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JULY 2017

REPORT ON THE COLLECTION OF DATA DURING THE ACOUSTIC-TRAWL AND DAILY EGG PRODUCTION METHODS SURVEY OF COASTAL PELAGIC FISH SPECIES AND KRILL (1604RL) WITHIN THE CALIFORNIA CURRENT ECOSYSTEM, 22 MARCH TO 22 APRIL 2016, CONDUCTED ABOARD FISHERIES SURVEY VESSEL *REUBEN LASKER*

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U.S. DEPARTMENT OF COMMERCE
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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, continuous underway fish-egg sampler (CUFES), and vertical conductivity-temperature-depth probes (CTD), and assessed using the Acoustic-Trawl Method (ATM) and the Daily Egg Production Method (DEPM) during the Spring CPS Survey (1604RL) aboard the NOAA Fisheries Survey Vessel (FSV) *Reuben Lasker* (hereafter, *Lasker*), 22 March to 22 April 2016. The objectives of the survey were to: 1) acoustically map the distributions and estimate the abundances of CPS, including, but not limited to 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 the biotic and abiotic environments of these species, and investigate linkages; and 3) gather information regarding the animals' life history parameters.

This report provides an overview of the survey objectives and includes a summary of the survey equipment, acoustic-system calibration, sampling and analysis methods, and preliminary results. The biomass of Pacific sardine from this survey were described in greater detail by Hill et al. (2017). Final biomass and abundance estimates for other CPS and krill will be reported separately.

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 (AST Leader)
- K. Stierhoff (Project Leader)

Acoustic Data Collection and Processing:

- K. Stierhoff (Leg I, Acoustician)
- S. Mau (Leg II, Acoustician)

Echosounder Calibration:

- D. Demer, S. Mau, J. Renfree, T. Sessions, and K. Stierhoff

Trawl Sampling:

- N. Bowlin, S. Charter, M. Craig, K. Gilmore, D. Gorman, D. Griffith (Project Leader), M. Human, B. Macewicz, B. Overcash, M. Sederat, W. Watson, E. Weber

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, the stock typically migrates north, compresses along the coast, and feeds in the upwelled regions (**Figure II.1**).

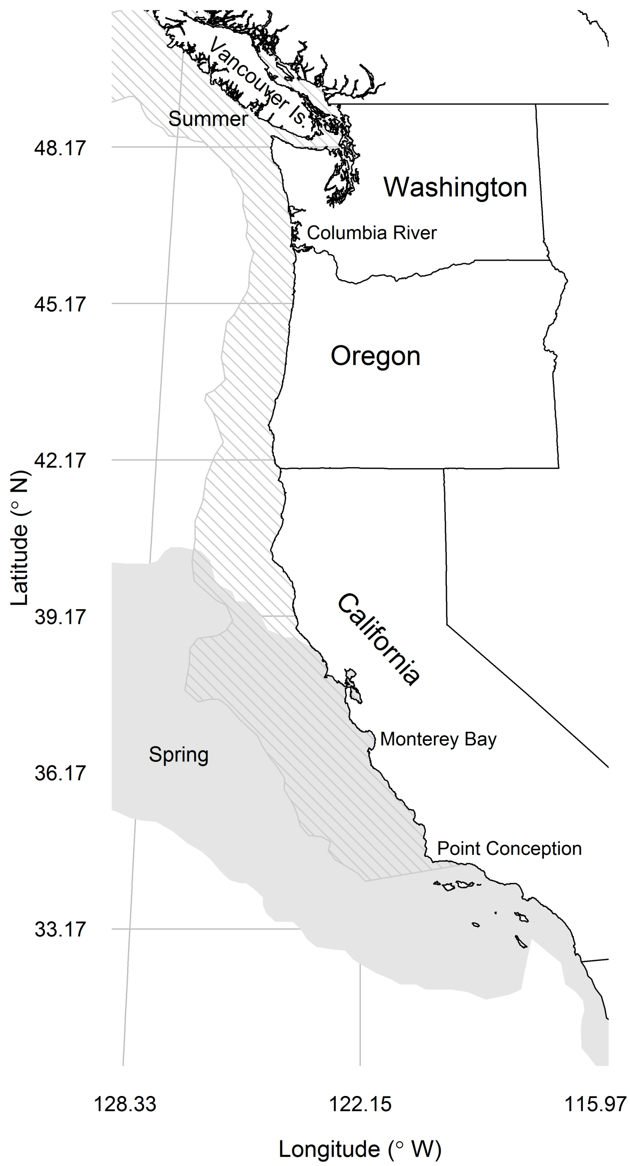


Figure II.1. Conceptual map showing the average seasonal distributions of Pacific sardine habitat during spring and summer along the west coasts of Mexico, the United States, and Canada (Zwolinski *et al.*, 2012). The distribution of potential habitat and catch information from the fishing industry are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

During spring 2016, part of the west coast of the United States was surveyed during the peak of the sardine spawning season, using *Lasker*. Transects were nearly perpendicular to the coast, with nominal separations of 20 or 40 nmi. Transect positions and spacings were adjusted according to the distribution of potential habitat for the northern stock of sardine at the time of the survey (**Figure II.2**; http://swfscdata.nmfs.noaa.gov/AST/sardineHabitat/habitat.asp). Due to warm conditions in the northeast Pacific Ocean during spring 2016, the sardine potential habitat extended unseasonably farther north than usual so the survey area was increased accordingly to begin off Newport, OR and progress southward toward Pt. Conception, CA (**Figure II.3**).

