doi:10.7289/V5/TM-SWFSC-559

NOAA Technical Memorandum NMFS

APRIL 2016

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U.S. DEPARTMENT OF COMMERCE
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Summary

The biomass of the northern stock of sardine during spring 2015 was estimated using the acoustic-trawl method (ATM) to be 29,048 metric tons (t), CV = 29.9%. The stock comprised two modal lengths. The larger sardine are primarily the remnant of a stronger than average recruitment from 2010, and the smaller ones were likely sardine spawned in 2014. The ATM-estimated sardine biomass during summer 2015 was 15,870 t, CV = 80.2%. In addition to the dominant 2010 and 2014 year-classes observed in the spring, the stock also included recruits from 2015. In summer 2015, the biomass of the northern stock of sardine was the lowest, and the extent of the summer migration was the shortest since the ATM surveys began in 2006.

Introduction

The acoustic-trawl method (ATM), which combines information collected with echosounders and nets, has been used to survey Coastal Pelagic fish Species (CPS; e.g., sardines, anchovies, and mackerels) off the west coast of the United States (U.S.) for more than 40 years (Mais, 1977; Mais, 1974; Smith, 1978). Currently, the ATM is used more widely 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 ATM, multi-frequency split-beam echosounders transmit sound pulses down 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 conspicuous, 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 provided that the average backscatter of those targets is known, the acoustic backscatter can be converted to numerical density (Simmonds and MacLennan, 2005) .

Acoustic and trawl data are often collected to span the entire distribution area of stocks, providing estimates of population abundances or biomass that can then be used to inform stock assessments or provide management decisions. Decades after a successful ATM campaign to survey abundant anchovy and mackerel populations off the coast of California (Mais, 1974), the ATM was reintroduced in the California Current Ecosystem (CCE) in spring 2006 to sample the then abundant sardine population (Cutter Jr. and Demer, 2008). Since 2006, this survey 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., 2011).

Two ATM surveys were performed in 2015 off the west coast of the U.S. to estimate the abundances and distributions of CPS, together with their biotic and abiotic habitat (Zwolinski et al., *in preparation;* Stierhoff et al., *in preparation*). Presented here are the resulting estimates of northern-stock Pacific sardine (*Sardinops sagax*) abundance, demographics, and distribution during spring and summer 2015.

Methods

The 2015 surveys were conducted onboard the NOAA Fisheries Survey Vessel (FSV) *Bell M. Shimada*. Acoustic data were collected during the day to allow sampling of fish schools aggregated throughout the surface mixed layer. Trawling was conducted during the night to sample fish dispersed near the surface (Mais, 1974). The spring survey occurred over 30 days (28 March to 1 May, 2015), and transects spanned the majority of the coastal sardine potential habitat (Zwolinski et al., 2011; Demer and Zwolinski, 2014). Due to warm conditions in the northeast Pacific Ocean, the sardine potential habitat extended farther north than usual for spring, and the survey was expanded to accommodate this expansion (Fig. 1). The survey started off Newport, Oregon and progressed south to Avila Beach, California.

The summer survey occurred over 80 days (20 June to 9 September, 2015), and transects spanned the west coast of the U.S. and Canada from San Diego to the northern end of Vancouver Island (Fig. 2). Further details on echosounder calibrations, survey design, and sampling protocols are detailed in Stierhoff et al. (*in preparation*) and Zwolinski et al. (*in preparation*).

Acoustic data from each transect were processed using estimates of sound speed and absorption coefficients calculated with contemporary 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 further averaged along 100-m intervals, and the resulting nautical area backscattering coefficients (s_A; m^2 $n.mi.^{-2}$) were apportioned based on the proportion of the various CPS found in the nearest trawl cluster. The s_A were converted to biomass and numerical densities using species- and length-specific estimates of weight and individual backscattering properties (see details in Demer et al., 2012; Zwolinski et al., 2014).

Survey data were post-stratified to account for spatial heterogeneity in sampling effort and sardine density. 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 (see Demer et al., 2012; Zwolinski et al., 2012, and references therein). 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 spring survey totaled 1843 n.mi. of daytime east-west tracklines and 55 night-time surface trawls resulting in the formation of 22 clusters that were used for species identification and length measurements. The summer survey totaled 2614 n.mi. of daytime east-west tracklines and 160 night-time surface trawls combined into 58 trawl clusters. Post-survey strata were defined for each survey, considering transect spacing, echoes or catches of CPS, sardine eggs in the Continuous Underway Fish Egg Sampler (CUFES), and the presence of sardine potential habitat (Figs. 1 and 2; Tables 1 and 2).

