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Aerial sardine surveys in the Southern California Bight

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Current survey indices used in annual stock assessments to manage the federal Pacific sardine (*Sardinops sagax caerulea*) fishery do not include nearshore sardine biomass in southern California waters. This survey uses direct observer estimates of sardine biomass in nearshore and offshore waters of the Southern California Bight to calculate an index of relative abundance. Surveys have been conducted since summer of 2012 and have continued through the spring and summer 2013 seasons. Aerial identifications of fish school species have been validated using boat sampling of aerial sightings, and demographic information obtained from collected samples. Additionally, habitat analyses compared sardine distribution with environmental variables (sea surface temperature and chlorophyll *a* concentrations).

Key Words: sardine, *Sardinops sagax caerulea*, Southern California Bight, aerial survey, fishery management

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Pacific sardine (*Sardinops sagax caerulea*; sardine) is an important commercial fishery off the Pacific coast of North America. Once the largest fishery in North America, it has rebounded from a stock collapse in the 1940s to rank among the top fisheries in California since the early 1990s. Two seasonally migrating stocks inhabit the waters of the California Current, a northern stock ranging from Punta Eugenia, Mexico to southern Alaska; and a southern stock from southern Baja California, Mexico to Point Conception, California (Felix-Uraga et al. 2004, 2005; Smith 2005). The fishery, as defined by the northern stock, has been federally managed since 2000 by the Pacific Fishery Management Council (PFMC) under the Coastal Pelagic Species Fishery Management Plan (PFMC 1998). Annual coast-wide harvest limits for the northern stock are derived from biomass estimates generated by an annual stock assessment (Hill et al. 2014). The stock assessment develops a population model that incorporates various data sources, such as age, other biological information, and multiple research surveys. Surveys have included daily and total egg production (DEPM, TEP) surveys conducted in the spring by the Southwest Fisheries Science Center (SWFSC) of the National Marine Fisheries Service (NMFS) in offshore waters within and around the Southern California Bight (SCB) and off the central coast of California (Lasker 1985, Lo et al. 2011); SWFSC coast-wide acoustic-trawl surveys (Demer et al. 2012); and an aerial survey in the Pacific Northwest conducted since 2009 by the northwest sardine fishing industry (NWSS; Jagielo et al. 2012). The sardine stock assessment has previously used aerial survey results from a spotter pilot survey, which was flown from 1985 to 2005 and covered the area from central California to Baja California, Mexico; however, this survey was removed from the assessment in 2007 (Lo et al. 1992, Hill et al. 2007).

The primary goal of our study was to collect data on distribution and abundance of sardine to ultimately determine a relative index of abundance for use in management. The survey added other pelagic species (CPS) such as northern anchovy (*Engraulis mordax*), Pacific mackerel (*Scomber japonicas*), and jack mackerel (*Trachurus sympetricus*) beginning with the summer season in 2013. These data were collected adapting previous aerial survey methods for use over southern California waters (Lo et al. 1992, Jagielo et al. 2012). In collaboration with the California Wetfish Producers Association (CWPA), we conducted daytime aerial surveys of southern California waters in 2012 and 2013, and included sampling effort in both open water areas and along mainland and island coastlines. The sampling of nearshore waters inside of 5.6 km from shore was important for two principal reasons: (1) in contrast to sardine aggregations typically observed in offshore, or open, waters of Washington and Oregon, sardine in California waters are more often seen in aggregations along the coast (Diane Pleschner-Steele, CWPA, personal communication); and, (2) no other survey adequately covers the coastal nearshore area within the 2.8-km range from shore. By covering nearshore areas, this survey can restore information about nearshore sardine abundance that was lost in removal of the spotter pilot survey from recent stock assessments. If results from future aging analyses indicate that the fish observed during the present survey are predominantly young recruits, the survey index would also constitute an index of recruitment. Through application of boat-sampling methods, we have not only sought to validate aerial species identification but also to collect data on size and age composition of sardine observed during the survey. Finally, data on environmental conditions such as sea surface temperature (SST; °C) and chlorophyll *a* concentrations associated with sardine observations were collected and mapped to characterize sardine habitat.

Materials and Methods

Study areas.—Our survey was conducted in waters off southern California, from near Point Conception to the U.S.-Mexico border, extending to approximately 120 km offshore. Specifically, the study area was defined by a straight line from Point Conception south to the western edge of California Department of Fish and Wildlife (CDFW) fishing block 657, south to block 732, and continuing southeastward from the southwest corner of block 732 to the southwest corner of block 884, along the southern boundary of block 884 to the southwest corner of block 878 and extending to the mainland (Figure 1).