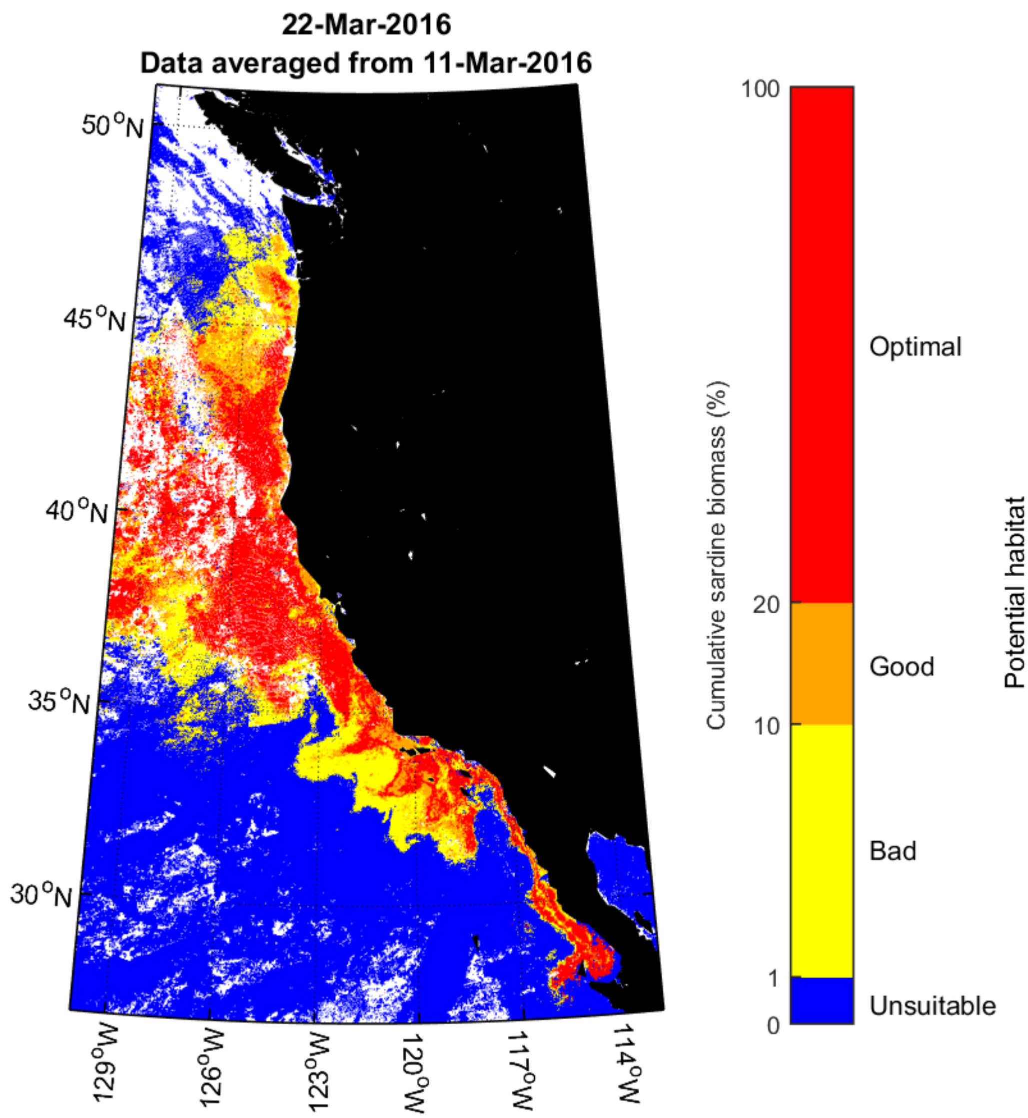


Figure II.2. Distribution of potential habitat for the nothern stock of Pacific sardine, on 22 March 2016, at the beginning of the Spring CPS Survey.

II.2 Acoustic sampling

II.2.1 Echosounders

Multi-frequency (18-, 38-, 70-, 120-, 200-, and 333-kHz) General Purpose Transceivers (Simrad EK60 GPTs), 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.

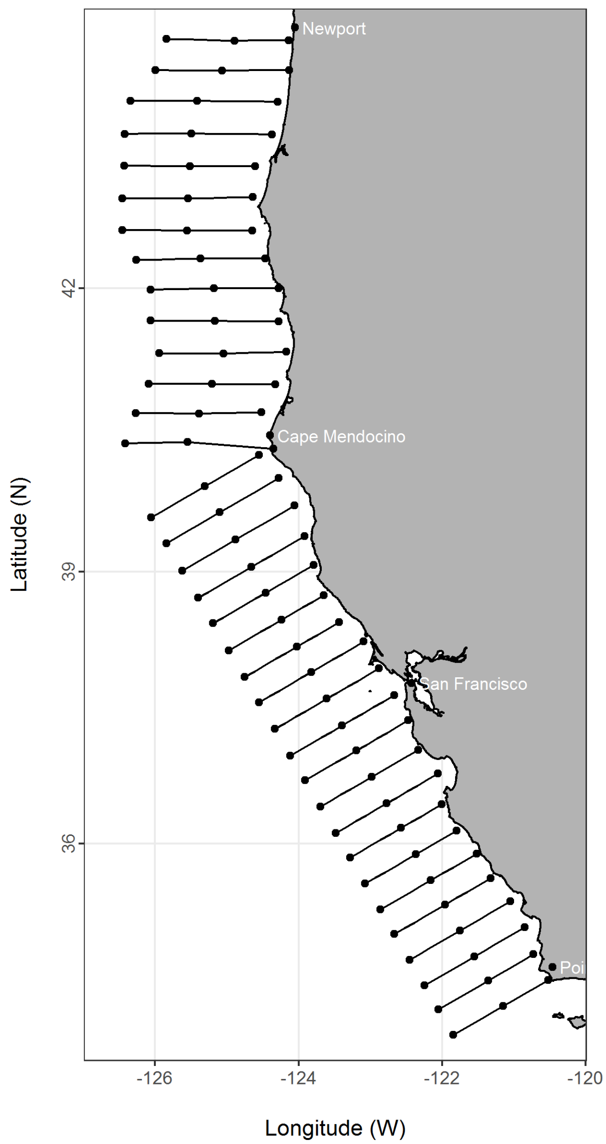


Figure II.3. Planned compulsory transect lines and fixed stationary sampling stations (dots).

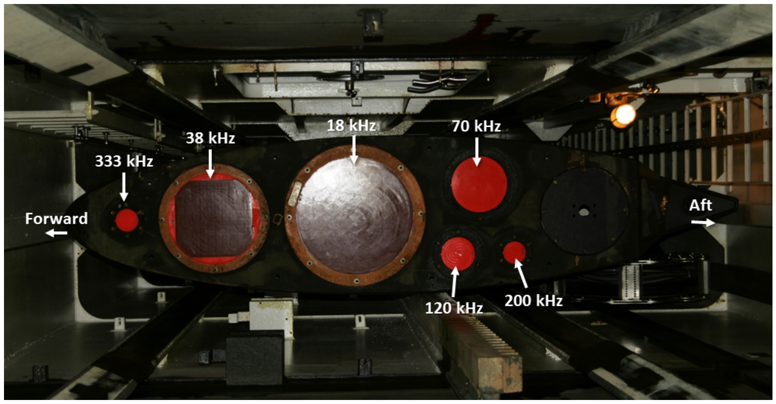


Figure II.4. Transducer locations on the bottom of the centerboard aboard *Lasker*.

II.2.2 Calibration

Prior to calibration, integrity of the equipment was verified by conducting impedance measurements of each transducer quadrant, individually and connected in parallel, using an LCR Meter (Agilent Model E4980A) and custom Matlab software. For each transducer, wideband measurements were made of resistance (R; Ω) and reactance (X; Ω), used to derive the complex impedance ($Z = R + \mathrm{j}\ X$; Ω) and admittance ($Y = X^{-1} = G + \mathrm{j}\ B$; S). The magnitude of impedance ($|Z|$, Ω), phase ($\theta = \arctan[X\ R^{-1}]$; °), and conductance ($G$; S) versus frequency, and G versus susceptance (B; S), were plotted for each quadrant (**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 **Appendix B**.

II.2.3. Data collection

The logging-computer clock was synchronized with the GPS clock (GMT) 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 avoiding aliased seabed echoes. 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 "1604RL_" 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 (~5 m) are indicated in **Appendix C**. Using SyncBack Free (2BrightSparks Pte. Ltd.), backups of all raw and processed sampling data were archived to a laptop computer and external hard disk drive at least daily.

To minimize acoustic interference, transmit pulses from a multibeam sonar (Simrad ME70) 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 captain occasionally operated the bridge echosounder (50 and 200-kHz Furuno), the Doppler velocity log, or both.