In the spring, there were no sardine in the high-intensity upwelling region near the coast (Fig. 3). Offshore, the sardine biomass was estimated in four strata: north, central-north, central-south, and south (Fig. 3; Table 1). The north stratum contained the largest concentration of CPS backscatter, trawl clusters with sardine present, and CUFES samples with sardine eggs (Figs. 1, and 3). The total survey area contained an estimated 29 048 t of sardine, $CI_{95\%}$ = [14 510, 50 650] t, CV = 29.9% (Table 1). The distribution of abundance-density weighted standard length (SL) had modes at SL = [19, 20] and [24, 25] cm (Table 3; Fig 4). The larger-sized cohort was first observed in the spring 2011 survey as sardine between 16 and 20 cm SL (Zwolinski et al. 2014). The absence of sardines in the spring 2010 survey (Zwolinski et al. 2014) indicates that the cohort was likely spawned in 2010. By the same reasoning, the smaller-sized cohort, first observed in the spring 2015 survey, is likely comprised of sardine spawned in 2014.

In the summer, the sardine potential habitat extended to the north of Vancouver Island, and the sardine stock was geographically split, with one portion centered off central California and the other off Oregon (Fig. 2). This northern extent of the sardine summer distribution was the farthest south since the summer ATM surveys began, in 2008. The survey area contained an estimated 15 870 t of sardine, $CI_{95\%}$ = [1 450, 44 620] t, CV = 80.2% (Table 2). The distribution of abundance-density weighted SL had a mode at [24, 25] cm (Table 3; Fig 6). This mode was exceeded in numbers, but not in biomass, by a 2015 cohort with SL = [6, 7] cm. The sardine from the putative 2010 and 2014 cohorts were found exclusively off Oregon, whereas those from the putative 2015 cohort were found off central California (Figs. 5 and 6). In 2015, despite some recruitment from 2014 and 2015 year-classes, the stock biomass is the lowest since 2006.

Discussion

The 2015 spring and summer ATM estimates of sardine biomass and demography are coherent, although the summer survey also indicated recruitment of sardine born in early 2015. While sardine potential habitat has continued to extend to north Vancouver Island during summers, the stock has not migrated there since 2013 (Zwolinski et al., 2014) and the migration of the declining stock has progressively contracted.

Acknowledgements

We thank David Griffith, Amy Hays, Sherri Charter, Sue Manion, Bill Watson, and others from the SWFSC for collecting and processing the trawl and plankton samples. We thank Gerard DiNardo, Paul Crone, and Emmanis Dorval for their constructive critiques of this work.

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Table 1. Sardine biomass by stratum during the spring 2015 survey (see Figs. 3 and 4).

Stratum		Transect		Trawls		Sardine		
Name	**Area (n.mi.^{2})**	**Number**	**Distance (n.mi.)**	**CPS clusters**	**Number of sardine**	**Biomass (10^3 tons)**	**95% confidence interval (10^3 tons)**	**CV (%)**
North	9217	7	501	5	31	22.118	8.011 – 42.471	37.9
Central-North	1134	2*	122*	3*	3	0.024	0.001 – 0.054	84.7
Central-South	5606	4	242	3	30	5.060	2.052 – 7.948	28.4
South	4466	2	131	3	3	1.8450	0.499 – 3.098	48.9
Total	**20423**	**13**	**875**	**9**	**64**	**29.048**	**14.506 – 50.653**	**29.9**

*The Central-North stratum had its average density obtained from the nearest transect in each of the adjacent strata.

Table 2. Sardine biomass by stratum during the summer 2015 survey (see Figs. 5 and 6).

