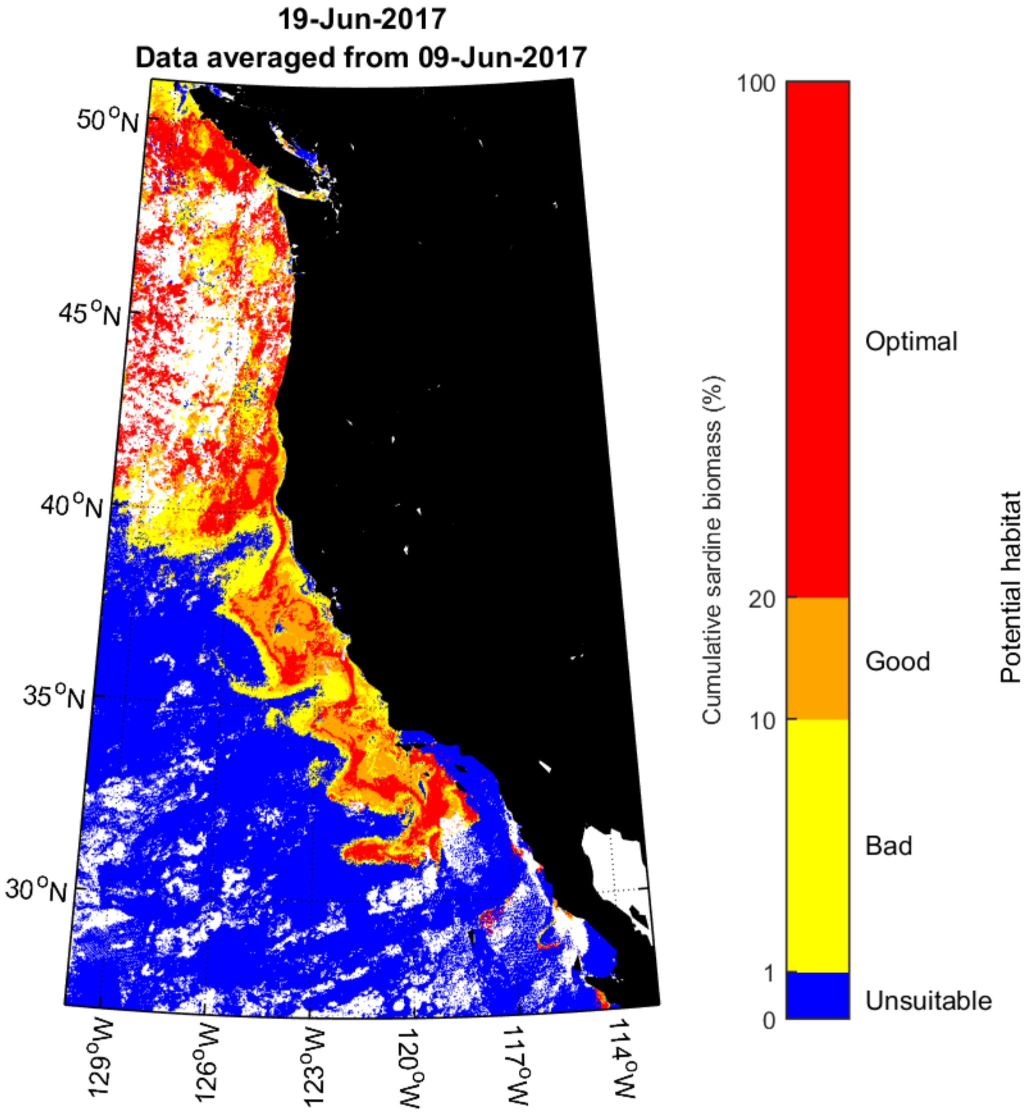


Figure II.3. Distribution of potential habitat for the northern stock of Pacific sardine on 19 June 2017 at the beginning of the survey.

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 (transducers ~5-m depth) during calibration, and extended to the intermediate position (transducers ~7-m depth) during the survey. Exceptions were made during shallow water operations, when the keel was retracted; or during times of heavy weather, when the keel was extended (transducers ~9-m depth) to provide extra stability and reduce the effect of weather-generated noise (**Appendix B**).

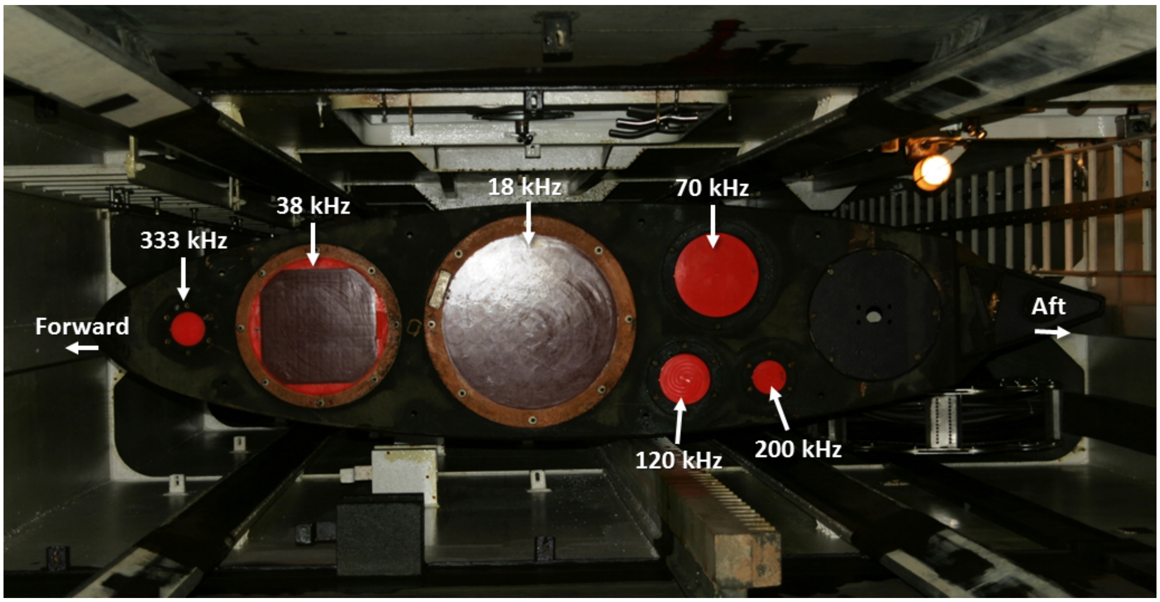


Figure II.4. Transducer locations on the bottom of the centerboard aboard *Lasker*.

II.2.2 Calibration

Prior to calibration, the integrity of each transducer 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, S), susceptance (B, S), and admittance circles (G vs. B) were plotted for each quadrant and for the quadrants in parallel (**Appendix A**).

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 **Table III.1**.

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. 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^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 350-m range, and stored in Simrad .raw format (50-MB maximum file size; each filename begins with "1706RL_EK60" and ends with the logging commencement date and time) using the GPT-control software (Simrad ER60 V2.4.3). Changes to the nominal transducer depth (~7 m) are indicated in **Appendix B**.

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 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 (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 V8.0.76.30859, Echoview Software Pty Ltd.) and the following procedure:

1. For each transect, the associated data files (.raw format) were loaded into an Echoview (.ev) file. Data were referenced to the transducer faces by setting transducer depths 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 350-m depth.
3. For each frequency:
   - "Noise-reduced" echograms (**Figure II.5a**) were generated by subtracting in the linear domain simulated background noise from the raw S_v
   - The noise-reduced echograms were smoothed by computing the median value in non-overlapping 11-sample by 3-ping cells.
   - 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 was created to ascribe regions as CPS where S_v-differences were within the expected ranges for CPS (**Table II.1.**).
   - Data collected when the ship approached or departed a sampling station, typically associated with a ship-speed less than 4 kn, were automatically marked as "bad data."
   - The provisional CPS regions 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_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.5b**).
   - 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.
   - 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, which was estimated using temperature profiles from CTD casts.
- 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.