II.2.4 Data processing

The calibrated echosounder data were processed on a dedicated computer, using commercial software (Echoview V7.0.81.28862, 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 simulated background noise from the raw S_{v} in the linear domain, were smoothed by computing the median value in non-overlapping 11-sample by 3-ping cell (**Figure II.5b**).
   - The smoothed, noise-reduced echograms were used to calculate S_{v}-differences using the 38-kHz echogram 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 was approaching or departing a sampling station, typically associated with a ship-speed less than 4 kn, were automatically marked as "bad data."
   - Provisional CPS regions created above were ascribed to CPS schools if the standard deviation (SD) 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 sardine 20-cm in length) 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 (VMR) (Demer *et al.*, 2009).
   - An integration-stop line was created at 250-m depth or, when shallower, 3 m above the estimated dead-zone height
   - Between the integration lines, to a maximum of 250 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.

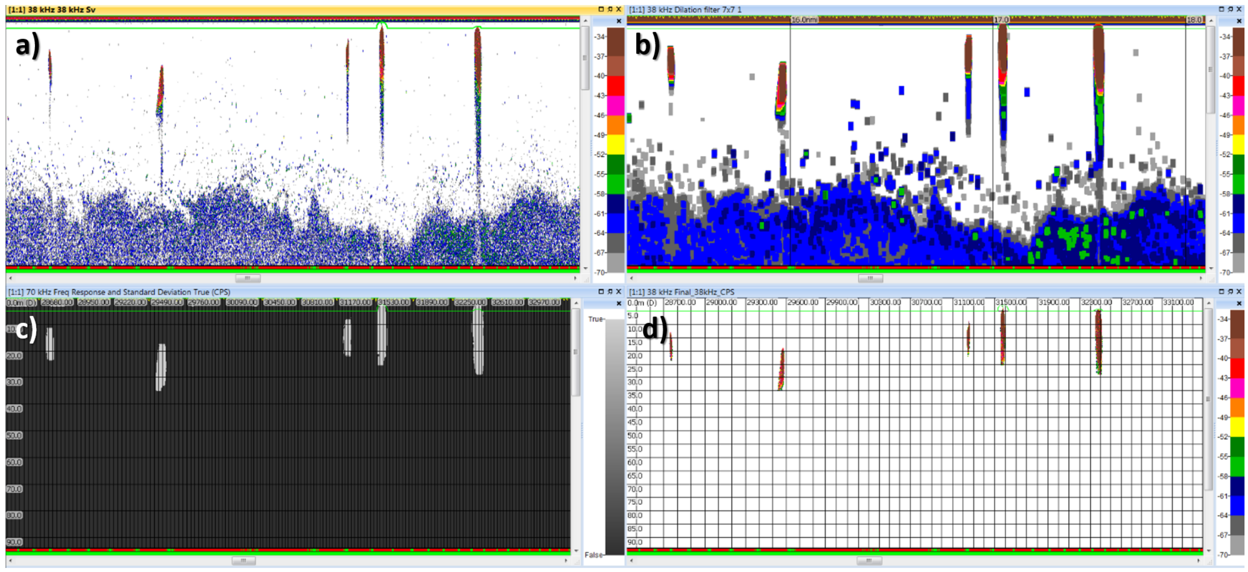


Figure II.5 Synchronized echograms of 38-kHz S_v after a) noise-subtraction, b) median smoothing, c) CPS masking, and d) final CPS-only 38-kHz S_v thresholding at -60 dB.

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

$S_{\mathrm{v70kHz}} - S_{\mathrm{v38kHz}}$	$S_{\mathrm{v120kHz}} - S_{\mathrm{v38kHz}}$	$S_{\mathrm{v200kHz}} - S_{\mathrm{v38kHz}}$
-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 species and their sizes 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 (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 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 from each of the target species were selected randomly. Those were weighed (g) and measured to either their standard length (L_s; mm) for sardine, northern 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 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 profiles

Day and night, conductivity and temperature versus depth to 350 m were measured with calibrated sensors on a CTD probe cast. 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). The CTD 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 echosounders were calibrated on 14 March 2016 (~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 = 18.1 °C) and salinity (s_w = 33.3 psu) were input to the GPT-control software, which derived estimates of sound speed (c_w = 1515.1 m s^{-1}) and absorption coefficients. Varying with tide, the seabed was 10.8 to 12.8 m from the transducers. The calibration sphere was positioned between 4.1 to 7 m below the transducers.

Measurements of beam-uncompensated sphere target strength (TS_u, dB) and the beam model are plotted in **Figure III.2**, beam-compensated sphere target strength (TS_c, dB) 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**.

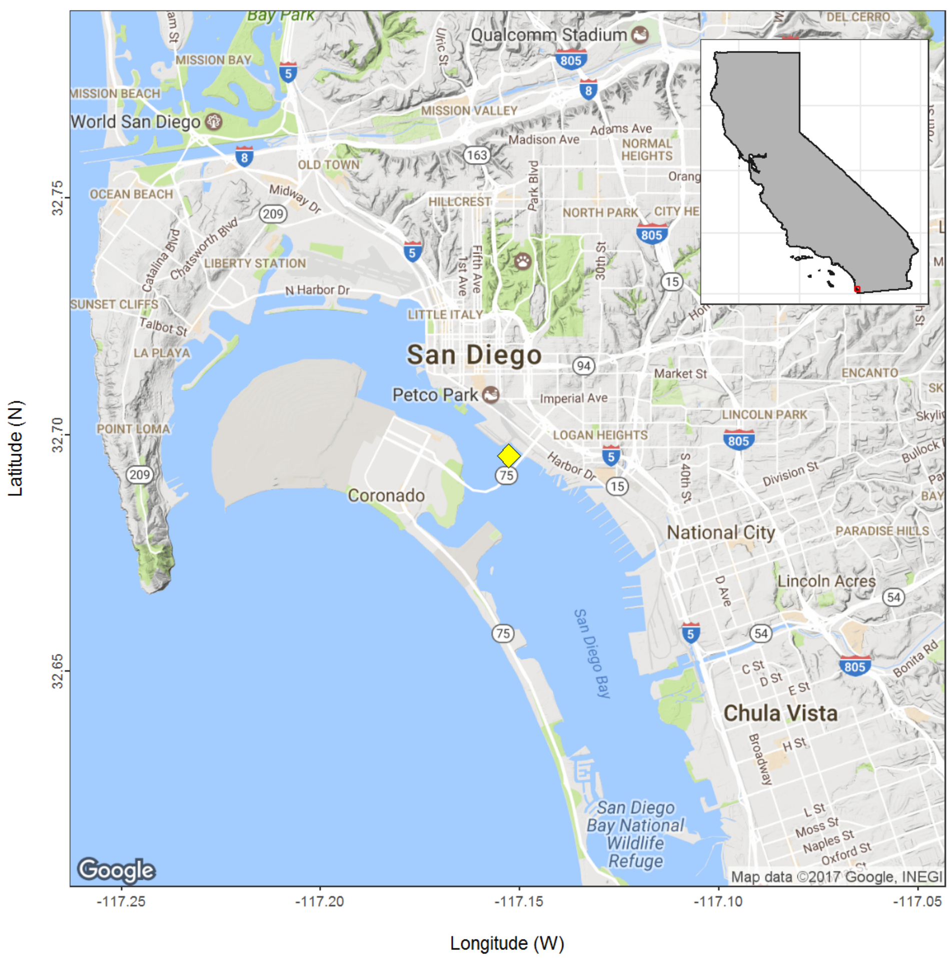


Figure III.1. Map of the calibration location (yellow diamond) near 10th Avenue Marine Terminal, San Diego Bay.

