March 30, 2017

Mr. Herb Pollard, Chair
Pacific Fishery Management Council
7700 NE Ambassador Place, Suite 101
Portland, OR 97220

Mr. Barry Thom, Regional Administrator
National Marine Fisheries Service
1201 NE Lloyd Blvd., Suite 1100
Portland, OR 97232

RE: Agenda Item G.2. Central Subpopulation of Northern Anchovy Overfishing Limit Process

Dear Chair Pollard, Mr. Thom, and Council members:

Northern anchovy are a keystone forage species in the California Current Ecosystem. They are preyed upon by a wide variety of marine wildlife, including mammals, sea birds, and commercially and recreationally valuable fish. Fishery management for the central subpopulation of Northern anchovy (CSNA) must be based upon the best available science, prevent overfishing, and account for the needs of dependent marine wildlife.

In November 2016, the Pacific Fishery Management Council (Council) directed the Southwest Fisheries Science Center (SWFSC), the Scientific and Statistical Committee (SSC), the Coastal Pelagic Species Management Team (CPSMT), and the Coastal Pelagic Species Advisory Subpanel (CPSAS) to continue work to develop "an integrated stock assessment and procedures for setting and updating" an overfishing limit (OFL), allowable biological catch (ABC), and minimum stock size threshold (MSST) for the CSNA.[1] The Council also directed the SSC to identify alternative approaches for developing a revised OFL for the CSNA and a process and timeline to consider OFL alternatives, for discussion at the April 2017 Council meeting.[2] This work must be consistent with the SSC's November report, which makes clear the current OFL for the CSNA is based on a model using historical data that was collected "under dramatically different environmental and abundance conditions" than exist today.[3]

We appreciate the Council's initiative to address the issues identified in the SSC report. While future methodology reviews and stock assessments may help to inform future updates to CSNA management, the Council must take actions immediately to update OFL, ABC, and MSST, and does not need to wait.

[1] PFMC, Draft Motion, Agenda Item G.4 (Nov. 2016), *available at* http://www.pcouncil.org/wp-content/uploads/2016/11/G4_CouncilAction_NOV2016.pdf.
[2] *Id.*
[3] PFMC, November 2016 Agenda Item G.4.a. Scientific and Statistical Committee, Supplemental Report on Northern Anchovy Stock Assessment and Management Measures 2, *available at* http://www.pcouncil.org/wp-content/uploads/2016/11/G4a_Sup_SWFSC_Rpt2_NOV2016BB.pdf

Responsible management of highly fluctuating fish stocks such as anchovy requires frequent assessments, precaution, and responsiveness. The CPS FMP currently bases anchovy fishery management on a bioeconomic model that estimated maximum sustainable yield (MSY) using data from 1964-1990, during which time stock and oceanic conditions were very different.[4] The best available science shows that the CSNA has collapsed and should be considered overfished, and that the current catch limits allow overfishing.[5] Concurrent declines of substitute prey species such as Pacific mackerel, Pacific herring, and Pacific sardines have resulted in unprecedented and undisputed evidence of prey limitation in multiple dependent predators. The current management of the CSNA under the CPS FMP is inadequate.

In order to achieve a sustainable fishery for the CSNA, the Council and National Marine Fisheries Service (NMFS) should take the following actions immediately:

1. Adopt an OFL based on the best available estimate of biomass in U.S. waters and the best estimate of the MSY fishing rate (F_{MSY}) using the method in Option C in the SSC/CPSMT report;[6]
2. Set an ABC that is sufficiently precautionary given the scientific uncertainty associated with the MSY estimate for this stock;
3. Adopt a minimum stock size threshold MSST for the CSNA based on the best scientific information available;
4. Close the directed fishery; and
5. Adopt a new annual catch limit (ACL) to allow for incidental catch based on the best available scientific information.

In addition, we request that the Council and NMFS:

1. Develop and complete a full stock assessment to inform future management (i.e., Option B in the SSC/CPSMT report[7]);
2. Establish a harvest control rule, including a sufficiently high CUTOFF, for setting ACLs that achieve optimum yield;
3. Establish time-area closures to anchovy fishing to protect dependent predators; and
4. Remove the “monitored” category in the CPS Fishery Management Plan.

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[4] Conrad, J.M. (1991) .A Bioeconomic Analysis of the Northern Anchovy. Working paper in agricultural economics. Department of Agricultural Economics. New York State College, Ithaca New York;
PFMC. (1998). Coastal Pelagic Species Fishery Management Plan Amendment 8. Appendix B, at 104.

[5] MacCall, A.D., Sydeman, W.J., Davison, P.C., and Thayer, J.A. (2016). Recent collapse of northern anchovy biomass off California. *Fisheries Research* 175, 87-94; Thayer, J.A., MacCall, A.D., Davison, P.C., and Sydeman, W.J. (2016). California Anchovy Population Remains Low, 2012-2015. Farallon Institute.

[6] PFMC 2017. April 2017 Agenda Item G.2.a. Joint SSC/CPSMT Report on CSNA Overfishing Limit Process. http://www.pcouncil.org/wp-content/uploads/2017/03/G2a_SSCandCPSMT_Rpt_Apr2017BB.pdf

[7] *Id.*

A. IMMEDIATE ACTION

Now is the time for NMFS and the Council to take swift action to prevent overfishing of this collapsed anchovy population. Immediate action is required to prevent exacerbation of the collapse[8] and limit negative impacts to dependent predators. We request the Council and NMFS immediately set measureable and objective reference points including status determination criteria (e.g., MSST, OFL), MSY, ABC, and annual catch limits (ACLs) and accountability measures which must be based on "the best scientific information available." 16 U.S.C. § 1851(a)(2).

1. <u>Direct the SSC to recommend a new OFL based on the most recent, best available estimate of stock biomass in U.S. water and estimate of F_{MSY} under current conditions.</u>

The current OFL for the CSNA was based on the MSY estimate of approximately 123,000 metric tons (mt) from a 1991 model that used population estimates from 1964-1990, when the stock was abundant.[9] Recent studies, however, have documented the stock has declined by over 95% since that period.[10] MSY should be set for every stock within the fishery and updated when "changes in long-term environmental or ecological conditions, fishery technological characteristics, or new scientific information" become available.[11] MSY must be set utilizing the best available science and must accurately reflect the ability of the fishery to persist at a healthy and sustainable level under current conditions. Therefore, the OFLs must be based on current conditions and current estimates of the MSY for the stock.

We commend the SSC's recent work to develop near-term and longer-term approaches to setting the OFL. We recommend that the Council immediately establish an OFL based on the method in Option C identified by the SSC, which is to "set OFL based on F_{MSY} (from an assessment or proxy) multiplied by an estimate of absolute abundance (not from an assessment)."[12] Option C is consistent with the OFL formula for actively managed species in the CPS FMP. However, contrary to the notion that a methodology review is necessary before adopting an updated OFL, it can be implemented now using the best available estimates of absolute abundance and F_{MSY}. Here we outline the available information for setting each of the three parameters necessary for calculating OFL under the Option C approach, where OFL = Biomass * F_{MSY} * Distribution.

a. Biomass

The acoustic-trawl method is used to assess anchovy stocks around the world and is the most direct estimate of adult biomass available. Data from the acoustic-trawl method (ATM) confirmed the low

[8] Essington et al. 2015. Fishing amplifies forage fish population collapses. Proceedings of the National Academy of Sciences: www.pnas.org/cgi/doi/10.1073/pnas.1422020112
[9] *Conrad, J.M. (1991), supra note 5.*
[10] MacCall et al. 2016, Thayer et al. 2016, Zwolinski et al. 2016.
[11] 50 CFR § 600.315(e)(i)(C)(v).
[12] PFMC 2017. April 2017 Agenda Item G.2.a. Joint SSC/CPSMT Report on CSNA Overfishing Limit Process. http://www.pcouncil.org/wp-content/uploads/2017/03/G2a_SSCandCPSMT_Rpt_Apr2017BB.pdf

anchovy biomass observed in the CalCOFI survey, with an estimated 2015 biomass for the portion of the CSNA in U.S. waters of 31,427 metric tons.[13] This method provides an estimate of absolute biomass within the survey area, which in 2015 was solely in U.S. waters.[14]

The most recent study of total CSNA biomass using the Daily Egg Production Method (DEPM) estimates the 2015 CSNA biomass to be 5,300 mt, and the four-year average CSNA biomass to be 24,300 mt over the years 2012-2015. These estimates are for the entire CSNA including U.S. and Mexican waters.[15]

In response to reports of massive nearshore abundance of anchovies by the fishing community and other observers, Davison et al. 2017 (attached) found:

> *…no evidence using additional and more recent data that 1) anchovy adults migrated north of the study area, 2) there was a large biomass of anchovies near shore, or 3) spawning was temporally missed by MacCall et al…. [T]he 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.* [16]

Therefore, these two biomass estimates, 24,300 mt (full stock) and 31,427 mt (U.S. only), represent the best available science for the absolute abundance of the CSNA and corroborate previous observations of dramatic declines in stock biomass. There has been no quantitative evidence that either method misses a significant portion of the anchovy biomass nor has there been a proposed adjustment factor. Therefore, the Council does not need to wait for the 2018 ATM methodology review to use these best available estimates.

b. F_{MSY}

The most recent analysis of biological reference points in the September 2016 NMFS MSST report found an average F_{MSY} of 0.266 derived from Stock Recruitment Fitting (SRFIT) models based on eight stock-recruitment relationship scenarios for the CSNA.[17] This F_{MSY} estimate could be immediately incorporated into current management to inform the OFL.

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[13] Zwolinksi, J.P., Demer, D.A., Macewicz, B.Jl, Cutter, G.R., Mau, S. Murfin, D., Renfree, J.S., Sessions, T.S. and Stierhoff, K. (2016). The Distribution and Biomass of the Central-Stock Northern Anchovy During Summer 2015, Estimated from Acoustic-Trawl Sampling. *Draft of NOAA Technical Memorandum November 2016*, Appendix 1, *available* at http://www.pcouncil.org/wp-content/uploads/2016/11/G4a_Sup_SWFSC_Rpt2_NOV2016BB.pdf

[14] CPS FMP Section 4.6.1, p. 39: "In the absence of a cooperative management agreement, the default approach in the CPS FMP sets harvest levels for U.S. fisheries by prorating the total target harvest level according to the portion of the stock resident in U.S. waters *or estimating the biomass in U.S. waters only*." (emphasis added)

[15] Thayer, J.A., MacCall, A.D., Davison, P.C., and Sydeman, W.J. (2016). California Anchovy Population Remains Low, 2012-2016. Farallon Institute.

[16] Davison, Sydeman, and J.A. Thayer. 2017. Are there temporal or spatial gaps in recent estimates of anchovy off California? CalCOFI Rep., Vol. 58, 2017

[17] NMFS (2016) Review and Re-evaluation of Minimum Stock Size Threshold for Finfish in the Coastal Pelagic Fisheries Management Plan for the U.S. Agenda Item E.1.a, Supplemental NMFS Report, Table 6.

