California Collaborative Fisheries Research Program (CCFRP) – Monitoring and Evaluation of California Marine Protected Areas

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CCFRP EXECUTIVE SUMMARY

Project Description and Background

The California Collaborative Fisheries Research Program (CCFRP) is a community-based science program involving researchers from six California universities, the captains and crew of 36 sportfishing vessels, more than 1700 volunteer anglers, and partnerships with conservation and resource management agencies. By combining the expertise and ideas of a diverse group, we have successfully established protocols to evaluate Marine Protected Areas (MPAs), the status of nearshore fish stocks, and how climate change is impacting marine resources in California. In 14 years, we have conducted over 600 sampling trips, caught and released more than 175,000 fish from 93 different species, and tagged nearly 60,000 fishes. The project has generated estimates of relative abundance, length frequencies, biomass, diversity, community composition, and movements of fishes across 16 MPAs and associated Reference areas statewide and contributed data to stock assessments of 7 species. Additionally, we conduct extensive education and outreach to the angling community and have designed and deployed socioeconomic surveys to gather diverse information including opinions of recreational fishermen about MPA performance, changes in sentiments towards MPAs following establishment, fisheries management, and attitudes towards conservation.

Methods

We incorporated local knowledge and expertise to develop a rigorous fishery-independent program that uses stratified random sampling of demarcated grid cells in shallow and mid-depth rock habitat (20-40 m depth), inside MPAs and corresponding Reference sites, to characterize fish abundance, size structure, biomass, and diversity using standardized scientific hook-and-line sampling. Fish are measured, tagged, and released at the site of capture. Subsequent recaptures by CCFRP or other recreational anglers provides information on fish movements and rates of spillover. To answer MPA performance questions, we calculated size frequencies, abundance (catch per unit effort), biomass (biomass per unit effort), metrics of diversity, community composition, and response ratios (i.e., magnitude of the difference between MPAs and paired Reference sites). We assessed changes in these metrics over time and across space in the three bioregions (Central coast = 14 years, North and South coast = 4 years), along with potential explanatory variables such as fishing pressure, MPA characteristics, and environmental conditions. We designed and deployed a socioeconomic survey that was distributed to all CCFRP volunteers to gauge perceptions about MPAs, fisheries management, and conservation.

Key Findings

- Fish are **larger in size** inside the MPAs across the state compared to Reference areas open to fishing; 79% of species were larger inside MPAs.
- Fish are **more abundant** (higher CPUE) inside MPAs in all regions; 71% of species were more abundant inside MPAs.
- Fish **biomass is higher** inside MPAs throughout the state; 73% of species had greater biomass (BPUE) inside MPAs.
- Fish abundance and biomass **increased more rapidly** inside MPAs over 14 years on the Central coast, where long-term data exists starting the year MPAs were first implemented.
- The strength of the MPA response on the Central coast **depended on the amount of external fishing effort** in the Reference sites. In locations with higher fishing pressure, populations increased inside the MPAs but not at Reference sites. In contrast, at locations with low fishing pressure, populations increased both inside and outside of the MPAs.
- The strength of the MPA response statewide **depended on the size of the MPAs**; larger MPAs experienced greater increases in abundance and biomass than smaller MPAs across the state.

- The strength of the MPA response statewide **depended on geography**; MPAs in southern latitudes exhibited stronger biomass responses than MPAs in northern latitudes.
- Fish communities changed in response to the 2014-2015 marine heatwave. Diversity (which increased inside MPAs before the heatwave) declined both inside and outside MPAs; however, **MPAs appeared more resilient** and diversity recovered more quickly following the heatwave.
- Tag-recapture data demonstrated **high site fidelity**, with 61% of recaptures (250 out of 408) occurring 0.25 km or less from the release location. While uncertainty remains due to a limited number of recaptures, for fishes caught and released inside MPAs, we detected a **spillover rate** of up to 20% (36 out of 180 recaptures), indicating some cross-boundary movements.
- Angler **opinions of MPAs became significantly more positive** after participating with CCFRP, with anglers reporting that they catch more fish, bigger fish, a higher diversity of fishes inside MPAs on CCFRP sampling trips. More positive responses occurred in anglers that participated more frequently in MPA monitoring.

Conclusions and Recommendations

1. CCFRP results indicate that the MPAs are working well across the statewide network. In the shallow and mid-depth rocky habitat (20-40 m depth) fish are larger in body size, more abundant, and higher in biomass in nearly every MPA sampled. The strength of the MPA response is continuing to increase on the Central coast, 14 years after protection first began, indicating that the positive benefits of the MPAs are continuing to accrue. Given the observation that MPA responses can be slow to build in some locations (>10 years), patience is necessary, especially in areas where fishing pressure is low.
2. The MPAs did not resist the effects of the marine heatwave, which depressed diversity and resulted in community changes. However, the MPAs were more resilient, such that diversity bounced back more rapidly than in fished areas. This may require a re-evaluation of expectations in how fish communities inside MPAs will respond to future climate change along the coast of California, as the forces driving distributional shifts and species turnover occur at broader spatial scales. This also highlights the important role MPAs play in helping to distinguish broad-scale environmental change from localized human-caused changes.
3. Populations inside larger MPAs responded more strongly to protection than those in smaller MPAs, such that biomass differences build up more rapidly in large reserves. If the goal is to protect species within MPA boundaries, we recommend that individual MPAs be made larger, not smaller. However, MPAs of all sizes exhibited positive responses to protection.
4. Despite evidence of spillover in some species, tag-recapture data indicated that the majority of fishes remained inside MPAs for extensive periods. These results signify that the MPAs are appropriately sized to encompass the home ranges of many nearshore species. Increasing or decreasing MPA size will impact rates of spillover and potential contributions of MPAs to fisheries.
5. Our findings indicate that external fishing pressure is the most important metric for understanding spatial differences in the efficacy of MPAs across the statewide network. Accurate high resolution spatial information on fishing pressure outside of MPAs can help set expectations in MPA planning and evaluation. Improving information on the spatial distribution of fishing effort for all fishing sectors should be a major priority for the state of California.
6. CCFRP has shown the power of collaborative research and long-term monitoring to conduct rigorous evaluations of MPAs in California. CCFRP data contributes to stock assessments, providing important information for fisheries management that is not currently available. Outreach and education to the fishing community has produced tangible benefits in terms of increasingly positive opinions of MPAs by the stakeholder group most vocally opposed to their creation. We recommend expanding opportunities more broadly for the fishing community to participate in marine reserve monitoring and to engage in shared resource management for a more sustainable future.

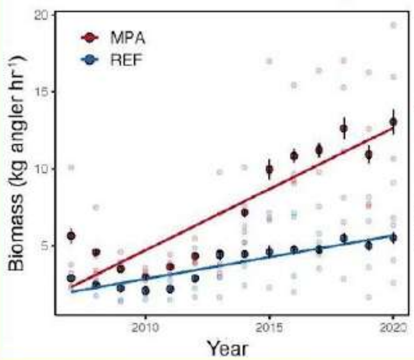
California Collaborative Fisheries Research Program (CCFRP)

Using community-based science to examine changes in fishes inside and outside of MPAs along the **Central coast** of California from 2007-2020

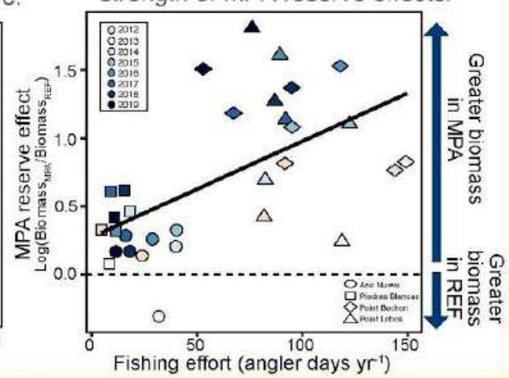
MPA effects on all fishes in Central CA

MPA - Marine Protected Area
REF - associated reference site

Fish biomass increases faster in MPAs than reference sites through time.



External fishing effort influences the strength of MPA reserve effects.



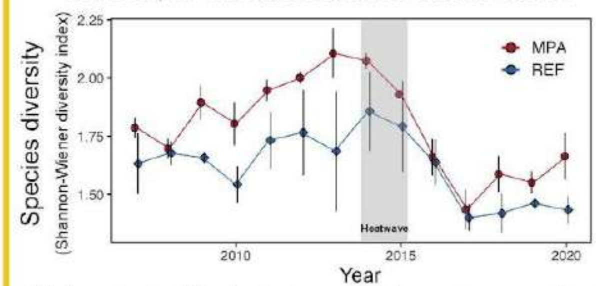
Top 10 most abundant species (average 2007-2020)

↑ Greater in MPA
↓ Greater in REF

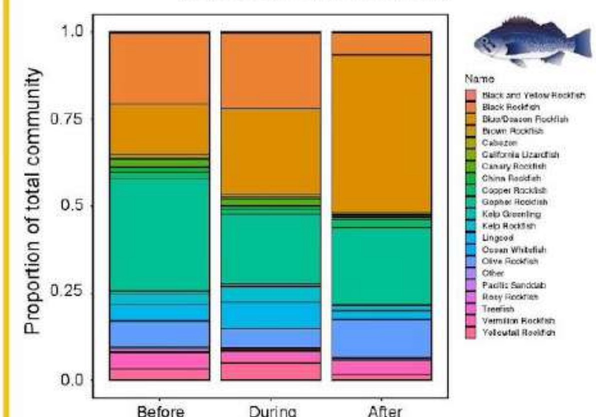
Species Common Name	Abundance	Length	Biomass
Black Rockfish	↓	↑	↓
Blue/Deacon Rockfish	↑	↑	↑
Canary Rockfish	↑	↑	↑
Copper Rockfish	↑	↑	↑
Gopher Rockfish	↑	=	↑
Kelp Rockfish	↑	=	↑
Lingcod	↑	↑	↑
Olive Rockfish	↑	↑	↑
Vermilion Rockfish	↑	↑	↑
Yellowtail Rockfish	↑	↑	↑

Changes in community structure

Diversity declined after the 2014-2015 **marine heatwave** in both MPAs and reference sites however, MPAs have started to recover faster.



Fish communities became more homogenous after the 2014-2015 **marine heatwave** dominated by Blue & Deacon Rockfish.



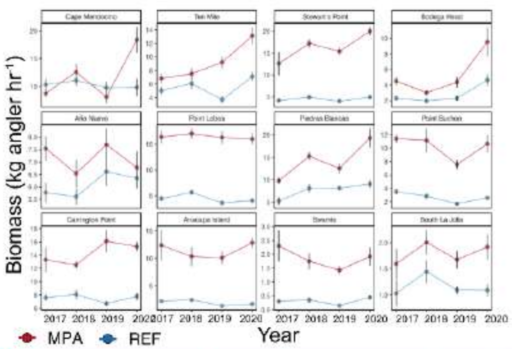
California Collaborative Fisheries Research Program (CCFRP)

Using community-based science to examine geographic variation in fishes inside and outside of MPAs across California 2017-2020

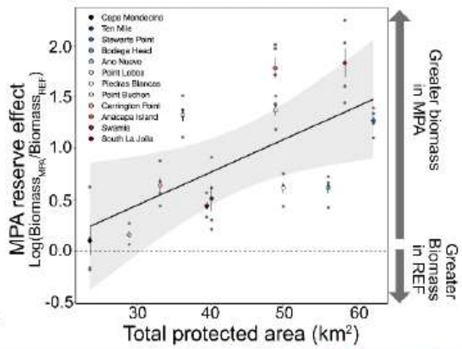
MPA effects on all fishes statewide

MPA - Marine Protected Area
REF - associated reference site

On average, MPAs have higher biomass than reference sites across the entire state.



Larger MPAs have more positive reserve effects than smaller MPAs.



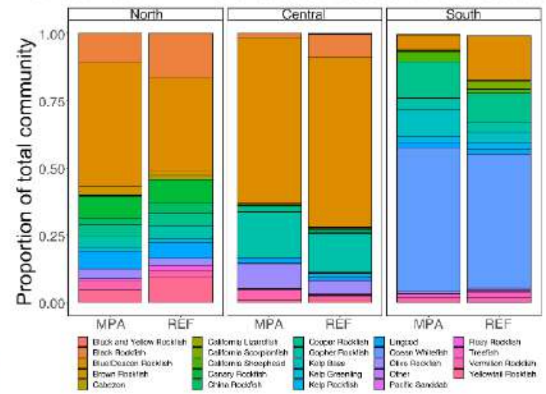
Top most abundant species in each region (2017-2020)

↑ Greater in MPA
↓ Greater in REF

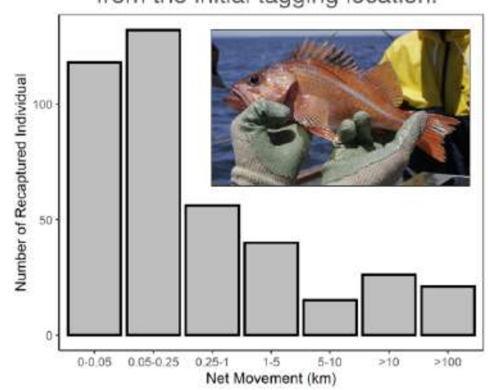
Region	Species Common Name	Abundance	Length	Biomass
North	Black Rockfish	=	↑	↓
	Blue/Deacon Rockfish	↑	↑	↑
	Canary Rockfish	↑	↑	↑
	Lingcod	↑	↑	↑
	Yellowtail Rockfish	↓	↑	=
Central	Black Rockfish	=	↑	=
	Blue/Deacon Rockfish	↑	↑	↑
	Gopher Rockfish	↑	↑	↑
	Olive Rockfish	↑	↑	↑
	Vermilion Rockfish	↑	↑	↑
South	California Sheephead	↑	↑	↑
	Copper Rockfish	↑	↑	↑
	Gopher Rockfish	↑	↑	↑
	Kelp Bass	↑	↑	↑
	Ocean Whitefish	↑	↑	↑

Fish communities & movement

Fish community structure varies by region but not between MPAs and associated reference sites.



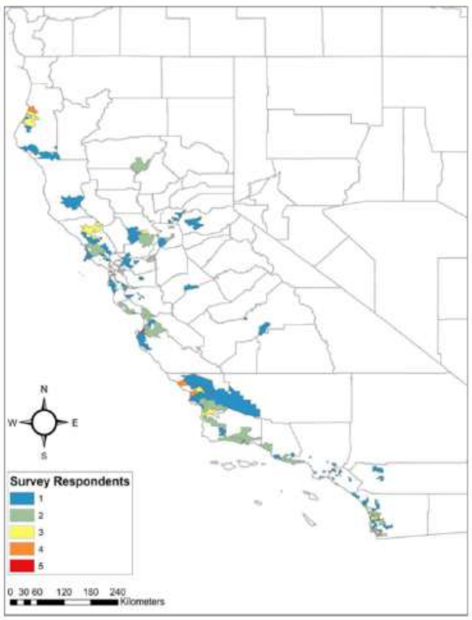
The majority of fishes move less than 0.25 km from the initial tagging location.



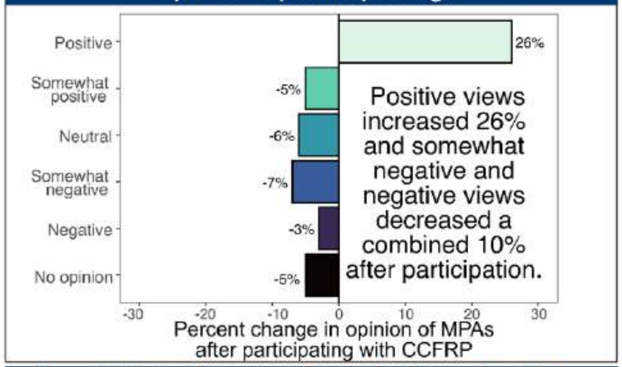
California Collaborative Fisheries Research Program (CCFRP)

Understanding how community-based science influences angler opinions of Marine Protected Areas as a management tool

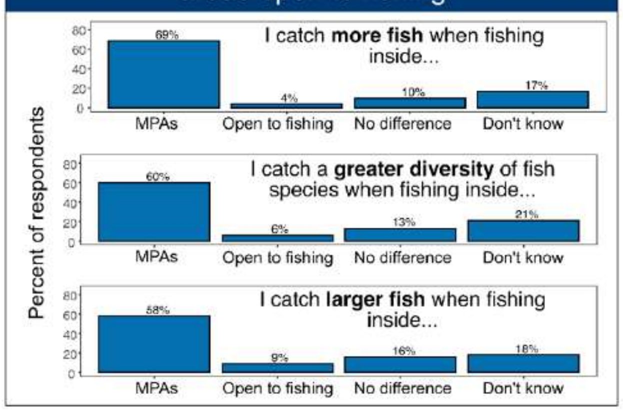
Between 2017-2021, CCFRP has successfully engaged anglers from across the entire state of California. Anglers traveled from 26 different counties, both coastal and landlocked, to participate in fisheries research.



After participating with CCFRP, anglers have more positive opinions of MPAs than prior to participating.



About 60% of respondents believe that fishes are more abundant, larger, and fish communities are more diverse in MPAs than in areas open to fishing.



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INTRODUCTION

Anthropogenic stressors, including overfishing, pollution, and climatic change have caused the loss of critical coastal habitats and ecologically important taxa in both aquatic and terrestrial systems. Within coastal ecosystems across the globe, these multiple interacting stressors have negatively impacted ecosystems and resulted in the decline of important fishery species. To mitigate the effects of these stressors, different forms of spatial management have been implemented to enhance ecosystem function, increase biodiversity, and maintain fisheries production. Marine protected areas (MPAs) in general, and no-take marine reserves specifically, are increasingly being used as a spatial management tool for both fisheries management and conservation of marine resources around the world (Marinesque et al. 2012; Fox et al. 2012; Micheli et al. 2012). Extensive empirical evidence for the ecological success of marine reserves is accumulating and meta-analyses of field studies show that marine reserves typically yield positive results with respect to an increase in the response variables of density, biomass, diversity, and body size of marine species within no-take reserves, and in particular for those species historically targeted by fishing activities (e.g., Halpern 2003; Micheli et al. 2004; Claudet et al. 2006, 2008; Lester et al. 2009; Guidetti et al. 2014). The magnitude and timing of changes in response variables across the world, however, varies greatly and depends upon the taxonomic groups protected, life history traits of species protected, size of reserves, protection level and amount of enforcement, oceanographic regime, and time since reserves were implemented (Lester et al. 2009; Molloy et al. 2009). Thus, the strength and outcome of these MPA effects are highly context-dependent, varying across both space and time in ways that are often difficult to predict or explain (Edgar et al. 2014; Caselle et al. 2015; Gill et al. 2017). This variability may be one reason why the debate continues about the value of marine reserves, especially in temperate environments (Paddack and Estes 2000; Lester et al. 2009), and provides strong rationale that monitoring is critical for the evaluation of reserves as an approach to managing marine resources (Cvitanovic et al. 2013).

Even across relatively small spatial scales, the influence of MPAs on their associated fish communities can vary substantially. For instance, Hamilton et al. (2010) reported significant differences in the composition of fish communities across the Channel Islands, California (~100km) and the differences in MPA responses were related to the geographic locations of reserves, distance from port, and local environmental conditions, such as sea surface temperature. Those spatial differences in the strength of the response after five years of protection were further magnified following 10 years of protection (Caselle et al. 2015). Modeling work has suggested that the responses of fish communities to MPAs should be related to MPA size, fish movements, time since protection, environmental conditions, as well as fishing effort or intensity (Moffitt et al. 2013; Nickols et al. 2019), and empirical work has found support for many of these factors (Woodcock et al. 2016; Sala and Giakoumi 2018). Since no-take marine reserves primarily restrict fishing, pre-existing or subsequent fishing pressure should strongly influence the MPA response (Nickols et al. 2019; Jaco and Steele 2020). Still, many models of MPA efficacy assume that fishing effort and fishing pressure is homogenous across an area, often because of a lack of data on fishing pressure (Lynch 2006). Given that the primary management action taken following the implementation of marine reserves is a restriction on fishing activities, it is expected that fishing pressure pre- and post-implementation is likely to influence the strength of MPA responses and the rates of recovery. Despite the potential importance of fishing, relatively few empirical studies have tested the effect of external fishing effort or pressure post-MPA implementation on the efficacy of MPAs (Lenihan et al. 2021). For example, Jaco and Steele (2020) examined the influence of pre-implementation fishing pressure on MPAs in Southern California and found the average lengths of targeted fish species to be larger in areas with higher fishing pressure prior to MPA implementation, compared to areas with lower fishing pressure.

Anthropogenic stressors from climate change, such as ocean acidification, hypoxia, and warming temperatures can affect individual species, community structure, and ecosystem function (He and Silliman 2019). Overfishing can reduce the resilience of kelp forest systems to respond to climate induced phase shifts by altering trophic structure and key species interactions (Ling et al. 2009). Networks of marine reserves, in contrast to single or stand-alone reserves, are predicted to provide resistance and resilience to various stressors (Micheli et al. 2012; Olds et al. 2014; Caselle et al. 2018), and there is some evidence that they buffer marine communities from heatwaves (Bates et al. 2019). Marine heatwaves are intense thermal anomalies where water temperature is elevated above the 90th percentile of the long-term average for more than five days (Hobday et al. 2016). Projections suggest an increase in the frequency and severity of marine heatwaves in the coming decades (Holbrook et al. 2019). While there is evidence that MPAs may be able to buffer some individual species from climate impacts (Micheli et al. 2012), there is not sufficient evidence to support the idea that MPAs can mitigate large-scale changes in marine communities in response to heatwaves, and in fact they may not prevent community changes at all (Freedman et al. 2020). California experienced a heatwave from 2014-2015, "the Blob", where ocean temperature anomalies were persistently elevated along the entire U.S. West Coast by up to 6°C (Jacox et al. 2019), causing changes in marine ecosystems (Cavole et al. 2016; Cavanaugh et al. 2019). To address the impacts of specific stressors, such as marine heatwaves, those stressors need to occur during the study and near the MPAs being monitored, with at least several years of data on either side of the impact, to detect the signal from the noise of short-term environmental variability that characterizes the dynamics of these temperate systems.

In the early 2000s, the state of California embarked on a process to design and implement a statewide network of MPAs spanning the entire coastline. After two unsuccessful efforts to establish MPAs, a comprehensive planning process was undertaken to design networks of MPAs that involved various stakeholder groups utilizing scientific guidance and recommendations on sizing and spacing, informed by data on habitat, abundances of key indicator species, home range size, and estimates of larval dispersal distances (Saarman et al. 2013). The goal was to ensure that the MPAs were designed to function as a network with connectivity between the MPAs (Kirlin et al. 2013; Saarman et al. 2013). The first set of these networks was established in Central California in 2007, containing 29 MPAs and protecting a total of 536 km^2 (18.1%) of nearshore habitats, with no-take marine reserves protecting 252 km^2 (8.5%) of the state's Central coast waters (MLPA Master Plan; 2016). The process continued with MPAs being established in the North Central coast in 2010 (395 km^2 protected in MPAs, 20% of state waters in that region), the South coast in 2011 (921 km^2 protected in MPAs, 15% of state waters in that region), and the North coast in 2013 (356 km^2 protected in MPAs, 13.4% of state waters in that region) (MLPA Master Plan; 2016). The theoretical benefits of the network of MPAs include providing habitat (and therefore species) diversity and redundancy, protection against localized environmental catastrophe and climate change, maintenance of genetic diversity, population persistence, and distribution of costs and benefits with respect to fisheries. California remains one of the few places globally where an extensive network of MPAs was designed and implemented using scientific best practices and extensive stakeholder input.

The state law that led to the formation of the new MPAs, the Marine Life Protection Act, contained six specific goals (Gleason et al. 2013; Marine Protected Area Monitoring Action Plan 2018). Two of these goals are related to the long-term benefits that are intended to accrue from increased resource protection: 1) to protect the natural diversity and abundance of marine life and the structure, function, and integrity of marine ecosystems, and 2) to help sustain, conserve, and protect marine life populations, including those of economic value, and rebuild those that are depleted. An additional long-term goal is: 3) to ensure that the state's MPAs are designed and managed, to the extent possible, as a network. The other three goals relate to recreation, education, intrinsic social values, and governance issues. Inherent in the development of the goals was the expectation to monitor and adaptively manage MPAs. Over the past 15 years, researchers have monitored California MPAs and sought to assess the efficacy of these protected areas for enhancing the abundance, biomass and diversity of species targeted by fisheries across multiple habitat types (e.g., kelp forest, nearshore and mid-depth rock; Hamilton et al. 2010; Caselle et al. 2015; Starr et al. 2015). Monitoring projects that provide data for adaptive management need be designed to evaluate changes in response variables such as species diversity, population density, biomass, age structure, and larval production. Although the level of detail needed to adaptively manage MPAs depends upon the spatial scale of the management action (e.g., at a broad level such as adding or deleting MPAs or at a fine scale such as changing boundaries of an existing MPA), at the root of adaptive management is the need to track changes in metrics over time. An effective adaptive management process thus requires a well-designed monitoring program with a statistically rigorous sampling design.

In 2006, we formed an alliance of academic and agency scientists, members of the fishing community, and non-governmental organizations to address the need for baseline data and continued monitoring of MPAs. This group, the California Collaborative Fisheries Research Program (CCFRP) (https://mlml.sjsu.edu/ccfrp/), adopted sampling protocols designed to monitor and evaluate the effectiveness of marine reserves, primarily with respect to nearshore fishes targeted by recreational anglers (Wendt and Starr 2009; Yochum et al. 2011; Starr et al. 2015). Because most of the species monitored by CCFRP are fished, they are the species expected to be most responsive to MPA establishment that restricts fishing activities inside the MPA. CCFRP also operates in the habitat (shallow rock and mid-depth rock; 20-40 m depth) that was most heavily fished prior to MPA establishment and thus this habitat should exhibit the strongest response to protection. The program has been sampling in Central California at four MPA and four Reference sites since 2007 and the program was expanded statewide to include Northern and Southern California (12 MPA and 12 Reference) sites starting in 2017. Over the summer and fall between 2007–2020, we worked with 36 Commercial Passenger Fishing Vessels (CPFVs), chartering over 600 catch-and-release fishing trips and working with over 1,700 different volunteer anglers to monitor MPAs (**Figure 1**). By combining the expertise and ideas of these diverse groups, CCFRP has successfully established rigorous and standardized scientific-fishing protocols to effectively monitor socioeconomically valuable fish species in MPAs relative to adjacent fished areas (Wendt and Starr 2009). In addition to monitoring MPAs and evaluating MPA performance, CCFRP contributes data used for fisheries management by NOAA's National Marine Fisheries Service (NMFS) and the California Department of Fish and Wildlife (CDFW), providing data used in stock assessments of seven nearshore groundfish (China Rockfish, Dick et al. 2016; Black Rockfish, Cope et al. 2016; Blue and Deacon Rockfish, Dick et al. 2017; Gopher and Black and Yellow Rockfish, Monk and He, 2019; and Vermilion Rockfish, Monk et al. *in progress*).

CCFRP also conducts extensive outreach and education to the recreational fishing community. While CCFRP was principally designed to collect data about nearshore groundfish populations, the design has provided the team with access to a large pool of volunteer anglers (i.e., citizen scientists). These citizen scientists are of additional value, as they can provide insight into how participation in this program impacts their opinions about MPAs, which is yet another important metric to evaluate success of the statewide MLPA network. To address this critical question, we conducted a survey of volunteer anglers who had participated in CCFRP research on the Central coast region. The results were very encouraging, indicating that angler opinions toward MPAs were more positive after volunteering with CCFRP. Furthermore, those who had volunteered for seven or more years with CCFRP were more likely than not to gain a positive opinion of MPAs (Mason et al. 2020). Thus, long-term engagement of stakeholders in collaborative research positively influences stakeholder opinions regarding marine resource management, one of the key goals of the MLPA process. Collectively, these results highlight CCFRP's success in engaging citizen science stakeholders in collaborative fisheries research.

Here we describe the approach we took to evaluate the performance of California's MPAs for the decadal review of MPA performance, using 14 years of monitoring from Central California and four years of monitoring from Northern, Central, and Southern California. Using data from the CCFRP program, we examined spatial and temporal variability in the responses of fish populations and communities inside and outside MPAs statewide, along with high resolution quantitative data on environmental conditions and fishing pressure. Specifically, we evaluated how fish abundance, lengths (size structure), biomass, diversity, and community composition changed after implementation of the MPA network and explored several external forces predicted to be associated with those changes. We also assessed how angler participation in the CCFRP program has affected their perceptions of MPAs and fisheries management statewide. We hypothesized that MPAs would have an overall positive effect on fish abundance, body size, biomass, and diversity, but the magnitude of change across the statewide network would be mediated by environmental conditions and fishing pressure. We also hypothesized MPA perceptions by volunteer anglers would improve because of CCFRP participation (i.e., as citizen scientists, witnessing firsthand how fish populations respond to MPA protection). Using the goals and questions outlined in the Marine Protected Area Monitoring Action Plan (2018) and further refined in the OPC-SAT Decadal Evaluation Working Group (DEWG) report (Hall-Arber et al. 2021), we addressed a series of questions related to the predicted responses of fish populations to marine reserve establishment:

1. Do indicator species inside of MPAs differ in size, numbers, and biomass relative to Reference sites? Are there differences in functional diversity, community composition, and trophic structure between MPAs and Reference sites?

2. How have indicator species or community response metrics changed over time in response to MPA network implementation?

3. Have endangered, special status species and/or culturally significant species benefited from the presence of California's MPAs?

4. What are the spatial scales of fish movements and the degree of spillover and connectivity between MPAs and Reference sites? Are MPAs sized appropriately to protect populations of key indicator species?

5. How does fishing pressure or environmental stressors impact the performance of MPAs over time?

6. How has knowledge, attitudes, and perceptions regarding the MPAs changed over time in the recreational angling community?

METHODS

CCFRP Program Summary

CCFRP is a collaborative effort among researchers from six California universities, the captains and crew of 36 commercial passenger fishing vessels (CPFVs), and more than 1,700 volunteer anglers, spanning the entire California coast (**Figure 1 & 2**). Incorporating an interdisciplinary approach, CCFRP has worked closely with the California Department of Fish and Wildlife (CDFW) and National Marine Fisheries Service (NMFS) scientists since the program's creation in 2006 to provide information for stock assessments and fisheries management. The program was developed in Central California in 2007, sampling four MPA and four Reference sites, and expanded in 2017 to the North and South regions, including 12 MPA and 12 Reference sites all within the Tier I and Tier II MPA designations (**Table 1; Figure 3**). Additional sites were sampled in a subset of years, which are not currently part of the core long-term MPA monitoring by CCFRP (**Table 2**). In 14 years, we have conducted over 600 sampling trips, caught and released more than 175,000 fishes from 93 different species, and tagged nearly 60,000 fishes (**Figure 2; Table 2**). The project has generated estimates of relative abundance, length frequencies, biomass, and movements of fishes across 16 MPAs and associated reference areas. Additionally, we have designed and deployed two socioeconomic surveys to our anglers (first from only the Central coast and more recently to all statewide regions) to gather diverse information including opinions about MPA performance and changes in angler sentiment about MPAs since they were established (Mason et al. 2020; *this study*).

Sampling and Experimental Design

We incorporated local knowledge and expertise into a fishery-independent sampling design that was adopted after a series of workshops with fishers, harbor officials, and scientists from agency, academic, and conservation organizations (Wendt and Starr 2009; Starr et al. 2015). Together, we developed protocols to monitor MPAs utilizing seafloor maps and fishermen's knowledge in a stratified random sampling design that could both account for the effect of habitat and also efficiently sample areas using standardized hook-and line fishing surveys (Starr et al. 2015). From the program's inception, we have distributed our effort across as broad a geographic region as is logistically feasible given the level of funding allocated (**Figures 3-6; Table 1**). We chose sampling sites with input from fishing and resource management groups. The 12 Tier I and II MPAs chosen to be sampled for long-term MPA monitoring were selected because: (1) they span the breadth of the California MPA regions, (2) the nearshore rocky habitats within them are sizeable and broadly representative of rocky habitats along the California coastal region, (3) these sites were popular fishing areas for both recreational and commercial fishermen, (4) they are near ports with CPFVs (i.e., logistically feasible and have been shown to be more influenced by fishing than areas further from port; Mulligan et al. 2017), and (5) they were historically monitored by CCFRP or co-located with sites monitored long-term by other groups. Corresponding Reference sites were selected based on the criteria that they share similar size, habitat, bathymetry, and oceanographic conditions with the MPAs but are far enough away to minimize the potential that fish populations inside a Reference site are greatly influenced by a nearby MPA (e.g., by spillover from the MPA). Given those criteria, Reference sites were located 0.5–10 km away from the corresponding MPAs (**Figures 4-6**). Collaborating fishers were helpful in choosing appropriate survey areas and Reference sites for the MPAs by applying their extensive knowledge of the historic fishing activity at the sites and the available habitat.

Each sampling area contained an MPA and paired Reference (REF) site (Wendt and Starr 2009; Yochum et al. 2011). We provided the collaborating CPFV captains with nautical charts, side scan sonar maps, and bathymetric data, and asked them to draw polygons around locations with suitable fish habitat within water depths less than 40 m (to limit fishing mortality from barotrauma). We asked captains to indicate areas that were logistically infeasible to sample and eliminated those areas from consideration. We then created multiple 500 m x 500 m grid cells to stratify our sampling within each MPA or Reference site (**Figures 4-6**). For example, on the Central California coast we have a total of 22 fixed grid cells at Año Nuevo, 17 cells at Point Lobos, 57 cells at Piedras Blancas, and 22 cells at Point Buchon (across MPAs and REF sites; **Figure 5**). Differences in the number of sampling cells reflect different sizes of the MPAs and amounts of suitable rocky habitat in the appropriate depth zones for sampling. We have conducted subsequent analyses of the habitat complexity in our MPA-Reference site pairs (using sidescan sonar data and bathymetry information along with spatial analysis in GIS) and found no significant differences in habitat quality, indicating that the Reference sites are appropriate comparisons for the MPA sites.

Surveys were conducted annually in the MPA and Reference sites in each region (from 2007 in the Central region (**Figure 5**) and 2017 in the North (**Figure 4**) and South (**Figure 6**) regions). Volunteer anglers were recruited from various fishing clubs, online fishing websites, and from previous collaborative studies. Surveys occurred in the late summer period from mid–July through November when ocean conditions are most consistent. In order to account for oceanographic variability, we sampled each MPA and Reference site 3-4 times at the same time of year. Power analyses have shown that three times a year is sufficient to keep coefficients of variation of sample means below 0.25 for all species combined. Before each day of fishing, four grid cells in a given MPA or Reference site were randomly chosen for sampling. Captains were instructed to locate three suitable fishing locations within each grid cell to complete fishing drifts of approximately 10-15 minutes each. For each drift, information on the number of anglers, time spent fishing, location (GPS coordinates), depth (ft), habitat relief, and other environmental variables were recorded. We used a standardized set of fishing gear (lead jigs, shrimp flies without bait, shrimp flies with squid bait, baited dropper loops, and swimbaits) in order to capture a variety of species and cover the spectrum of typical hook-and-line fishing gear used across each region. In each region, three of these gear types were deployed, with shrimp flies with bait serving as a standard gear type across all locations. Captured fishes were identified to species, measured to the nearest cm, tagged with a T-bar anchor tag (if in good condition), and released (**Figure 2**). Lengths reported are total length (cm), defined as the distance from the tip of the snout to the most posterior part of the caudal fin without compressing the tail. We recorded the locations (latitude and longitude) and depths where fishes were released. The effects of barotrauma (i.e., angling-induced pressure injuries) were reduced with descending devices, and by minimizing the duration of time that the fishes were on board the vessel. We aimed to process and release fish in < 5 min in order to minimize effects of barotrauma and handling stress (Jarvis and Lowe 2008). For each drift, we also recorded water temperature, wind speed, wave height, and habitat rugosity (3-point scale based on the captain's assessment of the amount of vertical relief).

Data Entry and Database Management

The monitoring teams at the six different universities were responsible for entering their field data into a Microsoft Access database. The Access database template was distributed statewide and was uniform to ensure consistency in data formatting. After extensive QA/QC by each monitoring group, the six different datasets were merged together to produce a single statewide database that contains all of the data collected from 2007 to 2020. Fishing drifts were mapped in ArcGIS to ensure that GPS coordinates were correct, and to confirm that drifts were appropriately excluded from future analyses if they started and ended in different cells or were conducted too far outside of grid cell boundaries. We worked with Diana LaScala-Gruenewald at MBARI/CenCOOS to prepare the metadata and the data package for submission to the DataONE portal. The database, including 2020 data, is now updated and publicly available as derived data tables on DataONE for 2007-2020 (doi:10.25494/P6P88K). The CCFRP data are also publicly available on the CenCOOS website with the catch rate (CPUE) data available for exploration using their mapper tool (https://data.cencoos.org/#map).

Response Variables

Response variables considered in this study include catch-per-angler-hour (CPUE), biomass caught-per-angler-hour (BPUE), egg production or fecundity per-angler-hour (FPUE), lengths (cm) of fishes caught during a sampling cell visit, species richness, diversity, evenness and measures of community composition. Tag and recapture data provided information on time at liberty, net distances moved between capture and recapture events, and adult spillover from the MPAs.

We used a variety of length metrics to examine changes in the size of fishes inside and outside MPAs. We examined the length frequency distribution of populations, calculated mean lengths, and extracted the upper length quartile (75th percentile) for each focal species across each region and year. We also calculated the proportion of individuals that were larger than the length at 50% maturity (L_{50}). We used published L_{50} values for the 10 most abundant species in each region (e.g., Love 2011). We summed the count of all individuals of a species with lengths (cm) greater than L_{50} and divided that number by the total number of individuals of that species in a region.

To standardize our sampling effort, we calculated catch per unit effort (CPUE) and biomass per unit effort (BPUE). CPUE was calculated by dividing the total number of fishes caught by total angler hours of fishing in a sampling cell in a day (catch per angler hr^{-1}). BPUE was calculated as the total weight of fish in kilograms divided by the number of angler hours fished (kg angler hr^{-1}) for each MPA and Reference site. We first calculated BPUE for each fish caught by converting total length to weight using published length-weight relationships for each species (Love et al. 1990; Froese and Pauly 2021). Expected reproductive output (FPUE) was calculated as the total estimated egg production for fish larger than 50% maturity divided by the number of angler hours fished (number of eggs angler hr^{-1}). We used length-fecundity relationships in the published literature for 10 common species to calculate egg production for each fish caught, with seven species represented in each region. CPUE and BPUE for each grid cell sampled on a given day was averaged to estimate CPUE or BPUE for the total fish community inside and outside each MPA in a given year of sampling. CPUE and BPUE in the 2007 and 2008 sample years were deemed to be starting conditions for the Central California study sites. Sampling in the North and South regions began several years after MPA implementation in those regions.

Using CPUE, BPUE or length values, a yearly response ratio was calculated to estimate the strength of the MPA effect on fish abundance (CPUE), biomass (BPUE) or length (cm) inside relative to outside the MPA. Response ratios were calculated by taking the log of the quotient between CPUE, BPUE, or length inside relative to outside the MPA.

$$RR = Log\left(\frac{X_{MPA}}{X_{REF}}\right)$$

A response ratio above zero indicates a positive effect of the MPA on fish abundance, biomass or lengths, while a value below zero indicates higher abundance, biomass, or lengths in the Reference site compared to the MPA.

We calculated the species richness, Pielou’s evenness, and Shannon-Wiener diversity index to determine changes in diversity across sites and through time. Species richness is the total number of unique species in a given area. Shannon-Wiener diversity is a measure of diversity that combines species richness and their relative abundances. Calculated as

$$H' = -\sum_{i=1}^{R} p_i \ln p_i$$

where p_i is the proportion of species *i* for *R* number of species present in the sample. Pielou's evenness is the proportion of the relative abundance of each species in an area between 0 and 1 and is calculated as

$$J' = \frac{H'}{\ln(S)}$$

where H' is Shannon-Wiener diversity and S is the total number of species in a sample, across all samples in the dataset.

Environmental Data Extraction

Environmental data (sea surface temperature, net primary production, wind speed, significant wave height, and wave orbital velocity) were extracted from the Central and Northern California Ocean Observing System (CenCOOS) Repository. Sea Surface Temperature (°C; SST) was originally collected from the Advanced Very High-Resolution Radiometer instrument aboard NOAA's Polar Operational Environmental Satellites. SST measurements were collected daily from 2004–2020 at a 1.47 km spatial resolution. Values are accurate to ± 0.7°C. Net Primary Production data (mg C m^{-2} day^{-1}; NPP) were collected by the California Current Merged Satellite daily from 1996–2020 at a 4-km spatial resolution. Wind Speed (m s^{-1}) was extracted from the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS) through the CenCOOS repository. COAMPS is a high-resolution meteorological forecast model with a 4-km resolution. Significant wave height (m) and wave orbital velocity (m s^{-1}; derived from wave height and dominant period) were extracted from the Coastal Data Information Program spectral files at the station nearest each MPA. For all environmental variables, we extracted the mean monthly data for each CCFRP grid cell for the time period during sampling between the months of July and October from 2007–2020.

We used the Multivariate Ocean Climate Indicator (MOCI) as a measure of oceanographic conditions for a cross-correlation analysis (described below). MOCI combines a number of local and regional oceanographic parameters into a single value for every three-month season of the year starting in January of 1990. This index includes seasonal averages for upwelling index, sea level, alongshore wind, sea surface temperature, air temperature, sea level pressure, the Multivariate ENSO index (MEI), the Pacific Decadal Oscillation (PDO), and the Northern Oscillation Index (NOI) (García-Reyes & Sydeman, 2017). The MOCI index produces separate values for the Northern, Central, and Southern California regions and captured the 2014 North Pacific marine heatwave as well as the 2015-2016 El Niño. For this analysis, we used the Central California MOCI values and limited the analysis to the more extensive 14-year time series on the Central coast to detect lag effects.

Fishery-Dependent Microblock Data to Estimate Fishing Effort

The levels of historical fishing around an MPA will also have strong effects on the rates of recovery. Populations and communities that have been subjected to heavier fishing pressure should show faster initial rates of recovery as fishing pressure – and the mortality it generates – is removed. However, areas that have been subjected to heavier fishing pressure may take longer to reach full recovery. We used the CDFW CRFS (California Recreational Fisheries Survey) data to generate estimates of recreational fishing pressure in Reference sites near MPAs. Fishing effort data were extracted from the California Recreational Fisheries Survey (CRFS) conducted by the CDFW from 2012–2019 and provided to us by Chenchen Shen of

CDFW. CRFS data are spatially distributed across 18.52 km x 18.52 km (10 x 10 nautical mile) fishing blocks. Each fishing block was further divided into 1.85 km x 1.85 km (1 x 1 nautical mile) microblocks. For each surveyed fishing trip, a variety of data were collected, including the number of anglers, time fished, geographic location, and species targeted. We focused on the CRFS Private and Rental Boat (PR1 and PR2) data and the metric of number of angler days for each unique fishing trip ID as a proxy for spatial and temporal variation in fishing effort. We elected not to use the CPFV observer data as the spatial coverage and temporal coverage was less extensive, resulting in large gaps in the data set. We extracted fishing effort data from the microblocks surrounding each CCFRP reference cell adjacent to each MPA for each year available. The total number of angler days per year within a microblock were summed and then averaged across all microblocks for a given year and MPA area.

Tag-Recapture Data to Quantify Movements and Spillover

To quantify coarse movements and spillover of nearshore fishes, we used tag-recapture information from fishes recaptured on CCFRP sampling trips and recaptures reported to us by the angling community. Out of the 472 reported tags, 408 were still attached to the fish we released, and most tag reports included the location and date of capture, fish species, fish health, fish length, tag bio-fouling, and whether or not the fish was re-released or retained. Some tag recaptures reported to our offices were not accurately recorded and/or did not contain enough detailed information to be useful in calculating distance moved. Distance moved was calculated as the distance measured between the location of release and the location of recapture. Time at liberty was calculated as the elapsed time (days) between release and recapture events. Spillover (i.e., the movement of a fish from inside an MPA to areas outside of the MPA boundary) was assessed by looking at the proportion of individuals that were recaptured outside of an MPA after being originally tagged and released within an MPA for a given region. We also assessed the proportion of individuals that were recaptured within the same site where they were initially tagged in (i.e., fishes tagged and recaptured in a specific MPA and fishes tagged and recaptured within a specific Reference area open to fishing).

2021 CCFRP Volunteer Angler Survey – Perceptions of MPAs and fisheries management

We designed and deployed a survey to CCFRP citizen scientists to gauge their opinions and knowledge of ocean issues, conservation, MPAs, and how their participation with CCFRP impacted their views. This research builds on two previous surveys: a pilot study conducted in collaboration with staff from the National Marine Fisheries Service's Southwest Fisheries Science Center (SWFSC), which was designed and deployed in 2018 through Cal Poly, and a second survey designed and distributed by our collaborators at Scripps Institution of Oceanography (SIO) in 2018. Both surveys were designed to assess angler opinions of MPAs, score anlger involvement with CCFRP, and gather information to improve citizen scientist retention and participation for anglers affiliated with Central California CCFRP institutions at Moss Landing and Cal Poly. From these surveys, we learned that long-term engagement with CCFRP has improved citizen scientist opinions regarding MPAs (Mason et al. 2020). The goal of the current survey was to build upon these previous surveys and deploy them to our statewide volunteer angler groups across all six CCFRP partner institutions, spanning the length of the California coast (Humboldt State University, Bodega Marine Laboratory of UC Davis, Moss Landing Marine Laboratories, Cal Poly San Luis Obispo, the Marine Science Institute at UCSB, and Scripps Institution of Oceanography at UCSD). We included material similar to the previous surveys and also added questions designed to assess citizen scientist opinions and knowledge of ocean issues and conservation.

Questions were crafted using two previous CCFRP surveys as a guide (Cal Poly San Luis Obispo, *unpublished data*; Mason et al. 2020). Respondents were asked about their experiences fishing with CCFRP, knowledge about and opinions of the effectiveness of fisheries management, and the impact their participation with CCFRP had on their opinions of marine protected areas (MPAs) and fisheries management (see **Appendix B** to view all survey questions). In addition, the survey asked for a variety of demographic information and the length of time they have participated in CCFRP. These questions provided context when analyzing participant responses to questions about fisheries management and MPAs, allowing us to compare CCFRP citizen scientists to the broader angling community, while providing a number of additional analytical options (e.g., does length of time participating in CCFRP correlate with opinions about MPAs?).

We converted the survey to an online format using Qualtrics, an online survey platform that allows the anonymous collection of survey responses. Respondents 18 years and older provided their consent by agreeing to participate in, filling out, and submitting the survey through Qualtrics. Qualtrics uses Transport Layer Security (TLS) which encrypts communications. Due to the use of TLS and the exclusion of any personally identifiable information, the data collected in this online format are secure and confidential. We also provided paper copies of the survey on a case-by-case basis to anglers who were unable to access or preferred not to use the online survey format. No personal identifying information was requested or recorded on the paper-based surveys and therefore survey respondents remained anonymous. Our methods were approved by the Cal Poly Human Subjects Institutional Review Board under approval # 2021-144.

Survey participants were recruited via email inquiries sent to all anglers who volunteered with CCFRP at each of the six CCFRP institutions, as well as via verbal recruitment during CCFRP summer research activities. All survey participants were given a copy of the Informed Consent Form (**Appendix C**), which included the name and email addresses of project researchers. This form also invited survey participants to contact the project researchers to be informed of the results of the study upon completion. Surveys were distributed by each of the six CCFRP institutions to their respective citizen scientists within one week of each other via an identical outreach email (**Appendix D**) that was crafted by the CCFRP Statewide Coordinator. Reminder emails were sent by each of the participating institutions at two, three, and four week intervals after the initial email was sent out. Data for this report was collected up through December 5, 2021.

For each question in the survey, we calculated the percentage of respondents that gave a particular answer. For questions about angler perceptions of MPAs, we calculated the change in opinions before and after participating with CCFRP. For each individual respondent, we also calculated the magnitude of their change in opinion, by ranking the responses from positive to negative and calculating the number of positions over which their opinion changed, either positively or negatively. This gave us a metric of the direction (positive vs. negative) and magnitude (strength of the shift in opinion) of an individual angler's change in opinion (value of zero = no change) before/after volunteering with CCFRP. To assess whether angler opinions of MPAs, experiences fishing in MPAs, or views of fisheries management changed regionally or due to demographics or level of participation with CCFRP, we reanalyzed the results in different ways. For example, to address regional differences we broke the respondents into those that tended to participate in the North, Central, or South regions of the state. To evaluate whether the frequency of participation with CCFRP influenced angler opinions, we compared responses for those that participated every year, every few years, or infrequently (1 or 2 times). We also examined differences in responses based on angler age and other provided demographics, reporting only in instances where interesting differences were observed.

Statistical Analyses

To assess differences in lengths among species inside and outside of each MPA we examined mean lengths, length frequency distributions and the proportion of individuals larger than the size at 50% maturity. To assess differences between mean lengths of individuals inside MPAs and in the associated Reference areas across years, we ran two-way Analysis of Variance (ANOVA) and a Tukey's Post-hoc test to examine pairwise comparisons. To determine differences in length frequency distributions between fish populations inside and outside of MPAs for a given time period (2007-2010, 2011-2013, 2014-2016, 2017-2020), we conducted a Kolmogrov-Smirnov (K-S) test for the top 10 most frequently caught species in each region. We paired the K-S test with a Kruskall-Wallis test to quantify the difference in median length for the paired species length distribution inside and outside the MPAs. To compare differences in the proportion of individuals of each species larger than the size at 50% maturity between MPA and Reference sites in each region, we ran serial one-way ANOVAs.

To assess total fish CPUE and BPUE in the MPA and Reference areas with time since MPA implementation, we ran a two-way interactive Analysis of Covariance (ANCOVA). To further assess the relative effect of protection (or fishing closure) on CPUE, mean lengths, and BPUE through time since MPA implementation in 2007 to 2020 along the Central coast, we ran generalized linear models on the calculated response ratios through time at each MPA area, independently. We visualized the average response of each species within a region to MPA implementation with tornado plots (2017-2020 all regions; 2007-2020 Central coast). The tornado plots were constructed by calculating the average response ratio (± 95% CI) across all years sampled ± 95% CI. We then examined the frequency of positive or negative species responses for each region with histograms. To determine differences in the overall response of species to MPAs among regions, we ran K-S tests for each regional comparison.

We examined the species-specific trends in abundance, biomass and length for the 10 species with the highest CPUE across all years and sites for each region. For the North coast these species included: Black rockfish, Blue/Deacon rockfish, Canary rockfish, China rockfish, Copper rockfish, Gopher Rockfish, Lingcod, Olive rockfish, Vermilion rockfish and Yellowtail rockfish. For the Central coast these species included: Black rockfish, Blue/Deacon rockfish, Canary rockfish, Copper rockfish, Gopher rockfish, Lingcod, Olive rockfish, Kelp rockfish, Vermilion rockfish and Yellowtail rockfish. For the South coast these species were Blue/Deacon rockfish, California sheephead, California scorpionfish, Copper rockfish, Gopher rockfish, Honeycomb rockfish, Ocean whitefish, Kelp bass, Kelp rockfish, and Vermilion rockfish.

To examine differences in diversity metrics (species richness, Shannon-Wiener diversity and Pielou's evenness) through time in MPA and Reference sites, we ran ANCOVAs. To assess changes in community structure as a function of MPA status, region and year, we ran a permutational analysis of variance (PERMANOVA). To visualize the dissimilarity among communities, we conducted a non-metric multidimensional scaling (nMDS) ordination with a Bray-Curtis distribution. We calculated the vectors for species, MPA attributes, and environmental variables that corresponded to differences in fish communities. To further assess which species are contributing the most to the shifts in community structure through time and between MPA and Reference sites, we conducted a Similarity Percentages (SIMPER) analysis. All multivariate analyses to assess diversity and community structure were conducted with the Vegan package in R (Oksanen et al. 2020).

To determine if human-induced stressors (i.e., fishing pressure) and environmental conditions significantly varied across years and MPAs, we serially conducted a two-way analysis of variance (ANOVA) for each environmental variable and external fishing effort for years with sufficient data. Environmental data that differed statistically by year and location (temperature and primary production) were included while variables that were not significant (wind speed, wave height and wave orbital velocity) were dropped from subsequent analyses. To determine the relative effect of environmental conditions (temperature and primary production), and fishing effort the strength of the MPA response (i.e., biomass response ratios), we ran generalized additive mixed models (GAMM) with the mgcv package in R to smooth the interannual stochasticity in the data (Wood 2011). Our models included net primary production, mean sea surface temperature during the sampling period, and the number of angler days per microblock as fixed effects with a smoothed random effect of year. The model with the best fit was selected using Akaike Information Criterion (AIC).

We examined the effects of the 2014-2015 marine heatwave on fish communities in MPAs and Reference sites using the long-term data from the Central coast. We binned eight years of data prior to, two years of data during, and four years following the anomalous marine heat wave to examine the impacts of increased temperatures (and resulting reductions in primary productivity) on fish communities and to determine how well MPAs may have moderated these effects. To explore the effect of the marine heatwave through time for the region, species richness, evenness and diversity indices were grouped by time period in relation to the marine heatwave and a one-way ANOVA was performed. We conducted a Tukey's Post-hoc test to determine pairwise comparisons between the time periods. To examine changes in community composition in relation to the marine heatwave, we ran a PERMANOVA. To further visualize the differences in community composition through time and in relation to the marine heatwave, we conducted a non-metric multidimensional scaling (nMDS) ordination. To examine how each species responded to the marine heatwave, we ran linear regressions and calculated the slopes for each species inside and outside the MPAs before and after the marine heatwave. To determine if the distributions of slopes inside MPAs or Reference sites varied before and after the marine heatwave, we conducted a K-S test.

Cross correlation analysis was used to test the effects of environmental conditions on rockfish recruitment inside and outside of MPAs on the Central coast. We focused on Blue rockfish for this analysis because they were among the most abundant rockfish species caught on CCFRP trips, and we were able to detect several size classes. We classified Blue rockfish into two size classes; juveniles (<21 cm) and adults (>21 cm) (Love et al. 2002). We calculated annual catch per unit effort (CPUE) values for both size classes. The correlations between calculated annual values for CPUE and MOCI values for each season in the year were calculated using a cross-correlation. CPUE and MOCI values from the same year were evaluated for each unique area, site, and season combination (e.g., Piedras Blancas MPA in the summer). MOCI values were then offset, or lagged, by one year so that the values from the previous year were evaluated against CPUE at present (e.g., MOCI value from 2012 evaluated against CPUE from 2013). Additional lags were used to calculate correlations for a maximum lag of eight years. Because there are only 14 years in the data set, there were not enough values to accurately calculate the cross-correlation beyond eight lags. We restricted lags such that CPUE in a given year was only evaluated against the MOCI index for that year or previous years, since there is no conceivable way for CPUE in one year to influence MOCI in subsequent years. The equation for this cross correlation is as follows,

$$r_2 = \frac{\sum_{i=1}^{n-k}(X_i - \bar{X})(Y_{i+k} - \bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2}\sum_{i=1}^{n}(Y_i - \bar{Y})^2}$$

where $\bar{X} = \frac{1}{n}\sum_{i=1}^{n} X_i$, $\bar{Y} = \frac{1}{n}\sum_{i=1}^{n} Y_i$, *n* is the number of values in the series, and *k* is the number of lags being evaluated. Missing CPUE values were kept initially as placeholders for each lag iteration. They were then omitted before the correlation was calculated. These placeholders were important for the lagged oceanographic time series to be correctly evaluated against the relative abundance. Missing values were not replaced since there is no way to estimate the CPUE of a missing area or site in a given year.

All analyses were conducted in R statistical software version 4.0.5 (R Core Team 2020). Statistical results not cited in the results section can be found in **Appendix A**: **Tables S1-S23**.

RESULTS

Ecological Domain

MPA Performance – Populations

Question 1: Do focal and/or protected species inside of MPAs differ in size, numbers, and biomass relative to reference sites?

Q1a. *Does the difference between MPAs and reference sites in the size of individuals of a focal and/or protected species increase over time?*

Central Coast time series (14 years)

To address questions about the change in body size of fishes following MPA implementation, we plotted the time series of mean length for the 10 most commonly caught species by CCFRP on the Central California coast (**Figure 7**). We found that there were clear differences in lengths between MPA and Reference sites and among species ($F_{9,240}$= 5.78, p<0.001; **Table S1**). We found that five of the 10 species (Black rockfish, Copper rockfish, Lingcod, Olive rockfish and Vermilion rockfish) were consistently larger in size inside MPAs compared to the Reference sites, and for many species the differences in size increased over time. For some species, differences in lengths between MPA and Reference sites occurred at the start of the time series and were maintained over time. There was also evidence of substantial interannual variability in lengths likely due to processes such as recruitment, progression through age and size classes, and sample size. Four of the species (Blue/Deacon rockfish, Canary rockfish, Gopher rockfish and Yellowtail rockfish) were larger in size inside MPAs in some of the years and not different in others, and one of top 10 most abundant species (Kelp rockfish) was similar in mean length inside and outside the MPA.

Using published information on size at maturity, we assessed how the proportion of fishes greater than the length at 50% maturity changed over time inside MPA and Reference sites in the Central California region for the top 10 most abundant species (**Figure 8**). For four of the species (Copper rockfish, Lingcod, Olive rockfish and Vermilion rockfish) a greater proportion of fishes were of mature sizes inside MPAs compared to reference areas (**Table S2**). For two of the 10 species (Blue/Deacon and Yellowtail Rockfish), on average a greater proportion of fishes tended to be of mature sizes inside MPAs compared to Reference sites; however, these differences were not statistically distinct. For two species (Canary rockfish and Black rockfish), very few mature sized individuals were encountered either in or out of MPAs (mature Black rockfish occur further north and mature Canary rockfish occur at deeper depths), and for two species (Kelp rockfish and Gopher rockfish) all sizes encountered were mature. To examine changes through time, we compared the proportion of fishes that were greater than the length at 50% maturity for each year of sampling (**Figure 8**). In Central California MPAs, the fraction of sexually mature Olive rockfish increased over time relative to the Reference sites, suggesting that the number of reproductive age fish increased the longer an MPA remained closed to fishing (RR: $r^2 = 0.62$, $p<0.001$). Overall, results show that Central coast MPAs contained a higher proportion of mature-sized fishes than did Reference sites.

Statewide time series (4 years)

We examined changes in body size of fishes in the North and South coast regions for the years 2017-2020, using the mean lengths of the 10 most commonly caught species by CCFRP in each respective region (**Figures 9 & 10**). It is important to note that for both North and South coast populations, we are unsure if differences in lengths are due solely to reserve effects as there are limited baseline data for these regions. For the North coast, we found that all 10 of the most commonly encountered species (Blue rockfish, Copper rockfish, Lingcod, Vermilion rockfish, Gopher rockfish, Black rockfish, China rockfish, Olive rockfish, Canary rockfish, and Yellowtail rockfish) were consistently larger in body size inside MPAs compared to Reference sites, however mean lengths were not statistically different ($F_{9,40}=0.21$, $p=0.99$; **Figure 9; Table S3**). For the South coast, seven of the 10 species (Blue rockfish, Ocean whitefish, Kelp bass, California sheephead, Copper rockfish, Honeycomb rockfish, and Vermilion rockfish) were consistently larger in size inside MPAs compared to Reference sites ($F_{9,40}=3.65$, $p=0.002$), although only California sheephead lengths were statistically different. Three species (California scorpionfish, Gopher rockfish, and Kelp rockfish) were similar in mean lengths inside and outside the MPA (**Figure 10; Table S4**).

We assessed differences in the proportion of the population that reached maturity in MPA and Reference sites on the North coast (**Figures 11**) between 20017-2020. For the North coast, we found that five of the top 10 most commonly encountered species (Black rockfish, Blue rockfish, Lingcod, Olive rockfish, and Yellowtail rockfish) tended to have a greater proportion of sexually mature sizes inside MPAs than Reference sites, although the differences were not statistically distinct (**Figure 11; Table S5**) over time. For four species (Canary rockfish, China rockfish, Copper rockfish, and Vermilion rockfish), there were no detectable differences in the proportion of fish over the size at 50% maturity, either inside or outside of MPAs (very few Canary rockfish were mature as those tend to be in deeper water), and for one species (Gopher rockfish) all sizes encountered were mature.

For the South coast, we found that two of the top 10 most abundant species (Ocean whitefish and Copper rockfish) had a greater proportion of fish over the size at 50% maturity inside MPAs compared to their Reference sites (**Figure 12; Table S6**) over time. For two species (Blue rockfish and Vermilion rockfish), there were no differences in the proportion of mature-sized fishes inside or outside of MPAs, and for five species (Kelp bass, California sheephead, Honeycomb rockfish, Kelp rockfish, and Gopher rockfish), nearly all sizes encountered were mature. Overall, results for the most recent four years of statewide sampling indicate that a large proportion of fishes were bigger in body size inside MPAs then their Reference sites and that a greater fraction of the population was of mature sizes and able to reproduce and contribute to the next generation inside the MPAs in all regions of the state.

Q1b. *Does the difference between MPAs and reference sites in density (or proportionate cover) of a focal and/or protected species increase over time?*

Central Coast time series (14 years)

Across the Central coast, for the top 10 most abundant species, CPUE was higher in MPAs compared Reference sites for all species, except Black rockfish and Kelp rockfish (**Figure 13**). Copper rockfish, Gopher rockfish, Olive rockfish and Vermilion rockfish all exhibited a significant increase in CPUE through time inside the MPAs and no change outside (**Figure 13; Table S7**). Blue/Deacon rockfish had the highest CPUE of the top 10 species with 21.0 fish per angler hour in 2017 (95% CI 19.9, 22.2) and CPUE increased over time in both the MPA and Reference sites, with consistently higher abundance inside the MPAs since 2015 ($F_{1,24}$=5.88, p=0.02; **Figure 13; Table S7**). Canary rockfish, Lingcod, and Yellowtail rockfish tended to have higher CPUE inside the MPAs, however the difference in abundance between the MPA and Reference sites peaked in 2014 and 2015, following strong recruitment years, before declining (**Figure 13; Table S7**). Black rockfish had higher CPUE in the Reference sites compared to MPAs for all years sampled, with a peak in abundance in 2013, while Kelp rockfish exhibited no differences between the MPA and Reference sites in CPUE (**Figure 13; Table S7**). We also detected site-specific differences in CPUE for the top 10 species at each Central coast MPA (**Appendix E**).

Using the 28 species on the Central coast where we had sufficient data from 2007-2020 to calculate a response ratio (i.e., a species caught in the same MPA and Reference site in at least one year), we compared how many species exhibited higher abundance (CPUE) inside the MPA compared to its associated Reference site. We found that 20 of the 28 species (71.4%) had positive response ratios (with 95% CI not overlapping zero), indicating higher abundance inside the MPAs, while only 8 species – most of which were uncommon – exhibited negative response ratios, suggesting lower abundance inside the MPAs on the Central coast (**Figure 14**). The species that showed the strongest responses to MPA protection were Grass rockfish, Olive rockfish, Vermilion rockfish, Brown rockfish, Copper rockfish, and Canary rockfish. Other than some rare species, Black rockfish was the primary species where CPUE was higher in the Reference sites, and this was primarily due to consistently high catches in the Año Nuevo Reference site.

<u>Statewide time series (4 years)</u>

For 10 indicator species that occur over substantial portions of the statewide coastline, we examined geographic variation in abundance (CPUE) from north to south, along with differences between MPA and Reference site pairs (**Figure 15**). Blue/Deacon rockfish were more abundant inside MPAs at 6 out of 11 MPA/Reference pairs and catch rates were highest on the Central coast and a few sites on the north coast, decreasing dramatically in abundance on the South coast. Cabezon tended to be more abundant in the Reference sites (particularly on the North coast at South Cape Mendocino and Ten Mile) and they declined in abundance from north to south. Copper rockfish were significantly more abundant inside MPAs at 8 of 12 MPA/Reference pairs, with similar CPUE levels statewide, except for a peak in CPUE at Carrington Point on the South coast. Gopher rockfish were significantly more abundant inside MPAs at 9 of 12 MPA/Reference pairs, and the highest catch rates occurred at Central coast sites. Kelp rockfish and Ocean whitefish were rare or absent from Northern coast sites, but were much more abundant in Central and South coast locations, with Kelp rockfish exhibiting higher abundance inside MPAs at 5 of 8 MPA/Reference pairs and Ocean whitefish being more abundant inside MPAs at 5 of 7 MPA/Reference pairs. Lingcod were more abundant inside MPAs at 9 of 11 MPA/Reference pairs and showed a geographic pattern of declining CPUE from north to south. Olive rockfish had higher CPUE inside MPAs at 5 of 11 MPA/Reference pairs and tended to be most abundant on the Central coast. Vermilion rockfish were significantly more abundant inside MPAs at 10 of 12 MPA/Reference pairs, with highest catch rates in the Central and North coast regions. Finally, Yellowtail rockfish were more abundant inside MPAs at 4 of 9 MPA/Reference pairs and exhibited the highest CPUE at North coast sites. It is important to note that for both North and South coast populations, we are unsure if differences in CPUE are due solely to reserve effects as there are limited baseline data for these regions.