Stratum		Transect		Trawls		Sardine		
Name	**Area (n.mi.^{2})**	**Number**	**Distance (n.mi.)**	**CPS clusters**	**Number of sardine**	**Biomass (10^3 tons)**	**95% confidence interval (10^3 tons)**	**CV (%)**
North	1346	2	86	2	1	0.000	0.000 – 0.000	52.4
Central-North	7555	8	376	9	1969	14.387	0.195 – 42.594	92.2
Central-South	9359	13	508	10	574	1.480	0.542 – 2.734	37.1
South	6506	9	321	6	3	0.004	0.000 – 0.008	53.7
Total	**24767**	**32**	**1290**	**27**	**2547**	**15.870**	**1.450 – 44.620**	**80.2**

Table 3. Sardine abundance versus standard length for spring and summer 2015 surveys.

	Spring	Summer
Standard length (cm)	**Abundance (millions)**	**Abundance (millions)**
4	0	0
5	0	0.58
6	0	139.34
7	0	108.29
8	0	62.56
9	0	0.13
10	0	0
11	0	0
12	0	0
13	0	0
14	0	0
15	0	0
16	0	0
17	0.70	0
18	0	0
19	14.56	0
20	44.24	1.44
21	0	4.32
22	0	1.48
23	3.98	2.88
24	65.09	20.79
25	43.09	37.76
26	7.28	5.13
27	0	0.04
28	0	0
29	0	0
30	0	0

Figure 1. Spring 2015 results. Acoustic backscatter (s_A, m^2 n.mi.^{2}) from coastal pelagic fish species (CPS) superimposed on the distribution of potential sardine habitat (dashed lines) defined at the mid-period of the survey (left); acoustic proportions of CPS in trawl clusters, including northern anchovy (*Engraulis mordax*), Pacific mackerel (*Scomber japonicus*), jack mackerel (*Trachurus symmetricus*), and Pacific herring (*Clupea pallasii*) (middle); and density (eggs min^{-1}) of sardine eggs from the continuous underway fish egg sampler (right).