The Council might also consider other available F_{MSY} estimates are available. In Amendment 14 to the CPS FMP, the Council adopted an MSY reference point of F_{MSY} = 0.3 for the northern subpopulation of the northern anchovy (NSNA). Also, the F_{MSY} value implicit in the Conrad 1991 MSY and B_{MSY} estimates is 16.7% [MSY/B_{MSY} = 123,000 mt/733,000 mt].

c. Distribution

Like other stocks in the CPS FMP, the CSNA is a transboundary stock shared between the U.S. and Mexico. The CPS FMP currently uses a fixed distribution of 82%, and biomass estimates in previous stock assessments using the DEPM method were multiplied by this distribution to estimate the biomass in U.S. waters. In the absence of a more robust method, this would be appropriate for the DEPM-based biomass estimates provided in MacCall et al. 2016 and Thayer et al. 2016. The current estimates of biomass from the ATM survey, however, are for U.S. waters only, thus a distribution of 100% is appropriate for the ATM survey-based estimate. If future stock estimates include some biomass outside U.S. waters, we recommend the Council develop more robust methods of prorating U.S. catch levels, for example based on the method proposed by Demer & Zwolinski 2017 for the sardine fishery.[18]

We suggest using the most recent biomass estimate in U.S. waters from the ATM survey (31,427 mt in 2015) and the most recent NMFS estimate of F_{MSY} (0.266) for calculating OFL, which results in a U.S. OFL of 8,360 mt (see Appendix).

2. **Set an ABC that is sufficiently precautionary given the scientific uncertainty associated with MSY estimates.**

In light of recent scientific information showing a major decline in CSNA biomass, the Council must update both the OFL and ABC. In particular, the knowledge that this stock is known to fluctuate in size by over 95% [19] necessitates either frequent monitoring or a sufficiently large precautionary buffer to prevent overfishing when the stock is low.[20] The rationale for a 75% buffer in the FMP does not account for this level of stock fluctuation. So, if the Council wishes to choose a static OFL, the ABC must be set such that it cannot exceed the actual MSY based on current conditions.

Allowable biological catch is defined as, "A level of a stock or stock complex's annual catch that accounts for the scientific uncertainty in the estimate of OFL, biomass estimates, time since last assessment, changes in environmental conditions, as well as any other scientific uncertainty."[21] The Council should

[18] David A. Demer & Juan P. Zwolinski (2017) A Method to Consistently Approach the Target Total Fishing Fraction of Pacific Sardine and Other Internationally Exploited Fish Stocks, North American Journal of Fisheries Management, 37:2, 284-293. http://dx.doi.org/10.1080/02755947.2016.1264510
[19] McClatchie et al. 2017. Collapse and recovery of forage fish populations prior to commercial exploitation. Geophysical Research Letters 44(4):1877-1885; MacCall, A.D., Sydeman, W.J., Davison, P.C., and Thayer, J.A. (2016). Recent collapse of northern anchovy biomass off California. *Fisheries Research* 175, 87-94.
[20] Essington et al. 2015. Fishing amplifies forage fish population collapses. Proceedings of the National Academy of Sciences: www.pnas.org/cgi/doi/10.1073/pnas.1422020112
[21] 50 CFR § 600.315(f)(ii)

set the ABC based on an updated OFL (described above) and fully account for uncertainty in the OFL (including uncertainty in stock size, F_{MSY}, and distribution) in the ABC. The current OFL no longer reflects the stock status and thus there is no basis for a claim that a 75% reduction is sufficiently precautionary for this stock. However, if the Council updates the OFL as per the recommendations above, the 75% reduction may be appropriate for near-term measures unless a better estimate is developed.

Using our recommended U.S. OFL of 8,360 mt, this would mean setting a U.S. ABC of 2,090 mt. We also examine and provide other possibilities for setting OFL and ABC based on available information in the Appendix to this letter, which also yields similar results.

3. Adopt an MSST for the CSNA based on the best scientific information available.

FMPs must "specify objective and measurable criteria for identifying when the fishery to which the plan applies is overfished."[22] The National Standard 1 guidelines define MSST as "the level of biomass below which the stock or stock complex is considered to be overfished."[23] While historically, the management of anchovy included an MSST set at 50,000 mt, the CPS FMP does not currently specify an MSST for the central subpopulation of northern anchovy.[24] Without a defined MSST or a meaningful estimate of biomass to compare to MSST, the CPS FMP currently lacks criteria to identify when the CNSA is overfished. The categorization of the CSNA as "monitored" does not alleviate the Council or NMFS of its obligation to meet this requirement.

The September 2016 NMFS report on MSSTs for CPS finfish puts forth MSST values for CSNA calculated using a combination of historical data and modern methods. This report produced MSST values of 69,781 mt and 69,049 mt based on two different methods and applying NS1 guidelines.[25] These current estimates for MSST produced by NMFS enable the Council to immediately adopt an MSST for the CNSA. While improvements could foreseeably be made with additional information from a full stock assessment, the Council must immediately adopt an MSST based on available information.

4. Close the directed fishery for CSNA.

The directed fishery should be closed immediately because the most recently available population estimates indicate the population is at perilously low numbers. The current best available science shows that the anchovy stock is well below any reasonable cutoff or MSST value for this stock. For example, Amendment 5 to the Northern Anchovy FMP adopted a cutoff that set the catch limit to zero when spawning biomass was below 300,000 mt in order "to prevent depletion of the resource and to provide

[22] 16 U.S.C. § 1853(a)(10)
[23] 50 CFR § 600.315(f)
[24] NMFS (2016) Review and Re-evaluation of Minimum Stock Size Threshold for Finfish in the Coastal Pelagic Fisheries Management Plan for the U.S. Agenda Item E.1.a, Supplemental NMFS Report, 2.
[25] NMFS (2016) Review and Re-evaluation of Minimum Stock Size Threshold for Finfish in the Coastal Pelagic Fisheries Management Plan for the U.S. Agenda Item E.1.a, Supplemental NMFS Report, Table 7 MSST calculations.

an adequate forage reserve for marine fishes, mammals, and birds."[26] This cutoff was largely to protect the brown pelican—which at the time was on the endangered species list—based on demonstrated relationships between anchovy population size and brown pelican fledgling success.[27] Pacific sardine and Pacific mackerel have cutoffs, and the current CPS FMP includes cutoff as part of the default harvest control rule for actively managed CPS stocks. Recent studies of forage fish populations[28] have further found that cutoff is the primary tool to prevent exacerbating natural declines and minimizing impacts to predators, especially when there are monitoring challenges detecting rapid declines. These studies of forage species populations have concluded that the optimal cutoffs set at 40-50% of mean unfished biomass maintain high levels of catch over the long term, while minimizing risks to forage fish stocks and their predators. Our recommendation to close the directed fishery is consistent with how the Council manages Pacific sardine and Pacific mackerel when they are below their respective cutoffs.

5. Set an ACL to allow for incidental catch in other fisheries.

In the immediate term, since the stock is below any reasonable cutoff for northern anchovy, the Council should close the directed fishery for CSNA and set a minimal ACL to accommodate incidental catch of anchovy in other CPS fisheries. At this time, the purpose of the ACL should be to limit the incidental catch of anchovy in other fisheries. Based on what we believe to be the most appropriate US ABC value (above), the ACL should be no greater than 2,090 tons. This approach would be generally consistent with the Council's management of Pacific sardines when they are below the cutoff.

B. RECOMMENDATIONS FOR FUTURE NORTHERN ANCHOVY MANAGEMENT ACTIONS

In addition to the immediate management actions we have identified the Council must take under the Magnuson-Stevens Fishery Conservation and Management Act (MSA), we request the Council embark on the following focal areas to improve northern anchovy management under the CPS FMP:

1. Request NMFS make a full assessment of the CSNA a top priority.

Since concerns first arose at the November 2013 Council meeting, conservation groups, fishing groups, and the Council have all requested NMFS complete a full stock assessment of the CSNA. In response, NMFS has repeatedly committed to complete such an assessment and failed to do so. While NMFS and the Council currently have available information to inform immediate management changes, the future of anchovy management will be greatly improved by additional information. Such information could

[26] PFMC 1990. Sixth Amendment to the Northern Anchovy FMP. ES-1 "Background and Current Management Regime. Available at: ftp://ftp.pcouncil.org/pub/Anchovy/North_Anchovy_A6_1990.pdf

[27] *Id.*; Anderson, D.W., Gress, F., and Mais, K.F. (1982). Brown Pelicans: Influence of Food Supply on Reproduction. *Oikos* 39(1), 23-31

[28] Essington et al. 2015. Fishing amplifies forage fish population collapses. Proceedings of the National Academy of Sciences: www.pnas.org/cgi/doi/10.1073/pnas.1422020112 *and* Pikitch et al. 2012. Little Fish, Big Impact: Managing a Crucial Link in Ocean Food Webs. Lenfest Ocean Program. Washington, D.C. 108pp.

inform future changes to OFL, ABC, ACL, MSST, and an ecosystem-based harvest control rule. In particular, this would enable the Council to base OFL on Option B as identified in the joint SSC/CPSMT report in the future.

2. Assess and specify OY, including a harvest control rule with a sufficient cutoff.

NMFS must consider relevant ecological, economic, and social factors in establishing OY for a fishery. The CPS FMP recognizes the important role of northern anchovy as forage and includes maintaining adequate forage for dependent predators as a management goal. The CPS FMP must identify the key ecological, economic, and social factors relevant to the management of northern anchovy and demonstrate how these factors are incorporated to achieve optimum yield. This should include ensuring the cutoff is sufficient to ensure the fishery minimizes harm to anchovy-dependent predators.

3. Consider and adopt time-area closures to protect dependent predators.

There are concerns both with the potential for localized prey depletion in the vicinity of key foraging grounds and the direct disturbance of predator foraging behavior by fishing activities. In November and December 2015, we requested that the PFMC and NMFS consider establishing time-area closures for anchovy and other CPS in known key foraging areas of Monterey Bay and the Channel Islands.[29] To date, there has been no serious consideration or discussion of these important management tools to protect predators. We suggest asking the CPSMT to consult with experts on key anchovy predators to identify a range of alternatives for time and area closures for future Council consideration.

4. Remove the “Monitored” category from the CPS FMP.

For “monitored” stocks, there is no periodic review of management measures or available science for these stocks, no way to determine whether these stocks are overfished, and inadequate precaution in the OFL/ABC buffer to prevent overfishing in light of the known degree of fluctuation in these stocks. The September 2016 report by the CPSMT[30] revealed many inconsistencies and a lack of clarity in the way in which the Council manages monitored stocks. We urge the Council and NMFS to remove the monitored category altogether.

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[29] Comments on Proposed Rule RIN 0648-XC808 December 21, 2015 from Andrea Treece, Earthjustice and Mariel Combs, Oceana *and* Oceana Public Comment, PFMC November 2015, Agenda Item H.3.b http://www.pcouncil.org/wp-content/uploads/2015/11/H3b_Sup_Public_Comment_7_ElectricOnly_Nov2015BB.pdf

[30] PFMC. September 2016 Agenda Itme E.3.a CPSMT Report on Anchovy Management Update. http://www.pcouncil.org/wp-content/uploads/2016/08/E3a_CPSMT_Rpt_SEPT2016BB.pdf

C. CONCLUSION

The Council and NMFS must take immediate action to respond to the scientific information showing a collapsed central subpopulation of Northern anchovy, establish fundamental fishery management reference points, and initiate a process to establish a robust, active management framework that complies with the MSA. In the face of climate change and other unprecedented threats, this comprehensive suite of actions will ultimately serve to improve the resilience of our West Coast fishing industry, other industries dependent on anchovy predators, and the broader marine ecosystem.

Sincerely,

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Attachment: Davison et al. 2017. "Are there temporal or spatial gaps in recent estimates of anchovy off California?" CalCOFI Rep., Vol. 58. 13 pp.

