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Pacific sardine (*Sardinops sagax*) abundances estimated using an acoustic-trawl survey method

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Abstract

The "northern" stock of Pacific sardine (*Sardinops sagax)* in the California Current have been surveyed by the Advanced Survey Technologies Program at the Southwest Fisheries Science Center during spring 2006, 2008, 2010, and 2011, and summer 2008, using acoustic-trawl (ATM) methods (Demer et al., in press; Zwolinski et al., in review). Here, the methods and results are briefly summarized. Multi-frequency echosounders are used to map acoustic backscatter from coastal pelagic fish species (CPS); the proportions of species in trawl catches, weighted by their length-dependent acoustic target strength (*TS*) values, are used to apportion the CPS backscatter to species; and the total backscatter from sardine is converted to biomass using estimates of sardine *TS* and survey area. The sardine biomass has been declining since 2006 as the last large cohort, spawned in 2003, diminishes. The sardine-length distributions from the trawl samples clearly track the 2003 cohort through 2011. The reduction in biomass from 2006 to 2010 indicates a total-mortality, exponential-decay rate of 0.66. These internally consistent fisheries-independent estimates can be used as absolute estimates of sardine distribution and abundance (PFMC, 2011). The surveys spanned the entirety of the potential sardine habitat (Zwolinski et al., 2011; Demer et al., in press; Zwolinski et al., in review) and thus sampled the entire northern stock. The coefficient of variation (*CV*) values ranged from a maximum of 43.3% in spring 2010 to only 9% in spring 2008; the latter resulted from high-density sampling of a coalesced spring-spawning aggregation.

Introduction

Acoustic-trawl method (ATM)

During spring 2006, 2008, 2010, and 2011, and summer 2008, the Southwest Fisheries Science Center (SWFSC) used the acoustic-trawl method (ATM) (Demer et al., in press; Zwolinski et al., in review), to survey the "northern" stock of Pacific sardine (*Sardinops sagax*) and other coastal pelagic fish species (CPS) off the west coast of the United States of America (US), from the US-Mexican to US-Canadian borders. The ATM uses ship-based, multiple-frequency echosounders to map the distribution of CPS; and trawl catches to apportion the echo energy to species, map their densities, and estimate their abundances. Details of the method and results of the 2006 to 2010 ATM surveys may be found in Demer et al. (in press) and Zwolinski et al. (in review). A synopsis of the 2006 to 2011 ATM survey methods and results is presented here.

Methods

Sampling equipment and platforms

ATM surveys of CPS in the California Current Ecosystem (CCE) were conducted from NOAA Fisheries Survey Vessels (FSVs) and contract fishing vessels (FVs) during spring 2006, 2008, 2010, and 2011, and summer 2008. Each ship was configured with multi-frequency split-beam echosounders (Simrad EK60s) configured with hull- or retractable-keel-mounted transducers (Simrad ES18-11, ES38B, ES70-7C, ES120-7C, and ES200-7C), operating at 38, 70, 120, and 200 kHz (FSV *David Starr Jordan* and F/V *Frosti*) and 18, 38, 70, 120, and 200 kHz (FSVs *Oscar Dyson* and *Bell M. Shimada*). Surface trawls were conducted using a midwater trawl (Nordic 264) with foam-filled doors and floats on the headline.

Sampling design

Parallel-line transects, perpendicular to the coast, extending from the US-Mexican to US-Canadian borders, were surveyed acoustically at a nominal speed of 10 kts. At night, the vessels trawled near the sea surface. Survey transects were planned with considerations to requisite California Cooperative Oceanic and Fisheries Investigations (CalCOFI) sampling in the Southern California Bight (SCB), and, during the latter portion of the time-series, sardine habitat predicted from satellite-sensed oceanographic conditions (Zwolinski *et al.*, 2011).

Acoustic and trawl sampling

Measurements of echo power (p_r; W) and interferometric-phase angle were sampled continuously throughout the surveys. To minimize potential bias from diel vertical migration of CPS, only the daytime data were included in the following analysis. At nighttime, during the same periods as above, when CPS are generally near to the sea surface and more dispersed compared to daytime, fish species and their lengths were sampled with the surface trawl at a minimum of two stations per night, from each vessel.