In examining the time series of CPUE for each region during the 4 years of statewide CCFRP sampling, we found that on the North coast, four of the 10 most common species were more abundant (i.e., higher catch rates and higher CPUE) inside MPAs than in associated Reference sites (Blue/Deacon rockfish, Copper rockfish, Gopher rockfish, and Vermilion rockfish), while six of the species showed no statistical difference in CPUE between the MPA and Reference sites (Black rockfish, Canary rockfish, China Rockfish, Lingcod, Olive rockfish, and Yellowtail rockfish; **Figure 16; Table S8**). For Blue/Deacon rockfish, Canary rockfish, Copper rockfish, Vermilion rockfish, and Olive rockfish, CPUE increased more rapidly inside the MPA compared to Reference sites between 2017-2020. For Lingcod, there was a consistently higher CPUE inside MPAs (not statistically different), but there was no clear change over time. For Black rockfish, China rockfish, and Yellowtail rockfish, CPUE increased over time in both the MPAs and Reference sites (**Figure 16; Table S8**).

On the South coast, we found that five of the 10 most common species (California sheephead, Copper rockfish, Gopher rockfish, Kelp bass, Ocean whitefish) were more abundant, with higher CPUE in the MPAs than the associated Reference sites, especially in the most recent years (**Figure 17; Table S9**). Vermilion rockfish tended to have higher CPUE inside the MPAs relative to the Reference sites in both 2019 and 2020, but the trend was not statistically distinct (**Table S9**). In contrast, one species had higher CPUE in the Reference sites (California scorpionfish) and three species showed no statistical difference in CPUE between the MPA and References sites (Blue/Deacon rockfish, Honeycomb rockfish, and Kelp rockfish; **Figure 17; Table S9**). California sheephead, Ocean whitefish and Vermilion rockfish appeared to increase in CPUE more rapidly inside the MPAs from 2017-2020, while the other species showing positive MPA responses exhibited similar differences in CPUE between the MPA and Reference sites over this four-year time period.

CPUE response ratio analyses (comparing CPUE inside vs. outside MPAs) from 2017-2020 in the three geographic regions demonstrated that most species were more abundant inside MPAs compared to associated Reference sites (**Figure 18**). For the North coast, 13 of the 18 species (72%) had positive response ratios, indicating they were more abundant inside MPAs, while only 5 species had negative response ratios. On the Central coast, 16 of the 21 species (72%) had positive response ratios and 5 of the 21 had negative response ratios. On the South coast, 21 of the 28 species (75%) had positive response ratios, while 7 of the 28 had negative response ratios. Overall, more than 71% of the species across the statewide MPA network at the sites sampled by CCFRP were more abundant inside MPAs than their associated Reference sites. Additionally, there were no differences in the distributions of positive or negative CPUE response ratios among any of the management regions (North-Central: D= 0.198, p=0.75; North-South: D=0.194, p =0.72; Central-South: D = 0.190, p=0.72), indicating that the proportion of species showing positive and negative MPA responses was similar on the North, Central, and South coasts.

***Q1c.** Does the difference between MPAs and reference sites in biomass of a focal and/or protected species increase over time?*

<u>Central Coast time series (14 years)</u>

We examined the species-specific trends in BPUE for the 10 most commonly encountered species along the Central coast (**Figure 19**). We found similar trends to CPUE (**Figure 13**) for BPUE for the top 10 most abundant species, and in general the differences between MPA and Reference sites were magnified when size and abundance were combined into a metric of biomass. Blue/Deacon rockfish had the highest BPUE for all species and Black rockfish was the only species where BPUE was highest in Reference sites compared to MPAs for all years sampled (**Figure 19**). Copper rockfish, Gopher rockfish, Olive rockfish, and Vermilion rockfish all exhibited a significant increase in BPUE through time inside the MPAs and no change outside (**Figure 19; Table S10**). Blue/Deacon rockfish BPUE increased over time in both the MPA and Reference sites, with consistently higher biomass inside the MPAs since 2015 (**Figure 19; Table S10**). Canary rockfish, Lingcod, and Yellowtail rockfish tended to have higher BPUE inside the MPAs, however the difference in abundance between the MPA and Reference sites peaked in 2014 and 2015, before declining (**Figure 19; Table S10**). Black rockfish had higher BPUE in the Reference sites compared to MPAs for all years sampled, although the difference was much less than that for CPUE because while more Black rockfish were caught in Reference sites, they were larger in size inside the MPAs, and thus biomass differences were muted (**Figure 19; Table S10**). We also detected site-specific differences in BPUE for the top ten species at each MPA (**Appendix F**).

Using the 29 species on the Central coast where we had sufficient data from 2007-2020, we compared how many species exhibited higher biomass (BPUE) inside the MPA compared to its associated Reference site. We found that 22 of the 28 species (79%) had positive response ratios, indicating higher biomass inside the MPAs, while only 6 species exhibited negative response ratios, suggesting lower biomass inside the MPAs on the Central coast (**Figure 20**). The species that showed the strongest biomass responses to MPA protection were Ocean whitefish, Grass rockfish, Copper rockfish, Olive rockfish, Brown rockfish, Vermilion rockfish, and Canary rockfish. Black rockfish, Black and Yellow rockfish, Treefish, Calico rockfish and Pacific Mackerel were the primary species whereby BPUE was higher in the Reference area, and many of these, except Black rockfish, were rarely caught by CCFRP.

Statewide time series (4 years)

For 10 indicator species that occur over substantial portions of the statewide coastline, we examined geographic variation in biomass (BPUE) from north to south, along with differences between MPA and Reference site pairs (**Figure 21**). Biomass of Blue/Deacon rockfish was higher inside MPAs at 7 out of 11 MPA/Reference pairs and catch rates were highest on the Central coast and a few sites on the North coast, decreasing dramatically in abundance on the South coast. Cabezon had higher biomass inside MPAs at only 4 of 10 MPA/Reference pairs, tending to have elevated biomass in the Reference sites (particularly on the North coast at South Cape Mendocino and Ten Mile) and they declined in abundance from north to south. Copper rockfish biomass was significantly higher inside MPAs at 10 of 12 MPA/Reference pairs, with similar BPUE levels statewide, except for Carrington Point on the South coast, where biomass was over 4 times higher than any other location. Gopher rockfish biomass was elevated inside MPAs at 9 of 12 MPA/Reference pairs, and the highest biomass occurred at Central coast sites. Kelp rockfish and Ocean whitefish were rare or absent from Northern coast sites, but were much more abundant in Central and South coast locations. Kelp rockfish exhibited higher biomass inside MPAs at 7 of 8 MPA/Reference pairs and Ocean whitefish had higher biomass inside MPAs at 5 of 7 MPA/Reference pairs. Lingcod biomass was higher inside MPAs at 9 of 11 MPA/Reference pairs and showed a geographic pattern of declining BPUE from north to south. Biomass of Olive rockfish was elevated inside MPAs at 5 of 11 MPA/Reference pairs and tended to be highest on the Central coast. Vermilion rockfish biomass was significantly higher inside MPAs at 11 of 12 MPA/Reference pairs, with highest biomass on the Central and North coasts. Lastly, Yellowtail rockfish biomass was higher inside MPAs at 5 of 9 MPA/Reference pairs, with the highest BPUE at North coast sites. It is important to note that for North and South coast locations, we are unsure if differences in BPUE are due solely to reserve effects as there are limited baseline data for these regions.

In examining the time series of biomass responses for the 4 years where data exists statewide (2017-2020), we observed that on the North coast four of the 10 most common species had statistically higher biomass (BPUE) inside MPAs than associated Reference sites (Blue/Deacon rockfish, Gopher rockfish, Lingcod, and Vermilion rockfish), four tended to have higher biomass inside MPAs than Reference sites, but the values were not statistically distinct (Black rockfish, Canary rockfish, Copper rockfish, and Olive rockfish), and two of the species showed no difference in BPUE between MPAs and Reference sites (China rockfish and Yellowtail rockfish; **Figure 22; Table S11**). For Blue/Deacon rockfish, Canary rockfish, Copper rockfish, Gopher rockfish, Vermilion rockfish, and Olive rockfish, BPUE increased more rapidly inside MPAs compared to Reference sites between 2017-2020, while for Lingcod there was a consistently higher BPUE inside MPAs, but no change over time. For China rockfish, BPUE increased in the MPAs while it was constant in the Reference sites, but BPUE was initially lower inside the MPAs. For Yellowtail rockfish, BPUE increased over time in both the MPAs and Reference sites (**Figure 22**).

On the South coast, we found that six of the 10 most common species (California sheephead, Copper rockfish, Gopher rockfish, Kelp bass, Ocean whitefish, and Vermilion rockfish) exhibited higher biomass in the MPAs than their associated Reference sites, with bigger differences in the most recent years (**Figure 23; Table S12**). In contrast, two species had higher BPUE in the Reference sites (Blue/Deacon rockfish and California scorpionfish) and one species (Honeycomb rockfish) showed no difference in BPUE between MPAs and Reference sites (except in 2020; **Figure 23; Table S12**). BPUE for California sheephead, Ocean whitefish and Vermilion rockfish appeared to increase more rapidly inside the MPAs from 2017-2020, while the other species showing positive MPA responses exhibited similar differences in BPUE between the MPA and Reference sites over this four-year time period.

BPUE response ratio analyses (comparing BPUE inside vs. outside MPAs) from 2017-2020 in the three geographic regions demonstrated that most species had higher biomass inside MPAs compared to associated Reference sites (**Figure 24**). For the North coast, 13 of the 18 species (72%) had positive response ratios, indicating they had higher biomass inside MPAs, while only 4 species had negative response ratios. On the Central coast, 17 of the 21 species (81%) had positive BPUE response ratios and 4 of the 21 had negative response ratios. On the South coast, 22 of the 28 species (79%) had positive BPUE response ratios, while 6 of the 28 had negative response ratios. Overall, more than 73% of the species across the statewide MPA network at the sites sampled by CCFRP had higher biomass inside MPAs than their associated Reference sites. Additionally, there were no differences in the distributions of positive or negative BPUE response ratios among any of the management regions (North-Central: D= 0.175, p=0.88; North-South: D=0.218, p =0.58; Central-South: D = 0.143, p=0.94), indicating that similar proportions of species were exhibiting positive and negative responses to MPAs in each region.

Q1d. *Does the difference between MPAs and reference sites in larval production of a focal and/or protected species increase over time?*

<u>Central Coast time series (14 years)</u>

We examined the species-specific trends in expected reproductive output (FPUE) for seven commonly encountered species that had published length-fecundity relationships along the Central coast inside MPAs compared to associated Reference sites over time. We found similar trends to BPUE, and in general the differences between MPA and Reference sites in egg production were magnified compared to metrics of abundance (CPUE) or biomass (BPUE) (**Figure 25**). Five of the 7 species had significantly higher FPUE inside MPAs compared Reference sites (**Table S13**). Blue/Deacon rockfish had the highest FPUE for all species and showed significant increases in FPUE with higher egg production inside the MPAs. Copper rockfish, Gopher rockfish, and Vermilion rockfish all exhibited a significant increase in FPUE through time inside the MPAs and no change outside (**Figure 25; Table S13**), with the differences in egg production increasing over time between the MPA and Reference sites. Lingcod had higher FPUE inside the MPAs, however the difference in expected reproductive output between the MPA and Reference sites peaked in 2014 and 2015, before declining (**Figure 25**) similar to CPUE and BPUE trends. Kelp rockfish and Yellowtail rockfish did not exhibit differences in expected reproductive output between the MPA and Reference sites, although Yellowtail rockfish had higher FPUE in recent years and the difference was marginally non-significant (**Table S13**).

Statewide time series (4 years)

In examining the time series of expected reproductive output (FPUE) for the four years where data exists statewide (2017-2020), we observed that on the North coast two of the seven commonly encountered species that had published length-fecundity relationships (Copper and Vermilion rockfish) had significantly higher FPUE inside the MPAs, while two additional species (Blue/Deacon and Canary rockfish) had marginally different FPUE. However, for all species, the trend was for FPUE to be higher inside the MPAs compared to Reference sites (**Figure 26; Table S14**). For Blue/Deacon rockfish, Canary rockfish, Copper rockfish, Vermilion rockfish, and Yellowtail rockfish, FPUE increased more rapidly inside the MPAs compared to their Reference sites between 2017-2020, while for Lingcod FPUE was higher inside MPAs, but did not change over time (**Figure 26**).

On the South coast, we found that three of the seven species (California sheephead, Gopher rockfish and Kelp bass) exhibited higher FPUE inside the MPAs compared to their associated Reference site (**Figure 27; Table S15**). Copper rockfish and Vermilion rockfish also tended to have higher FPUE inside the MPAs. In contrast, there was no difference in FPUE for Blue/Deacon rockfish or Kelp rockfish between the MPAs and Reference sites.

Q1f. *Does the difference between MPAs and reference sites in the size and age structure of populations of a focal and/or protected species increase over time?*

Central Coast time series (14 years)

We examined the shifts in the size frequency distributions of the top 10 most abundant species in the Central coast region from 2007-2020, using violin plots which display the frequency histograms for the MPA and Reference sites side-by side in 3-4 year time bins. For eight of the 10 species (Black rockfish, Blue/Deacon rockfish, Canary rockfish, Copper rockfish, Lingcod, Vermilion rockfish, Olive rockfish, and Yellowtail rockfish), fishes were larger in body size and the distributions were shifted to larger individuals inside the MPAs (**Figure 28; Table S16**). For two of the species (Gopher rockfish and Kelp rockfish), there were no clear differences in size frequency distributions between MPAs and Reference sites (**Figure 28; Table S16**), although for Gopher rockfish mean lengths were significantly greater in recent years inside the MPA (**Figure 7**). Over time, the differences in size frequency distributions between the MPAs and Reference sites increased for Copper rockfish, Lingcod, and Vermilion rockfish (**Figure 28**), with fish reaching larger sizes inside MPAs.

Using the 28 species on the Central coast where we had sufficient data from 2007-2020, we compared how many species exhibited larger lengths (cm) inside the MPA compared to its associated Reference site. We found that 22 of the 28 species (79%) had positive response ratios, indicating larger sizes inside the MPAs, while only 6 species exhibited negative response ratios, suggesting smaller sizes inside the MPAs on the Central coast (**Figure 29**). The species that showed the strongest size (length) responses to MPA protection were Ocean whitefish, California lizardfish, Striped surfperch, Copper Rockfish, Olive rockfish, Vermilion rockfish and Yellowtail rockfish. Pacific sanddab, Calico rockfish, Rock sole, and Pacific mackerel were the primary species whereby sizes were larger in the Reference area, however many of these species are rarely caught by CCFRP in the Central coast region.

Statewide time series (4 years)

Given that we only have 4 years of data statewide, we were not able to examine shifts in size frequency distributions over time at the North and South coast sites. Instead, we binned the data across the years 2017-2020 and examined differences in size-frequency between the MPA and Reference sites at the regional level (**Figures 30 & 31**). For the North coast region, we found that all 10 of the species (Black rockfish, Blue/Deacon rockfish, Canary rockfish, Copper rockfish, China rockfish, Lingcod, Gopher rockfish, Olive rockfish, Vermilion rockfish, and

Yellowtail rockfish) had size frequencies dominated by larger individuals inside MPAs compared to Reference sites (**Figure 30; Table S17**). For the South coast region, we observed that six of the top 10 species (Blue/Deacon rockfish, California sheephead, Copper rockfish, Kelp bass, Ocean whitefish, and Vermilion rockfish) exhibited size-frequencies shifted to larger individuals inside the MPAs (**Figure 31; Table S18**).

Length response ratio analyses (comparing mean length inside vs. outside MPAs) from 2017-2020 in the three geographic regions demonstrated that most species were larger in body size inside MPAs compared to their associated Reference sites (**Figure 32**). For the North coast, 18 of the 18 species (100%) had positive response ratios, indicating they were larger in size inside MPAs. On the Central coast, 17 of the 21 species (81%) had positive length response ratios and 4 of the 21 had negative length response ratios. On the South coast, 21 of the 28 species (75%) had positive length response ratios, while 7 of the 28 had negative response ratios. Overall, more than 79% of the species across the statewide MPA network at the sites sampled by CCFRP were larger in body size inside MPAs than their associated Reference sites. Additionally, there were no differences in the distributions of positive or negative length response ratios among any of the management regions (North-Central: $D= 0.318$, $p=0.21$; North-South: $D=0.254$, $p =0.39$; Central-South: $D = 0.214$, $p=0.58$), indicating that similar proportions of species exhibited positive or negative body size responses to MPAs in the North, Central, and South regions.

Q1g. *Does the difference between MPAs and reference sites in overall density and biomass of focal and/or protected species increase over time?*

<u>Central Coast time series (14 years)</u>

For the Central coast analyses, we focused on four MPAs sampled from 2007-2020: Año Nuevo SMR, Point Lobos SMR, Piedras Blancas (not sampled in 2007 and 2015), and Point Buchon SMR. To assess total CPUE and total BPUE in MPAs and associated reference sites with time since MPA implementation, we ran a two-way interactive Analysis of Covariance (ANCOVA). Overall, we observed that CPUE increased more rapidly inside MPAs than Reference sites along the Central coast (**Figure 33**). Across all Central coast sampling sites, the highest total fish CPUE was within Point Lobos SMR in 2018 (35.5 fish angler hr^{-1}, [95% CI 33.0, 37.9]) and the lowest CPUE was within the Point Buchon Reference area in 2010 (2.9 fish angler hr^{-1}, [95% CI 2.7, 3.1]). Across all 4 MPAs, CPUE increased through time in both MPAs and the associated reference sites (**Figure 33**). There was an interaction between site and year on total fish CPUE for Point Lobos and Point Buchon, indicating that the increase in CPUE across years was different between the MPA and associated Reference sites (i.e., differences among regression slopes). In both cases, CPUE increased significantly faster through time inside the MPA than the Reference site.

Total fish biomass increased in both MPA and Reference sites from the time of MPA implementation at all sampling sites (**Figure 34**). However, total fish biomass, as well as the difference in fish biomass between the MPA and Reference sites varied by location and across years. Año Nuevo sampling sites contained the lowest total biomass compared to all other areas with a maximum annual mean biomass per unit effort (BPUE) of 9.8 kg angler hr^{-1} (95% CI 8.9, 10.6). In contrast, maximum annual mean BPUE at Point Lobos was 22.3 kg angler hr^{-1} (95% CI 20.4, 24.1). At Point Lobos, Piedras Blancas, and Point Buchon there was a significant interaction between year and protection status (MPA vs REF) on changes in total fish BPUE (ANCOVA: Year x Protection Status, Point Lobos: $F_{1,24} = 21.8$ $p < 0.001$; Piedras Blancas: $F_{1,24} = 7.92$, $p = 0.011$; Point Buchon: $F_{1,24} = 33.6$, $p < 0.001$, respectively), with biomass increasing more rapidly inside the MPA at all three locations (**Figure 34**). At Año Nuevo, there was a significant increase in total fish BPUE over time (ANCOVA: Year, $F_{1,24} = 25.8$, $p < 0.001$), but no difference in the rate of biomass accumulation between MPA and Reference areas (ANCOVA: Year x Protection Status, $F_{1,24} = 1.42$, $p = 0.24$).

To further assess the relative effect of protection (or fishing closure) on fish biomass from the time of MPA implementation in 2007 until 2020, we ran generalized linear models on the calculated biomass response ratios through time at each sampling location (MPA and Reference pair). The average effect of fishing closure on total fish BPUE (i.e., biomass response ratio) was positive (higher biomass inside MPAs relative to Reference sites) for all years across Central coast MPAs surveyed, and the magnitude of the effect of the fishing closure on total fish BPUE increased with time since MPA implementation (Linear Regression: $F_{1,12} = 32.98$, $p < 0.001$, $r^2 = 0.71$; **Figure 35**). However, BPUE response ratios varied across MPA locations. BPUE response ratios were positive for all years post-MPA implementation at Point Lobos, Piedras Blancas, and Point Buchon, indicating higher fish biomass in MPAs compared to associated Reference sites (**Figure 35**). BPUE response ratios were positive at Año Nuevo for all years except 2007 (year of implementation, lnRR = -0.16) and 2013 (lnRR = -0.32), indicating that total fish biomass was higher in the MPAs compared to the References in all but those two years. BPUE response ratios increased significantly from the date of MPA implementation at Point Lobos (Linear Regression: $F_{1,12} = 13.22$, $p = 0.003$, $r^2 = 0.52$) and Point Buchon (Linear Regression: $F_{1,12} = 96.41$, $p < 0.001$, $r^2 = 0.89$). At Año Nuevo and Piedras Blancas, BPUE response ratios slightly increased from the date of MPA implementation to 2020; however, these relationships were not statistically distinct (Linear Regression: Año Nuevo: $F_{1,12} = 0.71$, $p = 0.41$, $r^2 = 0.06$; Piedras Blancas: $F_{1,12} = 1.77$, $p = 0.21$, $r^2 = 0.15$; **Figure 35**) because biomass increased at comparable rates in the Reference sites for both MPAs.

Statewide time series (4 years)

For total abundance (catch per unit effort; CPUE) and total biomass (biomass per unit effort; BPUE), we first examined geographic trends statewide from north to south along with differences between MPA and Reference site pairs (**Figure 36**). Total abundance was significantly higher inside MPAs at 10 of the 12 MPA/Reference pairs along the coast and CPUE tended to be elevated along the Central coast, with reduced catch rates at the two most northern and two most southern site pairs (**Figure 36**). In comparison, we observed bigger differences in total biomass, with biomass being significantly elevated inside MPAs in all 12 MPA/Reference pairs. Total biomass was relatively similar in the North and Central regions, but was depressed at the two southernmost site pairs (**Figure 36**). Interestingly, while CPUE was relatively low at South Cape Mendocino and Ten Mile, BPUE values were quite high at these two northernmost locations, likely due to catches of much larger bodied individuals.

For the statewide analyses of changes over time, we examined 12 sites from South Cape Mendocino to South La Jolla. We assessed total CPUE and BPUE in fished and unfished areas from 2017-2020, and we ran a two-way interactive Analysis of Covariance (ANCOVA). We found clear differences in total CPUE between MPAs and Reference sites at Stewart's Point ($F_{1,4} = 322.87$, $p<0.001$), Point Lobos ($F_{1,4} = 277.53$, $p<0.001$), Anacapa Island ($F_{1,4} = 136.33$, $p<0.001$), Swamis ($F_{1,4} = 33.86$, $p=0.004$), and South La Jolla ($F_{1,4} = 15.2$, $p=0.018$) whereby CPUE was always greater in the MPA than in the associated References sites (**Figure 37**). We also found an interaction between Year and Site at Anacapa Island ($F_{1,4} = 9.19$, $p=0.039$), indicating that the difference in CPUE between MPA and Reference sites varies across years sampled. We calculated response ratios through time for total abundance (CPUE) at all sites statewide, finding that 9 of the 12 sites consistently had higher CPUE inside the MPAs than the associated Reference sites (response ratios were greater than zero) between 2017-2020 (**Figure 38**). Total CPUE was higher in the Reference site at Año Nuevo each year, while at Cape Mendocino and Ten Mile in the North coast, CPUE was higher in the Reference site in 2017 and 2018, but then switched to being higher in the MPA in 2019 and 2020. Total CPUE was substantially higher inside the MPA at Stewarts Point on the North coast, at Point Lobos and Point Buchon on the Central coast, and at Anacapa Island and Swami's on the South coast.

We found statistical differences in BPUE between MPAs and Reference sites for all sampled areas with exception of South Cape Mendocino ($F_{1,4}$ = 0.62, p=0.474), Bodega Head ($F_{1,4}$ =3.97, p=0.117), and Año Nuevo ($F_{1,4}$ = 0.7.34, p=0.054; **Figure 39**), such that fish biomass was significantly higher inside the MPA compared to the Reference site at 9 of the 12 sites sampled statewide. To further assess the relative effect of protection (or fishing closure) on fish biomass, we ran generalized linear models on the calculated biomass response ratios through time at each MPA area, independently (**Figure 40**). The biomass response ratios are positive at all sites in 2020 and were positive at all sites except South Cape Mendocino in all other years sampled (2017-2019), indicating that total fish biomass is consistently higher inside MPAs compared to fished Reference sites statewide. The shift to consistently positive response ratios for BPUE compared to CPUE at South Cape Mendocino, Ten Mile, and Año Nuevo can be explained by the larger body sizes of fish encountered inside the MPAs, which increased the biomass metric despite relatively lower abundances (CPUE) inside the MPAs at those sites.

Question 7: How do species differ in their rate of response to MPA implementation?

Q7a. *How does the mean rate of response in abundance and size/age structure differ among species?*

Central Coast time series (14 years)

This question is best answered using the Central coast time series as we were better able to calculate the rate of change in abundance and biomass using the 14-year time series at the four MPA and four Reference sites monitored since 2007, when MPAs in this region were first implemented. The rates of response for individual species in the MPAs and Reference sites showed significant variability among species (**Figure 41**). Inside the MPAs, a few species exhibited dramatic increases in abundance over time using the CPUE metric (e.g., Blue/Deacon rockfish, Gopher rockfish, Olive rockfish, Vermilion rockfish, and Copper rockfish), while most other species increased much more gradually. Of the 21 species in this analysis 15 of them (71%) displayed positive slopes (increases in abundance), while six of them had negative slopes, indicating decreases in abundance on average (**Figure 42**). However, this obscures the trends in species like Canary rockfish, Lingcod, and Yellowtail rockfish that showed big increases in CPUE inside the MPAs compared the Reference sites until 2015, at which point their populations declined, likely due to offshore movements of larger individuals following a strong recruitment event. Thus, the flat or negative slopes of these species over the full time series are not fully representative of their true dynamics inside the MPAs. In the Reference sites, we only observed rapid increases in abundance in one species (Blue/Deacon rockfish) and moderate increases in one more (Olive rockfish) (**Figure 41**). Overall, 17 of the 21 species (81%) had positive slopes indicating that their CPUE increased over time in the Reference areas, while four species had negative slopes indicating declines in abundance (**Figure 42**). Similar to the MPA sites, all the declines in abundance for species in the Reference sites were mild and not significantly different from zero, thus within our sampling error ($t_{1,20}$=1.15, p=0.26). In comparing species between the MPA and References sites, in general the increases in abundance were more dramatic in the MPA and CPUE values were higher for more species inside the MPA (**Figure 42**).

We conducted a similar analysis using the BPUE metric to assess differences among species in the rate of change in biomass between the MPA and Reference sites along the Central coast. Here, we observed similar trends to CPUE, such that inside the MPA, more species exhibited positive changes in biomass over the 14-year time series than in the

Reference sites (**Figure 43**). Inside the MPAs, a few species showed dramatic increases in abundance over time using the BPUE metric (e.g., Blue/Deacon rockfish, Lingcod, Gopher rockfish, Olive rockfish, Vermilion rockfish, and Copper rockfish), while most other species increased much more gradually. Of the 21 species in this analysis, 18 of them (86%) displayed positive slopes (increases in abundance), while three of them had negative slopes, indicating decreases in abundance on average (**Figure 44**). As we found for the CPUE metric, many of these small measured declines in BPUE were not significantly different from zero, and species such as Canary rockfish peaked in 2015 inside the MPAs and then declined ($t_{1,20}$=-2.33., p=0.15). In the Reference sites, we only observed rapid increases in abundance in one species (Blue/Deacon rockfish) (**Figure 44**). Overall, 18 of the 21 species (86%) had positive BPUE slopes indicating that their biomass increased or stayed constant over time in the Reference sites, while three species had negative slopes, indicating potential declines in abundance that were not significantly different from zero ($t_{1,20}$=1.29, p=0.21; **Figure 44**).

Q7c. *Are differences in rate of species responses to MPA establishment related to life history (longevity, home range, dispersal distances) or demographic variables?*

<u>Central Coast time series (14 years)</u>

We examined associations between the rate of change in CPUE (i.e., slopes of CPUE vs. time) and life history traits, such as the maximum length and the length at maturity for each species inside the MPAs and their associated Reference sites (**Figure 45**). We did not find any significant associations between life history traits and the rate of response to MPA establishment ($F_{1,46}$=0.03, r^2<0.001, p=0.86 and $F_{1,34}$=1.32, r^2=0.04, p=0.26, respectively), but we plan to continue these analyses as we obtain other life history traits for our focal species.

Question 20: Are the size/age structure of recreationally valued species increasing in MPAs over time?

Virtually all the species encountered by CCFRP are recreationally important as they are caught using hook and line fishing gear by the anglers participating in our program and by anglers more generally along the coast of California. Thus, the answers to this question and all related sub-questions about recreationally important species can be addressed by any of the analyses we present in the report.

Question 23: Have endangered species and/or culturally significant species benefited from the presence of California's MPAs?

Q23a. *Has the difference between MPAs and reference areas in the abundance of endangered species or species of concern for management increased over time?*

For this analysis, we focused on trends in biomass of species currently of concern for fisheries management, as CCFRP does not encounter endangered species. The three species of management-concern that CCFRP catches include Copper rockfish (in the North, Central and South regions), Quillback rockfish (in the North region), and Yelloweye rockfish (in the North region). For Copper rockfish, we found that BPUE was significantly elevated inside the MPAs compared to the Reference sites in each of the three regions, with biomass being 8.5x greater inside the MPA along the Central coast in the year 2020 (**Figure 46**). On the Central coast, where we have the longest time series (14 years), Copper rockfish biomass increased dramatically since 2015 (a nearly 490% increase) inside the MPAs, while remaining fairly constant in the Reference sites. Interestingly, in the Reference sites there is no indication that this population has declined in the last 14 years as catch rates and biomass have remained stable. On the North coast and South coast, Copper rockfish biomass is consistently higher inside the MPAs, with biomass being 2x higher inside MPAs in the North coast and 3x higher inside MPAs on the South coast.

Quillback rockfish on the North coast had significantly higher biomass inside the MPAs in two years (2018 [1.6x] and 2020 [1.7x]), while there was no difference in BPUE between the MPAs and Reference sites in 2017 or 2019 (**Figure 46**). Over the four-year period where we have records, there is no evidence for a decline in biomass of this species at our North coast sites and instead the population appears to be fairly stable, but at relatively low biomass. For Yelloweye rockfish on the North coast, biomass was significantly higher inside the MPAs compared to the Reference sites (~2-5x higher; **Figure 46**), with mean biomass levels similar to that for Quillback rockfish.

Q23b. *Has the difference between MPAs and reference areas in the abundance of culturally significant species increased over time? (e.g., species used by the Tribes)*

For this question, we focused on the response of Rockfish (as a group), Cabezon, Lingcod, California sheephead, and Kelp bass as the species of fish with the most cultural significance. Given the different lengths of the time series in each region, we assessed trends in Rockfish, Cabezon, and Lingcod separately for each of the three regions (**Figure 47**). We found that Rockfish biomass (BPUE) was significantly higher inside the MPAs compared to their associated Reference sites in each region, and that Rockfish biomass increased from 2017-2020 on the North coast and from 2007-2020 on the Central coast. Cabezon occurred fairly rarely in our sampling and thus, there were no clear trends in biomass inside and outside the MPAs across our regions (**Figure 47**). Cabezon biomass was higher outside the MPAs on the North coast but exhibited similar biomass inside and outside MPAs on the Central and South coasts. Lingcod biomass was significantly higher inside MPAs compared to the Reference sites in each of the three regions (**Figure 47**). On the Central coast, Lingcod biomass exhibited a rapid rise inside the MPAs starting in 2011 and peaking in 2015, before declining to the levels seen in the Reference sites by 2020. Both California sheephead and Kelp bass display similar trends in biomass from 2017-2020 on the South coast, being consistently elevated inside the MPAs compared to the Reference sites (**Figure 47**).

Question 32: Do State Marine Reserve (SMR)/State Marine Conservation Area (SMCA) clusters provide greater protection than stand-alone SMRs?

Q32c. *Is there an increase over time in the difference between MPAs and reference sites in abundance (density, cover, biomass) of focal species and if so, are there differences between SMR and SMCAs of similar size?*

<u>Statewide time series (4 years)</u>

We modified this question to examine how variables such as MPA size (measured as the total area for both paired and unpaired SMCAs/SMRs at each site) influenced the strength of the MPA response for the total fish assemblage, using generalized linear models with the CPUE response ratio or the BPUE response ratio as our metric of differences between paired MPA-Reference sites. We found a clear positive relationship between the CPUE response ratio and the total protected cluster area of the MPAs across the state, such that larger MPAs exhibited bigger differences in catch rates between the MPA and Reference sites than smaller MPAs (r^2= 0.37, p<0.001; **Figure 48**). Similarly, we found a strong positive association between MPA area and the strength of the MPA response using the BPUE response ratio metric (r^2=

0.37, p<0.001; **Figure 49**), indicating that strength of the MPA response was higher in larger reserves compared to smaller reserves. Stating this another way, fish biomass was proportionally higher inside larger MPAs. Despite finding a strong positive effect of reserve area on MPA responses, we also observed positive response ratios in all sized MPAs.

New Question: Are there regional differences in the responses of species to MPAs along the coast?

Statewide time series (4 years)

We added a new question to address the potential for latitudinal differences in the strength of MPAs responses statewide. We found a negative relationship between latitude and the strength of the MPA response, using the BPUE response ratio metric ($F_{1,46}$=11.42, r^2=0.20, p=0.001; **Figure 50**). These results indicate that reserve effects are greatest in the South coast region and weakest in the North coast region, despite being implemented at similar times, and that the Central coast was intermediate in the strength of the MPA response, despite being implemented earlier. These geographic effects on MPA responses are likely due to environmental effects of temperature (which correlates with latitude) on fish growth, life history differences among the species that are common in each region (i.e., consistency of recruitment, growth rates in warmer waters, etc.), and differences in the amount of external fishing pressure outside the MPAs in each region (highest in Southern California). We did not find any relationship between latitude and MPA area, indicating that MPA size did not contribute to the latitudinal differences in the strength of the MPA response.

MPA Performance - Communities & Ecosystems

Question 2: Does community structure and/or functional diversity differ in MPAs relative to reference sites?

Q2a. Does the difference between MPAs and reference sites in community structure and/or species diversity within any given functional group increase over time?

Central Coast time series (14 years)

We examined differences in community composition between the four Central coast MPAs and their associated Reference sites from 2007-2020 using a permutational analysis of variance (PERMANOVA) and visualized the differences with a non-metric multidimensional scaling (nMDS) ordination. We found some evidence for spatial variation in fish communities, with the northern site of Año Nuevo being more different from the other sites ($F_{3,100}$ = 16.57, r^2= 0.29, p<0.001; **Figure 51**). There were no clear differences between the MPAs and their paired Reference sites. The geographic differences in fish communities on the Central coast were explained by greater abundance of Black rockfish, Cabezon, China rockfish, and Kelp greenling at Año Nuevo (**Figure 51A**), and also by physical factors and reserve characteristics, with the Año Nuevo reserve being cooler, more productive, and smaller in area (**Figure 51B**).

We did not find any significant differences between the MPA and Reference sites in the species richness over time on the Central coast ($F_{13,80}$ = 0.24, p=0.99; **Figure 52**). However, we did observe that diversity and evenness diverged over time, increasing inside the MPAs relative to the Reference sites (Tukey HSD: diff=0.15, p=0.001 & diff=0.05, p=0.06, respectively; **Figure 52**). Diversity and evenness decreased during the 2014-2015 marine heatwave and then increased again following the heatwave, but that increase in diversity was faster inside the MPAs (**Figure 51**; *see Question 5 below for more details*). On average, MPAs tended to have greater diversity and evenness than Reference sites (**Figure 51**; *see Question 5 below for more details*).

Statewide time series (4 years)

We broadly examined differences in community composition across management regions and between MPAs and Reference sites for all sampling events statewide from 2017-2020. We found that community composition varied greatly across regions ($F_{2,166}$=37.47, p<0.001), with large differences in fish assemblages between the North, Central, and South regions (**Figure 53**). There was more community overlap between the Northern and Central regions (communities dominated by various species of Rockfish and Lingcod) than the Central and Southern regions (dominated by species with more subtropical affinities like California sheephead, Ocean whitefish, Kelp bass, and California scorpionfish, among others; **Figure 53A**). Using a similarity percentages breakdown (SIMPER) procedure, we identified the species driving the major differences in community composition across regions. We found Ocean whitefish was the most influential species between the South and other management regions. Specifically, Ocean whitefish contributed to 20.2% of the difference in community composition between the Central and South regions and 16.4% of the difference between the North and South regions. The most influential species driving differences between the North and Central regions were Blue/Deacon rockfish (17.2%) and Lingcod (14.5%). Biogeographic changes in the distribution of the most commonly encountered species statewide highlight that Cabezon, Lingcod, and Yellowtail rockfish exhibit higher abundance and biomass in the North region, Blue/Deacon rockfish, Gopher rockfish, and Olive rockfish dominate the Central region, and Ocean whitefish and Kelp rockfish are more common in the South coast region (**Figures 15 & 21**). Those geographic differences in community structure occur in response to latitude, MPA area, water temperature, and wave exposure (orbital velocity and wave height), such that fish communities in the South region occur in warmer water with less wave exposure, while the North and Central communities are those that occur in cooler waters with more wave energy (**Figure 53B**). When we broke the regions down into their individual sites, the geographic trends were further apparent with a shift in community structure from the northern to the southern sites along nMDS axis 1 (**Figure 54B**). Here it is clear that communities are changing gradually along the latitudinal gradient in temperature and wave exposure. The latitudinal shifts in fish community structure are also evident when the sites (MPA and Reference combined) are displayed on the map of the California coast, with pie charts displaying species composition (**Figure 54A**). Dominance by Blue/Deacon, Black, and Canary Rockfish on the North coast, shifts to dominance by Blue/Deacon, Gopher, and Olive rockfish on the Central coast, with a more diverse and variable assemblage on the South coast, composed of Ocean whitefish, Kelp bass, various Rockfish species, and California sheephead.

We also detected significant shifts in fish assemblages between sites inside and outside of MPAs ($F_{1,166}$=14.81, p<0.001) within a region (**Figures 55 & 56**). In the North region, MPA sites had relatively higher abundance of Blue/Deacon rockfish and Lingcod, while Reference sites had proportionally more Black rockfish and Yellowtail rockfish (**Figure 55**). In the Central region, MPA sites were characterized by having proportionally more Vermilion rockfish, Olive rockfish, and Copper rockfish, while the Reference sites had more of the community represented by Black rockfish (**Figure 55**). In the South region, the MPA sites were dominated more by Ocean whitefish, Kelp bass, California sheephead, Copper rockfish, and Gopher rockfish, but fewer Blue/Deacon rockfish and California scorpionfish (**Figure 55**).

We did not detect any consistent differences in species richness, diversity, or evenness over time (2017-2020) between the MPA and Reference sites in the North, Central, or South coast regions ($F_{1,84}$=1.35, p=0.25, $F_{1,84}$=1.09, p=0.30 and $F_{1,84}$=0.43, p=0.52, respectively). As discussed earlier, there was higher diversity inside MPAs in the Central coast (**Figure 56**). We did detect some regional trends with higher diversity in the North coast compared to the Central and South coast (Tukey HSD: North-Central: diff=1.78, p=0.03; North-South: differ=2.15, p=0.007; **Figure 56**).

Q2b. *Does the difference between MPAs and reference sites in community structure and/or the diversity of functional groups increase over time?*

<u>Statewide time series (4 years)</u>

We observed regional differences in trophic group composition ($F_{10,18}$=7,12, p<0.001); however, there were no shifts between MPA and Reference sites in trophic group composition ($F_{1,84}$=1.35, p=0.25; **Figure 57A**). The North and Central regions were dominated by planktivore and piscivore/invertivore functional groups, while the South coast was dominated by micro-invertivores. We observed some shifts between the MPA and Reference sites in the North coast, such that planktivores comprised a larger proportion of the community inside the MPAs, while piscivores and macro-invertivores comprised a larger proportion of the community in the Reference sites. Communities were highly similar in trophic group composition between the MPA and Reference sites on the Central Coast. In the South region, relatively more micro-invertivores and fewer planktivores comprised the community inside the MPA than the Reference sites.

Based on the home range size of the species sampled by CCFRP, we found that the proportion of the community composed of different mobility guilds was highly similar across regions ($F_{3,16}$=2.44, p=0.09) and between MPA and Reference sites within a region ($F_{3,16}$=0.41, p=0.75; **Figure 57B**). Over half of the species encountered in each region have home ranges greater than 1 km. In the South region, we encountered a higher proportion of species with small home range sizes (<100 m).

Question 5: Does the nature of timing of recovery of natural communities from disturbance events differ in different types of MPAs relative to outside areas?

Q5a. *Does the nature of recovery of natural communities from disturbance events differ in MPAs relative to outside reference sites?*

<u>Central Coast time series (14 years)</u>

We examined changes in species richness, Pielou's evenness, Shannon-Weiner diversity, and community composition before, during, and after the 2014-2015 marine heatwave in MPAs and associated Reference sites along the Central coast region (**Figure 58**). We found that there were no differences in species richness before, during or after the 2014-2015 marine heatwave (ANOVA: $F_{2,102}$=1.58, p=0.211) or between MPAs and associated Reference sites (ANOVA $F_{1,102}$=1.92, p=0.169). However, both Pielou's evenness and Shannon-Weiner diversity decreased after the marine heatwave (ANOVA: $F_{2,102}$=15.52, p<0.001 and $F_{2,102}$=18.31, p<0.001, respectively), and MPAs on average had greater evenness and diversity than References sites (ANOVA: $F_{1,102}$=10.59, p=0.002 and $F_{1,102}$=13.37, p<0.001, respectively).

There were also shifts in overall community composition relative to the marine heatwave (PERMANOVA: $F_{2,102}$=19.96, R^2=0.26, p<0.001) and between MPAs and associated Reference sites (PERMANOVA: $F_{1,102}$=10.25, R^2=0.07, p<0.001) (**Figure 59**). Specifically, we found that certain species changed in relative abundance after the marine heatwave in both MPAs and Reference sites. These species were Blue/Deacon rockfish and Olive rockfish, which comprised a much larger fraction of the community following the heatwave, while Black rockfish and Gopher rockfish comprised a smaller proportion of the community ($SIMPER_{cum.contrib.}$ = 75.9%). The large increase in Blue/Deacon rockfish following the heatwave likely explains the decline in diversity and evenness that we observed (*see* **Figure 58**). When Blue/Deacon rockfish were excluded from the analysis, there was still a significant decline in diversity and evenness after the heatwave, however, the magnitude of decline was less. These results indicate that while Blue/Deacon rockfish are an important player, they are not the sole contributor to the shifts in diversity following the marine heatwave. Overall, MPAs had more similar and consistent communities, while Reference sites were a bit more variable before and after the heatwave (when comparing the size of the 95% confidence ellipses in the nMDS ordination; **Figure 59**).

Q5b. *Does the timing of recovery of natural communities from disturbance events differ in MPAs relative to outside reference sites?*

Species diversity and evenness were higher inside MPAs than Reference sites along the Central coast prior to the marine heatwave (**Figure 52**). Then, during the marine heatwave, diversity and evenness collapsed to low levels, becoming similar inside and outside the MPAs. However, there is evidence that following the marine heatwave, diversity and evenness recovered more rapidly inside the MPAs than their associated Reference sites where fishing is allowed (**Figure 52**).

We also calculated the rate of change in abundance (CPUE) of all species in the MPAs and References sites before the heatwave and after the heatwave (**Figure 60**). We observed that three species (Gopher rockfish, Copper rockfish, Olive rockfish, and Vermilion rockfish) exhibited much faster increases in abundance inside MPAs following the marine heatwave compared to the period prior to the heatwave (**Figure 60, Table S19**), whereas two species exhibited moderate changes in abundance (Brown Rockfish and Rosy rockfish). Blue/Deacon rockfish exhibited declines in the MPA after the heatwave but increased in the Reference sites. Additionally, Blue/Deacon rockfish had the highest overall CPUEs compared to all other species, and the apparent decline stems from a peak in abundance in 2017 followed by relative decreases in abundance in more recent years inside the MPAs. Overall, Blue/Deacon rockfish had significantly higher CPUE and BPUE in the period after the heatwave compared to the period before the heatwave (**Figures 13 & 19**).

Network Performance – Populations

Question 10: What is the rate and distribution of adult spillover of targeted fishery species from MPAs into adjacent areas?

Q10c. *How does adult spillover vary with species density inside MPAs?*

The CCFRP program is unique among the various monitoring programs in that empirical data are available to directly assess questions about fish movements and population connectivity. Over the last 14 years, we have tagged nearly 60,000 fishes and have recaptured 408 fishes with sufficient data to understand broad spatial movements (an approximate recapture rate of 0.7%). Preliminary analyses indicate high site fidelity in some species (e.g., multiple Copper and Gopher rockfish recaptured tens of meters from the tagging site) and much broader scales of movements in others (e.g., Black rockfish tagged in Central California and recaptured in Oregon, **Figure 61; Table 3**). Irrespective of species, the highest frequency of recaptures (61%) occurred with a net movement of 0.25 km or less (**Figure 62**), indicating that many fishes have relatively small home ranges. In contrast, only 12% of the recaptures occurred at scales greater than 10 km from the initial tagging site (**Figure 62**). In examining the average net movements for each species (given at least five recaptures), we found that 1 species (Olive rockfish) moved less than 1 km, 54% of the species moved 1-5 km, 15% moved

5-10 km, 15% moved greater than 10 km and one species (Black rockfish) moved more than 100 km on average from the site of tagging (**Figure 63**).

For seven of the nine species where we had a sufficient number of recaptures, we detected positive relationships between the time at liberty (i.e., time since being tagged and recaptured) and the net distance moved (**Figure 64**). Many of these relationships were weak, but the general trend was for recaptures to be at increasing distances with a greater elapsed time between the initial tagging event and subsequent recapture. Black rockfish exhibited the broadest net movements (mean of 190 km), with a maximum movement of 917 km from the site of release (**Table 3**), and the strongest association between time at liberty and distance moved. Ocean whitefish had the second highest net movement at 14 km from the site of release. Interestingly, Copper rockfish had the third highest net movement at 12 km from the release site, although this appeared to be driven by a few individuals. Most of the recaptured Copper rockfish occurred in the same CCFRP sampling cell where they were tagged, and this species exhibited high site fidelity for most individuals, even for fish captured almost 10 years after being initially tagged (**Figure 64**).

Using the tag-recapture data, we examined the proportion of recaptured fishes that remained within an MPA or area open to fishing, or that moved between MPAs and areas open to fishing (**Figure 65**). Overall, we recorded 408 tag-recaptures across the 12 MPAs and associated Reference sites with 29 from the Northern California region, 310 from the Central California region, and 69 from the Southern California region. Of those 408 tag-recaptures, 49.8% were reported by the angling community. In the North region, we found that 28% of recaptured fishes had moved from an MPA to areas open to fishing, 31% were tagged in an MPA and recaptured in the same MPA, and 41% were tagged and recaptured in areas open to fishing. On the Central coast, 0.3% of recaptured fish moved from a Reference site into an MPA, 7.7% were tagged in an MPA and spilled over to a Reference site, 36% remained in the MPA they were tagged in, and 56% stayed within Reference sites open to fishing (**Figure 65**). On the South coast, 6% of the fish moved from an MPA to a Reference site, 33% stayed within the MPA, and 61% remained in areas open to fishing. Given that the majority of recaptured fishes exhibited short net movements, less than a few kilometers, it is not surprising that relatively few of them moved from the site of capture.

Using the subset of recapture events where the fish was originally tagged and released inside an MPA, we were able to make rough calculations of spillover. Statewide, we found the rate of spillover for fishes tagged in the MPA to be less than the rate where individuals remained in the MPA. Overall, 80% of recaptures for fishes originally tagged in an MPA occurred in the same MPA they were originally tagged in, while 20% of those recaptured fishes moved to areas open to fishing. We found this pattern to be relatively similar for the Central (18% spillover) and South coast (15% spillover) regions, while the North coast region showed a 47% spillover and 53% retention rate of recaptured fishes originally tagged in MPAs, although the sample size was low with only 18 recaptured fishes of those originally tagged inside MPAs (**Table 4**). Generally, we observed greater spillover of Black rockfish (n=10), Gopher rockfish (n=7), Copper rockfish (n=7), Lingcod (n=6), and Kelp Bass (n=4), with an average net distance moved of approximately 217 km across all fishes (**Table 5; Figure 61**). For these spillover events, two of the 34 individuals were recaptured on CCFRP trips, the remaining recaptures were all reported by the angling community. The two CCFRP related spillover events included a Copper rockfish and a Gopher rockfish. The tag-recaptured Copper rockfish was originally tagged within the Piedras Blancas SMR and recaptured 1,500 days later at our CCFRP Reference site for the Stewart's Point SMR (moving approximately 266 km during its time at liberty) (**Figure 61**). The tag-recapture Gopher rockfish was originally tagged within the Point Lobos SMR and recaptured 2,148 days later, moving approximately 5 km into one of our CCFRP Reference sites for the Point Lobos SMR (**Figure 61**). Conversely, we detected a greater number of fishes staying within the MPA (n=144), with an average net distance moved of approximately 0.10 km across all fishes during an average of 464 days at liberty (**Table 6**). Copper rockfish (n=53) consisted of the greatest number of recaptures in MPAs, followed by Lingcod (n=25), and Gopher rockfish (n=13). These results indicated that the MPAs appear to be highly effective in protecting populations of most species within their borders. The Central coast MPAs had a sufficient number of recaptures to summarize the directionality and distances moved (**Figure 66**). The vector plots indicate that most fishes stayed within the MPA where they were originally tagged, and the bulk of those that moved outside of the MPAs only traveled a few kilometers. At Año Nuevo and Pt. Buchon, we only detected spillover to the north of the MPA, while at Pt. Lobos and Piedras Blancas, we detected spillover both to the north and south of the MPA.

Integrative Questions

Fisheries Integration - Ecological Perspective

Question 6: How does spatial variability in fishing effort and fishing mortality rates prior to and after MPA implementation affect the abundance and/or size/age structure of harvested species in MPAs?

***Q6c**. Are differences in the magnitude of change in abundance of focal species in response to MPA establishment related to differences between MPAs in the level of MPA-adjacent fishing mortality (or effort)?*

<u>Central Coast time series (14 years)</u>

Recreational fishing effort data were extracted from the California Recreational Fisheries Survey (CRFS) conducted by the California Department of Fish and Wildlife from 2012–2019. We focused on the CRFS Private and Rental Boat (PR) data, which are conducted at public launch ramps or access sites where CRFS samplers intercept anglers as they return from their fishing trips. We utilized both the PR1 and PR2 surveys. PR1 surveys were conducted between 2012–2019 at sites where 90% of important management species were historically landed, while PR2 surveys were conducted between 2012–2019 at sites that account for the remaining 10% of important management species were historically landed. Fishing effort data at the microblock scale (1.85 km x 1.85 km), showed high variability across years (ANOVA: $F_{1,23} = 6.8$, $p = 0.015$) and MPA areas (ANOVA: $F_{3,23} = 52.57$, $p < 0.001$), with Point Lobos and Point Buchon having 2-3x as many angler days per microblock as Piedras Blancas or Año Nuevo in a given year (**Appendix G: Figure S2**). Recreational fishing effort and year since implementation were both strongly related to BPUE response ratios, suggesting that the differences in fish biomass between the MPA and Reference sites depended on the level of fishing pressure outside the MPA (**Table S20**; **Figure 67A**). The best fit model included fishing effort, smoothed terms for sea surface temperature and net primary production, and a random effect of time since implementation (GAMM: $r_{adj}^2 = 0.807$; **Table S21**), although fishing pressure was the single most important variable in explaining spatial and temporal variation in biomass response ratios across all sites on the Central coast (**Table S20**). Specifically, there was a clear positive relationship between external fishing effort and biomass response ratios (GAMM: $t = 5.53$, $p < 0.001$), whereby the strongest MPA responses (i.e., differences between fished and unfished areas) occurred in locations with the highest fishing effort outside the MPA (**Table S20; Figure 67**). A random effect of time since MPA implementation also had a clear positive association with biomass response ratios (GAMM: $F = 6.16$, $p < 0.001$) indicating that the longer the MPA is in place, the larger the differences in biomass between MPAs and Reference sites become, regardless of the amount of external fishing effort. While smoothed temperature and net primary production values were included in the model as predictors of biomass response ratios, they did not have a clear positive or negative effect on response ratios (GAMM: temperature: F = 2.453, p = 0.131; productivity: F = 2.034, p = 0.154; **Figure 67B & C**). There were no clear temporal trends in fishing effort, temperature, or productivity that would be responsible for driving these responses (**Appendix G: Figure S1**). There was evidence at some sites (Point Lobos, Piedras Blancas) that within site year-to-year variation in fishing effort was associated with the strength of the biomass response ratios (**Figure S2**), however this effect was generally weak and thus the strong effects we observed across all sites are likely due to larger spatial differences in fishing effort among sites.

Statewide time series (4 years)

For the Central coast regions, there was a positive correlation between external fishing effort and the CPUE response ratios in the years 2017-2020 (Central coast: r^2= 0.65 p=0.002; **Figure 68A**), such that the strength of the MPA response is highest in locations with greater fishing effort in the Reference sites near the MPAs. There was also a positive relationship between fishing effort and CPUE response ratios in the North coast from 2017-2020 that may be ecologically relevant; however, this relationship was not statistically significant (North coast: r^2= 0.25 p=0.09). For the South coast, the relationship between fishing effort from 2017-2020 and biomass response ratios was marginally non-significant (r^2= 0.38, p=0.06), due to extremely high fishing effort near South La Jolla (**Figure 68A**) and a lack of sampling near the Channel Islands, that obscured the true level of fishing effort. It appears that the Private and Rental boater data from CRFS does not adequately capture the amount of fishing effort in the mainland vs. the islands of Southern California (where a disproportionate amount of effort is due to sportfishing vessels not included in this dataset). In contrast, this data set does a much better job at reflecting overall fishing effort in the Central and Northern regions. We observed similar patterns when using the biomass response ratio metric. The North and Central coast sites exhibited significant positive associations between fishing effort and the strength of the MPA response from 2017-2020, such that MPAs contained relatively more fish biomass than their Reference sites in locations with high fishing pressure (North coast: r^2= 0.41, p=0.02; Central coast: r^2= 0.71, p<0.001; **Figure 68B**). Model fits were further improved when using BPUE response ratios instead of CPUE. The response ratios declined with increasing fishing pressure on the South coast (r^2= 0.56, p=0.01), but we believe this is a spurious result due to poor estimates of the true fishing pressure at the offshore Channel Islands given the available Private and Rental boater data. When using mean length as the response ratio metric, we did not detect any significant associations between fishing effort and the difference in body size between the MPAs and Reference sites (**Figure 68C**), although the directions of the trends in each region were generally similar to BPUE described above.

Q6d. *Are differences in the magnitude of change in size/age structure of focal species in response to MPA establishment related to differences between MPAs in the level of MPA-adjacent fishing mortality (or effort)?*

The relationship between adjacent fishing effort and the mean length response ratio metric was not significant in any of the sampling regions (North coast: r^2= 0.07, p=0.41; Central coast: r^2= 0.006, p=0.80, South coast: r^2= 0.18, p=0.22; **Figure 68C**), although the directions of the trends in each region were generally similar to the CPUE and BPUE response ratios.

Question 38: How do other stressors impact the management of MPAs over time?

Central Coast time series (14 years)

From the cross-correlation analysis, we found strong correlations between juvenile Blue rockfish CPUE and MOCI (Multivariate Ocean Climate Indicator) values along the Central coast (**Figure 69**). In all area and site combinations, the highest correlation occurred between CPUE and MOCI values during the summer two years in the past (**Table S22**). All correlations were statistically significant at the 0.05 level except for the Point Lobos area. Adult Blue rockfish patterns were more variable (**Figure 70; Table S23**). The highest correlations included both summer and fall at two, three, and four year lags for all area and site combinations (p=0.05). Interestingly, CPUE during the present year correlated strongly with MOCI values 2-3 years ago in the summer (July-August-September) and fall (October-November-December) inside the MPAs, whereas in the adjacent Reference site, CPUE during the present year correlated strongly 3-4 years ago in the summer and fall.

Additionally, we identified significant variability in environmental conditions and in the amount of recreational fishing effort among years since MPA implementation (**Figure 71**). On average, sea surface temperature (°C) during the CCFRP sampling period ranged from ~13°C to 17.5°C and increased through time with peak temperatures during a marine heatwave in 2014 and 2015 at all sites (ANOVA: $F_{1,43} = 7.80$, $p = 0.007$). Along the Central coast temperatures were highest in the southernmost site at Point Buchon for all years sampled (ANOVA: $F_{3,43} = 3.83$, $p = 0.02$) compared to other MPA areas. Net primary production (mg C m^{-2} yr^{-1}) also varied across years (ANOVA: $F_{1,43} = 4.03$, $p = 0.05$), ranging from 1000 mg C m^{-2} yr^{-1} to upwards of 3000 mg C m^{-2} yr^{-1} across MPA areas in a single year (ANOVA: $F_{3,43} = 7.64$, $p < 0.001$).

Human Domain

Changes in Attitudes and Perceptions

Question 18: How are knowledge, attitudes, and perceptions regarding the MPAs changing overtime?

Q18a. *Have attitudes towards and perceptions of individual MPAs and the MPA network as a whole by stakeholders changed over time and why?*

The 2021 CCFRP Volunteer Angler Survey was distributed to 1,386 recipients (**Table 7**). We received 262 complete survey responses across all institutions as of December 5th, 2021, an 18.9% response rate. Respondents represented communities across the state of California, residing in zip codes from San Diego to Humboldt, with the majority from coastal counties (**Figure 72**). The survey will be open for further participation until December 31st, 2021. It is important to note that respondents were not required to answer all questions, so sample size was lower than the total sample size for some questions.

Question 14 from the survey asked respondents their views on the intended purpose behind the creation of the MPA networks. The vast majority (85%) responded that they believe the MPAs were created to conserve, restore and protect natural biodiversity and a similar percentage thought MPAs were created to prevent overfishing and the overuse of resources (**Figure 73**). In addition, high percentages believe the MPAs were created to restrict industrial use (58%) and to provide opportunities to experience these places (43%). Only a small minority believe there was no purpose (2%) to the creation of MPAs.

Questions 9 and 11 of the survey assessed angler opinions of MPAs, before and after volunteering with CCFRP. We found that 63% of respondents had a positive or somewhat positive view of MPAs prior to volunteering with CCFRP, while 84% had a positive view after volunteering with CCFRP, an increase of 21% (**Figure 74A**). Importantly, those with negative opinions of MPAs decreased; prior to participating with CCFRP, 17% of respondents had negative opinions of MPAs, while only 7% retained a negative opinion after volunteering with CCFRP. Overall, participants having the most positive views of MPAs increased by 26% after volunteering with CCFRP (**Figure 74B**), while the percentage of respondents in all other categories decreased. We calculated the direction (positive vs. negative) and magnitude (strength of the shift) of an individual angler's change in opinion (value of zero = no change) before/after volunteering with CCFRP. While the majority of people did not change their opinion of MPAs after volunteering with CCFRP (primarily because many of them had highly positive views to begin with and thus opinions could only become more negative), those that changed their opinion tended to have an increasingly positive view of MPAs, especially if they started with neutral to negative views (**Figure 74C**). Very few anglers developed a more negative opinion. Thus, in cases where there was room for positive improvement in sentiments towards MPAs, angler opinions changed in that direction after participating with CCFRP. Regionally, we observed similar patterns in the ways angler opinions changed after volunteering with CCFRP. Across all regions, we observed large increases in very positive attitudes towards MPAs (percent increase = 24% North, 29% Central, 26% South; **Figure 75**). However, there were interesting regional differences, with respondents in the South coast tending to start with more negative opinions of MPAs in general compared to the other regions. The result of this was that the largest magnitude of opinion change also occurred on the South coast, with respondents starting with more negative views towards MPAs but ultimately shifting those views much more positively after volunteering with CCFRP (**Figure 76**). The frequency with which respondents participated in MPA monitoring had a large impact on changes in perceptions of MPAs. Volunteer anglers that participated frequently with CCFRP (every year) had a much greater increase in positive views of MPAs (32% increase) than respondents that participated infrequently (1 or 2 years) with the program (16% increase) (**Figure 77**). This trend is further illustrated in that frequent CCFRP participants also exhibited a much larger magnitude of increase in positive opinions of MPAs, especially those that started with negative or somewhat negative opinions prior to assisting with MPA monitoring (**Figure 78**). Thus, participating longer with CCFRP has increasingly positive benefits for angler opinions of MPAs.

Questions 10 and 12 asked respondents before and after volunteering with CCFRP whether they believed that MPAs would result in increases in abundance and size of fishes. The majority of respondents believed that MPAs would result both in increases in abundance and increases in size (**Figure 79**). After participating with CCFRP, the percentage of respondents who thought MPAs would result in higher abundances and larger sizes of fish increased, mainly due to decreases in the percentage that did not know or had no opinion. For those anglers that have fished in both MPA and Reference sites, Question 16 asked whether anglers have experienced a difference in abundance (catch more fish), diversity (catch more species), and body size (catch larger fish) inside MPAs or at Reference sites; 69% of respondents reported that they caught more fish when fishing inside MPAs (**Figure 80**), 60% of respondents said that they remembered catching a greater diversity of species when fishing inside MPAs, and 58% of respondents thought that they caught larger sized fishes on average when fishing inside MPAs. Less than 10% of respondents reported catching more fish (4%), higher diversity (6%), or larger fish (9%) outside of MPAs (**Figure 80**). We observed interesting regional differences in this response, with a lower percentage of anglers on the South coast reporting that they catch more fish (67%), a greater diversity (52%), or bigger fish (46%) inside MPAs compared to the other regions (**Figure 81**). This difference was primarily attributed to a higher percentage of respondents observing no difference in these metrics between MPA and Reference sites on the South coast. Fishing pressure is generally much higher on the South coast and MPAs were implemented more recently, which may explain this result. Question 17 asked the primary reason anglers enjoy being able to fish inside MPAs on CCFRP trips, and a vast majority (63%)

responded that they appreciate the opportunity to help collect scientific data for MPA and fisheries management (**Figure 82**). Question 13 asked anglers the primary reasons explaining why MPAs are working to increase abundance and size of fishes. The majority of respondents believe this is due to enforcement (73%), location (66%) and size (53%) of the MPAs, and due to the protection provided for fish populations (60%); fewer believe this is due to voluntary compliance (43%) or MPA network effects (39%) (**Figure 83**).

Question 23 asked angler opinions about how well California groundfish stocks are managed in general. Here we found that 38% of CCFRP anglers felt that groundfish are managed adequately in the state, while 31% felt that they are managed well or very well (**Figure 84**). A combined 18% of respondents believed that groundfish are managed poorly, very poorly, or not at all, while 12% of respondents did not have an opinion on the quality of groundfish management. There were interesting differences on the regional scale, with anglers from the South coast viewing groundfish management more negatively than those from other regions. On the South coast, 28% of CCFRP anglers believe that groundfish stocks are poorly or very poorly managed, while only 14% of respondents had similar views on the North and Central coasts (**Figure 84**). Question 24 asked anglers to rank various types of fishing gear in relation to which ones they thought were most damaging to the marine environment. The average impact score was greatest for bottom trawling, gill nets, and long lines, and lowest for spearfishing and hook and line recreational fishing (**Figure 85**). Lastly, we asked people whether a set of ocean issues was a threat to California's marine environment, with strong majorities being concerned about pollution, rising temperatures, overfishing, ocean acidification and hypoxia, oil spills, marine debris, and the loss of biodiversity (**Figure 86**). Fewer respondents were concerned about invasive species and the fewest were concerned with wave energy and power development in the ocean.

Basic Demographics

The survey respondents were generally male and 55 years old or older (**Appendix H**). However, 15.0% of the survey respondents were either female or non-binary and 40.4% of the survey respondents were between 18 – 54 years old (**Appendix H**). 66.8% of the survey respondents attended or graduated from college (**Appendix H)**. The pre-tax annual income reported by the survey respondents ranged from less than $25,000 to more than $200,000, with 59.3% of them reporting pre-tax annual income between $50,000 and $200,000. Survey respondents were asked to report their zip code of residence (**Figure 72**). The majority of respondents reside within California (> 95%). The distribution of angler zip codes spanned much of the State, including both zip codes that share a border with the coast as well as many that do not border the coast. Some anglers reported living in counties that are hundreds of miles from the coast.

DISCUSSION

To be most effective, MPAs need to be fully protected from fishing and other extractive activities, including buy-in and support from stakeholders, and enforcement. In California, many of these conditions are met. Using data from CCFRP, we tested whether MPAs provided positive outcomes for biodiversity conservation and for the harvest of exploited species. According to the MPA Guide, fully protected and highly protected MPAs are expected to show an increase in abundance, age structure, biomass, species richness, reproductive output, protection for rare and endangered species, enhancement of genetic diversity, support for proper ecosystem functioning, and resilience to disturbances (Grorud-Colvert et al. 2021). MPAs are also predicted to benefit exploited species outside their borders through adult spillover, increased larval production and export, and insurance against management failure or stock collapse by safeguarding populations of overfished species and their vulnerable life stages. We provided evidence supporting many of these predicted responses in California's statewide MPA network for the decadal review, primarily in the Central coast, where monitoring started the year MPAs were implemented and has continued annually for 14 years. It is important to note that the limited monitoring/review period for MPAs in the Northern and Southern regions (4 years) is likely not sufficient to adequately characterize *all* MPA response metrics in these regions with a high level of confidence, especially because we are lacking data to assess whether conditions were similar or different in these regions when MPAs were first implemented.