Appendix:

Potential parameters and resulting reference points for CSNA based on most recently available information, including two options for biomass and three options for Fmsy. We recommend adoption of the parameters in Option 1 for setting U.S. OFL and U.S. ABC for the CSNA until better information becomes available.

Option	Biomass source	Fmsy source	Biomass (mt)	Fmsy	Dist.	ABC/OFL	CSNA OFL (mt)	US OFL (mt)	US ABC (mt)
1	Zwolinski et al. 2016 (2015 ATM survey)	NMFS 2016 MSST Report, Table 6	31,427	0.266	1	0.25	N/A*	8,360	2,090
2	Zwolinski et al. 2016 (2015 ATM survey)	Conrad 1991	31,427	0.167	1	0.25	N/A*	5,248	1,312
3	Zwolinski et al. 2016 (2015 ATM survey)	NSNA	31,427	0.300	1	0.25	N/A*	9,428	2,357
4	Thayer et al. 2016 (DEPM estimate 2012-2015 mean)	NMFS 2016 MSST Report, Table 6	24,300	0.266	0.82	0.25	6,464	5,300	1,325
5	Thayer et al. 2016 (DEPM estimate 2012-2015 mean)	Conrad 1991	24,300	0.167	0.82	0.25	4,058	3,328	832
6	Thayer et al. 2016 (DEPM estimate 2012-2015 mean)	NSNA	24,300	0.300	0.82	0.25	7,290	5,978	1,494

* The ATM survey does not include the portion of the stock in Mexican waters so a stockwide OFL may not be available with this method.

ARE THERE TEMPORAL OR SPATIAL GAPS IN RECENT ESTIMATES OF ANCHOVY OFF CALIFORNIA?

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ABSTRACT

MacCall et al. (2016) recently published an estimate of the biomass of the central stock of northern anchovy (*Engraulis mordax*) off the coast of California, and found that this stock experienced a population crash from 2009–15. However, anecdotal observations concurrent to the collapse suggested that anchovy were extremely abundant. We used central and southern California data from two trawling surveys, ichthyoplankton time series, and aerial surveys to investigate whether or not any anchovy spawning was missed by MacCall et al. We found no evidence using additional and more recent data that 1) anchovy adults migrated north of the study area, 2) there was a large biomass of anchovies near shore, or 3) spawning was temporally missed by MacCall et al. Thus, we conclude that the 2009–15 population crash is real and that the anchovy population remnant contracted to extremely nearshore habitat where it appeared paradoxically abundant to observers.

INTRODUCTION

MacCall et al. (2016) recently estimated the biomass of the central stock of northern anchovy (*Engraulis mordax*) off California from the California Cooperative Oceanic Fisheries Investigations (CalCOFI) ichthyoplankton time series calibrated to past stock estimates made using the daily egg production method (Lo 1985a; Jacobson et al. 1994). MacCall et al. found that the California anchovy stock is experiencing a population crash, and that the stock size may be as low as 15,000 t (2009–11; 95% CI <100,000 t). However, recent anecdotal reports state that anchovy are abundant (Bartolone 2014; Gaura 2015). Thus, it is possible that the MacCall et al. estimate missed spawning that was inshore, north of their study area off central California, or outside of their study periods (Parrish 2015). We examine the evidence in support of and against the argument that there remains a significant anchovy stock off central and southern California that was not observed by MacCall et al.

The anchovy is a schooling coastal pelagic fish species that has undergone large oscillations in abundance for thousands of years, with periodicity of ~60 y (Baumgartner et al. 1992; MacCall 1996; Field et al. 2009). Several authors have linked population oscillations to climate influences (Lehodey et al. 2006; Lindegren et al. 2013). Indeed, the current collapse described by MacCall et al. (2016) occurred in the absence of a significant fishery, and occurred ~60 y after the last anchovy population crash in the early 1950s. 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 population centers for anchovy on 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 (Schwartzlose et al. 1999; Zwolinski et al. 2012), and a southern stock off the Baja California coast.

MacCall et al. (2016) developed their anchovy biomass estimate using CalCOFI ichthyoplankton data from southern California. Although one cannot logically prove that there is no "hidden stock" of anchovies in the California Current system (CCS) that eluded the methods of MacCall et al., it is possible to test whether their conclusions are consistent with independent data and data that were excluded from their analysis. We compared egg, larval, and adult anchovy abundance and distribution in years when stock assessments were high, moderate, and low and logically tested whether the reported ichthyoplankton decline was consistent with migration of the SCB population inshore or north to central California. To address the possibility that spawning was missed temporally we looked at monthly means of CalCOFI ichthyoplankton abundance, and discuss the results in context with the phenology of anchovy in the CCS.

METHODS

We use data collected from several large-scale anchovy sampling programs operating approximately annually in the study area: CalCOFI ichthyoplankton, CalCOFI continuous underwater fish egg sampler (CUFES), the National Marine Fisheries Service (NMFS) Southwest Fisheries Science Center (SWFSC) juvenile rockfish sur-

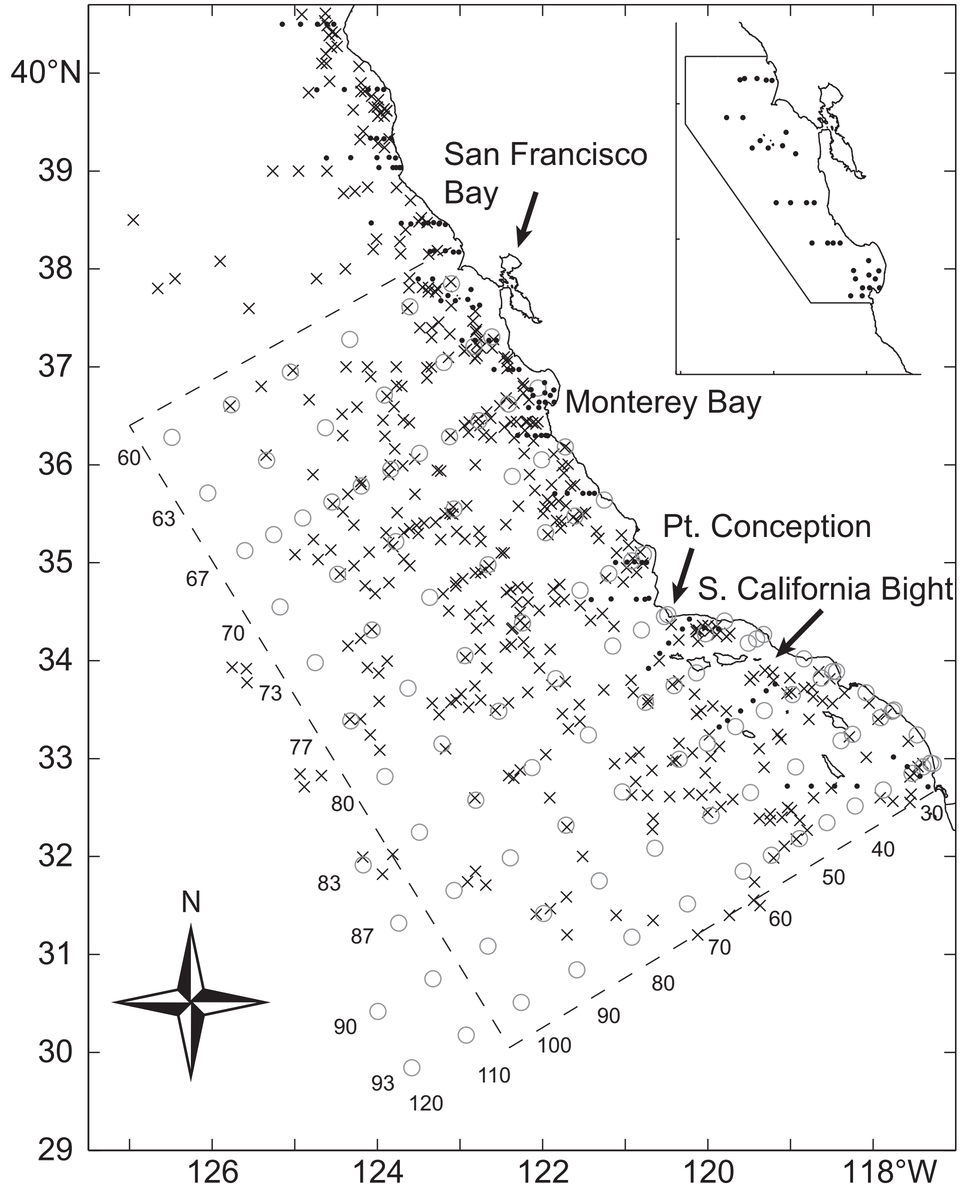


Figure 1. Central and southern California sampling. JRS stations are indicated with black dots, CalCOFI and SCCOOS stations are indicated with grey circles, CalCOFI ichthyoplankton data were used from within the dashed box, and the Spring CPS rope trawls are indicated as black crosses. The inset shows the "core" JRS region and stations. AT transects are not shown, but they generally cover the CalCOFI region and extend north of the displayed area. CalCOFI line numbers are indicated to the west of the study region, and station numbers to the south.

vey (JRS), the SWFSC Spring Coastal Pelagic Species (Spring CPS) rope trawl program, and we discuss the SWFSC acoustic trawl (AT) and California Department of Fish and Wildlife aerial surveys of coastal pelagic fishes (fig. 1). The methods for these data are presented by survey, whereas the results and discussion are organized into a comparison between central and southern California, long-term changes in abundance, abundance inshore of the standard CalCOFI stations, and seasonal patterns in anchovy abundance. Extensive time series are available for two of these surveys, the JRS and CalCOFI ichthyoplankton. We also use the underway CUFES data (2012–15) to assess the possibility that the anchovy stock has recently recovered. We compare anchovy abundance at several points in time, chosen from four published biomass estimate time series (Methot 1989; Jacobson et al. 1994; Fissel et al. 2011; MacCall et al. 2016). For "high" anchovy stock, we use 1975, for "moderate" biomass we use 1984, and for "low" biomass we use 2011 (fig. 2). We also use 2005 for an alternate period of "high" biomass, as there was a short-term recovery of the stock 2005–06 (fig. 2). We used the methods of MacCall et al. (2016)

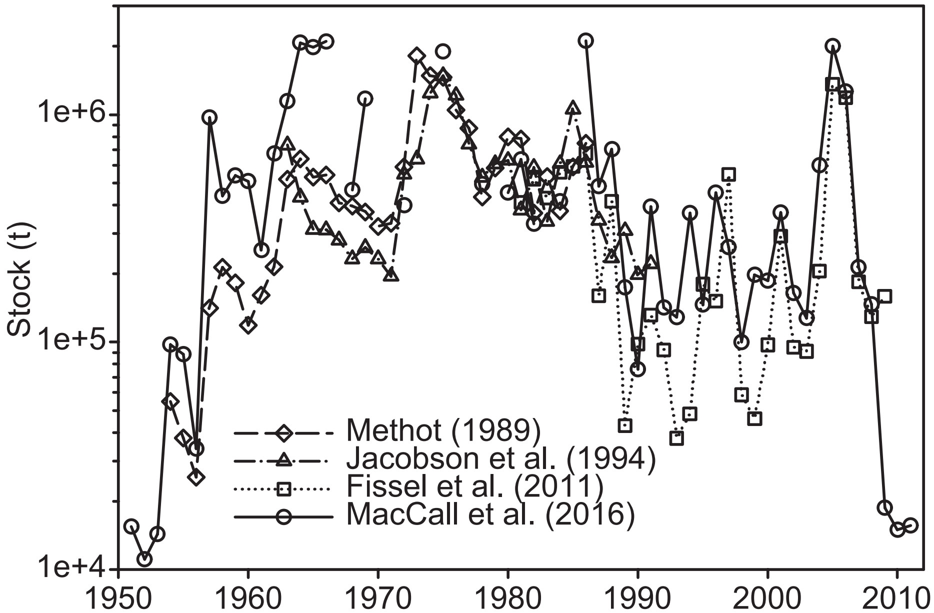


Figure 2. Published stock estimates for the central anchovy stock.