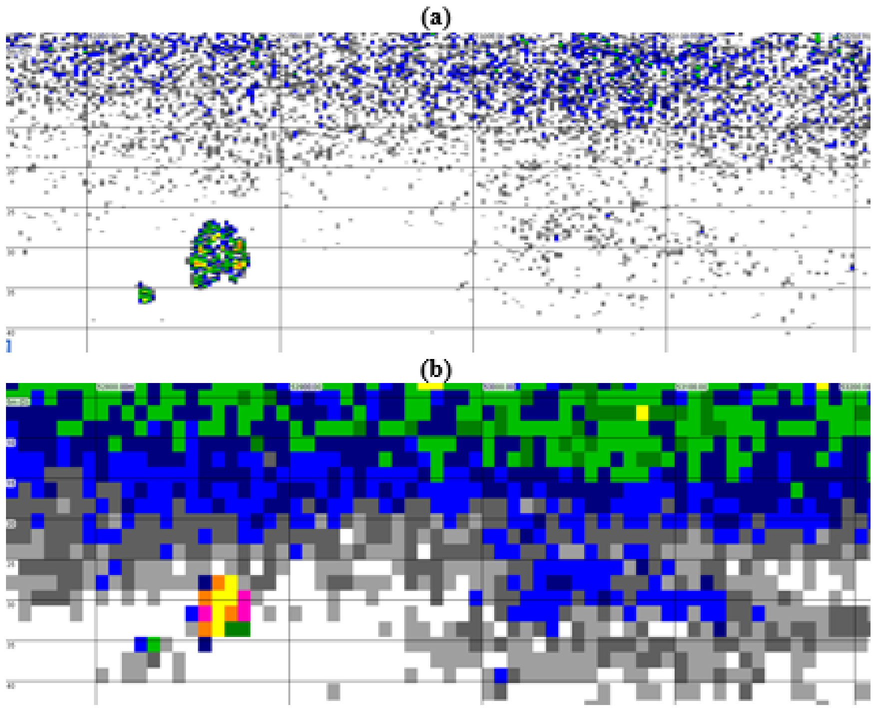


Figure II.5 Synchronized echograms of 38-kHz S_v after a) noise-subtraction and b) 38-kHz S_v thresholding at -60 dB (final, CPS-only).

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

$S_{v70kHz} - S_{v38kHz}$	$S_{v120kHz} - S_{v38kHz}$	$S_{v200kHz} - S_{v38kHz}$
-13.85, 9.89	-13.5, 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 length distributions of acoustic targets was performed at night.

The net, a Nordic 264 rope trawl (NET Systems; Bainbridge Island, WA), has a rectangular opening in the fishing portion of the net with an area of approximately 300 m^2 (~15-m tall x 20-m wide), variable-sized 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 (Dotson *et al.*, 2010). 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 were 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. In addition, otoliths were removed, sex and maturity recorded, and fin clips preserved in ethanol from up to 50 of the randomly selected individuals of each species. 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. CPS-catch data were summarized by Bev Macewicz.

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. CPS-egg data were summarized by Ed Weber. CalCOFI Bongo Oblique (CalBOBL, or bongo) nets (71-cm diameter; 505-μm mesh) were used to sample ichthyoplankton and krill at one station each day soon after sunset. 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°. Bongo samples were stored in 5% formalin. 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 and larvae from a depth of 70 m to the sea surface at a rate of 70 m min^{-1} at the same locations where bongo nets were deployed. These pairovet samples were preserved in 95% ethanol for future genetic analysis. Pairovet samples were also deployed at locations where CPS egg densities from CUFES 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 signal attenuation of the sound pulse between the transducer and scatters (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.

III. Results

III.1. EK60 echosounder calibration

The EK60s were calibrated on 14 June 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} = 20.9 °C) and salinity (s_{w} = 32.9 psu) were input to the GPT-control software, which derived estimates of sound speed (c_{w} = 1521.6 m s^{-1}) and absorption coefficients (see **Table III.1**). Varying with tide, the seabed was 7 to 8 m beneath the transducers. The calibration sphere was positioned 4 to 7 m below the transducers.

Figure III.1. Map of the calibration location (yellow diamond) near 10th Avenue Marine Terminal, San Diego Bay. The red box in the inset indicates the location and extent of the main map.

GPT information, configuration settings, and beam model results following calibration are presented in **Table III.1**. Measurements of beam-uncompensated sphere target strength (TS_{u}, dB re 1 m^2) are plotted in **Figure III.2** and relative beam-compensated sphere target strength (TS_{rel}, dB re 1 m^2) are plotted in **Figure III.3**. A time-series of calibration results for *Lasker*, including on-axis gain (G_0), S_{a} Correction (S_{a}corr), beamwidths (α_{-3dB} and β_{-3dB}), offset angles (α_0 and β_0), and RMS, are plotted in **Figure III.4**.

Table III.1 Simrad EK60 general purpose transceiver (GPT) information, pre-calibration settings, and beam model results following calibration (in **bold**). Prior to the survey, on-axis gain (G_0), beam angles and angle offsets, and S_a Correction ($S_\mathrm{a}$corr) values from calibration results were entered into the GPT-control software (Simrad ER60).

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	31206	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	22.74	24.99	27.07	26.64	27.46	25.63
S_a Correction ($S_\mathrm{a}$corr)	dB re 1	-0.66	-0.72	-0.41	-0.43	0.21	-0.26
Bandwidth (W_f)	Hz	1570	2430	2860	3030	3090	3110
Sample Interval	m	0.195	0.195	0.195	0.195	0.195	0.195
Eq. Two-way Beam Angle (Ψ)	dB re 1 sr	-17.1	-20.4	-20.2	-20.1	-20.1	-19.6
Absorption Coefficient (α_f)	dB km^{-1}	1.8	7.1	20.6	43.9	75.3	104.1
Angle Sensitivity Along. (Λ_α)	Elec.°/Geom.°	13.9	21.9	23	23	23	23
Angle Sensitivity Athw. (Λ_β)	Elec.°/Geom.°	13.9	21.9	23	23	23	23
3-dB Beamwidth Along. ($\alpha_{-3\mathrm{dB}}$)	deg	10.62	7.03	6.42	6.44	6.72	6.45
3-dB Beamwidth Athw. ($\beta_{-3\mathrm{dB}}$)	deg	10.74	7.03	6.47	6.48	6.96	6.65
Angle Offset Along. (α_0)	deg	-0.08	0.06	-0.01	-0.03	-0.03	-0.05
Angle Offset Athw. (β_0)	deg	-0.23	-0.03	-0.03	0	0.16	-0.05
Theoretical TS (TS_theory)	dB re 1 m^2	-42.44	-42.38	-41.63	-39.77	-38.81	-36.68
Ambient Noise	dB re 1 W	-128	-145	-154	-160	-161	-137
On-axis Gain (G_0)	**dB re 1**	**21.31**	**24.95**	**25.24**	**26.65**	**27.24**	**24.83**
S_a Correction ($S_\mathrm{a}$corr)	**dB re 1**	**-0.84**	**-0.65**	**-0.25**	**-0.24**	**-0.15**	**-0.15**
RMS	**dB**	**0.39**	**0.26**	**0.38**	**0.31**	**0.48**	**0.64**
3-dB Beamwidth Along. ($\alpha_{-3\mathrm{dB}}$)	**deg**	**12.15**	**6.79**	**6.33**	**6.4**	**6.4**	**6.35**
3-dB Beamwidth Athw. ($\beta_{-3\mathrm{dB}}$)	**deg**	**11.95**	**6.93**	**5.53**	**6.49**	**6.36**	**6.84**
Angle Offset Along. (α_0)	**deg**	**0**	**0.05**	**0.04**	**-0.03**	**-0.05**	**-0.03**
Angle Offset Athw. (β_0)	**deg**	**-0.24**	**-0.02**	**0.32**	**0.04**	**0.12**	**0**

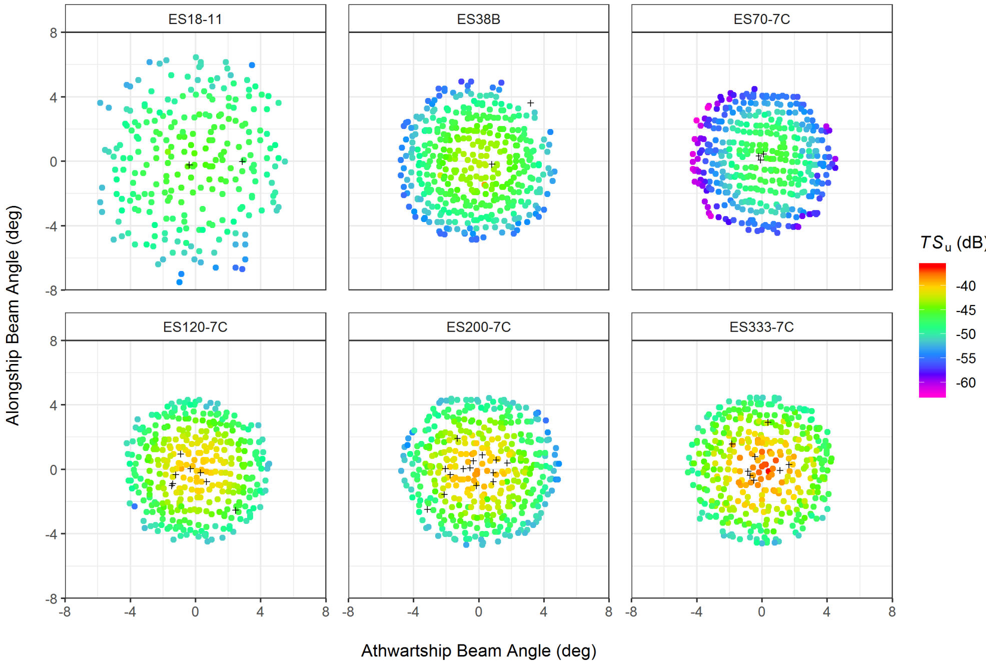


Figure III.2. Beam-uncompensated sphere target strength (TS_u, dB re 1 m^2) measurements of a 38.1-mm diameter sphere made from tungsten carbide (WC) with 6% cobalt binder material, at multiple EK60 frequencies (18, 38, 70, 120, 200, and 333 kHz). Crosses indicate measurements marked as outliers after viewing the beam model results.