Overall, we found strong effects of MPA protection on fish assemblages statewide in the shallow and mid-depth rocky habitats (20-40 m) sampled by the CCFRP program. For the majority of fish species (multiple species of Rockfish, Lingcod, Ocean whitefish, California sheephead, Kelp bass, etc.), we observed that individuals were larger in body size, more abundant (catch per unit effort), and thus exhibited higher biomass (biomass per unit effort) and expected reproductive output (egg production per unit effort) inside MPAs than their associated Reference sites. The strongest responses were detected in biomass and expected reproductive output, which combine the effects of abundance and size structure. Our results are in line with past global syntheses showing the strongest responses in biomass, then density, and lastly size (Halpern 2002; Lester et al. 2009). The rate of increase in abundance and biomass was more rapid inside the MPAs than the Reference sites for key indicator species and the total fish assemblage. We observed that the strength of the MPA response for fishes (i.e., relative difference in abundance and biomass between the MPA and Reference sites) increased over time on the Central coast at all sites, while the magnitude of that effect depended on fishing pressure outside the MPA. Sites with high fishing pressure outside the MPA exhibited an even greater difference in abundance and biomass between the MPA and Reference sites. The size of the MPAs and geographic location along the coast were also important in explaining spatial differences in the strength of the MPA response, such that we detected stronger responses in large MPAs than small MPAs, and stronger responses of fishes to protection in southern latitudes compared to northern latitudes. Communities inside the MPAs were more diverse (at least on the Central coast prior to the marine heatwave) and the assemblages differed between MPA and References sites, mainly due to higher abundance of key species inside the MPA boundaries. Disturbances such as the marine heatwave of 2014-2015 significantly reduced diversity and evenness of the community at both MPA and Reference sites along the Central coast and MPAs tended to recover faster than Reference sites in diversity following these disturbances. Tag and recapture data indicated that most fishes were recaptured within a few kilometers or less of their release site, even after multiple years, bolstering the evidence for limited movements across the MPA boundaries (less than 20% of recaptured fishes spillover from an MPA to a Reference site).

In the habitats that our program samples, we can conclude that the MPAs are highly effective in meeting conservation objectives, and the results align with those in the literature about the effects of MPAs globally (Halpern and Warner 2002; Micheli et al. 2004; Lester et al. 2009; Molloy et al. 2009; Guidetti et al. 2014; Edgar et al. 2014). When fishing pressure is reduced or removed from a location, it is predicted that species formerly targeted by those fishing activities should respond most rapidly to that management action (Hilborn et al. 2020). The strong direct effects of MPAs that we observed are at least partially because CCFRP samples species that are commonly targeted by fishermen in nearshore habitats. Similarly, previous studies evaluating the efficacy of the Channel Islands MPAs after 5 years (Hamilton et al. 2010) and 10 years (Caselle et al. 2015) of protection indicated that species targeted by fishing activities exhibit increases in density, size, and biomass inside MPAs compared to sites open to fishing. Marks et al. (2015), using similar methods to CCFRP, demonstrated that many groundfishes increased in abundance (CPUE) and size structure in deeper rocky reefs in the Rockfish Conservation Areas along the Central coast following 10 years of fisheries closures. In contrast, indirect effects of MPA protection on non-targeted prey species often require greater than 10 years before they are detected (Babcock et al. 2010). CCFRP also conducts MPA monitoring in the habitat most impacted in the past by nearshore recreational and commercial fishing activities, namely the mid-depth rocky habitat extending offshore from the edge of the kelp bed. Since this habitat is where fishing effort has historically been focused, it is not surprising that this habitat exhibited a significant increase in fish populations following the removal of fishing pressure. Our results highlight the importance of concentrating monitoring efforts on those locations within the MPAs that are predicted to be most affected by regulations that restrict fishing activities. Additional monitoring by CCFRP in the Northern and Southern regions will be critically important for delineating the long-term responses to decreased fishing effort in these regions, as they historically have experienced a wide spectrum of fishing intensity.

Responses of Indicator Species to MPAs

In examining the responses of fishes to MPAs, we observed that across all regions of the state, over 75% of the fish species sampled by CCFRP were bigger in size and more abundant, exhibiting elevated biomass inside the MPAs compared to Reference sites. Hamilton et al. (2010) reported similar trends in that 85% of targeted species had higher biomass inside MPAs across the Channel Islands following the first 5 years of protection. For most species, we observed a greater proportion of the individuals were mature inside the MPAs and for some fisheries targets, the largest end of the size distribution was only present inside the MPAs. Given that fishes were more abundant, more likely to be mature, and larger in size when mature, and that fecundity often scales with biomass, we also observed that expected reproductive output is likely to be substantially higher inside the MPAs compared to a similar sized area open to fishing activities. Thus, MPAs likely contribute a disproportionate amount of the larval production along the coast, relative to their area.

On the Central coast, where we had 14 years of continuous sampling, we detected a number of emerging temporal trends in numerous indicator fish species. Lingcod, Canary rockfish, and Yellowtail rockfish increased in abundance and biomass inside MPAs from 2007 until peaking in 2015, after which their populations declined in the MPAs to levels more similar to the Reference sites. The population increases likely occurred in response to strong recruitment in the California Current during this time period (Schroder et al. 2019) paired with proportionally lower mortality rates inside MPAs where fishing was restricted. Subsequent declines after 2015 likely occurred in response to ontogenetic migrations into deeper waters and areas further offshore, which are characteristic of these species (Love et al. 1991; Lea et al. 1999; Love 2011). In addition, Lingcod are relatively short-lived (Lam et al. 2021) and declines in their population may reflect a combination of offshore movements of larger individuals and natural mortality. Declines could also reflect responses of these species to the marine heatwave event (Cavole et al. 2016). In contrast, species such as Blue/Deacon rockfish, Copper rockfish, Gopher rockfish, Olive rockfish, and Vermilion rockfish experienced rapid increases in abundance and biomass inside the MPAs compared to the Reference sites starting in 2015. Successful recruitment of these rockfish species coastwide from 2013-2016 (Schroeder et al. 2019; Field et al. 2021), likely manifested in high catch rates beginning in 2015, due to the approximately 2-year lag required for these fish to grow to sizes at which they will be sampled by hook and line gear. We also detected a significant correlation between the MOCI climate index and catches of juvenile blue rockfish at a 2-year time lag, helping to corroborate this trend. Populations of these five rockfish species did not increase at similar rates outside of MPAs, potentially due to higher mortality rates in response to fishing in those locations.

Continued monitoring in the North coast and South coast by CCFRP will be necessary to adequately characterize state-wide long-term MPA responses and the extent to which they are ubiquitous. On the North coast and South coast, sampling did not begin until 2017 and thus only four years of data were available, precluding assessment of long-term trends since the year MPAs were implemented. Nevertheless, we were able to compare differences in size structure, abundance, and biomass between MPA and Reference sites, with some evaluation of temporal trends in a few species. For the North coast, we observed trends similar to that of the Central coast, with Blue/Deacon rockfish, Copper rockfish, Gopher rockfish, Olive rockfish, and Vermilion rockfish generally increasing in abundance and biomass inside MPAs, with those metrics either increasing much less or staying constant at the Reference sites. Thus, it appears likely that similar environmental drivers influencing fish recruitment were coherent throughout the California Current, influencing populations in both Northern and Central California. Indeed, Field et al. (2021) showed that while rockfish recruitment is typically highly heterogeneous in space and time, during 2013-2017 rockfish recruitment was elevated coastwide for many species. Populations inside MPAs were more abundant than those outside of MPAs, likely because of higher fishing mortality rates in the Reference sites. On the North coast, baseline surveys using CCFRP methodology by Mulligan et al. (2017) indicated that abundance (CPUE) was statistically similar between the MPA and Reference sites at the time when MPAs were first established at Ten Mile and South Cape Mendocino (the two North coast MPA sites for CCFRP that are represented in the baseline surveys) in 2014. Thus, it appears that fish lengths, abundance, and biomass have diverged since MPA implementation, now being higher in all metrics inside the MPAs at those sites. For the South coast, we did not observe any consistent temporal trends, but instead recorded consistently higher abundance and biomass of species such as California sheephead, Kelp bass, Ocean whitefish, Copper rockfish, Gopher rockfish, and Vermilion rockfish inside the MPAs. Because all these species are highly prized by recreational anglers in Southern California, their increased sizes, elevated abundance, and higher biomass are likely due to high fishing pressure, which selectively removes larger individuals and depresses populations outside of the MPAs where fishing is permitted (Harmelin-Viven et al. 2008, Jaco and Steele 2020). We do not have data from the time when MPAs were first established in Southern California, so the possibility exists that these differences were pre-existing. However, we feel that this explanation is less likely because past studies using nearshore scuba surveys at the Channel Islands indicated that MPA and Reference sites were similar in fish abundance, biomass, and habitat characteristics at the time MPAs were first enacted (including Anacapa and Carrington, two of our South coast sites; Hamilton et al. 2010; Caselle et al. 2015).

Rates of Response to MPA Implementation

On the Central coast, biomass response ratios (i.e., difference between the MPA and Reference site) increased over time since MPA implementation at all sites, although the trends were only statistically significant for the MPAs that experienced high fishing pressure outside their borders. The magnitude of the biomass response ratios is continuing to increase since MPA implementation, indicating that the benefits from these MPAs are still accumulating, even 14 years after the cessation of fishing inside the MPAs (Nickols et al. 2019). Hamilton et al. (2010) reported a similar pattern, showing that biomass response ratios (i.e., strength of the MPA response) increased over time for targeted species in the Channel Islands MPA network in the first five years after protection, while there was no difference in the biomass response ratios of non-targeted species. At the two lightly fished sites sampled by CCFRP on the Central coast, there is evidence that fish populations increased both inside and outside the MPA, while at the two sites that experienced high fishing pressure outside the MPA, fish populations only increased inside the MPAs. These trends explain why biomass response ratios only increased significantly where fishing pressure is intense, again highlighting that fishing pressure is the most likely driver of spatial differences in the strength of MPA responses (Harmelin-Viven et al. 2008, Jaco and Steele 2020). In many cases it took greater than 5 years to observe positive changes in size-frequency, abundance, and biomass of targeted fishes inside MPAs on the Central coast (Starr et al. 2015), but at nearly every location, there are now more fish and larger fish inside the MPAs.

In comparing the rate of change in abundance and biomass of individual species, we detected that more species showed faster rates of increase inside MPAs than Reference sites. In particular, Blue/Deacon rockfish, Copper rockfish, Gopher rockfish, Olive rockfish, and Vermilion rockfish displayed much faster rates of change inside compared to outside the MPAs. These species all increased rapidly following strong recruitment between 2013-2017 (Schroeder et al. 2019; Field et al. 2021) and they benefited from reduced fishing pressure inside the MPAs. Overall, 69% of the targeted species we sampled exhibited positive increases in BPUE inside the MPAs while 65% of targeted species also increased in BPUE outside the MPAs, although species inside the MPAs increased in biomass nearly 2x faster on average. This is a positive development, likely reflecting beneficial environmental conditions and strong rockfish recruitment that aided populations coastwide. Overall, populations of nearshore fishes have increased in abundance and biomass both in and out of MPAs, potentially due to added buffering and resilience provided by the MPAs.

The rate of change of targeted species outside of MPAs is a combination of four effects: (1) larval export and adult spillover from MPAs, (2) mortality due to natural causes and fishing activities, (3) changes in fisheries management and regulations outside of MPAs, and (4) general environmental effects on productivity and recruitment. In practice, it is difficult to disentangle these effects, however the trajectories of change provide no evidence that targeted fish species are being depleted outside of MPAs due to displaced fishing effort, which is a commonly cited criticism of MPAs (Osenberg et al. 2006). Our results tend to reflect those reported by Caselle et al. (2015), who showed that 100% of the species targeted by fishing in the Channel Islands MPAs showed positive rates of change in biomass over the first 10 years of protection and that 82% of targeted species also exhibited increases in biomass outside the MPA, even though those increases were 4x less on average. Thus, in two different California regions, the evidence indicates that MPAs have not inadvertently shifted fishing pressure to sites that remain open, and instead that MPAs may actually be benefiting populations outside their borders.

We did not find evidence on the Central coast to support the hypothesis that rate of change in fish abundance is related to life history traits, such as the maximum length or length at maturation, although some of these analyses are in the preliminary stage. Part of the explanation may be because the Central coast fish assemblage is dominated by Rockfish (genus *Sebastes*) which are characterized by relatively slow growth, late maturation, and long generation times (Love et al. 1990). In contrast, Claudet et al. (2010) conducted an analysis of European marine reserves, showing that for commercially exploited fish species, life history traits such as body size, adult habitat, mobility, and behavior had strong effects on the response to protection, while unexploited species showed little response to protection or relevance of life history and ecological traits. Similarly, in a nearly 40-year study of reserves in Kenya, the time course of recovery to equilibrium biomass depended on a species' life history and biological interactions (McClanahan et al. 2007). In addition, modeling studies suggest that population responses to protection are related to the generation time of the species of interest (Moffitt et al. 2013); the longer the generation time (i.e., slow growing, long-lived), the longer the response time. In the California current, cold upwelled water acts to slow metabolism and growth rates, increasing generation times of species that dominate Northern regions (rockfish and greenling) relative to those inhabiting Southern regions (sea basses and wrasses). Thus, we expect MPA responses to accrue more rapidly for species on the South coast than the North coast, which is what we observed in the analysis of the relationship between latitude and the strength of the MPA response. Given the stark differences noted in fish community composition across the three regions of the state, continued monitoring of CCFRP MPAs throughout the state will be necessary to elucidate any life history effects on MPA response rates.

Hamilton et al. (2010) reported strong responses of fish assemblages to MPA protection after 5 years of protection in Southern California, while Starr et al. (2015) did not observe many differences in Central California the first 5 years after protection. In contrast the Pt. Lobos MPA (established 40 years prior) did show large differences in abundance, size, and biomass, leading them to conclude it would take 10 years or more to see big differences on the Central coast. That was precisely the time scale we observed, as the biggest differences between MPA and Reference sites began to manifest after 10 years of protection. Data collection efforts in the Northern and Southern regions started in 2017, approximately 5 years after MPA implementation in those regions, and 14 years post-implementation of the Channel Islands MPAs, which encompass two of our South coast sites. Thus, we do not have data in those regions starting when the MPAs were first established, unlike on the Central coast, and cannot calculate accurate rates of change from the baseline period. At this point, we can only observe that large differences in size, abundance and biomass exist for targeted fish species inside the MPAs compared to their Reference sites, but we are missing the initial trajectory and do not know where they started. Based on results from the Channel Islands (Hamilton et al. 2010; Caselle et al. 2015) and our Central coast data, the assumption is that MPA and Reference sites likely started at much similar levels and diverged over the 5 years that elapsed from implementation until CCFRP began sampling in those regions. For the North coast region, where MPAs were established most recently, the evidence indicates that abundance and biomass are continuing to increase. Additional years of data, however, are required to expand those time series and detect continuing changes over time.

Species of Concern and Culturally Important Species Benefit from MPAs

Current species of concern for fisheries management in California include Copper rockfish, Quillback rockfish, and Yelloweye rockfish (Gertseva and Cope 2017). Data from CCFRP indicate that these species exhibit higher biomass inside MPAs, suggesting that the MPAs are protecting vulnerable components of these populations with the current spatial management scheme. We have the longest time series for Copper rockfish in the Central region, finding that biomass increased dramatically inside the MPAs since 2015. Similarly, biomass of Copper rockfish is diverging between the MPA and Reference sites in the North coast over the past 4 years (similar to the Central coast), while biomass in the South coast remains consistently higher inside the MPAs than the Reference sites. For Quillback rockfish, the results are more equivocal, with higher biomass inside the MPAs for 3 of the 4 years sampled. Yelloweye rockfish have consistently higher biomass inside the MPAs, likely reflecting lower mortality rates in areas closed to fishing. While biomass of all three species is relatively low outside the MPAs, the trends suggest that populations are relatively constant and not in drastic decline, at least over the last 4 years. Importantly, the populations are increasing inside MPAs, especially for Copper rockfish and Yelloweye rockfish.

Culturally important species for tribal interests and recreational and commercial fisherman have shown strong positive responses to the MPAs. For every species or species complex (i.e., all rockfish combined), except Cabezon (which are not caught in high abundance by our program), there is higher biomass inside the MPAs and evidence of increases over time since MPA implementation. Because these are the species that are highly valued and targeted by fishermen, it is not surprising that fish biomass increased significantly inside the MPAs once that fishing pressure was removed. The MPAs in California appear to be acting as a reservoir to conserve populations of fished species, providing a buffer for populations against climatic fluctuations, and acting as a source of larval export to replenish locations that remain open to harvest.

MPA Size and Geography Affect Reserve Responses

We detected strong positive associations between the strength of the MPA response and reserve size across the state, using metrics of total fish abundance (CPUE response ratio) and biomass (BPUE response ratio). Hence, differences in fish abundance and biomass between MPAs and their Reference sites are greater in locations where the MPA is larger in area. Theoretical studies have hypothesized that larger marine reserves would be more effective at increasing biodiversity (Botsford et al. 2003) and density of commercially important species (Hastings and Botsford 2003). Past studies have provided evidence that larger reserves are characterized by stronger increases in fish density (Claudet et al. 2008; Edgar et al. 2014), while other large-scale global synthesis of marine reserves are more equivocal on the importance of reserve size (Halpern 2003; Guidetti and Sala 2007; Lester et al. 2009). A biological mechanism explaining this result is that larger MPAs allow a higher proportion of fishes with broader home ranges to remain protected within the marine reserve, compared to smaller MPAs, where mobile species are more likely to spill over and be caught by fishermen. Using CCFRP data, the most abundant species and those that increased most in biomass in each region (e.g., various Rockfishes, Lingcod, Kelp bass, Ocean whitefish, etc.) tended to have moderate home ranges on the scale of 1-10 km, based on our tag-recapture data. Species with mobility on these scales are likely to be well protected by large MPAs, but may experience significant spillover in smaller MPAs. The species with the greatest net movements (>100 km), Black rockfish, exhibited no response or at best weak responses to MPA protection, as their average movements were greater than even the biggest California MPAs.

Recently, Ohayon et al. (2021) conducted a meta-analysis examining edge effects in MPAs that manifest due to fishing-the-line behavior. Their results, which include a number of Southern California MPAs, indicated that these edge effects in MPAs effectively reduce the MPA area. They reported that there is a prominent and consistent edge effect that extends approximately 1 km into the MPA, in which population sizes on the border are 60% smaller than in the core area at the center of the MPA (Ohayon et al. 2021). These MPA edge effects are particularly pernicious for small MPAs (those smaller than 10 km^2), which may only hold half of the population size that is implied by their area. The edge effects diminish as reserves increase in size. Another mechanism that may explain why larger MPAs are more effective is that larger reserves may increase larval retention, promoting self-recruitment and the build-up of biomass inside the reserve boundary (Botsford et al. 2003). Although we show that MPA effectiveness increases with marine reserve size, this does not imply that small MPAs are ineffective. Our results indicated that fish biomass (BPUE response ratios) was higher inside every MPA compared to its associated Reference site (11 of 12 were statistically significant) and that abundance (CPUE response ratios) was higher inside MPAs at 11 of 12 locations surveyed (9 of 12 were statistically significant). Thus, while small MPAs are also effective at protecting fish populations, we show that larger ones are even more effective.

We observed stronger responses to MPA protection in southern latitudes than northern latitudes (biomass response ratios were negatively correlated with latitude). This may be due to the differences in life history traits, growth rates, and consistency of recruitment of southern taxa (Kelp bass, California sheephead, Ocean whitefish) compared to northern taxa (Rockfish and Lingcod) (Love 2011), which may facilitate more rapid population responses in the warmer waters of Southern California. Hamilton et al. (2010) observed rapid increases in biomass of southern fish taxa following the establishment of the Channel Islands MPAs, while Starr et al. (2015) reported much slower response of Rockfish in the initial years following establishment of MPAs in Central California. Despite MPAs being established first on the Central coast, MPA responses were strongest on the South coast. While MPA age could confound this relationship, the MPAs showing the strongest response in each region, were not necessarily the ones that were older (established previously: Anacapa [1978, 2003], Carrington Pt. [2003], Pt. Lobos [1973; 2007]) and we saw comparable MPA responses in newer reserves in each region (e.g., Swami's [2012], Pt. Buchon [2007], Stewart's Pt. [2010]). The differences in MPA responses with latitude may also be explained by differences in fishing pressure, which can accentuate differences between MPAs and Reference sites. Overall, fishing pressure is much more intense in Southern California (~1 million recreational anglers) compared to Central and Northern California, which are comparatively lightly exploited, with sites farther from port along more exposed sections of the shoreline. In summary, our results with respect to this metric are unclear. Without continued monitoring across the state, the ability to elucidate differences in MPA responses with latitude will remain limited.

Responses of Fish Communities to MPAs and Marine Heatwaves

We observed large-scale geographic differences in fish communities, with shifts in species composition from the Northern and Central regions (dominated by multiple species of Rockfish and Lingcod) to the Southern region of the state (dominated by Ocean whitefish, Kelp bass, California sheephead). Overall, species richness declined from North to South, following well-established latitudinal diversity patterns (Horn et al. 2006), with community turnover shifting from species with cold-water affinities (rockfish and greenlings) in the North to those with warmer subtropical affinities (sea basses, wrasses, tilefish, etc.) down South. Environmental conditions were associated with these geographic shifts in fish communities. Communities up North were characterized by cooler waters and greater wave exposure, while those in the South were from warmer waters and locations with less wave action. We also observed geographic shifts in the trophic group structure, with greater representation by micro-invertivores and herbivores on the South coast, while a larger proportion of fish were classified as a planktivore or piscivore/invertivore on the North and Central coasts, reflecting shifts in productivity, prey availability, and phylogenetics of the predators.

We did detect some differences in fish communities between MPA and Reference sites, however those differences were dwarfed by the much larger effects of biogeography on fish communities. Hamilton et al. (2010) reported similar strong effects of biogeography on fish assemblages across the environmental gradient in the northern Channel Islands, concluding that existing geographic differences need to be accounted for in evaluating the performance of the MPA network on top of a background of changes in species composition. For this reason, many of our statewide analyses were conducted at a regional scale. When differences between MPA and Reference sites in community structure were detected, often those differences were explained by higher abundance or biomass of the species present, and less due to shifts in which species were present. Over the last four years of the statewide survey (2017-2020), communities inside MPAs were generally comparable to those in Reference sites in terms of richness, evenness, diversity, species composition, trophic group composition, and mobility group composition within each region.

Using the long-term time series from Central California (2007-2020), we did find strong evidence for environmental impacts on fish assemblages. Densities of Blue and Olive Rockfish in the beginning of our study decreased dramatically from 2007–2009. We believe the decline was caused by nutrient-poor ocean conditions that occurred in Central California from 2004–2006 (Starr et al. 2015). During those years, the multivariate El Niño–Southern Oscillation (ENSO) index was positive and the Pacific Decadal Oscillation showed a three-year warm period during a decade of cooling (Messié and Chavez 2011). In those years, the California Current was anomalously unproductive (Auth 2008, Dorman et al. 2011), causing poor recruitment in rockfishes and large mortalities of juvenile salmon (*Oncorhynchus* spp.), seabirds, and marine mammals (Parrish et al. 2008, Ralston et al. 2013).

Later, from 2014-2015 two warm water events, 'The Blob' and a moderately strong El Niño event affected California waters. These marine heatwaves impacted marine systems across the state (Cavole et al. 2016, Frölicher and Laufkötter 2018) and we observed that the marine heatwave also impacted fish communities on the Central coast. MPAs had higher diversity and evenness prior to the marine heatwave, however the MPAs did not resist the effects of the heatwave, which depressed diversity and evenness in both MPA and Reference sites, resulting in changes to the community. The reduction in diversity following the heatwave was actually greater inside the MPAs, as they started from a higher diversity score. These results mirror those reported by Freedman et al. (2020) in the Channel Islands, where fish communities both inside and outside of MPAs responded similarly to the heatwave, although those changes were mainly driven by increases in the abundance of non-targeted species with warm-water affinities, without commensurate declines in the cold-water affinity species. While CCFRP mainly encounters species targeted by fishing, we observed that rapid increases in the abundance of Blue/Deacon rockfish, Gopher rockfish, Copper rockfish, and Vermilion rockfish occurred after the heatwave, while Lingcod, Canary rockfish, and Kelp rockfish decreased. The declines in diversity and evenness were primarily driven by the rise in dominance of Blue/Deacon rockfish, which experienced strong recruitment in numerous years surrounding the heatwave (Schroeder et al. 2019; Field et al. 2021), and were the most numerically abundant species on the Central coast. Interestingly, the MPAs appeared to be more resilient in that diversity bounced back more rapidly inside the MPAs in the years following the heatwave compared to the Reference sites. Richness and evenness also tended to be higher inside MPAs after the heatwave. Theoretical predictions suggest that MPAs will enhance ecosystem resilience to disturbance (O'Leary et al. 2017; Bates et al. 2019) and we have some early indicators that this may have been the case on the Central coast. Caselle et al. (2018) provided an empirical example of long-standing MPAs better resisting invasions of temperate seaweeds in the Channel Islands, suggesting that reserves may enhance ecosystem functioning in a variety of ways.

Fish Movements, MPA Effects, and Rates of Spillover

MPAs are often designed with two contradictory purposes in mind: (1) to protect marine organisms from fishing, and (2) to benefit fisheries via spillover of adults beyond reserve boundaries. CCFRP is unique among the various monitoring programs in that empirical data are available to directly assess the latter. The tag-recapture data generated in this study demonstrates high site fidelity for a majority of recaptured fishes, with 61% of recaptures occurring 0.25 km or less from the original location of release. However, it is important to note that 76% of these fishes represent recaptures occurring on CCFRP trips, while the remaining 24% were reported by the angling community. Conversely, a majority (91%) of the fishes recaptured at distances greater than 0.25 km were reported by the angling community.

Generally, we found net movements of fishes to differ among individuals of the same species. All recaptures of fishes within MPAs showed high site fidelity and an average net distance traveled of 0.1 km. Copper rockfish, Gopher rockfish, Lingcod and Black rockfish made up a majority of the recaptures within MPAs, moving anywhere from 0.04 km (Lingcod) to 0.14 km (Copper rockfish) on average. These same species also comprised most of the spillover events, however, fewer individuals were recaptured outside than inside MPAs. Hence, MPAs can serve to both protect species and also enhance populations in fished areas through occasional adult spillover events. Similar observations of high site fidelity for certain individuals have been made by Matthews (1990) using tag-resight of Copper rockfish and by Greenley et al. (2016) and Green et al. (2011) using acoustic telemetry for Lingcod and Black rockfish, respectively.

Where no-take marine reserves have been established across the world, anglers often "fish-the-line" of the reserve, under the assumption that catch rates will be enhanced by the spillover of adult fish which cross the reserve boundary (McClanahan and Kaunda-Arara 1996; Kelly et al. 2002; Murawski et al. 2005; Goñi et al. 2006). We found spillover rates of nearshore fishes (20%) were lower than the retention rate within MPAs (80%). There is a high amount of uncertainty on these estimates given the relatively limited number of recaptures in the CCFRP program. We are not able to evaluate whether the spillover events are due to density-dependent effects, resulting in the build-up of densities inside the MPAs and emigration by fishes to locations outside the MPAs with lower levels of competition, or whether spillover simply reflects normal home range movements by individuals that happen to live near the MPA boundary. However, regardless of the mechanism involved, our data clearly show that some individuals tagged inside MPAs cross the boundary and can be caught in locations open to fishing. We also suspect that the spillover rates calculated from our tag-recapture data are likely an upper bound or overestimation of the true spillover rates. Recaptures inside MPAs are only made on CCFRP trips (4-6 days per year), while recaptures outside the MPAs are made by both CCFRP and the angling community in areas open to fishing (approx. 250 days per year). Thus, there is a higher probability to recapture fishes outside the MPA, which may serve to inflate the spillover rate relative to the retention rate. Additional sources of uncertainty on spillover rates include tag loss, failure of fishermen to report the capture of a tagged fish, and unbalanced fishing effort in areas surrounding each MPA. As CCFRP expanded statewide in 2017, it provided increased opportunities for tagging and releasing fishes inside MPAs. With continued sampling, we expect that there will be increased resolution of movement information and spillover rates of additional nearshore species across the entire state.

Fishing Pressure Shapes the Response of Fish Populations to MPA Protection

Our results present some of the first empirical evidence that the response of fish assemblages in MPAs are directly related to the amount of fishing pressure outside of a reserve and that these responses are mediated by the time since MPA implementation. Environmental conditions of water temperature and primary productivity explain additional variation in fish biomass responses, but their contribution is negligible compared to the effects of fishing pressure and MPA age. Specifically, we found that the differences in the amount of biomass inside MPAs, in comparison to external fished Reference sites, were greatest in locations with high fishing pressure post-MPA implementation. Point Lobos and Point Buchon, locations that experienced the highest fishing effort outside the MPA (50-150 angler days microblock^{-1}), exhibited the highest BPUE response ratios, indicating strong positive effects of the MPA on fish communities. In both of these locations, fish BPUE increased steadily inside the MPA, while biomass stayed at a relatively constant level in the References sites. This important finding suggests that the redistribution of fishing effort outside of the MPA did not depress fish populations in these Reference sites. While populations did not decline outside of MPAs in more intensely fished areas (Pt. Buchon and Pt. Lobos), continued fishing pressure likely contributed to the consistently lower biomass outside the MPAs. Biomass response ratios at locations with high fishing effort increased with time since MPA implementation, indicating that the benefits from these MPAs are still accumulating, even 14 years after cessation of fishing inside the MPA (Babcock et al. 2010; Starr et al. 2015; Nickols et al. 2019)

In contrast, at Piedras Blancas and Año Nuevo, areas with low relative fishing effort outside the MPA (<50 angler days microblock^{-1}), there was a much weaker and non-significant positive increase in biomass response ratios since MPA implementation. At these two locations, fish biomass increased through time in both the MPAs and Reference sites, potentially reflecting the effects of strong recruitment and year-class strength or adult spillover that was not erased by fishing pressure outside the MPA (Silva et al. 2015; Field et al. 2021). Previous studies have found that the amount of fishing pressure in an area prior to closure is one of the best indicators of MPA success for targeted fishes across tropical and temperate systems (Nillos Kleiven 2019; Jaco and Steele 2020; Lenihan et al. 2021). Given these results, we propose that angler behavior and fishing effort outside of an MPA post-implementation (i.e., adaptive human feedback; Thampi et al. 2018) may be a better indicator of MPA efficacy through time for targeted fish communities than pre-implementation fishing pressure. At both Piedras Blancas and Año Nuevo, the combination of distance from port and angler behavior across years dampened fishing effort outside the MPA, making it harder to detect benefits that accrued from MPA protection. This phenomenon emphasizes the need to incorporate socio-ecological interaction (Pollnac et al. 2010) and the optimization of fisheries management into the prediction of conservation outcomes, in addition to traditional metrics used in reserve network design (e.g., size, spacing, configuration, etc.; Gaines et al. 2010; Rassweiler et al. 2012).

Our best fit model of changes in biomass response ratios on the Central coast included environmental conditions such as sea surface temperature and net primary production. However, these variables did not show clear positive or negative effects on biomass response ratios at each site or across all MPAs. Therefore, to the extent that environmental conditions influence underlying annual variability in fish biomass within coastal systems, that effect seems to be independent of MPA protection status. Further evidence for this pattern comes from the marine heatwave that impacted the California coast between 2014-2015. This significant thermal anomaly impacted ecosystems across the state and also altered fish community composition of marine reserves (Freedman et al. 2020). While the community composition within MPAs experienced changes in diversity during this event, our results suggest that fish biomass changed similarly inside and outside of MPAs. Freedman et al. (2020) found that targeted species, which benefit the most from fishing closures, were least affected by the marine heatwave, which is consistent with our results.

Using the last four years of data statewide, we detected strong associations between fishing pressure and MPA responses in all regions. On the North coast, we found a positive relationship between fishing pressure and the strength of the MPA response that mirrored the patterns on the Central coast. Sites with high fishing pressure outside of the MPA exhibited a bigger difference in biomass between the reserves and fished sites. In contrast, we observed the opposite pattern on the South coast, where MPA responses were negatively related to fishing pressure. We think this is a spurious result due to poor data on the true level of fishing effort at sites in the offshore Channel Islands. Our high-resolution microblock fishing effort data from the CDFW CRFS Private and Rental Boat data likely underrepresents effort at the Channel Islands, which are fished much more intensely by Commercial Passenger Fishing Vessels (CPFVs), due to the distance offshore. In contrast, we believe that this data set provides a much stronger metric of overall fishing effort along the mainland coast, which tends to be accessible to more types of fishing vessels. Similar trends between fishing effort and MPA responses occurred when using the CPUE response ratio metric, although the model fits were stronger in all regions for BPUE. Length responses followed the same trends as CPUE and BPUE, however there were no statistically significant associations between length responses and fishing effort in any of the regions.

Shifts in Angler Sentiments Towards MPAs

Like Mason et al. (2020), who surveyed CCFRP participants along the Central coast of California, we saw an overall positive effect of community-based science participation on the perceptions of MPAs by anglers. Specifically, we found that across the state prior to volunteering with CCFRP, 43% of anglers that responded to our survey had a positive opinion of

MPAs, while 17% had a negative or somewhat negative opinion of MPAs. After participating with CCFRP, 69% of responders indicated having a positive opinion of MPAs (a 26% increase) and only 7% of anglers had a negative or somewhat negative opinion of MPAs. Hence, our results suggest that long-term engagement of stakeholders in collaborative research can positively change angler perceptions and opinions of MPAs. The magnitude of the positive increase in MPA perceptions following participation with CCFRP was greatest for those anglers that had a negative or somewhat negative opinion of MPAs at the outset. This is an encouraging sign that even anglers who perceive the MPAs negatively can shift their opinions. It is likely that this is due to anglers having an opportunity to fish inside MPAs and observe for themselves the differences in abundance, size, and diversity of fishes. Regional differences in angler perceptions of MPAs highlighted that the South coast region has a larger proportion of respondents with negative views of MPAs. This is an area where additional participation, outreach, and education could pay dividends in increasing support for MPA management. Similar to Mason et al. (2020) on the Central coast, we observed across the state that the frequency with which anglers participate with CCFRP affects the strength of the shift in MPA perceptions. People that volunteer with the program every year, have more positive views of MPAs than anglers who participate infrequently. We suspect that long-term engagement with MPA monitoring has allowed those anglers to observe changes over time inside MPAs and the cumulative effects that continue to build from the time of MPA implementation.

The majority of anglers expressed expectations that the MPAs would increase fish abundance and size of fishes. For those that fished in both MPA and Reference sites, over 60% of respondents indicated that they observed catching a greater diversity of fish species and that fishes were larger and more abundant inside MPAs compared to areas open to fishing. Angler observations were in agreement with their original predictions about MPA efficacy. We have shown that a collaborative research approach can serve as an educational tool and benefit the angler community by making scientific research and management decision-making more open and accessible. To this end, the vast majority of anglers responded that they enjoy fishing within MPAs in order to collect scientific data that can assist the state of California in making important resource management decisions. When asked why MPAs appear to be working, the highest percentage of respondents listed enforcement (or at least the perception that the MPAs are enforced), while others thought location and size of the MPAs were contributing factors to their success. Similar to our results, socioeconomic surveys of fishermen living near an MPA protected for 20 years in Brazil reported positive perceptions of the MPA, with the vast majority stating that the MPA was effective and improved their livelihoods by increasing fish stocks and prohibiting take by outside fishermen (Filho et al. 2021).

A lack of transparency between fishery managers and the angling community often leads to distrust of fishery assessments and management measures by anglers (Yochum et al. 2011). At the inception of CCFRP, it was believed that collaborative research could build trust in fisheries management among anglers in the state (Wendt and Starr 2009). In this study, 69% of CCFRP respondents believed groundfish stocks were managed well, very well or adequately. This is a relatively accurate assessment since many groundfish stocks are rebounding or have been declared rebuilt ahead of projected timelines (Pacific Fishery Management Council 2008; NOAA Fisheries 2019). Although not explicitly addressed in these preliminary results, it appears likely that CCFRP volunteer participation has influenced angler perceptions about groundfish stock management over time. It is also possible that CCFRP volunteer perceptions regarding groundfish stock health are influenced by historical perspectives, as older respondents (over ½ respondents were 55+) are more likely to have fished prior to the collapse and subsequent recovery of many groundfish stocks. Overall, results suggest that volunteering with CCFRP provides educational experiences that have shifted angler perceptions about MPAs as a fisheries management tool more positively across the state of California.

CONCLUSIONS AND MANAGEMENT RECOMMENDATIONS

As MPAs continue to be used as a prominent conservation strategy in coastal systems, managers should consider both the suite of human-induced (socio-ecological interactions) and environmental conditions that may alter MPA success, as well as establish long-term monitoring programs to fully assess the functionality of marine reserves into the future. Based on the biological results from the CCFRP program, the MPAs are working well across the statewide network. In the shallow and mid-depth rocky habitat (20-40 m depth) fish are larger in body size, more abundant, and higher in biomass in nearly every MPA sampled in all regions of the state. The strength of the MPA response is continuing to increase on the Central coast, 14 years after protection first began, indicating that the positive benefits of the MPAs are continuing to accrue. On the Central coast, it took a minimum of 5-7 years to begin seeing positive changes inside the reserves. Given the observation that MPA responses can be slow to build in some locations, patience is necessary, especially in temperate ecosystems along the California coast. For example, responses to MPAs are likely to be slower in areas where fishing pressure is relatively low may (it takes more time to detect a difference between MPA and Reference sites) and in the regions where species have life histories characterized by slow growth, late maturation, and episodic recruitment, such as the rockfishes that comprise the bulk of the species diversity in the North and Central regions.

The MPAs did not resist the effects of the marine heatwave, which depressed diversity and resulted in community changes. However, the MPAs were more resilient in that diversity bounced back more rapidly than the fished areas. This may require a re-evaluation of expectations in how fish communities inside MPAs will respond to future climate change along the coast of California as the forces driving distributional shifts and species turnover occur at broader spatial scales. We also found that populations inside larger MPAs responded more strongly to protection than those in smaller MPAs, such that biomass differences build up more rapidly in larger reserves, potentially due to the edge effects and fishing-the-line behavior. Smaller reserves have a relatively larger perimeter to area ratio, and thus are more prone to edge effects than larger reserves, with home ranges of a greater proportion of the species being likely to cross the boundary into locations open to fishing. If the goal is to protect species within the borders of the MPA, we recommend that individual MPAs be made larger, not smaller, or that more attention is placed on locating MPA boundaries in areas of habitat discontinuity (i.e., sand channels) to discourage spillover. However, if the goal is to enhance spillover of adults to supplement populations in fished areas, the MPAs could be smaller and/or placed in areas with continuous habitat, with the understanding that they will be less effective overall in meeting conservation goals. We recommend future research focusing on directly measuring spillover, through tagging studies, such as those conducted by CCFRP, as well as evaluation of seascape characteristics.

Our findings indicate that external fishing pressure is the most important metric for understanding spatial differences in the efficacy of MPAs across a network. Where fishing pressure was high, beneficial environmental conditions and strong recruitment manifested in dramatic increases in fish populations inside the reserves, but not outside the reserves in areas open to fishing. In contrast, where fishing pressure was relatively low, populations increased both in the MPAs and References sites. While abundance and biomass metrics were more similar in locations with lower fishing pressure in the Reference sites post-MPA implementation, this should not be taken to mean that those MPAs were not working. Accurate high-resolution spatial information on fishing pressure outside of MPAs can help set expectations in MPA planning and evaluation. While we found that the high spatial resolution (1 x 1 nautical mile microblock) fishing effort data from the Private and Rental boater survey was useful in the Central and North regions for characterizing fishing pressure, this data set was inadequate for the South coast. More effort should be placed into acquiring microblock scale fishing information from the Commercial Passenger Fishing Vessel fleet. Improving information on the spatial distribution of fishing effort for all fishing sectors should be a major priority for the state of California as future MPA evaluations will not be possible without reliable and accurate metrics of fishing pressure. Additional metrics, such as distance from port, or the amount of quality fish habitat surrounding an MPA, may also provide a more comprehensive prediction of the outcomes of these conservation tools.

Our program has also shown the power of collaborative research involving academic institutions, citizen scientists, the fishing industry, NGOs, and state and federal resource management agencies to conduct rigorous scientific research on the efficacy of MPAs in California. Complimentary to the biological MPA effects we detected, the outreach and education we have provided to the fishing community has also provided tangible human dimensions impacts in terms of increasingly positive opinions of the MPAs in program participants, who represent the stakeholder group most vocally opposed to the creation of the MPAs. By participating on CCFRP sampling trips and attending volunteer appreciation events to learn about the results each year, anglers are increasing their knowledge of the MPAs, fisheries management in general, and seeing with their own eyes how fisheries resources are changing in response to protection. This is one of the real strengths of the CCFRP program, beyond the biological results, and we recommend expanding opportunities more broadly for members of the fishing community to participate in marine reserve monitoring and engage in shared resource management for a more sustainable future. Educating anglers will pay huge dividends for increased acceptance and compliance with spatial management in the future.

The Future of CCFRP

CCFRP has demonstrated its utility for evaluating the efficacy of the statewide MPA network in the first decadal review, by providing critical information to support the MLPA goals and by engaging fishers in the monitoring and evaluation process. Critically, CCRFP is the only monitoring program to collaboratively engage these direct users of marine resources, and our data suggest that participation in this program positively impacts the views of MPAs by recreational anglers, one of the major goals of the MLPA. At the same time, CCFRP collects data to inform fisheries management of nearshore resources and that have been utilized in stock assessments for seven groundfish species. Our program can continue to provide information on stock status for emerging (Copper and Quillback rockfish) and continuing (Yelloweye rockfish) species of concern, as well as provide a baseline to detect changes in species that may require evaluation in the future. However, the program can only provide this information if it is properly supported statewide. While we can currently detect positive benefits of the MPAs in the North and South coast regions, we have only been sampling those areas since 2017 and more time is required to generate the time series needed to assess temporal trends and responses to the environment and external fishing pressure. Investing in continuing the time series in all regions of the state will pay important dividends, as evidenced by the strength of our 14-year time series on the Central coast that allowed us to answer the majority of the questions posed by the Marine Protected Area Monitoring Action Plan and the Decadal Working Group. To make an even bigger difference, the long-term goal is to expand the program to sample additional areas statewide (e.g., Orange County, Los Angeles, Catalina Island, mainland Santa Barbara Channel, Farallon Islands, etc.) and to engage with a greater number of anglers so that we can educate more people about the value of marine conservation and the benefits of MPAs as part of a sustainable ecosystem-based management approach that will safeguard California’s iconic marine resources for generations to come.

ACKNOWLEDGEMENTS

This research was made possible by the investment and dedication of the captains and crew members of the 36 Commercial Passenger Fishing Vessels: *F/V Admiral, F/V Aloha Spirit, F/V Avenger, F/V Caroline, F/V Chubasco, F/V Endeavor, F/V Fiesta, F/V Fishy Business, F/V Flying Fish, F/V Huli Cat, F/V Kahuna, F/V Kyndall Lynn, F/V New Captain Pete, F/V New Horizon, F/V Outer Limits, F/V Pacific Horizon, F/V Patriot, F/V Phenix, F/V Princess, F/V Queen of Hearts, F/V Rita G., F/V Sea Angler, F/V Sea Star, F/V Sea Watch, F/V Stardust, F/V Starfire, F/V Sum Fun, F/V Sur Randy, F/V Take Five, F/V Tigerfish, F/V Toni Rae II;* Central Coast Sportfishing, Morro Bay Landing, Patriot Sportfishing, Virg's Landing. We thank the more than 250 people who served as science crew, and more than 1,700 volunteer anglers for their invaluable assistance and participation in the project. We thank the California Coastal and Marine Initiative of the Resources Legacy Fund Foundation, the California Ocean Protection Council, the California Department of Fish and Wildlife, the California Sea Grant College Program, the David and Lucile Packard Foundation, the Keith Campbell Foundation for the Environment, FishWise, and Santa Monica Seafood for funding this research. Additional project partners included the NOAA National Marine Fisheries Service, Coastal Conservation Association, California Department of Fish and Wildlife Marine Protected Areas Management Team and Natural Resource Volunteer Program, California State Parks, Central Coast Sportfishing, Coastside Fishing Club, Half Moon Bay Fisherman's Association, Morro Bay Commercial Fishermen's Association, National Marine Sanctuaries Foundation, and The Nature Conservancy. Thanks to Big Hammer Baits, Monterey Bay Aquarium, J. Amaya, and P-Line for donations of angler prizes and tackle. Finally, we would like to thank the lead technicians (past and present) and those who contributed towards key sections of this report from our partnering institutions: J Chiu, C. Coscino, E. Satterthwaite, R. Fields, J. Mohay, E. Johnston, E. Brauer and L. Zaragoza.

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TABLES

Table 1. CCFRP site characteristics. *We did not consider an area a cluster if the SMCA allowed fishing from shore (e.g., Stewart's Point and Año Nuevo).

Region	MPA name	MPA Tier	Years sampled	Area of MPA (km^2)	Area of MPA Cluster? (km^2)	SMR/SMCA cluster
North	South Cape Mendocino SMR	Tier II	2017-2020	23.53	-	No
	Ten Mile SMR	Tier I	2017-2020	30.95	40.12	Yes
	Stewarts Point SMR	Tier I	2017-2020	62.24	-	No*
	Bodega Head SMR	Tier I	2017-2020	24.19	56.07	Yes
Central	Año Nuevo SMR	Tier I	2007-2020	28.88	-	No*
	Point Lobos SMR	Tier I	2007-2020	14.25	36.18	Yes
	Piedras Blancas SMR	Tier I	2007-2020	27.04	49.93	Yes
	Point Buchon SMR	Tier I	2007-2020	17.3	48.87	Yes
South	Carrington Point SMR	Tier I	2017-2020	33.1	-	No
	Anacapa Island SMR/SMCA	Tier I	2017-2020	18.9/29.9	48.82	Yes
	Swami's SMCA	Tier I	2017-2020	58.33	-	No
	South La Jolla SMR	Tier I	2017-2020	33.1	39.47	Yes

Table 2. Number of sampling trips, volunteer anglers, fishes caught and released, species, and fishes tagged for each MPA, separated by region and institution from 2007 to 2020. Sixteen MPA/Reference sitess have been sampled by CCFRP as a statewide program. MLML and Cal Poly sampled Año Nuevo SMR, Point Lobos SMR, Piedras Blancas SMR, and Point Buchon SMR since 2007, and all others were added during statewide expansion in 2017. Laguna Beach SMCA was sampled for one season in 2017 season, Point Conception SMR was sampled in 2018 and SE Farallon Islands SMR was sampled 2017-2019.

Region	Institution	MPA/Reference Site Pair	# Trips	# Anglers	# Fishes	# Species	# Tags
North	HSU	South Cape Mendocino SMR	24	--	2,311	19	888
		Ten Mile SMR	26	--	2,387	26	758
		Trinidad	12	--	1,402	15	383
		Total	**62**	**79**	**4,698**	**27**	**2,029**
	BML	Stewarts Point SMR	19	--	11,725	22	776
		Bodega Head SMR	21	--	3,230	21	1,842
		Total	**40**	**186**	**14,955**	**25**	**2,618**
Central	MLML	SE Farallon Islands SMR	11	--	3,103	22	706
		Año Nuevo SMR	108	--	37,272	39	11,427
		Point Lobos SMR	109	--	36,381	37	11,193
		Total	**228**	**796**	**73,653**	**50**	**23,326**
	Cal Poly	Piedras Blancas SMR	94	--	30,817	42	11,054
		Point Buchon SMR	116	--	30,111	46	11,445
		Total	**210**	**275**	**60,928**	**54**	**22,499**
South	UCSB	Point Conception SMR	6	--	456	23	185
		Carrington Point SMR	19	--	7,968	35	4,512
		Anacapa Island SMR/SMCA	19		5,420	33	1,648
		Total	**44**	**148**	**13,844**	**51**	**6,345**
	SIO	Laguna Beach SMR	4	--	406	21	289
		Swami's SMCA	20	--	1,626	33	1,154
		South La Jolla SMR	18	--	1,979	33	1,465
		Total	**42**	**204**	**4,011**	**47**	**2,908**
Total for All Areas (2007 - 2020)			**626**	**1,688**	**176,594**	**93**	**59,725**

Table 3. Fish movement statistics from tag-recapture data collected between 2007-2020 with CCFRP data.

Species	Number Tagged	Number Recaptured	Percent Recovered	Range of Time at Liberty (days)	Minimum Net Distance Moved (km)	Maximum Net Distance Moved (km)	Mean Net Distance Moved (km) ± SD
Barred Sand Bass	182	1	0.55%	20 - 20	0.15	0.15	0.15 ± 0.00
Black Rockfish	7,650	61	0.80%	0 - 1,526	0.01	916.75	189.83 ± 324.55
Black and Yellow Rockfish	157	1	0.64%	213 - 213	0.23	0.23	0.23 ± 0.00
Blue Rockfish	9,367	23	0.25%	1 - 1,038	0.02	13.23	1.25 ± 3.06
Brown Rockfish	780	17	2.18%	8 - 1,082	0.01	104.03	6.74 ± 24.36
Cabezon	381	5	1.31%	10 - 97	0.14	14.55	3.25 ± 5.65
California Scorpionfish	98	3	3.06%	0 - 0	0.03	0.55	0.27 ± 0.22
Canary Rockfish	1,032	7	0.68%	29 - 685	0.01	10.51	1.7 ± 3.61
China Rockfish	836	2	0.24%	6 - 358	0.02	0.65	0.34 ± 0.32
Copper Rockfish	3,525	84	2.38%	0 - 3,696	0.00	366.36	11.72 ± 49.95
Gopher Rockfish	12,178	66	0.54%	6 - 2,148	0.01	41.58	2.7 ± 7.61
Honeycomb Rockfish	98	1	1.02%	254 - 254	14.04	14.04	14.04 ± 0.00
Kelp Bass	1,150	22	1.91%	2 - 739	0.01	62.65	8.33 + 18.20
Kelp Rockfish	1,796	4	0.22%	271 - 1,161	0.01	0.97	0.32 ± 0.38
Lingcod	4,044	66	1.63%	0 - 1,860	0.00	85.01	4.35 ± 14.89
Ocean Whitefish	3,339	7	0.21%%	36 - 204	0.23	89.39	13.86 ± 30.85
Olive Rockfish	3,591	11	0.31%%	10 - 2,198	0.02	5.66	0.6 ± 1.60
Starry Rockfish	116	1	0.86%	645 - 645	0.75	0.75	0.75 ± 0.00
Treefish	368	4	1.09%	64 - 358	0.04	2.85	0.9 ± 1.15
Vermilion Rockfish	3,387	14	0.41%	0 - 1,779	0.01	33.37	3.35 ± 8.66
Yelloweye Rockfish	88	1	1.14%	22 - 22	0.06	0.06	0.06 ± 0.00
Yellowtail Rockfish	1,031	7	0.68%	20 - 1,159	0.02	9.30	1.41 ± 3.22

Table 4. Spillover rate (# tagged in an MPA that were recaptured outside the MPA) and retention rate (# tagged in an MPA that were recaptured in the MPA) of recaptured fishes that were originally tagged inside MPAs for each monitoring region and statewide.

Monitoring Region	# Recaptured Fishes Tagged in MPA	Spillover Rate Count (% of total)	Retention Rate Count (% of total)
North	17	8 (47.1%)	9 (52.9%)
Central	136	24 (17.6%)	112 (82.4%)
South	27	4 (14.8%)	23 (85.2%)
Statewide	**180**	**36 (20%)**	**144 (80%)**

Table 5. The top 5 species with the greatest spillover events across all MPAs surveyed statewide and the average distance of spillover for those species as well as all fishes combined.

Species	Count	Average of Distance Traveled (km) ± SD
Black Rockfish	10	612.5 ± 322.87
Copper Rockfish	7	105.07 ± 129.31
Gopher Rockfish	7	17.92 ±15.09
Kelp Bass	4	35.54 ± 26.87
Lingcod	6	21.71 ± 29.34
Overall	**34**	**216.77 ± 322.39**

Table 6. The top 9 species with the greatest number of recaptures within MPAs surveyed statewide and the average distance moved for those species within the MPA as well as for all fishes combined.

Species	Count	Average of Distance Traveled (km) ± SD	Average Time at Liberty (days)
Black Rockfish	10	0.057 ± 0.066	301
Blue Rockfish	6	0.16 ± 0.209	408
Brown Rockfish	6	0.085 ± 0.109	312
Copper Rockfish	53	0.137 ± 0.65	618
Gopher Rockfish	13	0.072 ± 0.065	442
Kelp Bass	7	0.155 ± 0.113	199
Lingcod	25	0.038 ± 0.027	269
Olive Rockfish	8	0.079 ± 0.049	546
Vermilion Rockfish	8	0.148 ± 0.197	593
Overall	**136**	**0.103 ± 0.415**	**464**

Table 7. Number of recipients of the 2021 CCFRP Angler Survey by institution. 259 respondents indicated an institution out of a total of 262 respondents.

CCFRP Institution	Number of Angler Recipients	Number of Respondents	Percentage of Recipients that Responded
Humboldt State University	86	21	24.4%
Bodega Marine Laboratories at UC Davis	160	50	31.3%
Moss Landing Marine Laboratories	626	63	10.1%
Cal Poly, San Luis Obispo	234	36	15.3%
Marine Sciences Institute at UCSB	123	22	17.9%
Scripps Institution of Oceanography at UCSD	157	67	42.7%
Total	**1386**	**262**	**18.9%**

FIGURES

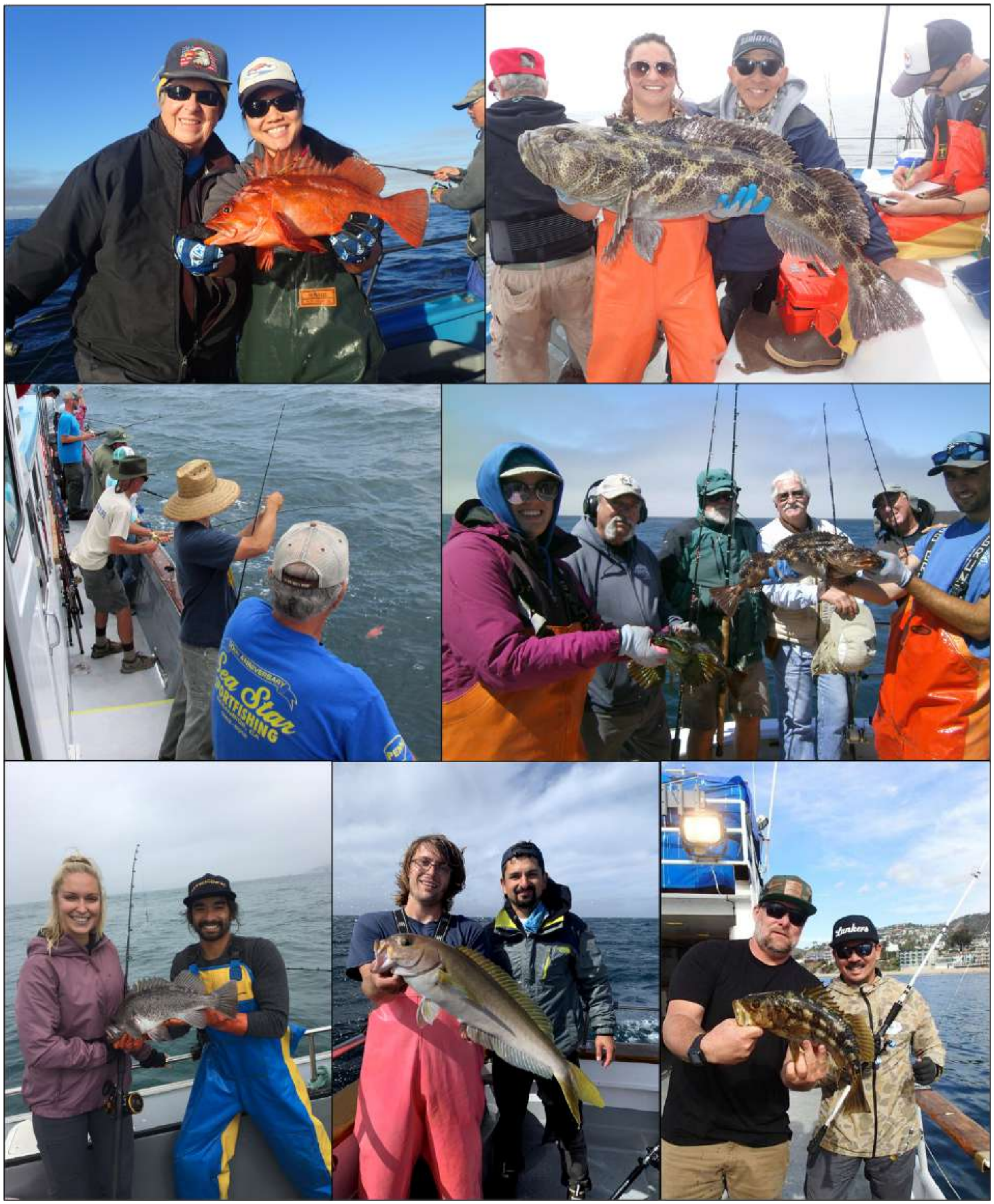


Figure 1. Examples of fish caught by anglers on CCFRP sampling trips and general participation by anglers in scientific research as part of our program. Photos from top to bottom (Copper rockfish, Lingcod, hook and line sampling, small Lingcod, Black rockfish, Ocean whitefish, Kelp bass).

Figure 2. Examples of collaborative fisheries research activities aboard CCFRP sampling trips. Images in order show fish measuring and tagging, data collection on catches and fish lengths for each angler, and the collaborative spirit of anglers participating on CCFRP trips.

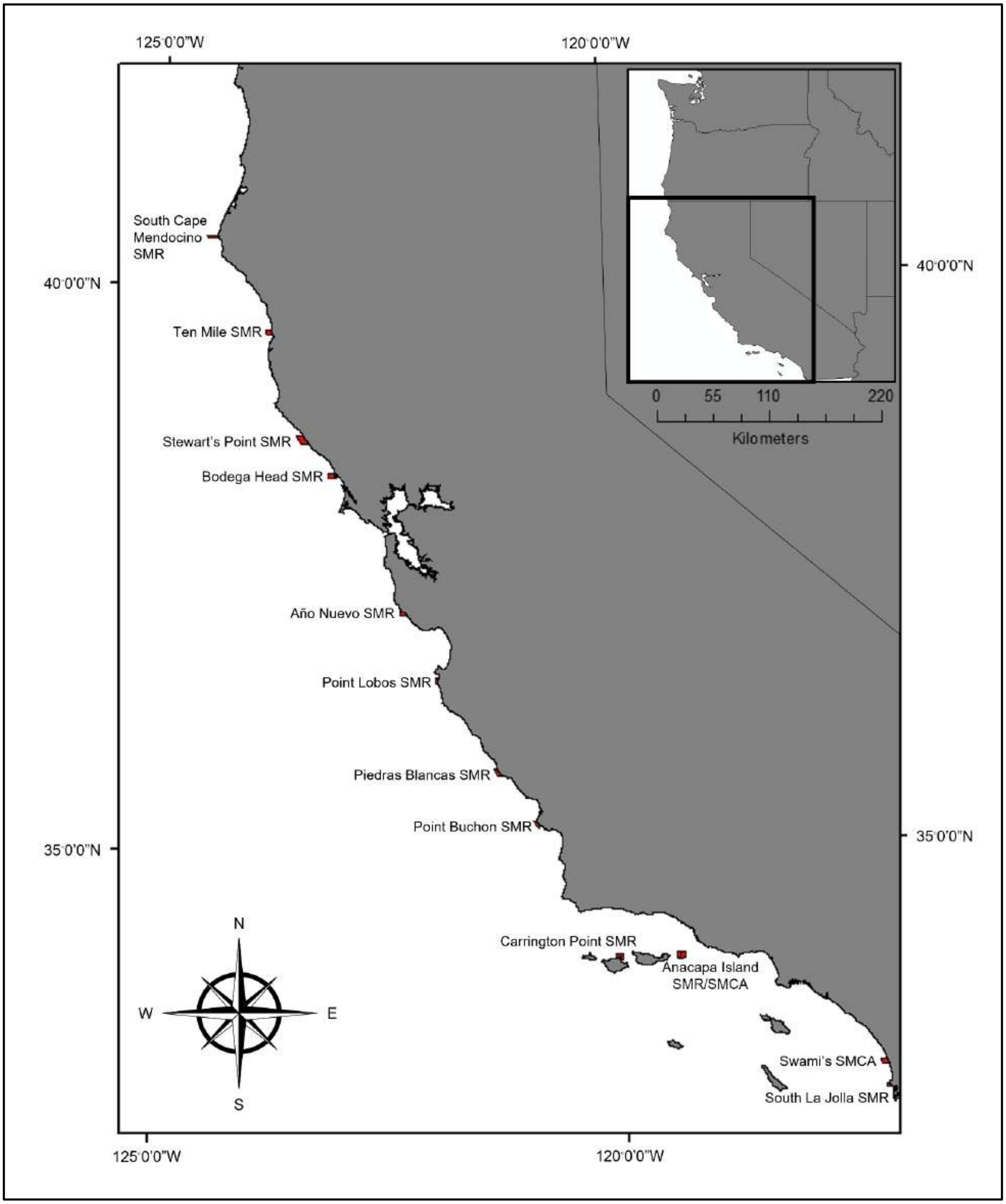


Figure 3. Map of the 12 MPA areas surveyed by CCFRP for long-term monitoring.

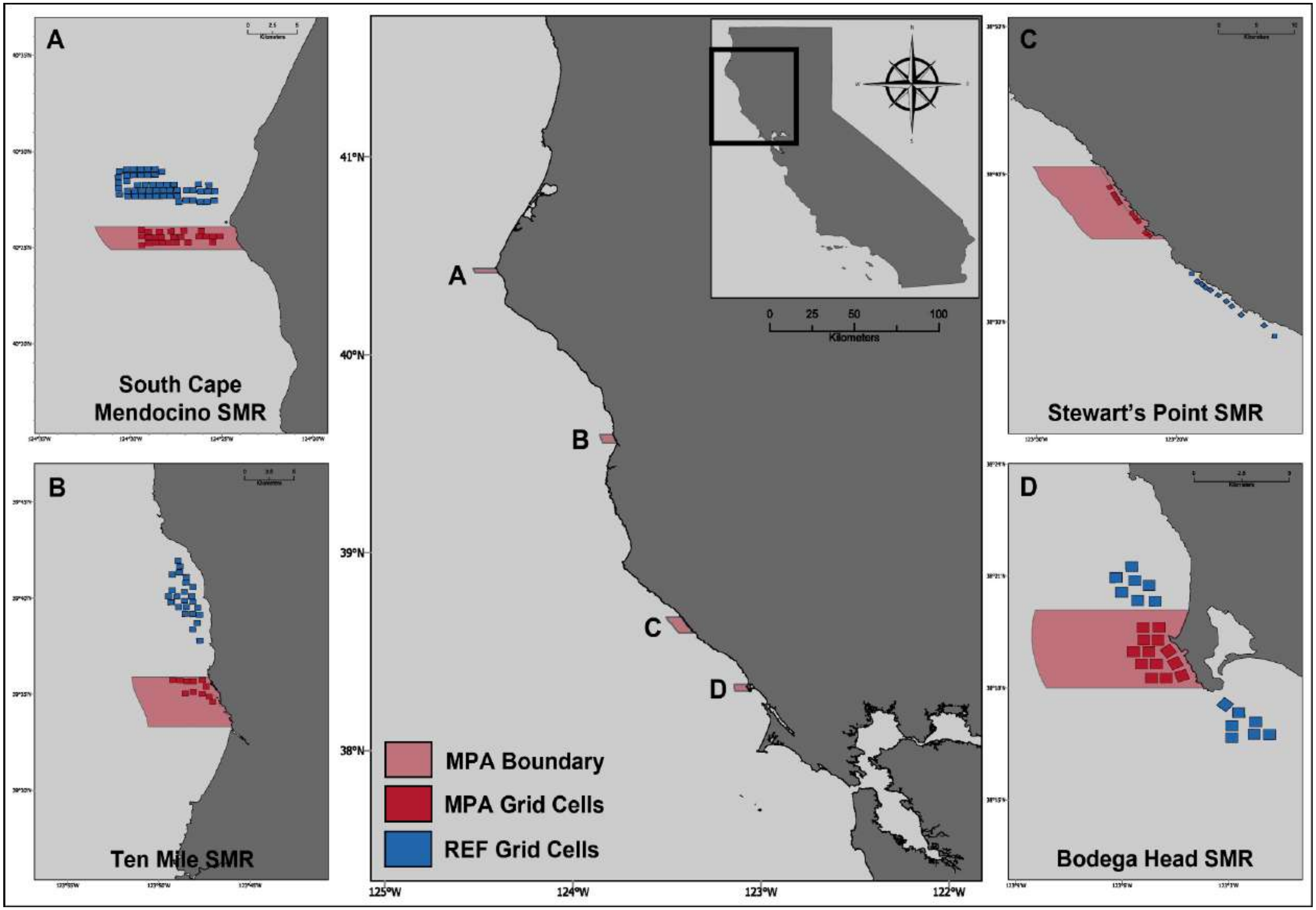


Figure 4. Map of MPA and Reference site (REF) sampling grid cells for the North region at (A) South Cape Mendocino (B) Ten Mile, (C) Stewart's Point, and (D) Bodega Head State Marine Reserves. Shaded red area indicates MPA boundaries. MPA grid cells in red. REF grid cells in blue.