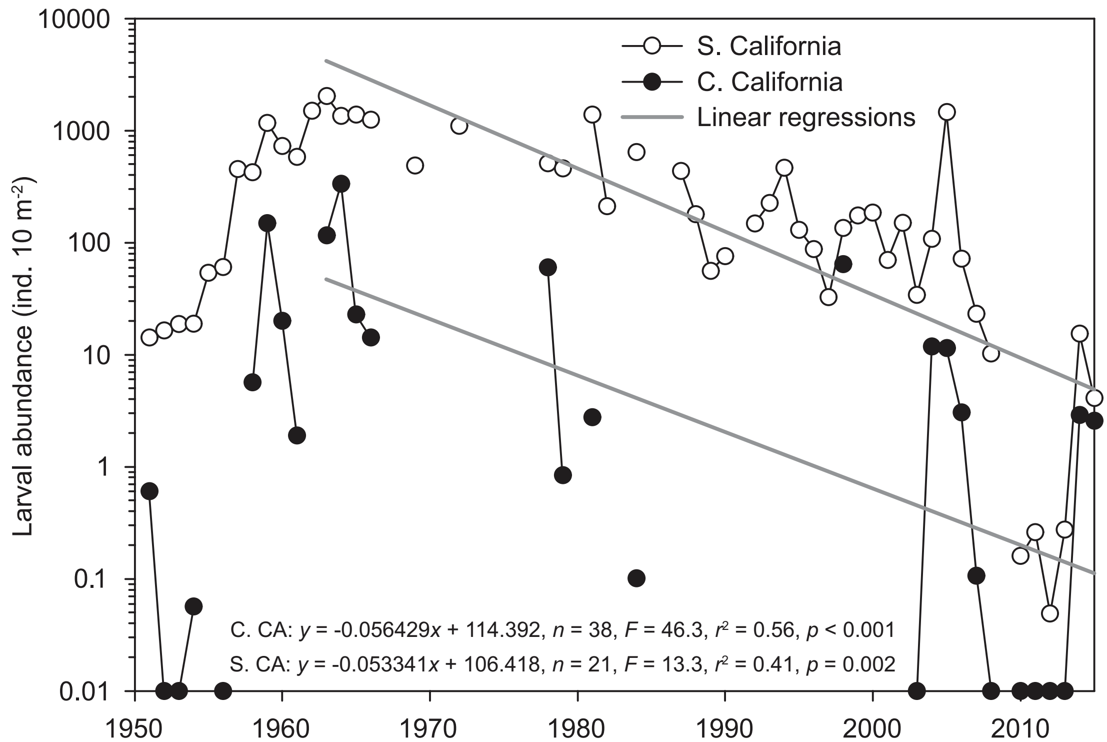


Figure 3. Spring CalCOFI mean anchovy larval abundance (ind. 10 m^{-2}) for central California (north of Pt. Conception; closed circles) and southern California (open circles). Linear regressions for 1963–2015 are shown as grey lines, neither passed the test for constant variance ($p < 0.05$).

to extend their spring larval abundance estimates to the year 2015 (fig. 3), and compared standard CalCOFI station results to those using the inshore Southern California Coastal Ocean Observing System (SCCOOS) stations for the period 2005–15.

CalCOFI

CalCOFI ichthyoplankton data were collected with plankton nets 1951–2015. During the early part of the time series, cruises were monthly, and during the later part quarterly. Between 1969 and 1981 CalCOFI cruises were made triennially. We did not group data collected in different months.

There were two major changes in sampling methods over the course of the time series; in 1969 the sampling depth was changed from 140 m to 210 m, and in 1978 the net design was changed from a 1 m ring net to a 0.7 m bongo net. The capture efficiency of the two net designs is roughly the same for the size classes of anchovy larvae that make up 90% of the catch (Hewitt 1980). For this reason, and because 100% of anchovy larvae were found shallower than 122 m (Ahlstrom 1959), the changes in sampling methods should have little effect on the abundance time series.

Anchovy abundance estimates based upon CalCOFI data are subject to spatial hyperstability bias because neither the fish nor the sampling stations are evenly distributed within the study area (MacCall et al. 2016; fig. 1). Spatial hyperstability was corrected by assigning sample locations to a 10 x 10 km grid, filling unoccupied grid elements using linear interpolation, and then averaging the entire interpolated grid. Multiple occupations of the same grid cell in the same month were averaged prior to interpolation. Only larval abundance was used, rather than larval and egg abundance, to better detect evidence of inshore spawning and to reduce any temporal mismatch between spawning and sampling. Larvae are more likely to be detected than eggs at widely spaced sampling stations and times due to advection and diffusion processes (Richardson 1981) because the egg stage is ~3 d duration in comparison to the 70–90 d spent as a larva (Hunter and Coyne 1982; Lo 1985b; Smith 1985).

We used CalCOFI station larval abundance in three ways: mean central California spring larval abundance north of Pt. Conception (lines 60–77 offshore to station 100) was compared with the southern California index of MacCall et al. (2016); we compared spring anchovy larval abundance in the SCB at the inshore SCCOOS stations to that at the inshore ends of CalCOFI lines 80–93; and we used mean monthly larval abundance data off southern California (1951–2015, all cruises, lines 77–93, stations ≤ 100) to study seasonality of spawning.

Underway anchovy egg concentration has been recorded during CalCOFI cruises using CUFES since 1996 (NOAA 2015). The CUFES device filters water pumped at ~650 l min^{-1} from an intake 3 m below the surface while the vessel is underway (Checkley et al. 1997). Fish eggs from the filtered samples were usually identified and counted every 5–30 min.

JRS

The NMFS SWFSC conducts an annual spring–summer survey in the CCS over the continental shelf and slope that is designed to collect juvenile rockfishes, although many other taxa are recorded (Ralston et al. 2015). The data used here span the years 1983–2013. Trawls made in August or later were excluded for seasonal consistency with the Spring CPS rope trawl. Marine fauna were collected at night with ~15 min tows of a modified Cobb midwater trawl with a mouth area of ~144 m^2 and a variable mesh terminating with a cod end liner mesh of 9.5 mm. The trawl was fished at ~2 knots at a station-specific standard depth (headrope at ~10 m or ~30 m). Nonstandard tows, tows made to nonstandard depths, and tows for which an error was noted were not used. JRS cruises occupy specific stations, often more than once per cruise, and central California stations that were added or dropped mid-series were not included in this study. An exception was made for two stations, which were combined because they are only ~7 km apart and were occupied for complementary halves of the time series. The "core" region of the survey off central California as defined above then consists of 32 stations that are occupied approximately three times annually (fig. 1). We used the mean station catch per unit effort (CPUE; ind. trawl^{-1}), and all "core" station means were then averaged to produce an annual mean. Additionally, mean station CPUE was calculated over several similar years corresponding to the "moderate" (1983–85) and "low" (2010–13) anchovy biomass periods in order to decrease trawl catch variability. JRS data north and south of the core area were available 2004–13 and processed similarly.

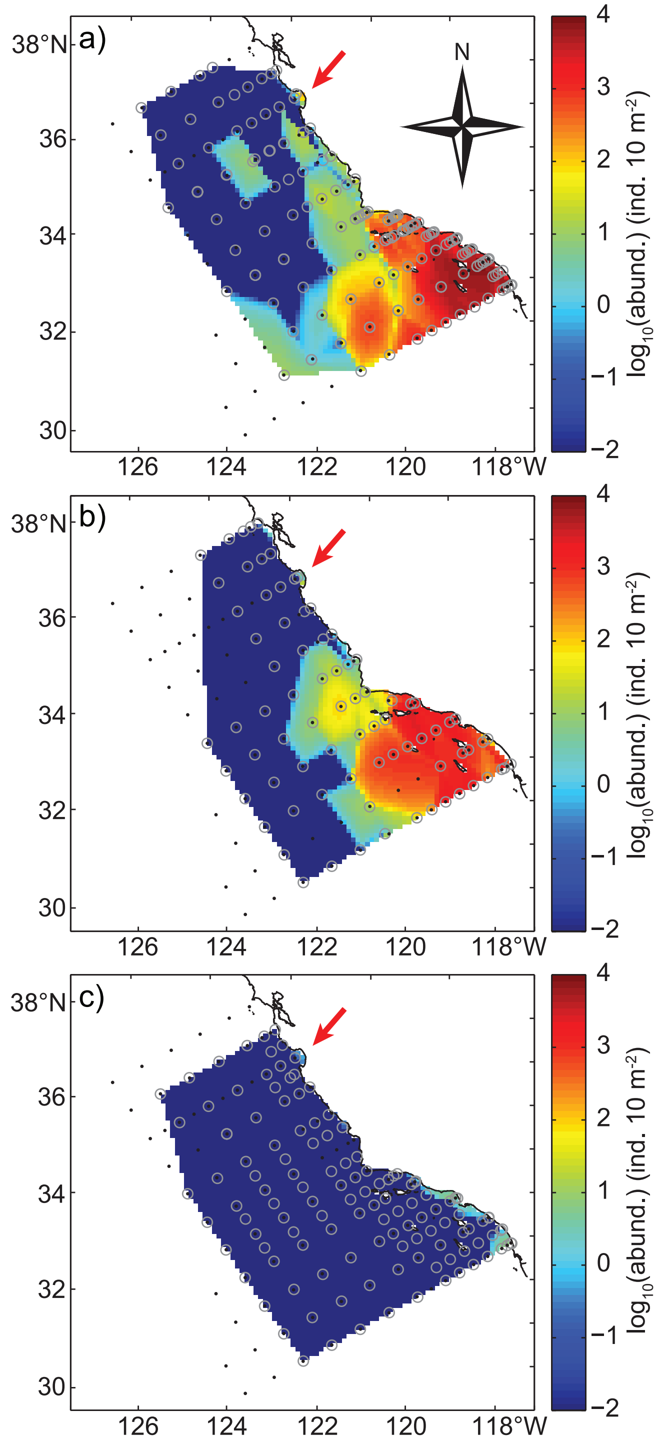
CPS

Spring CPS cruises sample pelagic nekton at night using a Nordic 264 rope trawl (Griffith 2008; Dotson et al. 2010). The rope trawl has a working mouth area of ~600 m^2 and is fished near the surface at ~3.5 knots. It has a variable mesh concluding with 8 mm mesh in the cod end liner. Because the sampling was somewhat sparse, and because several trawls may be made within a small area in the same night, we mapped the data to a 50 x 50 km square grid to avoid spatial bias, and used the mean of samples within each grid element. Data from the entire time period (2010–13) were grouped together to reduce the inherent variability in trawl catches.

