

## CALIFORNIA ANCHOVY POPULATION REMAINS LOW, 2012–16

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### ABSTRACT

Updated abundance estimates of the central subpopulation of northern anchovy (*Engraulis mordax*) are developed from California Cooperative Oceanic Fisheries Investigations (CalCOFI) data on egg and larval densities for 1951–2011, with new estimates for 2012–15. We followed the approach of MacCall et al. (2016; Fish. Res.) which corrected for a hyperstability bias due to nearshore concentration of CalCOFI stations and the tendency of the anchovy population to contract into this area when abundances are low. We corrected previous estimates based on calibration using an erroneous absolute biomass value from the 1980s, and extended estimates up through 2015. Anchovy spawning biomass remains below 100,000 metric tons, at an average of 20,700 metric tons over the past 7 years. Although the most recent 2016 CalCOFI data are not yet available, recent results from the continuous underway fish egg sampler (CUFES) do not indicate any substantial recovery of the anchovy population to date.

### INTRODUCTION

Northern anchovy is an important component of the forage fish community of the California Current ecosystem (CCE). Anchovy are schooling coastal pelagic fish that have undergone large oscillations in abundance for thousands of years, with periodicity of ~60 y (Baumgartner et al. 1992; MacCall 1996; Field et al. 2009) which have been linked to climate influences (Lehodey et al. 2006; Lindegren et al. 2013). Anchovy are a relatively small and short-lived species (most <16 cm in length; most fishes <5 y in age; Schwartzlose et al. 1999), with high fecundity and mortality, and are thought to do well in colder waters associated with high coastal upwelling (Rykaczewski and Checkley 2008; Lindegren et al. 2013). There are historically three oceanic population centers for anchovy along the Pacific coast of North America: a northern stock near the Columbia River mouth, a central stock concentrated in the Southern California Bight (SCB) and Monterey Bay, and a southern stock off of Baja California (Huppert 1980; Schwartzlose et al. 1999; Zwolinski et al. 2012).

Anchovy is an important prey resource for many upper trophic level predators in the CCE (Szloboszlai et al. 2015), and supported historically significant fish-

eries in California and Mexico (CDFG 2001). Anchovy stock assessments were conducted until 1995 (Jacobson et al. 1995); since then, only spawning biomass estimates exist (MacCall et al. 2016). After a spike in estimated spawning biomass briefly exceeding a million metric tons (MT) in 2005–06, the population subsequently collapsed by 2009 (MacCall et al. 2016). The systemic causes of the recent decline in abundance are not clear, although one of the proximal causes of the decline has been hypothesized to be the decrease in egg and larval survivorship during the 2000s (Fissel et al. 2011; MacCall et al. 2016). The cause of that mortality is not presently known, but intensified filter feeding cannibalism by the parents is a likely possibility (i.e., high density of adults can occur from the range contraction at low population sizes; MacCall 1990). The consequence was a severe reduction in the production of recruitment-age fish. Given the short timing and the magnitude of the decline in abundance, it happened faster than could be explained by poor recruitment alone, indicating that the natural mortality rate of adults also probably increased. The estimation approach of MacCall et al. (2016) excluded data from the extreme inshore region because those trawl stations were not sampled continuously through time, but separate analyses of these inshore stations revealed egg and larval densities similar to those in the continuously sampled area (Davison et al. 2017). Therefore, an unknown but probably large portion of the remaining remnant population thereafter consisted of conspicuous, concentrated, nearshore shoals, where it has been vulnerable to predators and the fishery as well as appearing paradoxically abundant to shore-based observers such as members of the public (MacCall et al. 2016; Davison et al. 2017).

Herein, we correct previous biomass estimates for the central subpopulation of northern anchovy, which were based on calibration using an erroneous absolute biomass value from the early 1980s. We also extend the spawning biomass estimates to 2015 as additional data have become available. We follow the MacCall et al. (2016) method that corrected for hyperstability bias (Hilborn and Walters 1992) due to the nearshore concentration of CalCOFI stations and the tendency of the anchovy population to contract into this area when abundances are low (MacCall 1990).