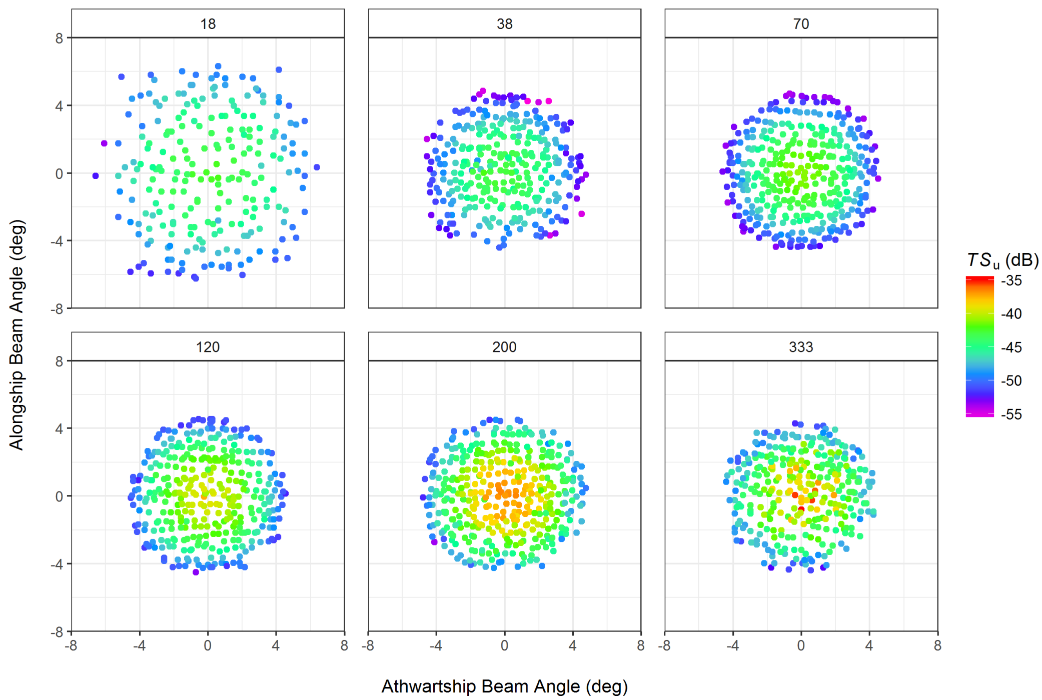


Figure III.2. Beam-uncompensated sphere target strength (TS_{u}, dB) measurements of a 38.1-mm diameter sphere made from tungsten carbide (WC) with 6% cobalt binder material, at multiple EK60 frequencies (18, 38, 70, 120, 200, and 333kHz). Crosses indicate measurements marked as outliers after viewing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

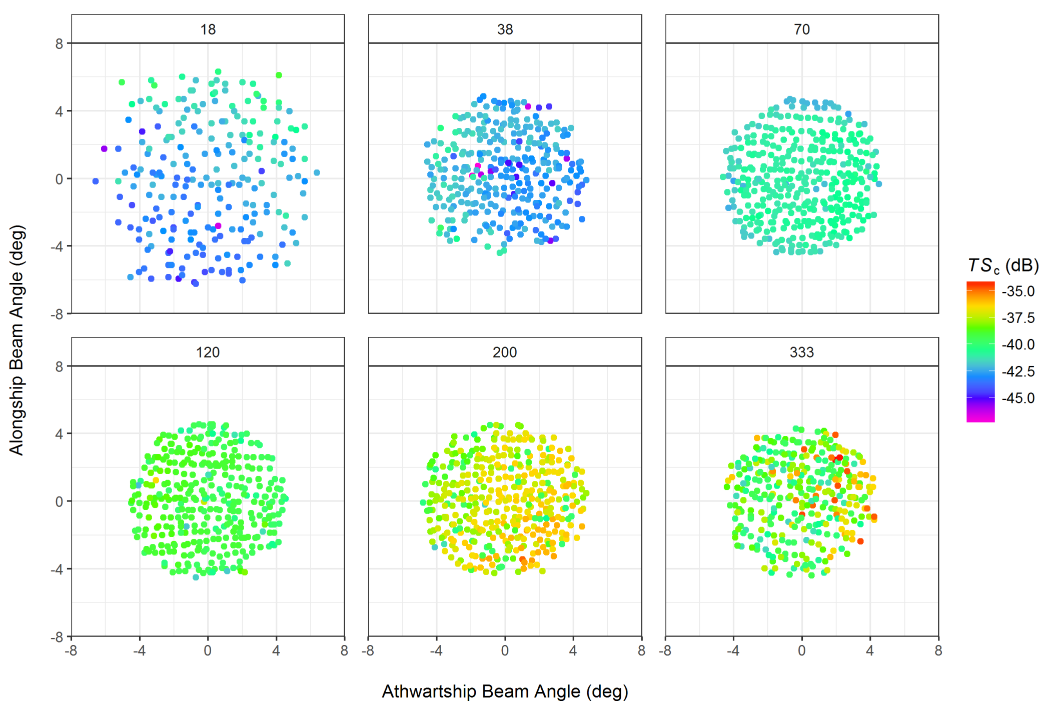


Figure III.3. Beam-compensated sphere target strength (TS_{c}, dB) measurements of a 38.1-mm diameter sphere made from tungsten carbide (WC) with 6% cobalt binder material, at multiple EK60 frequencies (18, 38, 70, 120, 200, and 333kHz). Crosses indicate measurements marked as outliers after viewing the beam model results.