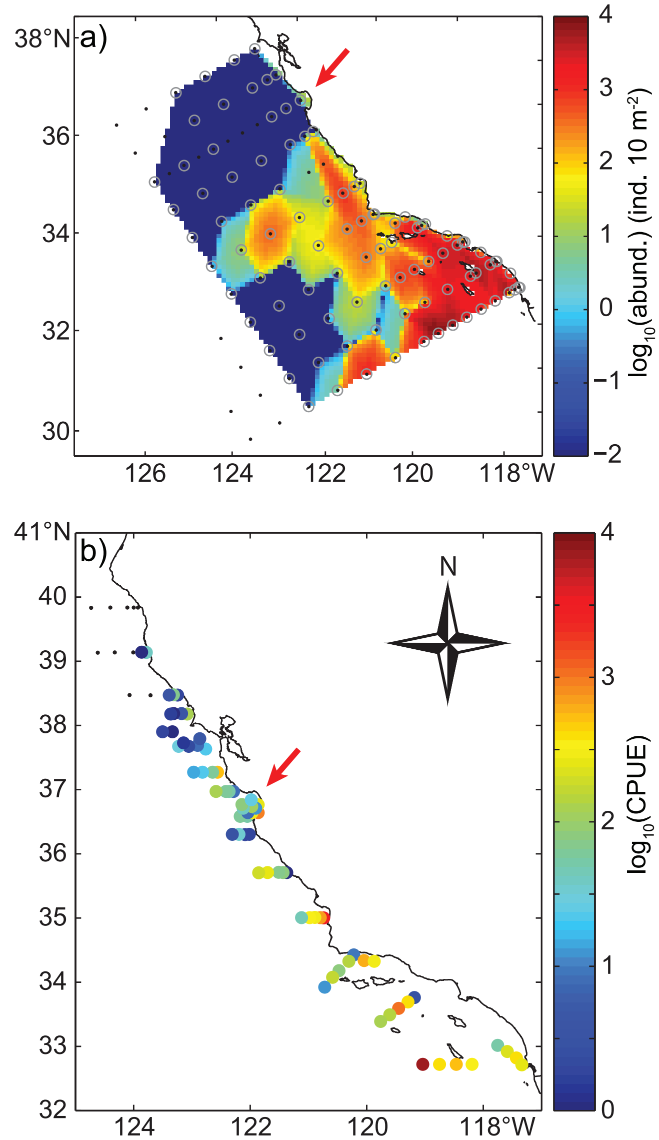
RESULTS

CalCOFI spring anchovy larval abundance in 1975, 1984, 2005, and 2011 was greatest in the SCB, with lower concentrations of larvae found north of Pt. Conception (figs. 4–5). The area of greatest larval concentration in 1975 and 1984 abutted the southern boundary of the study area.

CUFES data were not available from 1975 or 1984, but were available from the alternate "high" stock year of 2005 and the "low" years of 2010–15 (NOAA 2015). Anchovy egg distribution was predominantly in the



(Left) Figure 4. CalCOFI spring anchovy larval abundance for a) high biomass (1975), b) moderate biomass (1984), and c) low biomass (2011) years. Standard stations are indicated with black dots, and occupied stations with grey circles. The axes origin is 29.5˚N 127.5˚W. Monterey Bay is marked with a red arrow in panels a–c).



(Above) Figure 5. The short 2005–06 anchovy recovery showing a) spring 2005 CalCOFI anchovy larval abundance (standard stations are indicated with black dots, occupied stations with grey circles, and axes origin is 29.5˚N 127.5˚W), and b) 2005–06 JRS mean CPUE (stations with zero catch are shown as black dots). Monterey Bay is marked with a red arrow in both panels.

SCB in 2005, with few eggs found off central California (fig. 6). Anchovy eggs were rare and local 2010–15 off both central and southern California, with the greatest concentrations in 2014 near shore in the SCB.

The JRS anchovy CPUE off central California was greatest inshore between Pt. Conception and San Francisco Bay (figs. 5, 7). The JRS anchovy catch was not evenly distributed within the "core" area, and anchovy were significantly concentrated to the southeast (fig. 7 inset; Wilcoxon signed rank test, n = 31, Z = 4.52, p < 0.001). Within this subregion (1983–2013), anchovy CPUE was 196 (30% of the total nekton catch), but in the remaining portion of the "core" area anchovy CPUE was 15 (2% of the total catch).

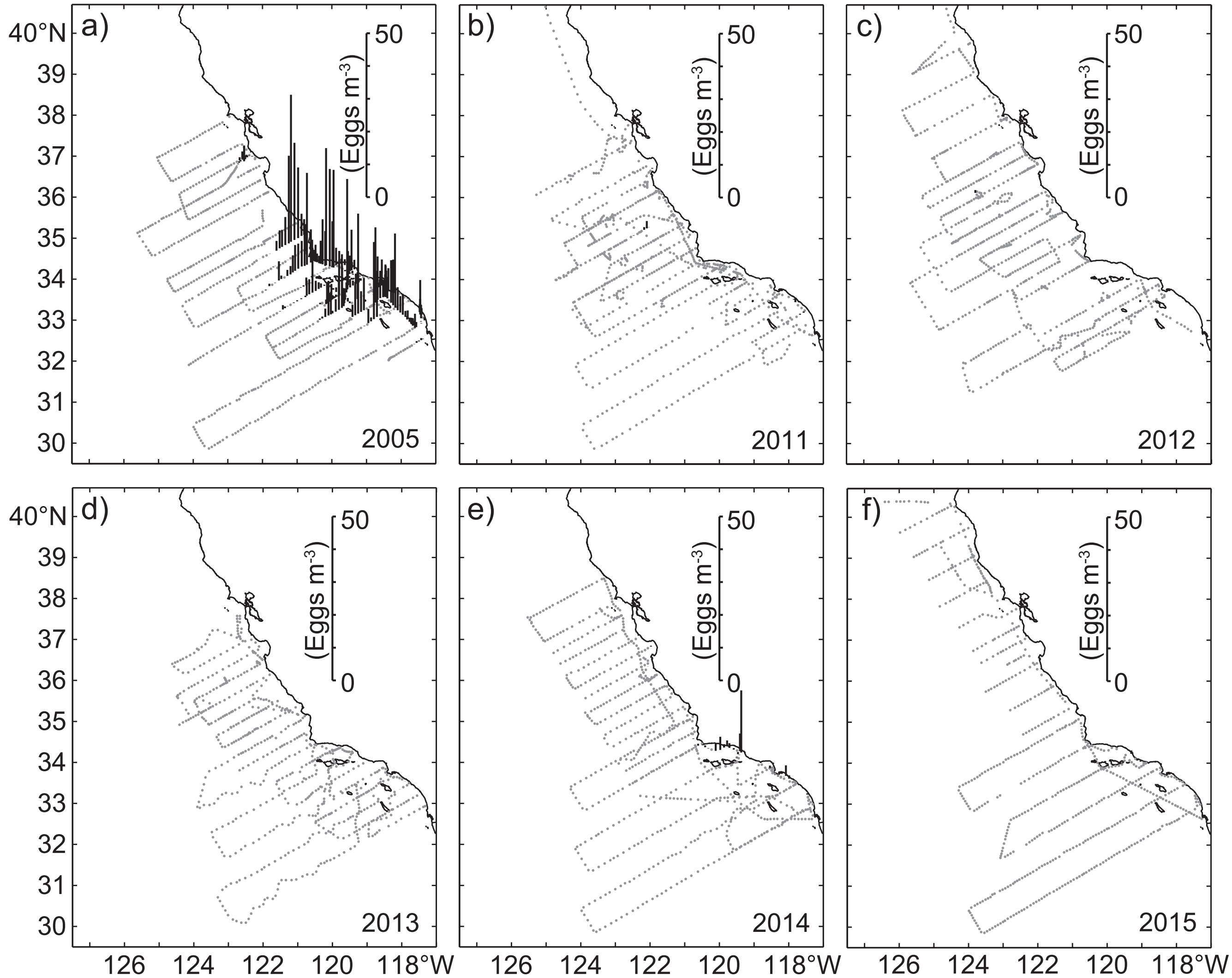


Figure 6. CalCOFI spring CUFES counts of anchovy egg density (2005, 2011–15). Zero concentration is indicated by grey dots. Data from 2015 (panel f), are preliminary and do not include seven unanalyzed stations. Data from 2010 (not shown) are similar to those from 2011–13.

A total of 524 Spring CPS rope trawl deployments were made off the entire US West Coast 2010–13 (fig. 8). Anchovy were only captured inshore in the SCB, near Pt. Conception, and off Washington State. No anchovy were collected off central California, despite the fact that it was the region of greatest effort (fig. 8).

Central and southern California anchovy abundance

April larval concentrations were compared north and south of Pt. Conception 1951–2015, with "north" defined as CalCOFI lines 60–77, north of the Pt. Conception, and "south" as the standard CalCOFI area. Larval anchovy abundance was significantly greater to the south (Wilcoxon signed rank test, $n = 26$, $Z = -4.457$, $p < 0.001$), and the north:south ratio of the mean abundance was 0.07 (fig. 3). Larval abundance was significantly greater to the south in years 1975, 1984, 2005, and 2011 (Table 1).

Only 18 of 738 CUFES samples were positive for anchovy eggs in 2011 (maximum 2.3 eggs m^{-3}), whereas in 2005, 228 of 851 samples were positive (maximum 44.9 eggs m^{-3}; fig. 6). Mean concentration was 144-fold greater in 2005 than in 2011. Egg concentrations were significantly higher to the south in 2005, but not in 2011 because there were few positive samples anywhere (table 1).

JRS anchovy CPUE was significantly greater south of Pt. Conception for both 2005–06 and 2010–13 (table 1), although in 2010–13 the median and mean were greater to the north due to the two large catches just north of Pt. Conception (fig. 7).

There was only one positive catch for anchovy off central California from the spring CPS 2010–13 (fig. 8),

