Central stock northern anchovy (CSNA) biomass estimation methodology

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See MacCall et al. (2016) and Thayer et al. (2017) for complete details of methodology and justifications.

Standardized sampling extends from 1951 to the present, in the "core" 6-line southern California CalCOFI region (http://www.calcofi.org; lines 76.7 to 93.3). Nine SCCOOS stations added in 2004 were excluded. Samples obtained off-transect were omitted, and samples between standard stations were assumed to represent the closest standard station.

As a statistical solution to hyperstability due to the nearshore concentration of CalCOFI stations and the tendency of the anchovy population to contract into this area when abundances are low (see MacCall 1990, MacCall et al. 2016), egg and larval densities were geo-spatially weighted. Two sets of CalCOFI cruises were used, winter (usually with some portion occurring in January) and spring (usually with some portion occurring in April). Egg and larval densities were expanded independently in winter and spring for each CalCOFI station to obtain local population estimates (so a complete year produced four indices), summed to estimate the overall abundance in the study region, developed into a combined index of productivity, and then calibrated to absolute biomass estimates.

For each cruise, a set of station-specific Thiessen polygons was constructed (also known as Voronoi diagrams or tessellations). Each Thiessen polygon defines an area of influence around its sample point so that any location inside the polygon is closer to that point than any of the other sample points (Okabe et al. 2000). The egg or larval population estimate (P_{ijk}) for each year (i), ichthyoplankton type (j = eggs or larvae) and season (k = winter or spring) is the sum of the products of station-specific (s) polygon areas (A_{iks}) and sampled density (D_{ijks}) or mean density if the station was sampled more than once (in some years, only one of the two seasons was sampled). Each of the four indices was scaled to unit mean for the period 1951–1999 (due to changes in the seasonal pattern, i.e., declining anchovy presence in winter surveys), and a combined index was produced by averaging the 2–4 indices for each year. Arithmetic means allow retention of cruises with zero estimates, i.e., where either no eggs or larvae were sampled.

$$P_{ijk} = \sum_{s} D_{ijks} A_{iks}$$

The resulting abundance index is calibrated to biomass by a least-squares fit to the daily egg production method (DEPM) absolute biomass estimates produced from 1980 to 1985 that covered the entire CSNA range (summarized in Jacobson et al. 1994). The final index is presented in units of 1000 metric tons and represents biomass in the entire CSNA range, scaled up to include central California and Mexico, and extending all the way inshore from use of tessellations (see Davison et al. 2017).

Precision of abundance estimates was calculated using a jackknife procedure to preserve the spatial structure of sampling. Each sample was deleted one at a time and unless multiple samples were taken (which occurred only rarely), the tessellation was recalculated so that regions of the deleted sample were reassigned to values of A_{iks} for expanded samples associated with adjacent samples; importantly, the total survey area remained constant for all years and all jackknife re-samplings. A new abundance estimate was obtained with each deletion, and results were combined to produce precision estimates (Efron and Stein 1981). The jackknife procedure provided variance estimates for each of our two to four indices (depending on the year and data available). A variance estimate for the combined index was estimated as:

$$Var\,(I_i) = \frac{1}{n^2}\sum_j Var\,(\Theta_{ij})$$

where Ii is the combined abundance index for year i, and Θ_{ij} are the two or four standardized individual indices, i.e., $j = 1, \ldots,$ n where n is either 2 or 4. This approximation for the combined index tends to overestimate the variance (MacCall et al. 2016).

Note: Larval data from 2000–2011 were excluded from estimates due to an apparent increase in egg or larvae mortality rates that would bias the larval index lower relative to the prior portions of the time series (see MacCall et al. 2016, Thayer et al. 2017).

Note: There were not sufficient spatial data with which to separately estimate biomass for central California and/or northern Baja, Mexico (see Lasker 1985; MacCall et al. 2016). The available core CalCOFI data covered most of the anchovy biomass in most years based on annual mapping (see Davison et al. 2017), but historical patterns suggest that our estimates may be relatively less precise at very low biomasses. For this reason, we suggest using an average of low years rather than an annual point estimate.

Note: Anchovy egg output is not determinate, and the number of spawnings varies with age composition (Parrish et al. 1986) and probably with general feeding conditions (Hunter and Leong 1981). However, the featured biomass time series method produces estimates relatively quickly and inexpensively, tracks biomass fairly well (see Davison et al. 2017, Fig. 2; Sydeman et al. 2020, Supp. Mat.), corrects error from not geo-spatially weighting egg/larval data, and is the only long-term time series available. Other methods might be able to produce more precise estimates (e.g., Lasker et al. 1985, Dorval et al. 2018), but unlike long-lived groundfish, managing a short-lived, quickly-fluctuating resource like anchovy does not benefit much from exact abundance estimates (which are also very expensive and time-consuming).

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