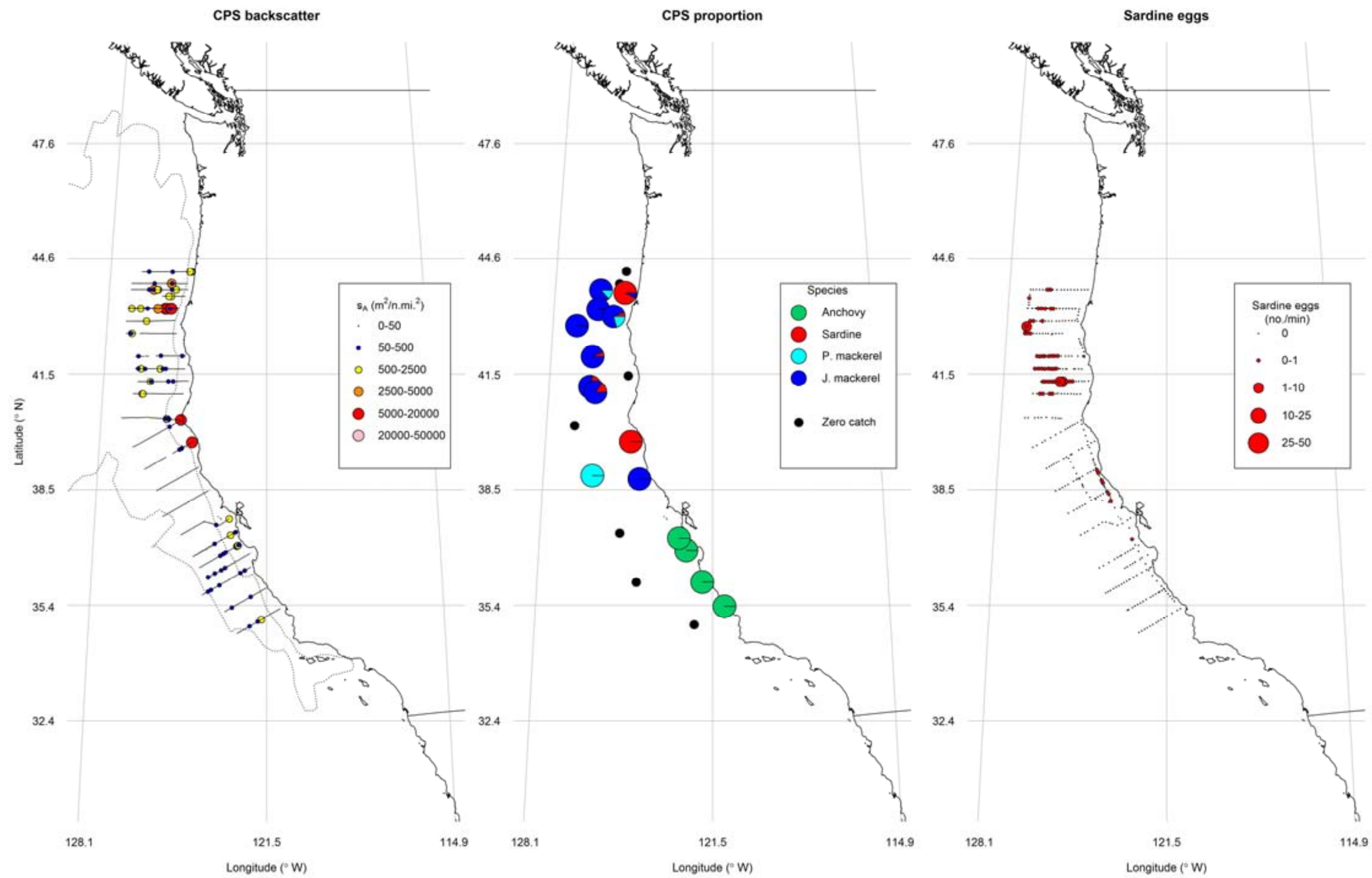

Figure 2. Summer 2015 results. Acoustic backscatter (s_A, m^2 $n.mi.^2$) from coastal pelagic fish species (CPS; left); acoustic proportions of CPS in trawl clusters (right), including northern anchovy (*Engraulis mordax*), Pacific mackerel (*Scomber japonicus*), jack mackerel (*Trachurus symmetricus*), and Pacific herring (*Clupea pallasii*). Egg samples are not shown because the primary spawning period for sardine is during spring.