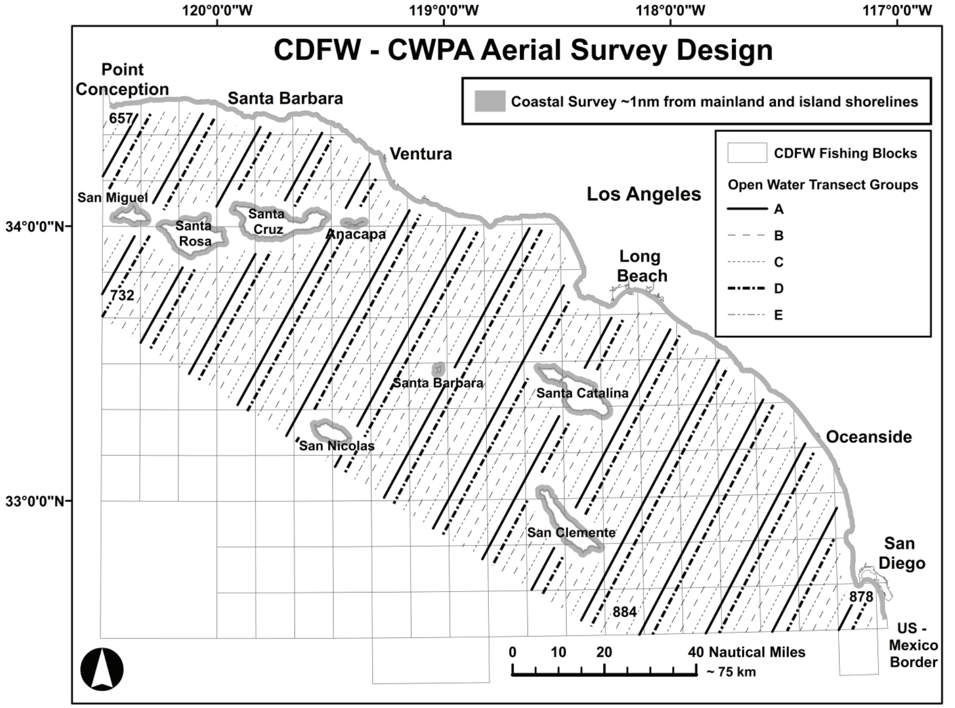

FIGURE 1.—Sampling design for aerial sardine surveys on coastal and open water transects in the Southern California Bight during 2012 and 2013. The surveys included coastal areas of the mainland and Channel Islands in the Southern California Bight, in addition to 16 open-water transects extending from shore. Open-water transects (Groups A-E) for random selection were arranged in five staggered groups separated by three nautical miles (~5.6 km). Group A was flown in summer 2012, and Group D in both spring and summer 2013.

The survey included two types of transects, one for the nearshore coastal area and one for the offshore open water area (Figure 1). For each season, transects were flown only once. Nearshore coastal transects were flown along the coastlines of the mainland and each of the Channel Islands, and were 1.8–2.8 km offshore, depending on the presence of macroalgae and variable contours of the coastline. Coastal transect width extended to the shore, except where visibility was limited by macroalgae. Open water transects were flown along sixteen transect lines spaced 27.8 km apart, originating at 5.6 km from the mainland and extending offshore to the outer Channel Islands. Open water transects were specifically designed to avoid intersection with coastal sampling areas; if these transects passed over islands, they ended and resumed at 5.6 km from island shorelines. Ocean surface area that did not fall either within the defined coastal sampling area of 1.8 km from shore, or within a 2.8-km strip on one side of an open water transect line was considered to be unsampled open water area.

We surveyed in summer (July–August) 2012, spring (April–May) 2013, and summer (August–October) 2013. The summer 2012 survey design used Group A for the open water transects (Figure 1). In 2013, open water transects were randomly chosen from 5 options: the 2012 design (Group A) and four others (Groups B, C, D, and E) based on offsetting the Group A transects by 5.6-km increments. Group D was selected for both the spring and summer 2013 surveys.

