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Summary

A minimum biomass estimate of the central subpopulation of northern anchovy in summer 2016 using the acoustic-trawl method (ATM) was determined to be 151,558 metric tons (t), CV = 41.0%. The anchovy, ranging from the Mexican border to north of San Francisco, CA, but primarily observed north of Point Conception, had standard lengths ranging from 6 to 15 cm with a prominent mode at 11 cm. This mode is consistent with growth of the 6-cm mode observed in 2015, and indicates that the 2015 year-class currently dominates the stock in the survey area.

Introduction

Acoustic-trawl method (ATM) surveys, which combine information collected with echosounders and nets, were introduced to the California Current Ecosystem (CCE) more than 40 years ago to survey coastal pelagic fish species (CPS; e.g., sardine, anchovy, and mackerels) off the west coast of the United States (U.S.) (Mais, 1974; Mais, 1977; Smith, 1978). Following a two decade hiatus, the ATM was reintroduced in the CCE in spring 2006 to sample the then abundant sardine population (Cutter Jr. and Demer, 2008). Since 2006, this sampling effort has continued and expanded through annual or semi-annual surveys (Zwolinski et al., 2014). Beginning in 2011, the ATM estimates of sardine abundance, age structure, and distribution have been incorporated in the annual sardine assessments (Hill et al., 2016). Additionally, ATM survey results are applied to estimate the abundances, demographics, and distributions of epipelagic and semi-demersal fishes (e.g., Swartzman, 1997; Williams et al., 2013; Zwolinski et al., 2014) and plankton (Hewitt and Demer, 2000).

In the present application of ATM surveys to the California Current Ecosystem (CCE) (Zwolinski et al., 2014), multi-frequency split-beam echosounders transmit sound pulses downward beneath the ship and receive echoes from animals and the seabed in the path of the sound waves. The backscattered signal, i.e., the sound that is scattered back to the transducer, is then compensated for absorption and spreading of the sound waves, providing an indication of the numbers and physical properties of the targets in the water column. Fish, particularly those with strong schooling behavior and highly reflective swimbladders (Foote, 1980), create high intensity echoes. Under certain conditions, the summed intensities of the echoes from a group of targets is linearly related to their numerical density, and when the average backscatter of those targets is known, the acoustic backscatter can be converted to numerical density (Simmonds and MacLennan, 2005). Ideally, acoustic and trawl data are collected across the entire distribution area of target stocks, providing estimates of their population abundances or biomasses that can be used to inform stock assessments and management decisions.

An ATM survey was performed in summer 2016, sampling the west coast of the U.S. to estimate the abundances and distributions of CPS, together with their biotic and abiotic habitat. Presented here are estimates of the abundance, and length and spatial distributions of the central stock of Northern anchovy (*Engraulis mordax*). Since the survey does not collect data across the entire distribution area of the central stock of northern anchovy, the provided estimate is considered a minimum population estimate. Until a Methodology Review of the current ATM survey can be undertaken to address concerns about the proportion of the anchovy population inshore of the survey area and in surface waters, present survey data cannot be used to provide a representative estimate of total absolute abundance of northern anchovy in the California Current Ecosystem. The estimate contained is this report does at least provide a credible lower bound for anchovy abundance in the survey area. If in the future there is indication that a small, yet non-negligible portion of the stock is contained in the shallow coastal habitats, a correction factor can be applied.

Methods

The 2016 summer survey was conducted using the NOAA Fisheries Survey Vessel (FSV) *Reuben Lasker* over 80 days (June to September 2016), and transects spanned the west coast of the U.S. and Canada, from the northern end of Vancouver Island, Canada, to the U.S.-Mexico border (Fig. 1). The maximum distance between transects was 20 n. mi.. The 10 n. mi. minimum transect distance was used in areas where large densities of CPS were expected or detected. Echosounders were calibrated prior to the survey as per Demer et al. (2015). Acoustic data were collected during the day to allow sampling of fish schools aggregated throughout the surface mixed layer. After sunset, CPS schools tend to ascend and disperse and are less likely to avoid a net (Mais, 1977). Therefore, trawling was conducted during the night to sample the dispersed fish near the surface and obtain their species, lengths and weights.

The trawl 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, the trawl head-rope is lined with floats, and the net is towed at 4 knots so the trawl remains at the surface.

