California Anchovy Population Remains Low, 2012-2016

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Word count: 2964

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 2012-2015. We followed the approach of MacCall et al. (2016; Fish. Res. 175:87–94) 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 which were based on calibration using an erroneous absolute biomass value from the early 1980s, and extended estimates up through 2015. Anchovy 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 the Pacific coast 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 fisheries in California and Mexico (CDFG 2001). Anchovy stock assessments were conducted until 1995 (Jacobson et al.1995); since then, only biomass estimates exist (MacCall et al. 2016). After a spike in estimated spawning biomass briefly exceeding a million metric tons (MT) in 2005-2006, the population subsequently collapsed (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 was 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 (MacCall 1990). The consequence was a severe reduction in the production of recruitment-age fish. The decline in abundance happened faster than could be explained by poor recruitment alone, indicating that the natural mortality rate of adults also probably increased. 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. in review).

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 biomass estimates to 2015 as additional data have become available. We follow the MacCall et al. (2016) method which 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).

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). DEPM estimates were corrected here prior to calibration. The erroneous 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). Both egg and larval samples were used for biomass estimates in 1951-1999 and 2012-2015, although larval samples had to be dropped in 2000-2011 due to exceptionally low larvae to egg ratios (MacCall et al. 2016; Fig. 2). The extended estimates included April and January data as was available in 2012-2014. 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 jack-knife procedure which 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 anchovy biomass estimates with coefficients of variation are presented in Appendix I. The anchovy 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 1951-1999 (Fig. 2). Therefore, both egg and larval samples were utilized for updating biomass estimates for 2012 through 2015.

The extended time series (2012-2015) shows that stock remains low after a collapse after 2005 (i.e., two orders of magnitude below the 2005 value). 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 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 values since the beginning of CalCOFI. Anchovy biomass remains below 100,000 metric tons, at a multi-year average of 20,000-25,000 metric tons. Predator responses and other trawl survey results also support this.

Recent available predator data included unusual mortality events for California sea lions in southern California in 2009-2010 (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 updated data are not yet available. More recently, poor breeding performance of brown pelicans off southern California (Henry 2015) and reductions in anchovy in sea lion diets in central California have been observed up through 2014 (J. Thayer unpublished data).

Spring CalCOFI cruises sample pelagic nekton at night using a Nordic 264 rope trawl (Davison et al. in review, Griffith 2008; Dotson et al. 2010). Rope trawl survey results from 2010-2013 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. in review). 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 2010-2013 (Sakuma 2015). In 2014-2015, adult northern anchovy catches remained low in all areas, including inshore sampling stations, as in prior years. 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).

While an increase of anchovy in the diet of both sea lions and rhinoceros auklets at Año Nuevo Island was documented in 2015, these were exclusively age-0 anchovy (Beck et al. 2015, J. Thayer unpublished data). It is still unknown if an increase of age-0 anchovy in 2015 predator diet and also reflected in the 2015 RRS trawls resulted in any 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 indicate egg distribution nearshore in a small area, and very low peaks of ~15 eggs/m^2. Thus, there has been no substantial recovery of the anchovy population in 2016.

Anecdotal observations (mostly visual) suggested that anchovy were extremely abundant. Davison et al. (in review) examined not only RRS and CalCOFI rope trawls, but additional data from the CalCOFI ichthyoplankton time series and nearshore SCOOS stations, and aerial surveys. He explored whether anchovy adults migrated north of the study area, whether there was a large biomass of anchovies near shore, 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 conclude with the current updates/corrections that the 2009-2016 population crash is real and that the remnant anchovy population contracted to extremely nearshore habitat where it has appeared paradoxically abundant to observers.

Additional doubts that have been raised as to the validity of the anchovy biomass estimate include the fact that fishery catch in 2015 surpassed the estimate of biomass that year. Similar anomalies were observed in the early 1950s, but we now understand better how they can be explained. First, since recent annual estimates of biomass are highly uncertain, as mentioned previously, an average of recent years should be utilized instead of any annual point estimate (such as 2015). Basically, such an anomaly can be caused by a small calibration error and small bias in the biomass estimate due to nearshore refuges from fisheries-independent surveys but not from fishers. 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 takes pre-spawning anchovies in the fall and winter, the biomass available to the fishery could substantially exceed the spawning biomass as of January-April. Also, at the high mortality rates (natural and fishing combined) of anchovy, the catch could even exceed the annual average standing biomass.