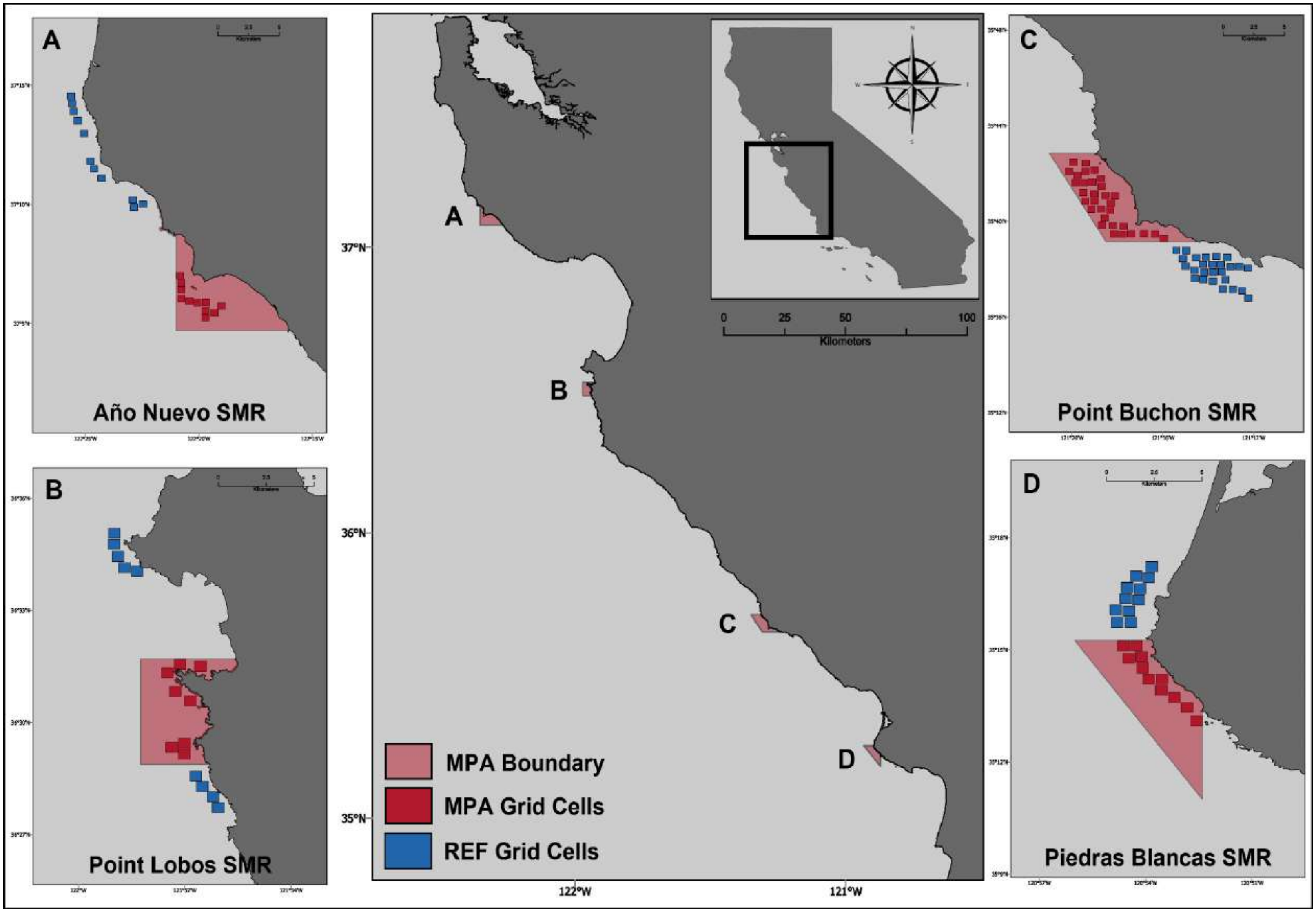


Figure 5. Map of MPA and Reference site (REF) sampling grid cells for the Central region at (A) Año Nuevo, (B) Point Lobos, (C) Piedras Blancas, and (D) Point Buchon State Marine Reserves. Shaded red area indicates MPA boundaries. MPA grid cells in red. REF grid cells in blue

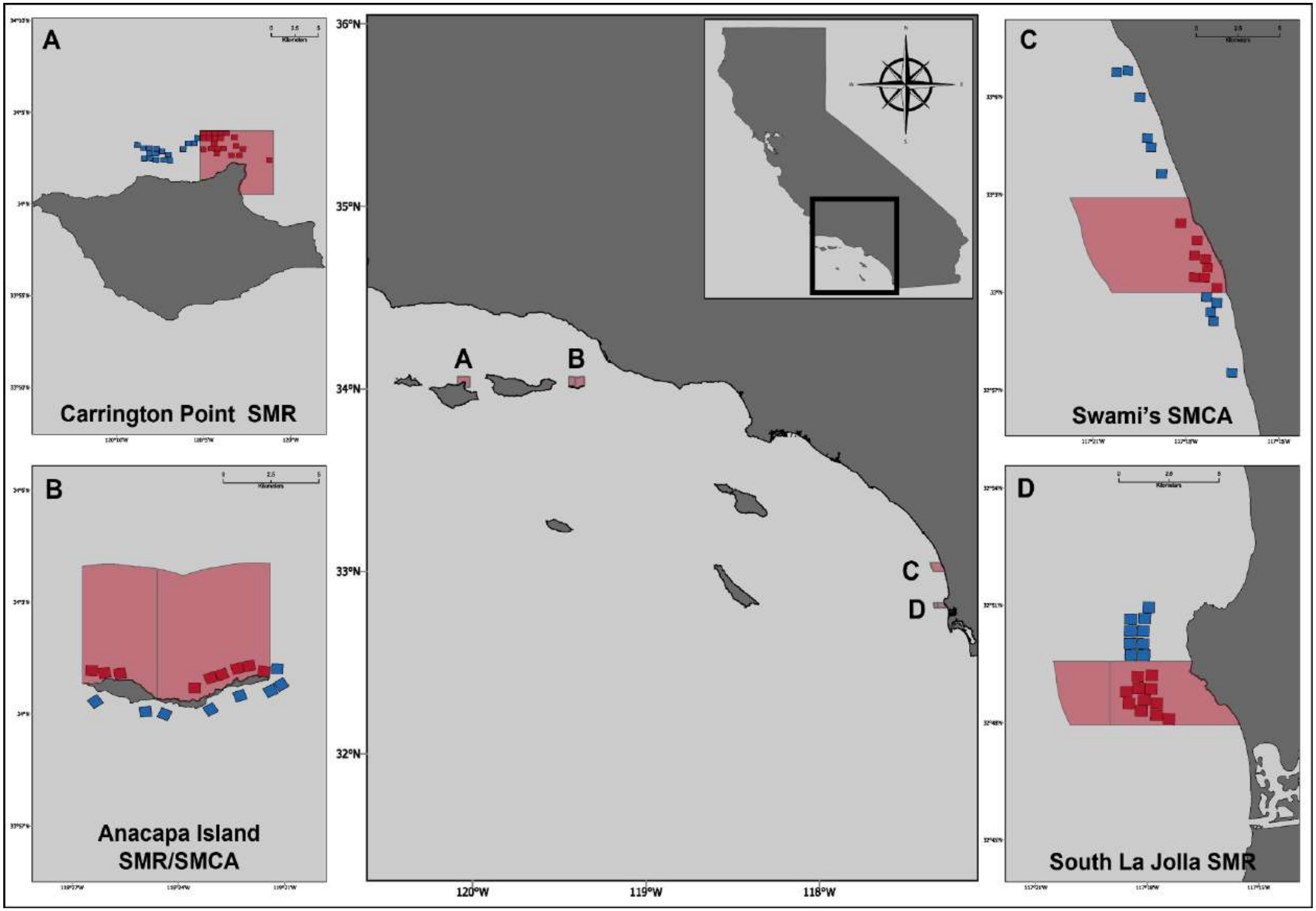


Figure 6. Map of MPA and Reference site (REF) sampling grid cells for the South region at (A) Carrington Point State Marine Reserve (SMR), (B) Anacapa Island SMR and State Marine Conservation Area (SMCA), (C) Swami's SMCA and (D) South La Jolla SMR. Shaded red area indicates MPA boundaries. MPA grid cells in red. REF grid cells in blue.

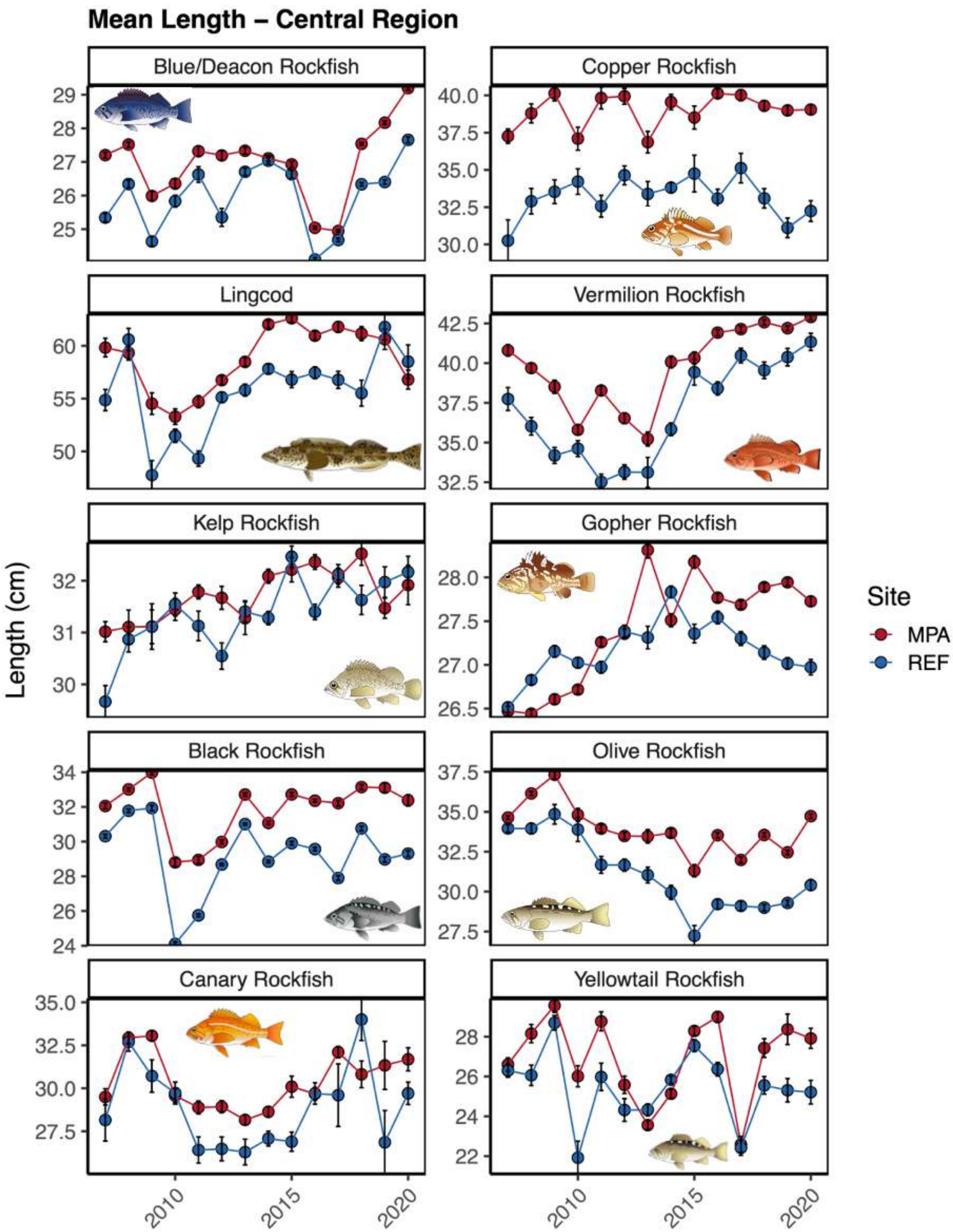


Figure 7. Time series of mean lengths inside and outside of MPAs for each of the ten most commonly caught species. Data are presented for all Central coast marine protected area (MPA) and Reference (REF) sites from 2007-2020. Shown are mean lengths each year ± 95%

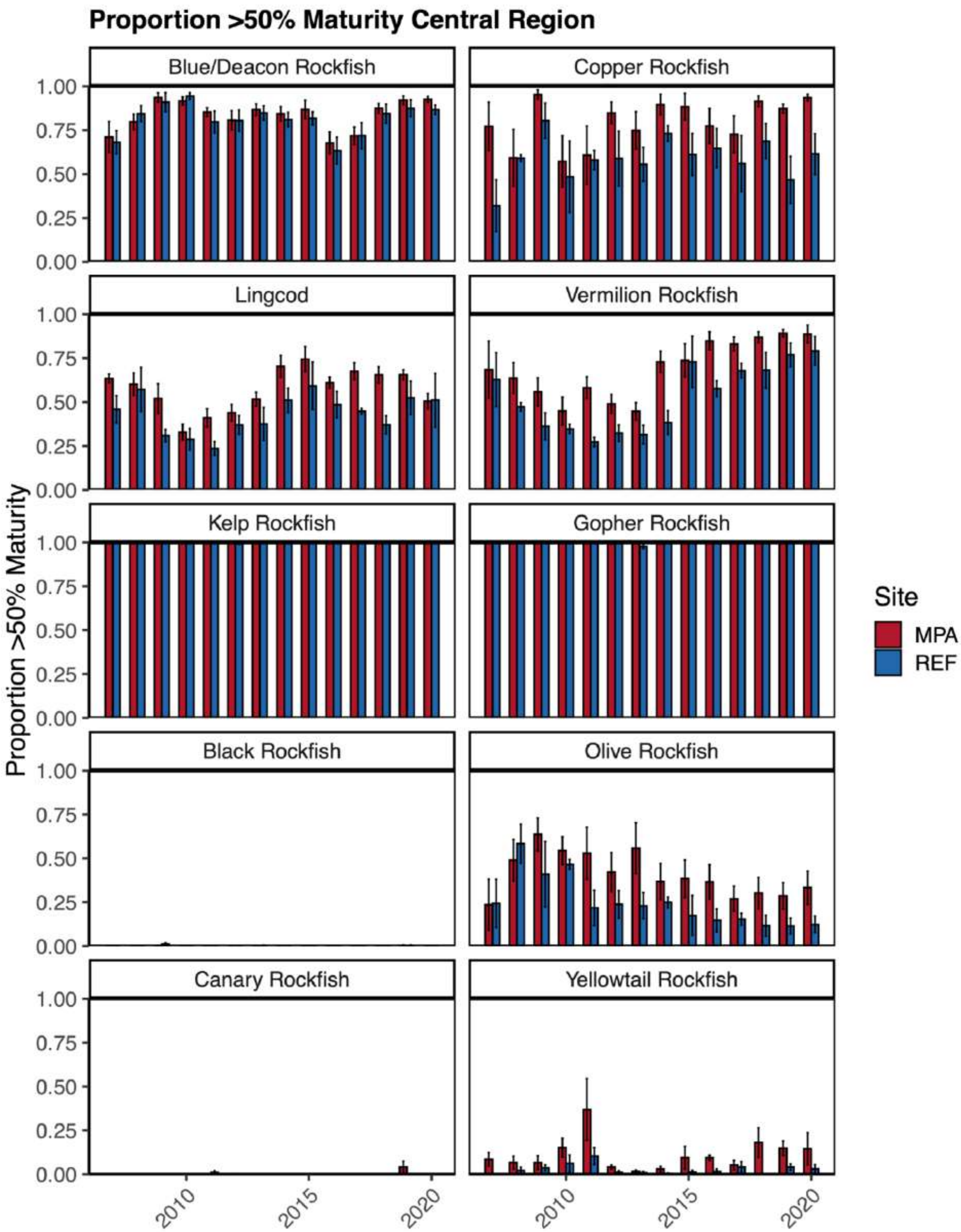


Figure 8. Proportion of individual fishes for each of the ten most commonly caught species that were greater than the length at 50% maturity. Data are presented for all Central coast marine protected area (MPA) and Reference (REF) sites from 2007-2020. Error bars are ± 95% CI.

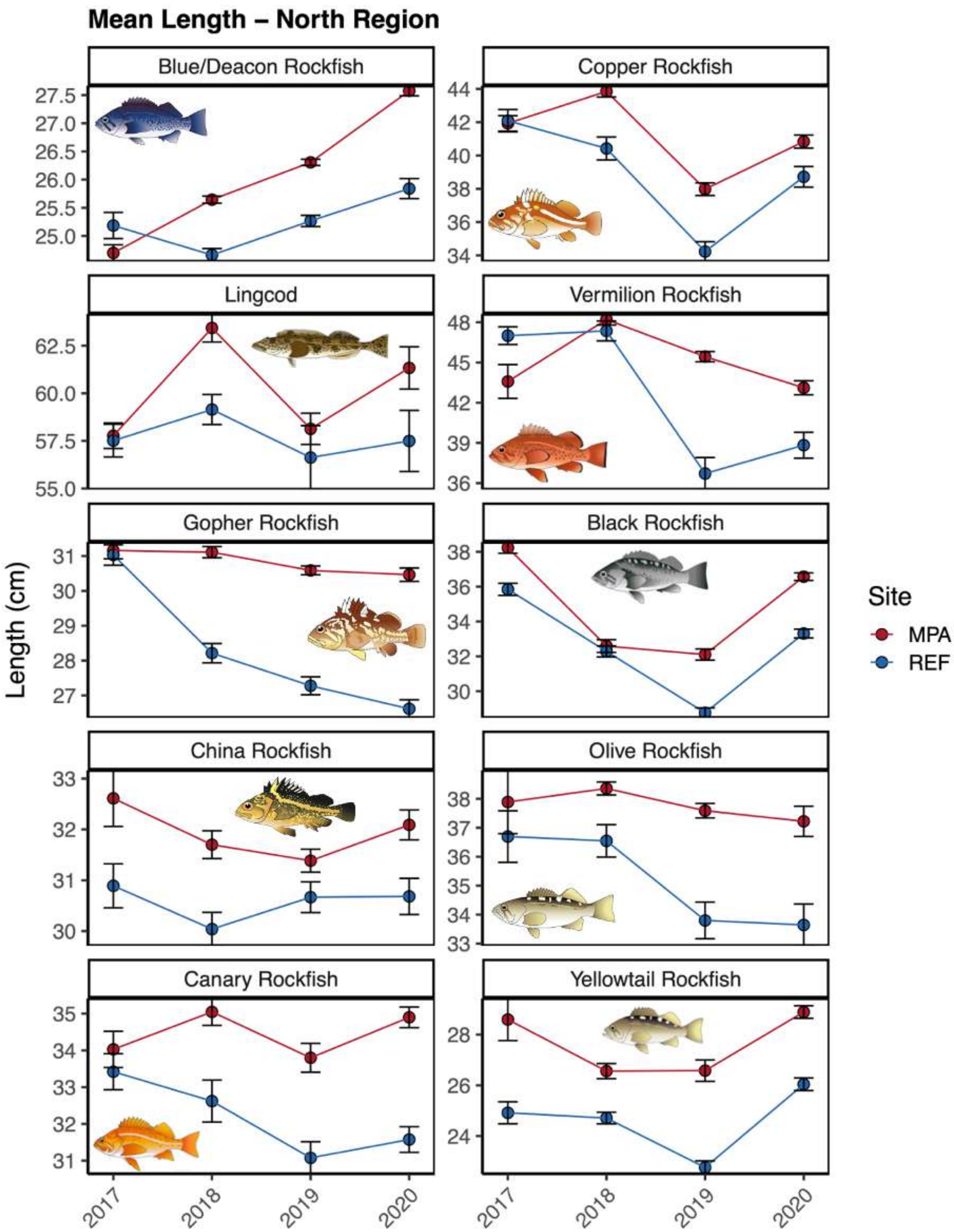


Figure 9. Time series of mean lengths inside and outside of MPAs for each of the ten most commonly caught species. Data are presented for the North coast marine protected area (MPA) and Reference (REF) sites from 2017-2020. Shown are mean lengths each year ± 95% CI.

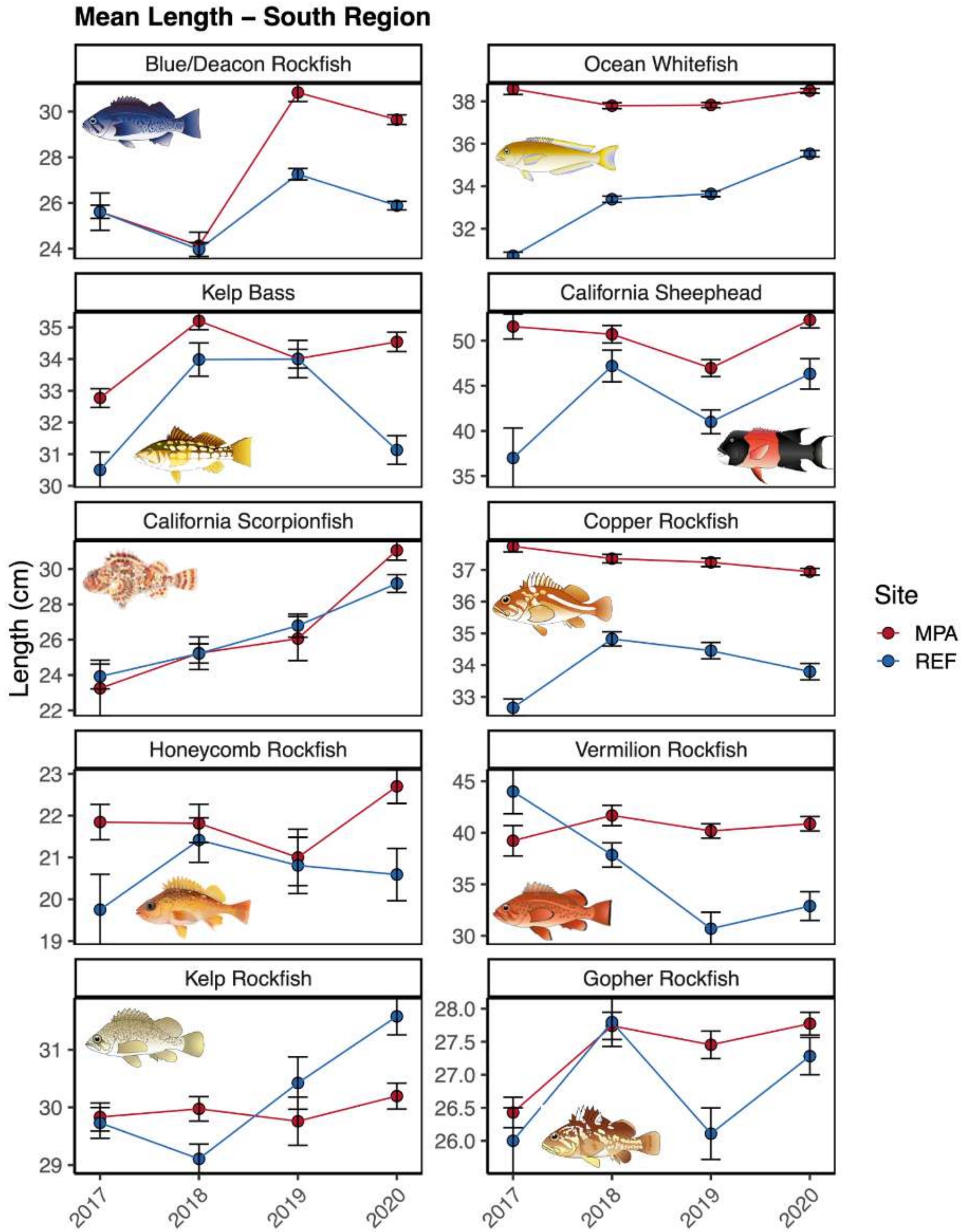


Figure 10. Time series of mean lengths inside and outside of MPAs for each of the ten most commonly caught species. Data are presented for the South coast marine protected area (MPA) and Reference (REF) sites from 2017-2020. Shown are mean lengths each year ± 95% CI.

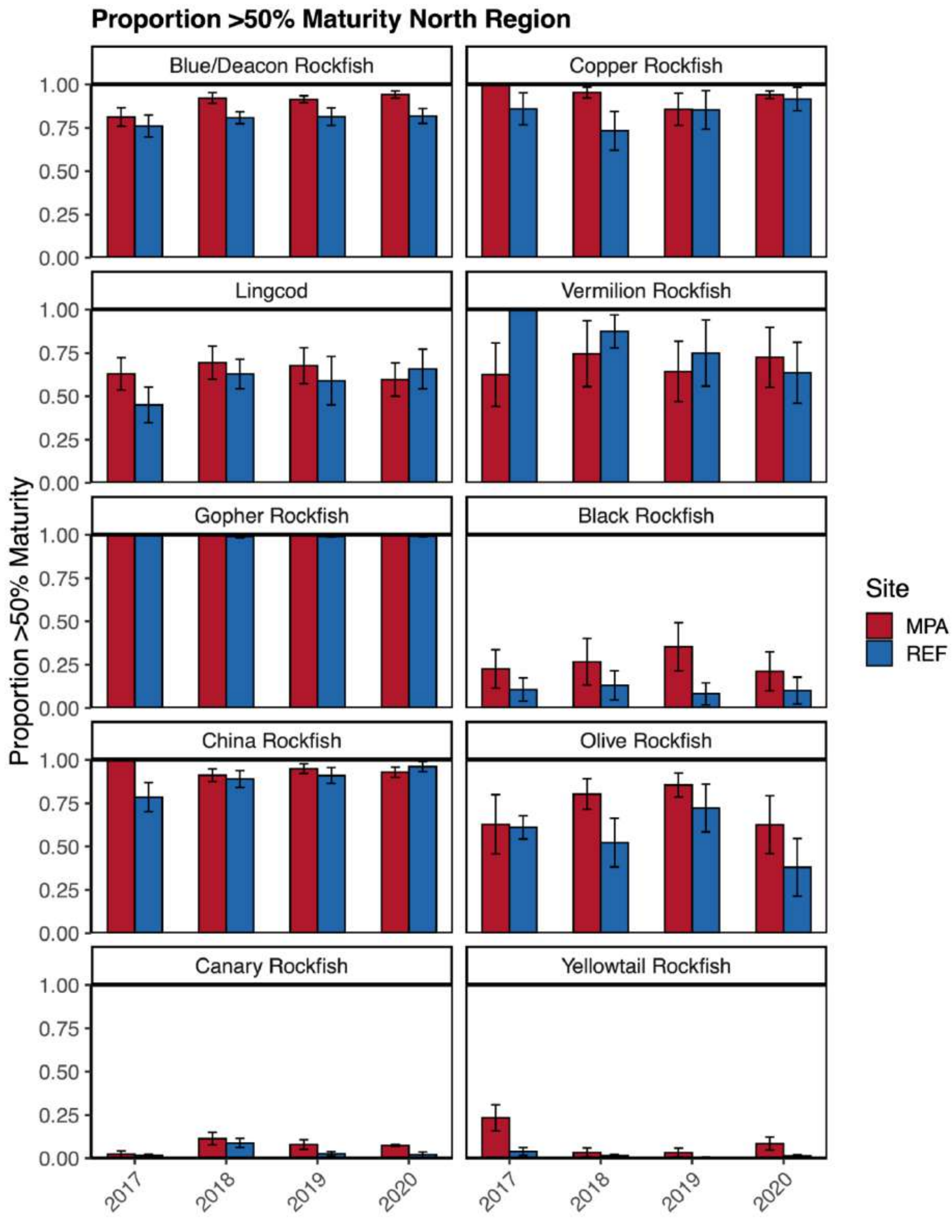


Figure 11. Proportion of individual fishes for each of the ten most commonly caught species that were greater than the length at 50% maturity. Data are presented for all North coast marine protected area (MPA) and Reference (REF) sites from 2017-2020. Shown are mean proportions ± 95% CI.

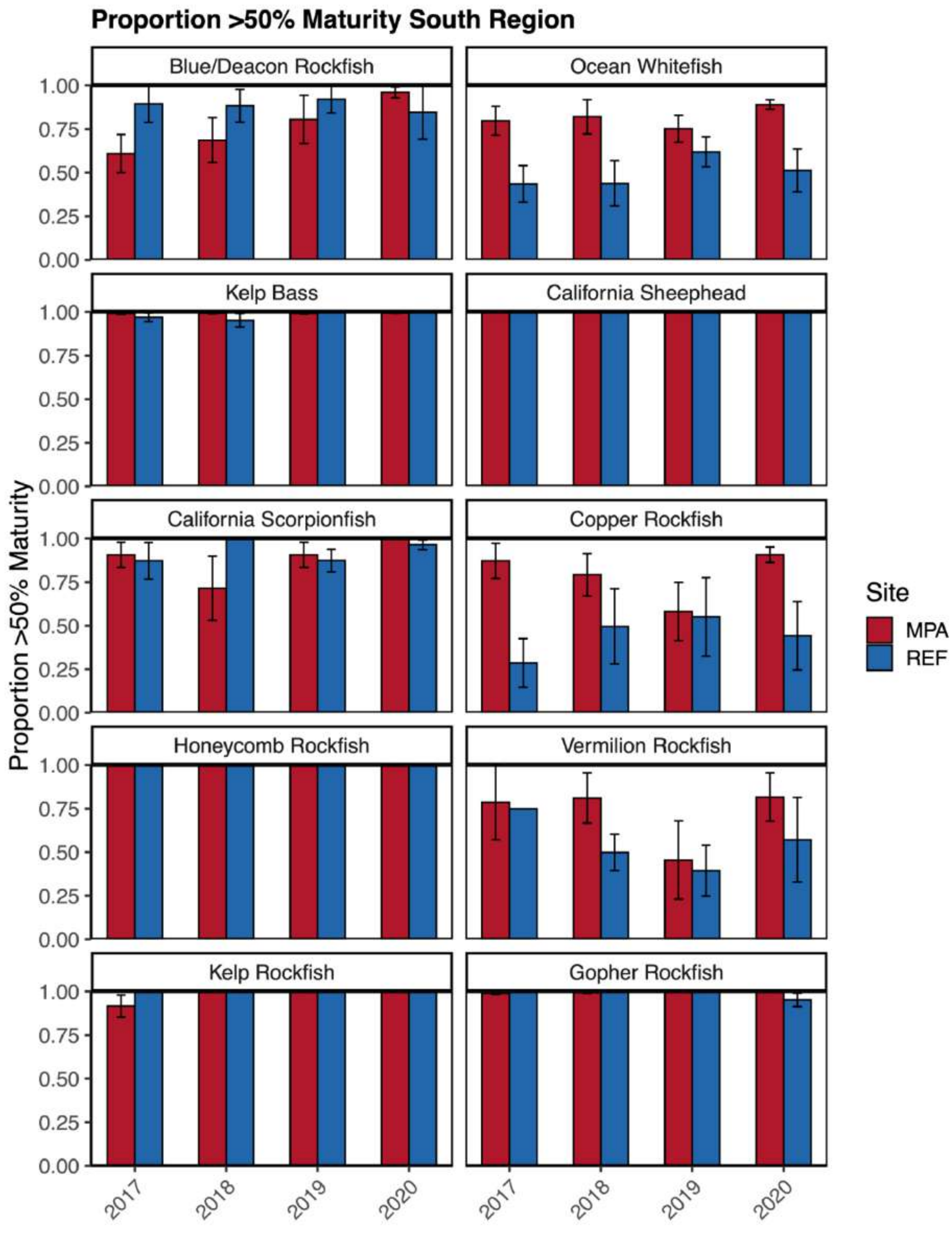


Figure 12. Proportion of individual fishes for each of the ten most commonly caught species that were greater than the length at 50% maturity. Data are presented for all South coast marine protected area (MPA) and Reference (REF) sites from 2017-2020. Shown are mean proportions ± 95% CI.

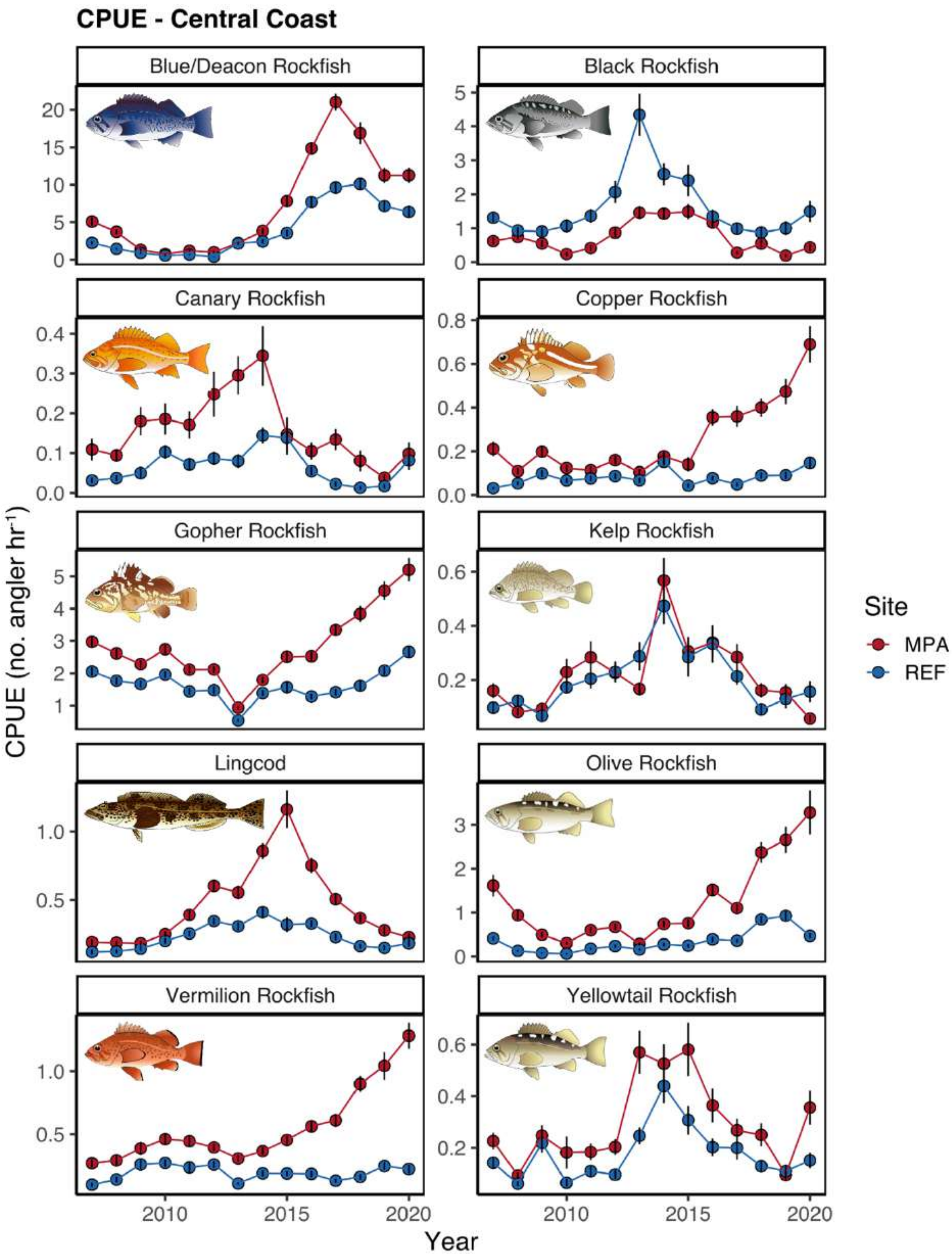


Figure 13. Mean catch per unit effort (CPUE) for the top 10 most abundant species caught across the Central coast. Red points denote mean CPUE across Central coast MPAs, and blue points denote mean CPUE across Central coast Reference areas. Error bars are ± 95% CI.

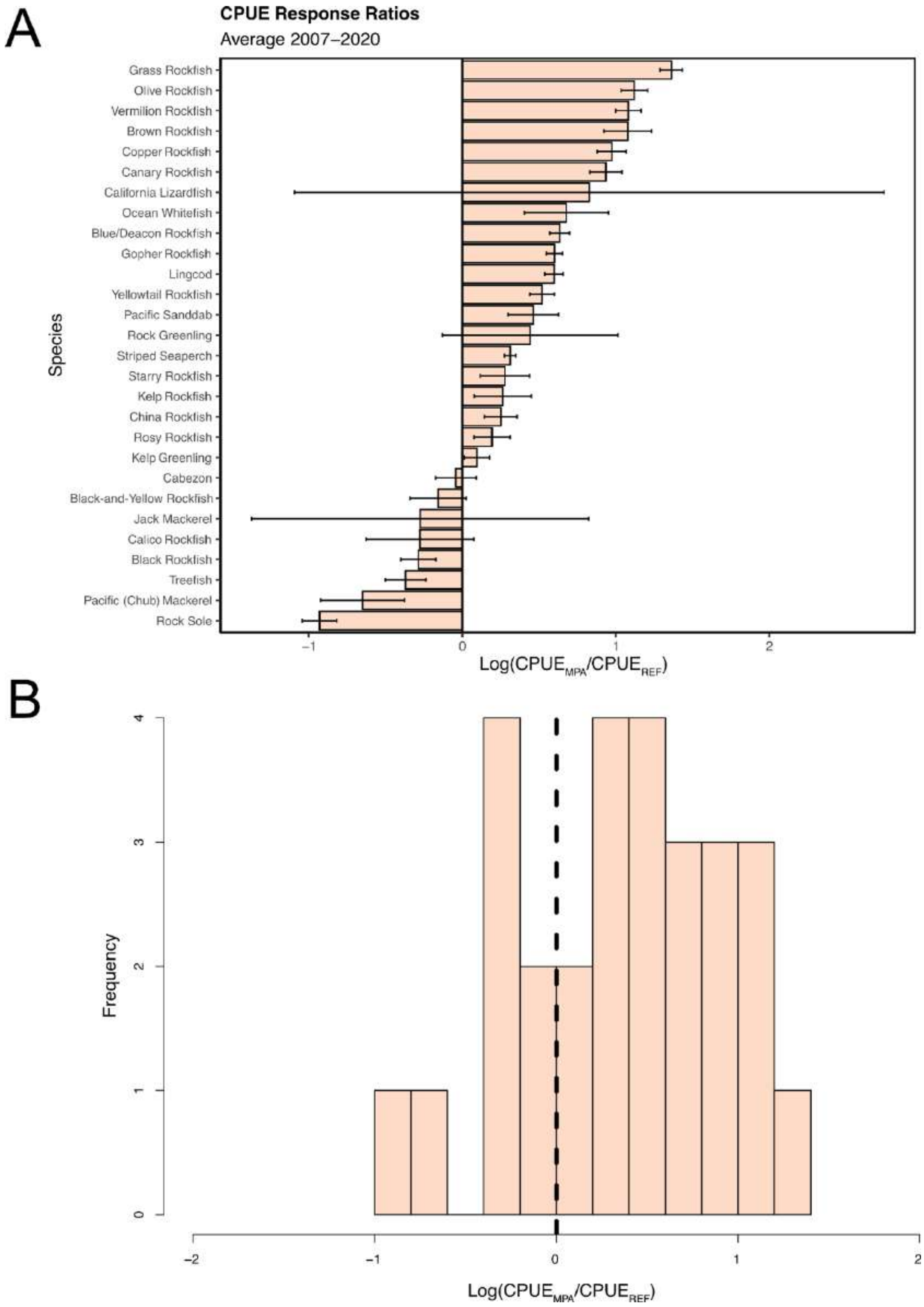


Figure 14. (A) Tornado plot of CPUE response ratios for all species surveyed between 2007-2020 in the Central coast. Bars are the mean response ratio per species and errors are ± 95% CI; (B) Histograms with the frequency of positive and negative CPUE response ratios in the Central coast.

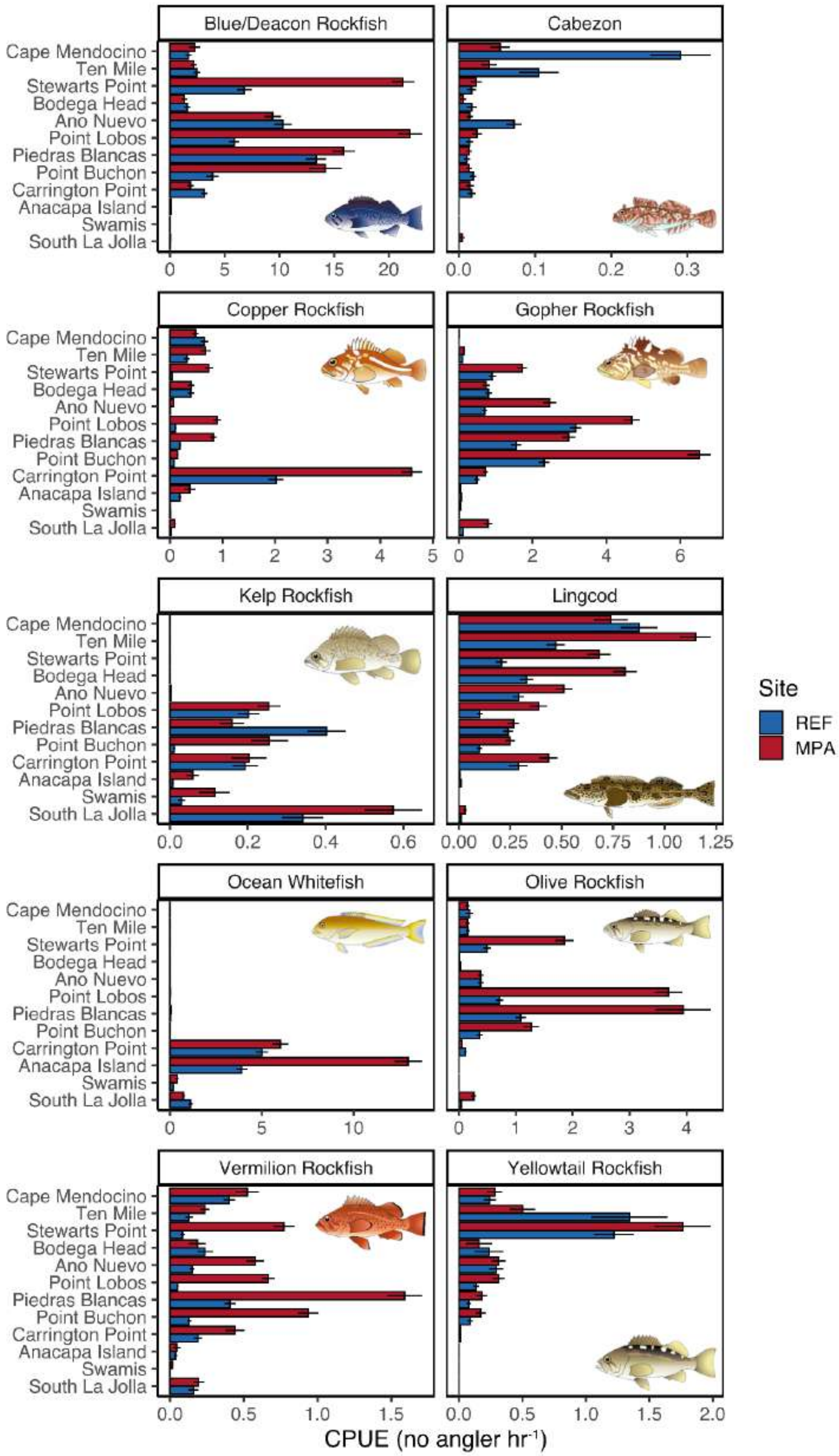


Figure 15. Mean catch per unit effort (CPUE) of indicator fish species from 2017-2020 across all sites sampled statewide. Sites are arranged from North to South to highlight geographic variation in biomass, with paired MPA (red) and Reference (blue) sites. Error bars are ± 95% CI.

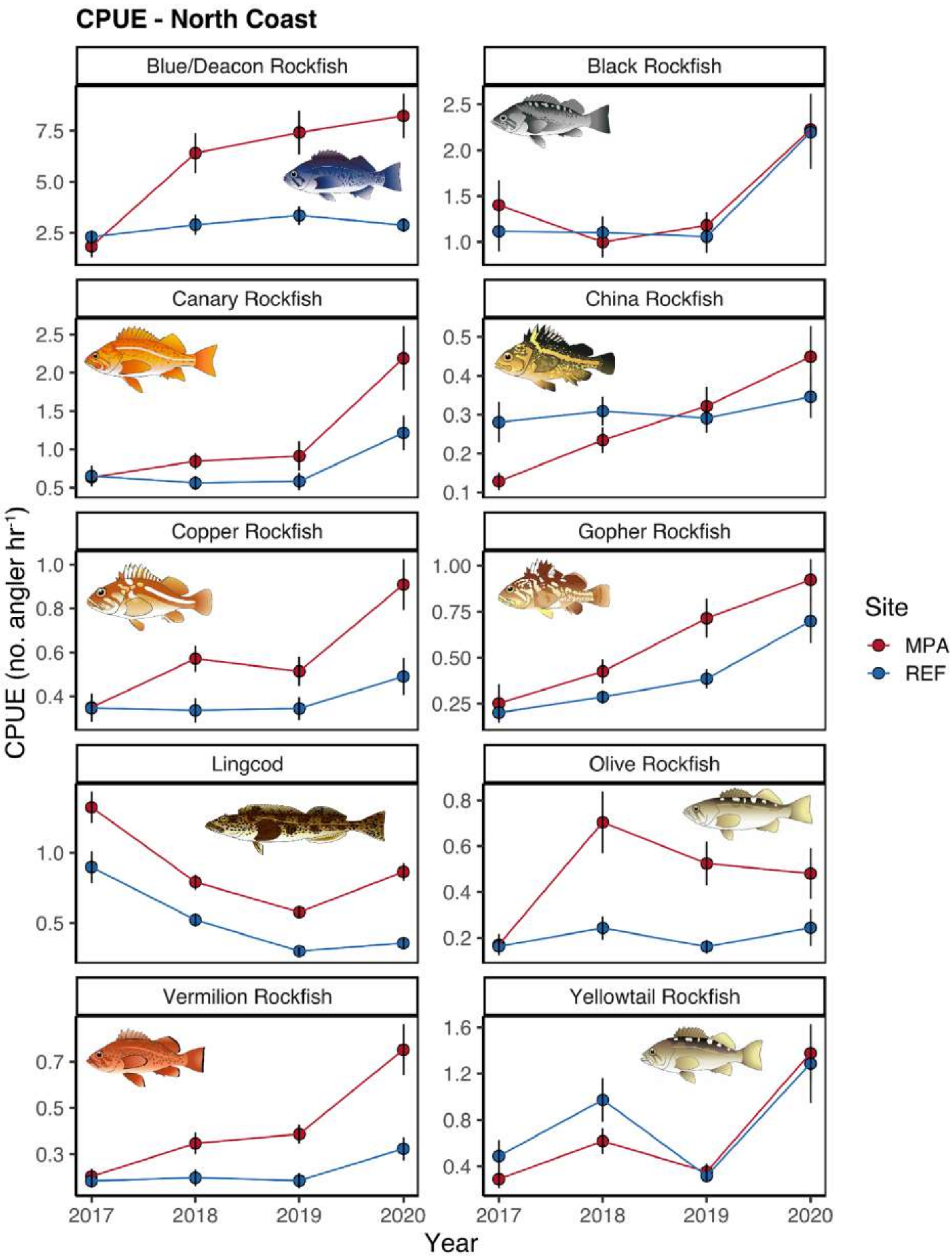


Figure 16. Mean catch per unit effort (CPUE) for the top 10 most abundant species caught across the North coast. Red points denote mean CPUE across North coast MPAs, and blue points denote mean CPUE across North coast Reference sites. Error bars are ± 95% CI.

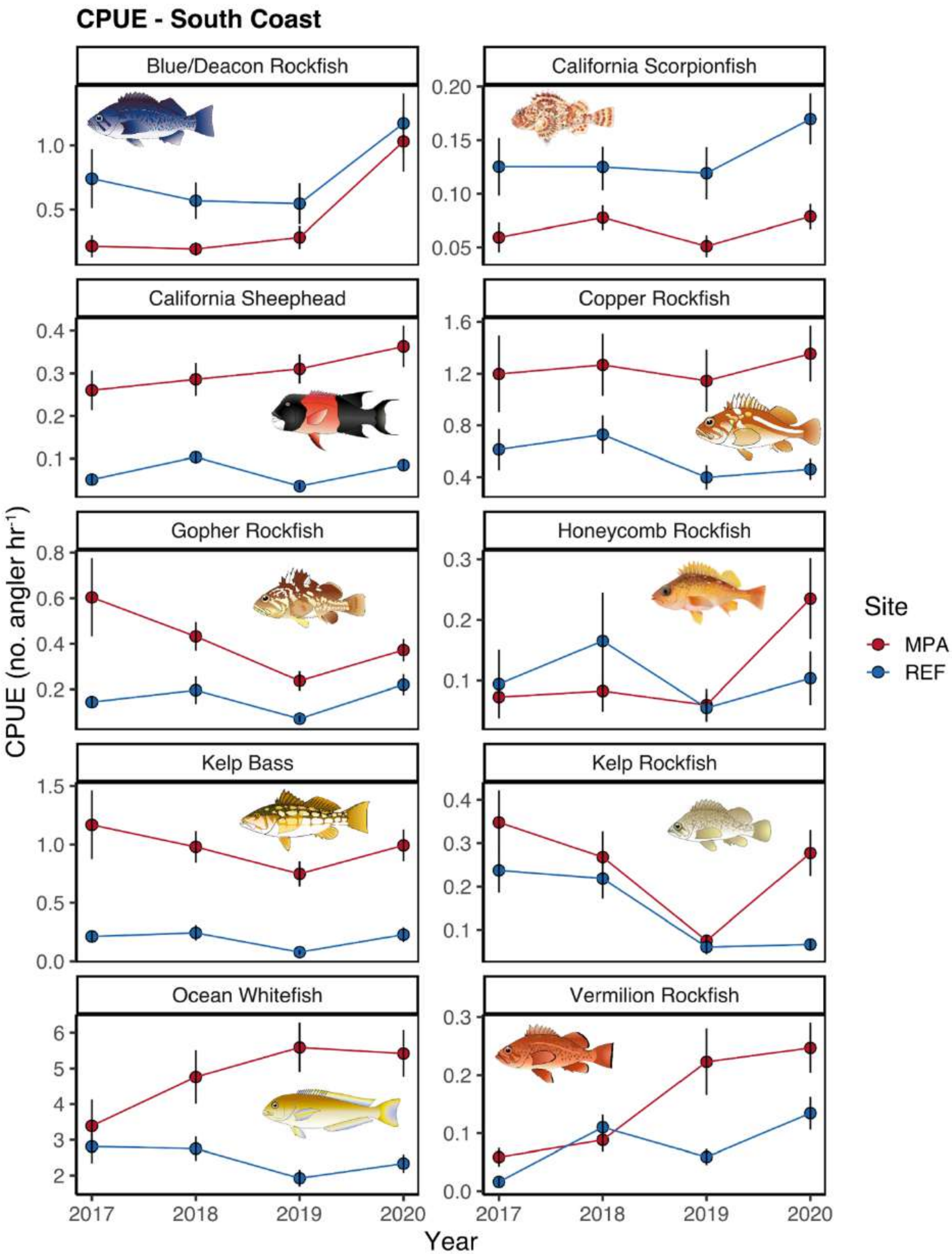


Figure 17. Mean catch per unit effort (CPUE) for the top 10 most abundant species caught across the South coast. Red points denote mean CPUE across South coast MPAs, and blue points denote mean CPUE across South coast Reference sites. Error bars are ± 95% CI.

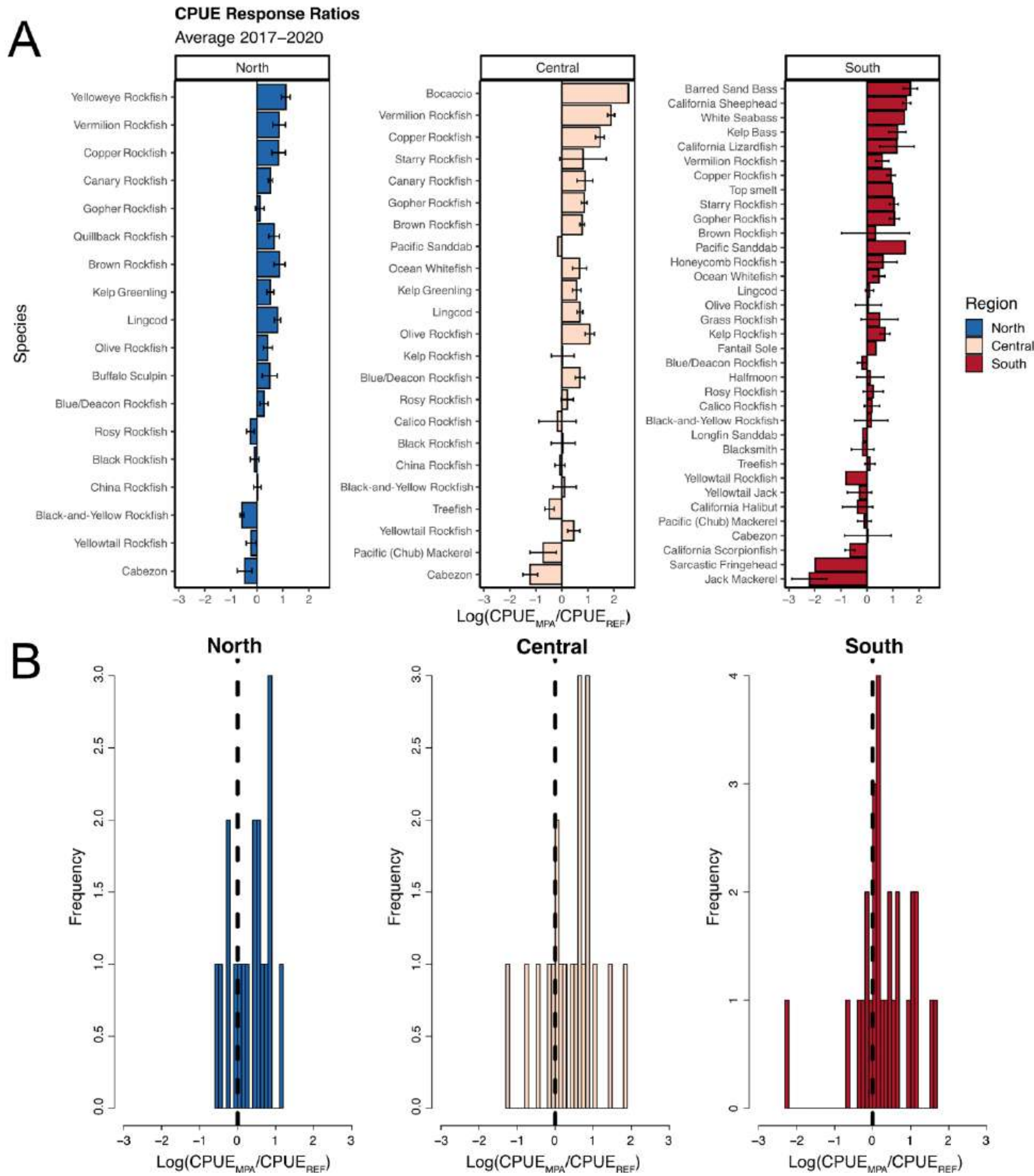


Figure 18. (A) Tornado plot of CPUE response ratios for all species surveyed between 2017-2020 across each region. Bars are the mean response ratio per species and errors are ± 95% CI; (B) Histograms with the frequency of positive and negative CPUE response ratios for each region.

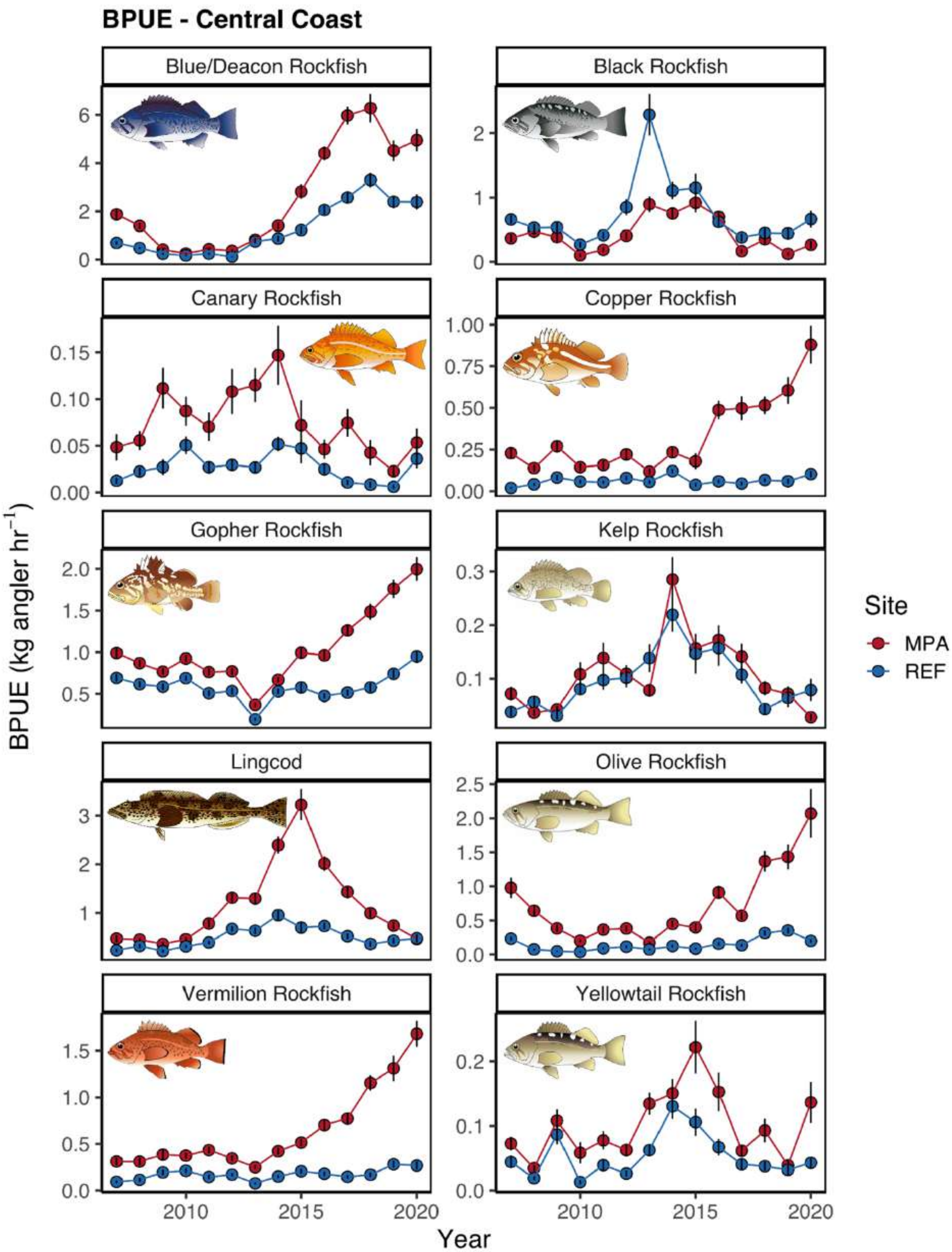


Figure 19. Mean biomass per unit effort (BPUE) for the top 10 most abundant species caught across the Central coast. Red points denote mean BPUE across Central coast MPAs, and blue points denote mean BPUE across Central coast Reference sites. Error bars are ± 95% CI.

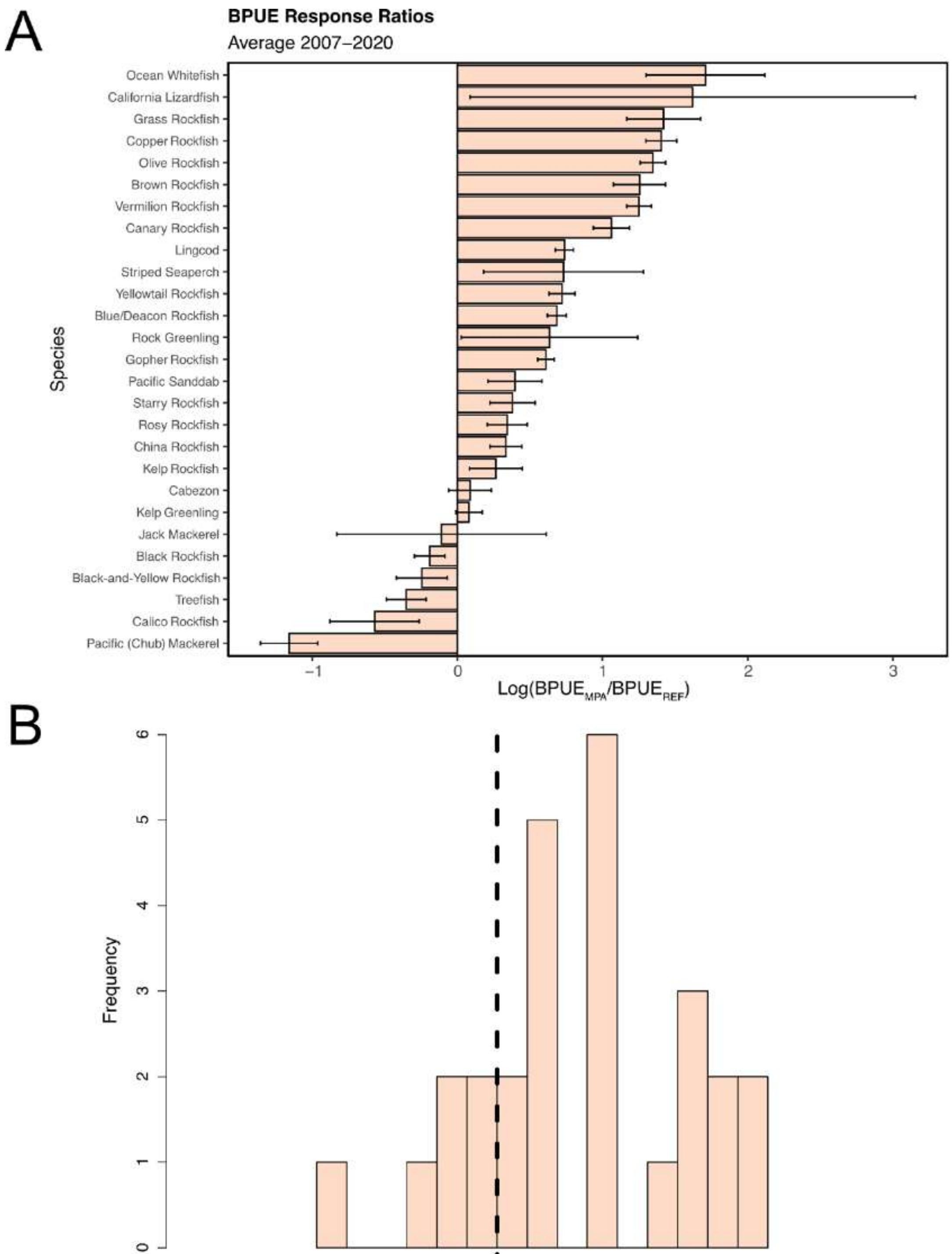


Figure 20. (A) Tornado plot of BPUE response ratios for all species surveyed between 2007-2020 in the Central coast; (B) Histograms with the frequency of positive and negative BPUE response ratios in the Central coast. Bars are the mean response ratio per species and errors are ± 95% CI.