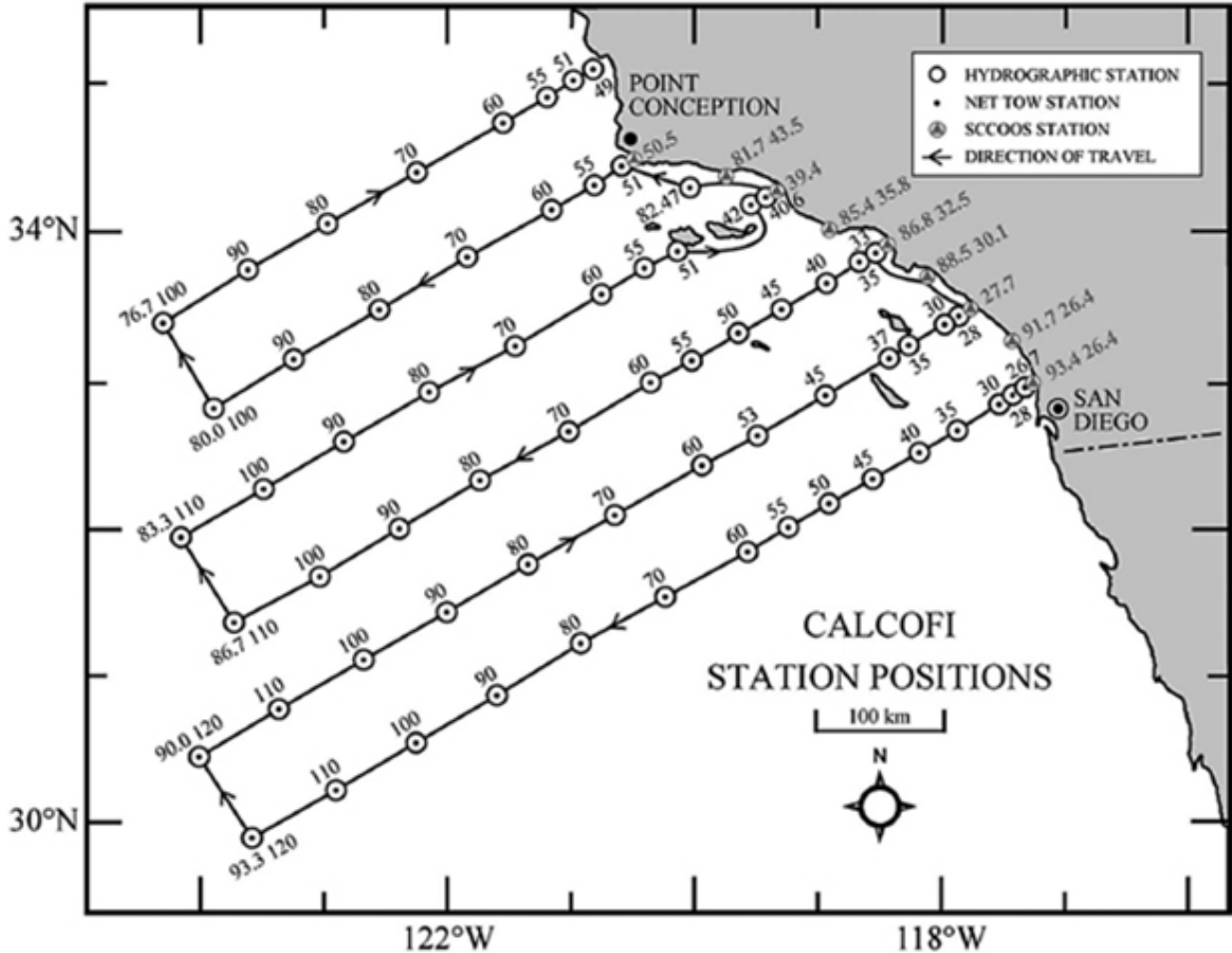


Figure 1. Locations of core southern California CalCOFI sampling stations (from MacCall et al. 2016), also showing location of the nine nearshore SCCOOS stations added in Fall 2004, but not included in our long-term timeseries due to standardization of survey locations.