Aerial surveys.—Timing and selection of transects to be flown during a field season were dependent on weather conditions and availability of staff and aircraft. For a chosen flight day, the determination of which specific transects were to be flown was contingent on local weather conditions and military and other airspace restrictions that day. Strip transects were flown using a CDFW Partenavia P.68 observer aircraft with an experienced industry spotter pilot serving as observer looking to the right. Coastal transects were flown at 325 m altitude to maximize observer identification, and open water transects at 650 m to maximize observer coverage and transect width. When fish schools were identified and confirmed, the aircraft was redirected directly over the fish. Photos were taken with a forward motion compensating (FMC) Nikon D700 camera system oriented downward through the open belly port of the plane. Images were taken at 60 percent photo overlap during the summer 2012 and spring 2013 seasons, and at 80 percent overlap for the summer 2013 season. The camera system software was interfaced with a GPS unit to record time, location, speed, altitude, and other information with each image taken. We recorded on a log sheet the time and frame number when photos of fish were being taken, the observer-estimated number of schools and metric tonnage (mt), including percent species composition of mixed schools, and other relevant comments such as weather, viewing conditions, and plane actions. Photos were used to supplement field notes for school location, size, and count. Additional schools seen on photos were verified with the observer, and if confirmed, were added to field-collected data and included in analyses. After observed schools were photographed, the plane and crew returned to the transect flight line path and resumed the survey. Starting in summer 2013, at the conclusion of each flight day on which fish were observed, we reviewed the photos and identified and matched those photos with log sheet information on time, location, and estimated mt and numbers of schools.

Boat sampling.—Separate flights from the transect flights were paired with boat-based sampling of CPS schools observed from the air. Boat surveys were guided by aircraft observations of CPS to specific areas for sampling. For both 2012 and 2013, we sampled in waters off Santa Catalina Island and off the northern Orange County coast. We used an 8.2-m Almar rigid hull inflatable vessel equipped with two 200 HP Yamaha marine outboard engines. Underwater video and hook-and-line sampling methods were used to validate aerial observer identification of species, and to provide information on size, maturity, and age of the observed fish. The 2012 sampling was done using a Deep Blue Pro Color tow camera and hook-and-line gear. Due to challenges from the tow camera disrupting fish behaviors and also to poor image visibility, beginning in 2013 video sampling was done by divers using a GoPro black edition (12 mp, F/2.8, 1080p) camera. Hook-and-line samples were collected using sabiki rigs with sizes 4, 6, and 8 hooks. A Secchi disk was used to determine water clarity, and a Bio Marine model ABMTC refractometer was used to measure salinity and specific gravity of the water. We also collected information on SST, temperature at depth, school density at relative depths, and water depth from SONAR. Sampled fish were bagged, tagged according to school, and preserved in ice for lab work. Once in the lab, we processed samples and recorded weight, length, sex, maturity, and age data (Yaremko 1996). Aerial species identifications were noted and compared with results of boat sampling.

Data analyses.—We calculated separate estimates of abundance for each season based on transect type. Estimates of abundance for mainland areas were the observer estimates in the field. Abundance estimates and standard errors for both island and open water areas were calculated using islands (n=8) and open water transects (n=16) as sampling units, respectively. The coastal mainland and island transects were considered to be a census of those areas, and we extrapolated the densities seen on the open water transects out to the entire open water area covered by those transects. We used 1.8 km as the coastal transect width and 2.8 km as the open water transect width. These were determined in consultation with the observer, as best representing the visible range and thus width of the survey strip for each type of transect.

Standard errors were calculated from estimates of variance for sampling with variable transect lengths (Buckland et al. 2001). We used R statistical software (Version 3.0.0) to run statistical comparison tests to determine if transect type (coastal mainland, coastal island, and open water) made a significant difference for any of three variables (mt, school count, and average school size) for each season and paired-season combination. The data failed to meet assumptions for ANOVA, so we tested for significance within season variables with a Kruskal-Wallis Rank Sum Test (Kruskal and Wallis 1952). Significant results from this test were then run through a Mann-Whitney *U* Test with Bonferroni correction to identify the source of the significant differences (Mann and Whitney 1942, Abdi 2007).

Habitat mapping.—Sea surface temperature and chlorophyll *a* (mg/m^3) were used as measures of habitat characteristics associated with the fish school observations. These data were collected from the NASA Aqua MODIS sensor, and were obtained by download from the NOAA Coastwatch website (http://coastwatch.noaa.gov/). Sea surface temperature data were downloaded as grid data at 0.0125 degrees resolution for daytime Western US coverage in a .nc file format suitable for import into ESRI ArcMap 10.1. For each fish school observation, SST or chlorophyll *a* data were selected based on the minimum temporal duration available for that observation date. In most cases, intraday or three-day average data were available; however, in a small number of cases, eight-day average data were used. Field data on sardine location, SST, and chlorophyll *a* were then imported and mapped in ArcMap 10.1 to determine the value of SST or chlorophyll *a* located nearest to each fish school observation. For those fish school observations that did not fall directly within a SST or chlorophyll *a* grid cell, the value of SST or chlorophyll *a* nearest each such observation was used.