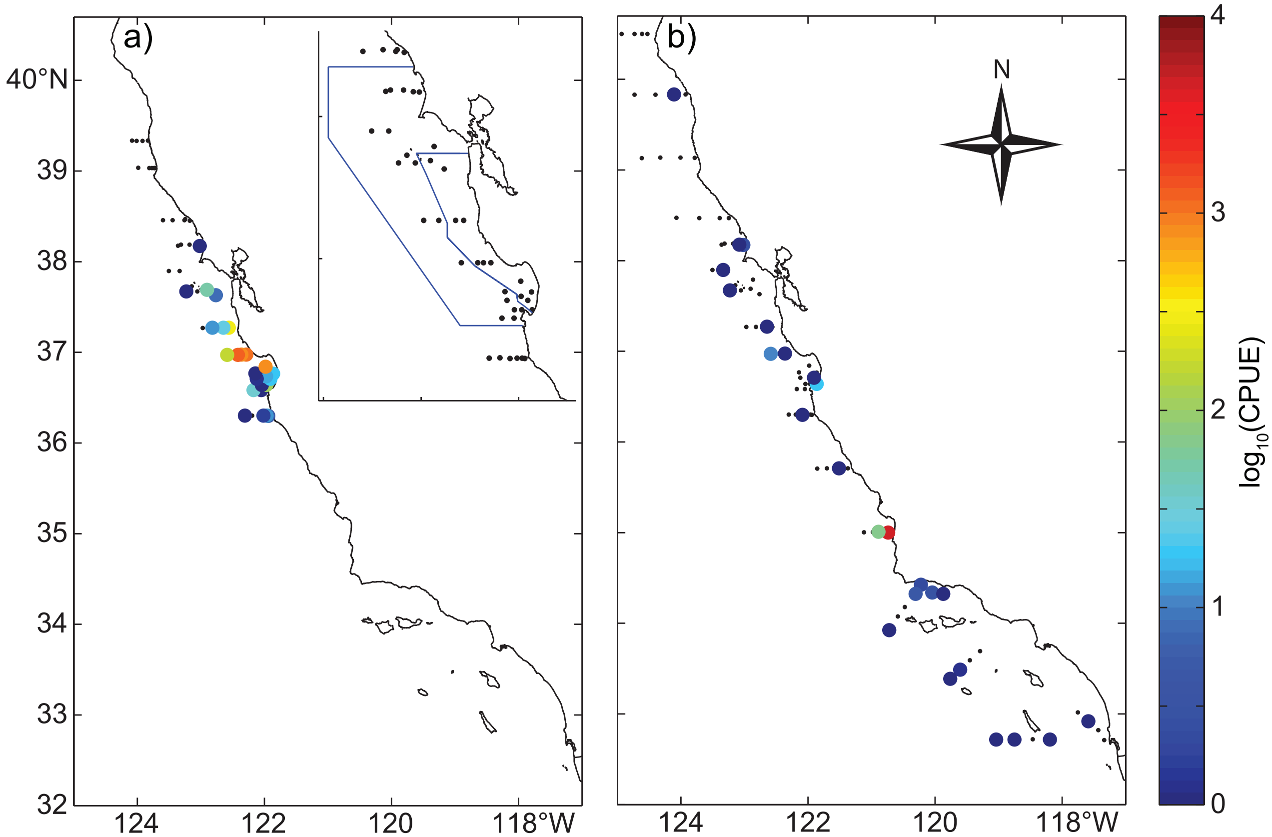


Figure 7. JRS station mean CPUE for a) moderate biomass (1983–85), and b) low biomass (2010–13) years. Stations with zero mean catch are shown as black dots. Inset in panel a) shows JRS stations off Central California as black dots. The outer blue polygon encloses the "core" stations, and the inner blue polygon encloses the region with elevated anchovy CPUE.

TABLE 1
Wilcoxon signed rank tests of anchovy abundance north (N) and south (S) of Pt. Conception.

	year	mean (N)	mean (S)	median (N)	median (S)	*n* (N)	*n* (S)	*Z*	*p*
CalCOFI larvae	1975	1.60	869.29	0	69.14	1500	1416	–36.89	<0.001
	1984	2.32	350.39	0	11.96	1198	1462	–26.96	<0.001
	2005	47.12	655.98	0	59.01	1541	1468	–22.15	<0.001
	2011	0.00	0.08	0	0	1260	1466	–4.68	<0.001
CUFES eggs	2005	0.60	1.59	0	0	325	536	–7.71	<0.001
	2011	0.01	0.01	0	0	343	415	0.89	0.375
JRS adults	2005–06	165.11	626.61	32.00	234.13	47	20	–3.45	0.001
	2010–13	103.98*	0.90	0	0.33	46	19	–2.31	0.021
CPS adults (inshore)	2010–13	0.08	53.07	0	1.05	12	8	–2.99	0.003

*Dominated by two extreme catches near Pt. Conception (fig. 7).

and southern California had significantly greater CPUE (table 1). Because there were no positive catches >50 km from shore off central or southern California, we used only the inshore grid elements between Pt. Conception and Pt. Reyes to reduce zero inflation.

Temporal patterns in abundance

The CalCOFI anchovy ichthyoplankton spring time series can be roughly divided into two temporal segments: a period of increasing abundance (1951–63), and a period of generally declining abundance (1964–2015). From 1963–2015 there is an exponential decline in anchovy larval abundance in both central and southern California (fig. 3). January–May monthly abundances all exhibit the same long-term pattern (fig. 9).

JRS pelagic trawl data off central California also suggest a long-term exponential decline in anchovy abundance 1983–2013, with a decreasing slope on a semilog scale (fig. 10). In the "moderate" biomass period (1983–85) anchovy were captured at more stations and in 1–2 orders of magnitude greater numbers than from 2010–13, even in their good habitat near Monterey Bay (fig. 7). JRS anchovy CPUE also declined over time as a fraction of nekton captured by trawls in the subregion of good

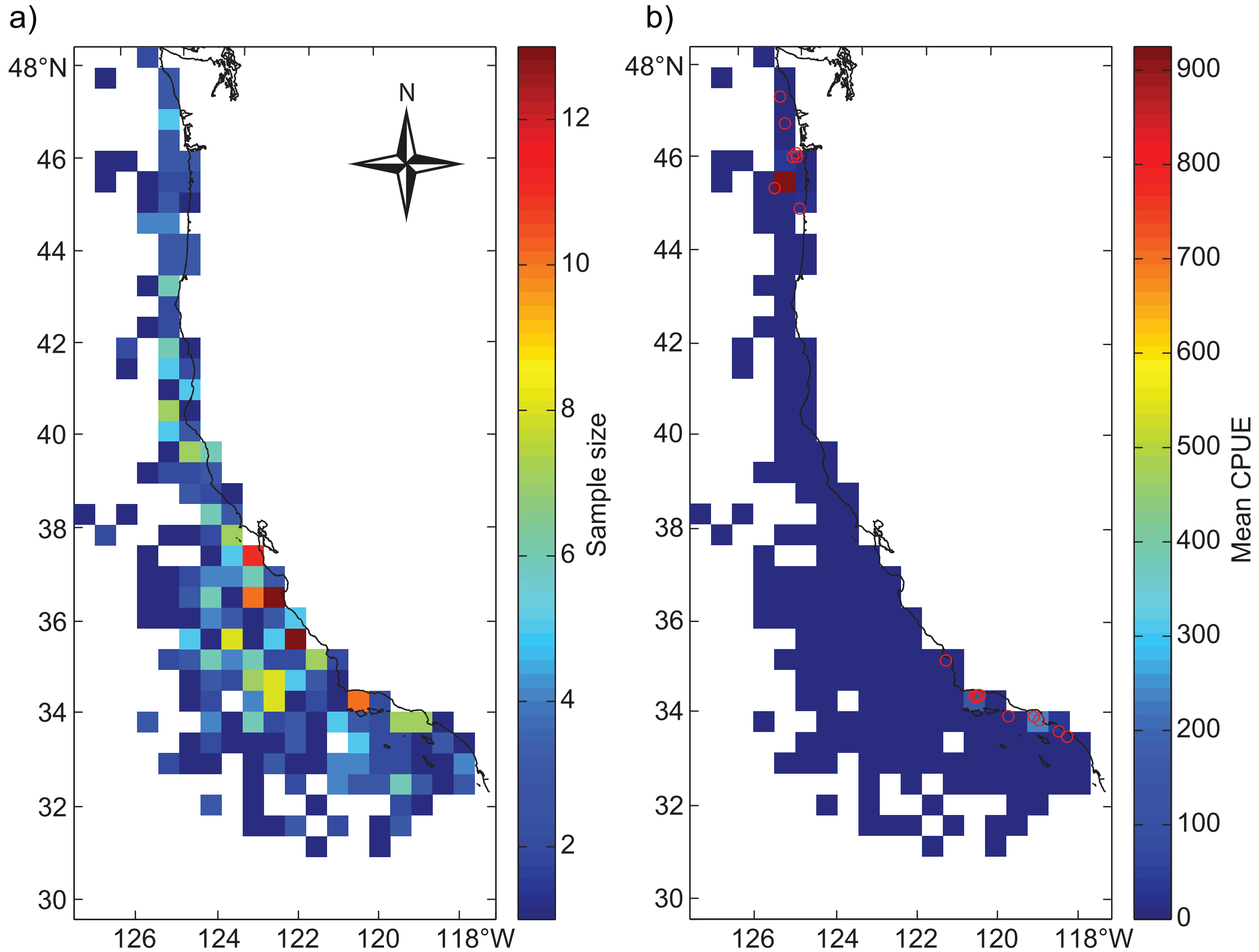


Figure 8. Spring CPS rope trawl a) spatially-averaged sample size, and b) anchovy mean CPUE (2010–13). The axes origin is 29.5°N 127.5°W, and the grid size is 50 x 50 km. Non-zero catches are marked with red circles.

habitat (fig. 7 inset). Anchovies comprised >40% of the overall CPUE in the 1980s and 1990s, 18% 2000–09, and only 0.1% 2010–13.

No CUFES data were available prior to 1996, so we used 2005 as an alternate "high" anchovy biomass year. Underway data from the CalCOFI CUFES program showed high anchovy egg abundance in 2005 throughout the SCB and north around Pt. Conception, whereas in the "low" biomass years (2010–15), few anchovy eggs were collected anywhere (fig. 6).

Undetected inshore spawning

April anchovy egg and larval abundance at nine nearshore SCCOOS stations (mean distance to shore 1.5 km) were compared to the innermost six CalCOFI stations between lines 80 and 93 (mean distance to shore 7.3 km) for the time period in which SCCOOS stations were occupied (2005–15). Neither egg nor larval abundance were significantly different between these two groups of stations (Wilcoxon signed rank test, $n = 8$; $Z = -0.14$, $p = 0.89$ for eggs; $Z = -0.84$, $p = 0.40$ for larvae). Inclusion of SCCOOS stations using the methods of MacCall et al. (2016) did not result in a significant difference in larval abundance estimates ($n = 8$, $t = -0.81$, $p = 0.45$).

Seasonal patterns in spawning

Over the course of the whole time series (1951–2015), monthly larval abundance was elevated January–May, with a peak in March (fig. 9). Egg abundance was also elevated January–May, but with peak abundance in April. January–May larval concentrations all exhibited the same long-term pattern, and (excluding April) had similar magnitudes clustering around a 1:1 ratio against April concentrations (fig. 9). Outliers from the ~1:1 ratio indicate relatively poor winter (1961, 1981, 2000–08) or spring spawning (2010–11, 2013), and most outliers were from the time period 2000–13.