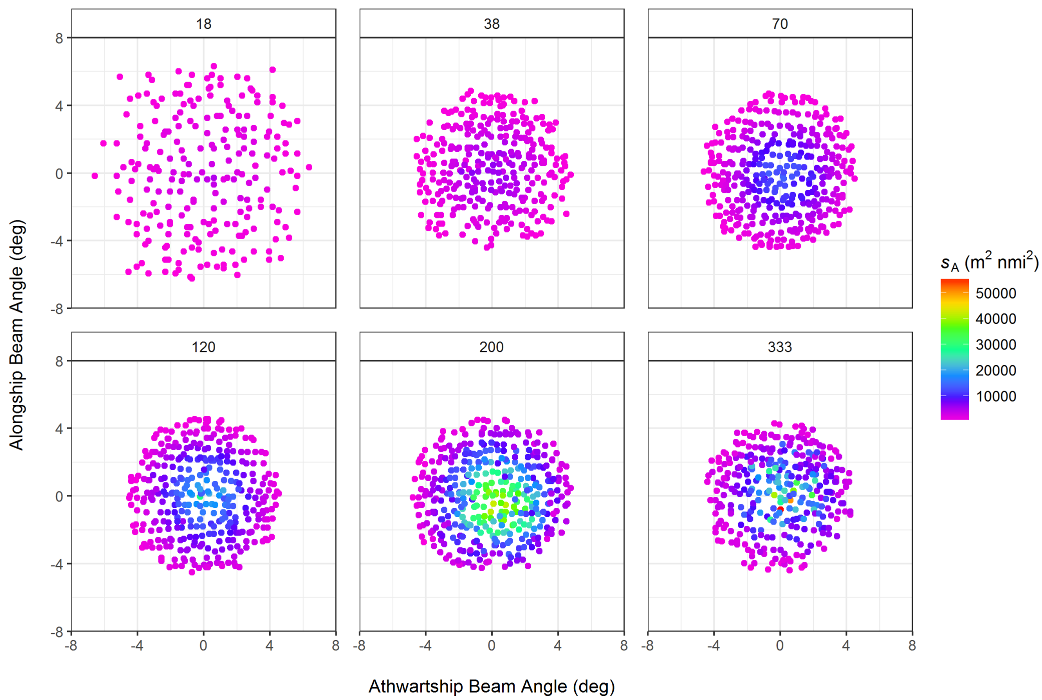


Figure III.4. Nautical area scattering coefficient (s_{A}, m^2 nmi^{-2}) measurements of a 38.1-mm diameter sphere made from tungsten carbide (WC) with 6% cobalt binder material, at multiple EK60 frequencies (18, 38, 70, 120, 200, and 333kHz). Crosses indicate measurements marked as outliers after viewing the beam model results.

III.2. Data collection

III.2.1. Acoustic and trawl sampling

The survey comprised 16 east-west transects totaling 2623 nmi, and 43 Nordic trawls, which were used for acoustic-trawl biomass estimation. The survey spanned an area from approximately Newport, OR to north of Bodega Bay, CA (**Figure III.5**). The concentration of adaptive samples off Oregon and damage to the trawl gear precluded sampling to the southern extent of the survey area.

Leg I, *Lasker* departed from 10th Avenue Marine Terminal on 21 March 2016 to conduct trawl gear trials with a minimal scientific party. On 22 March, the remaining scientists were put aboard via small boat *ca.* 16:30, after which *Lasker* transited to *ca.* 44°N (south of Newport, OR) to beging the survey. At *ca.* 18:00, *Lasker* arrived at the first onshore station *ca.* 15 nmi S. of Heceta Head Light. Acoustic sampling ceased at *ca.* 02:30 on 6 April during Transect 9 (near Cape Sebastian, OR) before transiting south toward San Francisco, CA. *Lasker* arrived at the sea buoy off San Francisco, CA on 7 April at *ca.* 12:30, and returned to Pier 15 (near the Exploratorium) at *ca.* 15:00.

Leg II, *Lasker* departed from Pier 15 in San Francisco, CA on 11 April 2016 at *ca.* 17:30. Acoustic sampling resumed along Transect 10 at *ca.* 16:00 on 12 April. On 14 April, the trawl net was irreparably damaged (starboard ribline parted and the top and bottom panels of the trawl body experienced severe longitudinal tears) so *Lasker* transited to Drake's Bay seeking calmer conditions to swap nets. On 17 April at *ca.* 15:00, acoustic sampling resumed along Transect 12. Survey operations for Leg II were concluded on 22 April at *ca.* 21:00 after sampling Transect 16 near Fort Ross, CA. *Lasker* returned to Pier 30/32 in San Francisco, CA on 23 April at *ca.* 14:00.

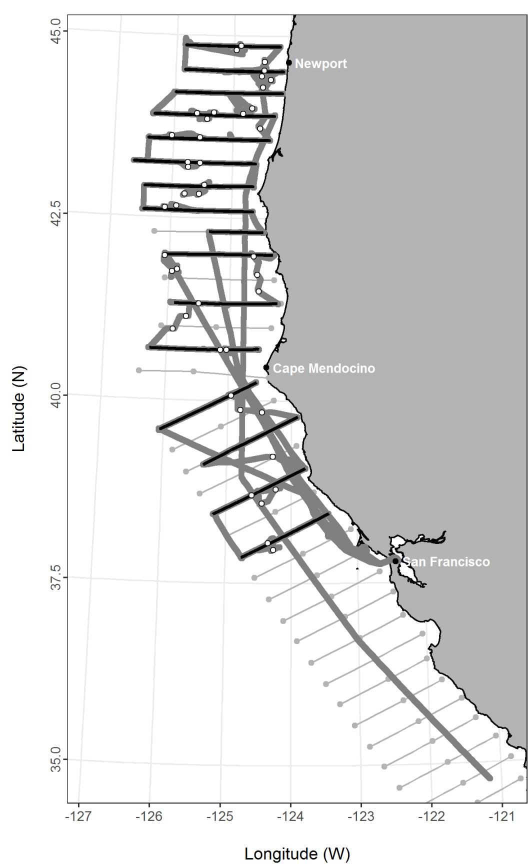


Figure III.5. Cruise track of *Lasker* (bold gray line), east-west acoustic transects (black lines), and locations of surface trawls (white points) superimposed on the proposed transects (light gray lines).

III.2.2 Ichthyoplankton and oceanographic sampling

A total of 55, 56, 61 CTD, bongo, and Pairovet samples were collected throughout the survey, respectively. In addition, 48 UCTD samples and 2988 CUFES samples were collected underway. The locations of CTD and UCTD stations are shown in Figure **III.6** and **Appendix D**.

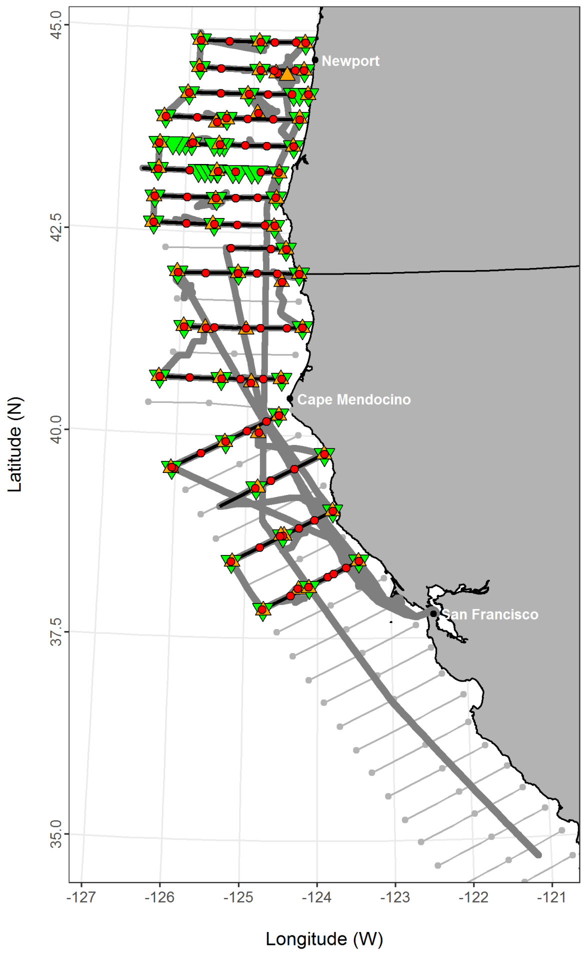


Figure III.6. CTD and UCTD locations (red circles) and plankton net samples (bongo net in orange triangles; Pairovet net in green triangles) relative to the vessel track (bold gray line), acoustic transects (black lines), and proposed transects (light gray lines).