Acoustic-trawl analysis

Measurements of volume backscattering strength (S_v; dB re 1 m^{-1}), target strength (TS; dB re 1 m^2), and nautical-area backscattering coefficients (s_A; m^2 $n.mi.^{-2}$) were derived from the echosounder power and angle data. Three-frequency (38, 120, and 200 kHz) S_v data were used to map CPS and estimate biomasses for sardine. To identify acoustic backscatter from CPS, differences in measured S_v values were compared to empirical predictions: $-17 \leq S_{v70} - S_{v38} \leq 10$; $-17 \leq S_{v120} - S_{v38} \leq 14$; and $-14 \leq S_{v200} - S_{v38} \leq 5$ dB. The s_A values attributed to CPS, averaged along two-kilometer-long intervals, were mapped throughout the survey region.

The s_A at 38 kHz corresponding to CPS (s_{A_CPS}) in the 100-m-long cells were apportioned to j species present using the catch proportions in the nearest (space and time) trawl samples (Nakken and Domasnes, 1975):

$$s_{A_i} = \frac{w_i \times 10^{\left(\langle TS_i \rangle / 10\right)}}{\sum_j w_i \times 10^{\left(\langle TS_i \rangle / 10\right)}} s_{A\_\mathrm{CPS}} \tag{1}$$

where w_i is the proportion of the mass of the catch (kg) for the i-th species, and $<TS_i>$ is its length-weighted mean target strength (TS; dB re 1 m^2/kg). Thus, each $<TS_i>$ is a mean TS, weighted in the linear domain by the distribution of total length (TL; cm) of the sampled fish of that species. The *TS* relationships employed are:

$$TS = -14.90 \times \log(TL) - 13.21, \text{ for sardine;} \tag{2}$$

$$TS = -12.15 \times \log(TL) - 21.12, \text{ for anchovy; and} \tag{3}$$

$$TS = -15.44 \times \log(TL) - 7.75, \text{ for mackerel.} \tag{4}$$

These relationships were originally estimated for anchovy (*Engraulis capensis*), sardine (*Sardinops ocelatus*), and horse mackerel (*Trachurus trachurus*), based on the combination of backscatter-versus-length and mass-versus-length measurements of *in situ* fish (Barange *et al.*, 1996). Because jack mackerel and Pacific mackerel have similar *TS* (Peña, 2008), equation (4) was used for both of these species. For each species, the s_{A_i} values were converted to fish-biomass density (ρ_i; kg/n.mi.^{2}) using:

$$\rho_i = \frac{s_{A_i}}{4\pi 10^{\left(\langle TS_i \rangle / 10\right)}} . \tag{5}$$

The estimated densities of Pacific sardine along two-kilometer-long intervals were mapped throughout the survey region (see Demer et al., in press; Zwolinski et al., in review).

Post-survey strata were defined based on the inter-transect spacing, the species composition in the trawls, and the spatial distribution of acoustic backscatter. With confirmed independence between the mean biomasses of the east-west transects, unbiased estimates were derived for the survey mean (Jolly and Hampton, 1990), and its variance (Efron, 1981). For each species, the point estimate of abundance was obtained by raising the stratum-mean biomass density to the stratum area. The stratum-mean biomass density was calculated as the average of the biomass density for each transect, using only daytime samples, weighted by the correspondent daytime-transect lengths.

The sampling variances and confidence intervals were estimated using bootstrap because it provides better statistical inference than traditional methods for data with unknown statistical distributions and small sample sizes (Efron 1981). The 95% confidence intervals for the mean biomass densities were estimated as the 0.025- and 0.975-quantiles of the distribution of 1,000 bootstrap survey-mean biomass densities. Coefficient of variation (*CV*) values were obtained by dividing the bootstrapped standard errors by the bootstrapped arithmetic means (Efron 1981). Given that the data within each transect are serially correlated, but the samples are independent between transects (confirmed via correlation analysis; Demer et al., in press), bootstrap resampling of the transect means provided unbiased estimates of the variance for the survey mean, even when there are several levels of variability nested at the intratransect level (Williams 2000).