## METHODS

Following the methods of MacCall et al. (2016), egg and larval sample densities from core CalCOFI surveys (fig. 1) for January and April were geo-spatially weighted, summed to obtain total abundance, developed into a combined index of productivity, and then calibrated to early 1980s absolute biomass estimates based on the daily egg production method (DEPM). These DEPM estimates spanned CalCOFI line 60 (off Pt. Reyes, California), to CalCOFI line 110.0 (at Bahia del Rosario, Baja California, Mexico) (Lasker 1985; Bindman 1986), allowing the core survey results to be scaled up to population biomass (Methot et al. 1989; Jacobson et al. 1994). DEPM estimates were corrected here prior to calibration. The erroneous spawning biomass value for year 1982 (used in all previous assessments) was due to the value in short tons estimated by Picquelle and Hewitt (1983) having been reported as metric tons in a summary by Bindman (1986).

The DEPM method includes sampling of spawning adult (mature) anchovies during ichthyoplankton collections to obtain information on size and age structure and female fecundity. Since such data were not available recently, we had to rely here on historical average values for such data, acknowledging that for indeterminate spawners such as anchovy where egg production is largely a function of adult condition, this is not ideal. However, there was no trend evident in spawning phenology, only a slight nonsignificant shift ( $-3$  d decade $^{-1}$ ; Asch 2015). Since the CalCOFI data used included surveys with any days in January or any days in April, so incorporating many February, March, and May data, the slight shift in peak spawning would not be expected to greatly affect results (Davison et al. 2017; MacCall et al. 2016).

Both egg and larval samples were used for biomass estimates in 1951–99 and 2012–15, although larval samples had to be dropped in 2000–11 due to exception-