III.3. Distribution of CPS

The majority of acoustic backscatter ascribed to CPS was observed nearshore between Newport, OR and Mendocino, CA (**Figure III.7, left panel**). Sardine,jack mackerel, and to a lesser extent Pacific mackerel, comprised the greatest proportion of catch in trawl samples north of Cape Mendocino, CA. Sardine were predominantly found in the northern portion of the survey area, nearshore between Newport, OR and Port Orford, OR. No sardine were found south of approximately Eureka, CA (41.00°N; **Figure III.7, center panel**). Jack mackerel and Pacific mackerel were present in trawl samples between Coos Bay, OR and Cape Mendocino, CA, where they comprised the greatest proportion of the trawl catch. No anchovy were observed in any trawl samples. Overall, the 43 trawls captured 1775.1 kg of sardine, anchovy and mackerels combined (**Appendix E**).

Sardine eggs were most abundant in CUFES samples in the inshore portion of transects conducted between Newport, OR and Coos Bay, OR; and in the offshore portion of transects conducted between Coos Bay, OR and Port Orford, OR (**Figure III.7, right panel**). No sardine eggs were observed south of approximately Port Orford, OR.

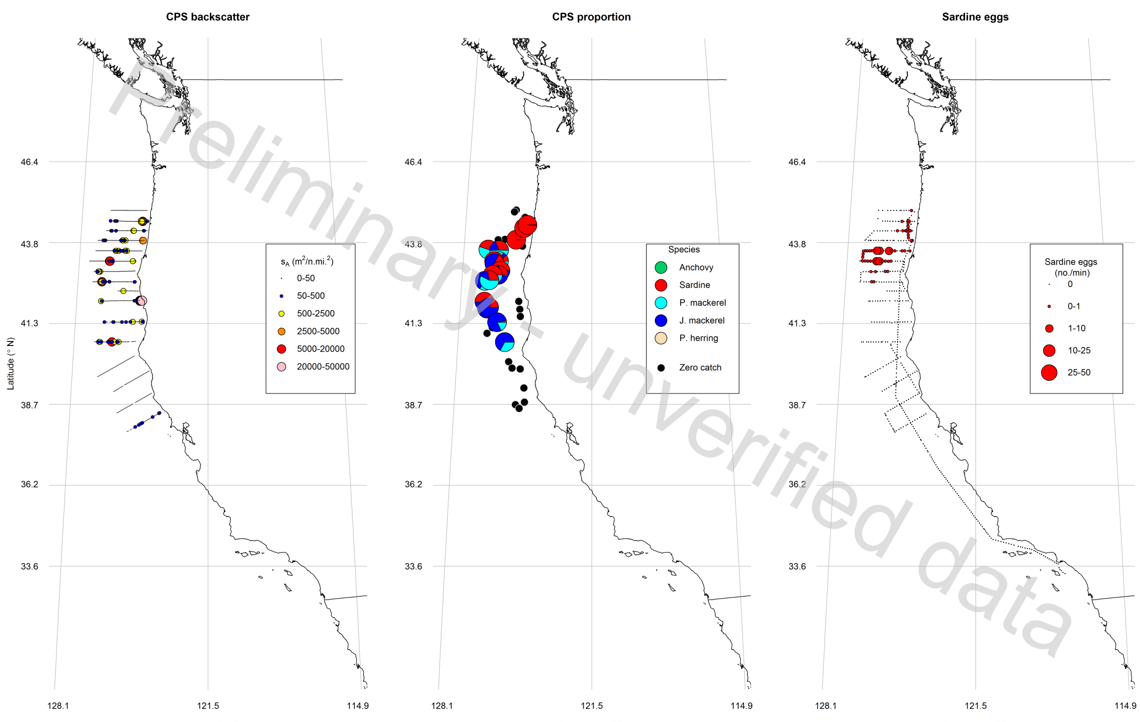


Figure III.7. Survey transects performed aboard *Lasker* overlaid with (a) the distribution of 38-kHz integrated backscattering coefficients (s_A, m^2 nmi^2) ascribed to CPS, averaged over 2000-m distance intervals and from 70-m deep to the integration start line (5 -m depth) superimposed on the distribution of potential sardine habitat defined at the mid-period of the survey (left panel); (b) proportions of CPS in trawl clusters used to apportion acoustic backscatter, including northern anchovy (*Engraulis mordax*), Pacific mackerel (*Scomber japonicus*), jack mackerel (*Trachurus symmetricus*), and Pacific herring (*Clupea pallasii*) (center panel); and (c) sardine-egg densities from the CUFES (right panel).

IV. Problems and Suggestions

The Nordic trawl was damaged (large longitudinal tears in the top and bottom panels of the trawl body) and required repair during Leg II, which resulted in the loss of approximately two survey days.

V. Disposition of Data

Archived on the SWFSC data server are approximately 52.7 GB of raw EK60 data and 589 GB of raw ME70 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).