Results

Aerial surveys.—A total of 105 observations (observations = positive fish sightings) were made (Table 1) on sardine and other CPS aggregations during the three combined seasons of summer 2012, spring 2013, and summer 2013. These sightings were predominantly nearshore (Figure 2), with 90 of 105 (86%) of total observations occurring within coastal areas. Of these 90 coastal observations, 60 (67%) were made along the mainland and 30 (33%) were made along islands. Across all three seasons, island coastal observations were made primarily around Santa Catalina (9), Santa Cruz (8), and San Clemente (7) islands. Flights at Anacapa, San Nicolas, and Santa Barbara islands yielded two observations each and no observations were made near San Miguel Island. Observations were either single-school observations or multiple school observations. More than half (57; 54%) of all observations were single-school observations. Biomass estimates for these schools ranged from 0.5 to 80 mt. More than half of all single-school observations (29) were ≤5 mt and 81% of single-school observations were ≤15 mt.

Table 1. —Aerial observation data for the first three seasons of surveys conducted in the Southern California Bight during 2012 and 2013. Observations include single or multiple schools and estimates of tonnage are metric tons. Variation in open-water sampled areas exists because some transect segments could not be flown as a result of adverse weather conditions.

	2012 Summer	2013 Spring	2013 Summer
Number of observations	34	27	44
Estimated metric tons (observer)			
Mainland	5,069	1,186	5,362
Island	1,475	213	333
Open water	3,020	1,133	24
Total	9,564	2,531	5,718
Estimated schools (observer)			
Mainland	208	37	476
Island	97	12	44
Open water	101	17	6
Total	327	66	526
Average metric tons per school			
Mainland	24	32	11
Island	15	18	8
Open water	30	67	4
Total	29	38	11
Range of estimated metric tons per observation	1 - 3,053	1 - 1,146	1 - 3,426
Sampled Area (km^2)			
Mainland	864	864	864
Island	889	889	889
Open water	3,816	3,810	3,728
Total	5,569	5,563	5,481
Density (metric tons/km^2)			
Mainland	5.9	1.4	6.2
Island	1.7	0.2	0.4
Open water	0.8	0.3	0.006
Total	1.7	0.5	1.0

Twenty-eight single-school observations occurred along the mainland, 17 occurred off islands and 12 occurred in open water areas. Multi-school observations comprised the balance of the data set (48; 46%), with school counts per observation ranging from 2 to 366 schools and estimated biomass ranging from 1 to 3,426 mt. The majority of multi-school observations (37) consisted of 10 schools or fewer and all but three were observed along coastal areas; of these, 32 observations were from mainland transects, and 13 were from island coastal transects. Only three multi-school observations occurred in open water. Of the six largest pure sardine observations, ranging from 1,000 to 3,426 mt, three were observed along the mainland coast, two in open water and one along an island coast (San Clemente).

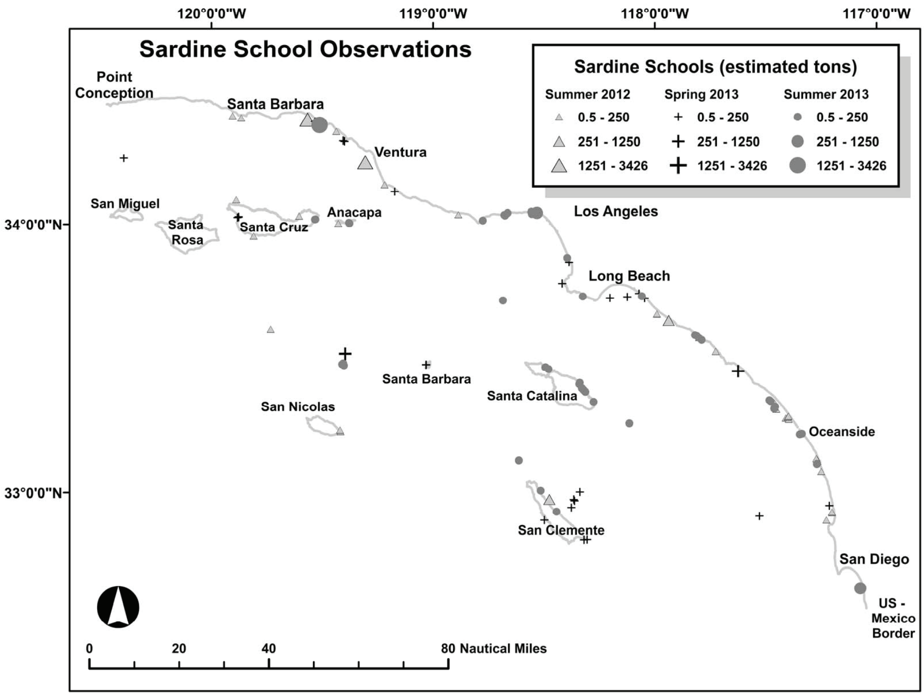

FIGURE 2.—Locations of sardine schools observed during aerial surveys in the Southern California Bight during 2012 and 2013. The largest schools were seen on the coastal shoreline between Santa Barbara and Ventura.