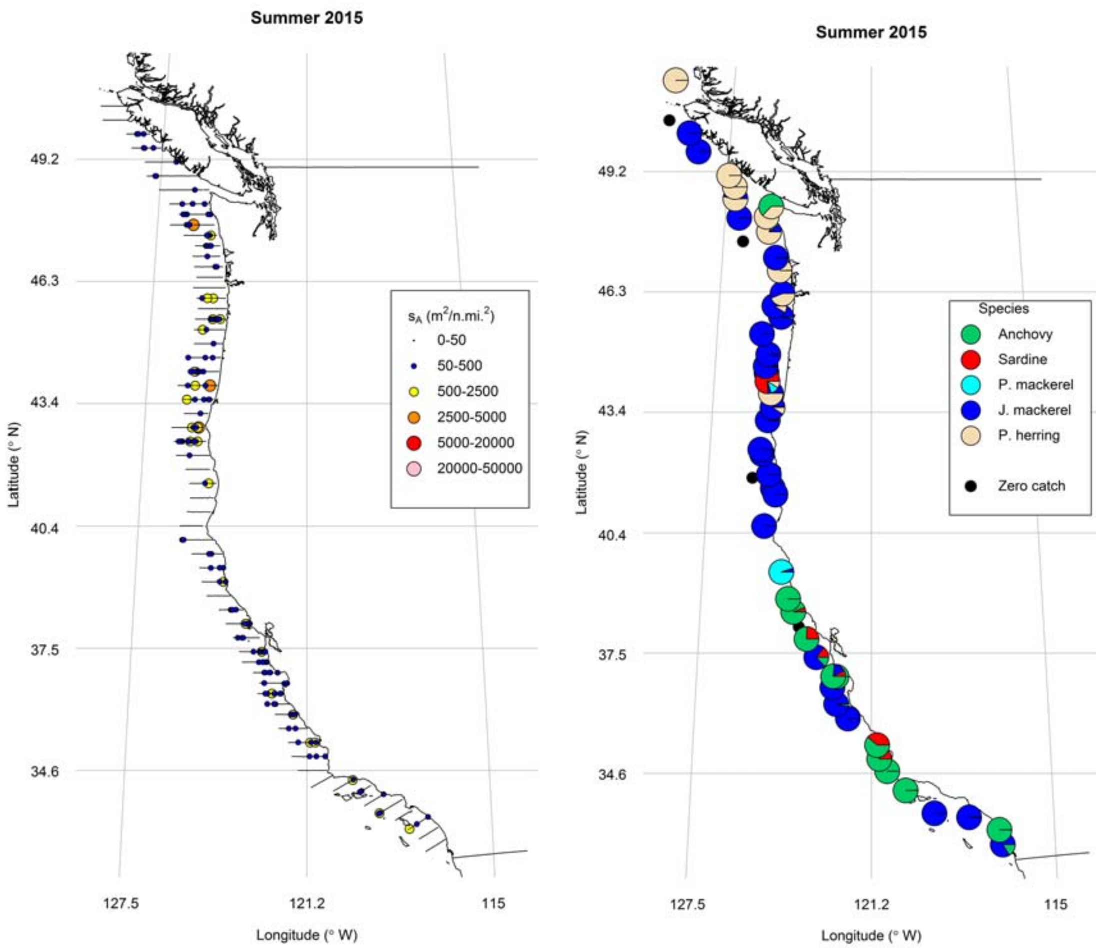

Figure 3. Sardine biomass densities versus stratum (Table 1) estimated using the acoustic-trawl method in spring 2015. The blue numbers represent the locations of trawl clusters with at least one sardine.