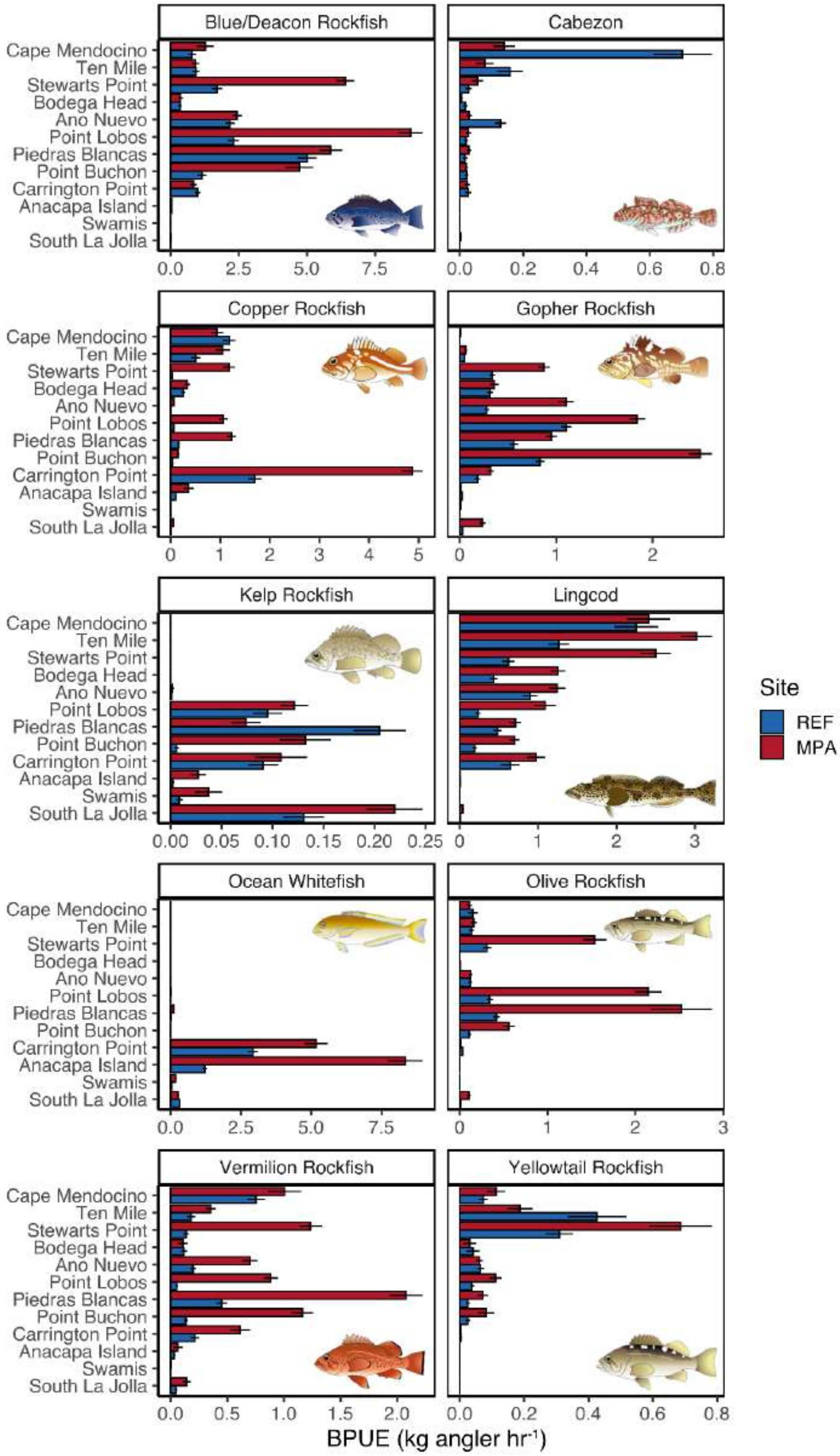


Figure 21. Mean biomass per unit effort (BPUE) of indicator fish species from 2017-2020 across all sites sampled statewide. Sites are arranged from North to South to highlight geographic variation in biomass, with paired MPA (red) and Reference (blue) sites. Error bars are ± 95% CI.

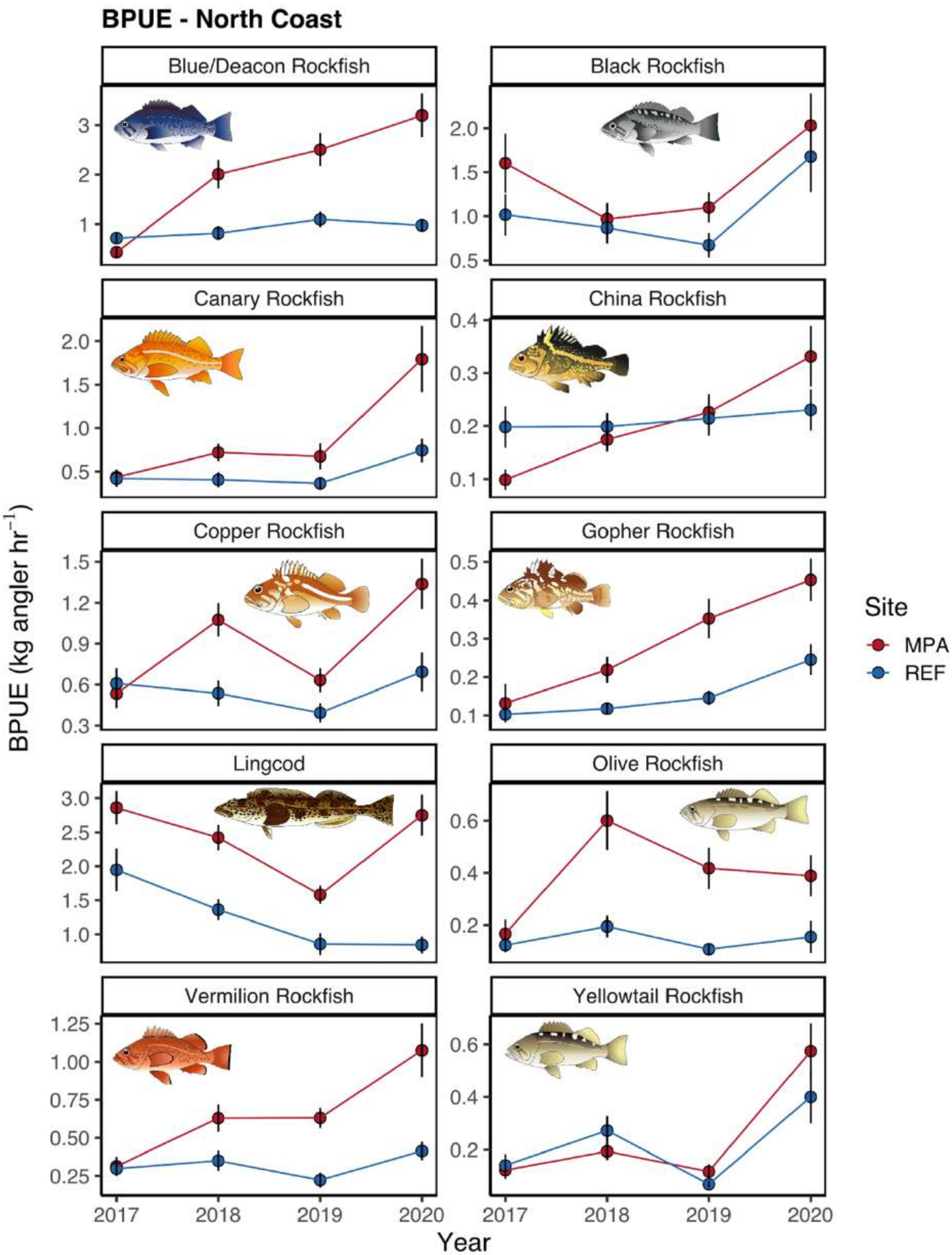


Figure 22. Mean biomass per unit effort (BPUE) for the top 10 most abundant species caught across the North coast. Red points denote mean CPUE across North coast MPAs, and blue points denote mean CPUE across North coast Reference sites. Error bars are ± 95% CI.

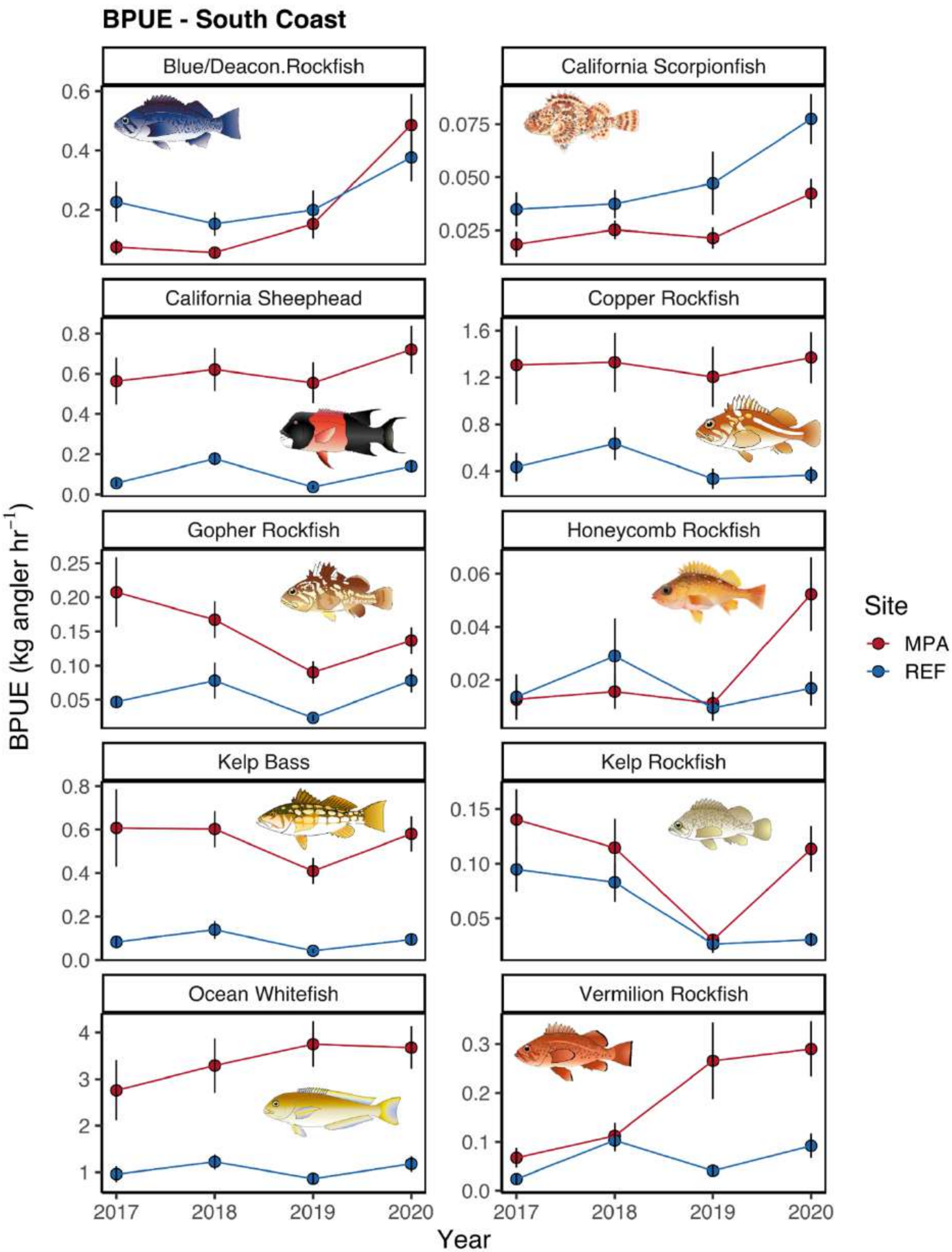


Figure 23. Mean biomass per unit effort (BPUE) for the top 10 most abundant species caught across the South coast. Red points denote mean CPUE across South coast MPAs, and blue points denote mean CPUE across South coast Reference sites. Error bars are ± 95% CI.

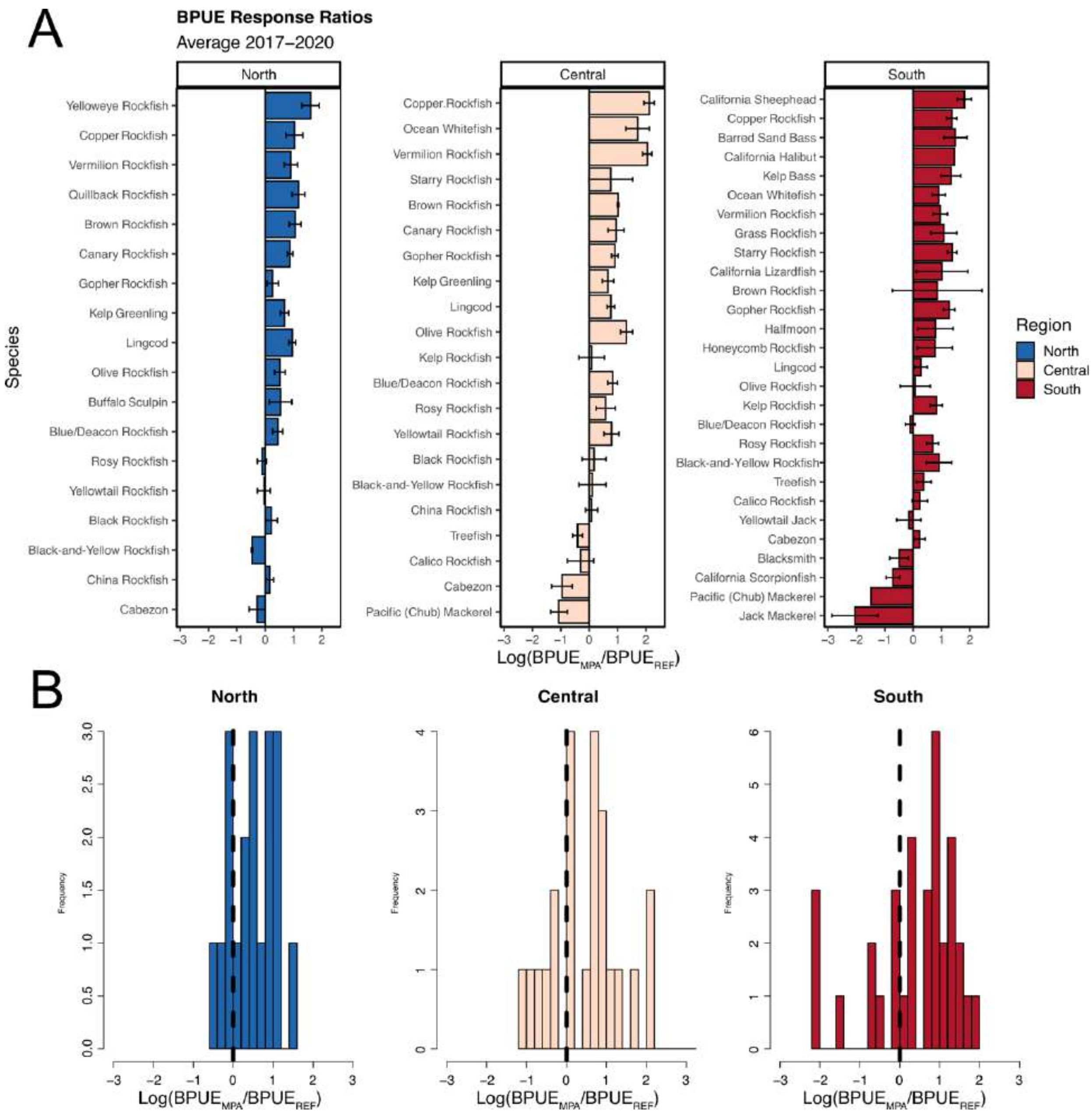


Figure 24. (A) Tornado plot of BPUE response ratios for all species surveyed between 2017-2020 across each region. Bars are the mean response ratio per species and errors are ± 95% CI; (B) Histograms with the frequency of positive and negative BPUE response ratios.

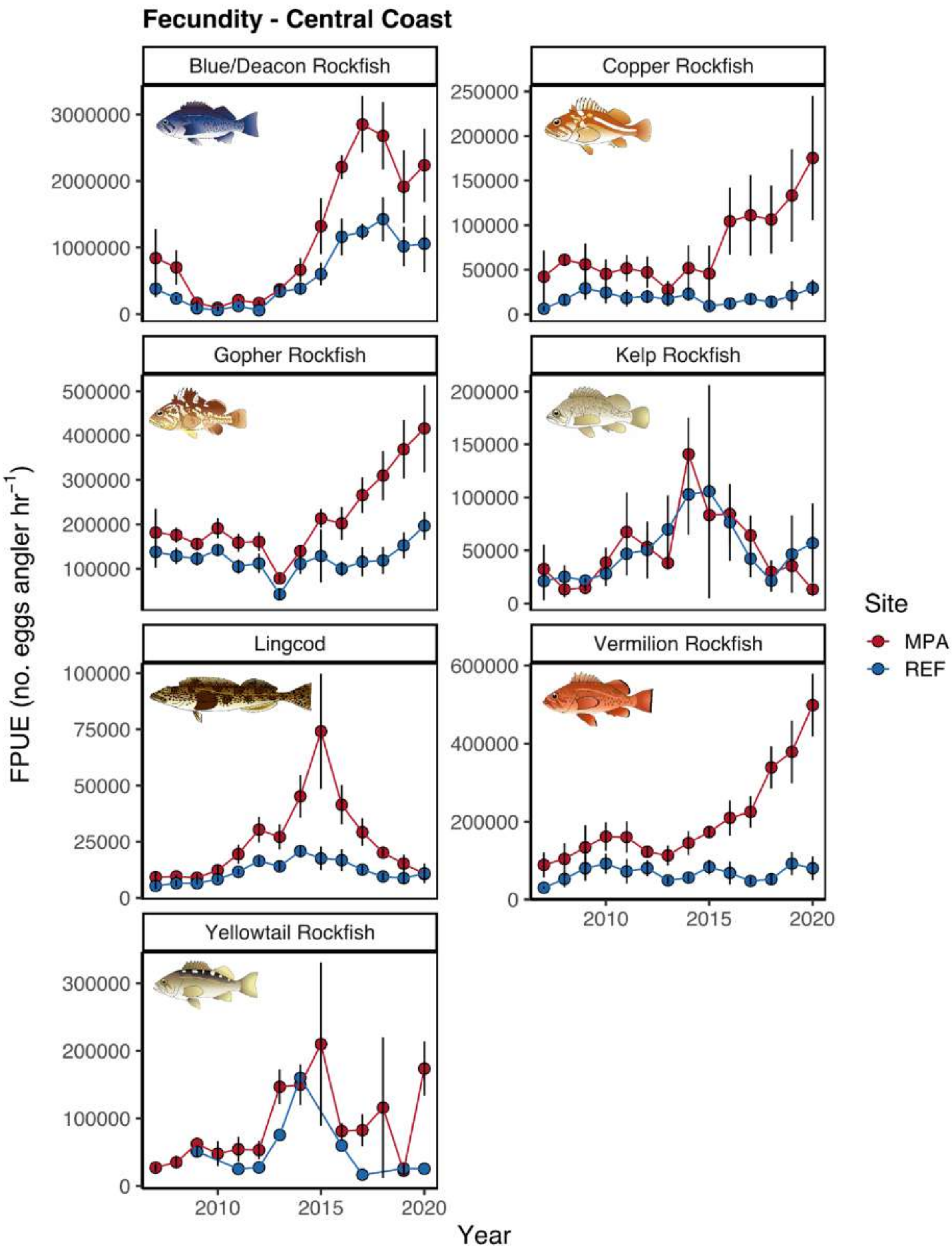


Figure 25. Mean fecundity per unit effort (FPUE) for the 7 of the top 10 most abundant species caught across the Central coast. Red points denote mean FPUE across Central coast MPAs, and blue points denote mean FPUE across Central coast Reference sites. Error bars are ± 95% CI.

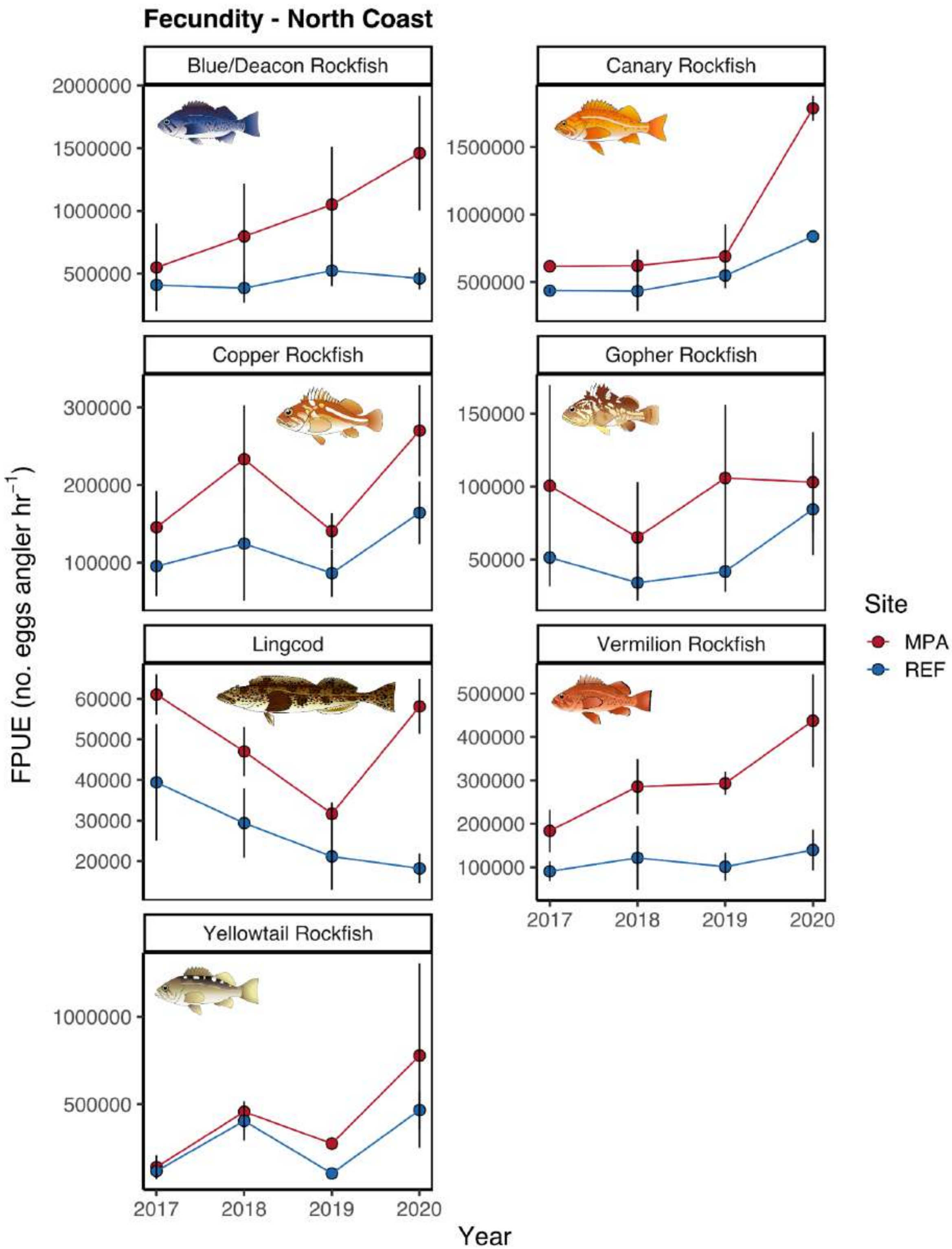


Figure 26. Mean fecundity per unit effort (FPUE) for 7 of the top 10 most abundant species caught across the North coast. Red points denote mean FPUE across North coast MPAs, and blue points denote mean FPUE across North coast Reference sites. Error bars are ± 95% CI.

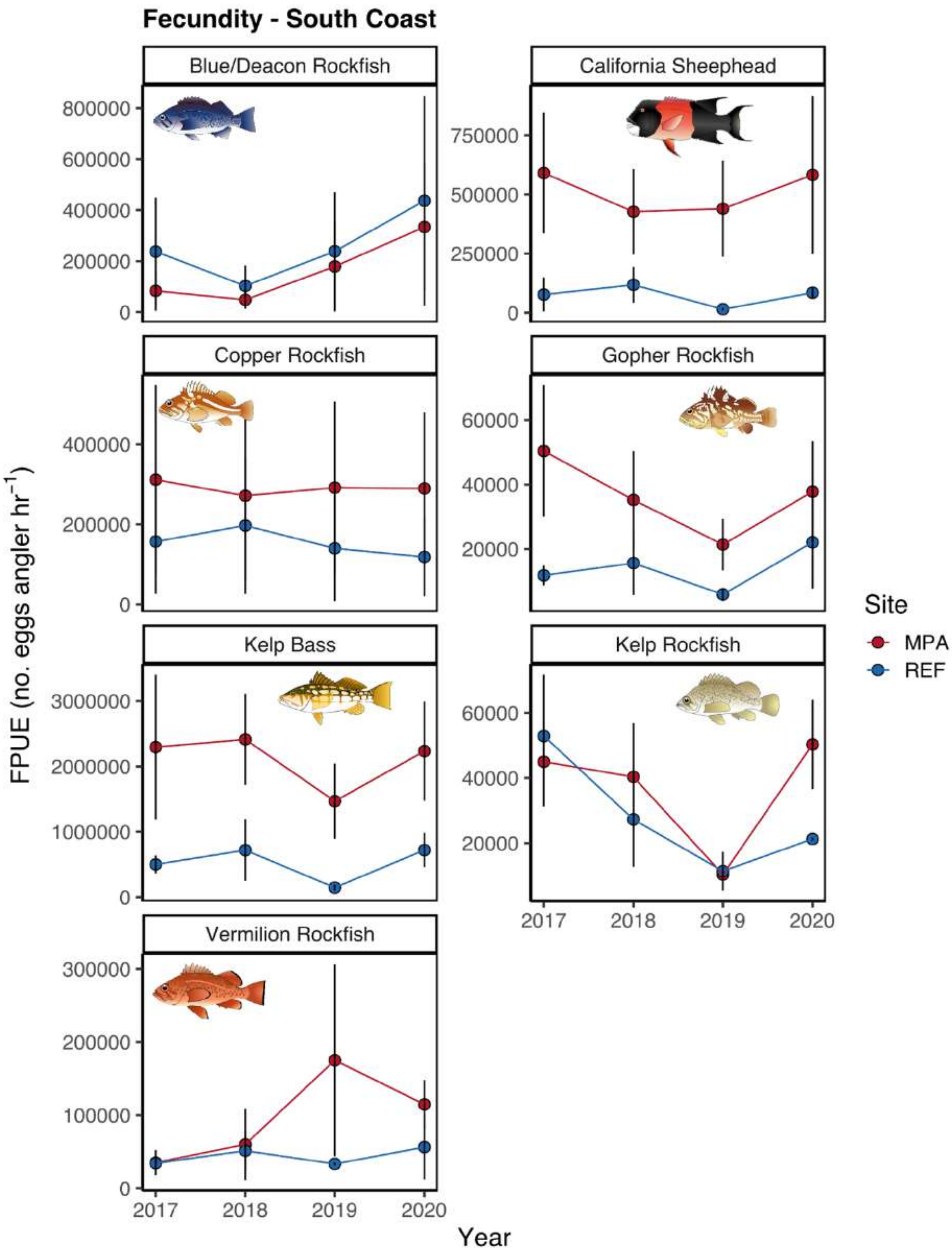


Figure 27. Mean fecundity per unit effort (FPUE) for 7 of the top 10 most abundant species caught across the South coast. Red points denote mean FPUE across South coast MPAs, and blue points denote mean FPUE across South coast Reference sites. Error bars are ± 95% CI.

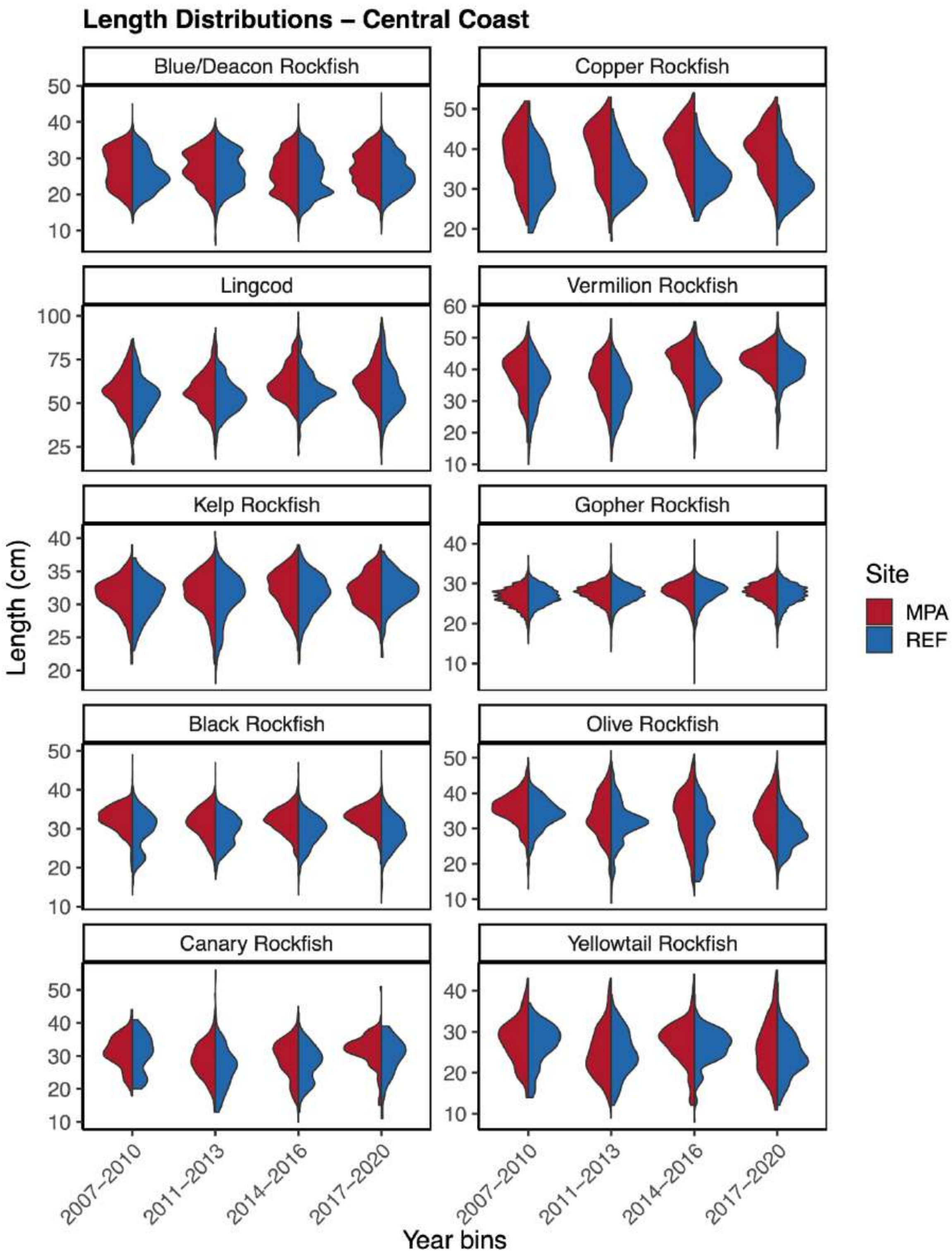


Figure 28. Length frequency distributions inside and outside of MPAs for each of the 10 most commonly caught species. Data are presented for all Central coast marine protected area (MPA) and reference (REF) sites from 2007-2020 with years binned into 3-4 year time frames. Size frequency histograms for MPAs (red) are on the left and for Reference sites (blue) on the right.

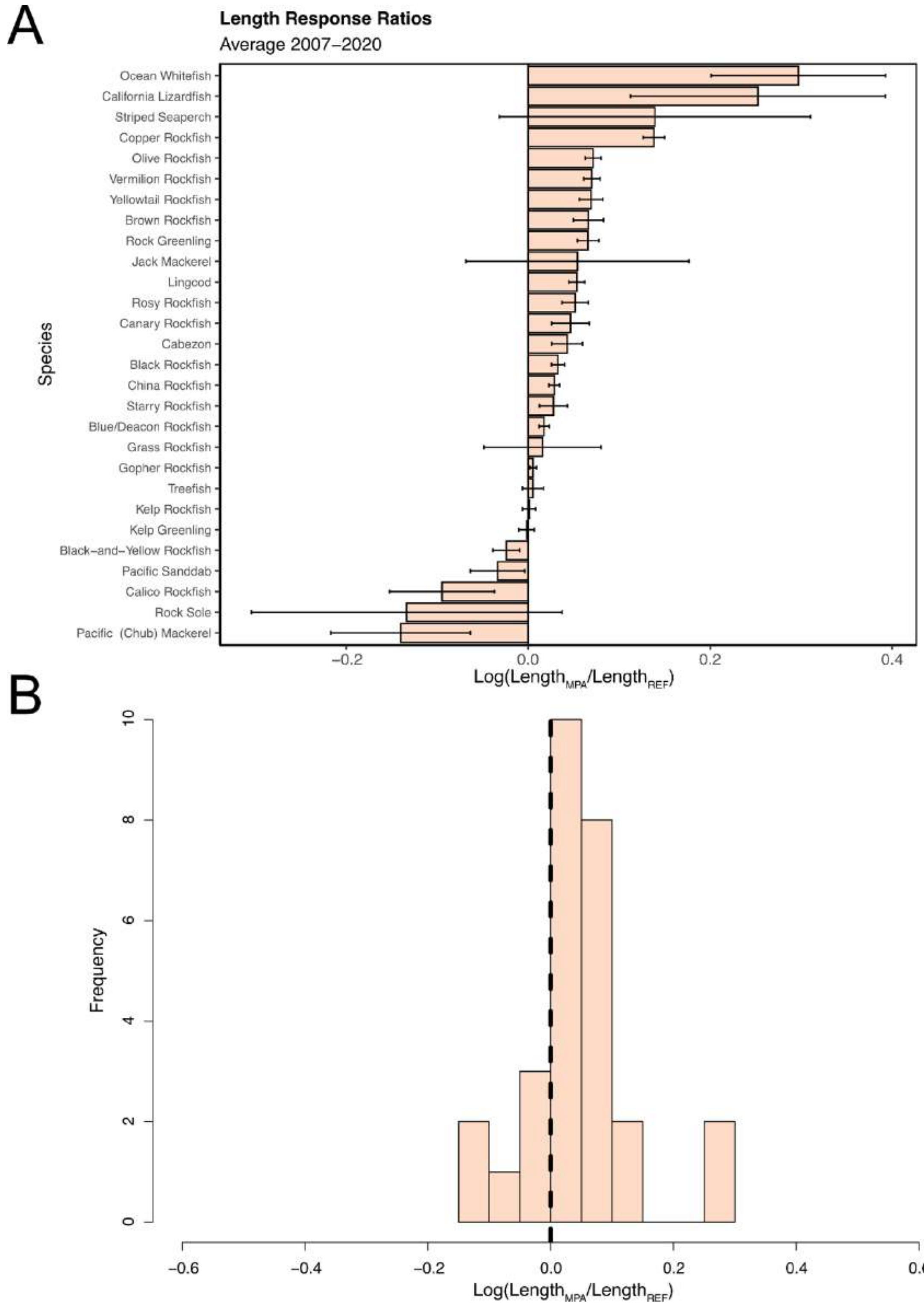


Figure 29. (A) Tornado plot of Length response ratios for all species surveyed between 2007-2020 in the Central coast; (B) Histograms with the frequency of positive and negative Length response ratios in the Central coast. Bars are the mean response ratio per species and errors are ± 95% CI.

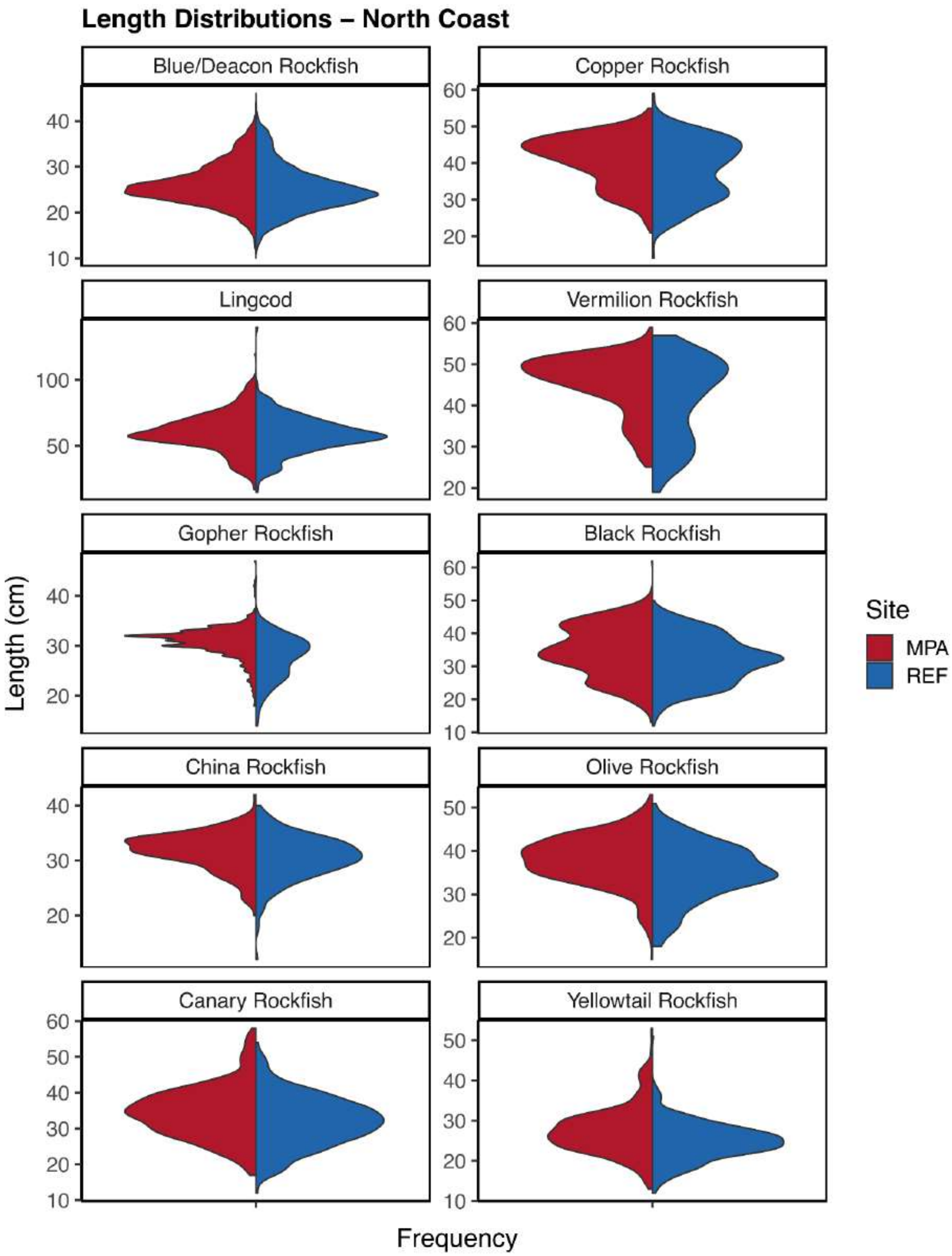


Figure 30. Length frequency distributions inside and outside of MPAs for each of the 10 most commonly caught species. Data are presented for all North coast marine protected area (MPA) and Reference sites from 2017-2020. Size frequency histograms for MPAs (red) are on the left and for Reference sites (blue) on the right.

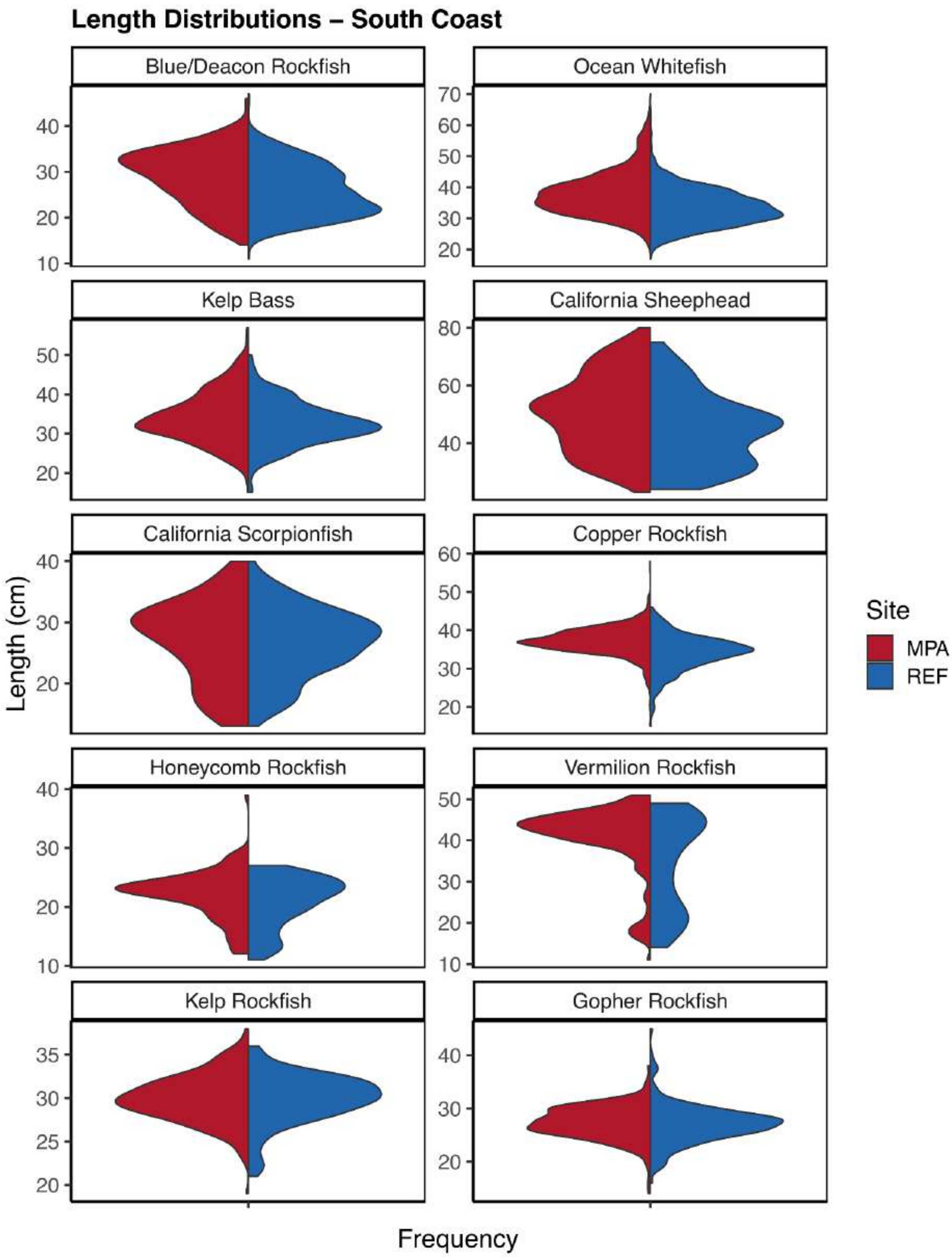


Figure 31. Length frequency distributions for inside and outside of MPAs for each of the 10 most commonly caught species. Data are presented for all South coast marine protected area (MPA) and Reference sites from 2017-2020. Size frequency histograms for MPAs (red) are on the left and for Reference sites (blue) on the right.

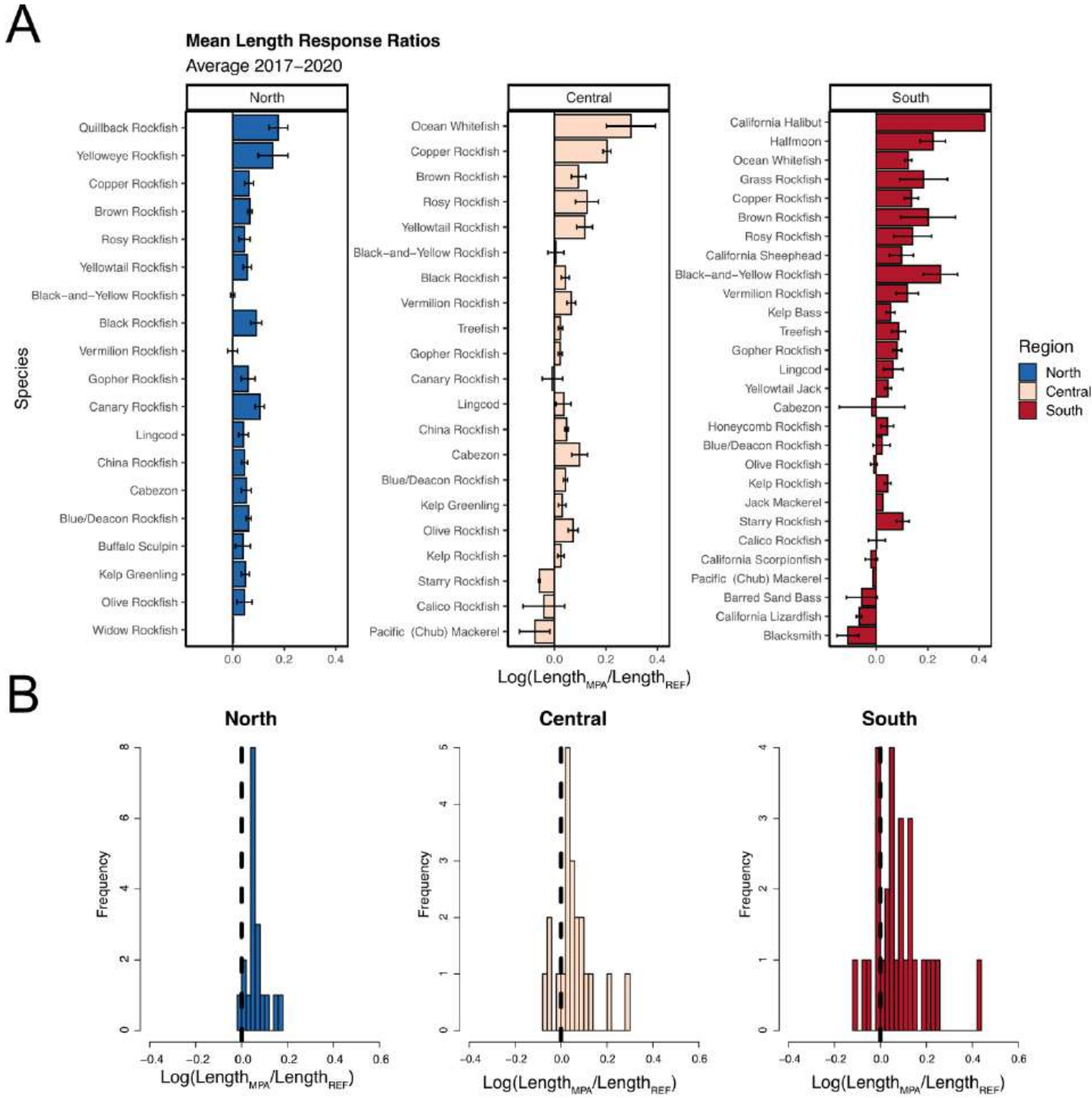
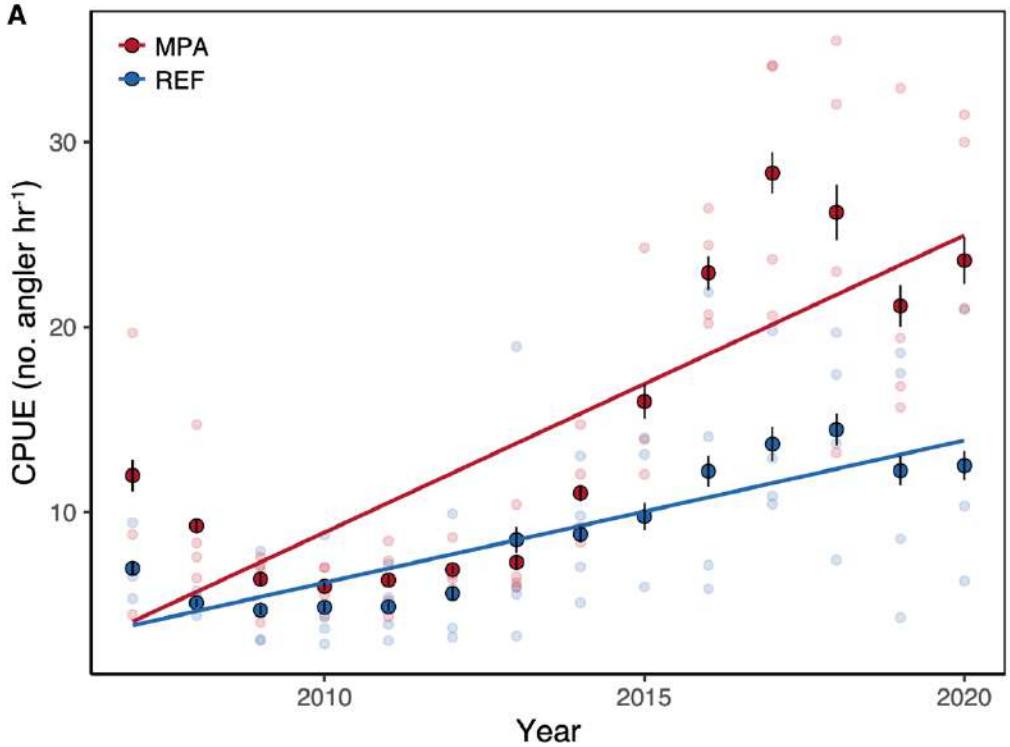


Figure 32. (A) Tornado plot of mean length (cm) response ratios for all species surveyed between 2017-2020 across each region. Bars are the mean response ratio per species and errors are ± 95% CI; (B) Histograms with the frequency of positive and negative length (cm) response ratios.



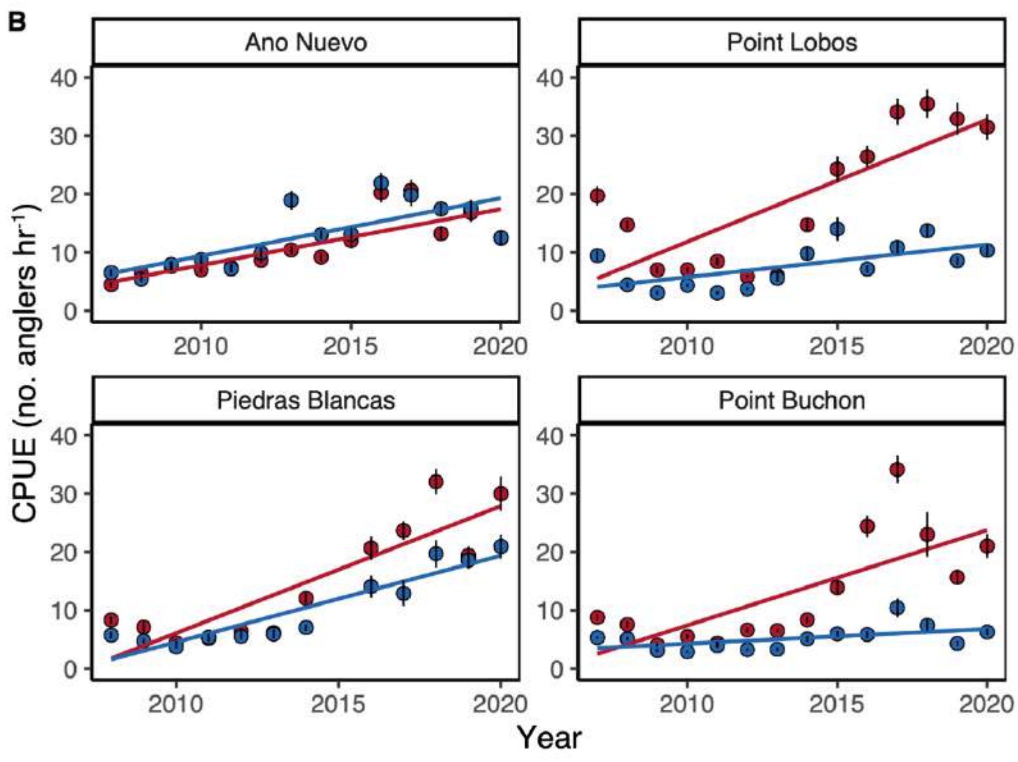


Figure 33. Total fish CPUE inside and outside of the (A) all Central coast MPAs and (B) each of the four MPAs sampled along the Central coast of California. All values are mean CPUE (catch per angler hour) ± 95% CIs. Trend lines are linear regressions for the effect of time since implementation (Year) on total fish biomass. Red indicates MPA and blue indicates Reference sites.

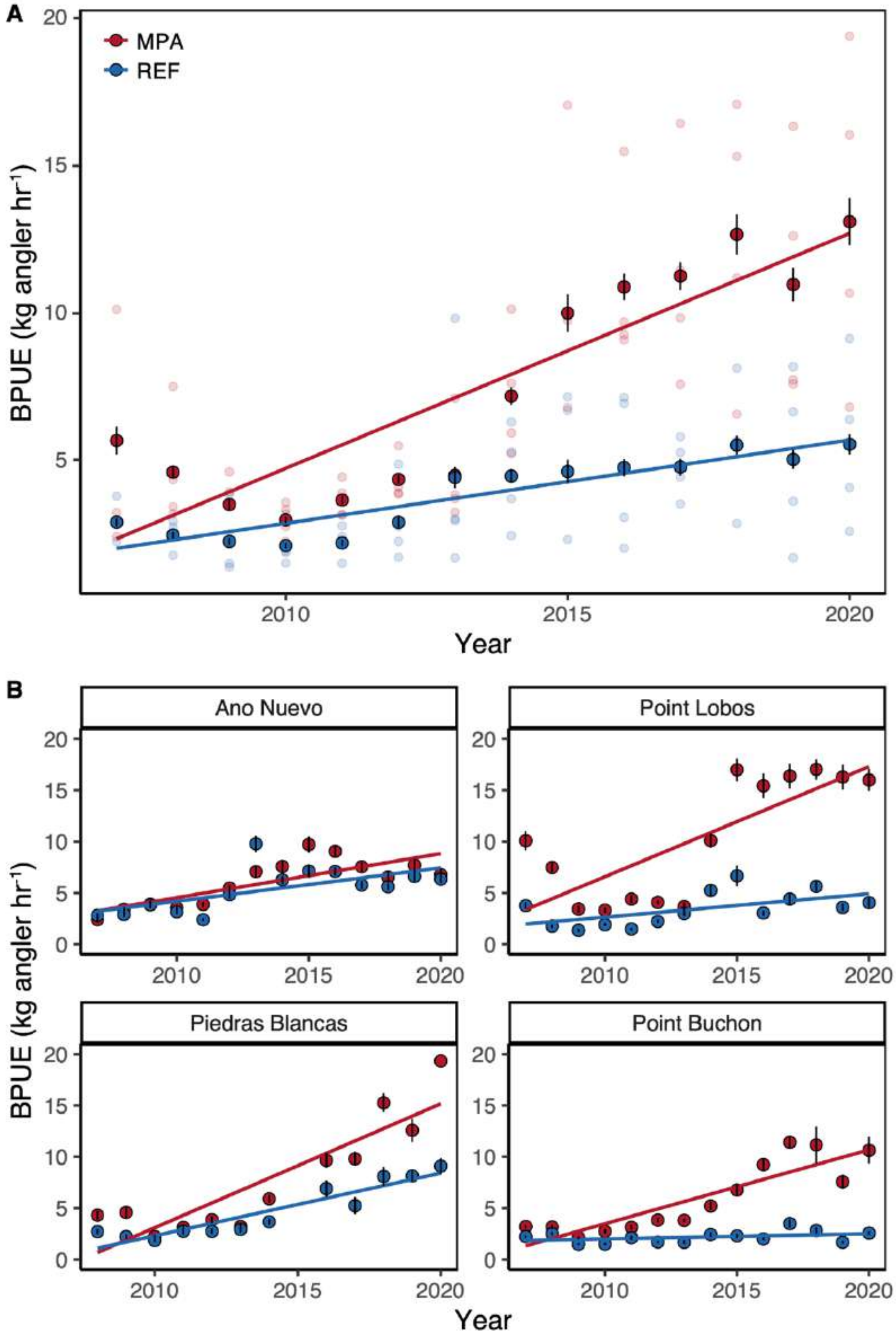


Figure 34. Total fish BPUE inside and outside of the (A) all Central coast MPAs and (B) each of the four MPAs sampled along the Central coast of California. All values are mean BPUE (biomass per angler hour) ± 95% CIs. Trend lines are linear regressions for the effect of time since implementation (Year) on total fish biomass. Red indicates MPA and blue indicates Reference sites.

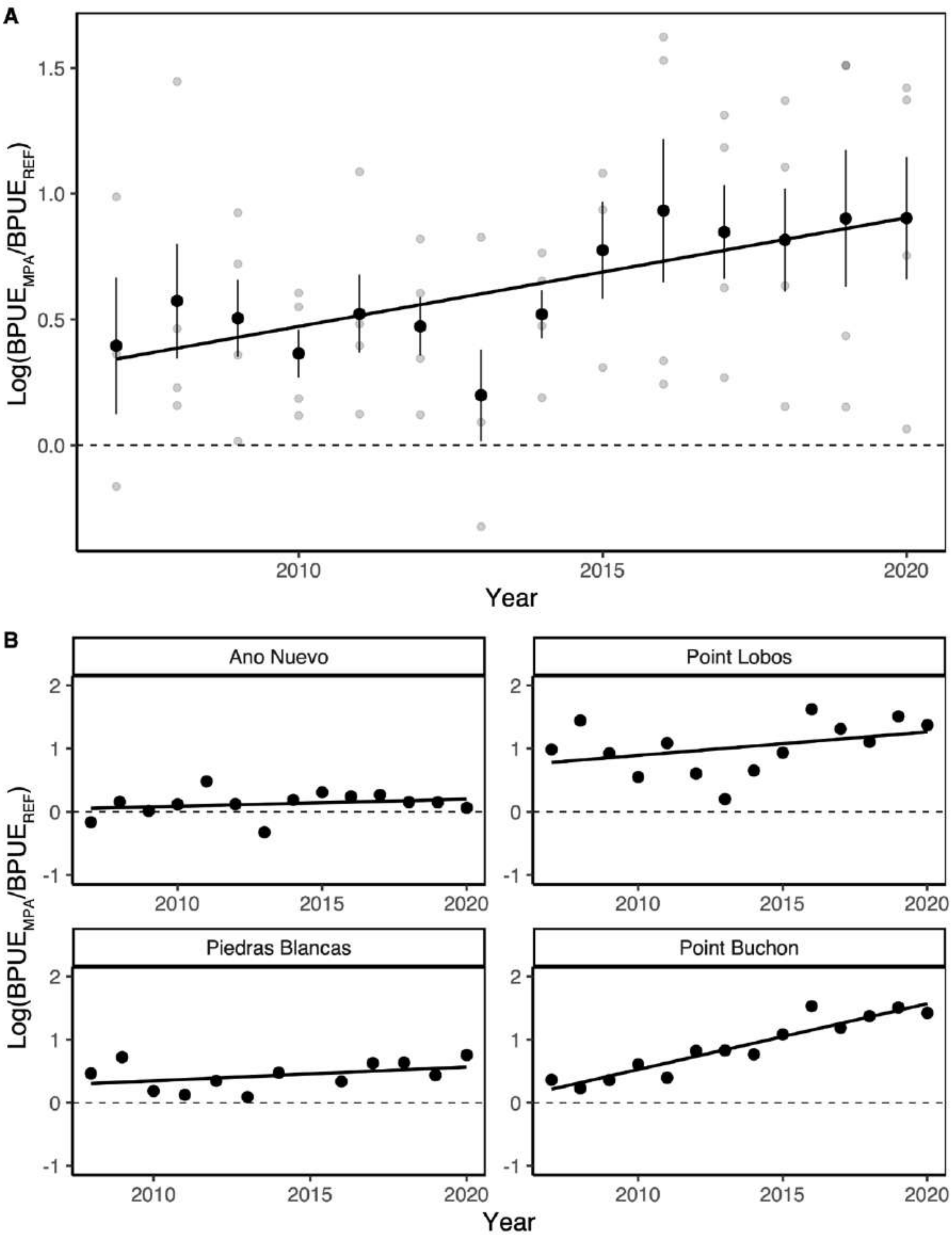


Figure 35. Biomass response ratios calculated from (A) all Central coast MPAs and (B) each of the four MPAs sampled along the Central coast of California. Lines are linear regressions examining response ratios as a function of time since MPA implementation. Values greater than zero indicate higher biomass per unit effort (BPUE) in the MPA compared to the paired Reference site, while values less than zero indicate higher BPUE in the Reference site compared to the MPA.

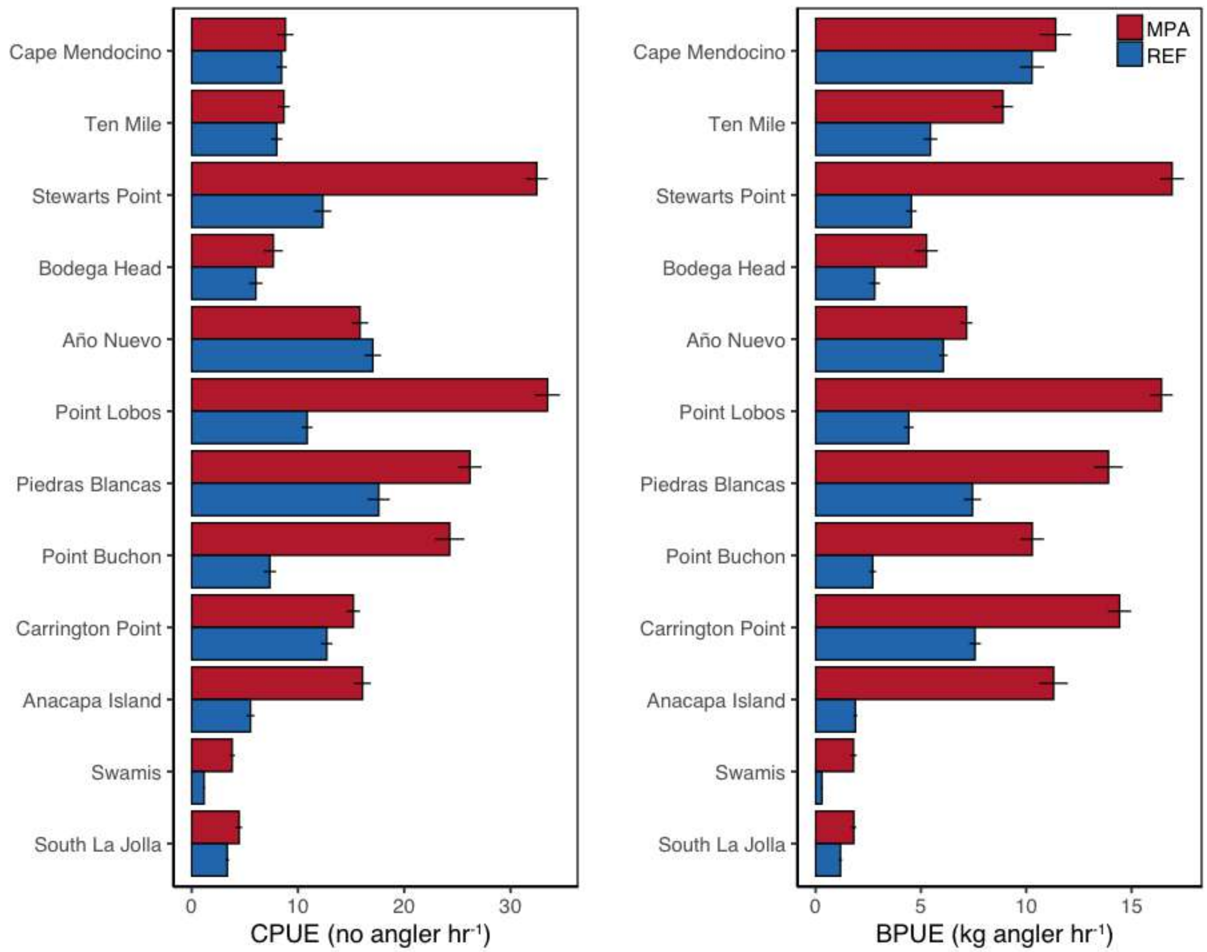


Figure 36. Geographic variation in total catch per unit effort (CPUE) and total biomass per unit effort (BPUE) across all sites sampled statewide from 2017-2020. Sites are arranged from North to South, with paired MPA (red) and Reference (blue) sites. Bars are annual means while error bars are ± 95% CI.