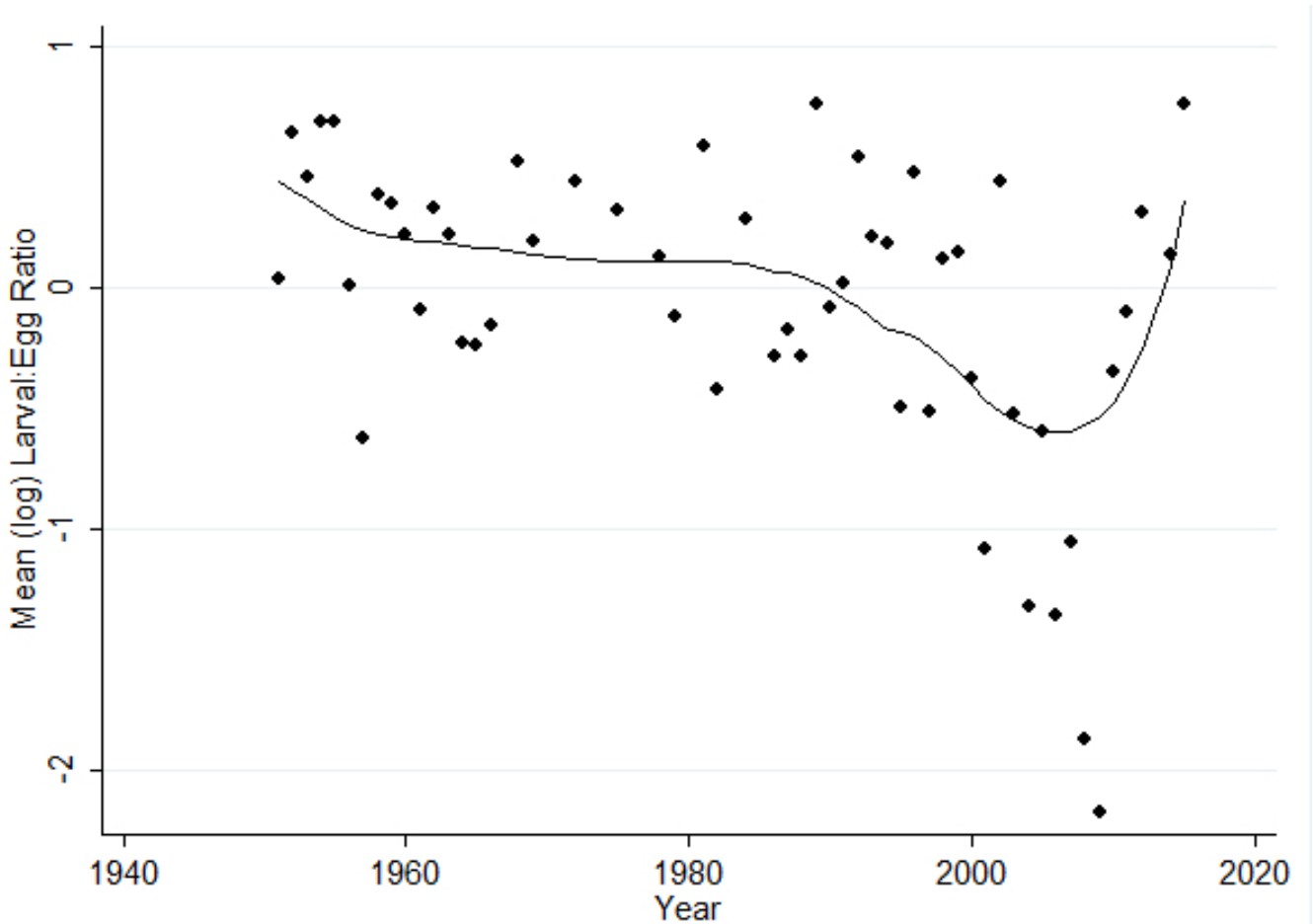


Figure 2. Geometric mean of January and April larvae to egg ratio for northern anchovy sampled by the CalCOFI program, 1951–2015. The ratio for 2013 was dropped as this value was an outlier:  $\log(65) = 1.8$ . Lowess smoothing function (bandwidth 0.6) shown.

ally low larvae to egg ratios (MacCall et al. 2016; fig. 2). The extended estimates included April and January data as was available in 2012–14. Only partial cruise track data were available in January 2014 due to ship engine malfunction. As of this analysis, January data were not yet available for 2015. Precision of abundance estimates was calculated using a jackknife procedure that provided variance estimates for each of our two to four indices (depending on the year and data available), January egg and larvae and April egg and larvae, and subsequent approximation to produce a variance estimate for the combined index, which tended to overestimate the variance (MacCall et al. 2016).

## RESULTS

Revised and extended northern anchovy spawning biomass estimates for the central subpopulation, with coefficients of variation, are presented in Appendix I. The biomass remains very low and probably at an all-time low since CalCOFI sampling began in 1951. Although the abundance estimates are imprecise at this low level, the biomass is almost certainly less than 100,000 mt.

Larvae to egg ratios decreased in the early 2000s, indicating poor survival. Post-2011, the larvae to egg ratio returned to values within the range seen in 1951–99 (fig. 2). Therefore, both egg and larval samples were utilized for updating biomass estimates for 2012 through 2015.

The extended time series (2012–15) shows that stock remains low after a collapse after 2005 (i.e., two orders of magnitude below the 2005 value; fig. 3). The coefficients of variation of recent biomass estimates are high due to low numbers of positive stations, etc., and therefore estimates for recent single years are imprecise and should not be used individually for interpretation. In the past 7 years, annual estimates for anchovy spawning biomass had an equally weighted average of 20,700 mt. In the past 4 years since the last anchovy biomass update, estimated biomass averaged 24,300 mt.