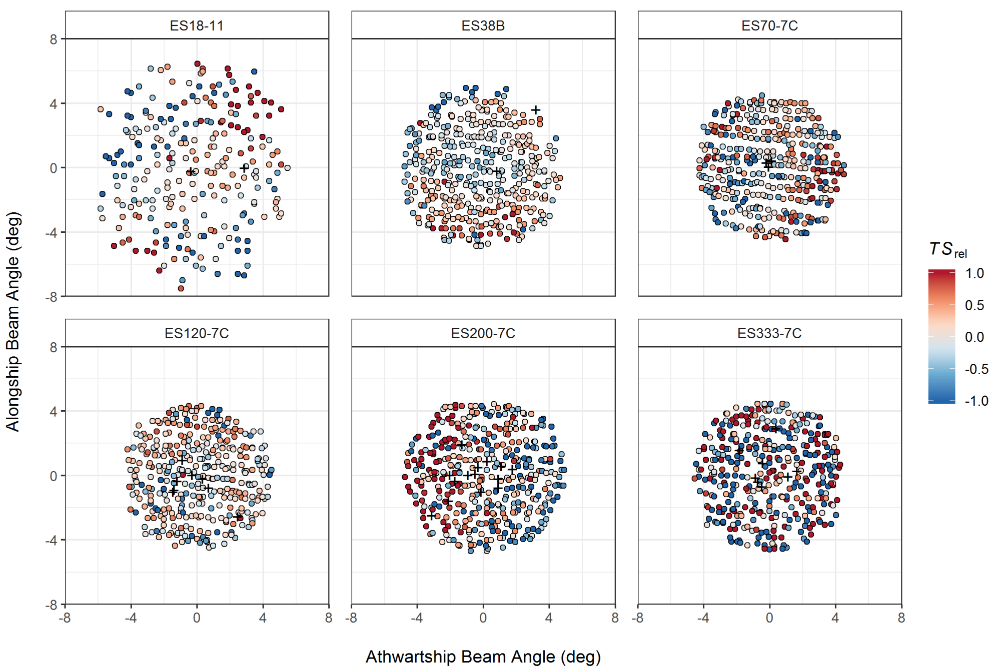


Figure III.3. Relative beam-compensated sphere target strength (TS_{rel}, dB re 1 m^2) measurements of a 38.1-mm diameter sphere made from tungsten carbide (WC) with 6% cobalt binder material, at multiple EK60 frequencies (18, 38, 70, 120, 200, and 333 kHz). TS_{rel} is calculated as the difference between the beam-compensated target strength (TS_c) and the theoretical target strength (TS_{theory}, see **Table III.1**). Crosses indicate measurements marked as outliers after viewing the beam model results.

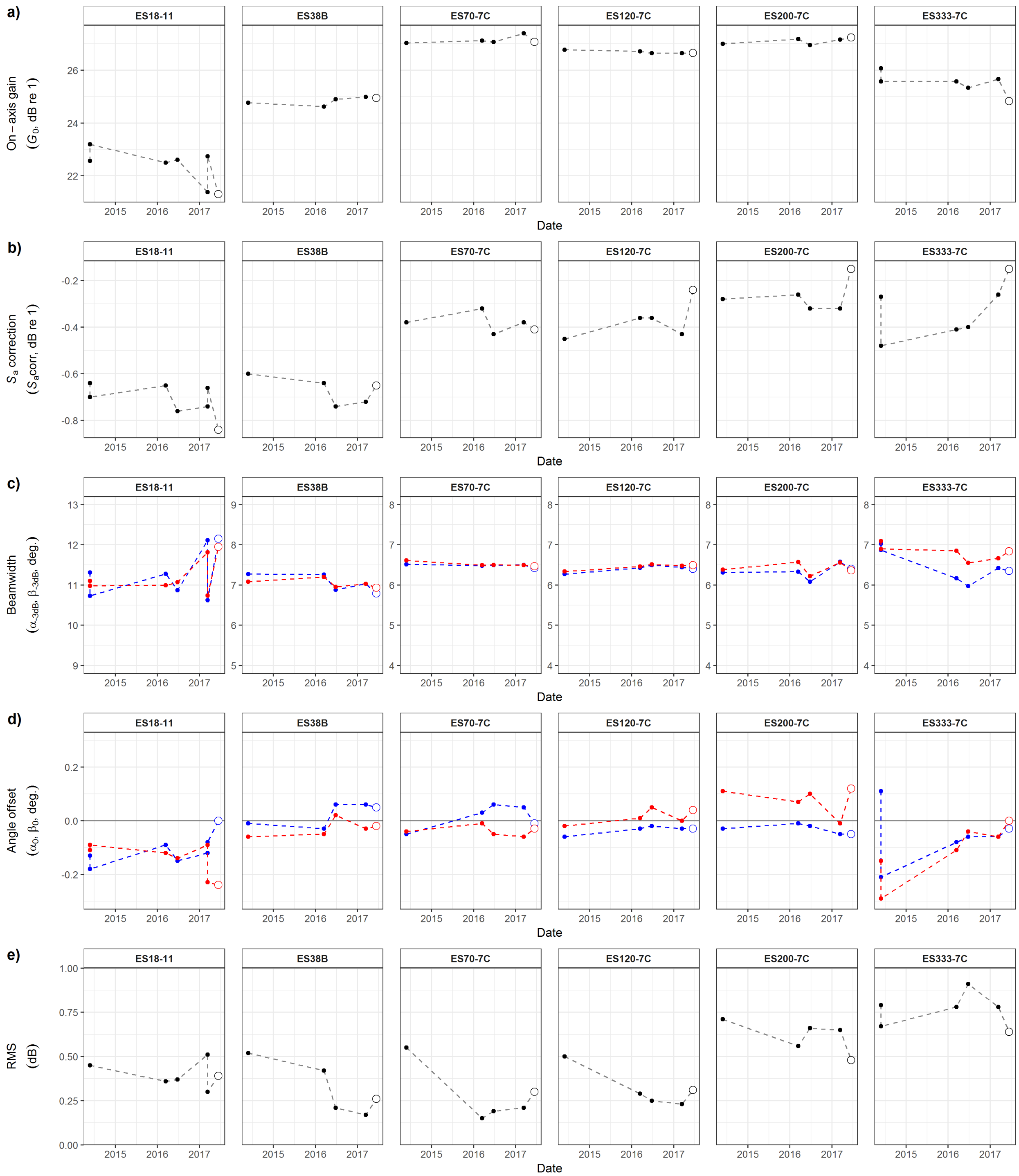


Figure III.4. Time series of beam model results of a) on-axis gain (G_0, dB); b) S_a correction ($S_\mathrm{a}$corr, dB re 1); c) alongship ($\alpha_{-3\mathrm{dB}}$, blue) and athwartship ($\beta_{-3\mathrm{dB}}$, red) beamwidths (deg); d) alongship (α_0, blue) and athwartship (β_0, red) offset angles (deg.); and e) RMS (dB) for each EK60 transducer frequency aboard *Lasker*. Unfilled circles indicate results from the current survey.

III.2. Data collection

III.2.1. Acoustic and trawl sampling

The survey spanned an area from approximately Cape Scott, British Columbia (northern end of Vancouver Island) to Point Conception (**Figure III.5**), with 105 east-west transects totaling 3540 nmi, and 83 Nordic trawls.