It remains that the core CalCOFI survey does not completely cover the range of the central anchovy subpopulation. Davison et al. (in review) showed that neither northern nor nearshore concentrations have substantially altered recent overall biomass estimates. More could be done in the future, such as using the central California and nearshore SCOOS station icthyoplankton data along with the core CalCOFI region to estimate biomass in 2016 (NOAA 2016). 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 numbers of the central subpopulation of northern anchovy.

Acknowledgements

We thank the Pew Charitable Trusts for funding this study. S.A. Thompson assisted with editing and M. Garcia-Reyes 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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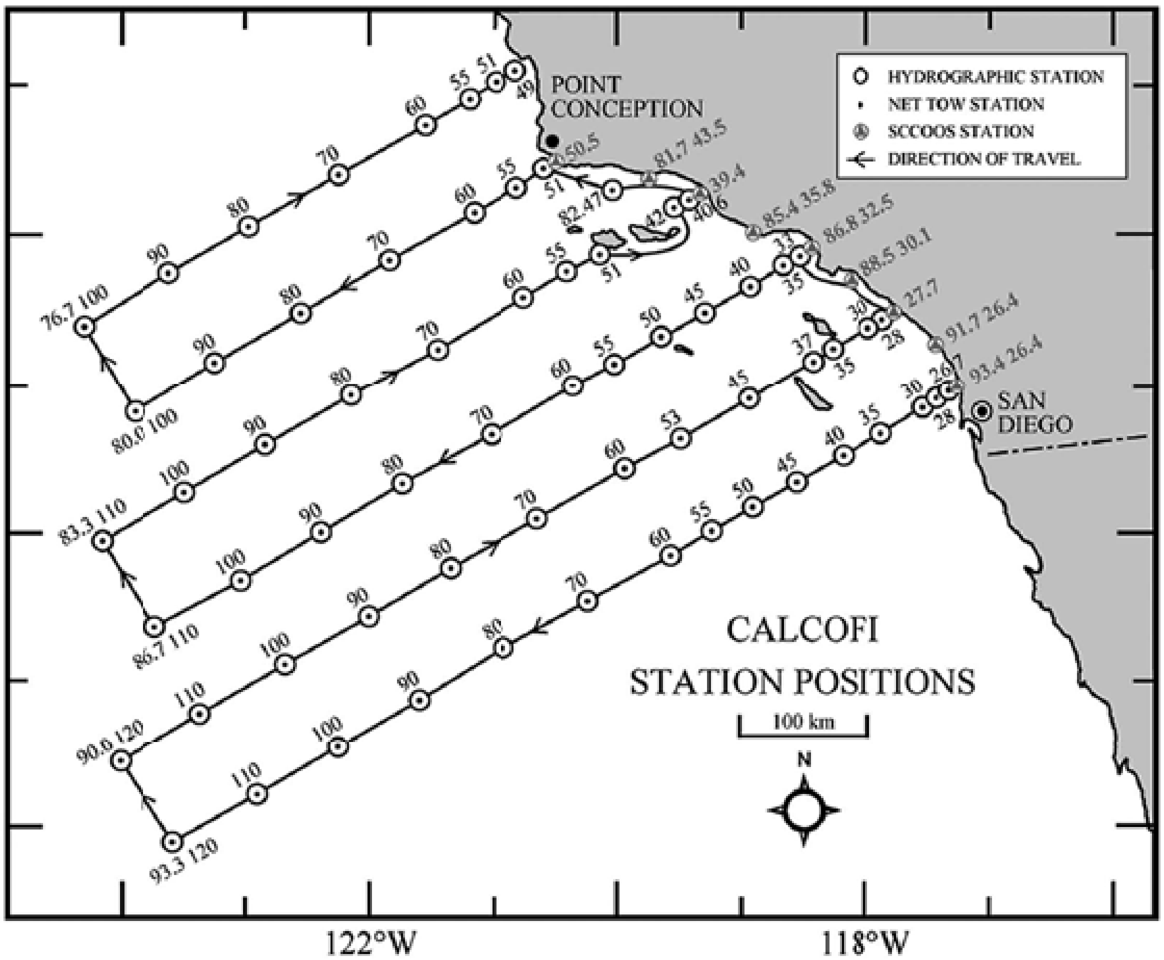
Figure 1. Locations of core southern California CalCOFI sampling stations (from MacCall et al. 2016), also showing location of the nine nearshore SCCOOS stations added in Fall 2004, but not included in our long-term timeseries due to standardization of survey locations.