Results

The acoustic-trawl sampling spanned the extent of the potential sardine habitat. During each spring, acoustically- and trawl-sampled sardine densities were largest offshore of southern and central California (**Fig. 1**). During summer 2008, sardine densities were highest nearshore, principally along the coasts of Oregon and Washington (**Fig. 1**). The biomass of sardine declined precipitously between 2006 and 2010 (**Table 1** and **Fig. 2**), corresponding to the mortality and growth of the strong 2003 cohort (**Figs. 3 and 4**). In spring 2011, a new, relatively small cohort was present (**Fig. 4**), which contributed to a slight increase in the total sardine biomass (**Table 1** and **Fig. 2**).

Tables

Table 1. The acoustic-trawl method (ATM) estimates of Pacific sardine biomasses for the 2011 survey. The second biomass estimate for summer 2008 (in parentheses) includes an extrapolated estimate of biomass (0.169 Mt) in the region (2,848 n.mi.^{2})_between the eastern ends of the transects and the coast (details in Demer et al., in press).

Surveys	Biomass (Mt)	CI_{95} (Mt)	*CV* (%)
2006 spring	1.947	0.897 – 3.139	30.4
2008 spring	0.751	0.611 – 0.870	9.2
2008 summer	0.632 (0.801)	0.303 – 1.098	30.9
2010 spring	0.357	0.094 – 0.690	43.3
2011 spring	0.494	0.221 – 0.816	30.4

Figures

Figure 1. Relative sardine biomass densities averaged over 2 km intervals off the west coast of the US during spring 2006, 2008, 2010, and 2011, and summer 2008.