With respect to mixed CPS-sardine aggregations, sardine-anchovy mixes were observed along the mainland, while sardine-Pacific mackerel mixes were observed around island coasts at Santa Catalina and San Clemente. Two extremely large sardine-anchovy aggregations — in excess of 3,000 estimated mt of sardine in each case — were observed along the mainland coast between Santa Barbara and Ventura during summer 2012 and summer 2013, respectively.

During the summer 2012 season, nine survey flights were conducted from 30 July to 17 August, yielding 34 observations comprising 327 sardine schools and a total observer-estimated biomass of 9,564 mt (Table 1). Of the 34 seasonal observations, 32 (94%) were coastal, with 25 made along the mainland coast and 7 along island coasts. Most of the mainland observations (19) were made along the southern half of the coast south of Redondo Beach, Los Angeles County. Only two open water observations were made during this season. Noteworthy was the occurrence of four observations estimated at >1,000 mt and up to ≈3,000 mt. An extremely large aggregation estimated at 3,000 mt was observed along the mainland coast off Punta Gorda, Santa Barbara County.

For the spring 2013 season, during eight survey flights conducted between 22 April and 21 May, 27 observations were made on 66 sardine and mixed CPS schools estimated to comprise 2,531 mt. Of 27 observations, 20 (74%) were noted as coastal, with 12 of 20 near the mainland and eight near islands. For the seven open water observations, one was noted as consisting of 8–10 schools estimated at 1,000 mt.

The summer 2013 season was plagued with unfavorable weather conditions (persistent overcast, high winds), in addition to the challenge of flying around airspace restrictions. During 12 flight days from 1 August to 4 October, 44 observations were made, consisting of 520 schools estimated at 5,718 mt. During this season, CPS other than sardine were formally included in the survey, and aggregations were noted for sardine mixed with Pacific mackerel or northern anchovy. Total sardine biomass for these schools was estimated at 5,718 mt.

Boat sampling.—Sardine schools proved very difficult to locate and sample by boat during daytime hours. Commercial fishery landing records (CDFW Commercial Fisheries Information System [CFIS]) and personal communications with fishery participants indicated that sardine and mixed CPS schools were captured by the fishing fleet at night around Santa Catalina Island during our study periods. During the time periods of our study, more single-species and mixed Pacific mackerel and northern anchovy schools were observed during the day relative to sardine schools.

During summer 2012, six schools were examined around Santa Catalina Island and the Seal Beach, Orange County, breakwall from surveys conducted 7–8 August and 27 September (Table 2). Site conditions averaged 21.7° C SST with up to 12.2 m of visibility, and underwater footage was best on 7 and 8 August. At Santa Catalina Island, five mixed CPS schools were positively identified using frame-by-frame underwater footage at depths

Table 2.—Comparison of aerial fish species identifications with species identified by boat sampling techniques in the Southern California Bight. These paired plane-boat surveys were conducted around Santa Catalina Island, with the exception of the second rows for 27 September 2013 and 27 April 2013 off Seal Beach, and for the last two rows for 18 October 2013 off Huntington Beach Pier. There were no attempts to sample the last two aerial sightings on 18 October 2013 because of extreme surface water conditions. Samples were taken for additional lab work to characterize sardine at the time of the surveys. PS = Pacific sardine, PM = Pacific mackerel, JM = jack mackerel, NA = northern anchovy.

Date	Aerial ID	Boat ID: Dive ID	Boat ID: Video ID	Boat ID: Hook and Line ID	Samples Taken
8/7/2012					
	PM, PS	-	UNID	PM, JM	5PM
	PM, PS	-	PM, JM	PM, PS	2PM, 1PS
8/8/2012					
	PM, PS (mostly PM)	-	UNID	PM, JM	05PM, 1JM
	PM, PS	-	PM?, PS?	PM, JM, Blacksmith	9PM, 1JM
9/27/2012					
	PS, PM? (mostly PS)	-	PM, PS	PM	0
	PS, NA	-	-	lizardfish, croaker, smelt spp.	0
4/27/2013					
	Mackerel (mixed?)	PM, PS	PS, PM	PM, JM, Blacksmith	0
	NA	None	None	NA	0
5/2/2013					
	Mixed	PS	PS?	PM, PS, JM	0
	Mixed	PM, PS	PS?	PM, PS, JM	4PM, 2PS, 1JM
10/18/2013					
	Mixed, mostly PM, some PS	PM, JM, a few PS under boat	PM, JM	PM, JM	1PM, 2JM
	Mostly PM	PM, JM	PM, JM	PM, JM	20PM, 4JM
	NA	None	None	None	0
	NA	None	None	None	0

ranging from 9 to18 m ($\bar{x}$ = 10.7 m) and results from hook-and-line sampling. Overall site depths at Santa Catalina Island and Seal Beach ranged from 7.6 to 31.1 m. Depths of school and overall site depths were confirmed by SONAR images.