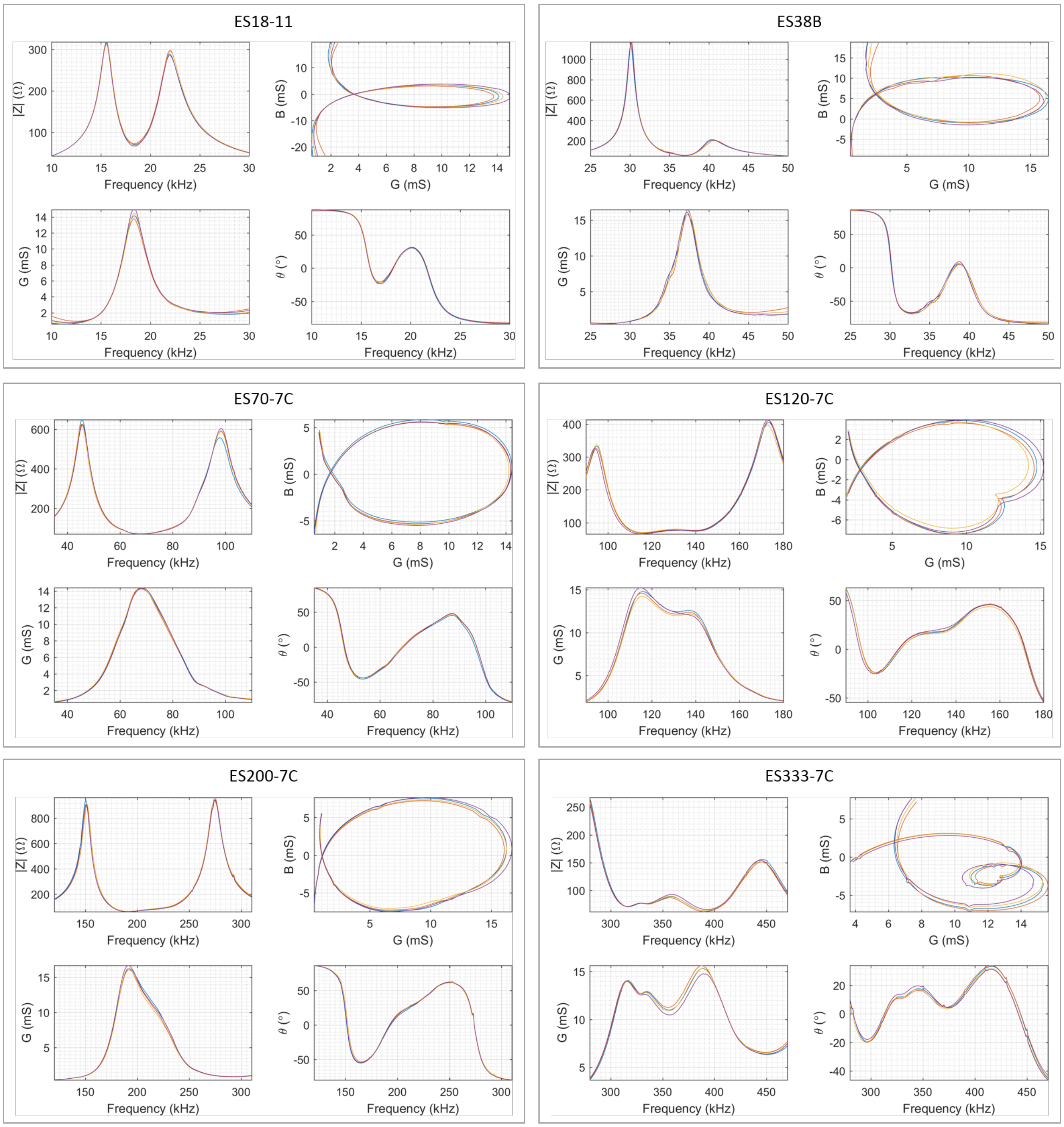
VI. Acknowledgements

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

Appendices

Appendix A. Echosounder transducer impedance measurements

The magnitude of impedance ($|Z|$, Ω), phase (θ, °), and conductance (G, S) versus frequency, and susceptance (B, S) versus G (admittance circle), for each quadrant 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, configuration 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	31206	233	783	513	124
Transmit Power (p_{et})	W	2000	2000	750	250	105	50
Pulse Duration (τ)	ms	1.024	1.024	1.024	1.024	1.024	1.024
On-axis Gain (G_0)	dB re 1	22.62	24.8	26.79	26.44	26.32	26.72
S_a Correction ($S_a$corr)	dB re 1	-0.75	-0.7	-0.36	-0.38	-0.37	-0.52
Bandwidth (W_f)	Hz	1570	2430	2860	3030	3090	3110
Sample Interval	m	0.193	0.193	0.194	0.194	0.193	0.193
Eq. Two-way Beam Angle (Ψ)	dB re 1 sr	-17.3	-20.6	-20.4	-20.3	-20.3	-19.8
Absorption Coefficient (α_f)	dB km^{-1}	2.2	8.5	21.5	43.2	60.7	86.4
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	10.82	7.06	6.65	6.56	6.43	6.22
3-dB Beamwidth Athw. (β_{-3dB})	deg	10.75	6.98	6.56	6.51	6.82	6.49
Angle Offset Along. (α_0)	deg	-0.33	-0.02	0.03	-0.02	0.03	-0.06
Angle Offset Athw. (β_0)	deg	-0.2	0.06	-0.03	0.05	-0.04	-0.19
Theoretical TS (TS_{theory})	dB re 1 m^2	-42.5	-42.4	-41.58	-39.67	-38.86	-36.63
Ambient Noise	dB re 1 W	-999	-999	-999	-999	-999	-999
On-axis Gain (G_0)	dB re 1	22.5	24.62	27.12	26.71	27.18	25.57
S_a Correction ($S_a$corr)	dB re 1	-0.65	-0.64	-0.32	-0.36	-0.26	-0.41
RMS	dB	0.36	0.42	0.15	0.29	0.56	0.78
3-dB Beamwidth Along. (α_{-3dB})	deg	11.28	7.26	6.48	6.43	6.33	6.17
3-dB Beamwidth Athw. (β_{-3dB})	deg	10.99	7.2	6.49	6.46	6.57	6.85
Angle Offset Along. (α_0)	deg	-0.09	-0.03	0.03	-0.03	-0.01	-0.08
Angle Offset Athw. (β_0)	deg	-0.12	-0.05	-0.01	0.01	0.07	-0.11

Appendix C. Centerboard positions

Transducer depths, associated 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
03/23/2016 21:11	Intermediate (7 m)	34.763500	-121.161167

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
03/26/2016 19:18	CTD Cast	43.9005	-124.2907
03/26/2016 21:35	UCTD Cast	43.9020	-124.6932
03/26/2016 23:16	UCTD Cast	43.9050	-125.0847
03/27/2016 00:55	CTD Cast	43.9057	-125.4132
03/27/2016 06:00	CTD Cast	43.8525	-125.5528
03/27/2016 15:23	UCTD Cast	43.9075	-125.8602
03/27/2016 18:16	CTD Cast	43.9075	-126.3403
03/27/2016 21:48	CTD Cast	44.2102	-125.9938
03/28/2016 00:57	UCTD Cast	44.2133	-125.5062
03/28/2016 07:17	CTD Cast	43.9768	-124.9217
03/28/2016 14:09	CTD Cast	44.2098	-125.0675
03/28/2016 16:45	UCTD Cast	44.2110	-124.7780
03/28/2016 18:33	UCTD Cast	44.2127	-124.4052
03/28/2016 21:00	CTD Cast	44.2120	-124.1538
03/29/2016 06:00	CTD Cast	44.4735	-124.6367
03/29/2016 17:45	CTD Cast	44.5088	-124.2220
03/29/2016 19:08	UCTD Cast	44.5097	-124.3620
03/29/2016 20:36	UCTD Cast	44.5083	-124.6917
03/29/2016 21:42	CTD Cast	44.5077	-124.8973
03/30/2016 15:26	UCTD Cast	44.5193	-125.5127
03/30/2016 17:05	CTD Cast	44.5245	-125.8390
03/30/2016 21:18	CTD Cast	44.8597	-125.8397
03/31/2016 06:11	CTD Cast	44.8553	-124.9010
03/31/2016 18:02	UCTD Cast	44.8578	-125.3943
03/31/2016 21:09	UCTD Cast	44.8543	-124.6847
03/31/2016 22:33	UCTD Cast	44.8533	-124.3528
03/31/2016 23:18	CTD Cast	44.8522	-124.1990
04/01/2016 10:59	CTD Cast	43.5693	-124.3765
04/01/2016 15:48	UCTD Cast	43.5730	-124.7847
04/01/2016 19:14	UCTD Cast	43.5760	-125.1148
04/01/2016 21:10	CTD Cast	43.5787	-125.4955
04/02/2016 00:50	UCTD Cast	43.5778	-125.9407
04/02/2016 05:53	CTD Cast	43.5942	-125.9117
04/02/2016 15:44	CTD Cast	43.5762	-126.4243
04/02/2016 18:56	CTD Cast	43.2550	-126.4260
04/03/2016 00:04	UCTD Cast	43.2512	-125.9458
04/03/2016 03:17	CTD Cast	43.2493	-125.5185
04/03/2016 15:32	UCTD Cast	43.2472	-125.2515
04/03/2016 18:04	UCTD Cast	43.2485	-124.8668
04/03/2016 19:24	CTD Cast	43.2465	-124.6015
04/03/2016 21:47	CTD Cast	42.9358	-124.6397
04/03/2016 23:39	UCTD Cast	42.9318	-124.9107
04/04/2016 01:11	UCTD Cast	42.9253	-125.2440
04/04/2016 02:46	CTD Cast	42.9183	-125.5345
04/04/2016 16:08	UCTD Cast	42.9215	-125.9665
04/04/2016 18:37	CTD Cast	42.9202	-126.4547
04/04/2016 21:24	CTD Cast	42.5977	-126.4578
04/05/2016 00:34	UCTD Cast	42.5963	-125.9650