## DISCUSSION

Although it was not possible to estimate spawning biomass precisely with available data, the analysis clearly supports the conclusion that abundance of the northern anchovy central subpopulation is at the lowest val-

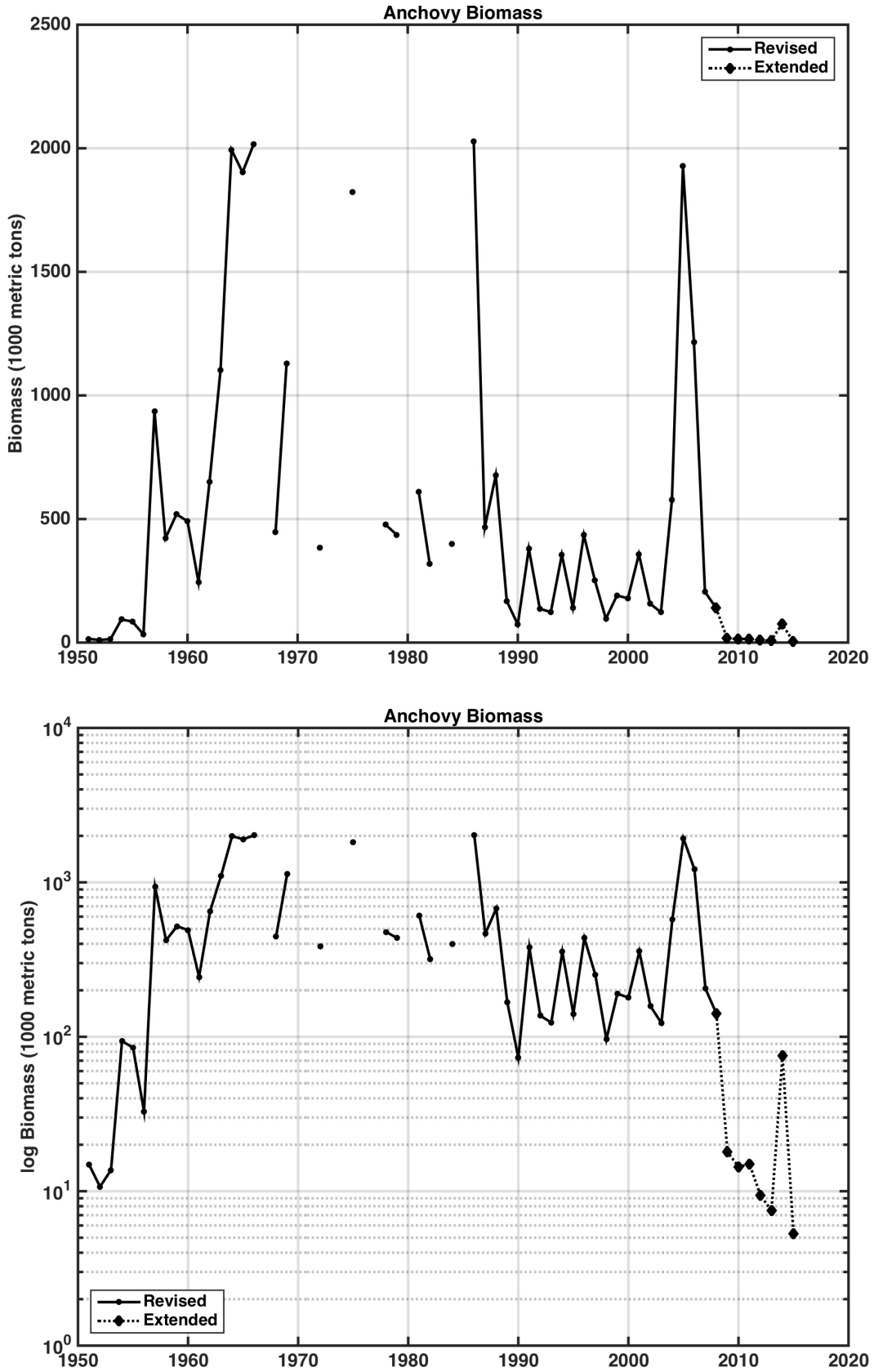


Figure 3. Anchovy biomass estimates on (a) numeric and (b) log scale. As extended estimates are based on few positive stations, CVs are imprecise. After removing larvae from estimates in 2000–11, adding larvae back into estimates for 2012–15 (dotted lines) does not change the pattern, but does improve precision.

ues since the beginning of CalCOFI surveys. Anchovy spawning biomass remains below 100,000 metric tons, at a multiyear average of 20,000–25,000 metric tons. Other fisheries-independent trawl survey results and predator responses also support this.