Nighttime trawls, typically spaced by 10 nautical miles, were conducted in areas where echoes from CPS schools were observed earlier. The trawl catches were sorted by species, counted, and weighed. Measures of standard length (SL; mm; sardine, anchovy, and Pacific herring (*Clupea pallasii*)), fork length (FL, mm; jack and Pacific mackerel), and total weight (W; g) were made if catches were less than 75 fish, or, otherwise, of a subsample of 50 fish. For anchovy, SL was converted to total length (TL) using the following equation: TL =

1.165*SL + 2.056 (mm). The catch data for each night were combined, with even weighting, into a cluster, providing a sample with smaller variance than that of the individual trawls.

Acoustic data from each transect were processed using estimates of sound speed and absorption coefficients calculated with contemporaneous data from Conductivity-Temperature-Depth (CTD) probes. Echoes from schooling CPS were identified with a semi-automated data processing algorithm as described in Demer et al. (2012). The CPS backscatter was integrated within an observational range of 10 m below the sea surface to the bottom of the surface mixed layer or, if the seabed was shallower, to 3 m above the estimated acoustic dead zone (Demer et al., 2009). The vertically integrated backscatter was averaged along 100-m intervals, and the resulting nautical area scattering coefficients (s_A; m^2 $n.mi.^{-2}$) were apportioned according to the catch proportion and average backscattering cross-section (the linear counterpart of the target strength - TS; MacLennan et al., 2002; Imai and van Dyk, 2005) of the various species of pelagic fish found in each cluster (see details in Demer et al., 2012; Zwolinski et al., 2014).

The TS of swim bladder fishes depends on many factors, but mostly on the sizes and orientation of their swim bladders. For echosounder sampling as in this survey, TS is a function of the dorsal-surface area of the swim bladder. The relationship between fish TS and total length (TL; cm) can be estimated as $TS = 20\log_{10}(TL) - b_{20}$ (dB re 1 m^2), where b_{20} is a genus or species-specific parameter. For *Engraulis*, reports of b_{20} in different systems vary by as much as 20 dB, or in linear scale, by 2 orders of magnitude (ICES, 2010). Such disparity can be partly attributed to the local behavior, physiology and depth distribution of anchovy at the time of the measurements. Recent studies have verified that increasing depth promoted a substantial reduction in TS as result of swim bladder compression (Ona, 2003; Zhao et al., 2008). When accounting for that factor, independent TS measurements of the genus *Engraulis* both in the wild (Zhao et al., 2008; Madirolas et al., 2016) and in controlled conditions (Kang et al., 2009) provided consistent b_{20}.

In 2011, a CIE panel reviewed the ATM surveys in the California Current and recommended that staff "make efforts to obtain in situ target strength measurements for CPS species in California Current Ecosystem" (Simmonds, 2011). In the summer 2016, for the first time since the review, adult northern anchovy were observed in conditions conducive to multiple independent *in situ* measurements of TS. TS of anchovy off southern California were measured for acoustically resolvable fish present during three trawl surveys in which catches of anchovy comprised more than 99% of all CPS with swim bladder. The mean TS = -45.3 dB (sd =5.7) of *in situ* anchovy with mean TL = 12.1 cm (sd=1.1) indicates a b_{20} = 67.3 dB. Taking into consideration the average depth of the observations (mean = 13 m; range = 9.9 - 18.7 m) the value is nearly identical to that of the reported for Japanese anchovy (*Engraulis japonicus*; Kang et al., 2009), when compensated for swim bladder compression (Zhao et al., 2008), i.e., b_{20} = 67.2 dB. This evidence indicates that the TS to TL model from Kang et al. (2009) likely provides a better basis for TS estimation for northern anchovy than the TS to TL model previously used, which was based on measurements from *Engraulis capensis* off South Africa (Barange et al., 1996). Applying the TS to TL model of Kang et al. (2009) to a depth of 21.0 m, the depth of the center of mass of the daytime anchovy schools observed acoustically during the summer 2016 survey, results in a b_{20} estimate of 68.1dB. Therefore, the following TS equation was used in this analysis:

$$TS = 20\log_{10}(TL) - 68.1 \text{ dB} .$$

Fish biomass densities were calculated for 100-m intervals by dividing the integrated area backscatter coefficients for each species by the mean backscattering cross-sectional estimated in the nearest cluster. Survey data were post-stratified to account for spatial heterogeneity in sampling effort and anchovy density in a similar way to that performed for Pacific sardine (Zwolinski et al., 2016). Total biomass in the survey area was estimated as the sum of the biomasses in each individual stratum. Sampling variance in each stratum was estimated from the inter-transect variance, and total sampling variance was calculated as the sum across strata (Demer et al., 2012; Zwolinski et al., 2012). The 95% confidence intervals were estimated as the 0.025 and 0.975 percentiles of the distribution of 1000 bootstrap survey-mean biomass densities. The bootstrap estimates were constructed by resampling the transects within the strata with replacement (Efron, 1981). Coefficient of variation (CV) for each of the mean values was obtained by dividing the bootstrapped standard errors by the point estimates (Efron, 1981).

Results

The summer survey totaled 4,627 n.mi. of daytime east-west tracklines, which represents a 77% increase over the tracklines sampled in 2015 (Zwolinski et al., 2016). One hundred and sixty nighttime surface trawls were performed and were further combined into 58 trawl clusters. Three post-survey strata were defined considering transect spacing, and the densities of echoes attributed to anchovy (Figures 1 and 2; Table 1).

The central subpopulation of northern anchovy was spread off the coast of central California, and to a lesser extent in the Southern California Bight (Figures 1 and 2). The biomass of northern anchovy was estimated at 151,558 t, $CI_{95\%}$ = [34,806; 278,024] t, CV =41.0% (Table 2). The distribution of density-weighted standard length (SL) had a mode at 11 cm (Table 2; Figure 4). Since the current ATM survey does not encompass the full distribution of northern anchovy, the biomass estimate provided in this report should be considered a minimum estimate in the survey area.

Discussion

Before 2015, abundances of the central sub-population of northern anchovy were estimated from egg and larval surveys to be below 20,000 t, with CVs ranging from 3% to 5.47% (MacCall et al., 2016). However, in summer 2015, the ATM survey indicated an increase in anchovy abundance, predominantly from recruitment that year (See Appendix I of Agenda Item G.4.A Supplemental SWFSC Report, November 2016). Although ATM estimates of young-of-year of small pelagics are extremely uncertain and negatively biased (Hill et al., 2016 and references therein), the widespread occurrence of young of the year anchovy in 2015 is indicative of a significantly strong recruitment. Comparing the length distributions of anchovy in 2015 and 2016 with earlier age-at-length observations (Parrish et al., 1986), it appears plausible that the larger 2016 biomass reported here, recruited in the 2015.

The area south of the U.S.-Mexico border was not sampled. Therefore, the portion of the central sub-population of northern anchovy in Mexican waters is unknown (Figure 1). Also, in the survey area, some unknown portion of the anchovy stock may have been closer to the shore than the survey ship could navigate, or residing near the surface and avoiding the ship. To quantify the magnitudes of these potential biases, the acoustic-trawl survey has been augmented in 2017 with drone-based aerial-optical observations of near-surface fish schools in proximity to the ship and close to shore.

The TS measurements of *in situ* northern anchovy (*Engraulis mordax*) made during the summer 2016 survey were nearly identical to those for Japanese anchovy (*Engraulis japonicus*; Kang et al., 2009) compensated for swim bladder compression at depth (Zhao et al., 2008). While application of TS to TL model from Kang et al. (2009) likely provides a better basis for estimating northern anchovy biomass, previous estimates were based on the Barange et al. (1996) TS to TL model. In 2015, biomass was estimated to be 31,427 mt, and applying the same model (Barange et al., 1996) to the 2016 data results in a biomass estimate of 290,159 mt (CV=50.1%). While the TS to TL equation used in this study is supported by recent studies and contemporary observations, the large variability observed indicates that further research, in particular tank trials at the SWFSC and *in situ* TS measurements are necessary to estimate the TS of northern anchovy (*Engraulis mordax)* in conditions similar to those of the surveys in the California Current.

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Table 1. Northern anchovy biomass (metric tons) by stratum for the summer 2016 survey (see Figure 2).