On 7 August 2012, one sardine was caught using a sabiki rig size 8 hook on the backside of Santa Catalina Island near Eagle Rock. Despite aerial identification of a sardine/anchovy mixed school on 27 September, green, murky conditions as well as buoyed traps at the Seal Beach breakwall made it difficult to capture them with underwater footage or hook-and-line methods. Species caught incidentally and released by hook-and-line during the three days of boat sampling included: Pacific mackerel, California lizardfish (*Synodus lucioceps*), blacksmith (*Chromis pinctipinnis*), jack mackerel (*Trachurus symmetricus*), white croaker (G*enyonemus lineatus*), and jacksmelt (*Atherinopsis californiensis*).

During 2013, eight schools were observed around Santa Catalina Island, Huntington Beach Pier (Orange County), and the Seal Beach breakwall (Orange County). Boat sampling was conducted on 27 April and 2 May during the spring, and on 18 October as a follow-up to the summer 2013 portion of the survey. Site conditions averaged 18.8 °C with visibility up to 15.0 m, and underwater footage was best on 2 May and 18 October. At Santa Catalina Island, five mixed CPS schools were positively identified by divers, frame-by-frame underwater footage at depths ranging from 7.6 to 15.2 m ($\bar{x}$ = 11.4 m), and results from hook-and-line catches. Overall site depths at Santa Catalina Island, Huntington Beach, and Seal Beach ranged from 6.1 to 76.2 m. School depths and overall site depths were confirmed by SONAR pictures.

Aerial confirmation of northern anchovy was established by hook-and-line catches outside the Seal Beach breakwall for the spring 2013 survey on 27 August. However, aerial identification of northern anchovy around Huntington Beach Pier on 18 October was not confirmed on the boat due to windy and choppy conditions. For surveys on 2 May and 18 October at Santa Catalina Island, Pacific mackerel, sardine, and jack mackerel were caught by hook-and-line; these samples confirmed aerial identification of mixed schools of sardine and Pacific mackerel. Blacksmith was also caught incidentally and released.

Results from the boat sampling were generally consistent with CPS schools identified from the aircraft (Table 2). For the 2012 boat surveys, species identification of five of six schools (84%) identified by plane were confirmed by boat sampling; in 2013, all six schools were confirmed. Two additional anchovy schools in summer 2013 were identified from the aircraft, but boat sampling was not attempted due to rough waters. In some cases, positive identification of species was difficult due to poor video quality or potentially insufficient sampling by hook-and-line.

Data analyses.—Overall sardine biomass estimates have declined since the first season in summer 2012 (Table 3). Mainland biomass has remained relatively constant over the two summer seasons, but estimated biomass for island and open water areas greatly declined across all seasons. Large standard errors are due to the small number of sampling units, but the estimates still illustrate a decline in observed abundance.

The Kruskal-Wallis test revealed three season-variables as significant: summer 2013 mt, summer 2013 school count, and (spring 2013+summer 2013) school count (Table 4). This result indicated that within these season-variables was a pair of transect types that differed significantly. Subsequent Mann-Whitney multiple comparison tests with a Bonferroni correction revealed significant differences between coastal mainland and open water data for summer 2013 mt, summer 2013 school count, and (spring 2013+summer 2013) school count (Table 5).

Table 3.—Sardine biomass estimates by transect type and season in the Southern California Bight during 2012 and 2013. Mainland estimates are from single-survey replicates. Island and open water estimates and standard errors are calculated from multiple sampling units per season (individual islands and open water transects, respectively).

	Biomass estimates (mt)		
Location	2012 Summer	2013 Spring	2013 Summer
Mainland	5,069	1,186	5,362
Island (n=8)	1,475	213	333
Standard error	957	194	196
Open water (n=16)	23,321	8,501	199
Standard error	25,085	8,107	136

Table 4.—Results of Kruskal-Wallis tests comparing season-variables for transect types (nearshore coastal and open water) from aerial sardine surveys conducted in the Southern California Bight during 2012 and 2013.