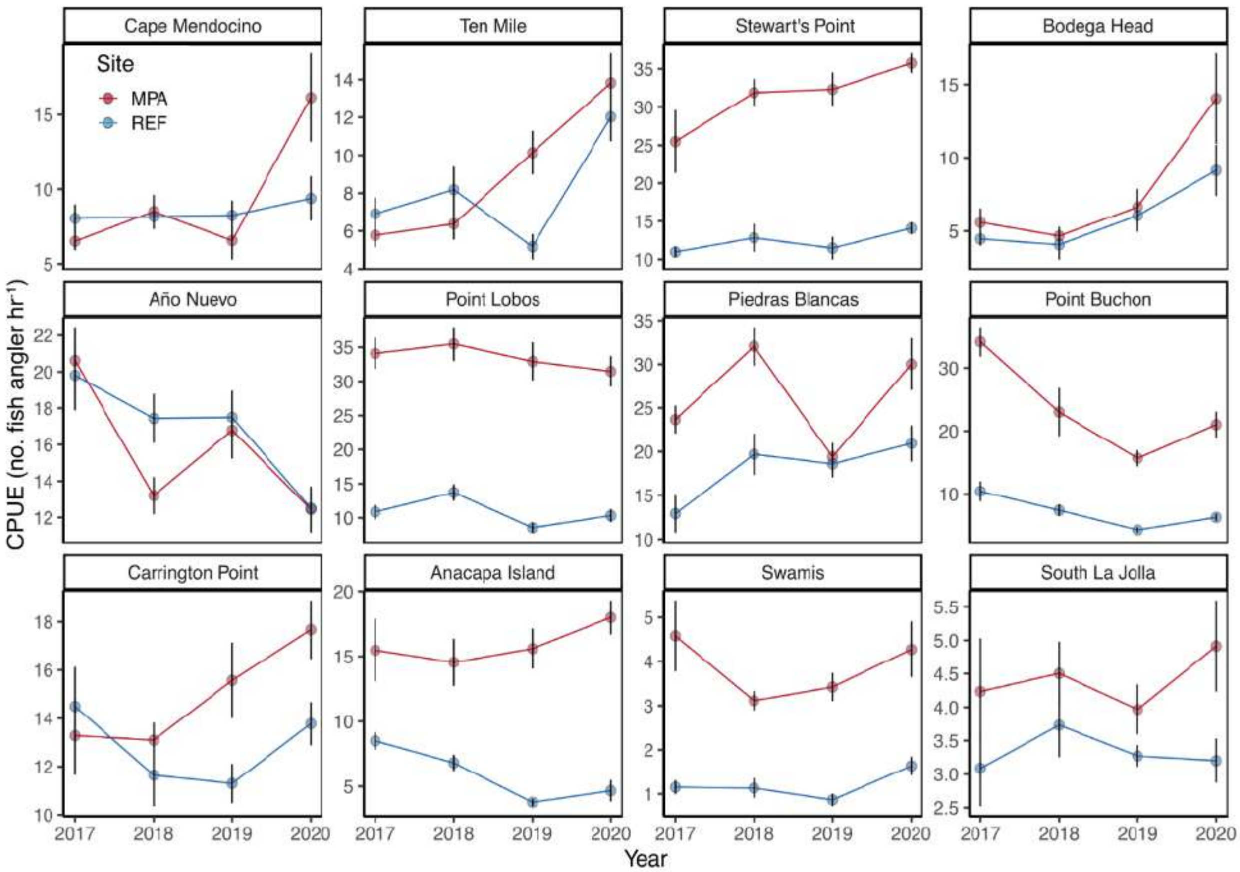


Figure 37. CPUE inside 12 MPAs and associated Reference sites sampled statewide from 2017-2020. Red points denote mean CPUE inside MPAs, and blue points denote mean CPUE in Reference sites. Points denote means ± 95% CI.

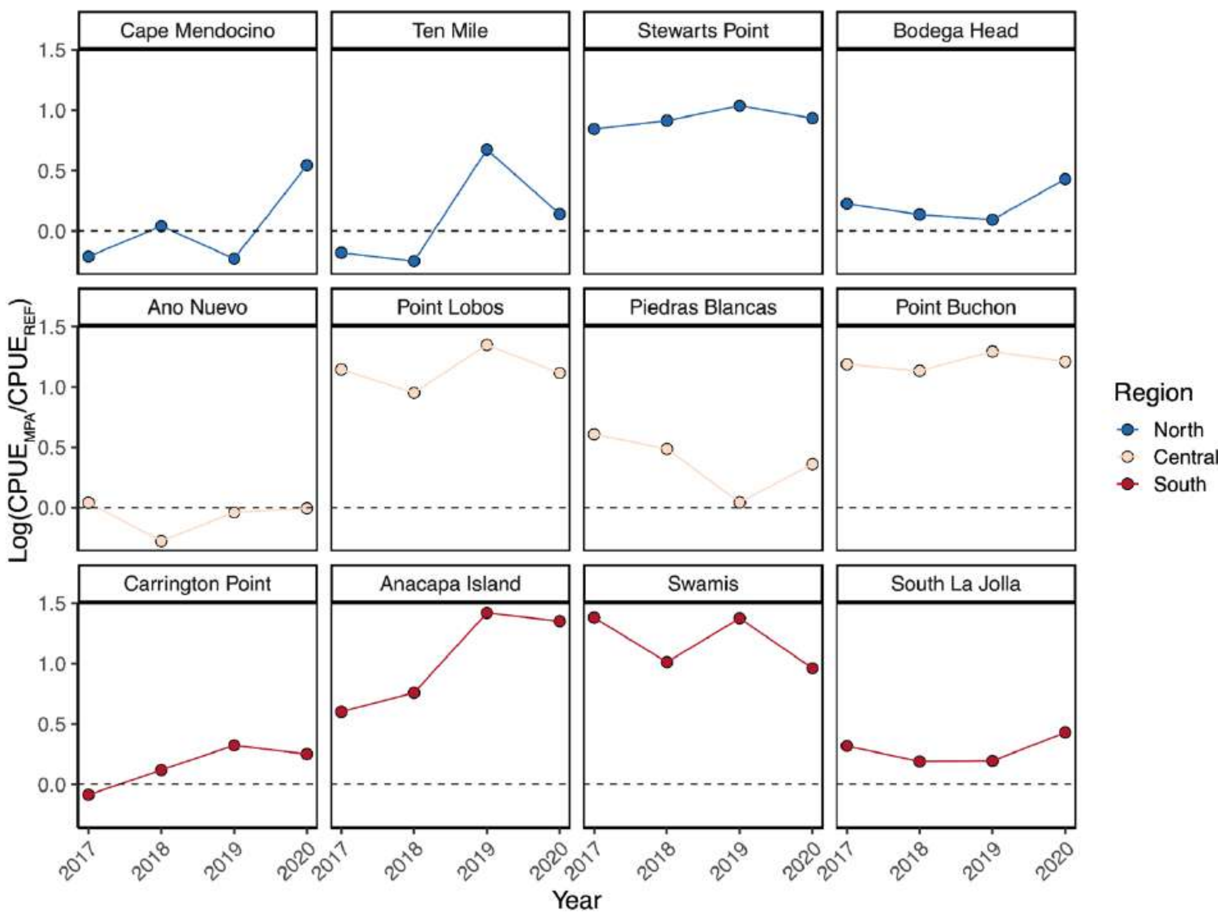


Figure 38. CPUE response ratios for 12 areas sampled statewide from 2017-2020. Values greater than zero indicate higher CPUE in the MPA compared to the paired Reference site, while values less than zero indicate higher CPUE in the Reference site compared to the MPA.

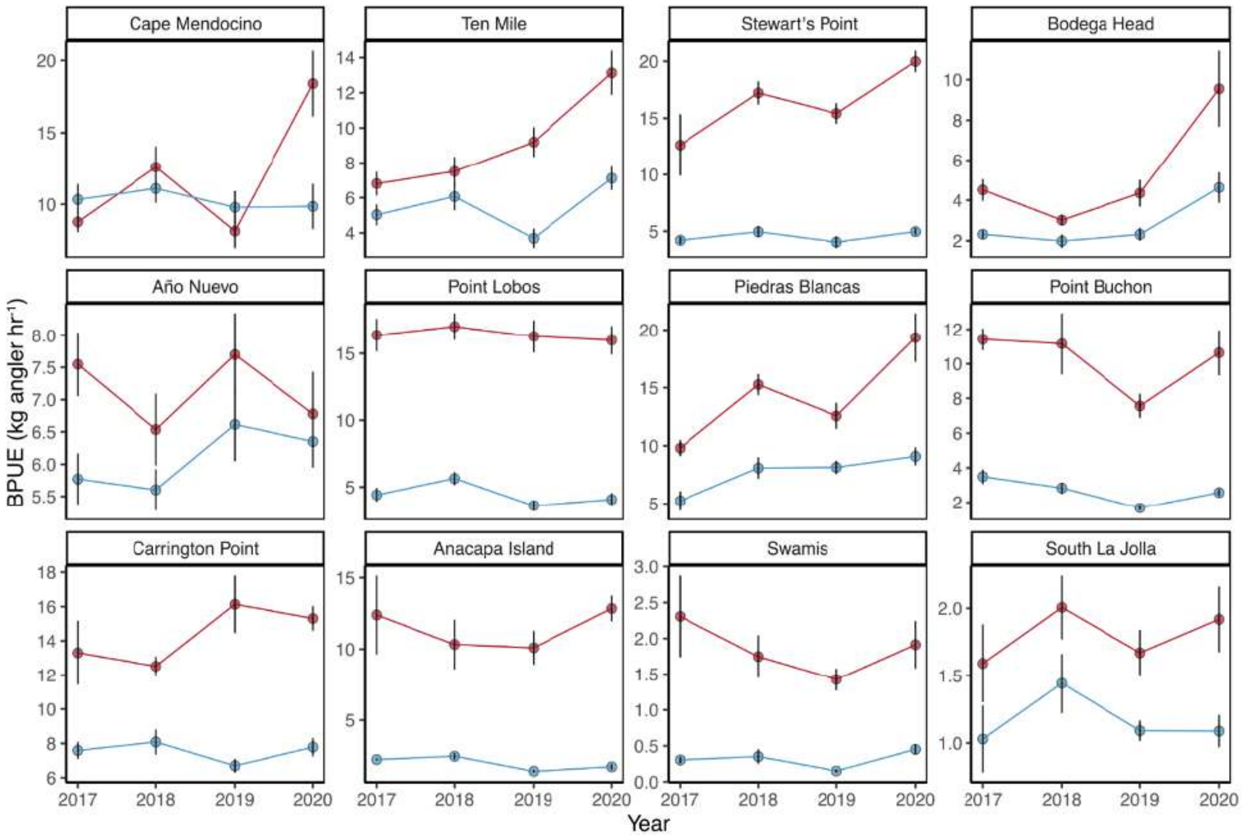


Figure 39. BPUE inside 12 MPAs and associated Reference sites sampled statewide from 2017-2020. Red points denote mean BPUE inside MPAs, and blue points denote mean BPUE in Reference areas. Points denote means ± 95% CI.

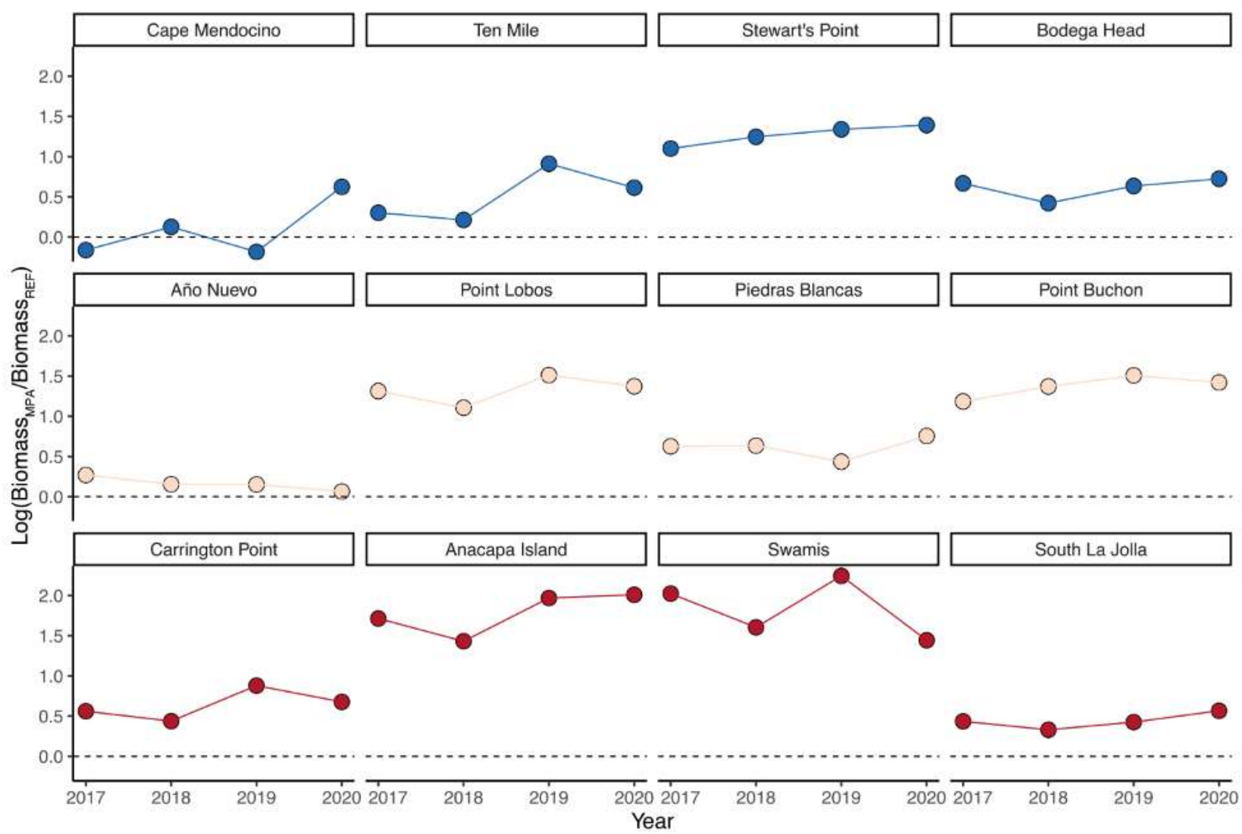


Figure 40. Biomass response ratios for 12 areas sampled statewide from 2017-2020. Values greater than zero indicate higher biomass per unit effort (BPUE) in the MPA compared to the paired Reference site, while values less than zero indicate higher BPUE in the Reference site compared to the MPA.

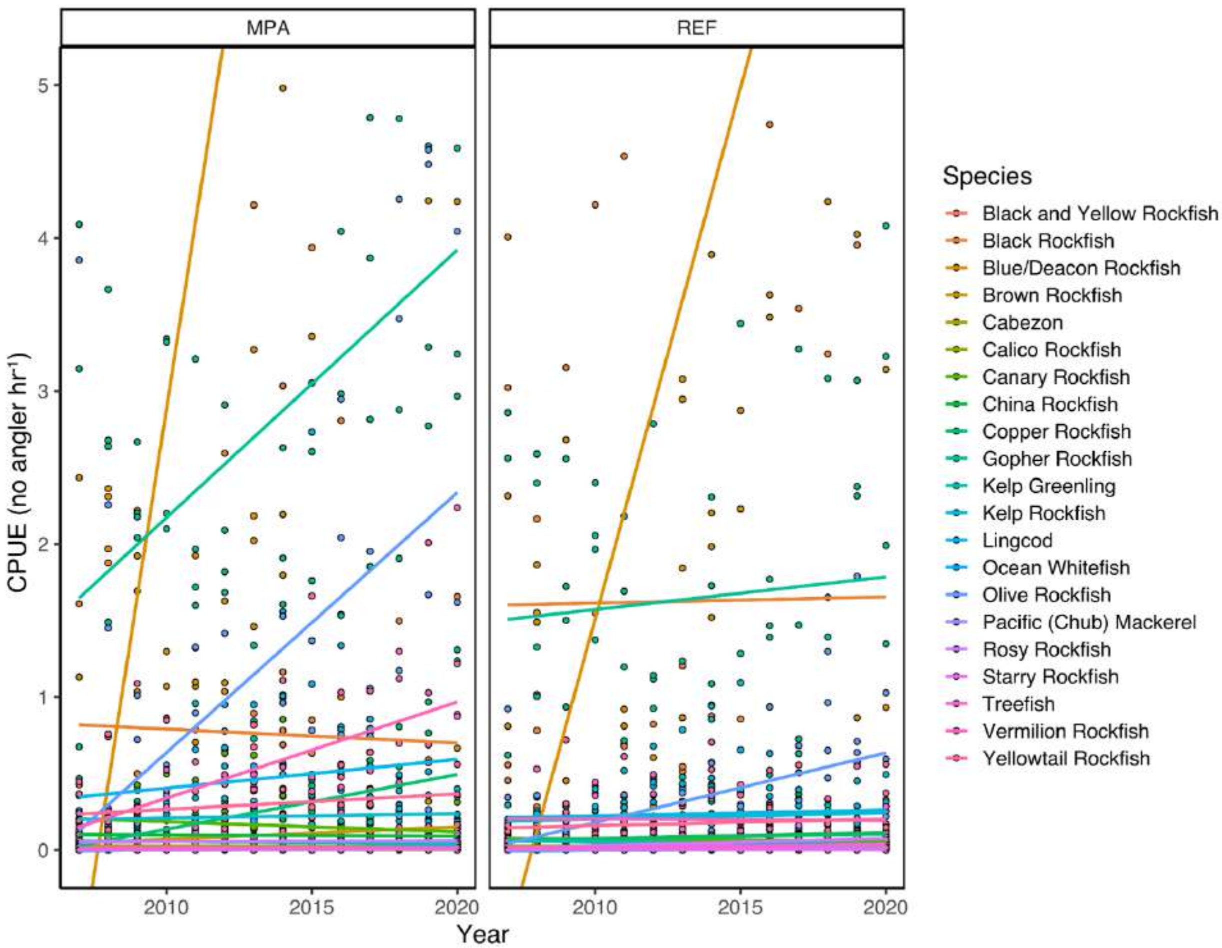


Figure 41. CPUE values for all species sampled more than three years along the Central coast between 2007 and 2020. Trend lines are linear regressions for the effect of time since implementation (Year) on CPUE for each species.

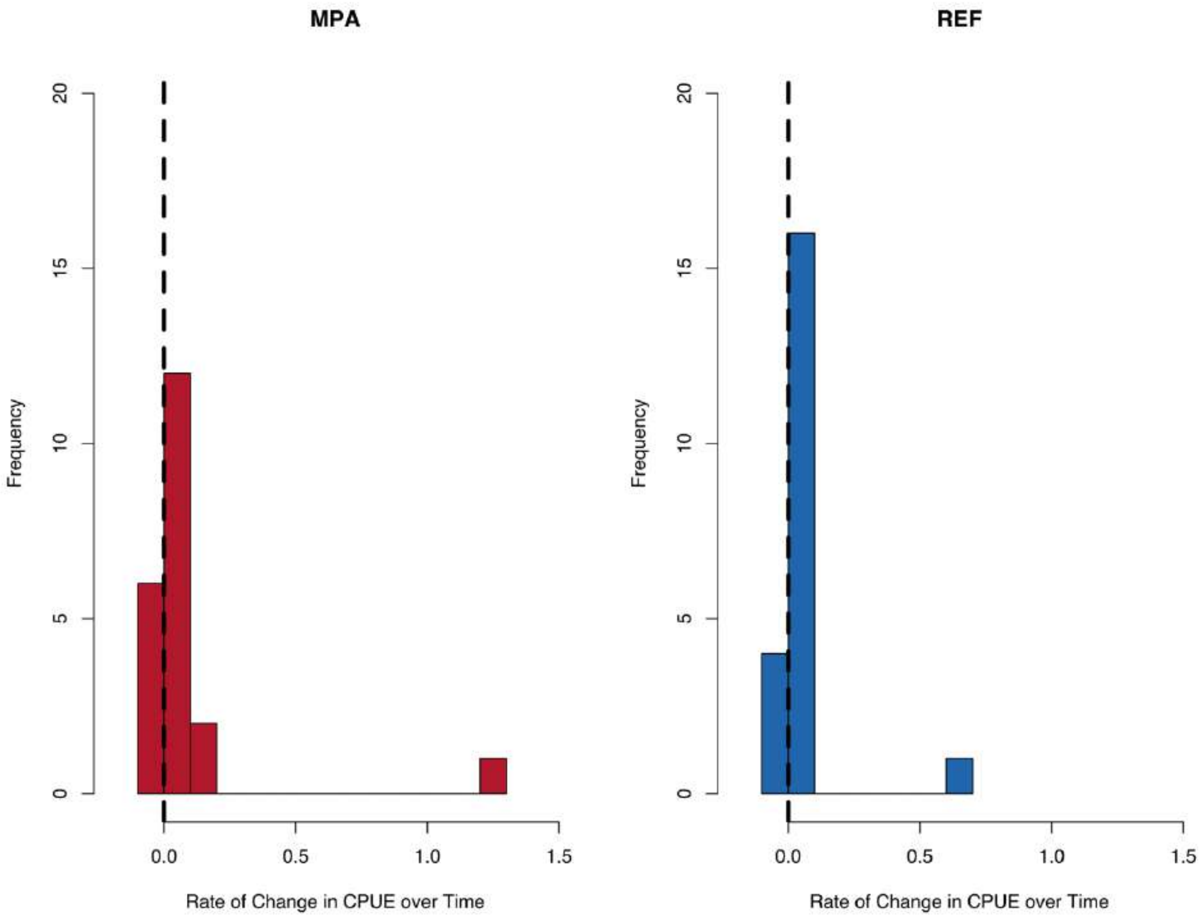


Figure 42. Histogram showing the frequency of positive versus negative rates of response (i.e., slope) in CPUE for all species caught inside and outside the Central coast MPAs.

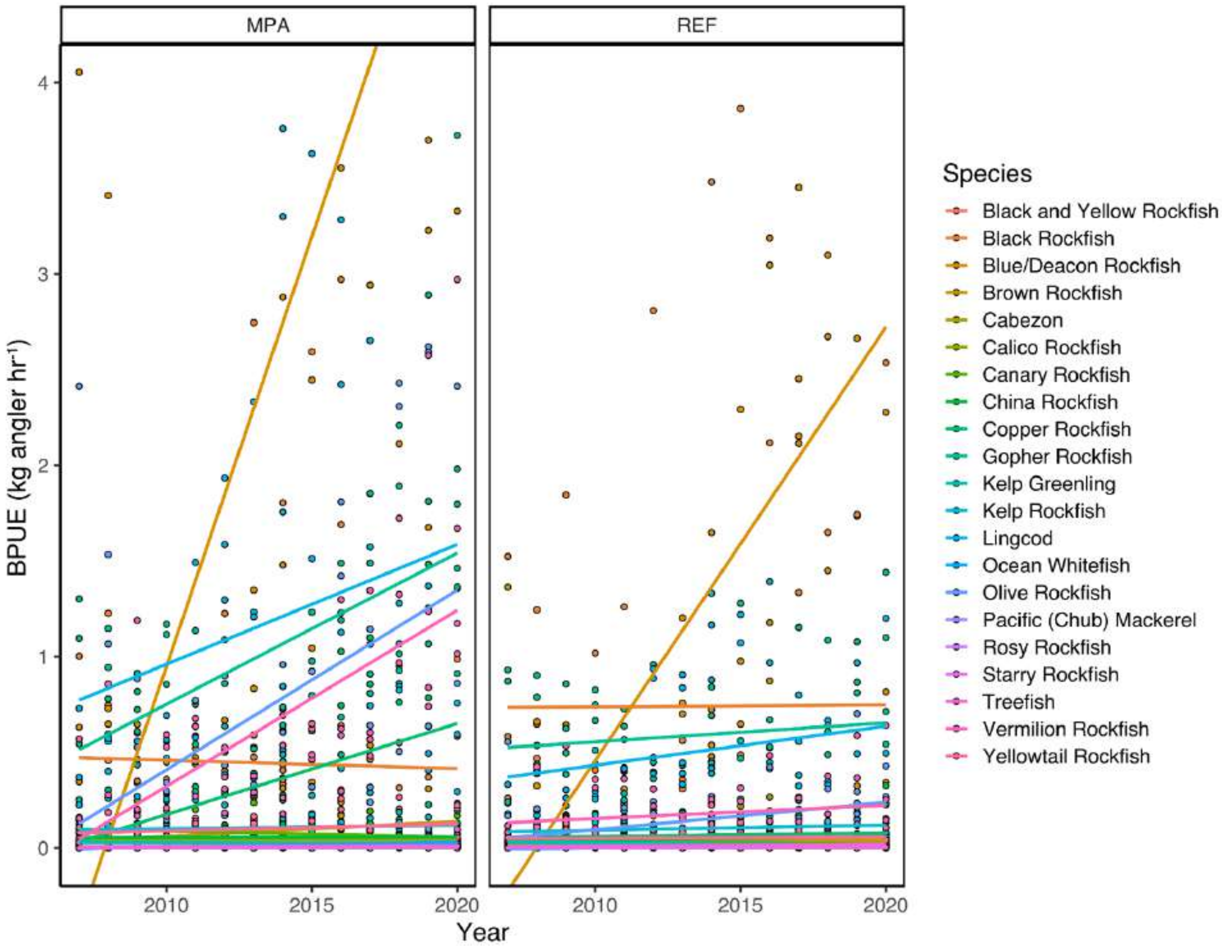


Figure 43. BPUE values for all species sampled more than three years along the Central coast between 2007 and 2020. Trend lines are linear regressions for the effect of time since implementation (Year) on biomass per unit effort (BPUE) for each species.

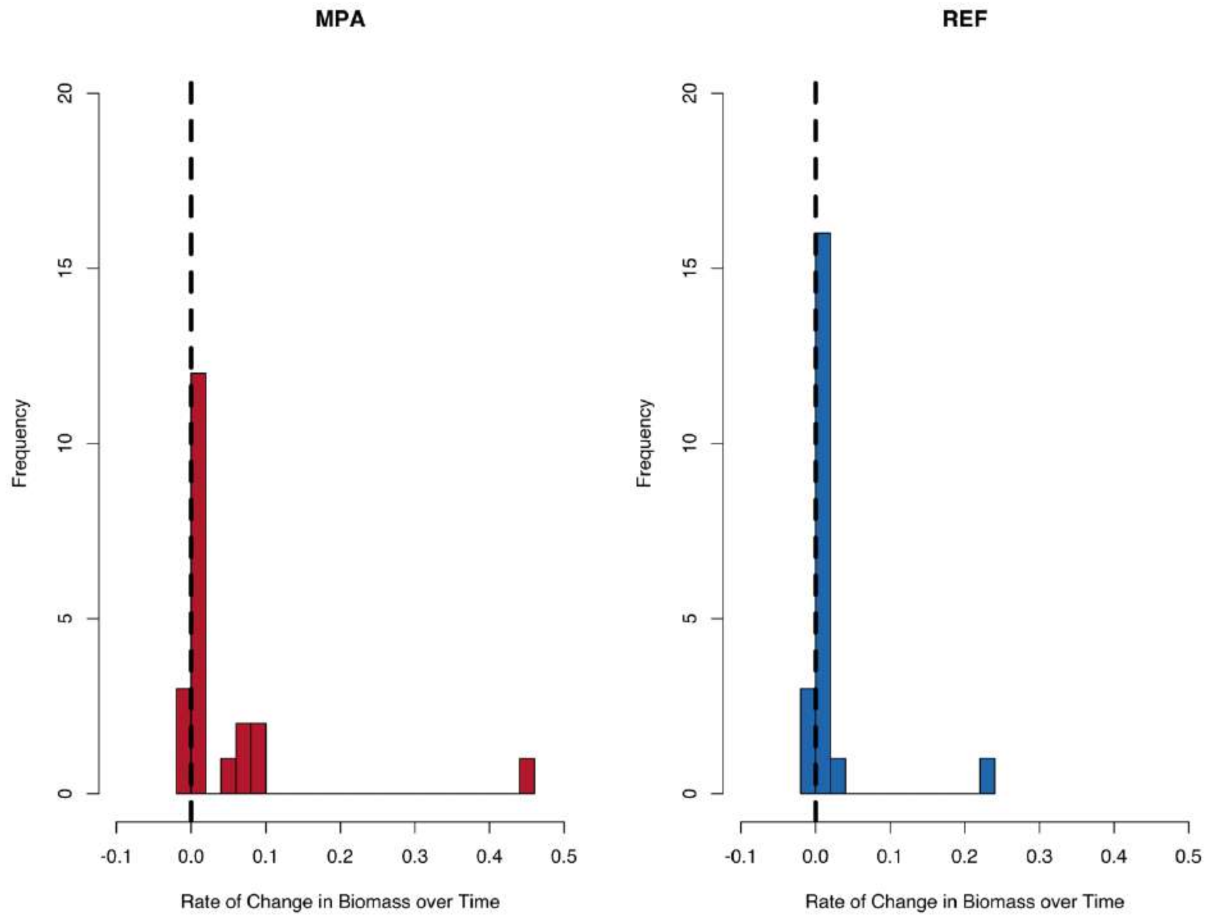


Figure 44. Histogram showing the frequency of positive versus negative rates of response (i.e., slope) in BPUE for all species caught inside and outside the Central coast MPAs.

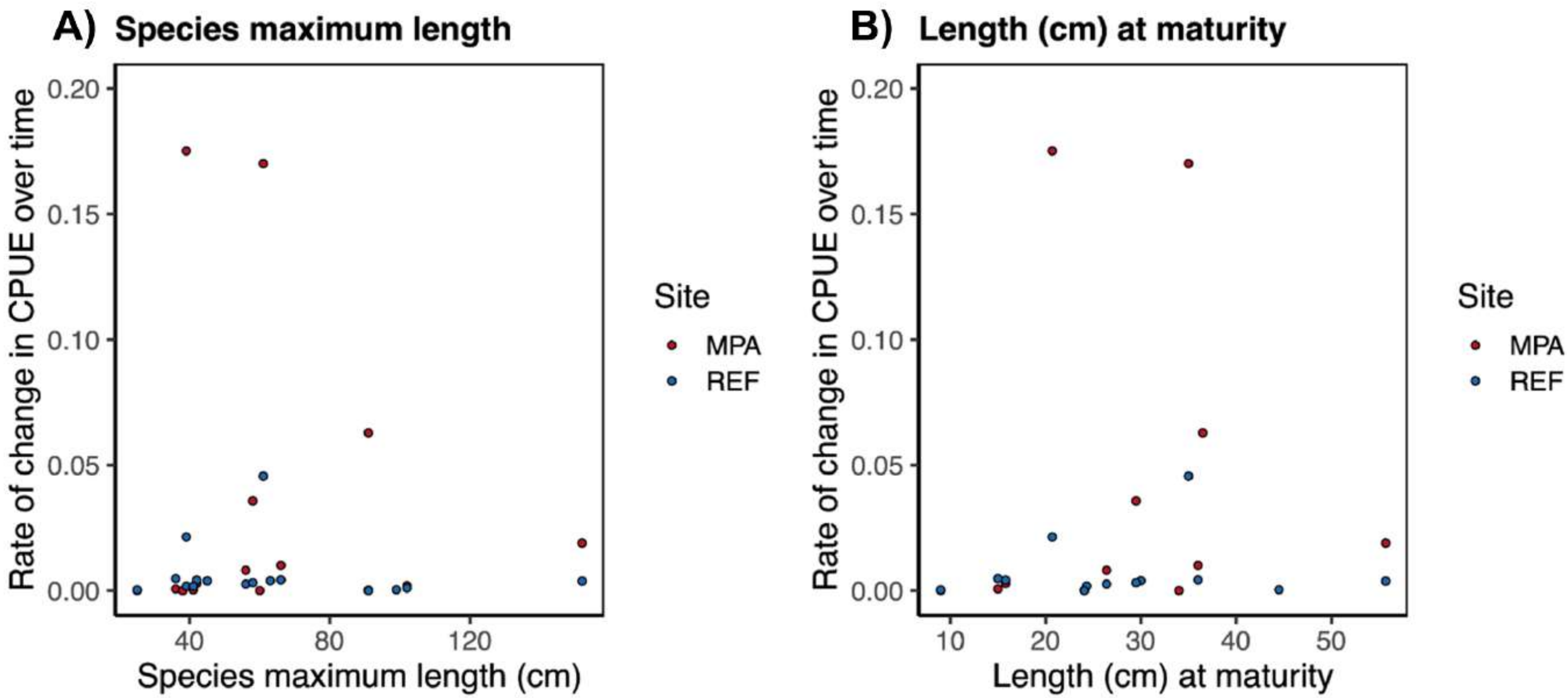


Figure 45. Rate of Change in CPUE over time in relation to species traits: (A) maximum length recorded for each species obtained from FishBase and (B) the average length at maturity. Blue/Deacon Rockfish outliers were removed (slopes=1.22 in MPAs and 0.70 in Reference sites) to better visualize the majority of trends.

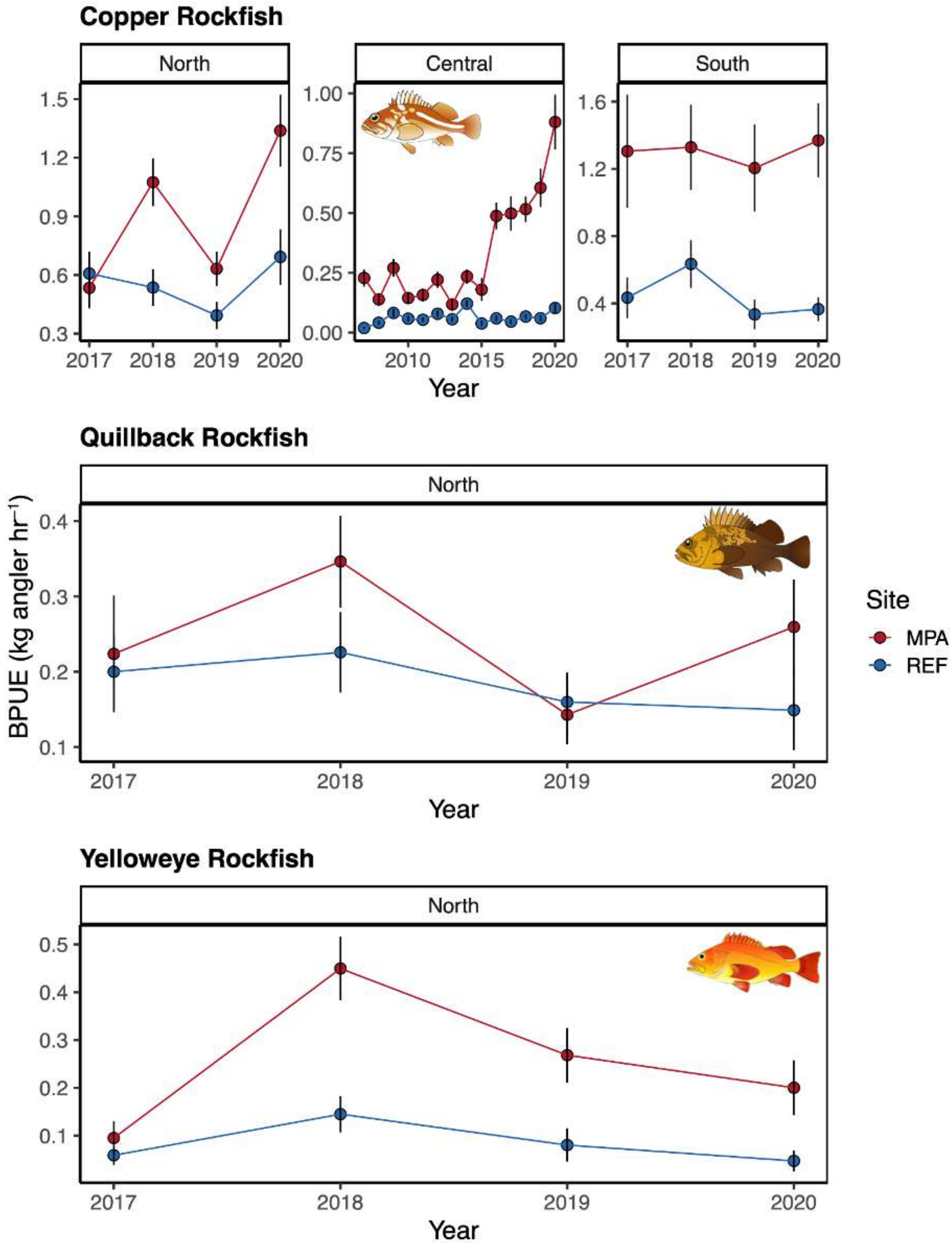


Figure 46. Mean BPUE through time for management species of interest aggregated across all sites sampled. MPAs denoted in red and Reference sites in blue. Copper Rockfish are sampled across all three regions, while both Quillback Rockfish and Yelloweye Rockfish were only captured in the North region. Error bars are ± 95% CI.

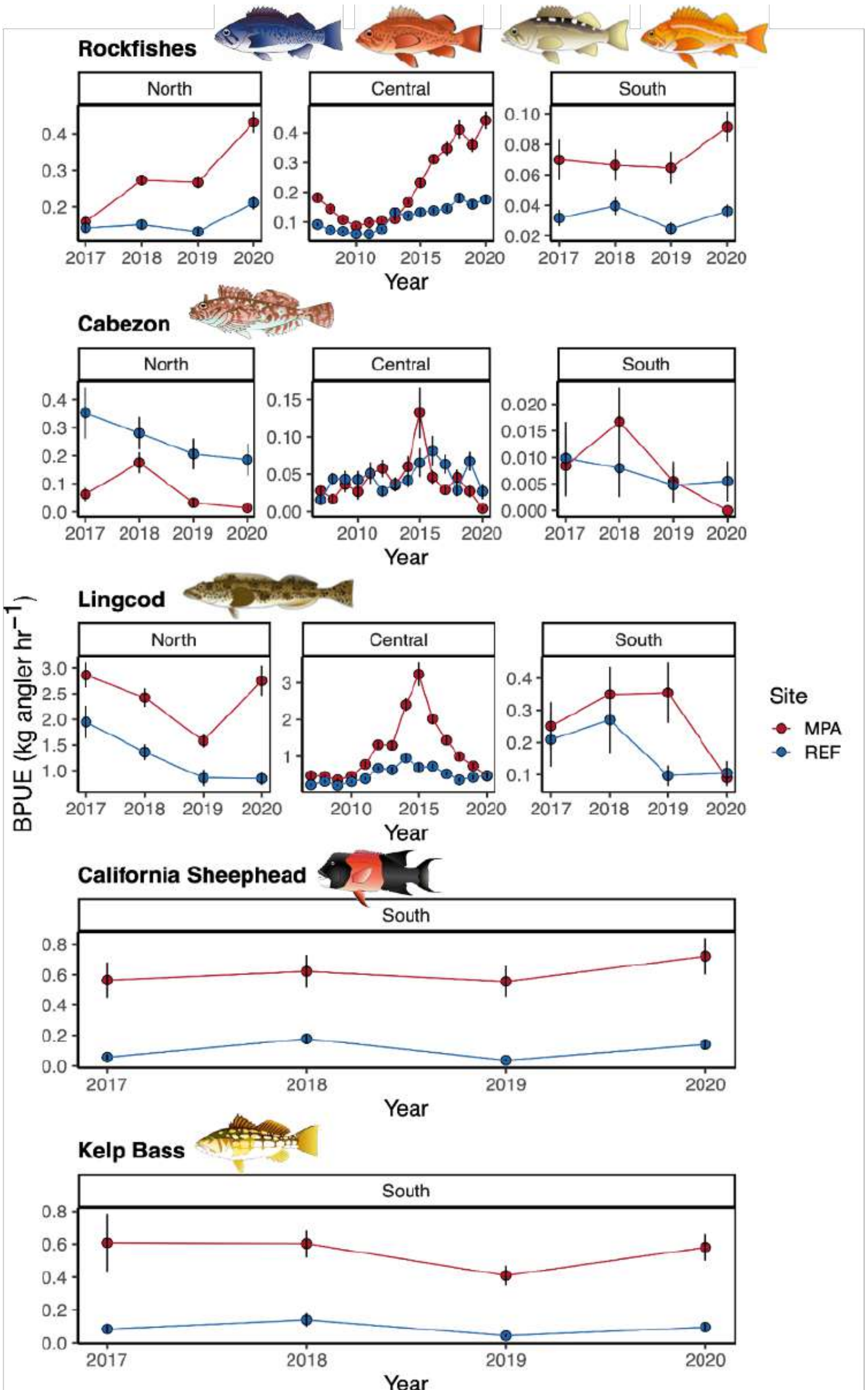


Figure 47. Mean BPUE through time for culturally important groups or species for each region sampled by CCFRP. MPAs denoted in red and Reference sites in blue. These species include all Rockfishes, Lingcod, Cabezon, California sheephead and Kelp Bass. Error bars are ± 95% CI.

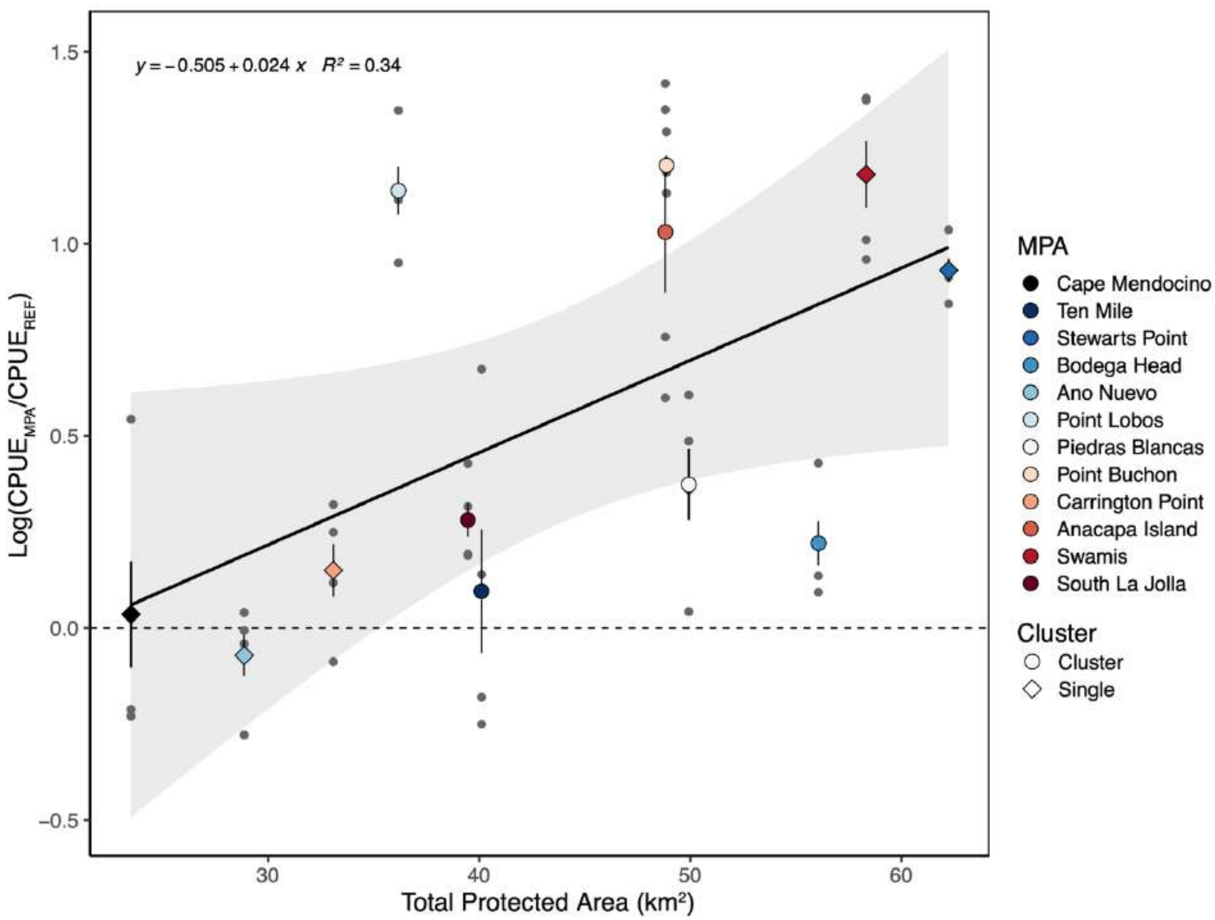


Figure 48. Average CPUE response ratios for 12 MPAs sampled along the California coast in relation to the amount of protected area. Cluster area includes the area of the MPA for solitary reserves and for paired MPAs (clusters) includes the area of both the SMR and SMCA. Trend lines are linear regressions for the relationship between total protected area and CPUE response ratios. Dark grey dots represent site-year replicates, while colored symbols represent the mean response ratio for each site. Shaded gray area is 95% CI on the regression line and error bars are ± 95% CI on the points.

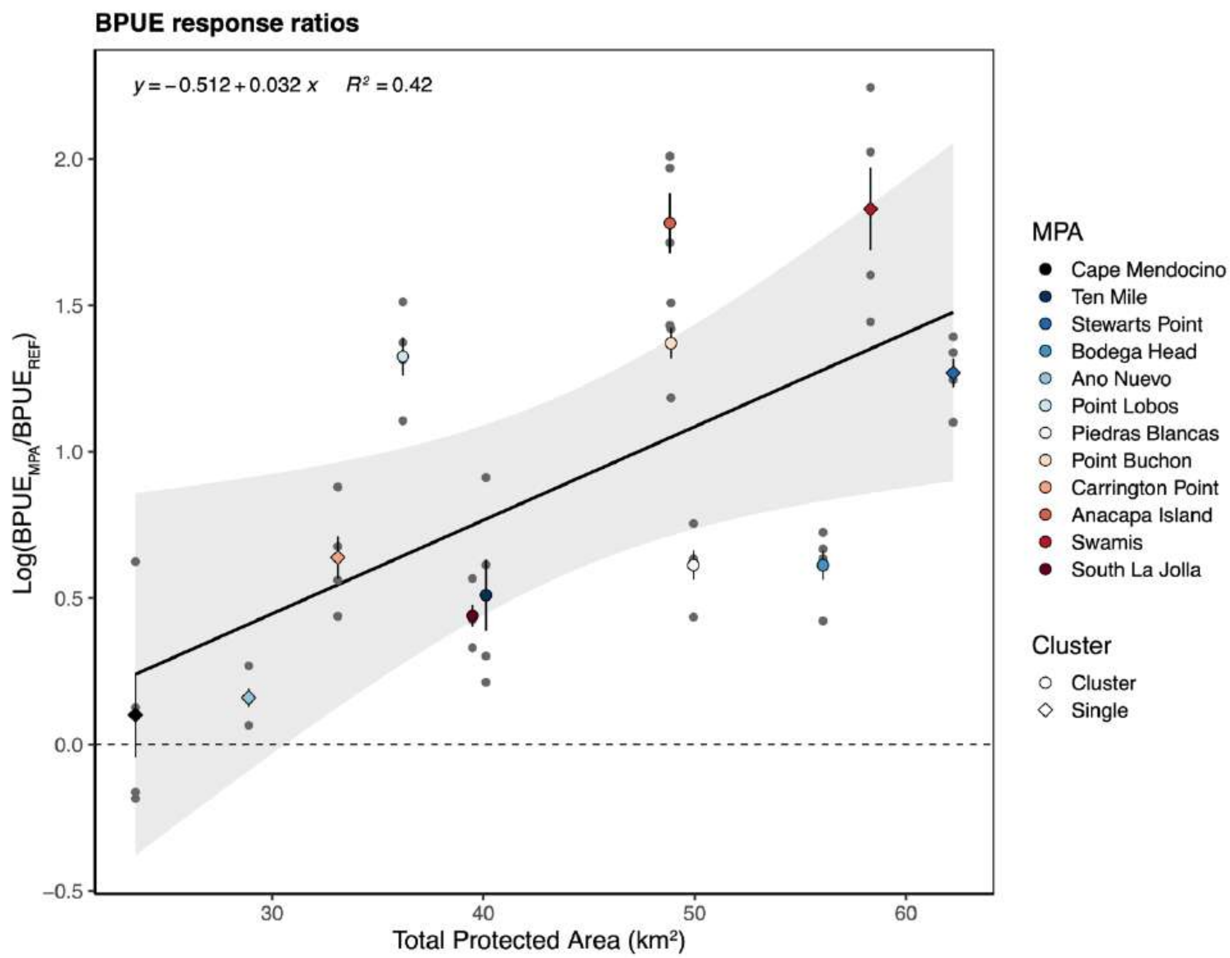


Figure **49.** Average biomass response ratios for 12 MPAs sampled along the California coast in relation to the amount of protected area. Total protected area includes the area of the MPA for solitary reserves and for paired MPAs includes the area of both the SMR and SMCA. Trend lines are linear regressions for the relationship between total protected area and biomass response ratios. Dark grey dots represent site-year replicates, while colored symbols represent the mean response ratio for each site. Shaded gray area is 95% CI on the regression line and error bars are ± 95% CI on the points.

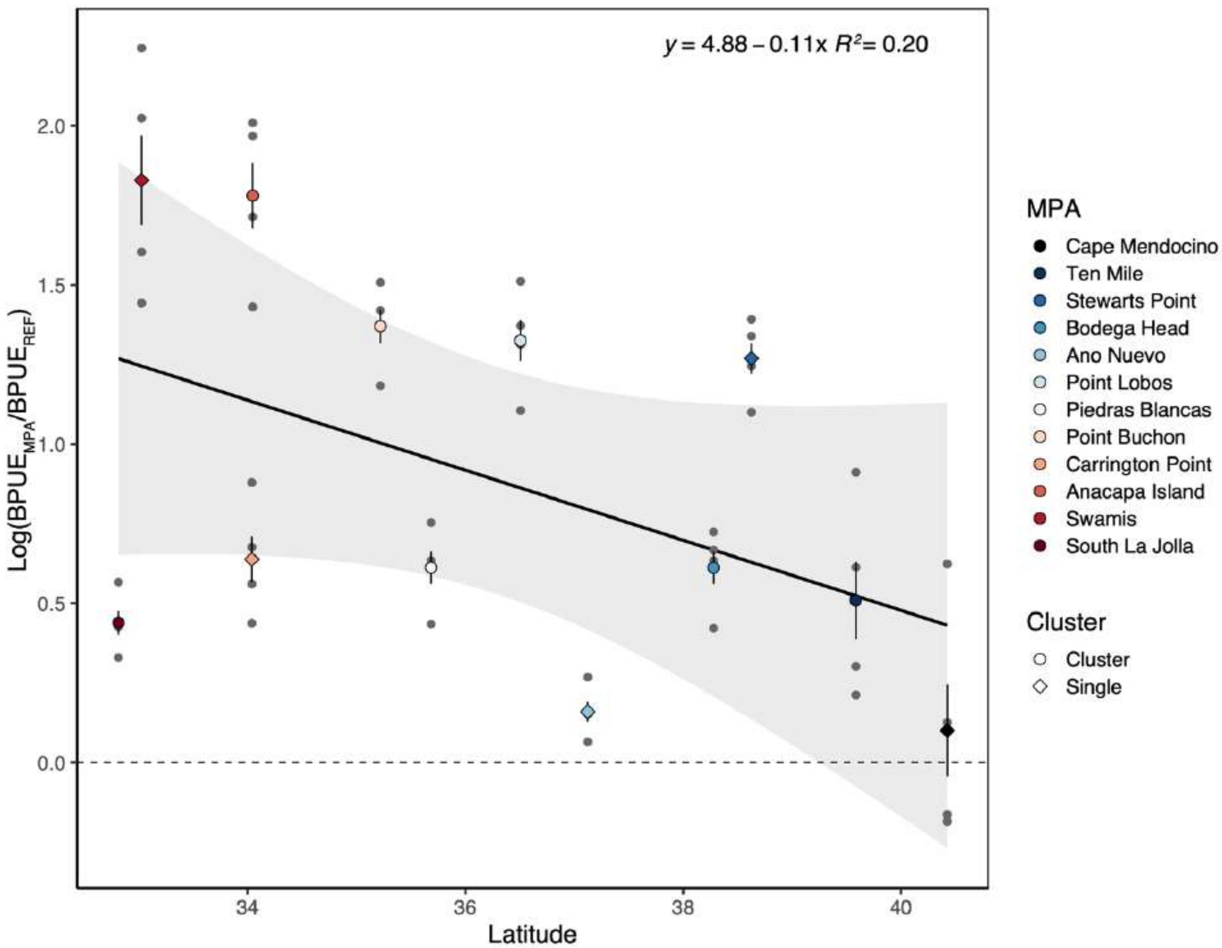


Figure 50. The relationship between latitude and mean biomass response ratio for 12 MPAs sampled statewide. Total protected area includes the area of the MPA for solitary reserves and for paired MPAs includes the area of both the SMR and SMCA. Trend lines are linear regressions for the relationship between total protected area and biomass response ratios. Dark grey dots represent site-year replicates, while colored symbols represent the mean response ratio for each site. Shaded gray area is 95% CI on the regression line and error bars are ± 95% CI on the points.

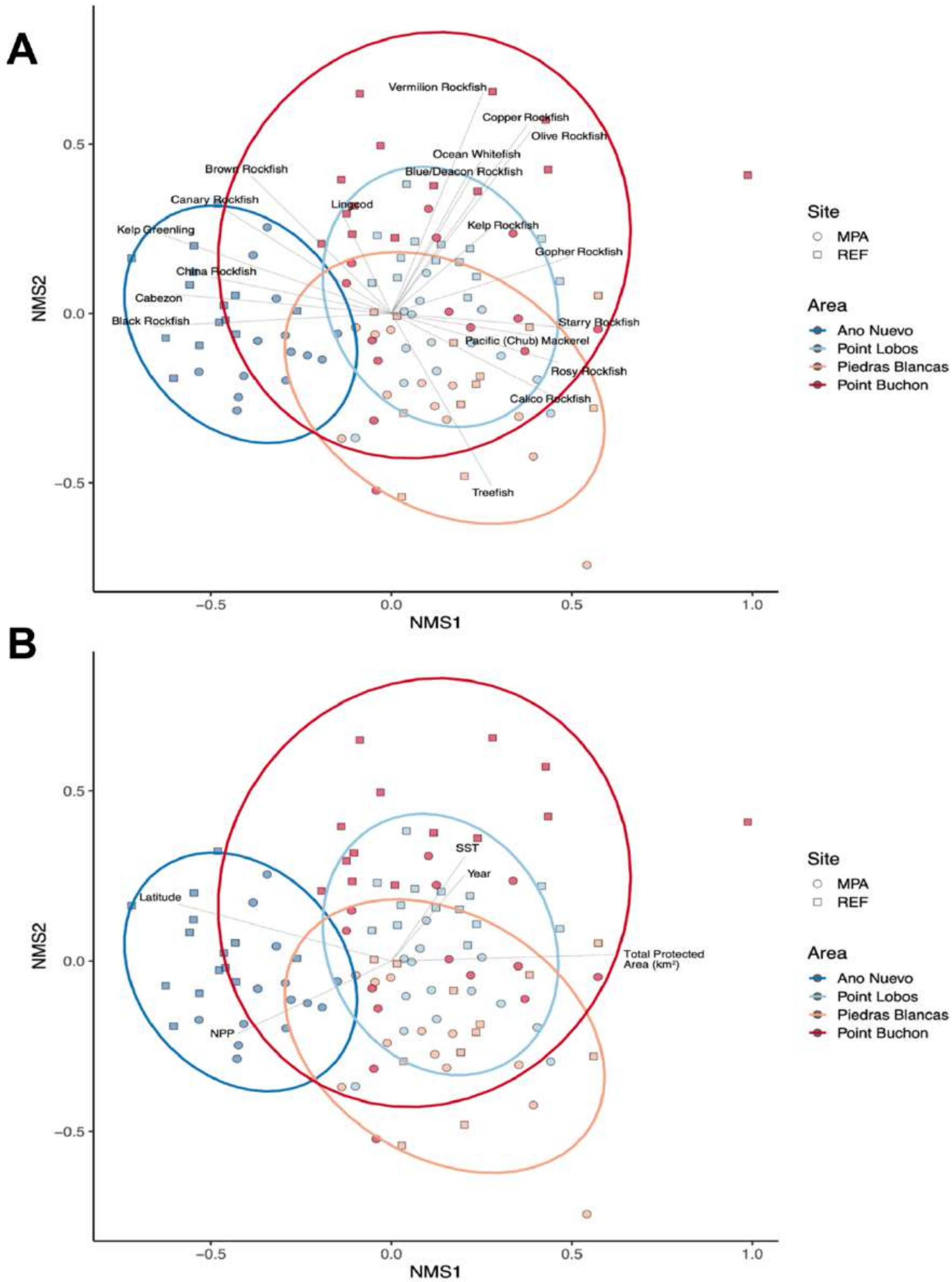


Figure 51. Non-metric multidimensional scaling ordination of community composition for each MPA and associated Reference site sampled in Central California between 2007-2020. Ellipses are 95% CI and vectors show the fish species (A) and physical factors (B) that are driving geographic separation of communities on the Central coast.

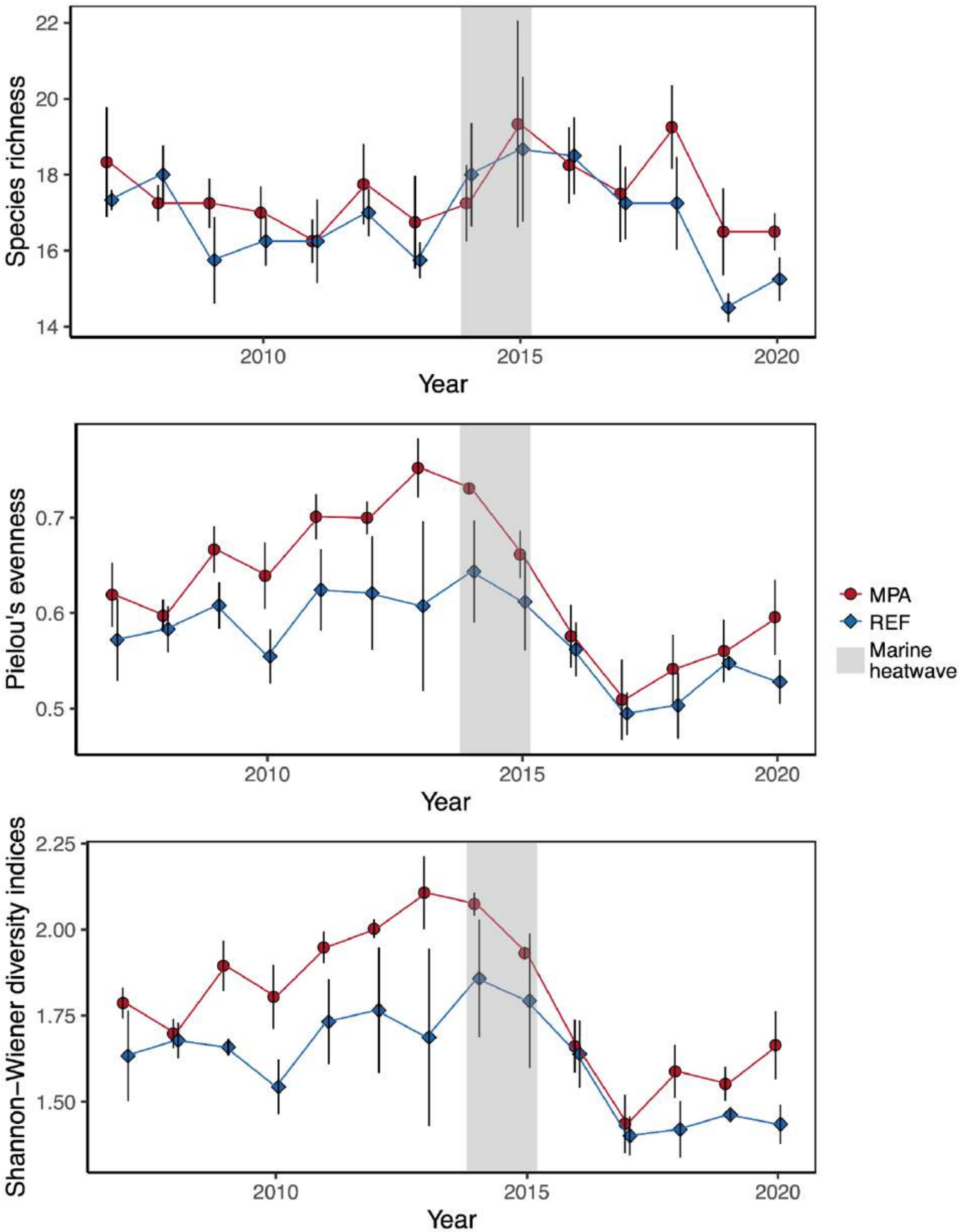


Figure 52. Temporal trends in richness, diversity, and evenness for MPA (red) and Reference (blue) sites along the Central coast from 2007-2020. Gray shaded box indicates the 2014-2015 marine heatwave. Shown are means ± 95% CI.

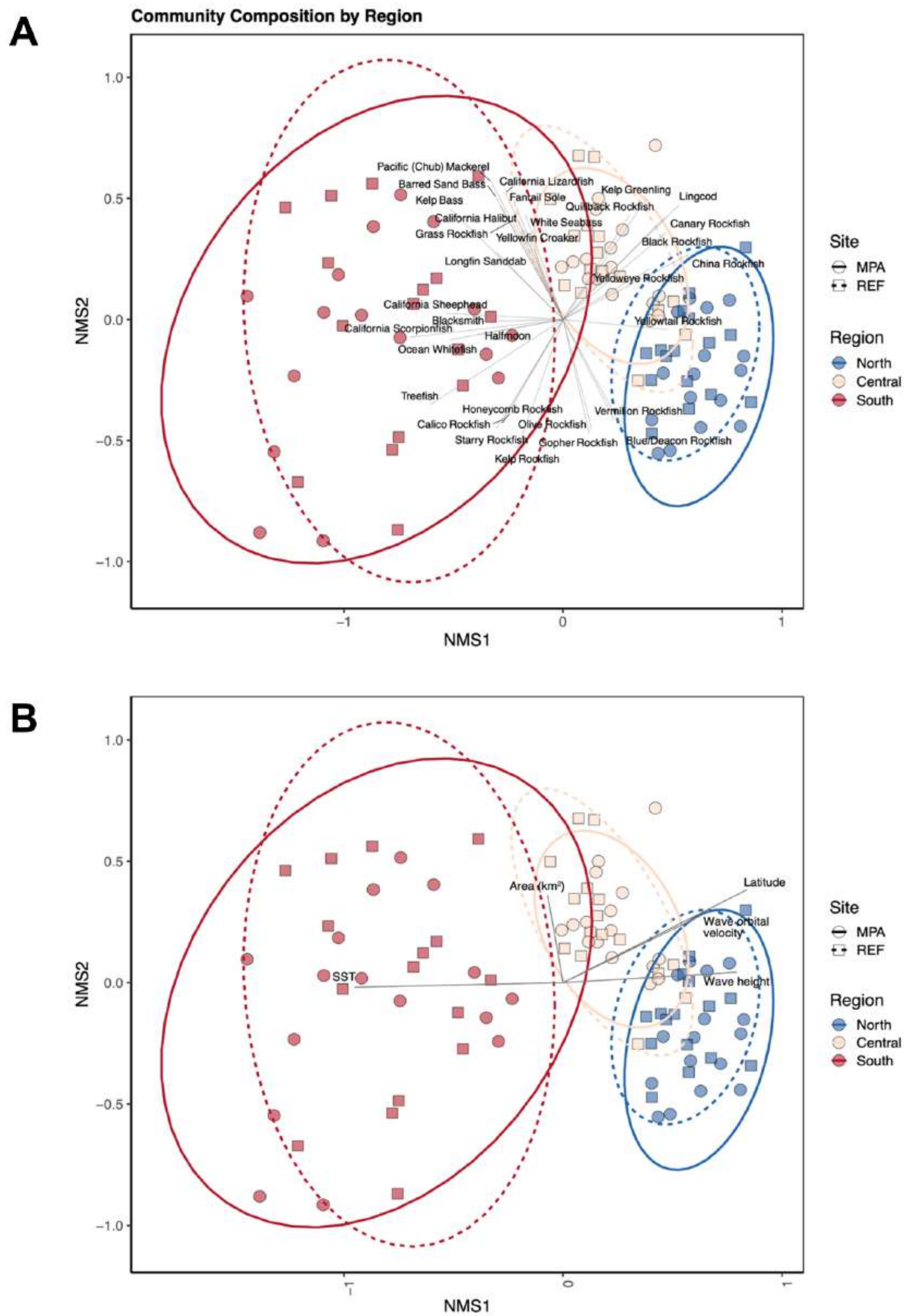


Figure 53. Non-metric multidimensional scaling ordination of community composition for each MPA and associated Reference sites sampled statewide between 2017-2020. Ellipses are 95% CI.