04/05/2016 02:38	CTD Cast	42.5943	-125.5507
04/05/2016 15:37	UCTD Cast	42.5935	-125.2092
04/05/2016 17:32	UCTD Cast	42.5920	-124.7968
04/05/2016 18:29	CTD Cast	42.5890	-124.6475
04/05/2016 21:16	CTD Cast	42.3030	-124.4705
04/05/2016 23:05	UCTD Cast	42.3058	-124.7008
04/06/2016 02:02	UCTD Cast	42.3055	-125.2930
04/12/2016 13:56	UCTD Cast	39.5693	-126.0155
04/12/2016 14:36	CTD Cast	39.5818	-126.0537
04/12/2016 17:57	UCTD Cast	39.7652	-125.6492
04/12/2016 19:53	CTD Cast	39.9177	-125.3050
04/12/2016 22:31	UCTD Cast	40.0513	-125.0050
04/12/2016 23:56	UCTD Cast	40.1745	-124.7295
04/13/2016 01:05	CTD Cast	40.2537	-124.5572
04/13/2016 06:20	CTD Cast	40.0365	-124.8353
04/13/2016 14:37	CTD Cast	39.7782	-123.9093
04/13/2016 17:45	UCTD Cast	39.5940	-124.3257
04/13/2016 19:32	UCTD Cast	39.4477	-124.6545
04/13/2016 22:38	CTD Cast	39.3473	-124.8715
04/17/2016 04:02	CTD Cast	41.9870	-126.0630
04/17/2016 17:05	UCTD Cast	41.9922	-125.6605
04/17/2016 19:24	CTD Cast	41.9970	-125.1783
04/17/2016 21:41	UCTD Cast	41.9990	-124.9028
04/17/2016 23:03	UCTD Cast	41.9985	-124.6000
04/18/2016 00:43	CTD Cast	41.9963	-124.2773
04/18/2016 05:42	CTD Cast	41.8983	-124.5332
04/18/2016 13:05	CTD Cast	41.3350	-124.2277
04/18/2016 14:53	UCTD Cast	41.3303	-124.4523
04/18/2016 16:39	UCTD Cast	41.3247	-124.8395
04/18/2016 17:45	CTD Cast	41.3200	-125.0482
04/18/2016 21:14	UCTD Cast	41.3205	-125.5047
04/18/2016 23:27	CTD Cast	41.3215	-125.9448
04/19/2016 05:46	CTD Cast	41.3137	-125.6247
04/19/2016 14:33	CTD Cast	40.6958	-126.2717
04/19/2016 17:40	UCTD Cast	40.6932	-125.8422
04/19/2016 19:55	CTD Cast	40.6917	-125.3835
04/19/2016 22:20	UCTD Cast	40.6947	-125.1127
04/19/2016 23:53	UCTD Cast	40.7000	-124.7852
04/20/2016 01:21	CTD Cast	40.7010	-124.5203
04/20/2016 06:55	CTD Cast	40.6458	-124.9612
04/20/2016 20:55	CTD Cast	39.0760	-123.7922
04/20/2016 22:56	UCTD Cast	38.9608	-124.0432
04/21/2016 00:10	UCTD Cast	38.8617	-124.2630
04/21/2016 01:31	CTD Cast	38.7648	-124.4798
04/21/2016 05:41	CTD Cast	38.7583	-124.5193
04/21/2016 15:37	UCTD Cast	38.6197	-124.7998
04/21/2016 17:58	CTD Cast	38.4402	-125.1938
04/22/2016 00:34	CTD Cast	37.8520	-124.7520
04/22/2016 05:47	CTD Cast	38.1178	-124.2728
04/22/2016 14:16	UCTD Cast	38.0273	-124.3712
04/22/2016 15:46	CTD Cast	38.1385	-124.1265
04/22/2016 18:28	UCTD Cast	38.2600	-123.8632
04/22/2016 18:57	UCTD Cast	38.2975	-123.7798
04/22/2016 19:55	UCTD Cast	38.3733	-123.6113

04/22/2016 21:05	CTD Cast	38.4547	-123.4330

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.

Haul	Date/Time	Lat (N)	Lon (W)	Anchovy	Sardine	P. mackerel	J. mackerel	All CPS
1		43.851	-125.442					
2		43.942	-125.331					
3		43.930	-125.616					
4		43.934	-124.826		1.45			1.45
5		44.006	-124.677					
6		44.447	-124.517					
7		44.297	-124.498		2.71			2.71
8		44.401	-124.361		396.81	3.41		400.22
9		44.528	-124.472					
10		44.642	-124.466					
11		44.865	-124.879					
12		44.807	-124.961					
13		43.734	-124.537					
14		43.615	-126.028		0.06	0.08		0.14
15		43.597	-125.555		192.09	300.08	116.11	608.27
16		43.250	-125.544		29.71	213.03	15.72	258.45
17		43.250	-125.750		92.73	62.79	24.93	180.45
18		43.190	-125.736		0.17		0.83	1.00
19		42.947	-125.458		0.36		0.07	0.43
20		42.821	-125.543		0.51	0.05	1.56	2.12
21		42.824	-125.782		8.28	1.96	3.84	14.09
22		42.627	-126.105		70.43	91.30	106.19	267.92
23		42.655	-125.917		1.35	2.77	0.72	4.84
24		40.066	-124.947					
25		39.874	-124.802					
26		39.843	-124.460					
28		41.968	-126.077		0.23	0.06	0.16	0.46
29		41.753	-125.946				0.14	0.14
30		41.786	-125.869		0.10		0.49	0.59
31		41.979	-124.618					
32		41.730	-124.557					
33		41.503	-124.529					
34		41.324	-125.503		0.93	5.11	22.77	28.81
35		41.145	-125.695					
37		40.695	-125.035					
38		40.694	-125.138			0.98	1.99	2.97
39		38.707	-124.608					
40		38.593	-124.454					
41		38.786	-124.240					
42		38.051	-124.353					
43		37.960	-124.274					

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