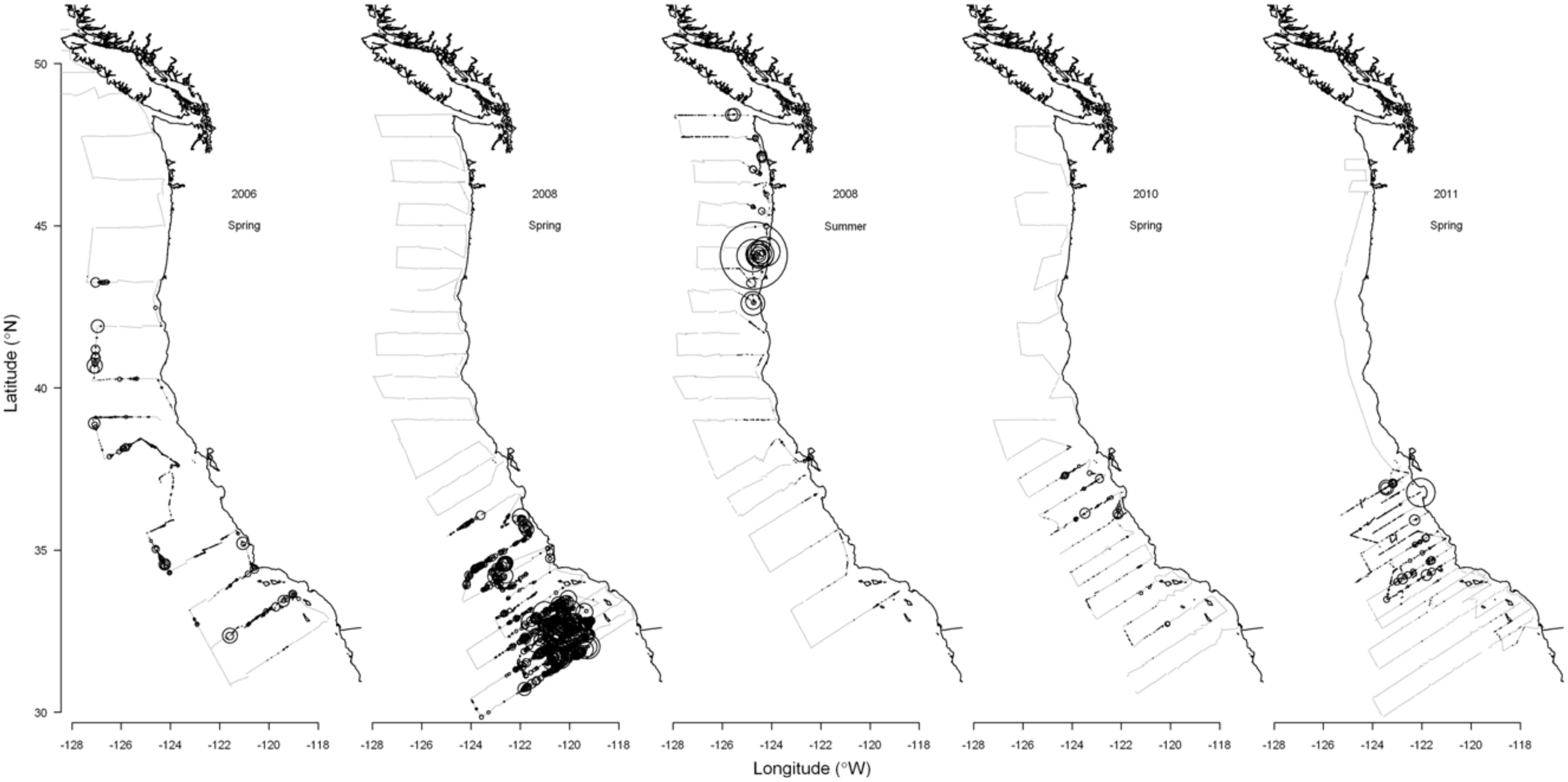


Figure 2. Total-sardine biomass off the west coast of the US surveyed during spring 2006, 2008, 2010, and 2011, and summer 2008, estimated from the acoustic-trawl survey (red); the age 1+ biomass estimated from the *preliminary* stock assessment model (Hill *et al.,* 2011; blue). In 2011, the trajectories of both the total-sardine biomass (solid red) and the biomass of the 2003 cohort are indicated (dashed red).

