Assessing climate change, oceanographic context, larval abundance and distribution, and pelagic habitat characteristics in the context of the California MPA Network

Contributions of the California Cooperative Oceanic Fisheries Investigations (CalCOFI) to the MPA Decadal Management Review Report

A partnership of Scripps Institution of Oceanography, UCSD & Southwest Fisheries Science Center, NOAA, & California Department of Fish and Wildlife

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Overview of the CalCOFI program

The California Cooperative Oceanic Fisheries Investigations (CalCOFI) is a long-term ocean observing program along the coast of California that generates information that can be used in the evaluation of California marine protected areas (MPAs), especially related to assessing climate change, oceanographic context, larval abundance and distribution, and pelagic habitat characteristics. In addition, the CalCOFI program supports outreach, education, and stakeholder engagement, providing fora, such as the CalCOFI Conference, to bring together California researchers and practitioners to discuss marine resources along the California coast.

CalCOFI is one of the world's longest- running, integrated ocean ecosystem sampling programs that simultaneously collects biological, chemical, and physical observations and specimens across the California Current System (CCS) to inform research and management. CalCOFI is a collaborative program of state, federal, and academic partners that samples quarterly in state, federal, and international waters from San Diego to north of San Francisco to provide a holistic understanding of the oceanographic processes operating off the coast of California (Figure 1). Specifically, CalCOFI stations occur within three State

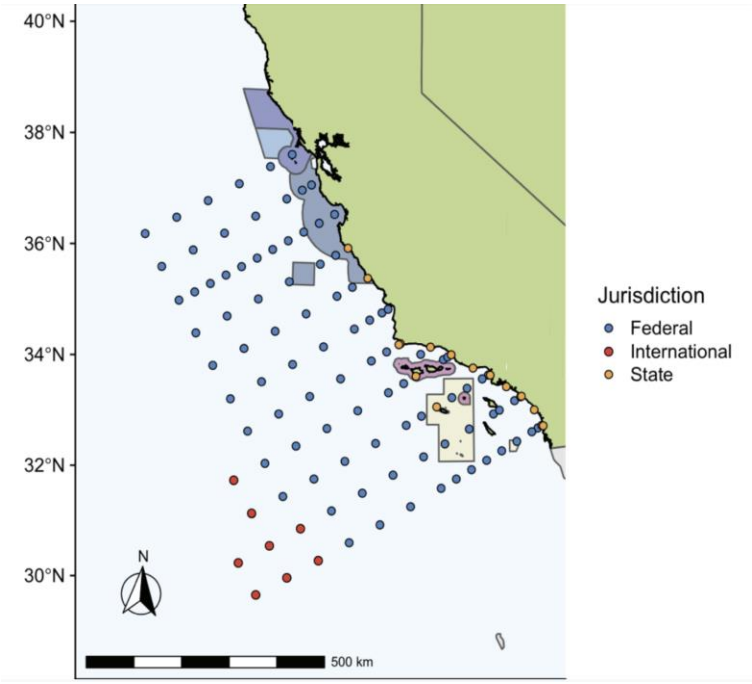

Figure 1 (reprinted from Engeman et al. 2020). CalCOFI sampling locations along the California coast. CalCOFI sampling extends from Point Reyes south to San Diego and extends about 667 km offshore. CalCOFI samples in state waters (13 stations), federal waters (83 stations), and international waters (8 stations).

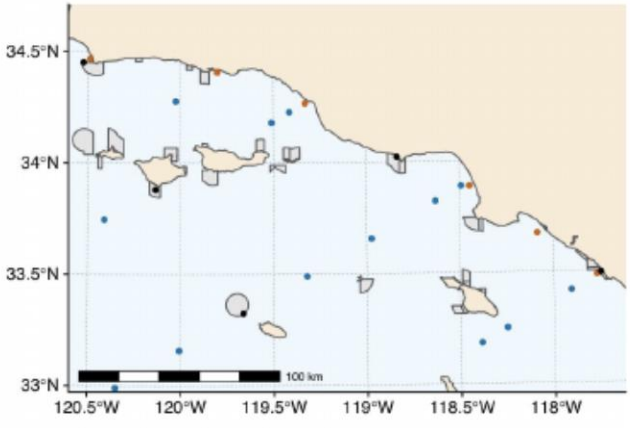

Figure 2 (reprinted from Gallo et al. 2019). Five CalCOFI stations occur within California MPAs, and occur mostly on the southern California coast.