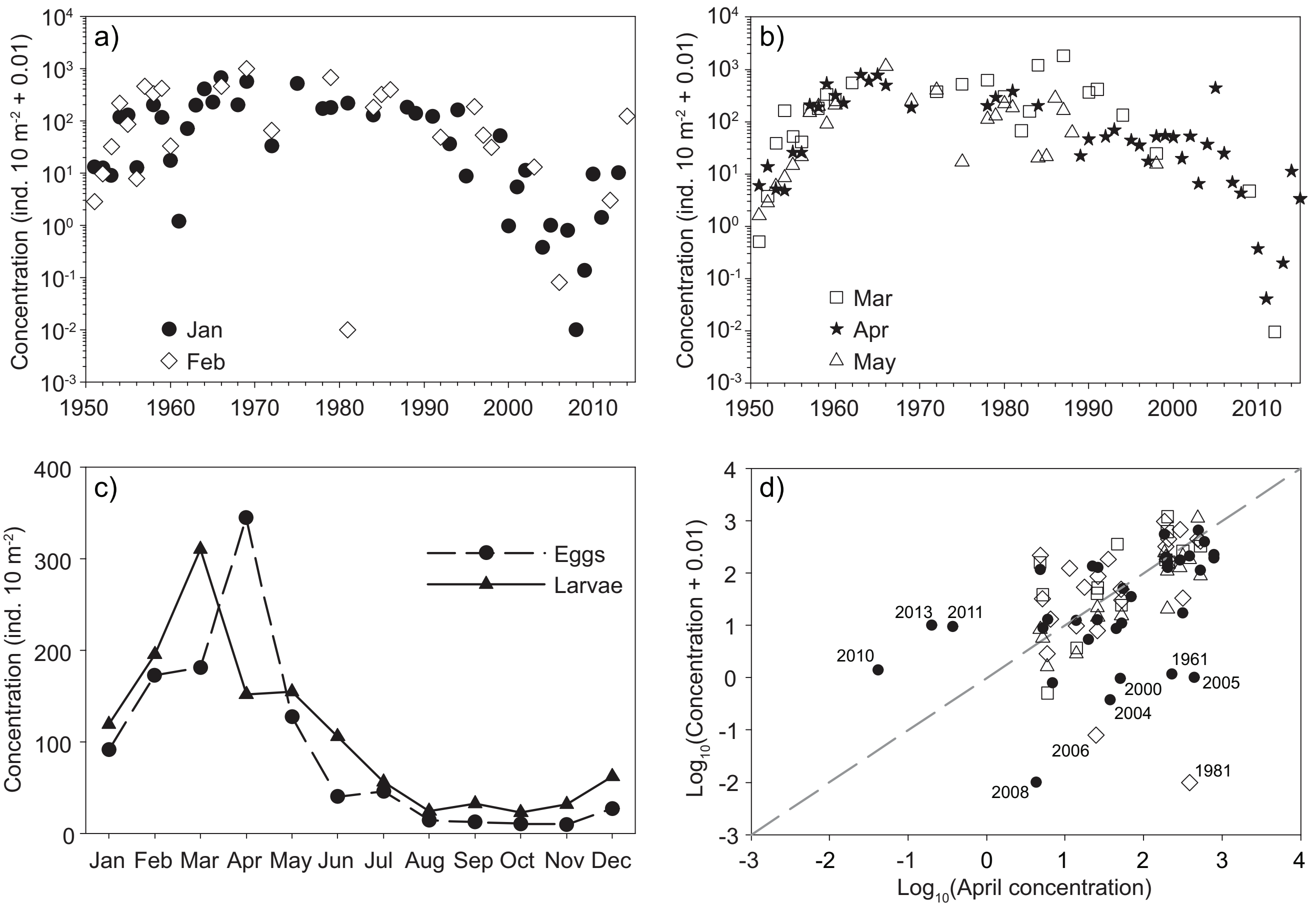


Figure 9. Southern California anchovy ichthyoplankton abundance showing a) winter larval concentration by month and year, b) spring larval concentration by month and year, c) mean concentration of larvae and eggs by month (1951–2015), and d) January–May (excluding April) monthly larval concentrations plotted against April concentration with outlier years labeled. Panel d) uses the same legend symbols as panels a) and b). The 1:1 ratio is plotted as a grey dashed line.

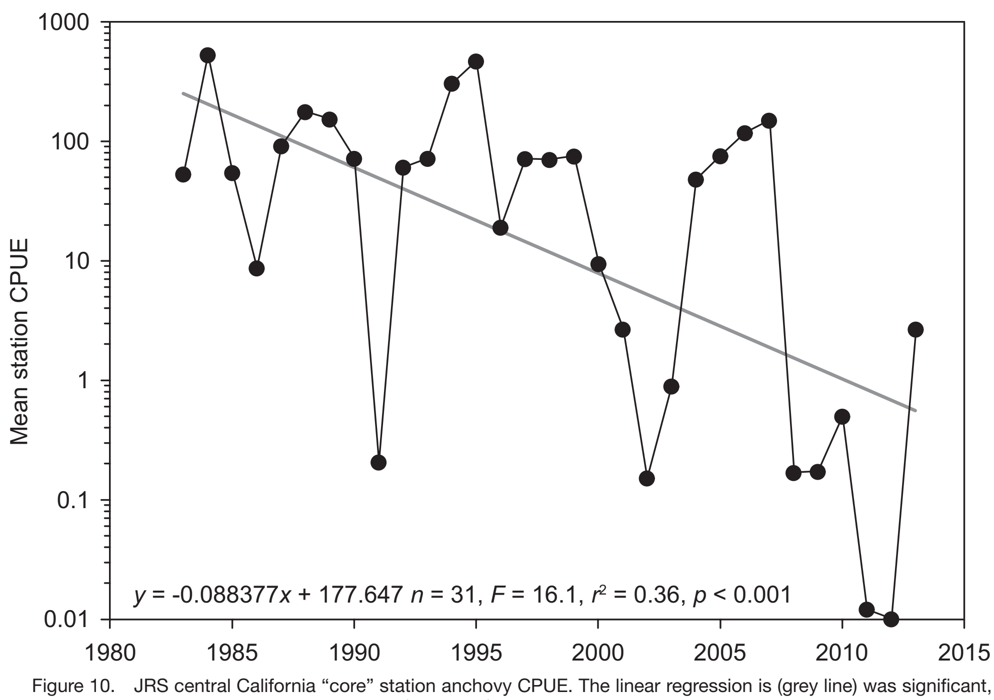


Figure 10. JRS central California "core" station anchovy CPUE. The linear regression is (grey line) was significant, but failed the constant variance assumption (p = 0.018).

DISCUSSION

Recent central and southern California anchovy populations

The central California coast from San Francisco Bay to Monterey Bay has been noted anecdotally and scientifically as a hotspot for anchovy and their cetacean predators (Santora et al. 2012; Drake 2013). The region of good anchovy habitat with elevated CPUE (fig. 7 inset) is relatively small, ~3,500 km^2, whereas the surface area of the SCB inside the Channel Islands is ~30,000 km^2. Larval concentrations were at least one order of magnitude lower off central California than they were in the SCB in years of high, moderate, and low biomass (1975, 1984, 2005, and 2011; figs. 3–5; table 1). Mean annual anchovy larval concentration (1951–2015) north of Pt. Conception was 7% of that to the south. Adult and egg abundance were also lower north of Pt. Conception, although from 2010–13 the data were sensitive to outliers or amounted to a comparison of zeros (figs. 6–7; table 1).

It has been known for decades that most of the central anchovy stock resides in or about the SCB (Smith 1972; MacCall and Prager 1988; Jacobson et al. 1994; Schwartzlose et al. 1999). The most important spawning habitat for anchovy is in the SCB, both in terms of larval concentrations and areal extent (figs. 3–5). The CPUE of both pelagic trawls and underway egg density sampling have consistent spatial distribution with that of larval abundance (figs. 5–6, 8). Anchovy were captured in the SCB by the Spring CPS rope trawl 2010–13, but no adult anchovy were captured off central California, despite greater effort there (fig. 8). Anchovy egg, larval, and adult abundance between Pt. Conception and Cape Mendocino was so low 2010–13 as to be inconsequential to the central stock as a whole (figs. 3–4, 6, 8). During the period of high anchovy biomass (1966–79), the fraction of total larval catch from waters north of Pt. Conception was estimated to be 0%–6% (Hewitt 1980).

Even a cursory glance at anchovy larva distribution indicates that there may be substantial spawning or advected ichthyoplankton in Mexican waters just south of San Diego (figs. 4–5). This fraction was variable and estimated to be 11%–59% of the total larval catch 1966–79 (Hewitt 1980). It is not clear whether some CalCOFI ichthyoplankton were from the southern stock. The Baja California coast has not been surveyed by CalCOFI cruises after 1981, although it has been sampled by the Mexican investigations of the California Current (IMECOCAL) program 1998–present. Thus, the current "standard" CalCOFI station pattern (lines 77–93) does not cover the full range of anchovy spawning habitat when the stock is large. If a variable amount of spawning occurs outside the standard CalCOFI station plan, this will introduce error into stock estimates based only upon US ichthyoplankton data.

Temporal patterns in abundance

The various anchovy stock estimates were in approximate agreement for the "high" (mid-1970s), and "moderate" (early 1980s) biomass periods (fig. 2). Our observation of increasing anchovy ichthyoplankton abundance 1951–63 (fig. 3) was consistent with reports of an increasing anchovy stock 1951–69 (Smith 1972). The low 2011–15 anchovy ichthyoplankton abundances (figs. 3–4, 6; MacCall et al. 2016) were consistent with catches of adults. Only two JRS net tows off southern California 2010–13 captured many anchovy (both near Pt. Conception; fig. 7), in contrast to the many trawls over a wide area that captured anchovy in a year when anchovy were abundant (fig. 5). Few anchovy off southern California and none off central California were captured by the Spring CPS rope trawl (2010–13; fig. 8). An acoustic estimate of anchovy stock size in the study area was attempted by the NMFS AT survey (2006–11), which concluded that anchovy were too low in abundance and too patchily distributed for a good estimate from 2006–10 (Zwolinski et al. 2012), and that the anchovy biomass was <10,000 t in 2011 (Demer et al. 2013).

Despite short recoveries in 1986 and 2005–06 (fig. 2), both adult and larval anchovy spring abundance have declined exponentially since the early 1960s (figs. 3, 10). Adult anchovy off central California have also declined over time as a fraction of nekton CPUE. Because both central and southern California ichthyoplankton abundances have declined together (fig. 3), few eggs have been observed between Pt. Conception and Cape Mendocino (fig. 6), and catches of adults off central California have similarly declined or are nil (figs. 7–8), there is no evidence that the anchovy stock has migrated north out of the southern California study area of MacCall et al. (2016). There is also no evidence from ichthyoplankton, trawling, or CUFES data that the stock has recovered 2012–15 after the period covered by MacCall et al. (2016).

Inshore anchovy population

The CalCOFI ichthyoplankton sampling may miss anchovy spawning close to shore. However, southerly winds in the study area advect surface water offshore, and the moving surface water can be expected to transport weakly swimming anchovy larvae. A ~5-fold inshore/offshore difference in abundance of the smallest (youngest) size classes of anchovy larvae is evidence of this larval advection offshore (Smith 1972). Prior studies of the distribution of anchovy ichthyoplankton relative to the coast found that larval abundance (ind. m^{-2}) increased with bottom depth from 8–70 m (Brewer and Smith 1982; Barnett et al. 1984), that nearshore habitat (8–36 m bottom depth) was not preferred for spawning by anchovy in comparison to the CalCOFI sampling area (Brewer and Smith 1982), and that the peak abundance of anchovy larvae was 60 km from shore (Richardson 1981). The inner stations of the five CalCOFI lines in the SCB (plus the Santa Barbara Basin station) are 2–19 km from shore at a median bottom depth of 63 m (depth range 34–578 m). The nine SCCOOS stations in the SCB are 0.1–3.7 km from shore at 20 m bottom depth, but these stations were not used by MacCall et al. (2016) because they were only occupied since 2005. There was no significant difference in larval or egg concentrations between the SCCOOS stations and the inner CalCOFI stations, or between abundance estimates made with and without SCCOOS stations, and thus there is no evidence that inshore spawning was missed by MacCall et al. (2016) in the SCB.

Egg concentrations are a more accurate index of parent stock size than larval concentration due to variable mortality rates in the egg and larval stages (MacCall et al. 2016), but are less precise due to greater patchiness. Indeed, there has been a sharp increase in anchovy egg/larva mortality in recent years (Fissel et al. 2011; MacCall et al. 2016). We used anchovy larval concentration here, rather than egg concentration, in order to reduce patchiness effects and better detect "missing" evidence of inshore spawning. The anchovy egg stage lasts 2–7 d, whereas the larval stage lasts 70–90 d (Hunter and Coyne 1982; Lo 1985b; Smith 1985). Thus, larvae are more dispersed than eggs due to movements of the water and more likely than eggs to be detected by sampling at CalCOFI stations some distance from possible close-to-shore spawning habitat (Richardson 1981).