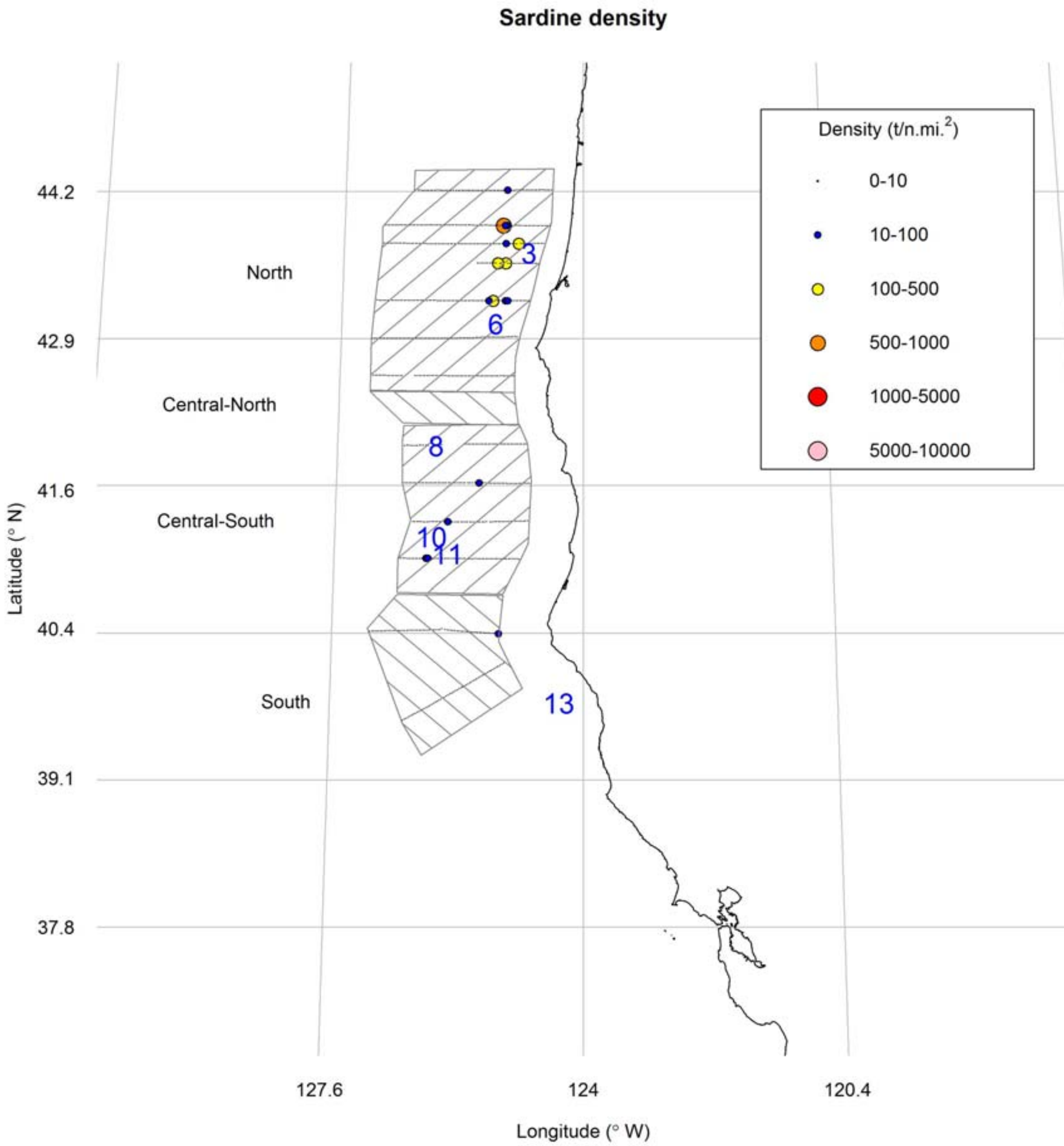

Figure 4. Estimated sardine abundance by length-class for the entire survey area and for the three main strata (Fig. 3) for the spring 2015 survey. The corresponding number of sardine sampled in each stratum is provided in Table 1. The contribution from the Central-North stratum to the total abundance was negligible and therefore its data are not included.

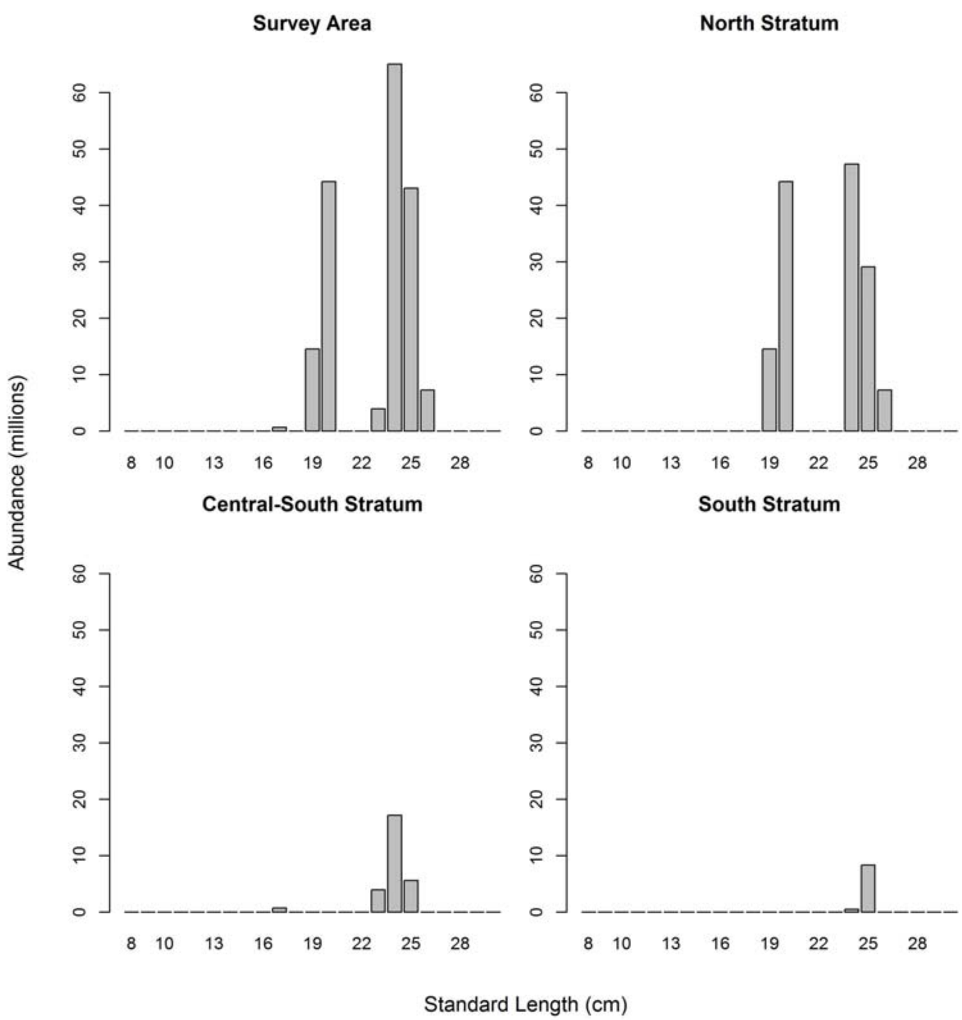

Figure 5. Sardine biomass densities versus stratum (Table 2) estimated using the acoustic-trawl method during summer 2015. The blue numbers represent the locations of trawl clusters with at least one sardine.