Marine Reserves (South Point, Begg Rock, and Point Conception) and two State Marine Conservation Areas (Point Dume and Dana Point) (Figure 2). Given that only a few CalCOFI stations fall within MPAs, the value the CalCOFI program brings to MPA research stems less from opportunities for inside versus outside comparisons, although these are possible, and more from its ability to provide oceanographic context on the broader California Current System that many of the state's MPAs are set within.

CalCOFI has collected environmental and hydrographic data for 73 years including ocean temperature, salinity, dissolved oxygen, nutrients as well as inorganic carbon system measurements (e.g., pH, Dissolved Inorganic Carbon) for nearly 14 years (since 2008). In addition, the biological data collected by CalCOFI and the associated collaborative programs have extensive taxonomic resolution and include: larval fish and egg data (~700 taxa) for 70 years; zooplankton abundance (~93 taxa), which consists of mainly holoplankton (e.g., krill, copepods, and other plankton that spend their entire life in the open ocean) for 70 years; marine mammals, seabirds, and turtles (~189 taxa) for over 30 years; primary productivity, phytoplankton biomass, and diversity (~374 taxa) for over 38 years; and microbes (e.g., Prochlorococcus, Synechococcus, and heterotrophic bacteria) for over 17 years. Invertebrate larvae have been collected continuously since the program's inception, but only some invertebrate larvae/meroplankton have been enumerated opportunistically (e.g., California Spiny Lobster was sampled for over 50 years until 2008 and Dungeness crab postlarvae was enumerated from 2003-2014). Consequently, CalCOFI has extensive openly accessible data (found at wp.calcofi.org/wp/data) that can be used and combined with existing MPA data to inform future reviews (please contact CalCOFI Coordinator: Erin Satterthwaite for more information on data availability and access).

Oceanographic baseline context needed to evaluate the MPA network

Due to the 73 year time series of physical, chemical, and biological data, CalCOFI provides information regarding climate and biological change that is essential for understanding the larger scale, longer-term oceanographic context to assess the region of the California MPA network, especially related to the South and Central coast of California. This information is needed to evaluate changes within MPAs and the extent to which those changes may be driven by MPA implementation relative to regional- and basin-scale environmental and climate change. Climate change was identified as an overarching influencing factor that should be considered when assessing the MPA network within the context of the social-ecological system framework (Recommendation 1a; Hall-Arber et al. 2021). CalCOFI data can facilitate understanding the

efficacy of MPAs and Conservation Areas and provide essential oceanographic context for which to understand changes over time within MPAs as well as differences among MPA and reference sites (Recommendation 2a; Hall-Arber et al. 2021). For example, the scale and timing of biomass or size structure changes inside MPAs should be considered relative to the scale and timing of those metrics outside MPAs. Caselle et al. (2015) incorporated satellite derived sea surface temperature as a potential driver of abundance in models examining impacts of California MPAs on both targeted and nontargeted fish species. CalCOFI data provides opportunities for more detailed accounting for environmental conditions in similar analyses including temperature at the surface and at depth as well as other aspects of ocean chemistry.

Data from CalCOFI surveys are increasingly being used to reconstruct spatial and temporal variations of ocean acidification and hypoxia (Gallo et al. 2019), and can be used to contextualize changes in ocean chemistry within the MPA network. In addition, ocean acidification and hypoxia have been shown to impact fish and invertebrates, including those of commercial importance (Hauri et al. 2009). Research examining past CalCOFI samples is helping us to understand which species are likely to come in contact with acidified waters, at what frequency, and what the potential impacts may be. Similarly, CalCOFI research may be able to show if certain MPAs or habitats contained within MPAs are able to serve as sources of greater productivity under changing ocean conditions. For example, the population model used in the lobster Fisheries Management Plan to calculate the Spawning Potential Ratio (SPR) accounts for larger sized lobsters having higher reproductive output within MPAs and the SPR is one of three reference points in the