Leg I

Lasker departed from 10th Avenue Marine Terminal in San Diego, CA on 19 June 2017 at ~2100 (all times GMT), and arrived at the first transect (Transect 125) at the north end of Vancouver Island, British Columbia at ~1630 on 25 June to begin survey operations. On transect 125, the UCTD probe was lost when the deployment line parted. Consequently, stationary CTDs were conducted with 15 nmi-spacing between each cast to continue collecting temperature, salinity, and sound speed profiles for acoustic data processing. On 26 June, the CTD winch malfunctioned, which prohibited casts until the ship was able to embark a technician from Rapp Hydema on the morning of 29 June near Neah Bay, WA for repairs. The winch was successfully repaired and CTD casts resumed on transect 104 at ~0100 on 29 June. The experimental net with multiple codends was lost at sea during the first trawl on 28 June. Trawling resumed with the standard Nordic rope trawl at 1655 on 28 June. On 1 July, a personnel transfer was conducted near Gray's Harbor in Westport, WA. Survey operations ceased after completing transect 083 near Newport, OR, and the ship transited to port. *Lasker* arrived at the Exploratorium (Pier 15/17) in San Francisco, CA on 13 July at ~1730.

During Leg 1, *Lasker* and *Lisa Marie* conducted coordinated sampling between Westport, WA and Newport, OR to quantify nearshore CPS. Aboard *Lisa Marie*, SWFSC's split-beam echosounder (Simrad EK60 GPT) was connected to the vessel's 38 kHz transducer (Simrad ES38-B), which was calibrated while on anchor near Westport (46.9223, -124.1127) on 22 June. Analog video output from *Lisa Marie*'s Furuno sonar was converted to digital using a conversion box (AV.IO HD) and recorded using VLC Media Player. Transmit pulses from the echosounder and sonar were not synchronized. From 1 to 9 July, *Lisa Marie* conducted echosounder-sonar transects between the eastern ends of *Lasker*'s acoustic transects and shore. *Lisa Marie* conducted parallel transects with *Lasker* on transects 4, 12, 16, and 26. Between 3 and 5 July, the GPS input to *Lisa Marie*'s ER60 failed; the location of the vessel during that time was later retrieved from the Automatic Information System (AIS) database or, when unavailable from AIS, by manually transcribing positions displayed on the sonar video every 2 min. When fish schools were observed by a spotter pilot, hook-and-line sampling was conducted from *Lisa Marie* to determine whether sardine were present; however, only anchovy were caught and therefore the purse seine was not deployed. All hook-and-line samples of anchovy were frozen and later processed by the Washington Department of Fish and Wildlife (WA-DFW). At sunrise on 6 July, industry fishermen aboard *Lasker* were transferred to *Lisa Marie* and put ashore at the Point Adams Cannery, after which *Lisa Marie* resumed acoustic transects. On 8 July, *Lisa Marie* completed acoustic sampling and returned to Westport on 9 July at ~1700.

Leg II

Lasker departed from the Exploratorium (Pier 15/17) in San Francisco, CA on 18 July at ~1700, and arrived at the first transect (transect 82) near Waldport, OR on 20 July to resume survey operations. On 30 July, a personnel transfer was conducted outside Bodega Harbor near Bodega Bay, CA. Weather was good during Leg II and seas were calm until the final night of operations (9 Aug). Although only one trawl was possible on the final night, the previous period of calm seas permitted the planned sampling. Survey operations ceased after completing transect 24 near Morro Bay, and the ship transited back to port to complete the survey. *Lasker* arrived at 10th Avenue Marine Terminal in San Diego, CA on 11 August, and scientific gear was unloaded.

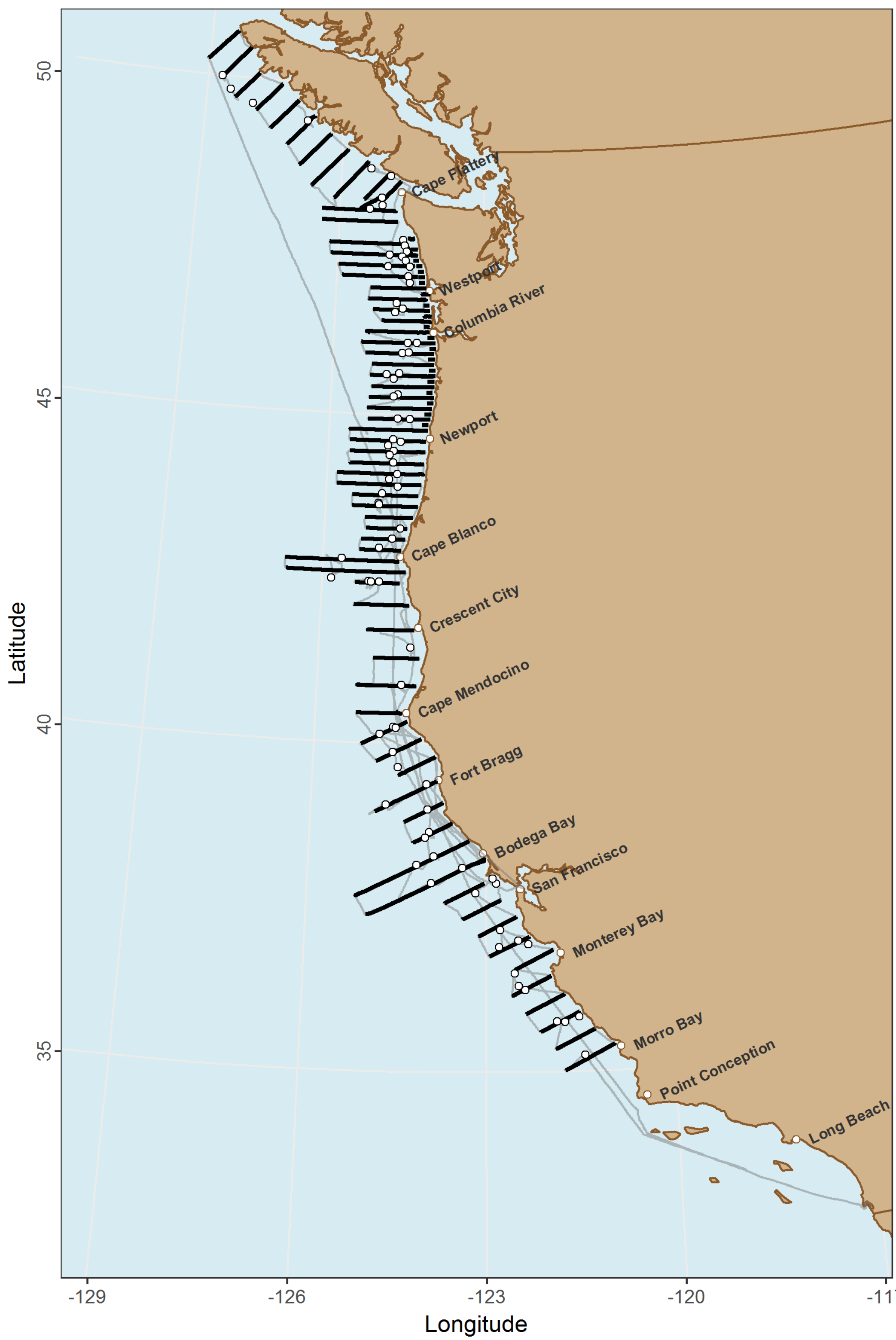


Figure III.5. Cruise track of *Lasker* (gray line), east-west acoustic transects (black lines), and locations of surface trawls (white points) superimposed on the vessel track (light gray lines).

III.2.2 Ichthyoplankton and oceanographic sampling

A total of 120 CTD casts, 25 bongo tows, and 33 Pairovet tows were conducted throughout the survey. In addition, 4 UCTD casts were conducted and 1226 CUFES samples were collected underway. The locations of CTD and UCTD stations are shown in Figure **III.6** and **Appendix C**.

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.3. Distribution of CPS

The majority of acoustic backscatter ascribed to CPS was observed along the coast of Vancouver Island; between the Straight of Juan de Fuca and Crescent City, CA; around Cape Mendocino, and between Monterey and Morro Bay, CA (**Figure III.7a**). To a lesser extent, CPS backscatter was observed along the central CA coast near San Francisco (**Figure III.7a**) and around the northern Channel Islands in the SCB. CPS backscatter was coincident with concentrations of anchovy and sardine eggs in the CUFES. Some acoustic backscatter ascribed to CPS was also observed by *Lisa Marie* nearshore between La Push, WA (north of Westport) and Newport, OR (**Figure III.8**).

Anchovy eggs were most abundant in the CUFES samples offshore near Westport, WA and south of the Columbia River plume between Washington and Oregon (**Figure III.7b**). Lower densities of jack mackerel eggs were observed from Westport, WA to Cape Blanco, off Bodega Bay, and to a lesser extent between San Francisco and Monterey (**Figure III.7b**). Sardine eggs observed in the CUFES were most abundant offshore near the Columbia River to Cape Blanco; some sardine eggs were present in CUFES between Crescent City and Bodega Bay (**Figure III.7b**). There was little overlap in the distribution of anchovy and sardine eggs in CUFES.