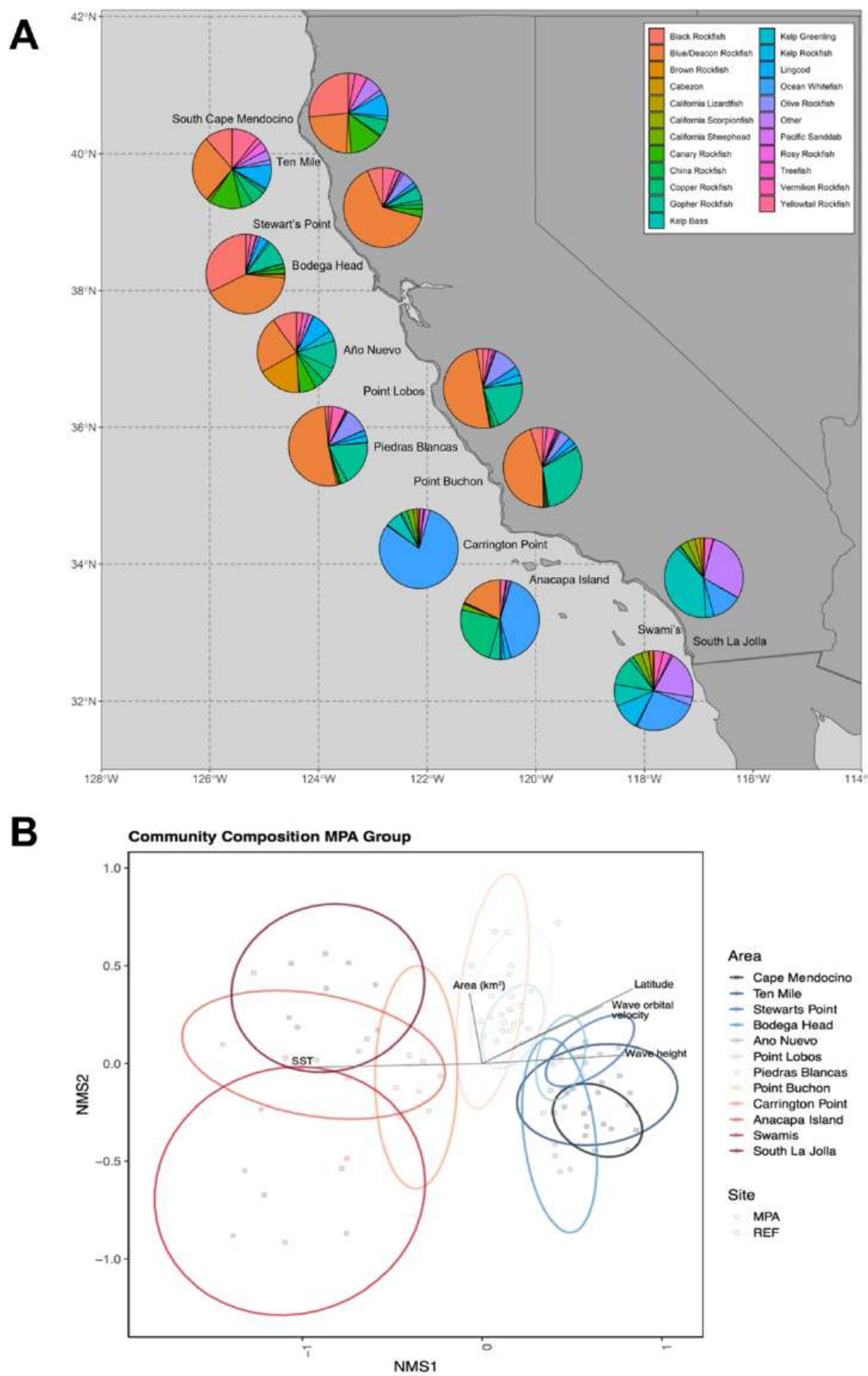


Figure 54. (A) Map showing the CCFRP sampling areas and the percent composition of the 22 most frequently caught species from 2007 (Central region) and 2017 (North and South regions) for each area. The percent composition charts include data from both MPA and their paired Reference sites. (B) Non-metric multidimensional scaling ordination of community composition for each of the 12 areas sampled statewide between 2017-2020. Ellipses are 95% CI.

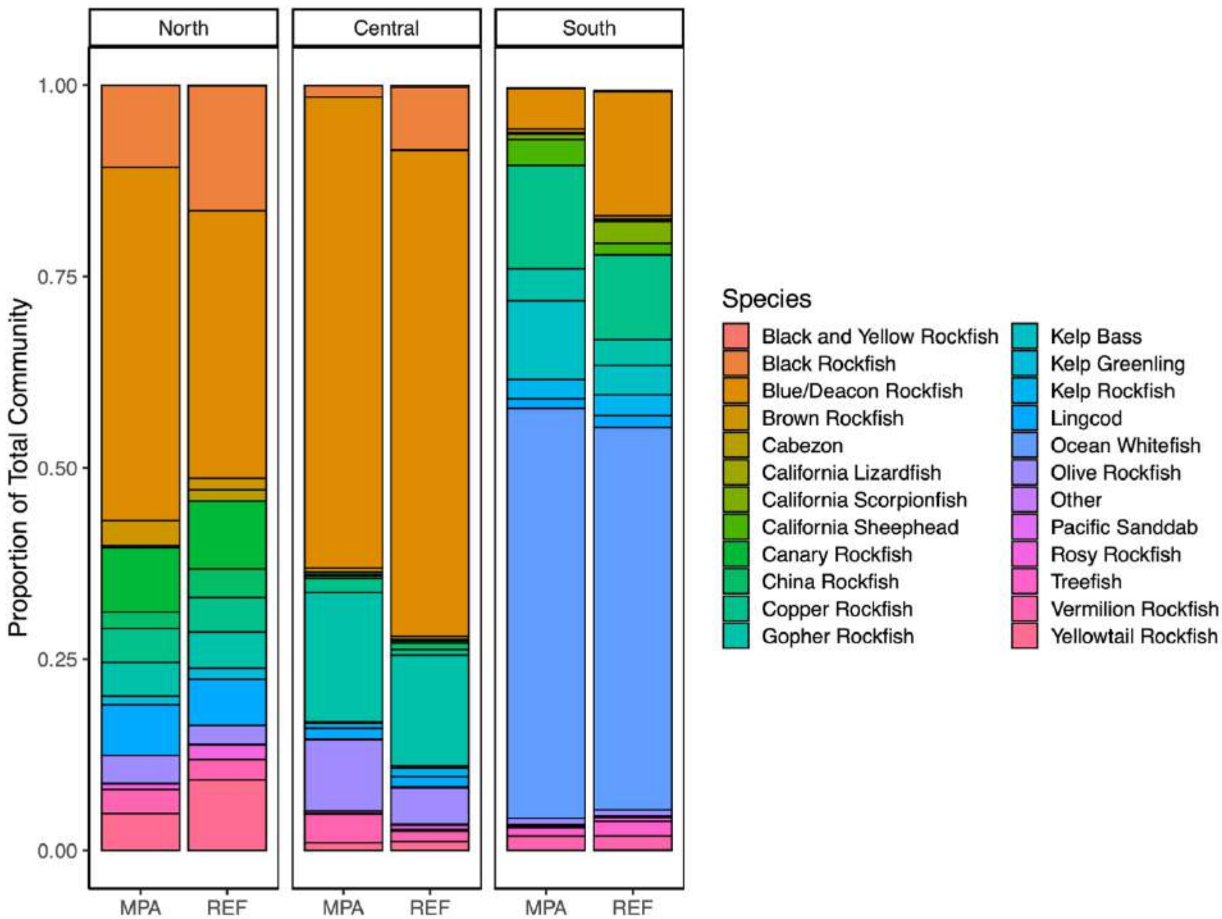


Figure 55. Stacked bar plots showing the proportion of the total community represented by different fish species at the MPA and Reference sites in each region.

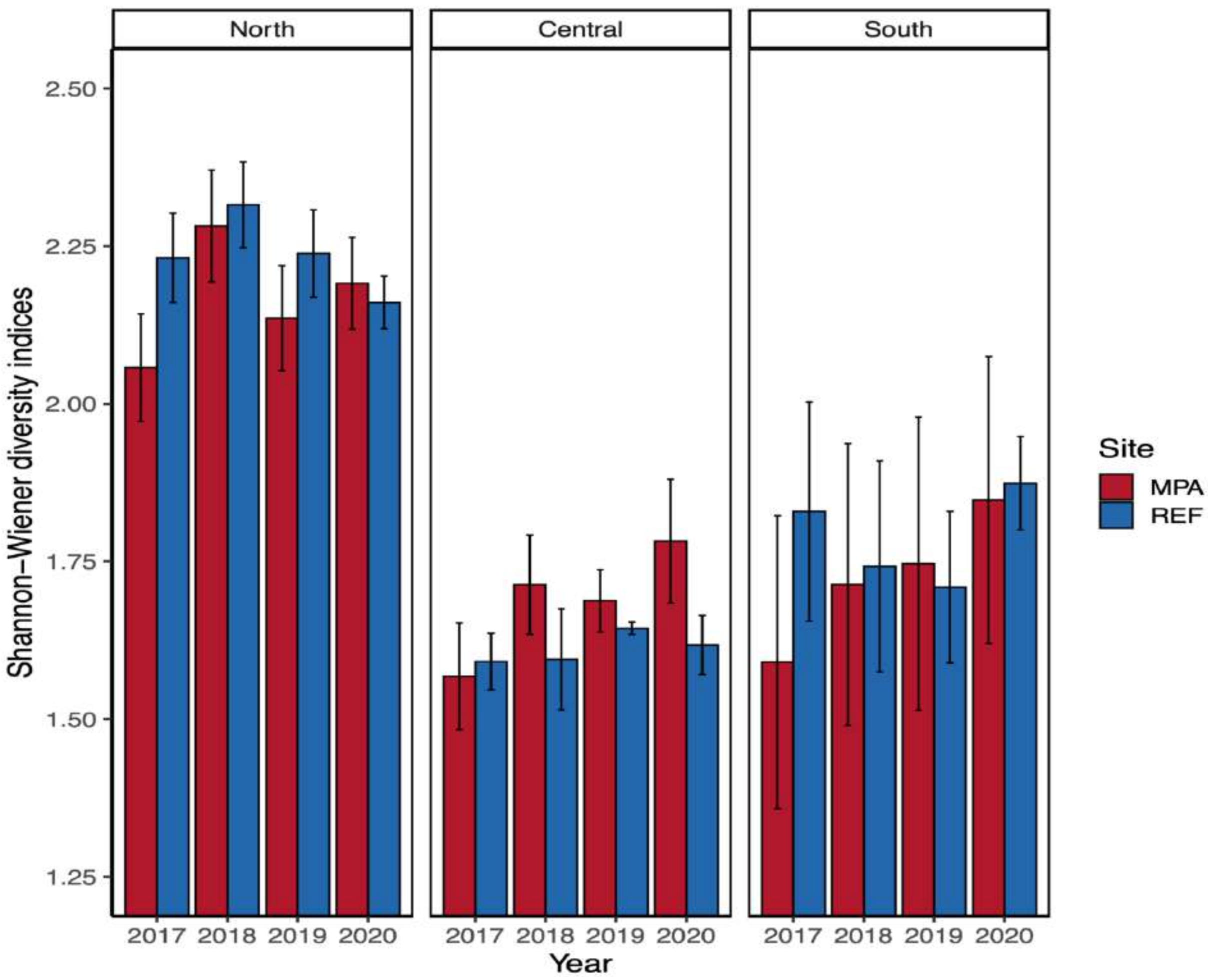


Figure 56. Temporal trends in diversity for MPA (red) and Reference (blue) sites in the North coast, Central coast, and the South coast between 2017-2020. Shown are means ± 95% CI.

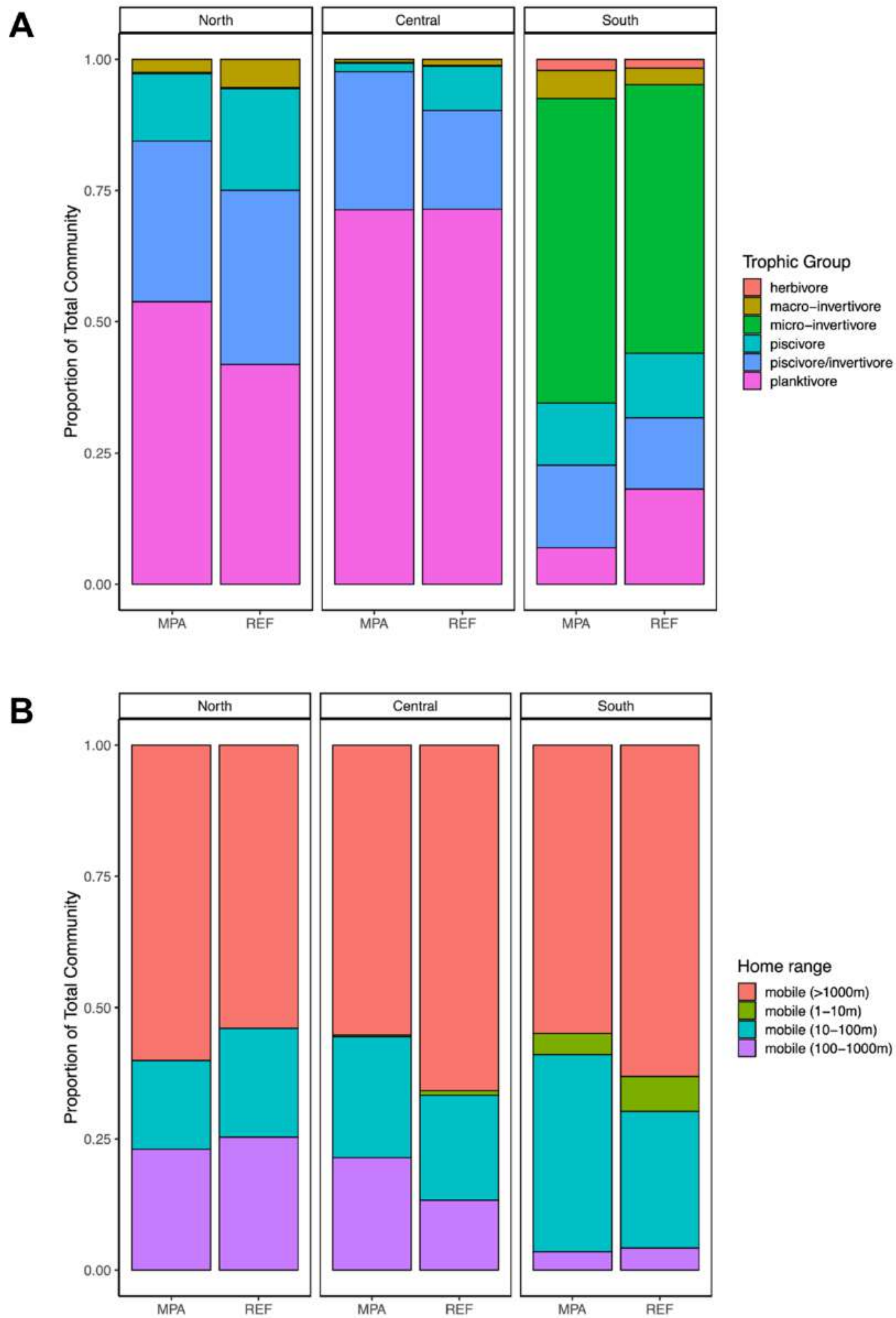


Figure 57. Stacked bar plots showing the proportion of the total community represented by different (A) trophic groups and (B) mobility groups at the MPA and Reference sites in each region.

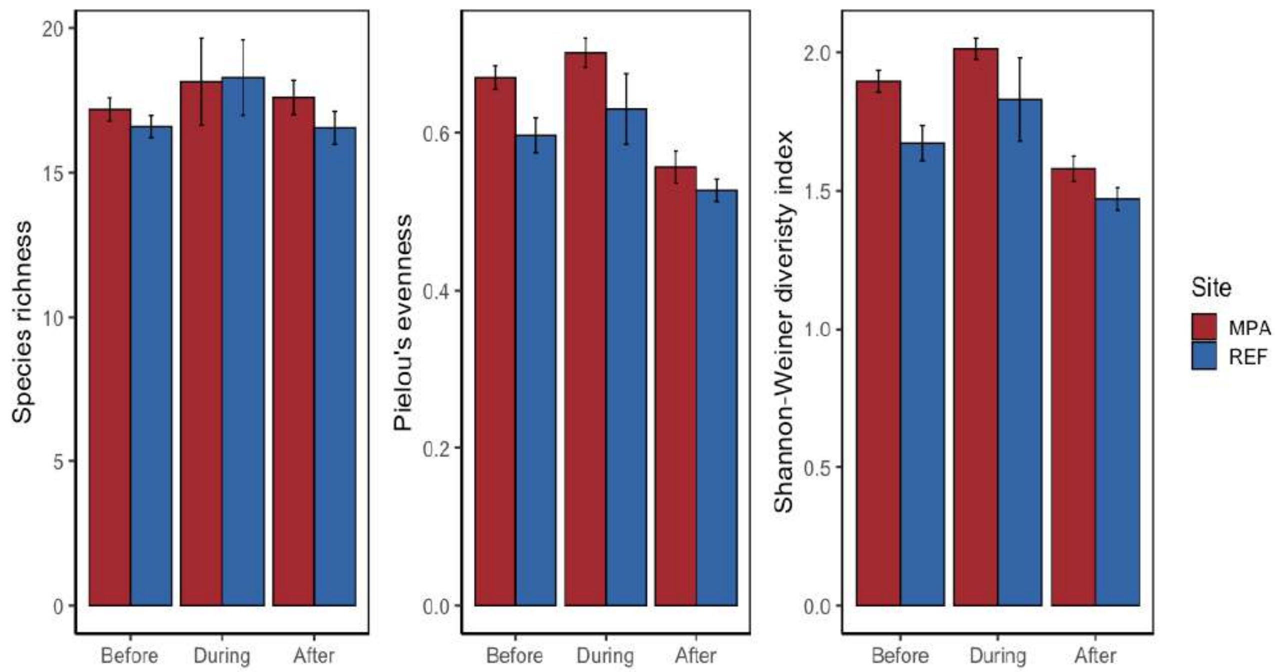


Figure 58. Changes in species richness, evenness and diversity before, during, and after the 2014-2015 marine heatwave for MPAs and associated Reference sites along the Central coast. Shown are means ± 95% CI.

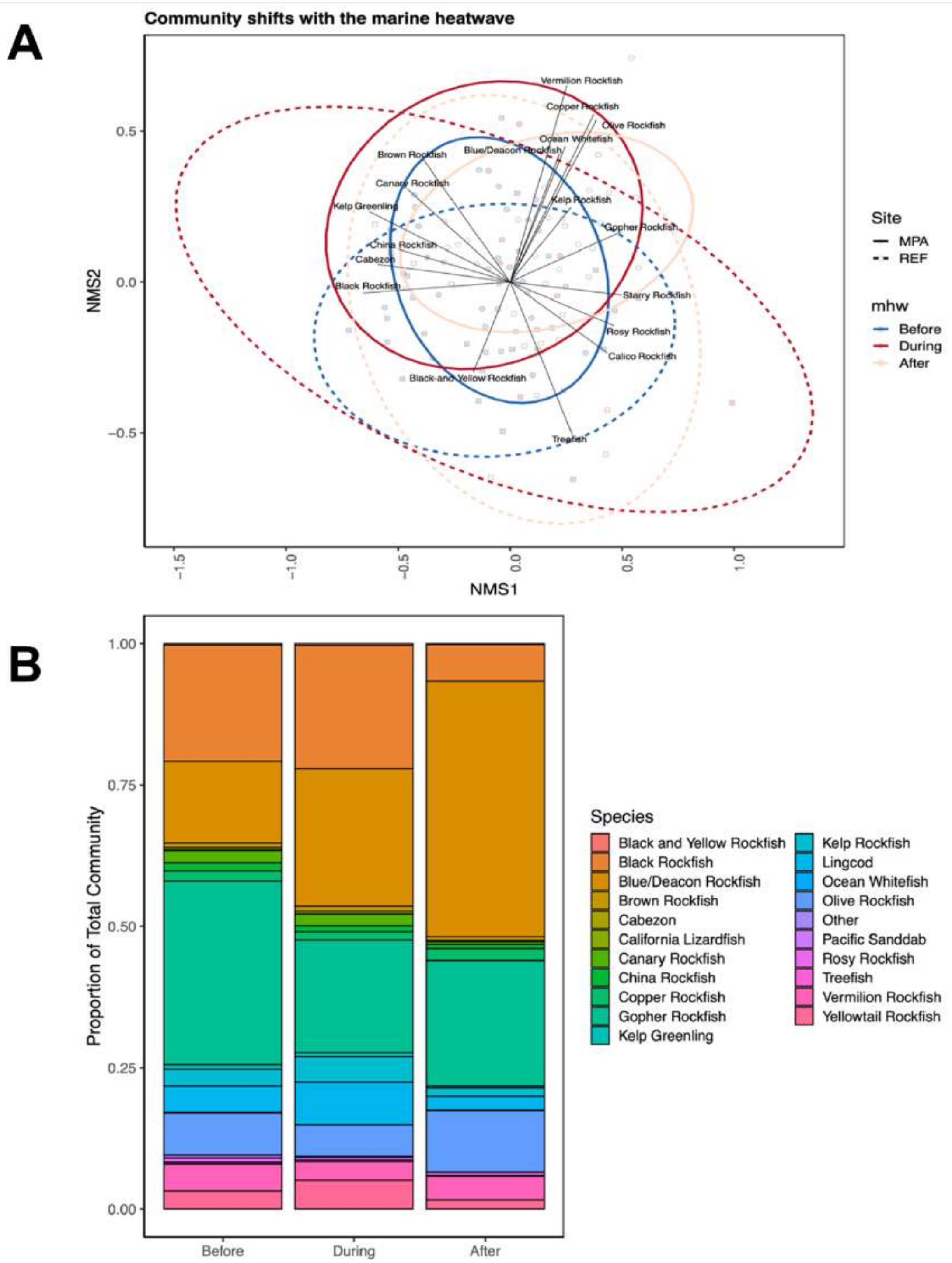


Figure 59. (A) Non-metric multidimensional scaling ordination of community composition for each MPA and associated Reference site on the Central coast sampled before (2007-2013), during (2014 & 2015), and after (2016-2020) the marine heatwave. Ellipses are 95% CI on the community compositional differences in the MPA (solid line) and Reference (dashed line) sites during the three heatwave periods. Vectors indicate the species that are driving the differences in community structure over time. (B) Stacked bar plots showing the proportion of the total community represented by different species before, during, and after the marine heatwave.

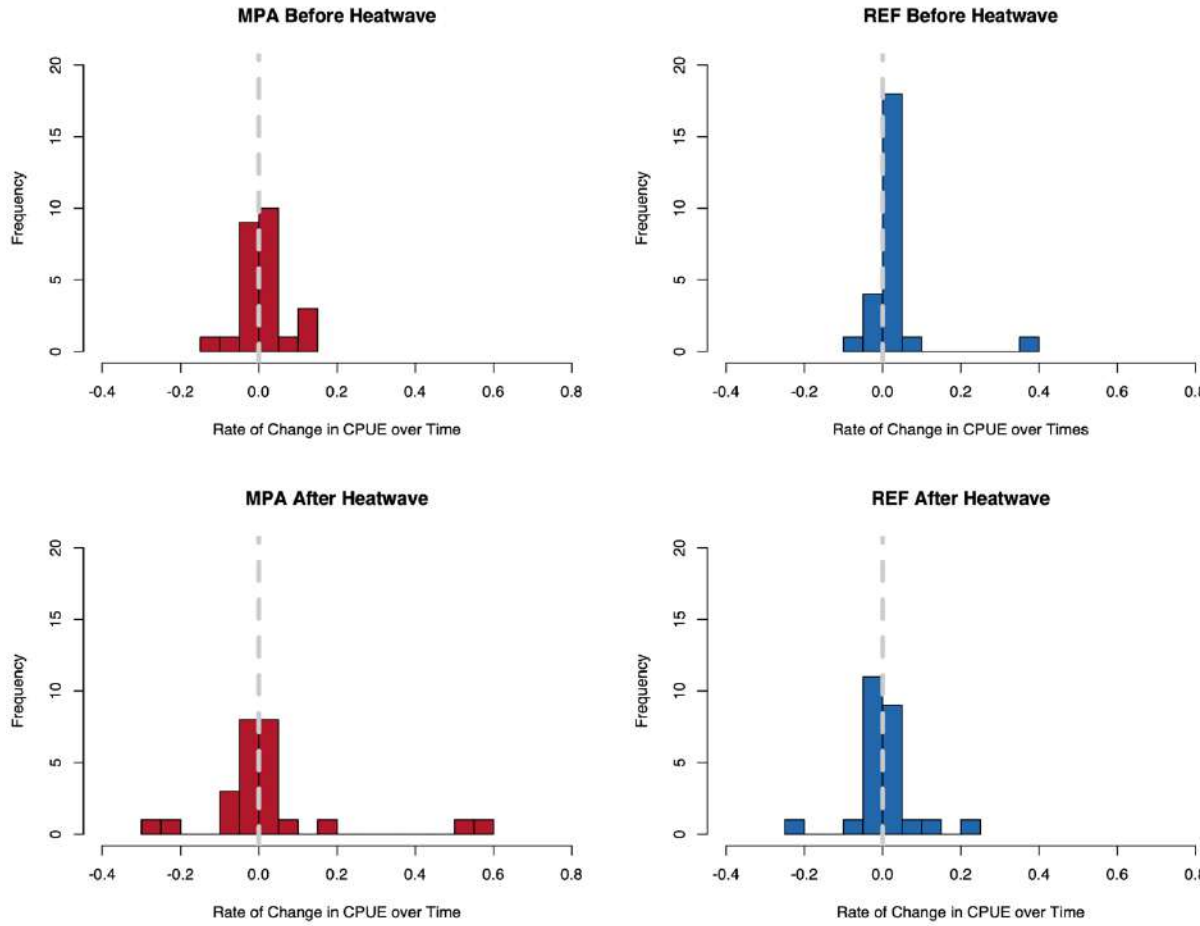


Figure 60. Histograms with the rates of change in CPUE over time for all species before and after the 2014-2015 marine heatwave in MPAs and Reference (REF) sites.

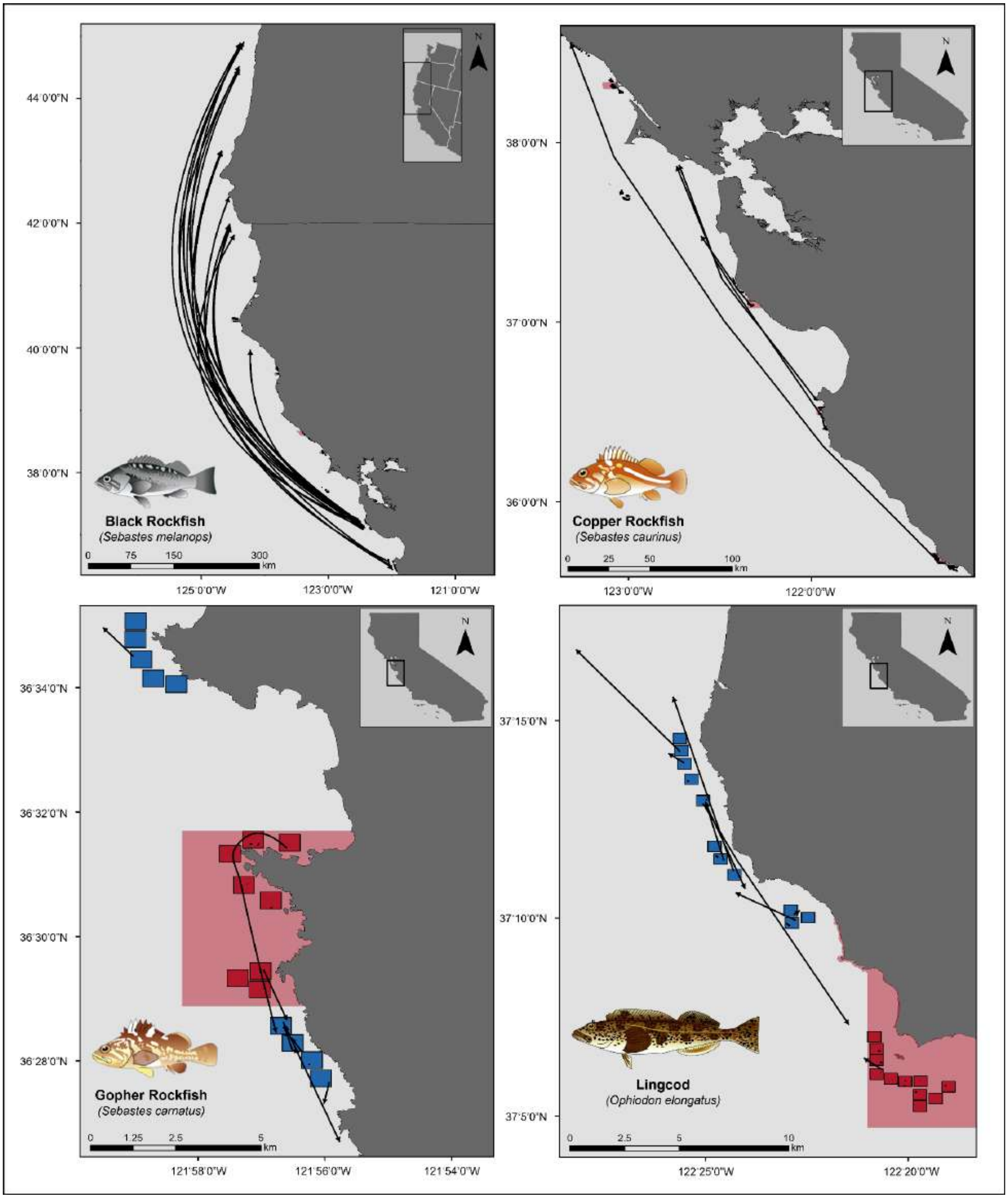


Figure 61. Examples of net movements by Black rockfish, Copper rockfish, Gopher rockfish and Lingcod tagged and released by CCFRP on the Central California coast.

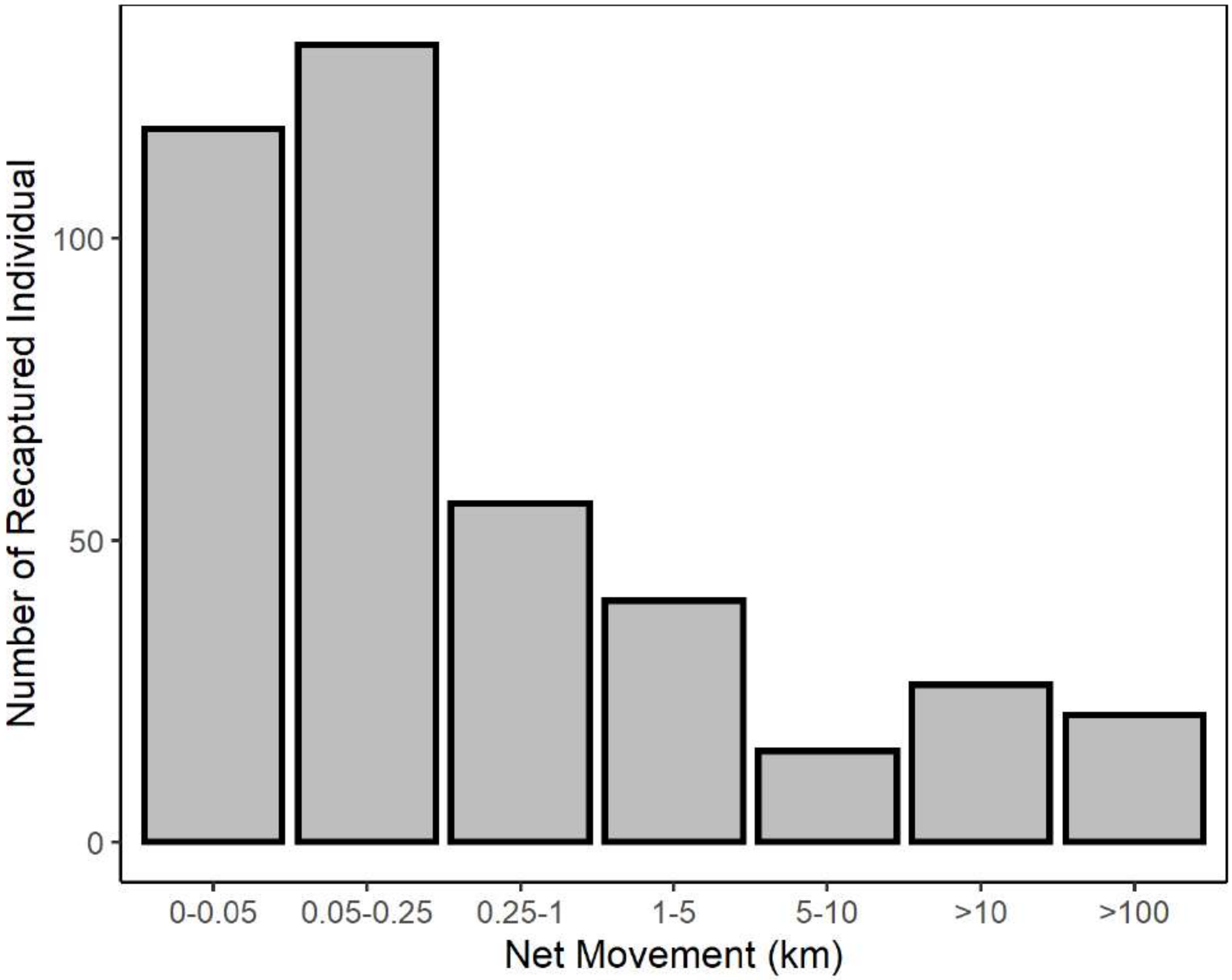


Figure 62. Net movement of individual fishes tagged and recaptured as part of CCFRP monitoring activities.

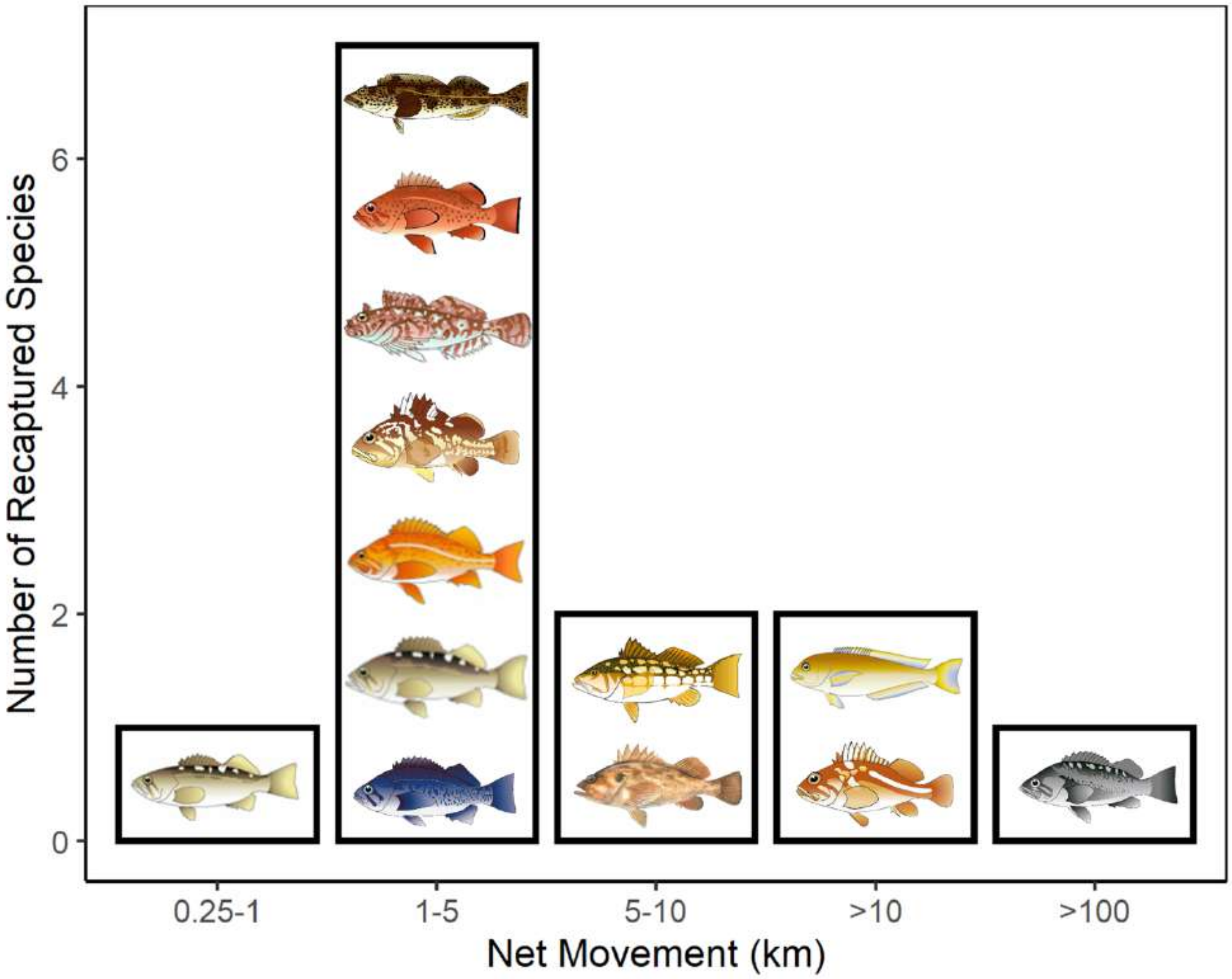


Figure 63. Number of species exhibiting mean net movements from CCFRP tag and recapture data. Shown are examples of the species falling within each net movement category.

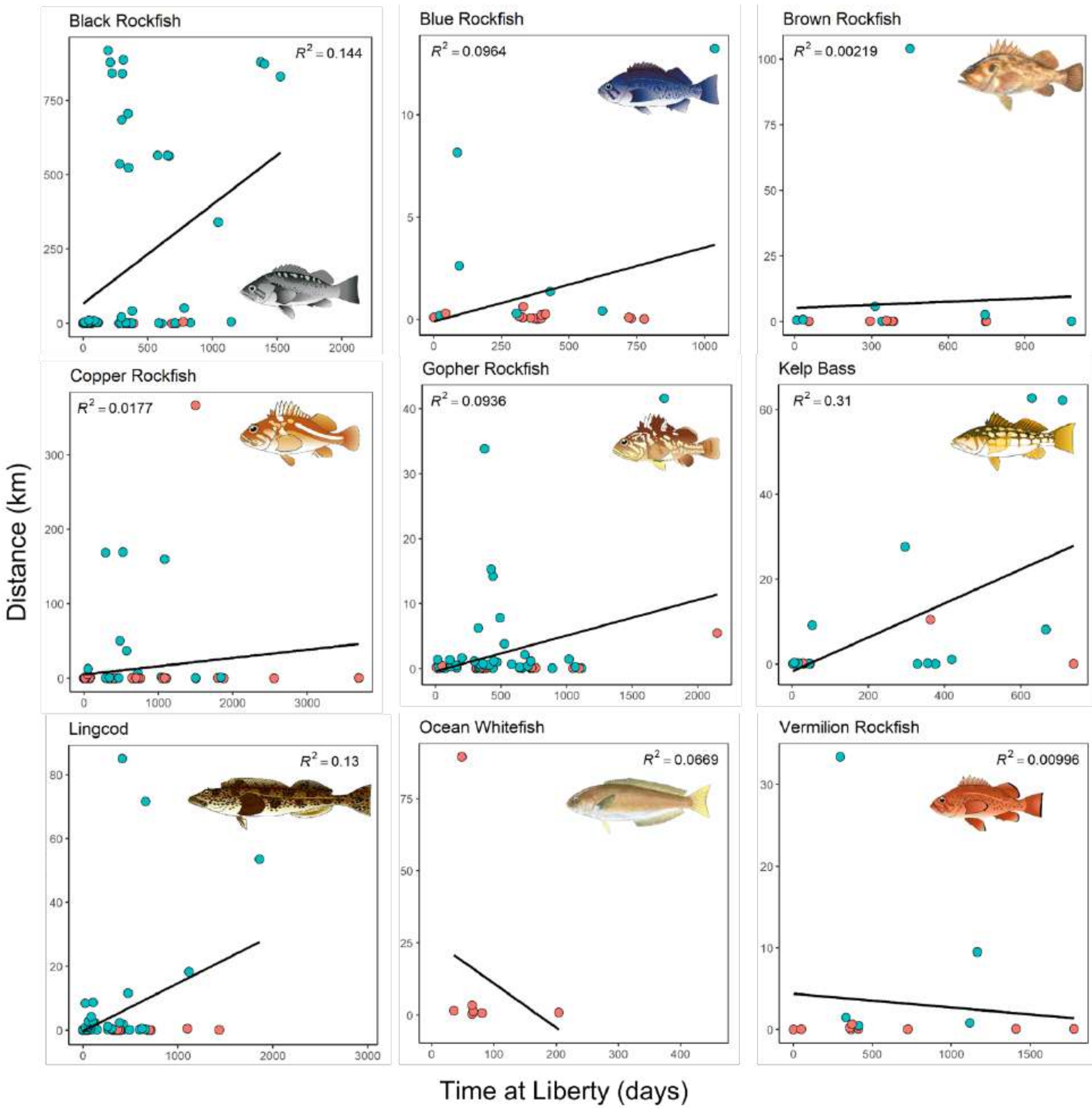


Figure 64. Distance traveled (km) during time at liberty (days) for the top 9 species with greater than 15 recaptures statewide. Red points denote recaptures on CCFRP sampling trips, blue points denote recaptures reported by recreational anglers.

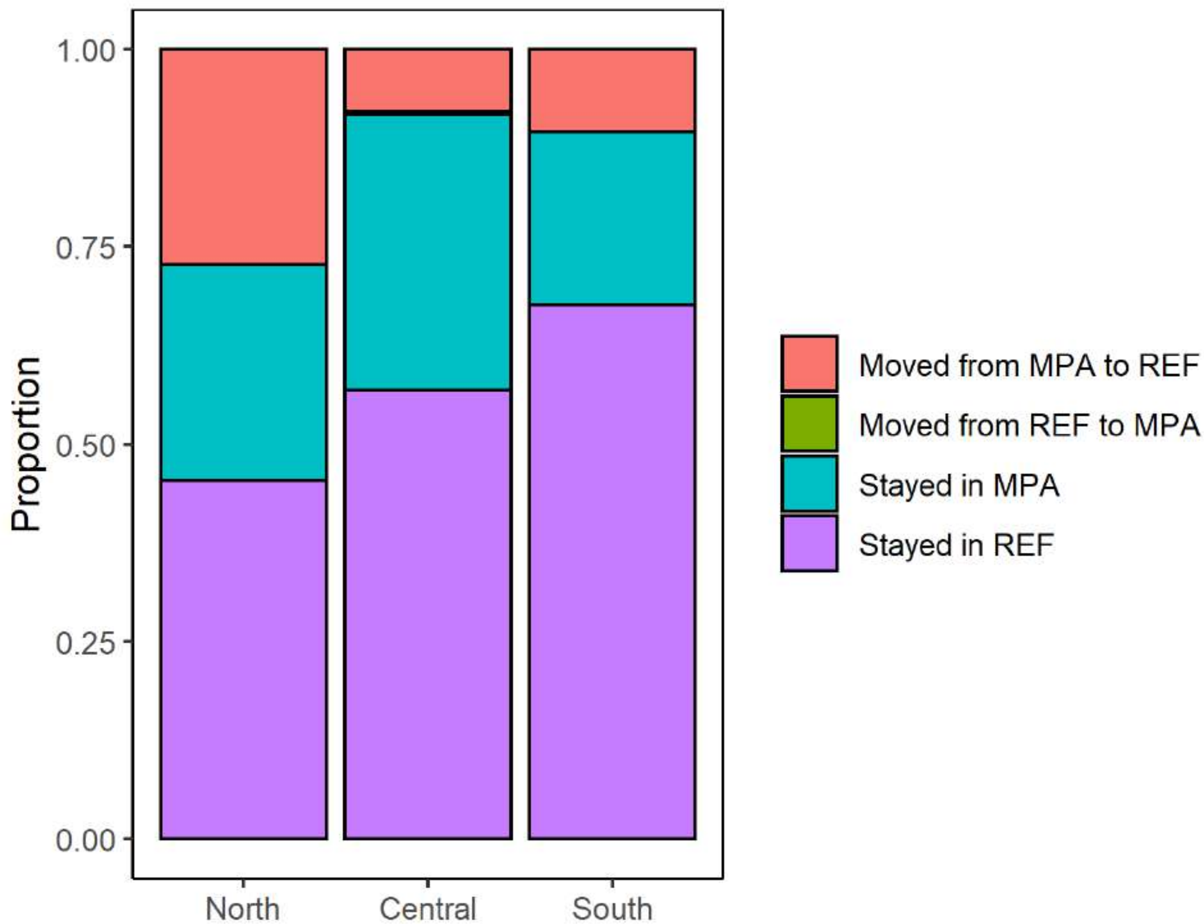


Figure 65. Proportion of recaptured individuals that moved out of or into an MPA or were recaptured in the same area open to fishing or MPA sites where they were tagged and released.

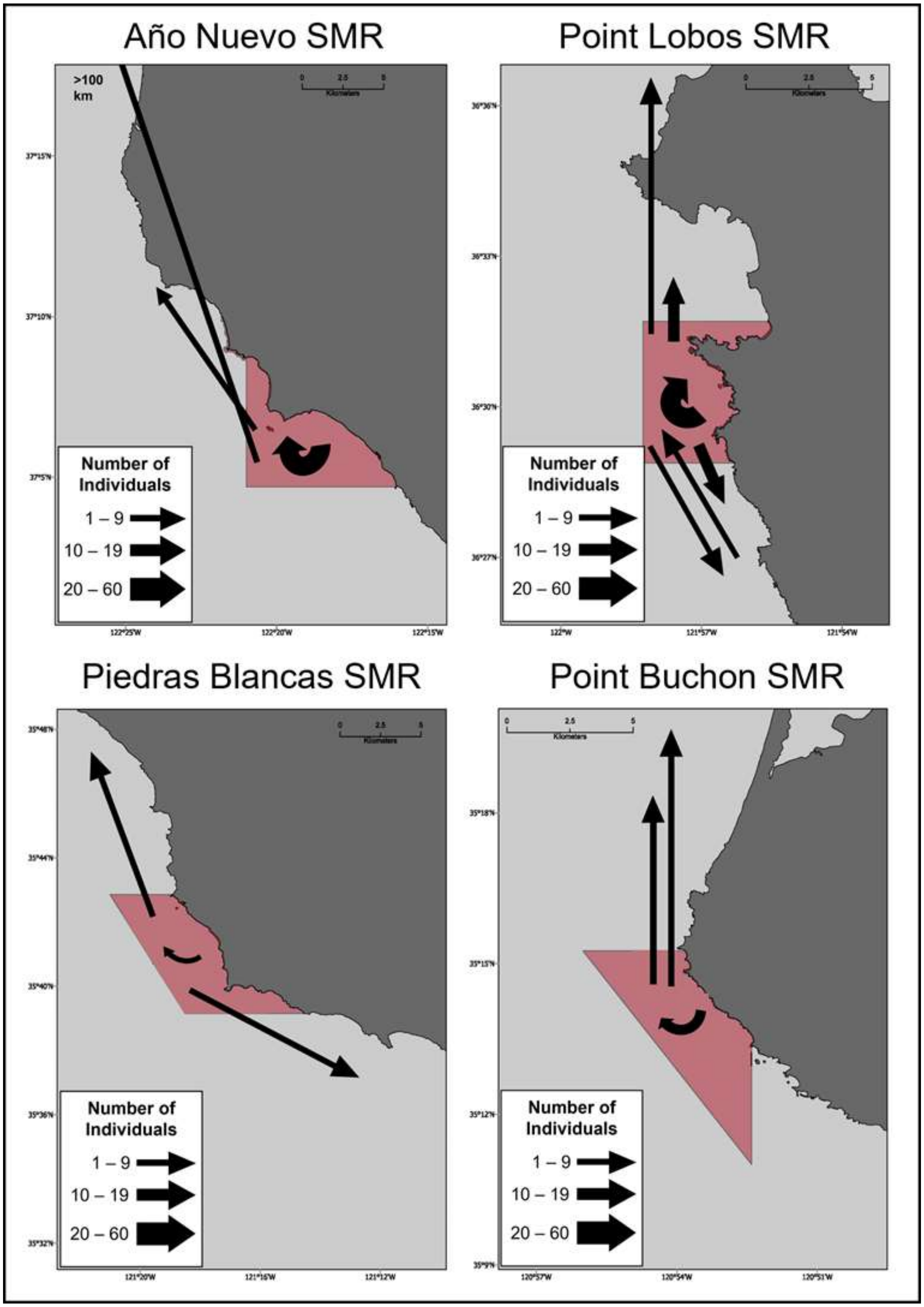


Figure 66. Movement vector maps of recaptured fishes originally tagged and released inside the four Central coast MPAs. Some fishes were recaptured within the same MPA where they were tagged and released, while other individuals were recaptured at varying distances outside of the MPA where they were originally released. Thickness of arrows indicates number of individuals and length of arrows indicate distance traveled.

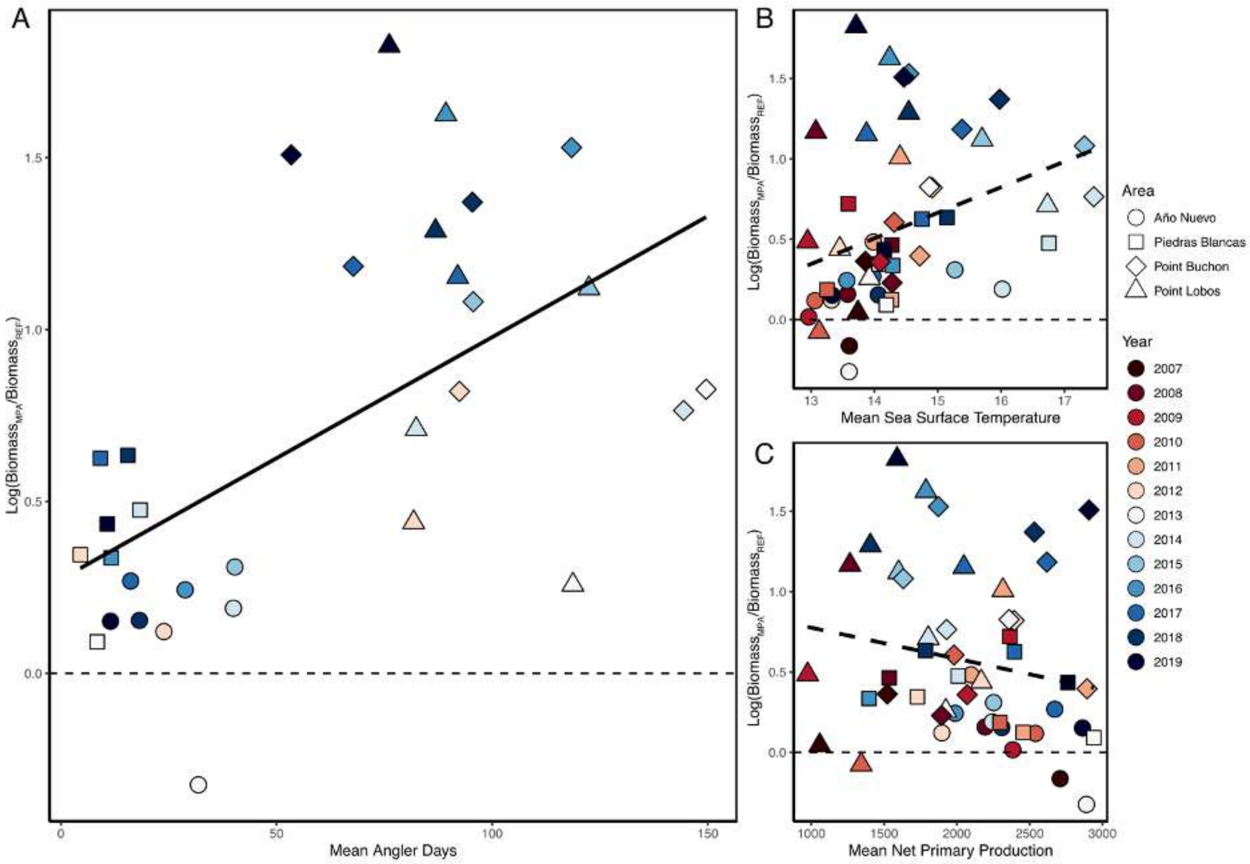


Figure 67. Fishing effort (A) and environmental variables [SST (B) and NPP(C)] in relation to biomass response ratios for the four MPAs along the Central coast for years with sufficient data between 2007 and 2019. Trend lines are linear regressions for the effect of each variable on biomass response ratios.

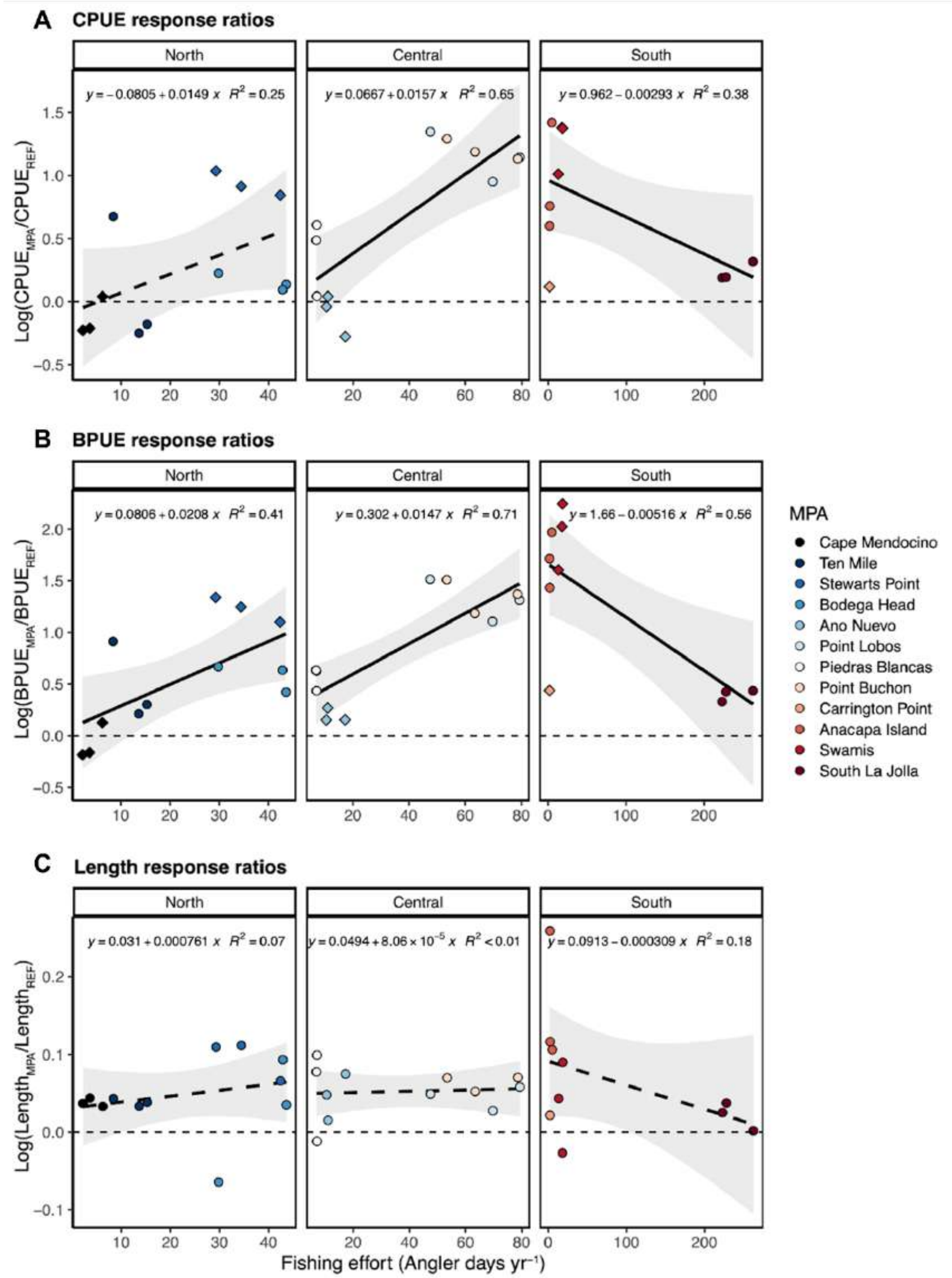


Figure 68. Average CPUE (A), BPUE (B) and Length (C) response ratios for 12 MPAs sampled along the California coast in relation to the amount of adjacent fishing effort. Fishing effort was calculated as the average number of angler days in fishing microblocks surrounding Reference sites. Trend lines are linear regressions for the relationship between total protected area and CPUE, BPUE, or Length response ratios. Solid lines are statistically significant relationships. Dashed lines are non-significant trends. Shaded gray area is 95% CI.

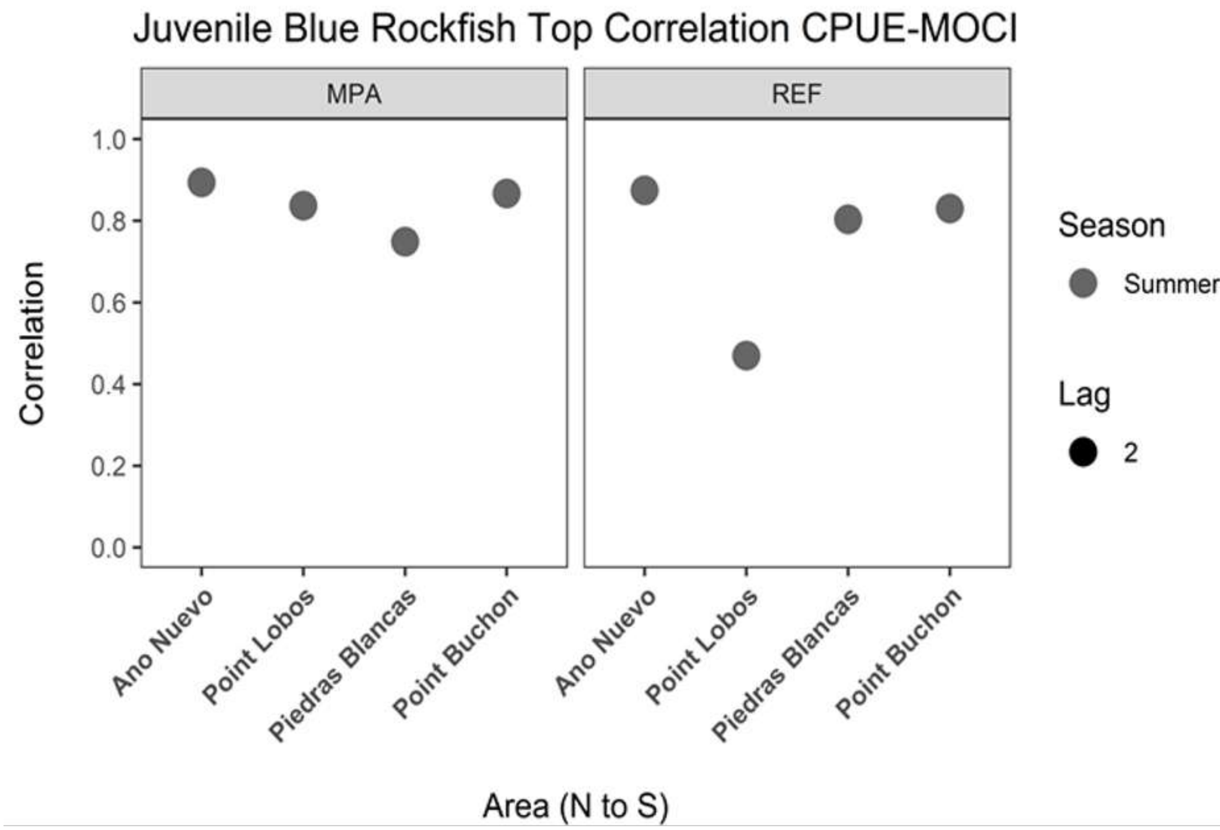


Figure 69. Correlations between the CPUE of juvenile Blue rockfish (<21 cm in length) and the Multivariate Ocean Climate Index (MOCI) at a lag of two years. This figure indicates that CPUE of juvenile Blue rockfish is strongly positively correlated with MOCI values two years previously during the summer (July-August-September).

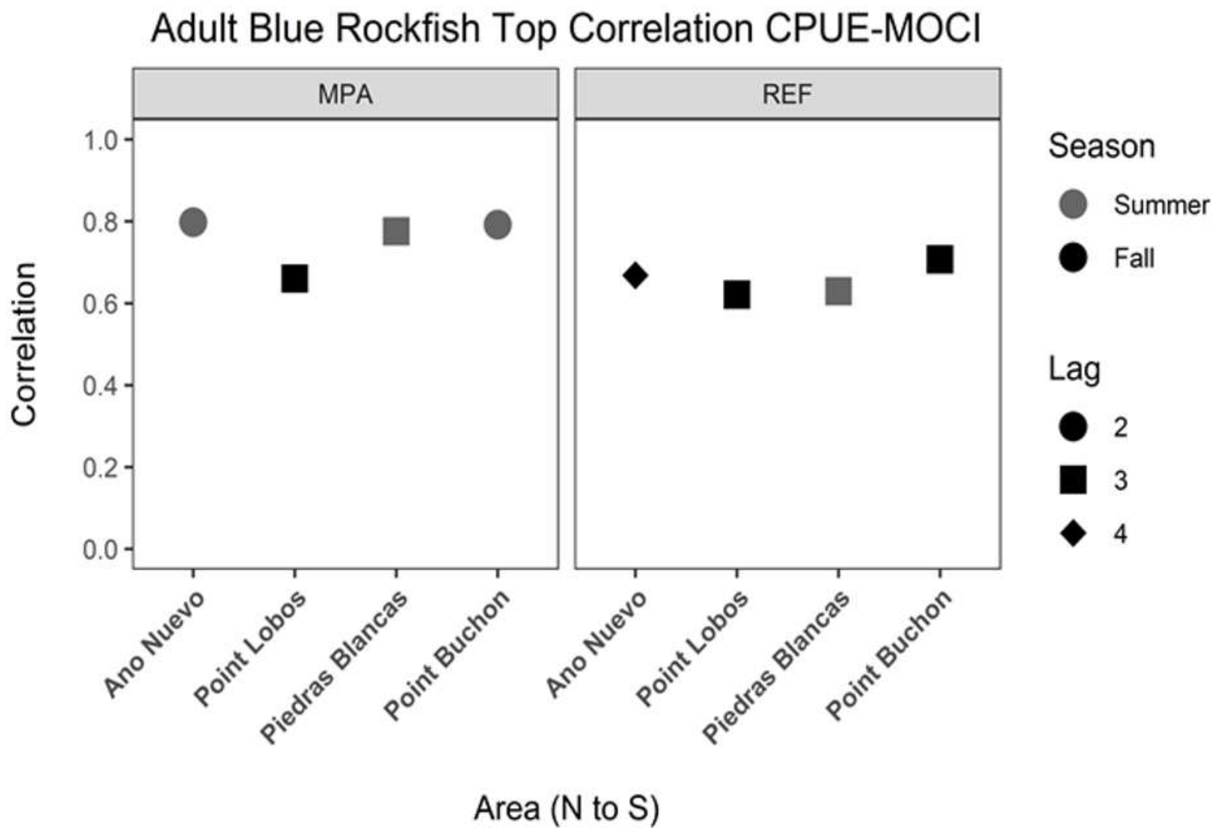


Figure 70. Correlations between the CPUE of adult Blue rockfish (>21 cm in length) and the Multivariate Ocean Climate Index (MOCI) at various time lags. This figure indicates that in the MPAs, CPUE correlates strongly with MOCI values 2-3 years ago in the summer (July-August-September) and fall (October-November-December). In the adjacent Reference sites, CPUE during the present year correlates strongly with MOCI values 3-4 years ago in the summer and fall.

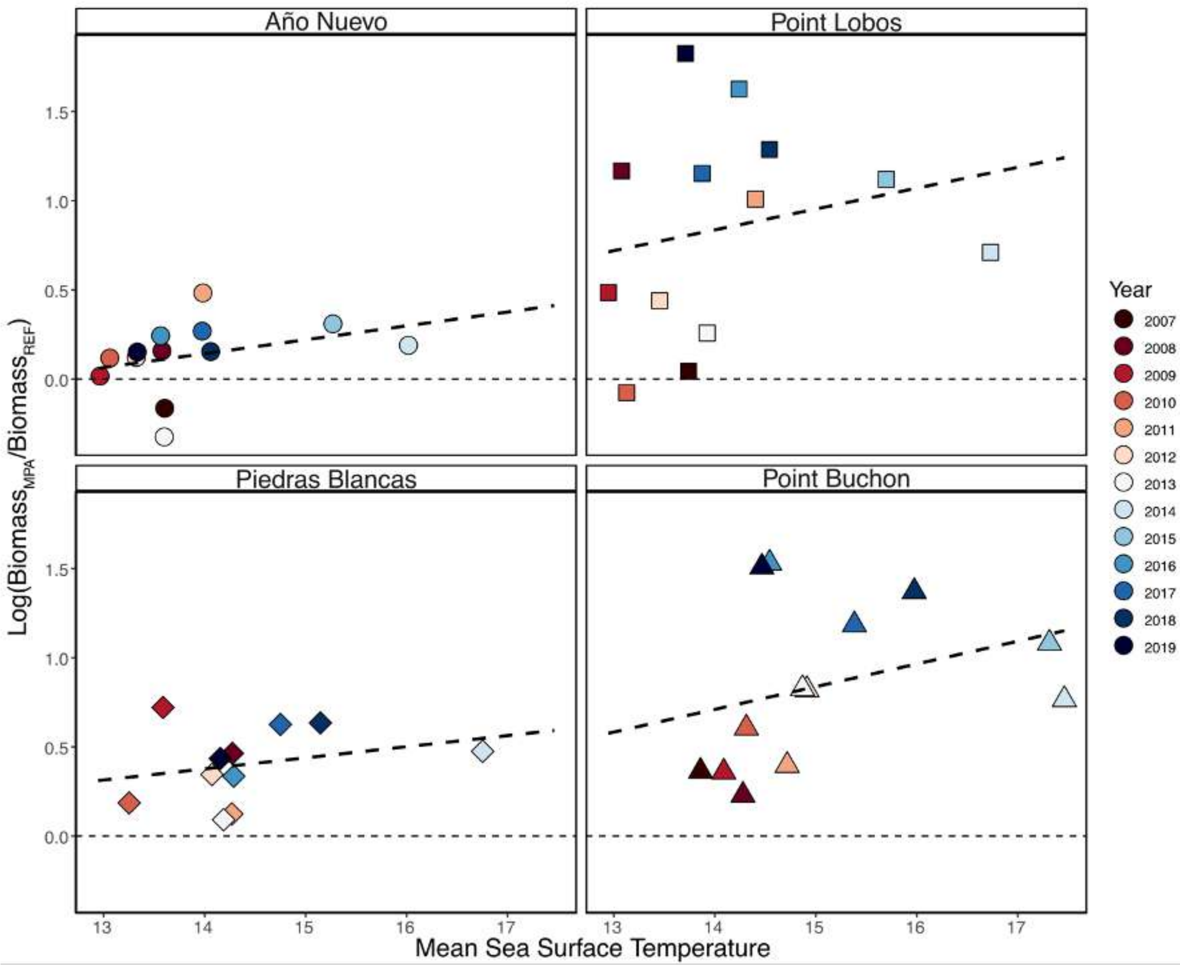


Figure 71. Biomass response ratios as a function of mean sea surface temperature for the CCFRP sampling period for each site and year sampled.