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, 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 recent years rather than an annual point estimate.

Recent independent trawl survey data supported our results of sustained low anchovy spawning biomass. Spring CalCOFI cruises sample pelagic nekton at night using a Nordic 264 rope trawl (Davison et al. 2017; Griffith 2008; Dotson et al. 2010). Rope trawl survey results from 2010–13 showed that anchovy were only captured inshore in the Southern California Bight, near Pt. Conception, and off of Washington State. No anchovy at all were collected off of central California, despite the fact that it was the region of greatest effort (Davison et al. 2017). The National Marine Fisheries Service (NMFS) Rockfish Recruitment and Ecosystem Assessment Survey (RRS) also had very low catches of age 0 and age 1+ anchovy in 2010–13 (Sakuma 2015). In 2014–15, adult northern anchovy catches remained low in all areas, including inshore sampling stations. Catches of larvae and pelagic juveniles, however, increased in the southern California region in 2014, and in all regions of California in 2015 (southern, central and northern; Sakuma 2015). The NMFS Acoustic-Trawl Survey (ATS) estimated a low total anchovy biomass for the central subpopulation in 2015 (<35,000 mt; Zwolinski et al. 2016). The ATS catch had a range of <4–13 cm with a mode of 6 cm indicating primarily young-of-the-year; this included almost exclusively small anchovy (<10 cm) in the central California region.

Recent available predator data included unusual mortality events for California sea lions in southern California in 2009–10 (Melin et al. 2010, 2012). Declines in seabird abundance at sea (Sydeman et al. 2015; Santora and Sydeman 2015) and reductions of anchovy in seabird diets in both central and southern California were seen at least through 2012 (e.g., Elliott et al. 2015). More recently, poor breeding performance of brown pelicans off southern California (Henry 2015) and reductions in anchovy in sea lion diets in central California were observed up through 2014 (J. Thayer, unpublished data). Increases in anchovy in predator diets in central California were observed in 2015, almost exclusively age-0 fish (Beck et al. 2015; J. Thayer/Farallon Institute,

unpublished data), mirroring increased catch of age-0 anchovy in 2015 acoustic and trawl surveys.

Anecdotal observations (mostly visual) suggested that anchovy were extremely abundant in recent years (e.g., newspaper reports summarized in Davison et al. 2017). Davison et al. (2017) examined not only RRS and CalCOFI rope trawls, but additional data from the CalCOFI ichthyoplankton time series, nearshore Southern California 85 Coastal Ocean Observing System (SCCOOS) stations and aerial surveys. He explored whether anchovy adults migrated north of the study area, whether there was a large biomass of anchovies nearshore, or whether spawning was temporally missed in our analyses, yet found no evidence of any of the above. Thus, we adhered to our previous methodology, and maintain with the current updates/corrections that the 2009–16 population crash is real and that the remnant anchovy population contracted to extremely nearshore habitat where it has appeared paradoxically abundant to observers.

Another seeming contradiction was that fishery catch of anchovy in 2015 surpassed the estimate of spawning biomass that year. Similar anomalies were observed at low spawning biomasses in the early 1950s, but we now understand better how they can be explained. As detailed in Davison et al. (2017), such an anomaly can result from a small calibration error and bias in the biomass estimate due to nearshore refuges from fisheries-independent surveys but not from fishers. While our spawning biomass estimate represents the entire central subpopulation, core CalCOFI station data were collected in southern California and calibrated using the 1980s DEPM data, which span from Baja California to Pt. Reyes in the north. Fishery catch in 2015 occurred largely in central California (CDFW 2016). Furthermore, direct comparison of CalCOFI-based spawning biomass estimates with fishery catches is misleading because it assumes they have similar age structure, which is not necessarily the case. To the extent that the catch includes pre-spawning anchovies (immature) and occurs in the fall and winter, the total biomass available to the fishery could substantially exceed the spawning biomass estimated as of January–April. (Indeed, 2015 trawls and predator diet contained a high proportion of immature anchovy; Sakuma 2015; Zwolinski et al. 2016; Beck et al. 2015; J. Thayer unpublished data.) Therefore, a more meaningful comparison is between catch and total biomass—2015 fishery catch was just over half of the preliminary total biomass estimate from southern and central California ATS data (Zwolinski et al. 2016). The anchovy population crash occurred in the near-absence of fishing and therefore was a natural phenomenon (MacCall et al. 2016; McClatchie et al. 2017), yet fishing pressure at the current low population levels may be high.