Season	Variable	KW $\chi 2$	*df*	*P*
Summer 2012	Tons	1.85	2	0.40
	School count	0.51	2	0.77
	Mean school size	2.10	2	0.35
Spring 2013	Tons	0.55	2	0.76
	School count	0.55	2	0.76
	Mean school size	1.38	2	0.50
Summer 2013	Tons	8.47	2	< 0.05
	School count	7.74	2	< 0.05
	Mean school size	3.82	2	0.15
Summer 2012 + Spring 2013	Tons	0.96	2	0.62
	School count	0.27	2	0.88
	Mean school size	2.66	2	0.26
Summer 2012 + Summer 2013	Tons	4.28	2	0.12
	School count	3.84	2	0.15
	Mean School Size	3.08	2	0.21
Spring 2013 + Summer 2013	Tons	3.12	2	0.21
	School count	7.47	2	< 0.05
	Mean school size	0.61	2	0.74

Table 5.—Mann Whitney *U* test results for significance among transect types for season-variables from aerial sardine surveys conducted in the Southern California Bight during 2012 and 2013. A Bonferroni correction was applied, resulting in α=0.0167.

Season	Variable	Comparison	*W*	*P*
Summer 2013	Metric tons	Coastal Mainland v. Coastal Island	118.5	0.1098
		Coastal Mainland v. Open Water	117.5	< 0.0167
		Coastal Island v. Open Water	69.0	0.0660
	Schools (*n*)	Coastal Mainland v. Coastal Island	123.0	0.1209
		Coastal Mainland v. Open Water	114.0	< 0.0167
		Coastal Island v. Open Water	60.0	0.1307
Spring 2013 + Summer 2013	Schools (*n*)	Coastal Mainland v. Coastal Island	303.5	0.0910
		Coastal Mainland v. Open Water	325.5	< 0.0167
		Coastal Island v. Open Water	178.5	0.2343

Habitat mapping.—Sardine were observed in warmer waters during the summer 2012 and 2013 seasons compared to the spring 2013 season (Table 6). The observations during spring 2013 were also associated with higher productivity, based on chlorophyll *a* levels.

Table 6.—Number of sardine schools and associated sea surface temperatures and chlorophyll *a* concentrations observed during aerial surveys conducted in the Southern California Bight during 2012 and 2013.

SST (°C)

Date	*n*	Mean	Median	Range Low	Range High
Summer 2012	34	20.8	21.2	17.3	23.1
Spring 2013	27	16.2	16.1	12.1	19.1
Summer 2013	44	20.5	20.5	18.6	22.9

Chlorophyll *a* (mg/m^3)

Date	*n*	Mean	Median	Range Low	Range High
Summer 2012	34	3.9	1.3	0.3	23.4
Spring 2013	27	35.9	4.1	0.3	367.1
Summer 2013	44	0.9	0.8	0.2	2.6

Discussion

We found much higher density and larger aggregations of sardine in the coastal waters of the Southern California Bight than in offshore open water areas (Figure 2, Table 1, Table 5). The high percentage of coastal observations within 0.54 km of the mainland and island coasts indicates that this survey provides a unique window into nearshore sardine and mixed CPS distribution and abundance not accounted for by other surveys. In particular, mainland coastal areas yielded the largest number of observations within and across seasons. On a seasonal basis, the two summer seasons showed higher school counts and biomass than did the spring season. However, the relatively low frequency of open water observations does not mean open water areas are lacking in abundance of sardine or other CPS. Rather, it is probable that schools are typically below some visibility threshold in deeper waters and not detectable during daylight hours (N. Lo, NMFS, personal communication), and may also reflect a tendency for sardine to be at depth during the day (Giannoulaki et al. 1999) and thus more available for sampling at shallower depths at night (Krutzikowsy and Emmett 2005). Our observations of sardine primarily in specific nearshore areas corresponds with commercial landings of sardine during the time of our surveys, especially off the northern coastal areas near Ventura, Ventura County, for both summer seasons (CFIS).

Aerial species identification of fish was consistent with identification from boat surveys. Additional sampling for pure sardine schools and other species such as northern anchovy would help establish aerial identification accuracy across a broader range of species. Also, a more varied geographic range for boat sampling, such as off the north coast or one of the northern Channel Islands, would be helpful, as logistics allow. Further attempts to collect greater numbers of sardine samples across more of the study area would better describe the demographics of sardine at the time of the survey, and inform size and age selectivity within the assessment model used for management.