Jack mackerel comprised the greatest proportion of catch in trawl samples between the Columbia River and Monterey Bay (**Figure III.7c**). Pacific herring comprised the greatest proportion of catch in trawl samples inshore along the coast of Vancouver Island, between Cape Flattery and Westport, and around Newport (**Figure III.7c**). Anchovy were predominantly found in trawls conducted between Monterey and Morro Bay, with some present north of Westport and near Bodega Bay (**Figure III.7c**). The few trawl samples that contained sardine were collected offshore south of Newport and in one trawl offshore near Monterey. Overall, the 83 trawls captured a combined 6245 kg of CPS (404 kg sardine, 2103 kg anchovy, 2027 kg jack mackerel, 1023 kg Pacific mackerel, and 687 kg Pacific herring; **Appendix D**).

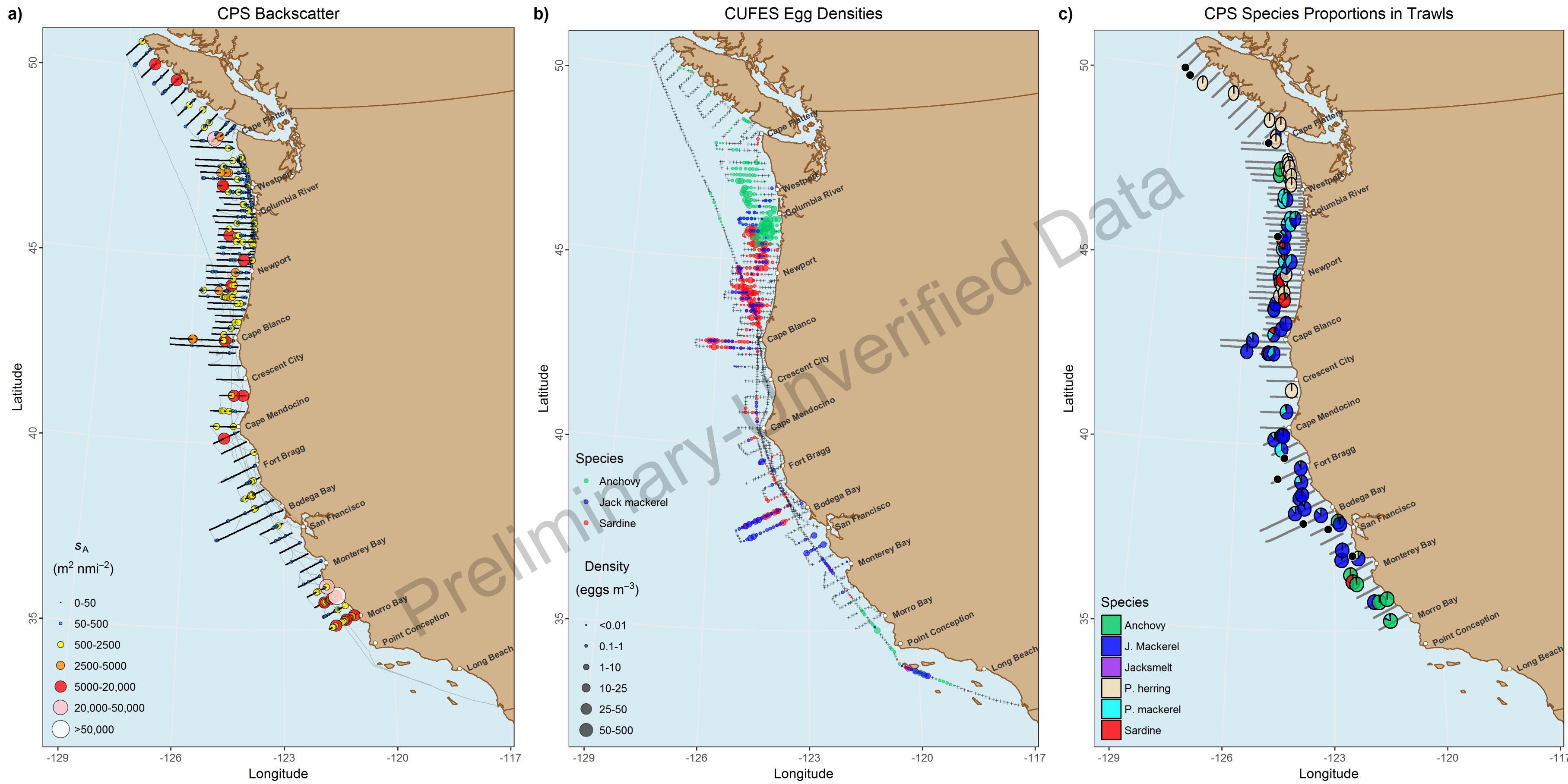


Figure III.7. Survey transects performed aboard *Lasker* overlaid with (a) the distribution of 38-kHz integrated backscattering coefficients (s_A, m^2 nmi^{-2}; averaged over 2000-m distance intervals and from 350 to 5-m deep) ascribed to CPS; (b) anchovy-, jack mackerel-, and sardine-egg densities (eggs m^{-3}) from the CUFES; and (c) proportions of CPS species in trawl clusters (black points indicate trawls with no CPS).

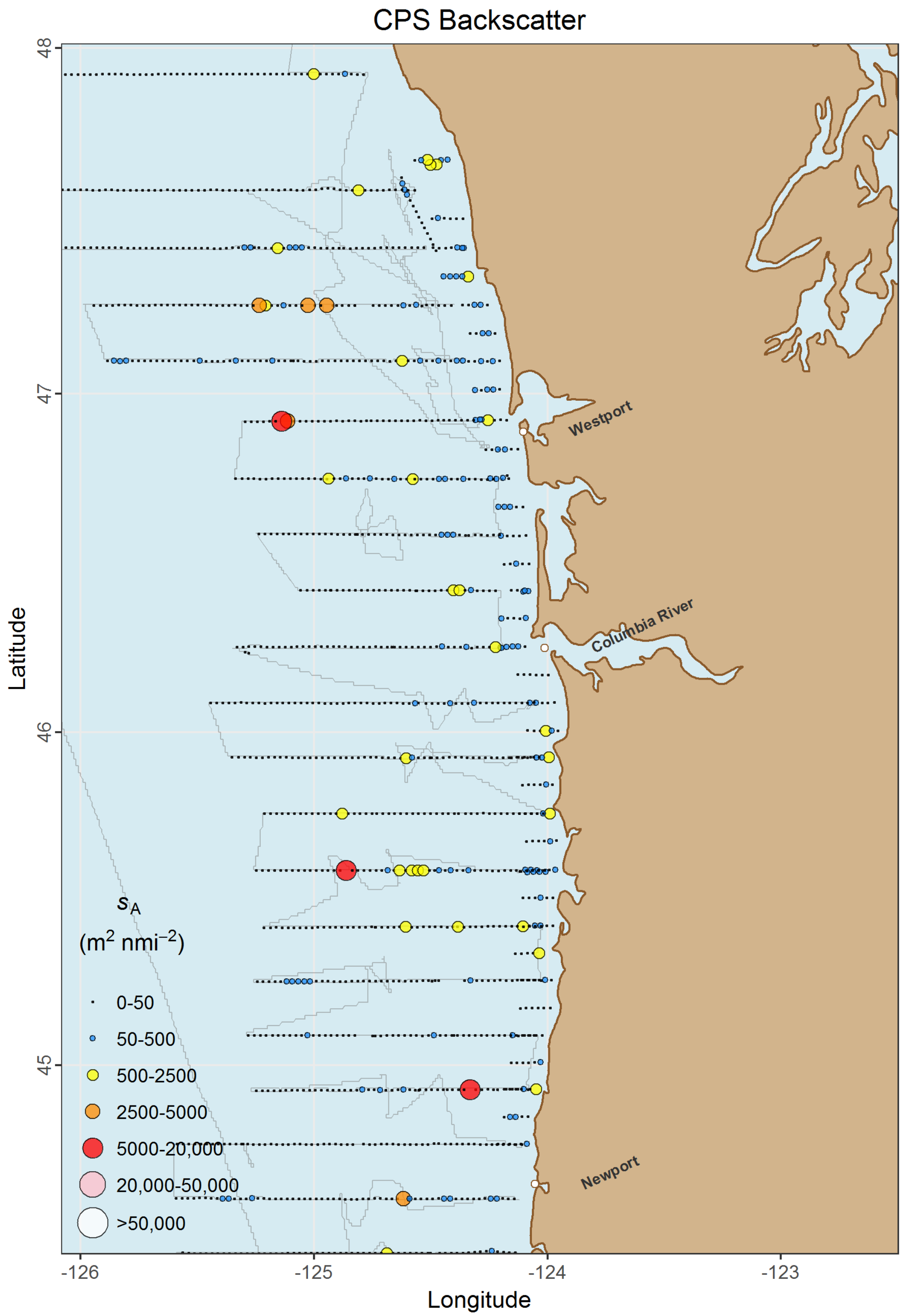


Figure III.8. A zoomed view of paired survey transects performed aboard FV *Lisa Marie* and FSV *Lasker* showing the distribution of 38-kHz integrated backscattering coefficients (s_A, m^2 nmi^{-2}; averaged over 2000-m distance intervals and from 350 to 5-m deep) ascribed to CPS.