The tendency of anchovy to contract inshore at low population sizes makes them more susceptible to fishing and many predators. Landings may actually go up when the population is depressed (Beverton 1990). Many anchovy predator populations have been increasing (Szloboszlai et al. 2015; Caretta et al. 2014; Grandin et al. 2016), and sequential poor recruitment events have likely had substantive impacts on anchovy abundance and trends. The population spiked in 2005–06, then crashed from 2007–09; a linear regression of the log of biomass vs. year yields a slope of  $-1.15$ . If we ignore fishery catches and assume there was no recruitment, this would mean that mortality  $M$  was nearly double the value of 0.6 used by Jacobson et al. (1994). These anchovies live about 4 years (longer in very cold water but such conditions have not occurred since before 1975; Mais 1981; McGowan et al. 2003). Anchovy  $M$  increases with age (MacCall 1974), so the older age structure after several years of recruitment failure could also contribute to an increase in population  $M$ .

It is still unknown if a 2015 increase of age-0 anchovy in central California acoustic and trawl surveys and reflected in predator diet resulted in much survival of anchovy to age 1+. Although the most recent 2016 CalCOFI data are not yet available, results from the continuous underway fish egg sampler (CUFES) from recent surveys indicated egg distribution nearshore in a small area at very low peaks of  $\sim 15$  eggs/m<sup>2</sup> (fig. 4). Thus, there is no indication of substantial recovery of the anchovy population in 2016.

It remains that the core CalCOFI survey does not completely cover the range of the central anchovy sub-population. While estimates may be relatively precise in large biomass years, they are more imprecise at low population sizes. However, Davison et al. (2017) showed that neither northern nor nearshore concentrations have substantially altered recent overall spawning biomass estimates. More could be done in the future, such as using the central California and nearshore SCOOS station ichthyoplankton data along with the core CalCOFI region to estimate biomass in 2016 (NOAA 2016), for which new calibrations would be needed. Additional effort to collaborate with Mexico is needed to determine present and recent biomass in Mexican waters, potentially from the IMECOCAL program (Investigaciones Mexicanas de la Corriente de California). At present, however, all available data point to continued extraordinarily low spawning biomass of the central subpopulation of northern anchovy.

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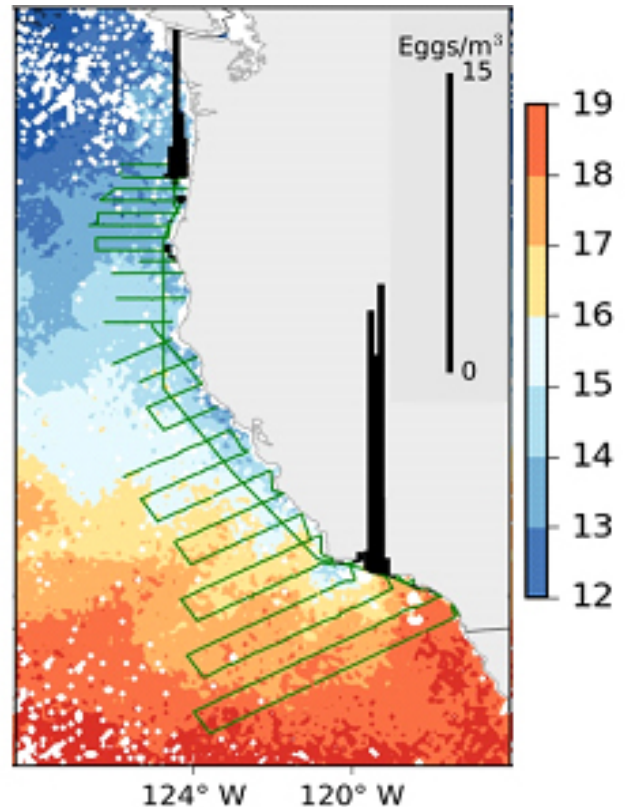