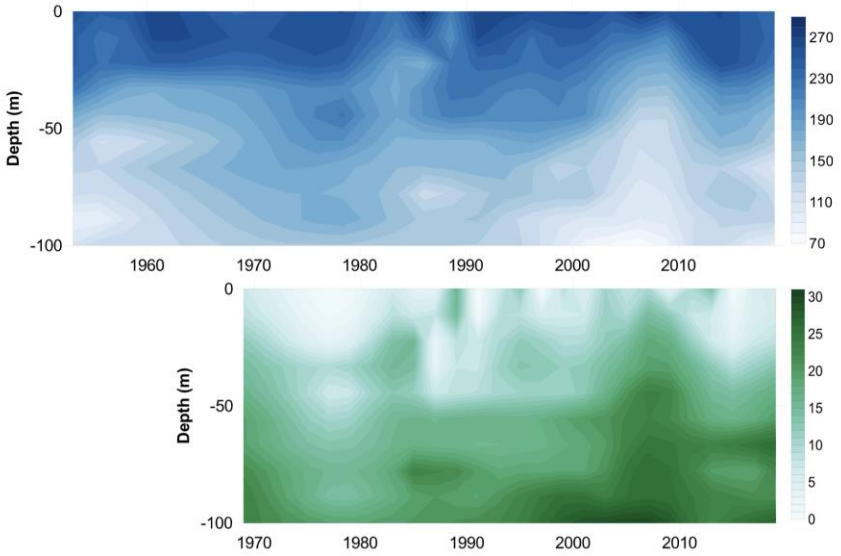

Figure 3. Plot examples showing mean O2 (µmol/Kg) on top and NO3 (uM) on the bottom at line 83.3, station 51 west of Santa Rosa Island in spring (March-May) during the period of 2002-2012. In the recent decade, with the exception of the marine heatwave years (2014-2016), there has been more NO3 rich and O2 poor deep water intruding on the shelf and moving closer to the surface particularly in 2000-2010. This could indicate more upwelling around that location.

harvest control rule. As such, CalCOFI data could help to predict changes in population characteristics that are essential in generating harvest policy.

At regional to basin-wide scales, CalCOFI data provide insight into large-scale patterns of oceanographic variability within the California Current such as the El Niño Southern Oscillation (ENSO), the Pacific Decadal Oscillation (PDO), and the North Pacific Gyre Oscillation (NPGO). For example, the oceanographic data collected by CalCOFI has been used to understand the circulation of the California Current System (Bograd & Lynn 2003) and the links between climate oscillations (e.g., ENSO and PDO) and ecosystem change in the North Pacific (Di Lorenzo et al. 2008). At local to regional scales, CalCOFI data are unique in that they can provide more specific insight into trends of physical, chemical, and biological parameters within an MPA site or across the entire southern California Current region. For example, CalCOFI provides insight into trends of changing oxygen and nutrients across depth over time, within the context of an individual MPA location, such as the CalCOFI station (Line 83.3, Station 51) which is located in the South Point State Marine Reserve on the backside of Santa Rosa Island (Figure 3).

Since CalCOFI conducts integrated, long-term sampling of the physics, chemistry, and ecology of the system, the data and information can be used to advance understanding of the ecological aspects of MPA performance and the linkage to influencing factors, such as climate change (Recommendation 6c; Hall Arbor et al. 2021). On an annual basis, the State of the California Current Reports are produced by CalCOFI and partners and provide an annual assessment of the California Current ecosystem (e.g. Weber et al. 2021), which could be integrated into a decadal synthesis of the state of the California Current.