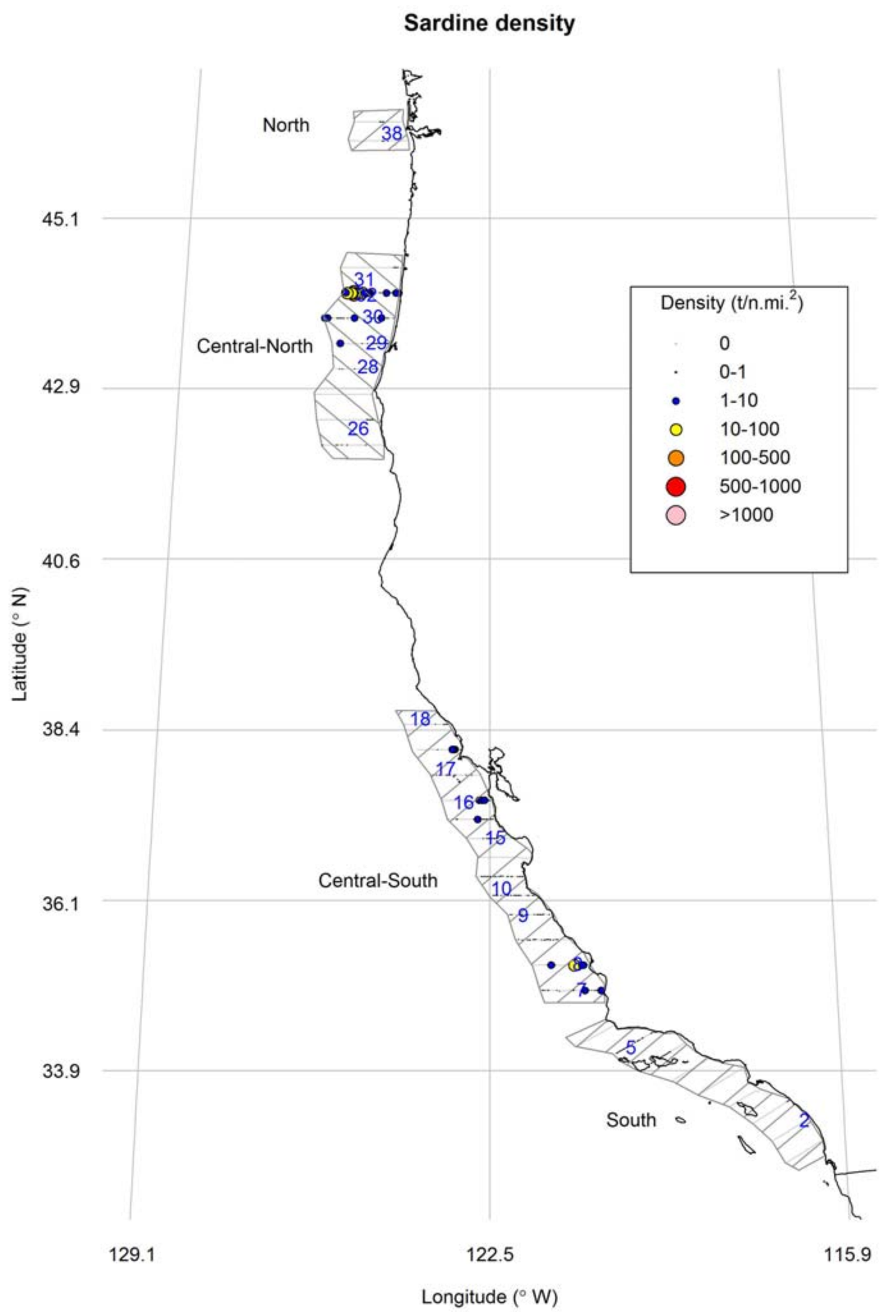

Figure 6. Estimated sardine abundance by length-class for the entire survey area and for the three main strata (Fig. 5) for the summer 2015 survey. The corresponding number of sardine sampled in each stratum is provided in Table 2. The contribution from the North stratum to the total abundance was negligible and therefore its demographics not included.