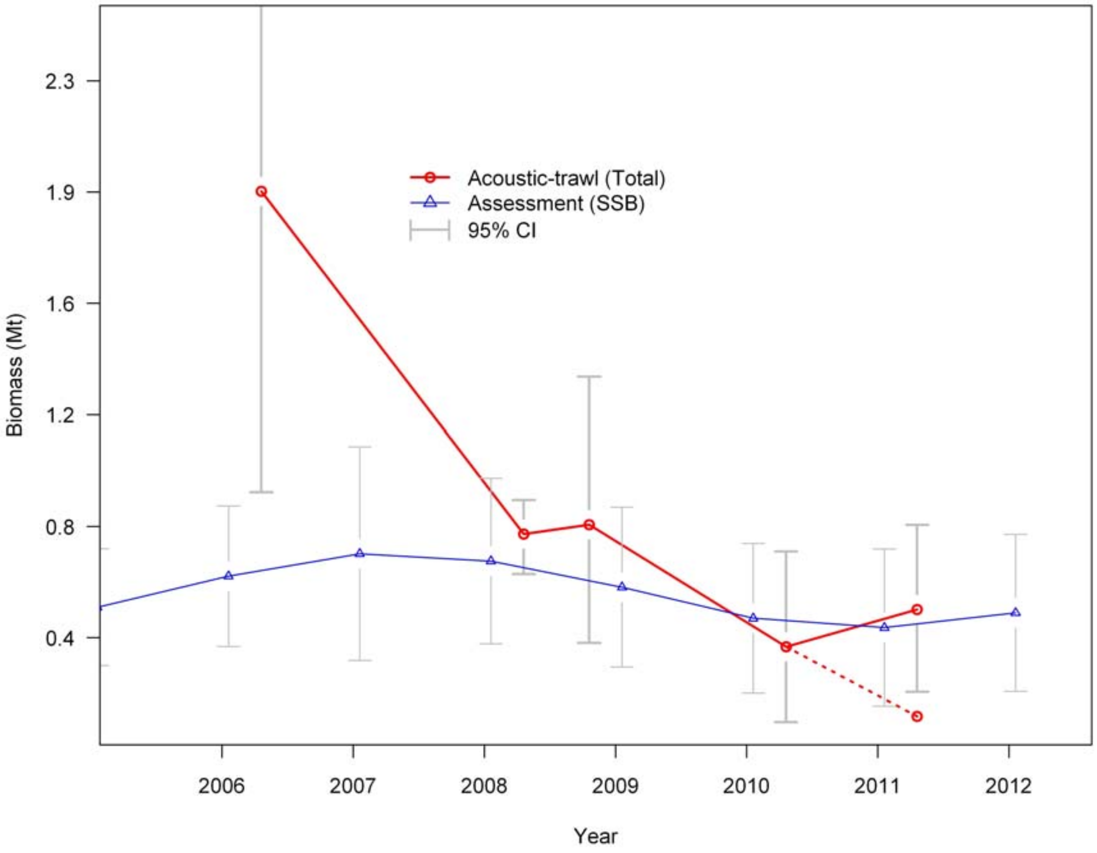


Figure 3. Decay rate of the Pacific sardine population, comprised mainly from one cohort, estimated from the acoustic-trawl estimates of biomass from 2006, 2008, 2010, and 2011. The 2003 cohort, which dominated in spring 2006, is clearly tracked through 2011 (**Figs. 2-4**). In spring 2011, the sardine biomass was dominated by a new, but small, cohort (**Figs. 2 and 4**).