Stratum		Transect		Trawls		Anchovy		
Name	**Area ($n.mi.^2$)**	**Number**	**Distance (n.mi.)**	**CPS clusters**	**Number of Anchovy**	**Biomass (10^3 tons)**	**95% confidence interval (10^3 tons)**	**CV (%)**
1	4740	14	490	4	13657	1.482	0.338 – 2.720	45.8
2	2084	5	202	2	5196	136.30	19.23 – 262.10	45.4
3	9981	18	989	11	6306	13.77	6.773 – 21.208	27.6
1+2+3	**16806**	**37**	**1680**	**17**	**25159**	**151.558**	**34.81 – 278.02**	**41.0**

Table 2. Northern anchovy abundance versus standard length for the summer 2016 surveys.

Standard length (cm)	Abundance (millions)
4	0
5	0
6	9.41
7	10.65
8	126.08
9	848.90
10	3107.99
11	6456.21
12	1188.75
13	151.35
14	2.58
15	0.15
16	0
17	0
18	0
19	0
20	0

Figure 1. Summer 2016 results: Nautical area scattering coefficients (s_A, m^2 $n.mi.^2$) from coastal pelagic fish species (CPS; left); acoustic proportions of CPS in trawl clusters (right), including northern anchovy (*Engraulis mordax*), Pacific mackerel (*Scomber japonicus*), jack mackerel (*Trachurus symmetricus*), and Pacific herring (*Clupea pallasii*).