IV. Disposition of Data

Archived on the SWFSC data server are approximately 212 GB of raw EK60 data, 16.4 TB of raw EK80 data, 1 TB of raw ME70 data, 411 GB of raw MS70 data, and 1.29 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).

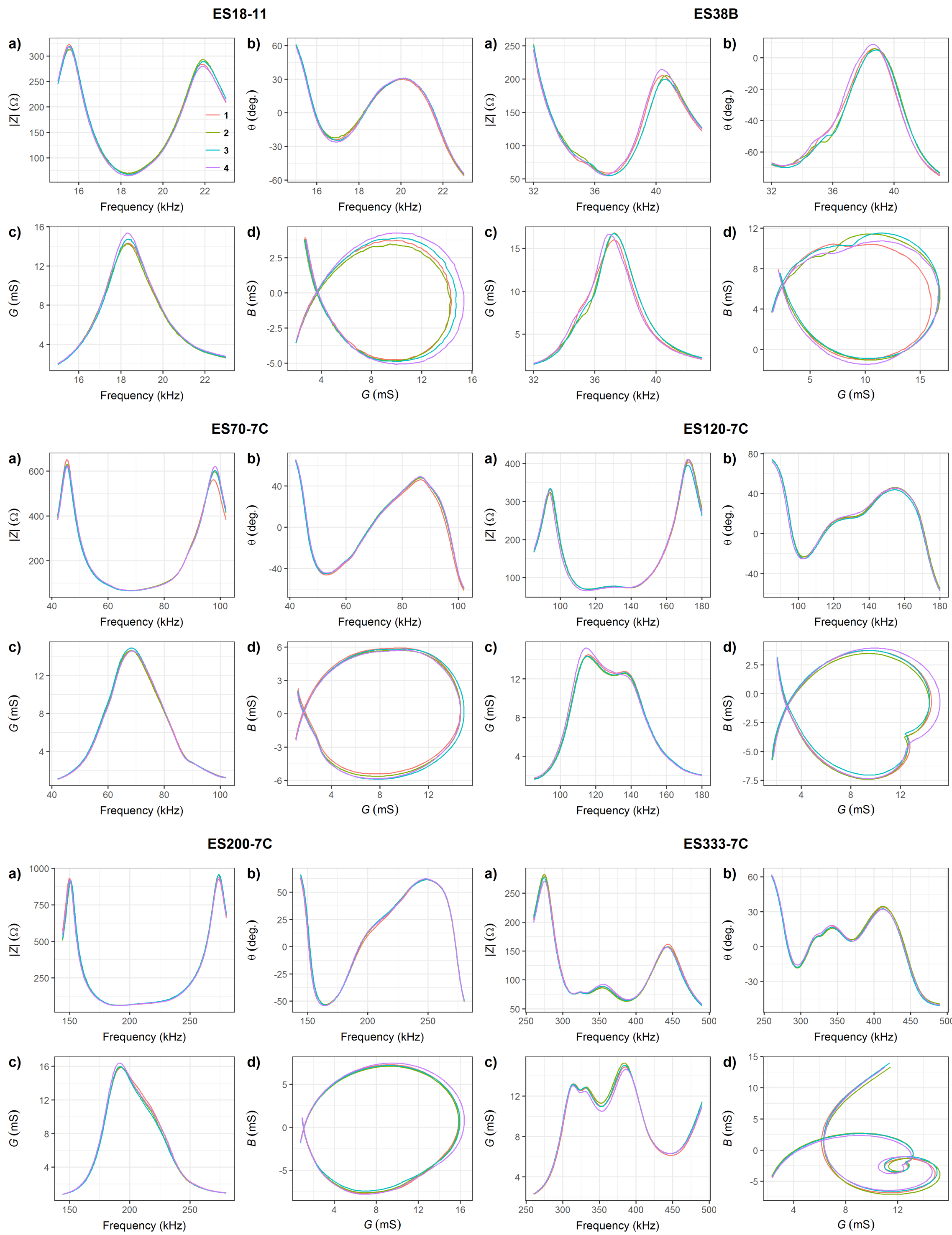
V. Acknowledgements

We thank the crew members of FSV *Lasker* and FV *Lisa Marie*, as well as the scientists and technicians that participated in the sampling operations at sea. Critical reviews by Andrew Thompson and Gerard Dinardo improved this report.

VI. Appendices

Appendix A. Echosounder transducer impedance measurements

The magnitude of impedance ($|Z|$, Ω; panel a), phase (θ, $^\circ$; panel b), and conductance (G, S; panel c) versus frequency, and susceptance (B, S) versus G (admittance circle; panel d), for each quadrant (various colors).



Appendix B. Centerboard positions

Transducer depths, associate with the centerboard position (retracted ~5-m, intermediate ~7-m, extended ~9-m) during the survey.

Date	Button	Latitude	Longitude
06/19/2017 22:21	Intermediate (7 m)	32.63067	-117.2293
07/18/2017 18:09	Intermediate (7 m)	37.79583	-122.7247
07/24/2017 19:38	Extended (9 m)	42.93567	-125.2537
07/27/2017 21:59	Intermediate (7 m)	41.79717	-124.4583

Appendix C. CTD and UCTD sample summary

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

Date	Event	Latitude	Longitude
06/24/2017 22:04	UCTD Cast	47.38967	-126.9657
06/25/2017 01:05	UCTD Cast	47.76567	-127.2122
06/25/2017 16:57	UCTD Cast	50.27850	-128.9832
06/25/2017 18:50	CTD Cast	50.51167	-128.6803
06/25/2017 20:27	CTD Cast	50.62767	-128.5173
06/26/2017 00:38	CTD Cast	50.25000	-128.3752
06/29/2017 23:04	CTD Cast	48.09133	-124.9552
06/29/2017 23:07	CTD Cast	48.09067	-124.9547
06/30/2017 01:05	CTD Cast	48.09283	-125.3362
06/30/2017 15:34	CTD Cast	48.09117	-126.1277
06/30/2017 21:29	CTD Cast	47.92783	-125.5182
06/30/2017 23:25	CTD Cast	47.92733	-125.1425
06/30/2017 23:29	CTD Cast	47.92600	-125.1428
07/02/2017 01:20	CTD Cast	47.58767	-125.0632
07/02/2017 03:19	CTD Cast	47.59050	-124.6920
07/02/2017 23:51	CTD Cast	47.42300	-125.2622
07/02/2017 23:52	CTD Cast	47.42300	-125.2623
07/03/2017 01:44	CTD Cast	47.42233	-124.8923
07/03/2017 01:45	CTD Cast	47.42200	-124.8927
07/03/2017 13:47	CTD Cast	47.25783	-124.5360
07/03/2017 15:35	CTD Cast	47.25667	-124.9045
07/04/2017 01:26	CTD Cast	47.09350	-125.0892
07/04/2017 01:27	CTD Cast	47.09317	-125.0893
07/04/2017 05:55	CTD Cast	47.12750	-124.5702
07/04/2017 13:08	CTD Cast	46.92317	-124.4113
07/04/2017 14:58	CTD Cast	46.91850	-124.7810
07/04/2017 20:16	CTD Cast	46.75017	-124.9378
07/04/2017 22:10	CTD Cast	46.75050	-124.5723
07/05/2017 01:35	CTD Cast	46.58400	-124.3357
07/05/2017 01:37	CTD Cast	46.58317	-124.3363
07/05/2017 11:55	CTD Cast	46.59000	-124.7790
07/05/2017 16:12	CTD Cast	46.42217	-124.9253
07/05/2017 18:10	CTD Cast	46.42167	-124.5613
07/05/2017 21:43	CTD Cast	46.25450	-124.3145
07/05/2017 23:24	CTD Cast	46.25533	-124.6727
07/05/2017 23:25	CTD Cast	46.25533	-124.6727
07/06/2017 14:08	CTD Cast	46.08883	-124.1778
07/06/2017 15:50	CTD Cast	46.08533	-124.5457
07/07/2017 00:21	CTD Cast	45.92617	-124.4997
07/07/2017 02:06	CTD Cast	45.92383	-124.1548
07/07/2017 02:21	UCTD Cast	45.92367	-124.1560
07/07/2017 14:12	CTD Cast	45.76000	-124.3782
07/07/2017 15:59	CTD Cast	45.75850	-124.7360
07/07/2017 22:23	CTD Cast	45.58917	-124.4850