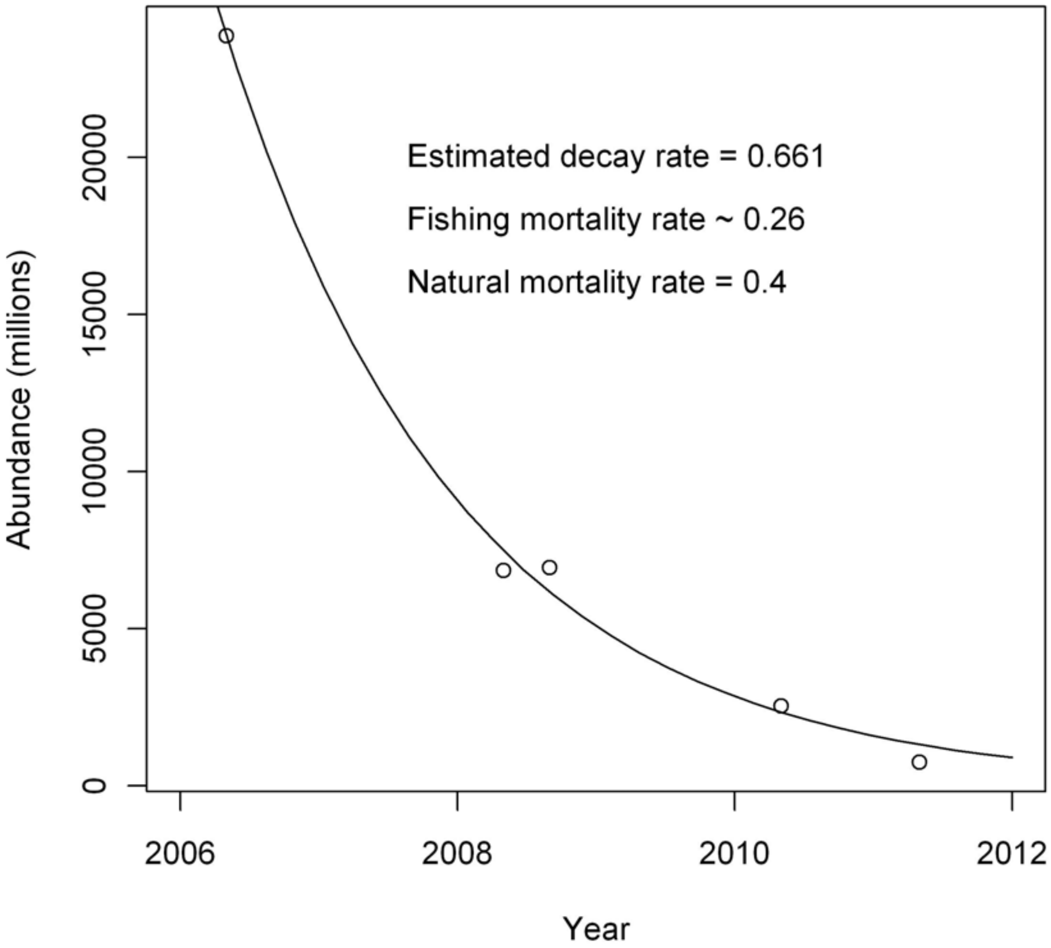
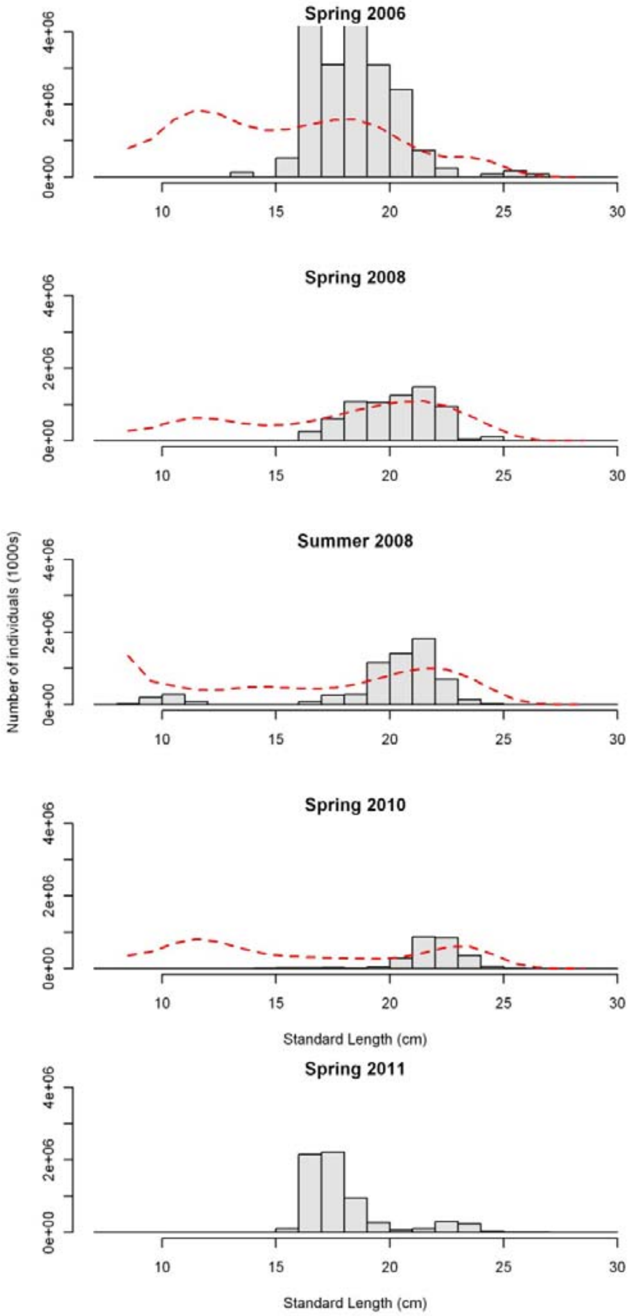


Figure 4. Lengths of Pacific sardine from trawl samples during the 2006, 2008, 2010, and 2011 surveys of CPS off the US west coast (bars) and those estimated from the stock assessment model (dashed line; Hill *et al.,* 2010). The 2003 cohort, which dominated in spring 2006, is clearly tracked through 2011. The rate of decline for this cohort throughout this period is approximately 0.66 (**Fig. 3**). In spring 2011, the sardine biomass was dominated by a new, but small, cohort (see also **Fig. 2**). The smaller fish indicated by the assessment model (dashed red lines in 2006 to 2010) might result from the inclusion of summer landings data from the Californian and Mexican fisheries. These fish likely represent the "southern" stock of Pacific sardine and their inclusion appears to confound the assessment.



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