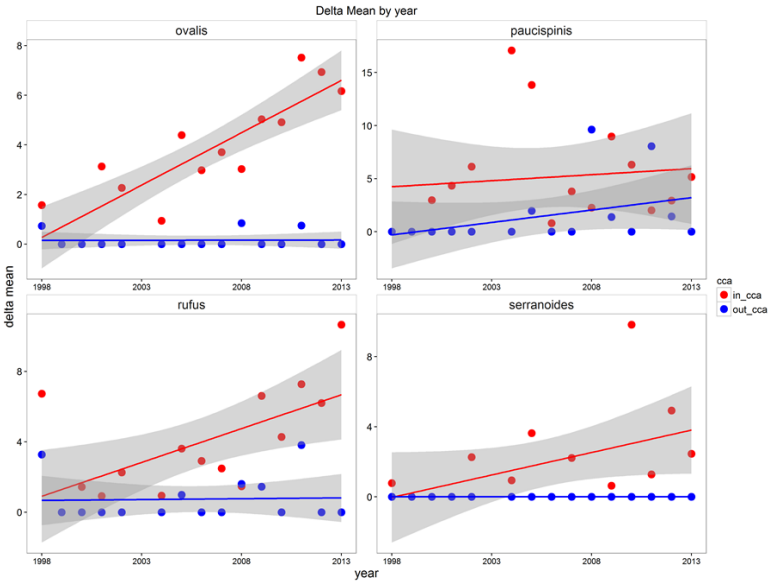

Figure 4. Annual mean larval abundances from stations with similar environmental conditions inside (red) and outside (blue) of the CCAs for four rockfishes that are targeted by fishing from 1998 to 2013. Abundances increased at a significantly higher rate inside versus outside the CCAs for three of four species.

Larvae of key MPA species allow for analysis of population dynamics

CalCOFI has information on larval abundances of key MPA species that can allow for the integration of life history stages into assessments and analyze population connectivity and persistence. For example, larval abundances are used as indices of spawning stock biomass for stock assessments of several rockfishes including bocaccio, *Sebastes paucispinis* (He et al. 2015). As such, CalCOFI data and samples can support long term characterization of ecosystems and species that were a part of the South Coast and Central Coast MPA Baseline Monitoring Program. For example, CalCOFI routinely collects larvae of fish (e.g., halibut, rockfish, and other nearshore fish) and invertebrate species (e.g., California Spiny Lobster) in the plankton that settle as adults in rocky intertidal, sandy beach, subtidal, and kelp and shallow rock habitats. Larvae from several state-managed fishes are present in CalCOFI samples, and these data or retrospective analysis of samples can be used to better understand their population fluctuations. As an example of a multi-species analysis, CalCOFI larval rockfish data showed that spawning output increased faster within versus outside the Cowcod Conservation Areas (CCAs) demonstrating that these large MPAs facilitated rockfish recovery from overfishing (Figure 4; Thompson et al. 2017).

In addition, CalCOFI larval and plankton data can be used in MPA network models to assess connectivity across the MPA network. In some cases, invertebrate larvae have been collected but not enumerated (e.g., some crabs and echinoderms), so retrospective analysis of samples to enumerate key invertebrate species could allow for further baseline characterization of larval supply, delivery, and connectivity patterns within the MPA network. For example, ethanol-preserved bongo samples could allow for the characterization of genetic connectivity, dispersal, shifts in distribution, and assessment of diversity within versus outside of MPAs. In addition, otoliths extracted from ethanol-preserved larvae can determine larval age and circulation models can then predict the origin and destination of the larvae. In cases where CalCOFI cannot provide direct larval abundance information for certain indicator species, then CalCOFI could provide proxies for larval abundance and distributions, such as through associated or proxy species, physical conditions and water mass characteristics that promote their productivity, or the trends in their predators and prey.

Finally, CalCOFI observes seabirds and marine mammals, including migratory and nearshore species, so can support with understanding regional dynamics of seabird and marine mammal species to contextualize changes within and across the MPA network.

Characterization of pelagic habitats within MPAs and regionally

CalCOFI observations provide a characterization of pelagic habitats across the broader region of the MPA network. CalCOFI data provides key spatial information on physical, chemical, and biological parameters that allows for the assessment of regional pelagic habitat quality and availability. These include the status and persistence over time of pelagic habitats within MPAs and within the MPA Network (Recommendation 4a; Hall-Arber et al. 2021). For example, CalCOFI data is being used to build species distribution models (SDM) that predict the distribution of key forage species within and around MPAs and throughout the California Current. Outputs from a recently developed anchovy SDM successfully predicted the distribution and reproductive success for sea lions in the Channel Islands and three species of sea birds from Southeast Farallon Island (Fennie et al. under review). Thus, CalCOFI data could be used to understand the amount and persistence of certain pelagic habitat qualities in MPAs that are conducive to presence, spawning, or other ecological characteristics of certain species.