(continued)

Date	Event	Latitude	Longitude
07/08/2017 00:28	CTD Cast	45.58717	-124.1178
07/08/2017 15:25	CTD Cast	45.41700	-124.7333
07/08/2017 17:30	CTD Cast	45.41850	-124.3822
07/08/2017 20:52	CTD Cast	45.25867	-124.1417
07/08/2017 22:36	CTD Cast	45.25733	-124.4972
07/09/2017 15:06	CTD Cast	45.08767	-124.7482
07/09/2017 17:10	CTD Cast	45.08817	-124.4018
07/09/2017 20:35	CTD Cast	44.92783	-124.2048
07/09/2017 22:31	CTD Cast	44.92467	-124.5557
07/10/2017 14:11	CTD Cast	44.76233	-124.4535
07/10/2017 15:53	CTD Cast	44.75867	-124.8165
07/11/2017 02:17	CTD Cast	44.59333	-124.5938
07/20/2017 15:26	CTD Cast	44.42200	-124.4820
07/20/2017 17:13	CTD Cast	44.42833	-124.8342
07/21/2017 02:25	CTD Cast	44.24900	-124.6238
07/21/2017 13:58	CTD Cast	44.25067	-124.2733
07/21/2017 17:13	CTD Cast	44.09217	-124.5273
07/21/2017 19:20	CTD Cast	44.08850	-124.8730
07/22/2017 14:33	CTD Cast	43.92517	-124.6620
07/22/2017 16:29	CTD Cast	43.92500	-124.3178
07/22/2017 20:02	CTD Cast	43.76267	-124.5878
07/22/2017 21:59	CTD Cast	43.76183	-124.9285
07/23/2017 14:32	CTD Cast	43.59883	-124.7143
07/23/2017 16:36	CTD Cast	43.59833	-124.3718
07/24/2017 08:50	CTD Cast	43.25833	-124.5690
07/24/2017 14:46	CTD Cast	43.09433	-124.8195
07/24/2017 16:47	CTD Cast	43.09433	-125.1620
07/24/2017 21:07	CTD Cast	42.92967	-125.0088
07/24/2017 23:14	CTD Cast	42.92783	-124.6623
07/25/2017 03:26	CTD Cast	42.76250	-124.9090
07/25/2017 15:19	CTD Cast	42.76200	-125.2542
07/26/2017 16:58	CTD Cast	42.59467	-124.9090
07/26/2017 19:17	CTD Cast	42.59400	-124.5725
07/26/2017 23:08	CTD Cast	42.42333	-124.8438
07/27/2017 01:13	CTD Cast	42.42750	-125.1852
07/27/2017 17:01	CTD Cast	42.09483	-124.8243
07/27/2017 19:09	CTD Cast	42.09650	-124.4918
07/28/2017 00:55	CTD Cast	41.71583	-124.6392
07/28/2017 04:29	CTD Cast	41.71117	-124.9517
07/28/2017 14:08	CTD Cast	41.29117	-124.2922
07/28/2017 16:01	CTD Cast	41.29050	-124.6313
07/29/2017 00:02	CTD Cast	40.86983	-124.8820
07/29/2017 08:00	CTD Cast	40.86983	-124.5575
07/29/2017 14:02	CTD Cast	40.45133	-124.6108
07/29/2017 16:03	CTD Cast	40.45033	-124.9407
07/31/2017 14:51	CTD Cast	40.20767	-124.6675

(continued)

Date	Event	Latitude	Longitude
07/31/2017 17:07	CTD Cast	40.07417	-124.9485
07/31/2017 23:35	CTD Cast	39.89483	-124.5083
08/01/2017 01:31	CTD Cast	40.02033	-124.2265
08/01/2017 14:23	CTD Cast	39.54533	-124.4382
08/01/2017 16:29	CTD Cast	39.67267	-124.1577
08/01/2017 21:29	CTD Cast	39.39617	-123.9297
08/01/2017 23:31	CTD Cast	39.25233	-124.2283
08/02/2017 16:31	CTD Cast	38.97617	-124.0163
08/02/2017 18:38	CTD Cast	38.84283	-124.2980
08/02/2017 23:32	CTD Cast	38.61200	-123.9543
08/03/2017 01:23	CTD Cast	38.73650	-123.6882
08/03/2017 15:11	CTD Cast	38.27250	-123.8428
08/04/2017 15:00	CTD Cast	38.39683	-123.5643
08/04/2017 19:30	CTD Cast	38.19733	-123.1163
08/04/2017 21:13	CTD Cast	38.09050	-123.4043
08/05/2017 16:00	CTD Cast	37.74933	-123.3115
08/05/2017 17:54	CTD Cast	37.62367	-123.5855
08/05/2017 22:39	CTD Cast	37.46067	-123.1127
08/06/2017 00:38	CTD Cast	37.57233	-122.8540
08/06/2017 15:37	CTD Cast	37.24250	-122.7725
08/06/2017 17:39	CTD Cast	37.10883	-123.0432
08/06/2017 22:19	CTD Cast	36.89683	-122.6598
08/07/2017 00:27	CTD Cast	37.01550	-122.3895
08/07/2017 16:42	CTD Cast	36.73683	-122.1575
08/07/2017 18:39	CTD Cast	36.61350	-122.4243
08/07/2017 23:55	CTD Cast	36.28367	-122.3177
08/08/2017 01:50	CTD Cast	36.41533	-122.0388
08/08/2017 17:35	CTD Cast	36.05500	-121.9938
08/08/2017 19:44	CTD Cast	35.93350	-122.2562
08/09/2017 00:25	CTD Cast	35.74767	-121.8288
08/09/2017 15:17	CTD Cast	35.38600	-121.8042
08/09/2017 17:20	CTD Cast	35.51150	-121.5367
08/09/2017 21:52	CTD Cast	35.36683	-121.0307
08/09/2017 23:46	CTD Cast	35.23917	-121.2957

Appendix D. 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	Latitude	Longitude	Anchovy	Sardine	P. mackerel	J. mackerel	P. herring	Jacksmelt	All CPS
1	06/25/2017 21:32	49.993	-128.697							
2	06/26/2017 00:23	49.797	-128.495							
3	06/26/2017 21:39	49.613	-126.994					2.542		2.542
4	06/27/2017 01:00	49.408	-126.785					2.724		2.724
6	06/28/2017 21:16	48.624	-124.958					1.708		1.708
7	06/29/2017 00:47	48.728	-125.380					8.183		8.183
8	06/29/2017 21:26	48.291	-125.127				0.246	1.233		1.479
9	06/30/2017 00:30	48.173	-125.117					5.942		5.942
10	06/30/2017 03:00	48.110	-125.379							
11	06/30/2017 21:10	47.425	-124.938	0.080						0.080
12	07/01/2017 00:59	47.251	-124.960	0.428						0.428
13	07/01/2017 21:32	47.651	-124.666					0.198		0.198
14	07/02/2017 00:27	47.569	-124.636					0.836		0.836
15	07/02/2017 03:04	47.478	-124.584					2.385		2.385
16	07/02/2017 21:37	47.402	-124.678	0.024		4.371		17.418		21.812
17	07/03/2017 01:23	47.339	-124.606		0.051			18.971		19.022
18	07/03/2017 03:14	47.249	-124.518					2.844		2.844
19	07/03/2017 23:06	47.101	-124.542	0.027				0.541		0.568
20	07/04/2017 01:16	47.008	-124.509	0.050				7.102		7.151
21	07/04/2017 21:28	46.607	-124.639	1.373	0.343	40.002	43.485			85.203
22	07/05/2017 00:02	46.557	-124.785			6.441	1.327			7.768
23	07/05/2017 02:29	46.695	-124.765	0.324		0.464				0.788
24	07/05/2017 23:03	46.094	-124.526	1.164		21.335	0.282			22.781
25	07/06/2017 01:49	46.097	-124.344	5.362		14.442	40.982			60.786
26	07/06/2017 22:42	45.936	-124.631	10.725	5.613	10.812	36.419			63.569
27	07/07/2017 01:17	45.948	-124.496	8.953		360.591	190.110			559.654
28	07/07/2017 21:21	45.623	-124.672	0.352	2.040	21.913	124.052			148.357
29	07/07/2017 23:34	45.541	-124.778		0.804		1.110			1.914
30	07/08/2017 02:29	45.602	-124.927							
31	07/08/2017 21:44	45.302	-124.693		6.624	1.737	21.215			29.575