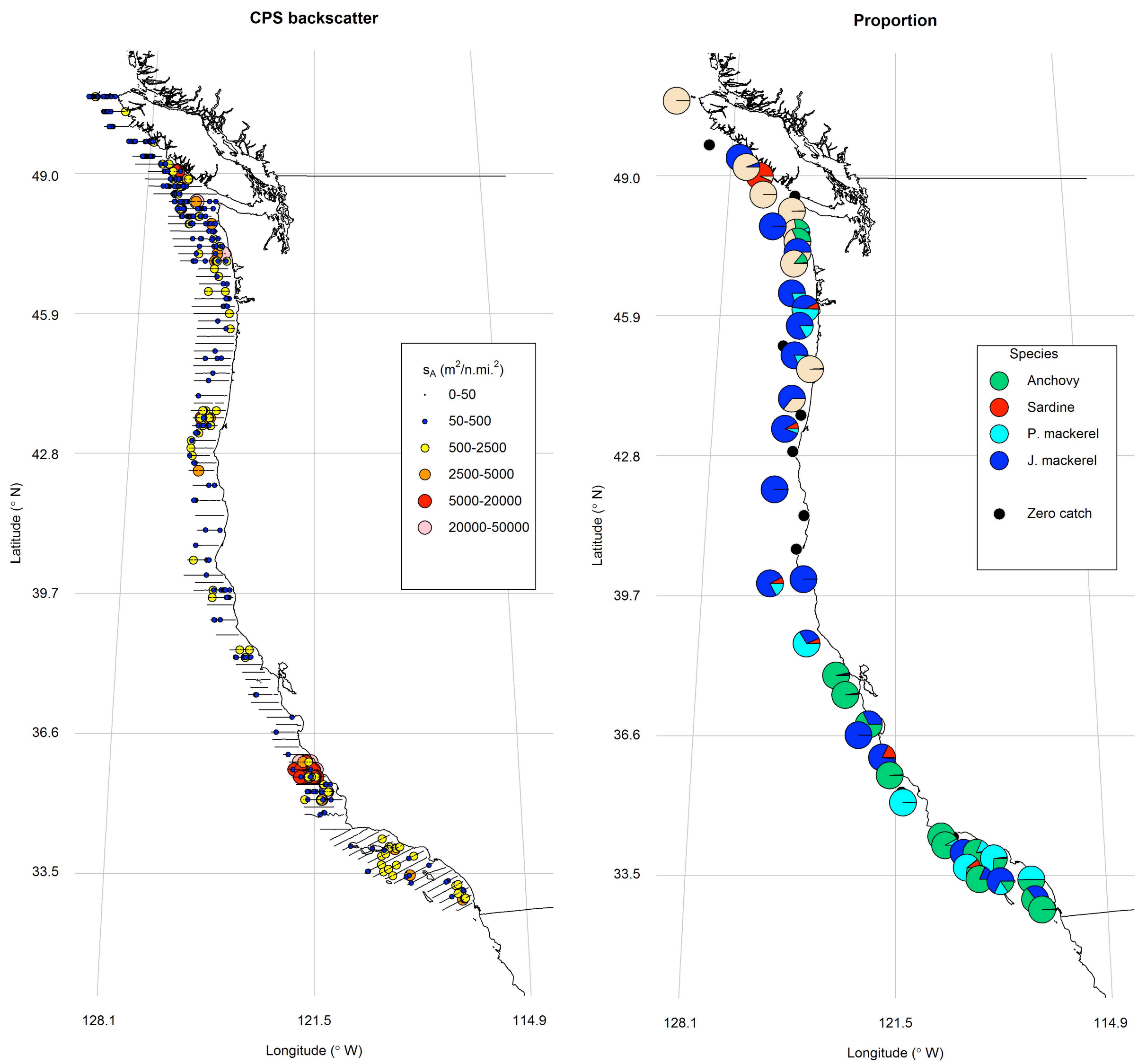

Figure 2. Biomass densities of the central sub-population of northern anchovy in the three strata off central and southern California (Table 1) estimated using the acoustic-trawl method in summer 2016. The blue numbers represent the locations of trawl clusters with at least one anchovy (Figure 3).

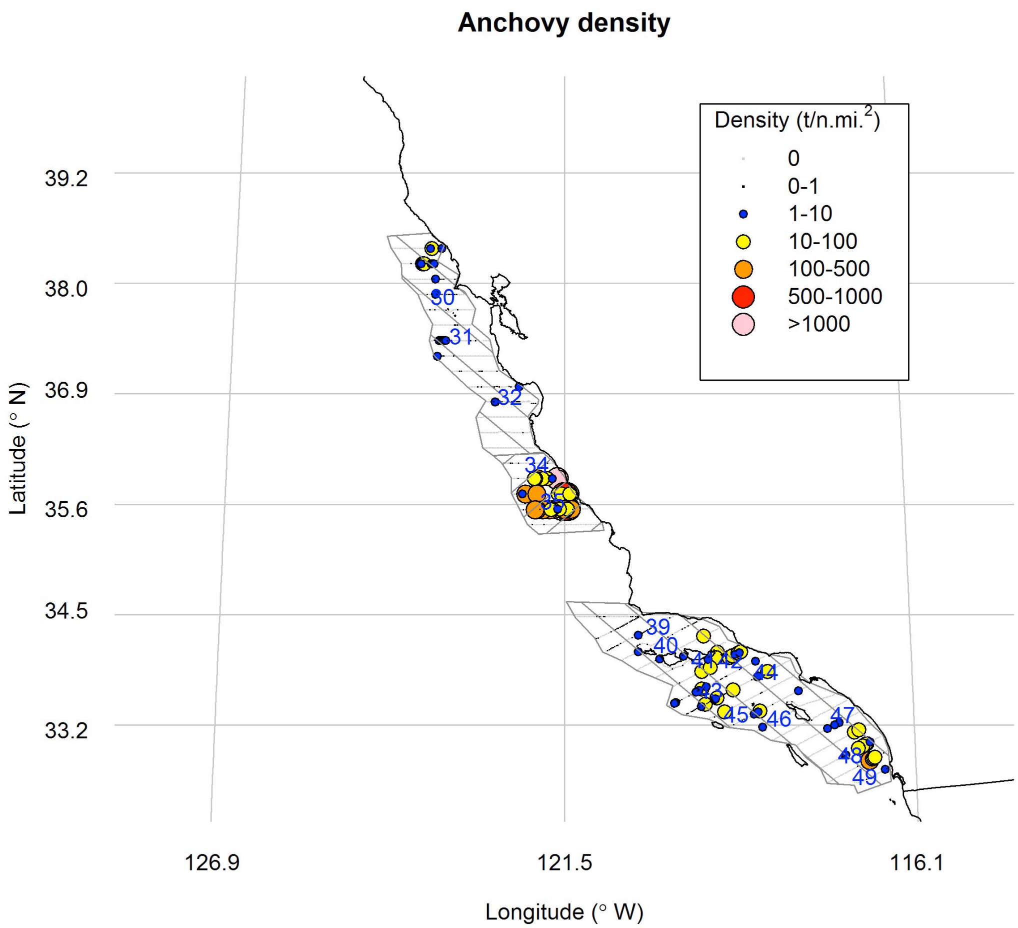

Figure 3. Standard-length distributions of anchovy per stratum and nighttime cluster (Figure 2), the number of individuals caught, and their percentage contribution to the density-weighted length distribution in the respective stratum.