Integration with other MPA assessment data

CalCOFI oceanographic, larval, and pelagic habitat data could be combined with data from other MPA monitoring efforts to provide more complete life history information or broader regional context to much of the MPA assessment. For example, the CalCOFI larval fish data could be combined with the California Cooperative Fisheries Research Program (CCFRP) data on adult fishes, such as rockfish and lingcod, to better understand recruitment dynamics of essential fish populations across the region of the MPA network.

Outreach, education, & stakeholder engagement

In addition to data and research, CalCOFI can also contribute to outreach, education, and stakeholder engagement throughout the MPA review process through the annual CalCOFI Conference and community engagement to provide feedback from the broader community of ocean

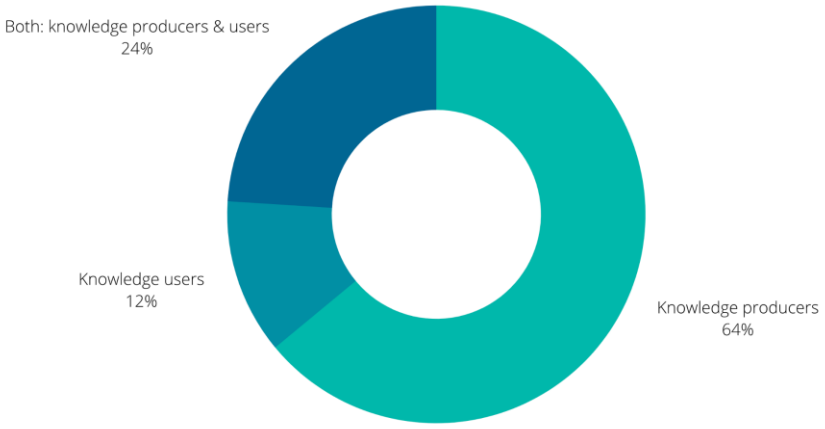

Figure 5. Distribution of CalCOFI Conference 2021 attendees that consider themselves knowledge producers (64%); knowledge users (12%); and both knowledge producers & users (24%).

users and stakeholders. A key aspect of CalCOFI is the participatory, collaborative nature of the program, including engagement of researchers, practitioners, and ocean constituents through events. For example, the annual CalCOFI Conference serves as an opportunity to bring together the CalCOFI community to share interdisciplinary, use-inspired research related to sustainability and resilience in the California Current. The conference is held annually the first week of December and usually consists of a symposium with contributed talks and posters. With the more recent shift to virtual engagement, the CalCOFI Conference has evolved to include keynotes, panels and discussion groups. For example, the most recent CalCOFI Conference 2021 brought together over 270 people at peak attendance (443 registrants) from 131 different organizations and institutions across academic, government, civil society/non-profits, industry, and foundations. Nearly two thirds (64%) of conference registrants were knowledge producers (e.g., researchers), 12% knowledge users (e.g., policy-makers, managers, decision-makers, practitioners), and a quarter (24%) were both knowledge producers and users (Figure 5). Registrants worked from local (city/county) to international scales, with most working along the West Coast.

In addition, CalCOFI can contribute to ongoing and future citizen and community science efforts related to MPA assessment, since the CalCOFI program has been in the preliminary stages of developing a citizen science application that could play a role in further MPA monitoring. The app will allow recreational fishers to upload detailed information on species they caught or observed. Users will be able to record the species name, the time and location of the observation, and the size and weight of individual specimens, as well as upload a photo. The app will provide additional functionality related to MPAs, including a real-world map providing locations of California's Marine Protected Areas, and the ability for users to view statistical information of observations at their location.

Conclusion

CalCOFI's extensive time series of data and samples can contribute information to assess climate change, provide oceanographic context, larval abundance and distributions, and pelagic habitat characteristics and qualities relevant to the California MPA Network. CalCOFI could provide more comprehensive monitoring data for the future MPA assessments, such as enhanced sampling within MPAs, better visualization and merging of data products for ease of access for managers, the generation of new research, as well as data products and index development. In addition, CalCOFI's stakeholder engagement, outreach, education, and

participatory science efforts can continue to support the MPA process, assessment, and engagement.

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