(continued)

Trawl	Date	Latitude	Longitude	Anchovy	Sardine	P. mackerel	J. mackerel	P. herring	Jacksmelt	All CPS
32	07/09/2017 00:07	45.275	-124.774			14.435	5.032			19.467
33	07/09/2017 21:21	44.936	-124.686		1.125	2.704	5.432			9.261
34	07/10/2017 00:56	44.932	-124.444		0.510	28.814	46.956			76.281
35	07/10/2017 23:03	44.586	-124.613	0.030	0.698	12.342	10.331	48.198		71.599
36	07/11/2017 01:20	44.617	-124.757		1.666	48.998	80.818			131.481
37	07/11/2017 03:25	44.526	-124.851			4.784	18.373			23.157
39	07/20/2017 21:23	44.441	-124.739		77.952	2.120	27.240	30.270		137.582
40	07/21/2017 00:34	44.381	-124.816		31.527	32.720	4.330	27.107		95.684
41	07/21/2017 02:35	44.264	-124.746		36.888	0.950	4.809	254.272		296.919
42	07/21/2017 21:33	44.013	-124.816			0.316	4.721	252.659		257.696
43	07/21/2017 23:46	44.094	-124.666					1.609		1.609
44	07/22/2017 02:18	43.896	-124.645		173.493	16.903	5.346	0.380		196.122
45	07/22/2017 21:17	43.648	-124.999			0.551				0.551
46	07/22/2017 23:36	43.790	-124.939		2.635	3.786	41.882			48.303
47	07/23/2017 01:53	43.626	-124.986				0.569			0.569
48	07/24/2017 02:09	43.264	-124.582				22.403			22.403
49	07/24/2017 21:57	42.962	-124.965		21.995	31.398	83.258			136.651
50	07/25/2017 02:26	43.108	-124.728				9.427			9.427
51	07/25/2017 21:45	42.789	-125.652			1.094	6.964			8.058
52	07/26/2017 02:25	42.483	-125.827			3.557	31.560			35.117
53	07/26/2017 21:03	42.454	-125.138		0.196	0.263				0.459
54	07/26/2017 23:50	42.447	-125.093				3.054			3.054
55	07/27/2017 02:49	42.446	-124.946			4.470	8.281			12.751
57	07/28/2017 02:01	41.459	-124.348					0.100		0.100
58	07/28/2017 21:11	40.888	-124.490		28.104	148.888	353.436			530.428
59	07/31/2017 00:25	40.246	-124.617			0.378	2.818			3.196
60	07/31/2017 02:25	40.231	-124.570				3.601			3.601
61	07/31/2017 22:19	40.131	-124.852			3.956	32.146			36.102
62	08/01/2017 01:00	39.863	-124.620		0.302	116.047	71.429			187.778
63	08/01/2017 03:23	39.634	-124.525							
64	08/01/2017 22:14	39.062	-124.713							
65	08/02/2017 03:43	39.377	-124.017		0.634	13.379	159.041			173.054
66	08/02/2017 21:23	38.996	-123.997		8.371	27.411	101.718			137.500

(continued)

Trawl	Date	Latitude	Longitude	Anchovy	Sardine	P. mackerel	J. mackerel	P. herring	Jacksmelt	All CPS
67	08/03/2017 00:48	38.655	-123.966		0.244	10.903	288.425			299.572
68	08/03/2017 03:34	38.565	-124.035		1.925	4.253	78.767			84.945
69	08/03/2017 23:14	38.151	-124.166			3.095	25.897			28.992
70	08/04/2017 02:20	38.286	-123.886		0.156	1.005	17.356			18.517
71	08/04/2017 22:36	37.874	-123.915							
72	08/05/2017 02:40	38.113	-123.397			0.740	4.874			5.614
73	08/05/2017 20:27	37.874	-122.833	0.092		0.310	7.586			7.989
74	08/05/2017 22:23	37.946	-122.892	19.717						19.717
75	08/06/2017 01:34	37.727	-123.176							
76	08/06/2017 20:26	37.169	-122.770				0.004			0.004
77	08/06/2017 23:20	36.902	-122.789	0.001			0.029			0.030
78	08/07/2017 02:31	37.003	-122.470							
79	08/07/2017 04:33	36.944	-122.307	0.002			0.015	0.005		0.022
80	08/07/2017 22:06	36.500	-122.538	0.070						0.070
81	08/08/2017 00:39	36.312	-122.470	0.020	0.020					0.040
82	08/08/2017 03:07	36.249	-122.361	0.972	0.015		0.008			0.995
83	08/08/2017 20:12	35.834	-121.501	2051.236						2051.236
84	08/08/2017 23:54	35.754	-121.728	1.349						1.349
85	08/09/2017 02:11	35.763	-121.865	0.025			0.031			0.056
86	08/09/2017 21:30	35.243	-121.424	0.977	0.025	0.180	0.012			1.194

References

Checkley, D. M., Ortner, P. B., Settle, L. R., and Cummings, S. R. 1997. A continuous, underway fish egg sampler. Fisheries Oceanography, 6: 58–73.

Cutter, G. R., and Demer, D. A. 2008. California current ecosystem survey 2006. Acoustic cruise reports for NOAA FSV *Oscar Dyson* and NOAA FRV *David Starr Jordan*. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-SWFSC-415: 98 pp.

Demer, D. A. 2004. An estimate of error for the CCAMLR 2000 survey estimate of krill biomass. Deep-Sea Research Part II-Topical Studies in Oceanography, 51: 1237–1251.

Demer, D. A., and Hewitt, R. P. 1995. Bias in acoustic biomass estimates of *Euphausia superba* due to diel vertical migration. Deep-Sea Research Part I-Oceanographic Research Papers, 42: 455–475.

Demer, D. A., Zwolinski, J. P., Byers, K. A., Cutter, G. R., Renfree, J. S., Sessions, T. S., and Macewicz, B. J. 2012. Prediction and confirmation of seasonal migration of Pacific sardine (*Sardinops sagax*) in the California Current Ecosystem. Fishery Bulletin, 110: 52–70.

Demer, D., Berger, L., Bernasconi, M., Bethke, E., Boswell, K., Chu, D., and Domokos, R. *et al.* 2015. Calibration of acoustic instruments. ICES Cooperative Research Report No. 312: 147 pp.

Dotson, R., Griffith, D., King, D., and Emmett, R. 2010. Evaluation of a marine mammal excluder device (MMED) for a nordic 264 midwater rope trawl. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-SWFSC-455: 19.

Foote, K. G., Knudsen, H. P., Vestnes, G., MacLennan, D. N., and J., S. E. 1987. Calibration of acoustic instruments for fish density estimation: A practical guide. ICES Cooperative Research Report, 144: 69 pp.

Kim, M., H. J., and McGowan, J. A. 2005. Decadal variations of Mixed Layer Depth and biological response in the southern California current. Sixth Conference on Coastal Atmospheric and Oceanic Prediction and Processes. San Diego.

Mais, K. F. 1974. Pelagic fish surveys in the California Current. State of California, Resources Agency, Dept. of Fish and Game, Sacramento, CA: 79 pp.

Renfree, J. S., and Demer, D. A. 2016. Optimising transmit interval and logging range while avoiding aliased seabed echoes. ICES Journal of Marine Science, 73: 1955–1964.

Simmonds, E. J., and MacLennan, D. N. 2005. Fisheries acoustics: Theory and practice, 2nd edition. Blackwell Publishing, Oxford.

Smith, P. E., Flerx, W., and Hewitt, R. 1985. The CalCOFI Vertical Egg Tow (CalVET) Net. R. Lasker (editor), An egg production method for estimating spawning biomass of pelagic fish: Application to the northern anchovy, (*Engraulis mordax*). U.S. Department of Commerce, NOAA Tech. Rep. NMFS 36., 36: 27–32.

Zwolinski, J. P., Emmett, R. L., and Demer, D. A. 2011. Predicting habitat to optimize sampling of Pacific sardine (*Sardinops sagax*). ICES Journal of Marine Science, 68: 867–879.

Zwolinski, J., Demer, D., Cutter Jr., G. R., Stierhoff, K., and Macewicz, B. J. 2014. Building on fisheries acoustics for marine ecosystem surveys. Oceanography, 27: 68–79.