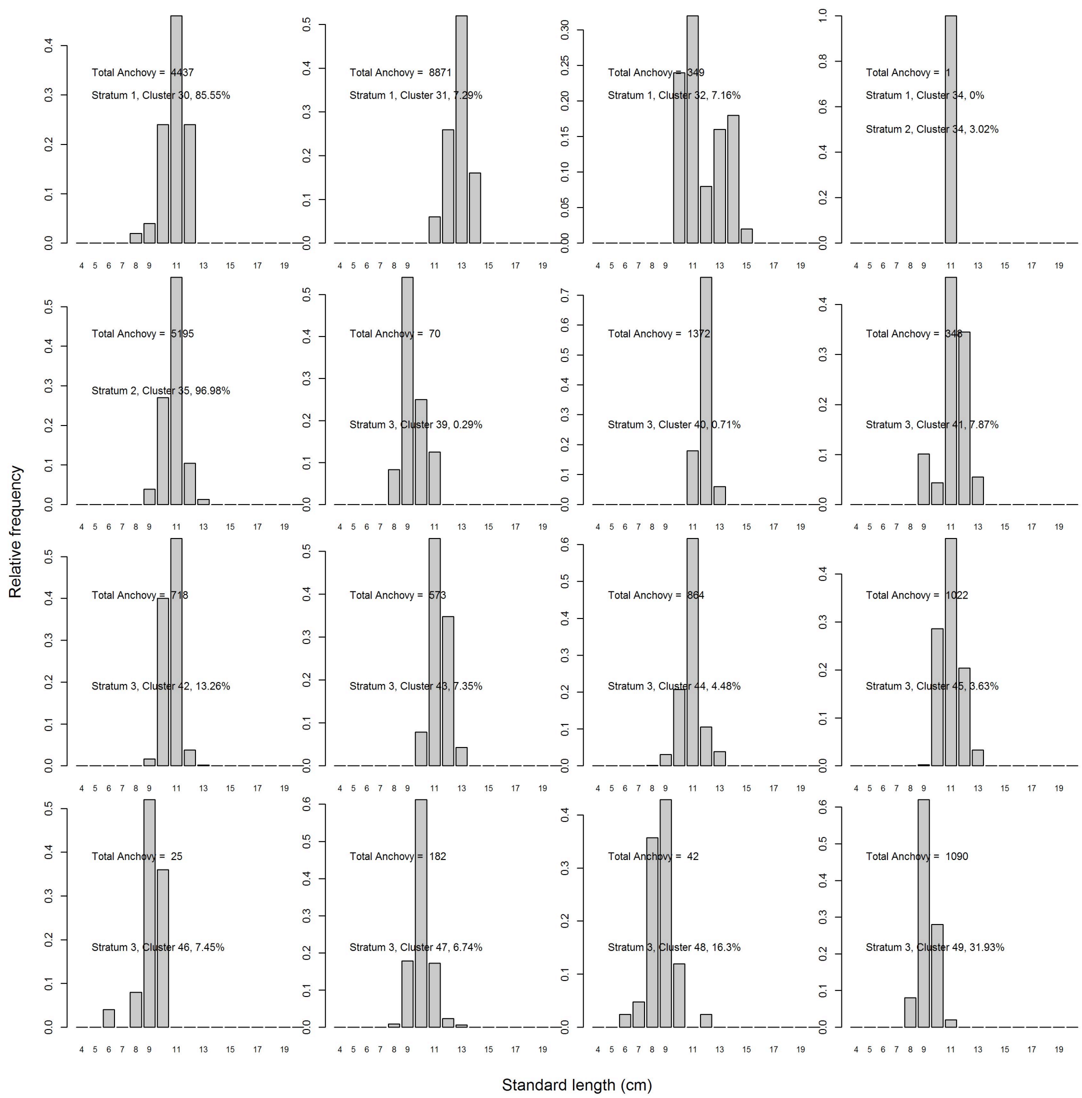

Figure 4. Estimated length-disaggregated abundance (upper panel) and biomass (lower panel) of the central stock of northern anchovy in the survey area (Figure 2) during the 2016 summer survey.