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.

Figure 3. Anchovy biomass estimates on (a) numeric and (b) log scale. As extended estimates have are based on few positive stations, CVs are imprecise. After removing larvae from estimates in 2000-2011, adding larvae back into estimates for 2012-2015 (dotted lines) does not change the pattern, but does improve precision.

Figure 4. Preliminary CUFES survey results from spring 2016 showing anchovy egg catch and distribution. Note the continued very nearshore distribution and low values. Red and green survey tracks are from different vessels. (https://swfsc.noaa.gov/textblock.aspx?Division=FRD&ParentMenuId=218&id=1340)



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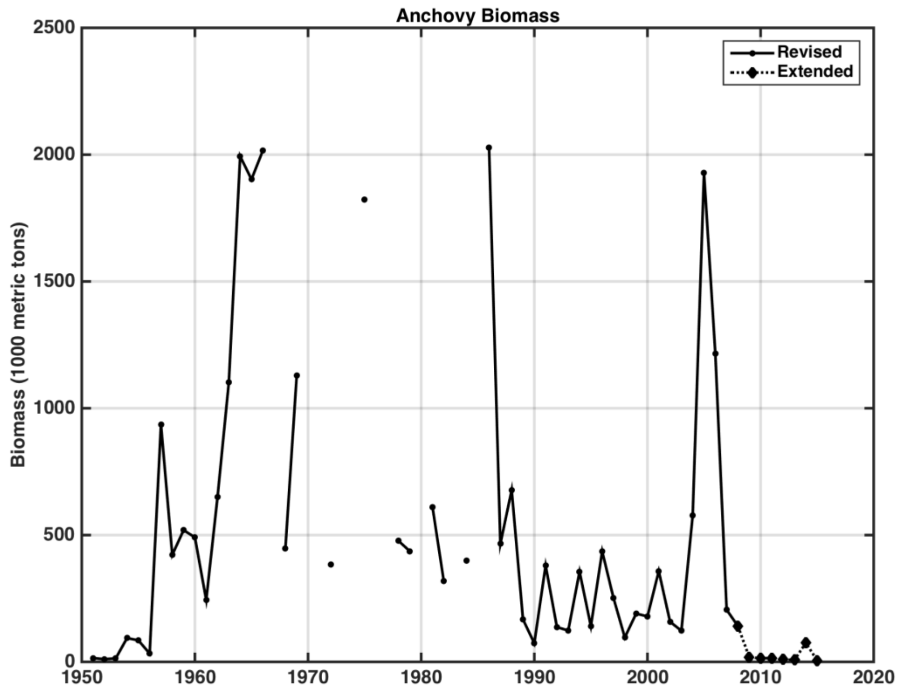