The recent period of very low anchovy catches contrasts with newspaper reports of huge anchovy schools close to shore in Monterey Bay 2013–15 (Drake 2013; Goode 2013; Bartolone 2014; Gaura 2015) and in the SCB (Herreria 2014), and it may be argued that these fishes were missed by the mostly deeper-water CalCOFI and JRS surveys. In low biomass periods, anchovy are known to contract their range inshore (Schwartzlose et al. 1999; MacCall et al. 2016). Aerial surveys are well-suited to observe these inshore shoals. Aerial surveys of the SCB, the population center of the central anchovy stock, showed that in the "low" biomass period (2012–14) anchovy were almost entirely found <4 km from shore (Lynn et al. 2015). The maximum biomass observed aerially was 14,532 t in 2013. Thus, it is clear that even though there is a dense population of anchovy nearshore, it doesn't amount to a large biomass due to the restricted spatial distribution. Sporadic, large catches of anchovy at inshore stations by the AT survey (Zwolinski et al. 2012; Demer et al. 2013), JRS (fig. 7), and Spring CPS rope trawl (fig. 8) are consistent with a small but dense population of anchovy close to shore in low biomass years. CUFES data from 2014–15 are also consistent with a population distribution very close to shore (fig. 6). Anchovies were essentially absent from their historical offshore habitat 2009–15 (figs. 4–5), yet they paradoxically appeared unusually abundant to nearshore observers.

Seasonality of spawning

Anchovy spawn all year with a peak March–April (fig. 9; Parrish et al. 1986; MacCall and Prager 1988; Asch 2015). The use of winter and spring (January and April) anchovy ichthyoplankton abundance generally captures the peak spawning season, and the January–May monthly abundances are similar in both magnitude and long-term pattern (fig. 9). The period of steepest decline in larval abundance is characterized by relatively poor winter (2000–09) or spring abundances (2010–13), consistent with a shortening of the spawning season and perhaps match-mismatch processes (Cushing 1990).

Monthly averages of anchovy abundance (fig. 9c) were lower but otherwise similar to previously published material (Moser et al. 2001) for larvae, but differed for eggs in that February and March averages were also relatively lower in comparison to April concentrations. The overall reduced abundance is due to extension of the time series to include the recent anchovy collapse. The sharpening of the egg abundance peak resulted from our correction for spatial bias in sampling locations relative to anchovy spawning habitat (Moser et al. used an average of occupied stations).

Peak anchovy spawning in the CalCOFI area is (non-significantly) shifting –3 d decade^{-1} (Asch 2015), or ~18 days across the whole CalCOFI time series. Because February larval densities were greater than those from January, May larval densities were similar to those from April, and MacCall et al. (2016) incorporated many February, March, and May cruises in their indices, the phenological shift in the timing of peak spawning would not be expected to greatly change their results. Indeed, recent CalCOFI January larval abundances would be expected to increase with such a shift relative to the early portion of the time series, producing an overestimate of the anchovy stock.

Parrish et al. (1986) found striking seasonal differences in individual anchovy fecundity from histological samples (1977–84) and the age distribution of commercial landings and scientific catches (1966–80). Therefore, Parrish (2015) argued that the use of January ichthyoplankton indices for anchovy stock assessments is difficult to justify because January egg production (1%–3%

of annual) is so small in comparison to the spring peak, and may thus be sensitive to small shifts in spawning seasonality or range. However, the great seasonal fecundity difference observed in dissected specimens (Parrish et al. 1986) is not consistent with what was observed in the water on CalCOFI cruises (fig. 9). Mean annual CalCOFI January egg concentrations were 44% of the April concentration for the period 1977–84 corresponding to Parrish et al.'s data, and 45% for all years with both January and April cruises.

Calibration

Ichthyoplankton concentration is not a direct measurement of biomass and thus requires calibration to a benchmark stock assessment in order to estimate biomass from the index. It does not matter if the index incorporates data from the time and location of maximum abundance, as long as the relationship between the benchmark and index does not change. Because the calibration stock assessments were only performed in three years overlapping with the CalCOFI ichthyoplankton surveys (MacCall et al. 2016), there is likely some error in the calibration. The accuracy of future stock estimates made from ichthyoplankton surveys will improve with additional benchmark stock assessments for calibration.

In low population years, anchovy landings may be similar to or even exceed stock assessments (Parrish 2015). Non-breeding migration of other stocks to the survey area may inflate local landings data relative to the local stock size. In addition, if the calibration stock assessment did not incorporate all anchovy habitat (e.g., extremely nearshore or waters off Mexico) then ichthyoplankton abundance is calibrated to an underestimated stock. While the calibration error may be small in years when the stock is large, it will grow in relative size as the population declines, and can lead to apparent paradoxes in low biomass years.

CONCLUSION

In regards to the question of whether or not there is an unobserved spawning population of anchovy off central California, the answer is likely "no," or at least not a big one. Both the JRS and Spring CPS rope trawl sampling programs focus their effort in central California waters (figs. 7–8). The JRS anchovy CPUE exponentially declined 1983–2013 off central California (fig. 10). The Spring CPS rope trawl captured zero anchovy off central California 2010–13 (fig. 8). Anchovy egg sampling (CUFES) observed moderate concentrations of eggs off central California in high biomass years, and few to none when the population was low (fig. 6). Larvae were present off central California in both high and low biomass years, but their concentration was not only 1–2 orders of magnitude lower than the SCB concentration but spread out over a much smaller area (figs. 3–5). Although there were anecdotal reports of large anchovy schools close to shore (Goode 2013; Herreria 2014), even if anchovy spawned there unobserved by CalCOFI ichthyoplankton sampling, underway CUFES egg sampling, JRS trawls, Spring CPS rope trawls, and the AT survey, it must have been confined to a narrow strip along the shore. A large concentration of fishes multiplied by a small surface area results in a small biomass at oceanic scales. However, there may have been substantial spawning activity in Mexican waters just south of San Diego (figs. 4–5), and it is not clear what fraction of anchovy spawning by the central stock was south of the survey area.

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March 30, 2017

Mr. Herb Pollard, Chair
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via email: pfmc.comments@noaa.gov

Re: Agenda Item G.2 – *Central Subpopulation of Northern Anchovy Overfishing Limit Process*

Dear Chair Pollard and Council Members:

Wild Oceans, Coastal California Association of California, the International Game Fish Association and American Sportfishing Association are writing to ask the Pacific Fishery Management Council (Council) to ensure that management of the central subpopulation of northern anchovy (CSNA) is sufficiently protective of the stock and its ecological functions now and in the future. Anchovy play a foundational role in the California Current food web, providing a main food source for recreational species when availability of other favored forage fish such as sardine are low. For example, according to stomach content analysis conducted by the Southwest Fisheries Science Center, anchovy comprised 40% of Pacific bluefin tuna prey in 2016.[1] Further north, anchovy make up as much as 20% of the diet of west coast salmon.[2]

[1] Agenda Item J.5.b, Supplemental SWFSC PPT, March 2017, *available at http://www.pcouncil.org/wp-content/uploads/2017/03/J5b_Sup_SWFSC_PPT_DiNardo_Mar2017BB.pdf*.
[2] Koehn, L.E., T.E. Essington, K.N. Marshall, I.C. Kaplan, W.J. Sydeman, A.I. Szoboszlai, J.A. Thayer. 2016. Developing a high taxonomic resolution food web model to assess the functional role of forage fish in the California Current ecosystem. *Ecological Modelling* 335:87-100.

When anchovy are scarce, their predators may instead target recreational species, such as juvenile salmon. For example, when ocean conditions are poor, common murres in the California Current Ecosystem (CCE) tend to forage closer to shore and prey predominantly on anchovy as well as on juvenile salmonids at a rate of up to 9%.[3] For these reasons, we ask the Council to continue its ongoing work to develop a twenty-first century management regime for CSNA.

The Scientific and Statistical Committee (SSC) recently concluded that the best available indices indicate that the relative abundance of CSNA has remained low over the past decade, relative to the higher levels observed in the 1980s and the mid-2000s.[4] With this in mind, we urge the Council to take the following actions today:

Provide the SSC and the Southwest Fisheries Science Center (SWFSC) with guidance to develop a revised overfishing limit (OFL) for CSNA.

The central subpopulation of northern anchovy is classified as a monitored stock under the Coastal Pelagic Species Fishery Management Plan. Monitored stocks lack periodic stock assessments; however, changes to harvest specifications may be made if new scientific information becomes available to warrant changing them. In November, the Council tasked the SSC with preparing approaches for developing a new OFL for CSNA. The SSC and Coastal Pelagic Species Management Team (CPSMT) prepared a Joint Report for the Council, [5] which we have reviewed.

We encourage the Council to specifically support development of an OFL that incorporates a biomass estimate from the acoustic-trawl methodology (ATM) survey.

Forward a schedule and process to explore changing CSNA from monitored to active management status.

In November, the CPSMT reported that they intended to explore changes to CPS management categories.[6] We urge the Council to task the CPSMT with developing a range of alternatives for anchovy management that explicitly account for the needs of dependent predators and safeguard anchovy's role as forage in the CCE. The work could happen either concurrently or consecutively with an evaluation and development of an OFL for CSNA. Either way, when

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[3] Wells, B.K., J.A. Santora, M.J. Henderson, P. Warzybok, J. Jahncke, R.W. Bradley, D.D. Huff, I.D. Schroeder, P. Nelson, J.C. Field, D.G. Ainley. In review. Caught in the middle: Top-down impacts on salmon are dependent on bottom-up mechanisms. *Journal of Animal Ecology*.
[4] Agenda Item G.4.a, Supplemental SSC Report, November 2016, *available at http://www.pcouncil.org/wp-content/uploads/2016/11/G4a_Sup_SSC_Rpt_NOV2016BB.pdf*.
[5] Agenda Item G.2.a, Joint SSC/CPSMT Report, April 2017, *available at http://www.pcouncil.org/wp-content/uploads/2017/03/G2a_SSCandCPSMT_Rpt_Apr2017BB.pdf*.
[6] Agenda Item G.4.a, Supplemental CPSMT Report, November 2016, *available at http://www.pcouncil.org/wp-content/uploads/2016/11/G4a_Sup_CPSMT_Rpt_NOV2016BB.pdf*.

developing a range of alternatives, the CPSMT should consider the ongoing ATM survey being conducted by the SWFSC and the Center's commitment to completing an integrated stock assessment of the CSNA as soon as the appropriate biological and ecological information can be collected, verified, and processed.[7]

Thank you for discussing a process and schedule for updating the anchovy harvest control rule and for committing to a management framework that considers the overall forage base in order to maintain adequate, diverse forage for the ecosystem. If we fail to account for predator needs, we risk setting anchovy catch limits too high, leading to overfishing with negative impacts to predators and the entire California Current ecosystem.

Sincerely,

Theresa Labriola
Pacific Program Director
Wild Oceans

Bill Shedd
Chairman
Coastal Conservation Association California

Jason Schratwieser
Conservation Director
International Game Fish Association

Mike Leonard
Ocean Resource Policy Director
American Sportfishing Association

[7] Agenda Item G.4.a, Supplemental SWFSC Report, November 2016, *available at* *http://www.pcouncil.org/wp-content/uploads/2016/11/G4a_Sup_SWFSC_Rpt2_NOV2016BB.pdf*.