Figure 4. Preliminary CUFES survey results from spring 2016 showing anchovy egg catch and distribution. Note the continued very nearshore distribution and low values of 15 eggs/m<sup>2</sup> or less. (<https://swfsc.noaa.gov/textblock.aspx?Division=FRD&id=1121>).

helped with figures. We also thank the many people who for decades have contributed to CalCOFI surveys, and who have made the data available for analysis.

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APPENDIX I

**Table 1. Previously published (MacCall et al. 2016) and updated biomass values and coefficients of variation for the central subpopulation of northern anchovy. Blank cells indicate no data available. Note that both egg and larval abundances were used for estimating 1951–99 and 2012–15 (light gray), while larval abundances were dropped in 2000–11 when larvae to egg ratios declined (dark gray).**

Year	Published Values		New Values		Year	Published Values		New Values	
	Biomass (1000 mt)	total CV	Biomass (1000 mt)	total CV		Biomass (1000 mt)	total CV	Biomass (1000 mt)	total CV
1951	15.5	1.51	14.9	1.51	1984	415.5	0.33	400.0	0.31
1952	11.1	1.78	10.7	1.78	1985				
1953	14.3	1.57	13.7	1.57	1986	2106.6	0.30	2028.0	0.28
1954	97.5	0.62	93.8	0.61	1987	483.4	0.56	465.4	0.55
1955	88.3	0.65	85.0	0.64	1988	703.9	0.27	677.6	0.25
1956	34.0	1.02	32.8	1.02	1989	173.9	0.47	167.4	0.46
1957	972.3	0.41	936.0	0.40	1990	76.0	1.36	73.2	1.36
1958	438.3	0.32	422.0	0.31	1991	394.8	0.61	380.1	0.61
1959	539.6	0.29	519.4	0.28	1992	142.2	0.52	136.9	0.51
1960	510.0	0.30	491.0	0.29	1993	128.4	0.54	123.6	0.54
1961	253.3	0.40	243.8	0.39	1994	369.4	0.34	355.6	0.33
1962	675.2	0.27	650.0	0.26	1995	146.2	0.51	140.7	0.50
1963	1145.4	0.23	1102.7	0.21	1996	452.6	0.31	435.7	0.30
1964	2070.9	0.20	1993.7	0.18	1997	261.4	0.39	251.7	0.39
1965	1976.3	0.20	1902.6	0.18	1998	100.0	0.61	96.3	0.60
1966	2093.6	0.20	2015.5	0.18	1999	197.6	0.45	190.3	0.44
1967					2000	186.2	0.88	179.3	0.87
1968	465.1	0.57	447.8	0.56	2001	371.7	0.63	357.9	0.63
1969	1173.8	0.23	1130.1	0.21	2002	164.3	0.93	158.1	0.93
1970					2003	127.6	1.06	122.8	1.05
1971					2004	599.6	0.50	577.2	0.50
1972	399.2	0.33	384.3	0.32	2005	2002.5	0.30	1927.7	0.29
1973					2006	1263.6	0.68	1216.4	0.68
1974					2007	213.2	0.82	205.2	0.82
1975	1892.7	0.31	1822.1	0.30	2008	146.6	0.99	141.1	0.98
1976					2009	18.7	5.47	18.0	5.47
1977					2010	15.0	3.06	14.4	3.06
1978	495.5	0.30	477.0	0.29	2011	15.6	3.00	15.0	3.00
1979	453.1	0.31	436.2	0.30	2012			9.4	0.12
1980					2013			7.5	0.50
1981	634.5	0.28	610.9	0.26	2014			75.3	1.30
1982	330.5	0.67	318.2	0.66	2015			5.3	1.23
1983									