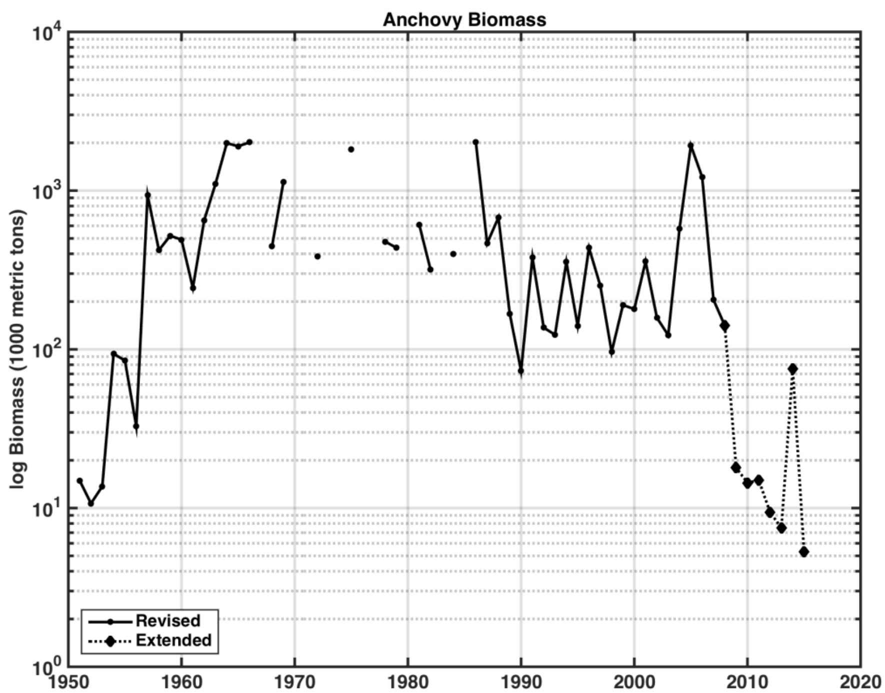

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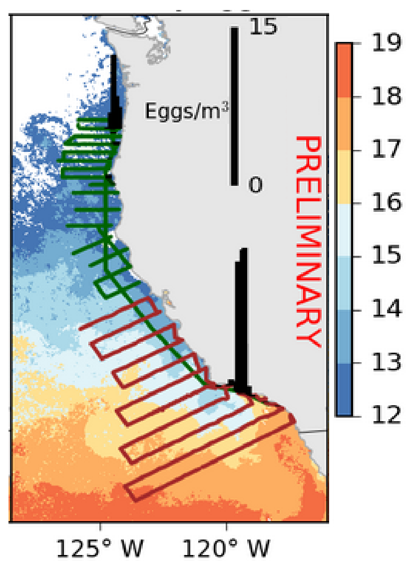

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Appendix I.

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 1951-1999 and 2012-2015 (light gray), while larval abundances were dropped in 2000-2011 when larvae to egg ratios declined (dark gray).

	Published Values		New Values	
Year	Biomass (MT)	total CV	Biomass (MT)	total CV
1951	15.5	1.51	14.9	1.51
1952	11.1	1.78	10.7	1.78
1953	14.3	1.57	13.7	1.57
1954	97.5	0.62	93.8	0.61
1955	88.3	0.65	85.0	0.64
1956	34.0	1.02	32.8	1.02
1957	972.3	0.41	936.0	0.40
1958	438.3	0.32	422.0	0.31
1959	539.6	0.29	519.4	0.28
1960	510.0	0.30	491.0	0.29
1961	253.3	0.40	243.8	0.39
1962	675.2	0.27	650.0	0.26
1963	1145.4	0.23	1102.7	0.21
1964	2070.9	0.20	1993.7	0.18
1965	1976.3	0.20	1902.6	0.18
1966	2093.6	0.20	2015.5	0.18
1967				
1968	465.1	0.57	447.8	0.56
1969	1173.8	0.23	1130.1	0.21
1970				
1971				
1972	399.2	0.33	384.3	0.32
1973				
1974				
1975	1892.7	0.31	1822.1	0.30
1976				
1977				
1978	495.5	0.30	477.0	0.29
1979	453.1	0.31	436.2	0.30
1980				
1981	634.5	0.28	610.9	0.26
1982	330.5	0.67	318.2	0.66
1983				

Year	Published Values Biomass (MT)	Published Values total CV	New Values Biomass (MT)	New Values total CV
1984	415.5	0.33	400.0	0.31
1985				
1986	2106.6	0.30	2028.0	0.28
1987	483.4	0.56	465.4	0.55
1988	703.9	0.27	677.6	0.25
1989	173.9	0.47	167.4	0.46
1990	76.0	1.36	73.2	1.36
1991	394.8	0.61	380.1	0.61
1992	142.2	0.52	136.9	0.51
1993	128.4	0.54	123.6	0.54
1994	369.4	0.34	355.6	0.33
1995	146.2	0.51	140.7	0.50
1996	452.6	0.31	435.7	0.30
1997	261.4	0.39	251.7	0.39
1998	100.0	0.61	96.3	0.60
1999	197.6	0.45	190.3	0.44
2000	186.2	0.88	179.3	0.87
2001	371.7	0.63	357.9	0.63
2002	164.3	0.93	158.1	0.93
2003	127.6	1.06	122.8	1.05
2004	599.6	0.50	577.2	0.50
2005	2002.5	0.30	1927.7	0.29
2006	1263.6	0.68	1216.4	0.68
2007	213.2	0.82	205.2	0.82
2008	146.6	0.99	141.1	0.98
2009	18.7	5.47	18.0	5.47
2010	15.0	3.06	14.4	3.06
2011	15.6	3.00	15.0	3.00
2012			9.4	0.12
2013			7.5	0.50
2014			75.3	1.30
2015			5.3	1.23