We observed sardine in relatively warmer SST conditions (>17°C, Table 6) in both summer 2012 and 2013 compared to spring 2013. This is consistent with a habitat model for sardine developed by Zwolinski et al. (2011), which indicated the suitability of the SCB environmental regime during summer for the southern stock. Felix-Uraga (2004, 2005) proposed using temperature to partition commercial landings into northern and southern stocks. Much of the northern stock migrates northward during a transitional period during May and June as surface temperatures increase (Emmett et al. 2005). The results from the spring 2013 survey (median SST=16.1°C, range 12.1–19.1°C) suggest a mixed group of northern and southern stock sardine; this may be due to northern stock sardine in the process of their northward migration. Our results can be used to determine the presence of sardine in SCB waters at specific times of the year and under specific environmental regimes. This information can help apportion commercial sardine landings information to the appropriate stock, for use in stock assessment modeling. Allocation of catch to stock has been done (Demer and Zwolinski 2014) by applying habitat models and SST data to catch data. These stock differentiation studies based on environmental factors can supplement other work that distinguishes stocks based on other factors, such as otolith morphometrics (Felix-Uraga et al. 2005, Javor et al. 2011).

Chlorophyll *a* values associated with sardine observations were lower in both summer 2012 and 2013 compared to the spring 2013. Other studies have indicated chlorophyll *a* levels tied to both sardine landings (Lanz et al. 2009, George et al. 2012) and recruitment (Gomez et al. 2012), with evidence showing a stronger relationship between chlorophyll *a* and fish abundance than with SST (Lanz et al. 2009). Our results showed no relationship between SST or chlorophyll *a* levels and abundance, but with more data over time may serve as a measure of sardine-habitat associations, especially for nearshore areas.

The spotter pilot index that was formerly used in the sardine stock assessment was no longer considered suitable for the assessment in 2007 for a number of reasons (Hill et al. 2007). In addition to reduced sampling due to less usage of spotter pilots, there were difficulties in reconciling the results with other research surveys within the assessment model. There were also concerns over the lack of a formal survey design, since it did not have set transects, but was an adaptive survey based on areas and seasons frequented by the fishery. Finally, there were also questions about survey age selectivity. Our survey uses spotter pilot identifications, but is based on a set transect design, and boat sampling is used to validate species identification as well as collect biological information on sardine within the study area. The inclusion of nearshore areas in this survey, formerly addressed by the previous spotter survey, supplements the current coverage in offshore waters by ship-based surveys.

These nearshore surveys can supplement the current acoustic surveys. The abundance of sardine within a few miles of the coast can account for many fish missed by the furthest nearshore extent of acoustic surveys of about 2 km or shallower than 40 m (D. Demer, NMFS, personal communication). This survey observed 74% of the total sardine biomass and 83% of the total number of sardine schools within 2 km of shore. However, the acoustic surveys are not as constrained by weather conditions and the limits of visibility through the water column. Comparative studies of both methods over the same time and space may be useful in assessing the strengths and weaknesses of each (K. Hill, NMFS, personal communication). The expansion of open water biomass estimates over the total open water area assumes homogeneity in habitat; the use of habitat models, such as those developed by Zwolinski et al. (2011) can account for habitat variation within the study area when estimating abundance. In addition, the possibility of the survey missing fish in deeper offshore areas that sardine frequent during the day is problematic. As a result, estimates from this survey are minimum biomass estimates. A focus on the nearshore shallow water areas for future surveys may be warranted to best use resources and possibly obtain multiple replicates. Because younger (0–2 years) sardine are more frequently found in waters within 27 km of shore (N. Lo, NMFS, personal communication), these results likely represent an index of sardine recruitment, pending confirmation from age and maturity analyses from boat survey samples. If these are shown to be young fish, they may be from the northern stock that are not fit to migrate during the summer months.

With the recent decline of the northern stock of sardine (Hill et al. 2014), it has been posited that the northern anchovy (Chavez et al. 2005) stock will become more prominent and perhaps replace sardine as the dominant California CPS fishery under a changing environmental regime towards cooler sea temperatures. Beginning in summer of 2013, other CPS (including northern anchovy and Pacific mackerel) in addition to sardine have been included in our survey protocol. Data from this survey may be useful in future stock assessments and management of other species within the CPS assemblage, especially northern anchovy, which are commonly found in coastal waters (Baxter 1967).

This survey collected data on sardine and other CPS from nearshore areas using direct observations in identifying and estimating abundance of schools. Observer species identifications were verified with boat survey results. The information obtained can be used to track abundance of nearshore sardine that are not sampled by other existing surveys, provide data on sardine population structure and dynamics, and describe sardine habitat associations in terms of environmental variables. These survey results can provide additional information for stock assessments for these species not only for management purposes, but also to elucidate questions related to stock migration and differentiation. Future aerial surveys should consider increased sampling and focused range of coverage to better gauge uncertainty and improve confidence in the accuracy of results.

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