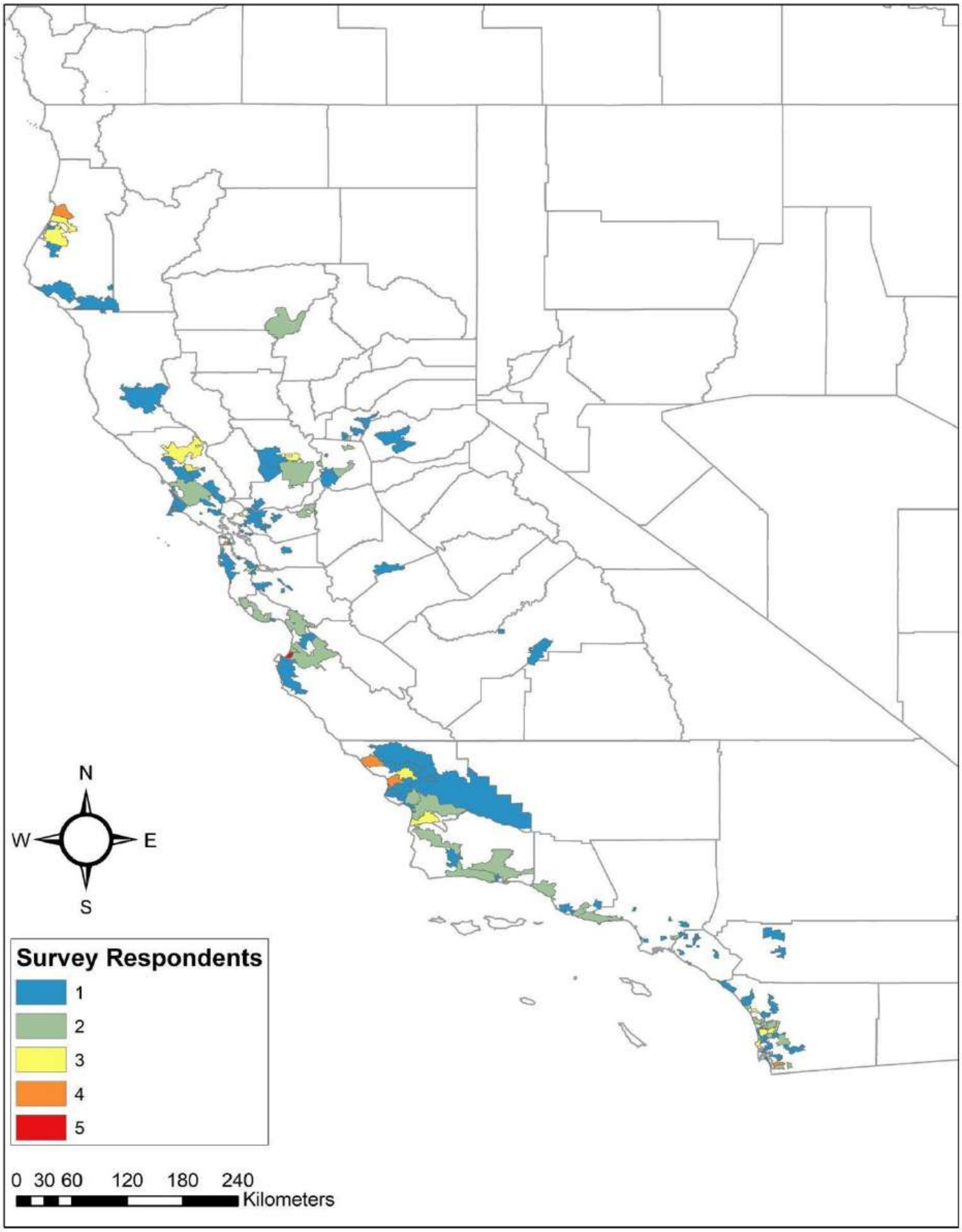


Figure 72. Map of zip codes of residence for respondents who reside in California. Counties are represented by lines and zip codes are represented by color shaded shapes. The number of survey respondents by zip code is represented by the color scale where cooler colors are fewer respondents and warmer colors are more respondents (n = 259).

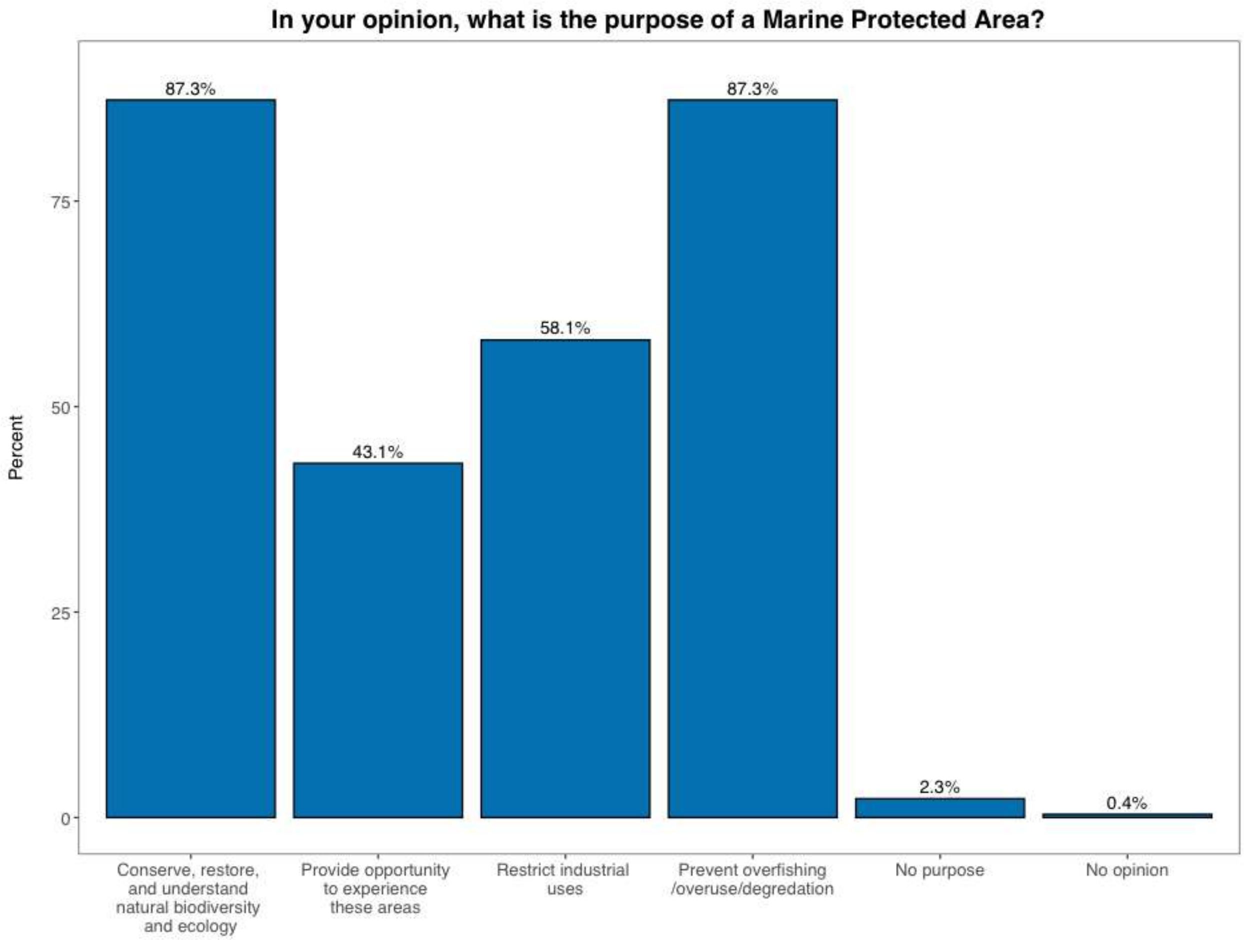


Figure 73. Percent of respondents having particular beliefs about the intended purpose of MPAs in California.

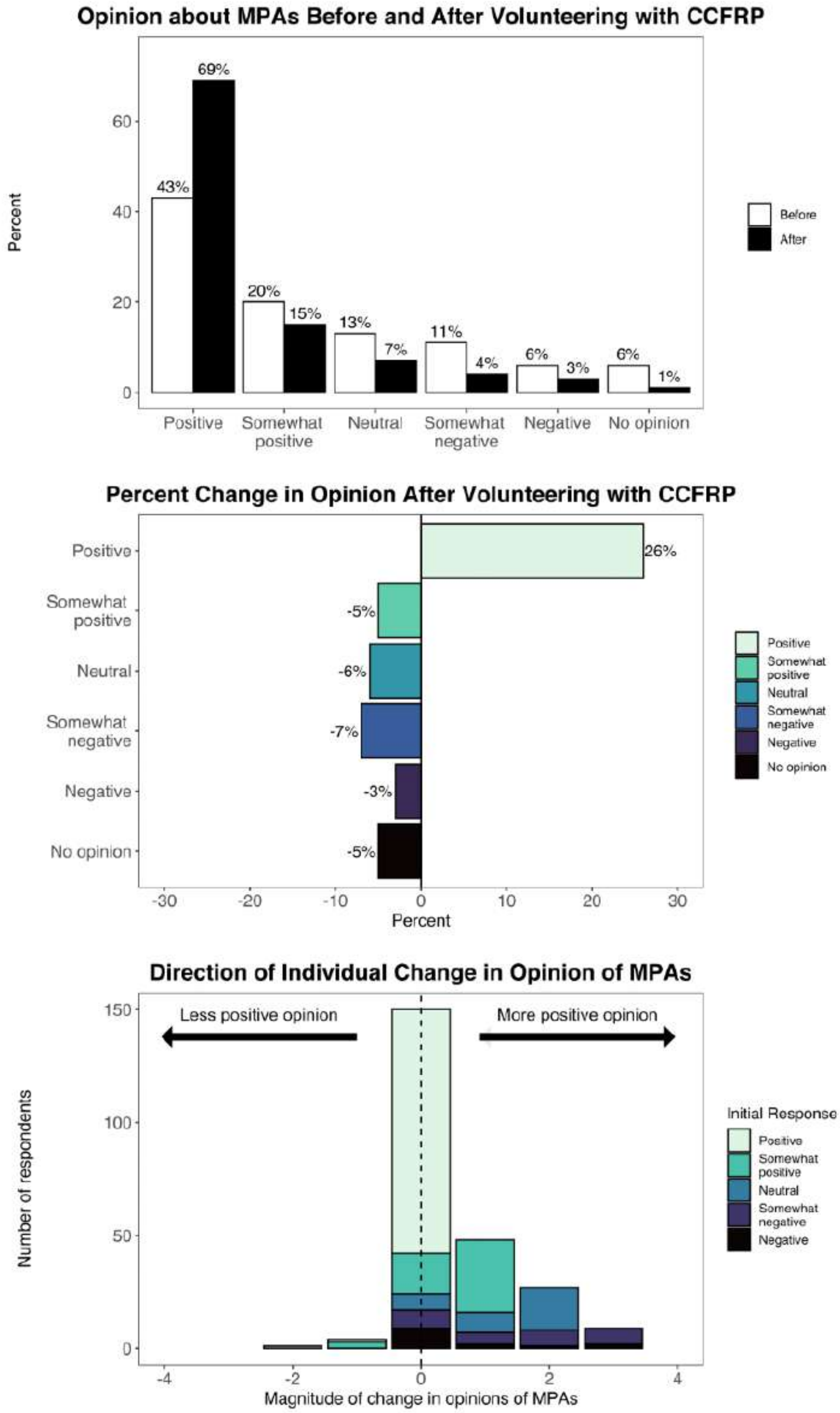


Figure 74. Angler opinions of MPAs become more positive after volunteering with CCFRP. (A) Opinions of MPAs before and after volunteering with CCFRP. (B) Percent change in opinion in each category before and after volunteering with CCFRP. (C) Magnitude of change in opinion about MPAs relative to the initial opinion of the respondent (n = 261). Note, a value of zero signifies the respondent did not change their opinion of MPAs after volunteering with CCFRP.

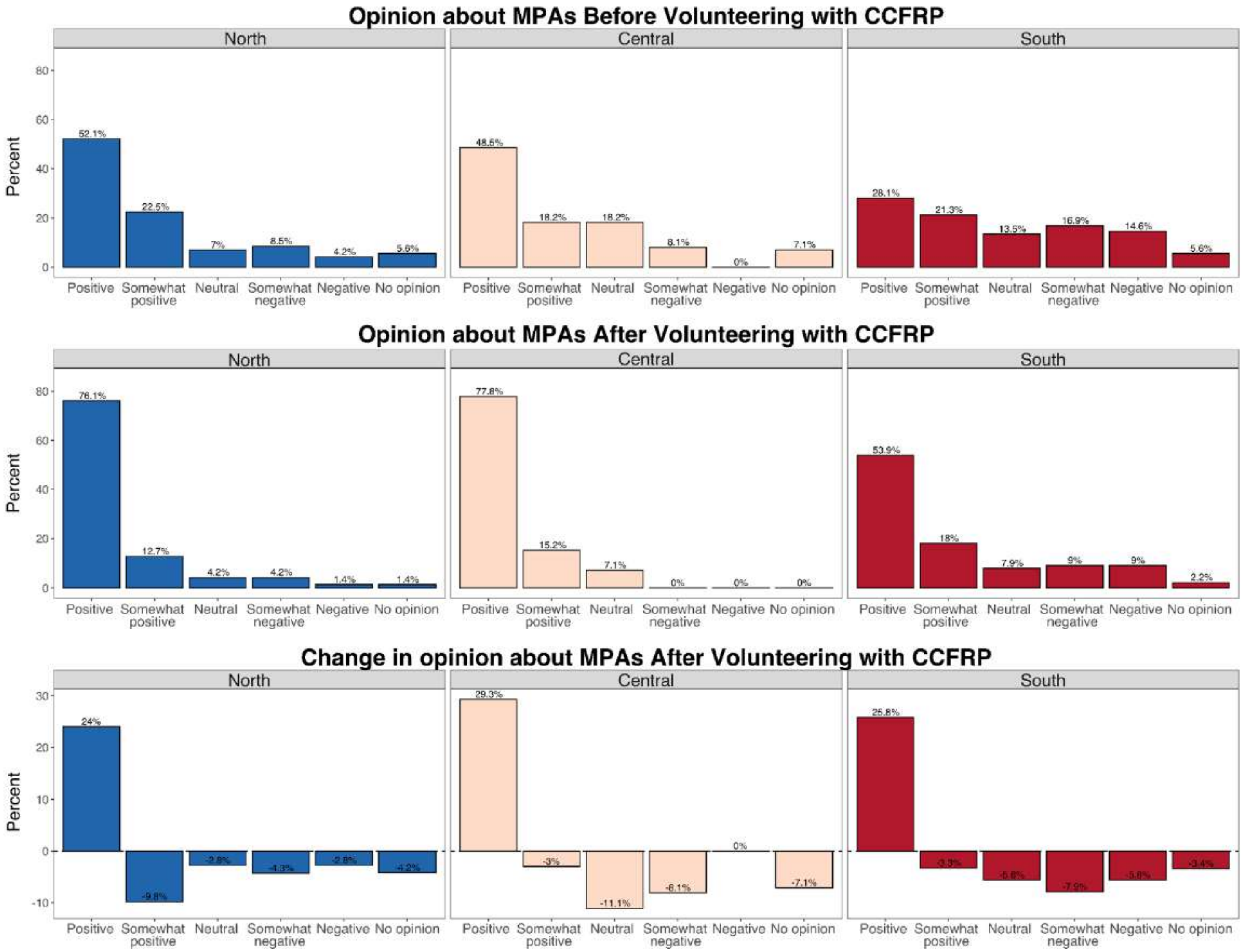


Figure 75. Angler opinions before (top) and after (middle) volunteering with CCFRP, along with the change in opinion of MPAs (bottom) based on the region where the respondent volunteers.

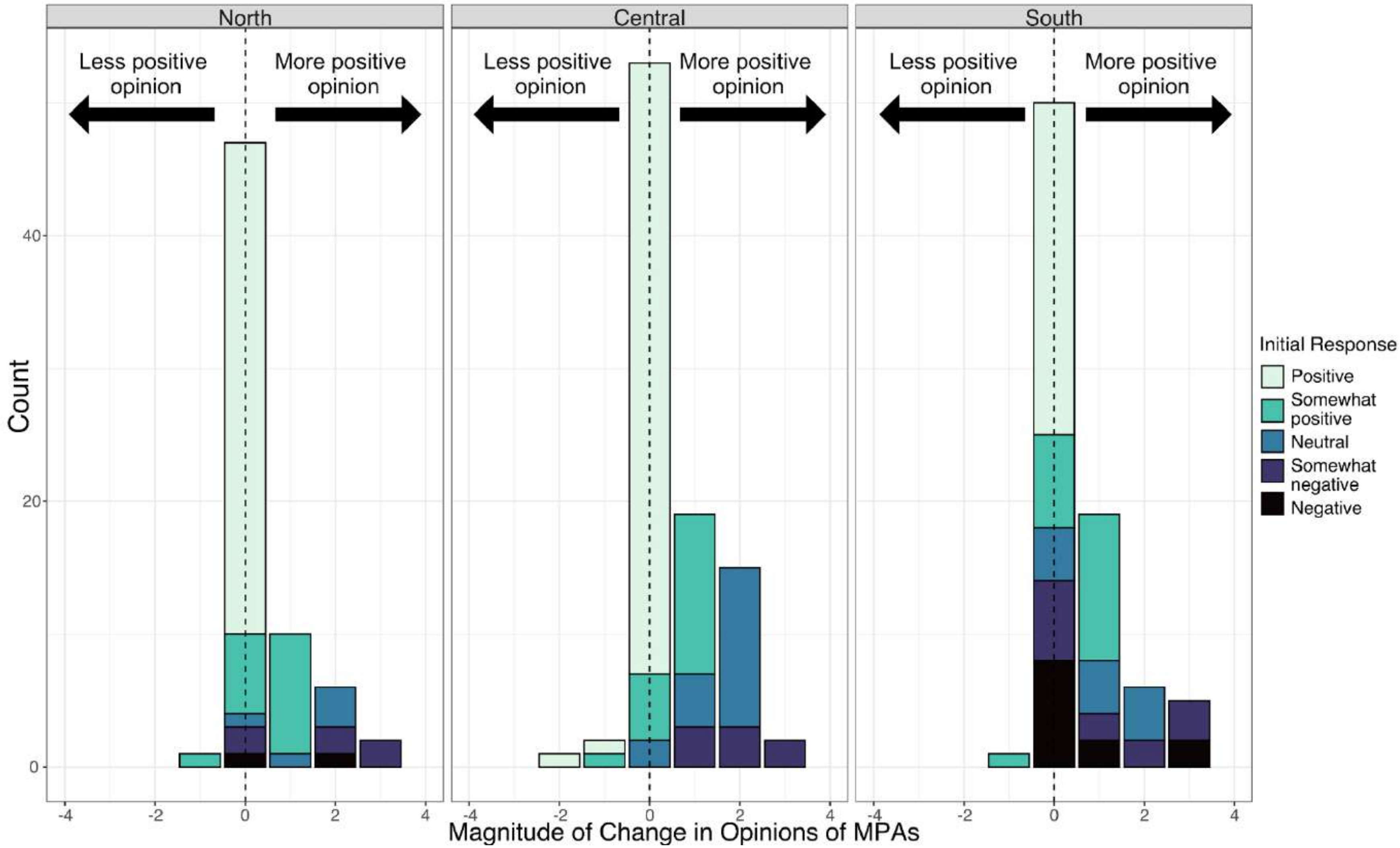


Figure 76. The magnitude of change in angler opinions about MPAs after volunteering with CCFRP, broken down by the region where each respondent participates. Note, a value of zero signifies the respondent did not change their opinion of MPAs after volunteering with CCFRP.

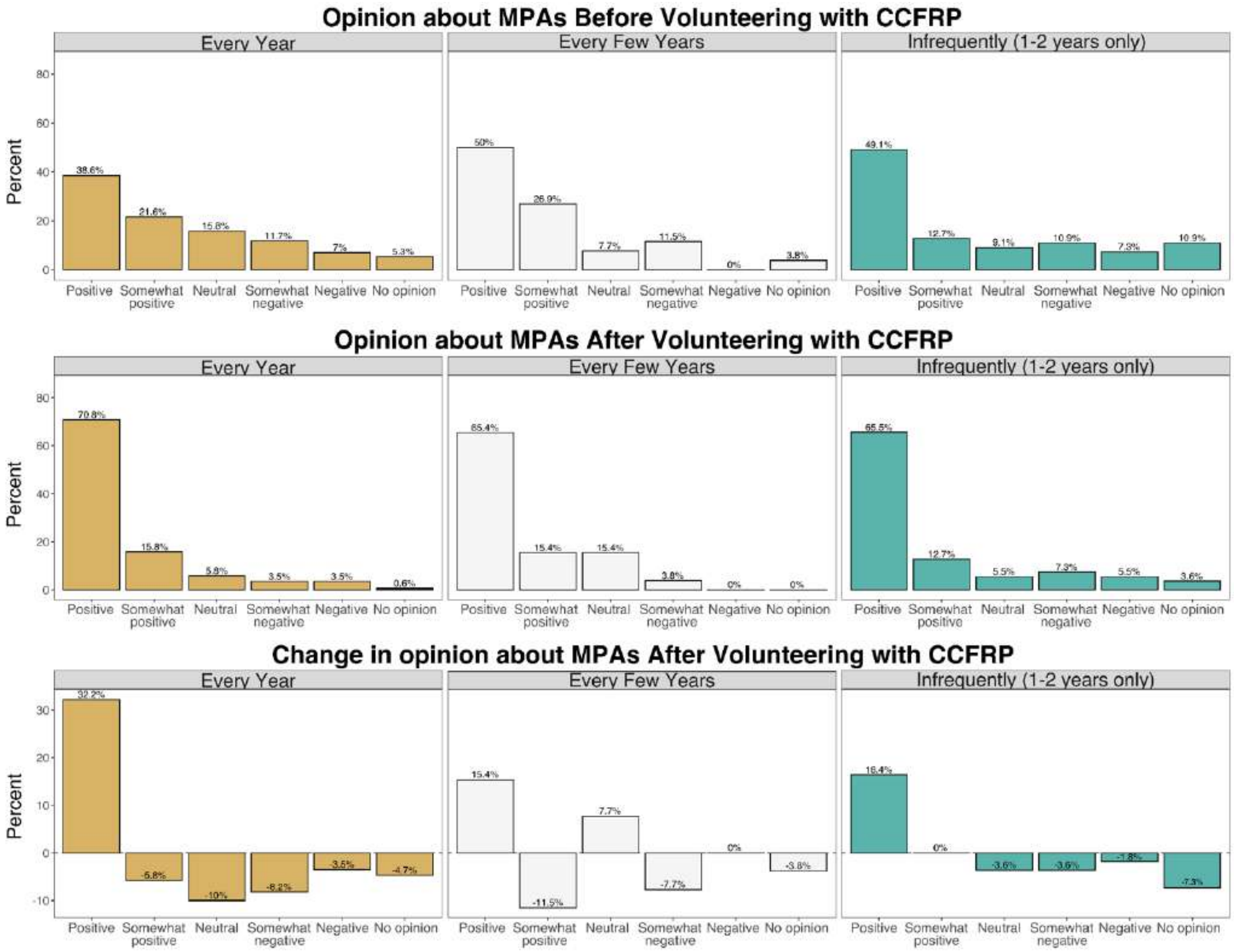


Figure 77. Angler opinions before (top) and after (middle) volunteering with CCFRP, along with the change in opinion of MPAs (bottom) based on the frequency with which the respondent participates in monitoring.

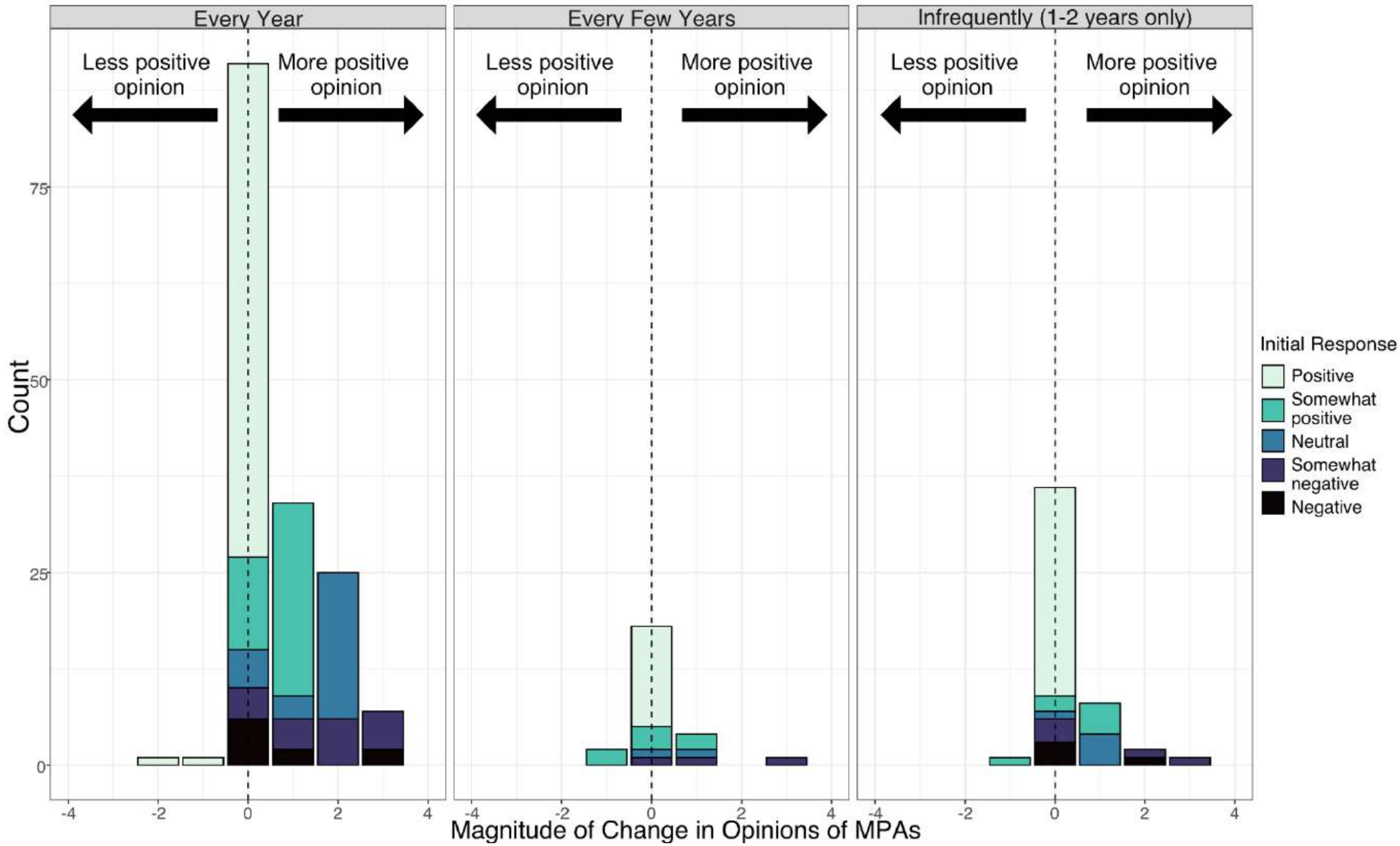


Figure 78. The magnitude of change in angler opinions about MPAs after volunteering with CCFRP, broken down by the frequency with which each respondent participates in monitoring. Note, a value of zero signifies the respondent did not change their opinion of MPAs after volunteering with CCFRP.

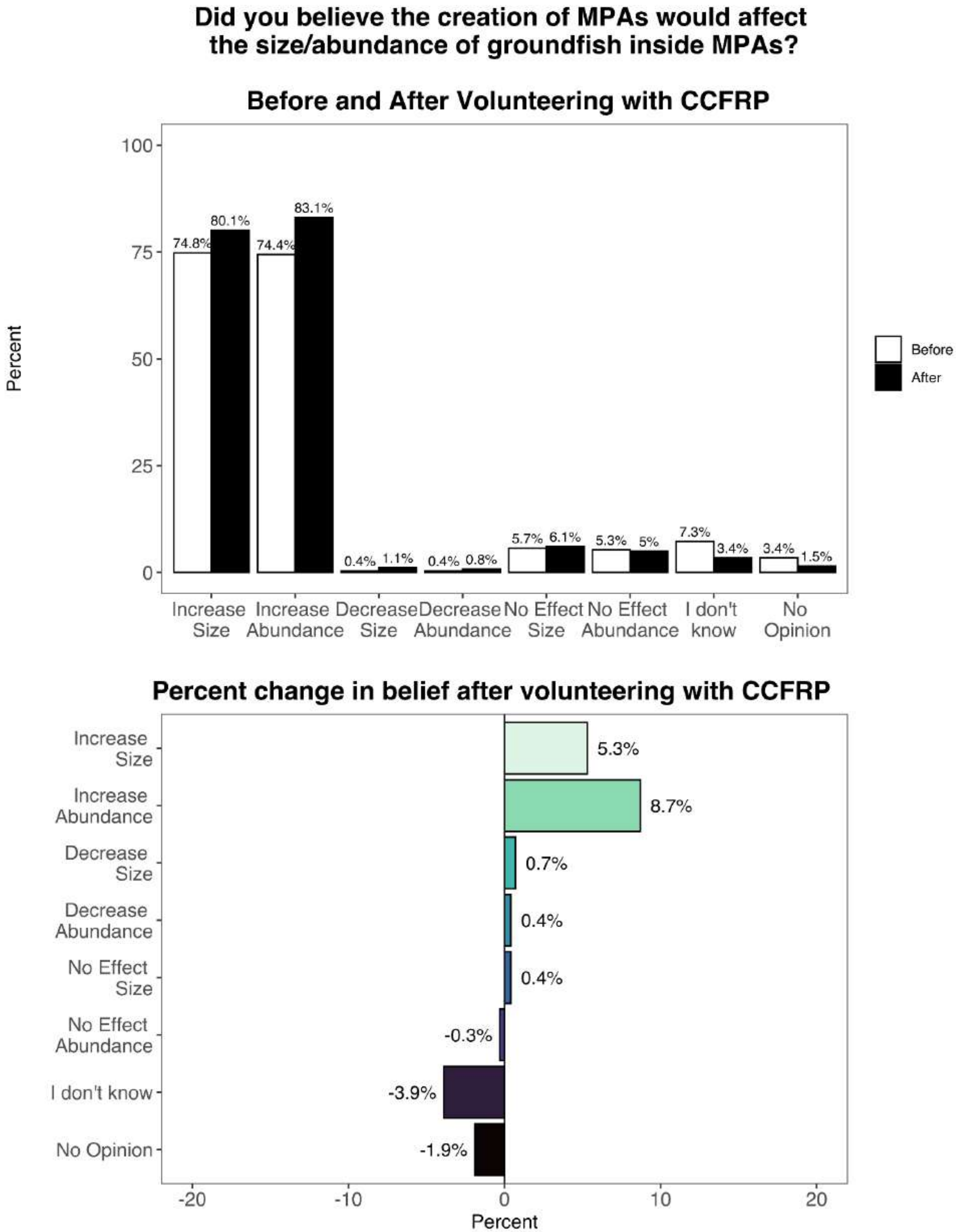


Figure 79. Views of volunteer anglers about the anticipated effects of MPAs on size and abundance of fishes inside MPAs.

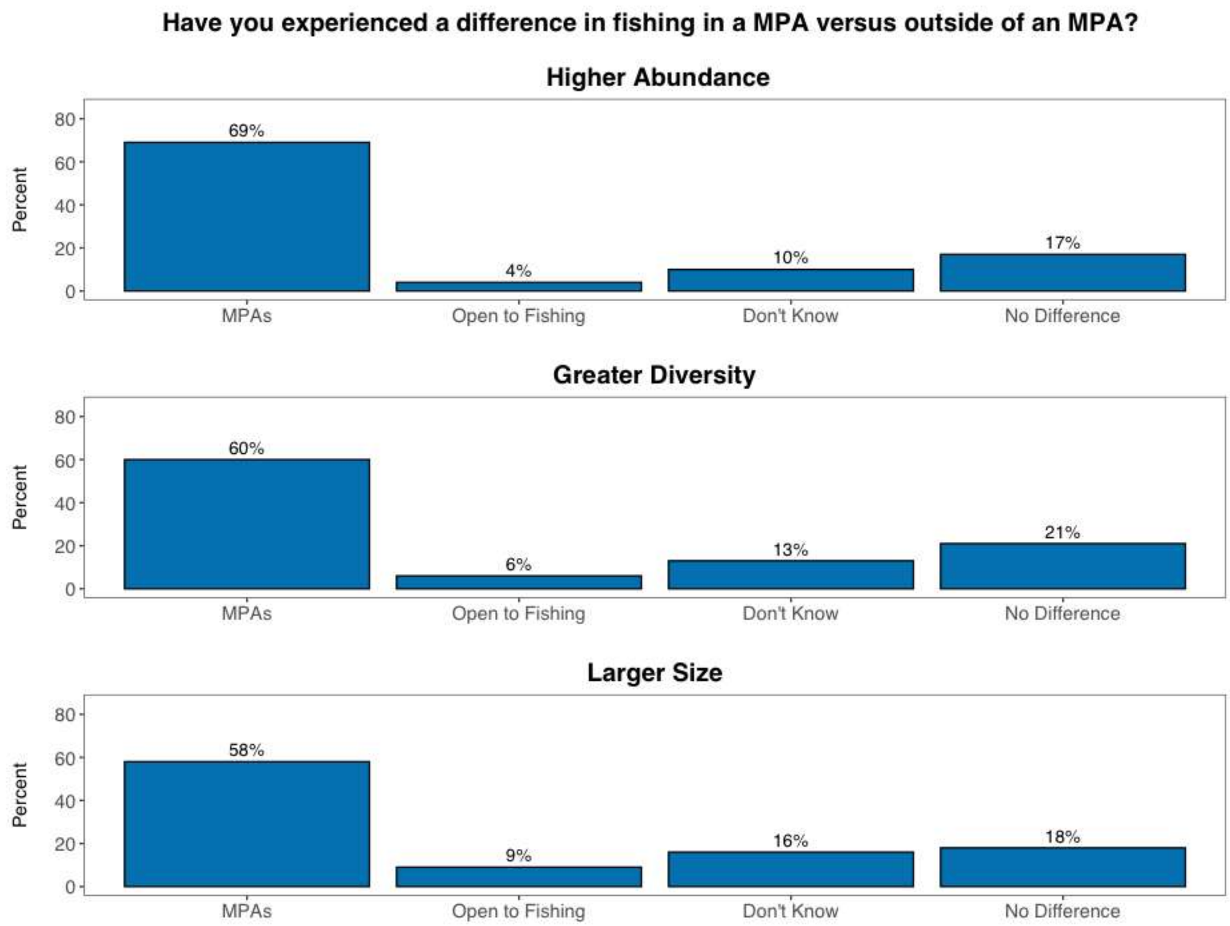


Figure 80. For volunteer anglers that have fished both inside and outside of MPAs with CCFRP, this plots the percentage that report having caught more fish (top), a higher diversity of species (middle), or larger individuals (bottom) inside MPAs.

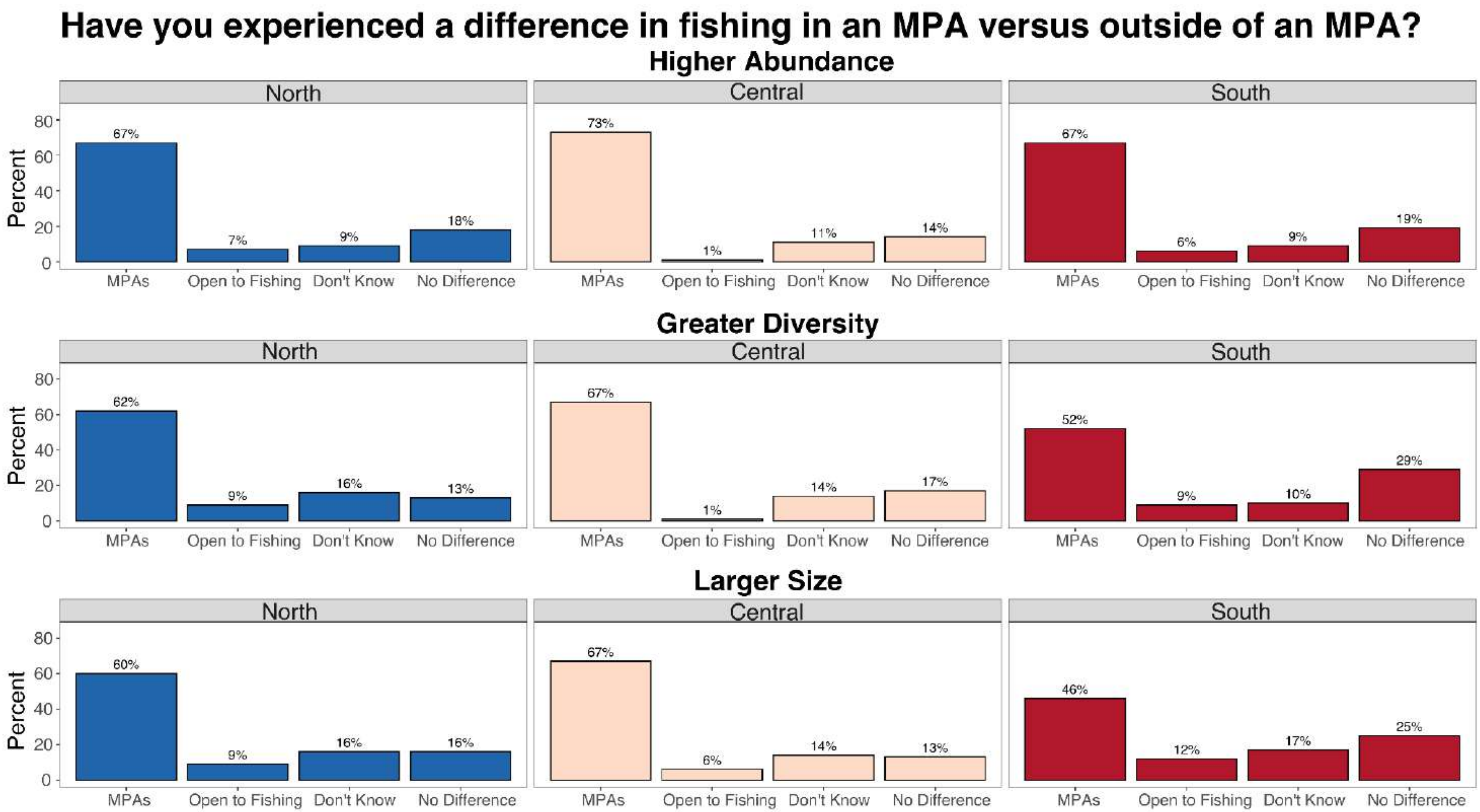


Figure 81. Breakdown by region of the percent of respondents who report catching more fish (top), a greater diversity of species (middle), or larger fish (bottom) inside MPAs.

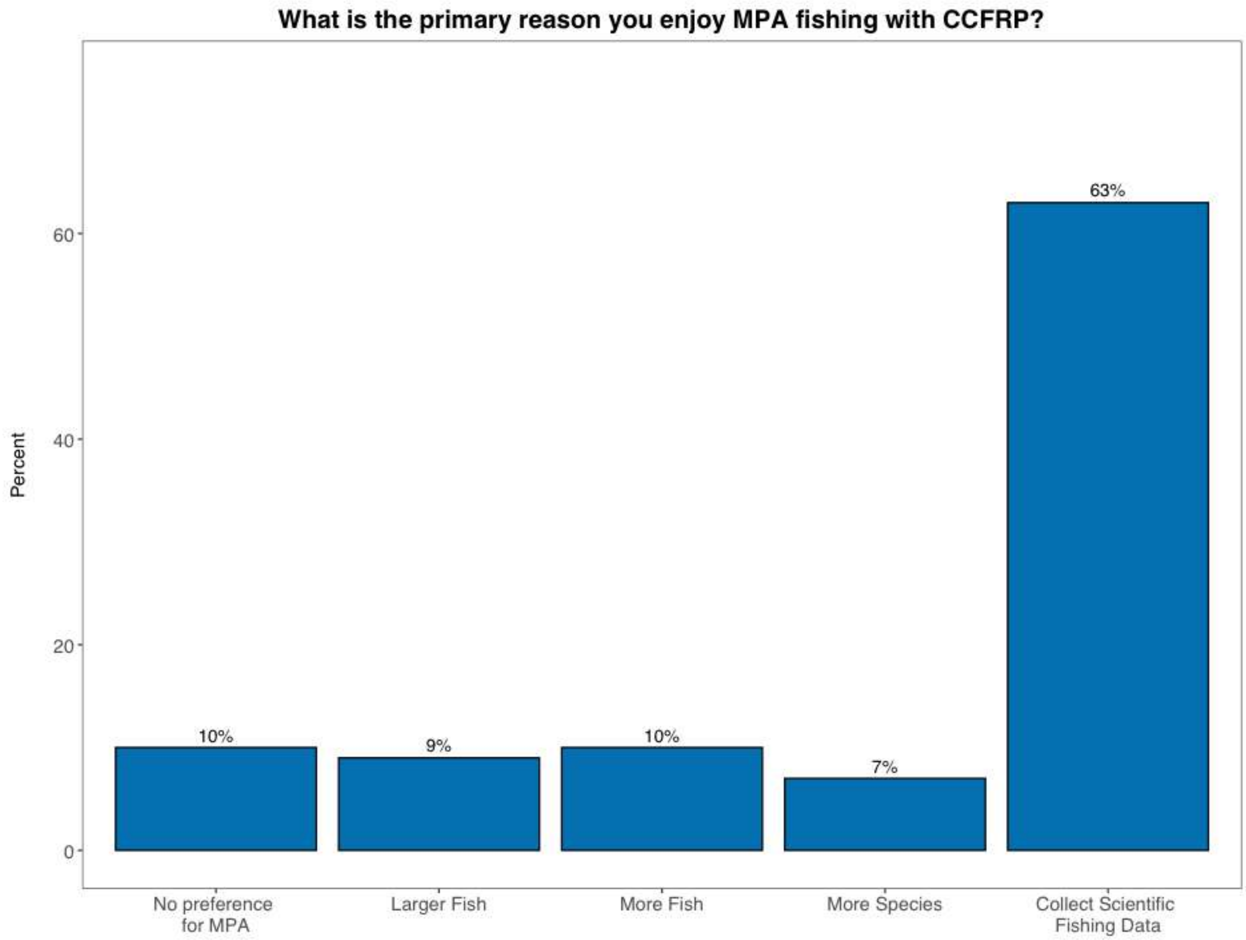


Figure 82. For volunteer anglers participating with CCFRP that have fished inside MPAs, this plots the primary reasons that respondents enjoy fishing in MPAs.

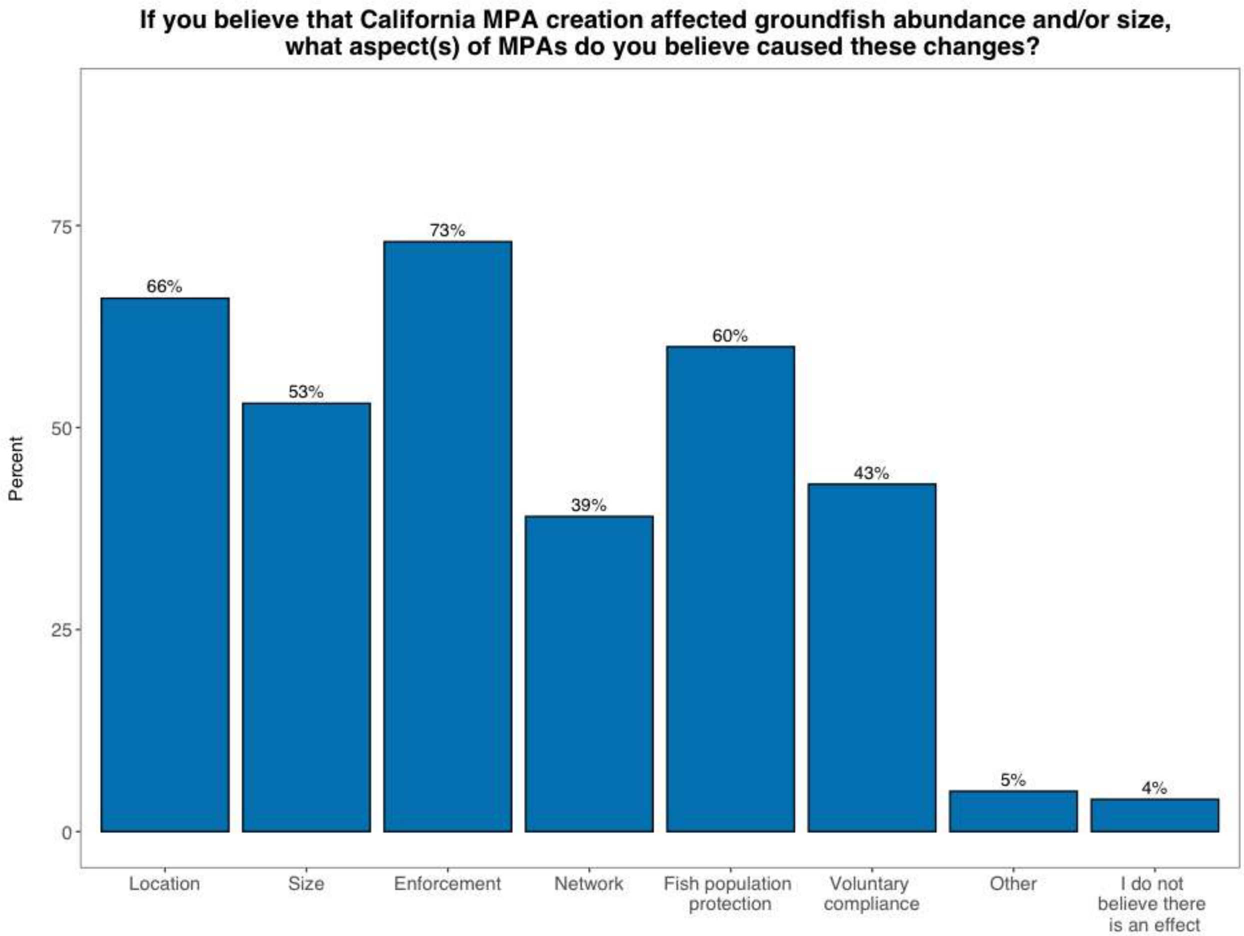


Figure 83. Impressions of volunteer anglers about the factors explaining why California's MPAs will result in increases in abundance and size of groundfish.

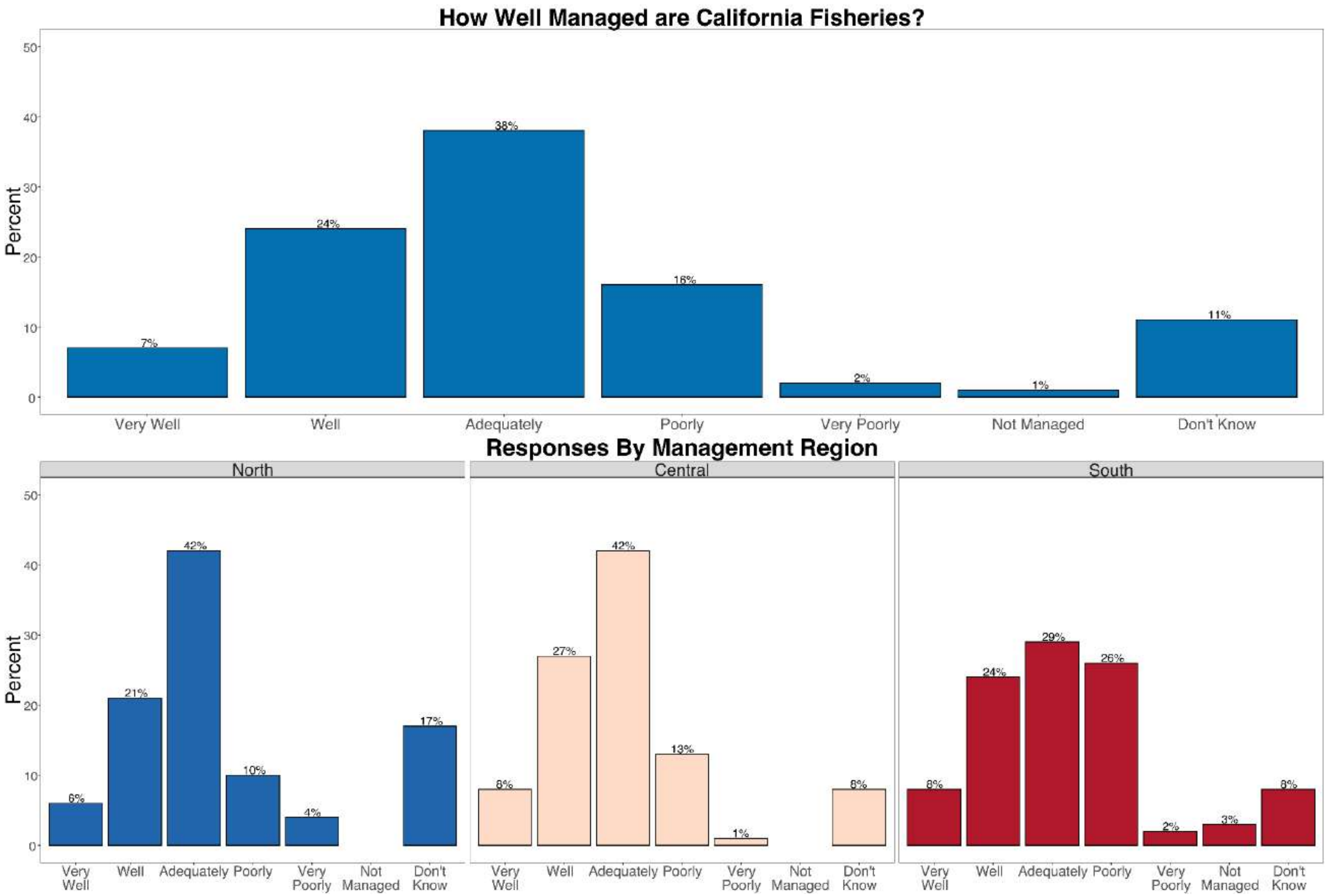


Figure 84. Distribution of volunteer angler opinions about the management of California groundfish stocks (top). Regional breakdown in angler opinions about how well groundfish stocks are managed (bottom).

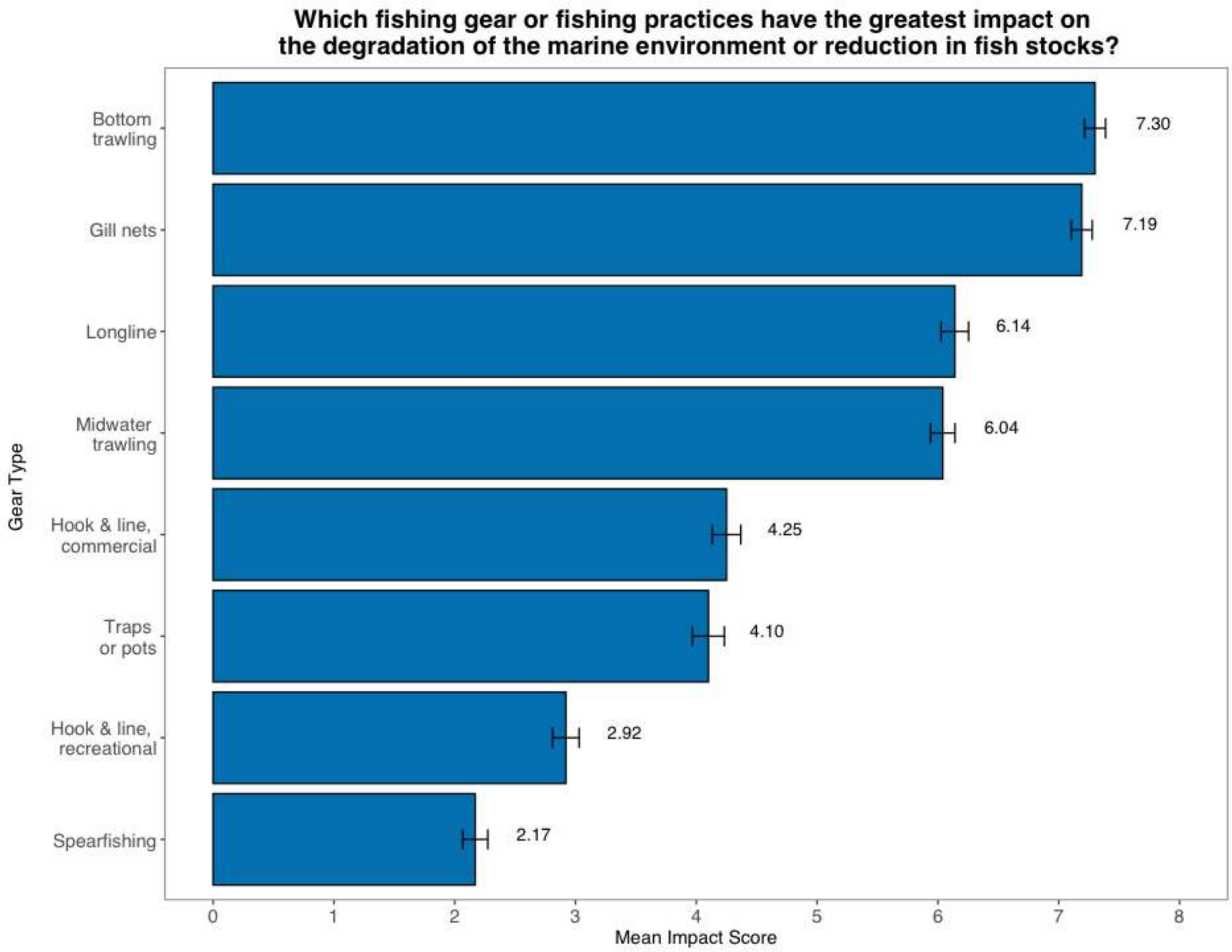


Figure 85. Volunteer angler opinions about which types of fishing gear are more destructive (higher impact score) for the marine environment. Bars denote means ± standard error.

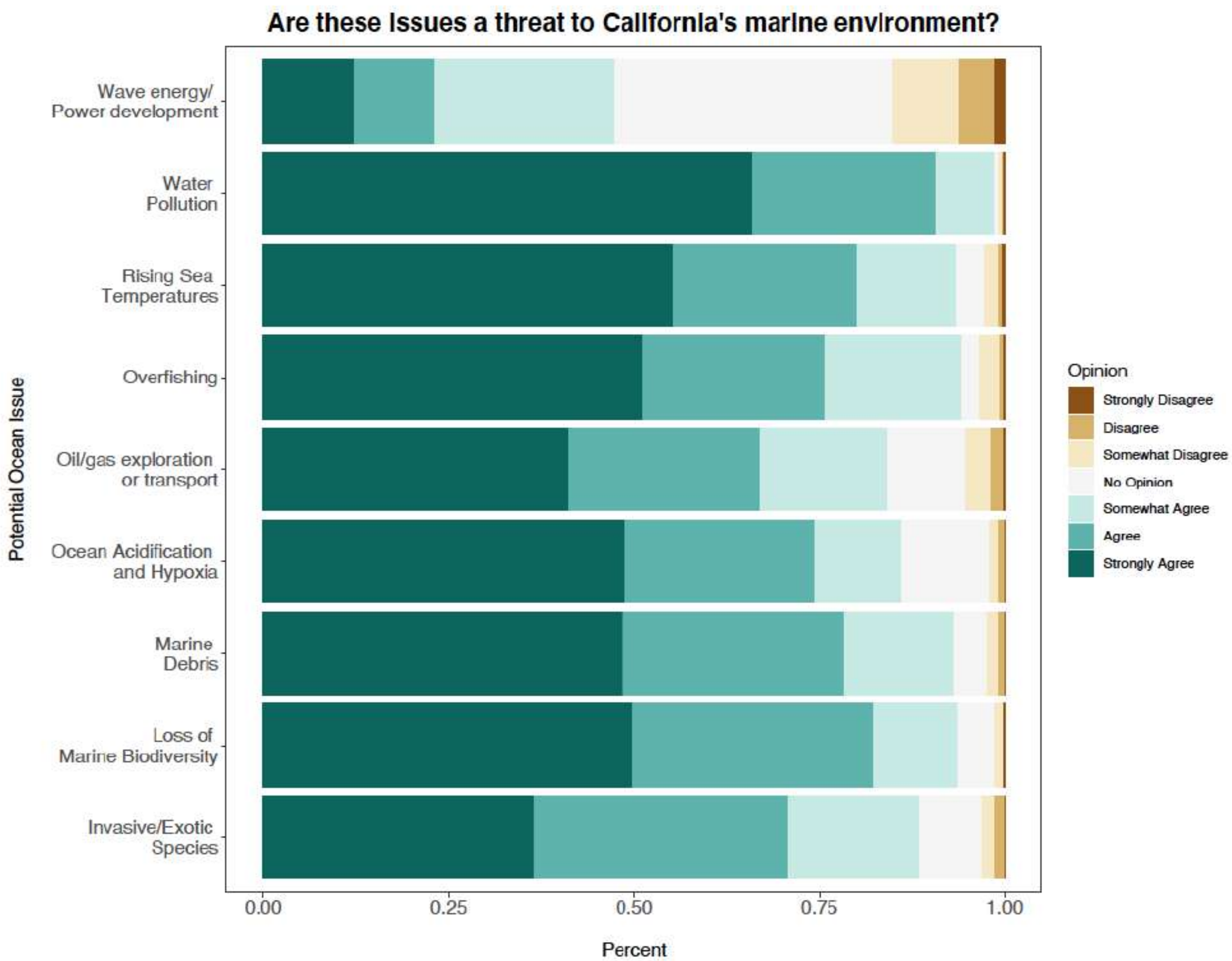


Figure 86. Views of volunteer anglers on whether particular ocean issues represent a threat to California's marine environment.

APPENDIX A

Table S1. Mean total lengths (cm) of the ten species most commonly caught during surveys along the Central California coast region for MPA and Reference (REF) sites for all years combined (2007-2020). Results from Tukey's post-hoc pairwise comparison test (difference between MPA and REF factoring site and year).

Common name	Mean total length (cm)		difference	p-value
	MPA	REF		
Black rockfish	32	29	2.69	0.05
Blue/Deacon rockfish	26	26	1.01	0.99
Canary rockfish	30	28	1.5	0.89
Copper rockfish	39	33	5.77	<0.001
Gopher rockfish	27	27	0.25	1
Kelp rockfish	32	31	0.33	0.99
Lingcod	60	56	2.09	0.007
Olive rockfish	34	30	2.85	0.03
Vermilion rockfish	40	36	2.87	0.02
Yellowtail rockfish	26	26	1.51	0.89

Table S2. Published values for size at which 50% of the population is mature and the proportion of fishes greater than the size at 50% maturity for the ten species most commonly caught during surveys along the Central California coast region for MPA and Reference (REF) sites for all years combined (2007-2020). Results from Tukey's post-hoc pairwise comparison test (difference between MPA and REF factoring site and year).

Common name	Size at which 50% of the population is mature	Proportion of fishes greater than size at 50% maturity		difference	p-value
		MPA	REF		
Black rockfish	41	0.00	0.00	0.0008	1
Blue/Deacon rockfish	22	0.84	0.82	0.02	1
Canary rockfish	44.5	0.00	0.00	0.003	1
Copper rockfish	31	0.79	0.59	0.2	<0.001
Gopher rockfish	17	1.00	1.00	0.0008	1
Kelp rockfish	21	1.00	1.00	0.0003	1
Lingcod	57	0.57	0.43	0.14	0.02
Olive rockfish	35	0.41	0.24	0.16	0.002
Vermilion rockfish	38	0.69	0.52	0.17	0.001
Yellowtail rockfish	35	0.11	0.03	0.08	0.73

Table S3. Mean total lengths (cm) of the ten species most commonly caught during surveys along the Northern California coast region for MPA and Reference (REF) sites for all years combined (2017-2020). Results from Tukey's post-hoc pairwise comparison test (difference between MPA and REF factoring site and year).

Common Name	Mean Total Length (cm)		difference	p-value
	MPA	REF		
Black rockfish	35	32	0.17	0.17
Blue/Deacon rockfish	26	25	0.09	0.84
Canary rockfish	35	32	2.27	0.99
China rockfish	32	31	1.38	0.99
Copper rockfish	41	38	2.28	0.99
Gopher rockfish	31	28	2.55	0.98
Lingcod	60	58	0.07	0.99
Olive rockfish	38	35	0.08	0.99
Vermilion rockfish	45	41	2.61	0.97
Yellowtail rockfish	28	25	3.05	0.89

Table S4. Mean total lengths (cm) of the ten species most commonly caught during surveys along the Southern California coast region for MPA and Reference (REF) sites for all years combined (2017-2020). Results from Tukey's post-hoc pairwise comparison test (difference between MPA and REF factoring site and year).

Common Name	Mean Total Length (cm)		difference	p-value
	MPA	REF		
Blue/Deacon rockfish	29	26	1.88	0.99
California sheephead	50	44	7.5	0.003
California scorpionfish	27	27	0.12	1
Copper rockfish	37	34	3.39	0.85
Gopher rockfish	27	27	0.55	1
Honeycomb rockfish	22	21	1.2	0.99
Kelp bass	34	33	1.73	0.99
Kelp rockfish	30	30	0.27	1
Ocean whitefish	38	33	4.85	0.27
Vermilion rockfish	41	34	4.13	0.55

Table S5. Published values for size at which 50% of the population is mature and the proportion of fishes greater than the size at 50% maturity for the ten species most commonly caught during surveys along the Northern California coast region for MPA and Reference (REF) sites for all years combined (2007-2020). Results from Tukey's post-hoc pairwise comparison test (difference between MPA and REF factoring site and year).

Common name	Size at which 50% of the population is mature	Proportion of fishes greater than size at 50% maturity		difference	p-value
		MPA	REF		
Black rockfish	41	0.26	0.11	0.16	0.25
Blue/Deacon rockfish	22	0.90	0.80	0.097	0.94
Canary rockfish	44.5	0.08	0.04	0.04	1
China rockfish	27	0.95	0.89	0.6	0.99
Copper rockfish	31	0.94	0.84	0.097	0.94
Gopher rockfish	17	1.00	0.99	0.006	1
Lingcod	57	0.65	0.58	0.068	0.99
Olive rockfish	35	0.71	0.55	0.17	0.17
Vermilion rockfish	38	0.68	0.82	0.13	0.6
Yellowtail rockfish	35	0.09	0.02	0.08	0.99

Table S6. Published values for size at which 50% of the population is mature and the proportion of fishes greater than the size at 50% maturity for the ten species most commonly caught during surveys along the Southern California coast region for MPA and Reference (REF) sites for all years combined (2007-2020). Results from Tukey's post-hoc pairwise comparison test (difference between MPA and REF factoring site and year).

Common name	Size at which 50% of the population is mature	Proportion of fishes greater than size at 50% maturity		difference	p-value
		MPA	REF		
Blue/Deacon rockfish	22	0.78	0.89	0.12	0.88
California sheephead	21	1.00	1.00	<0.001	1
California scorpionfish	18	0.88	0.93	0.004	0.99
Copper rockfish	31	0.77	0.43	0.35	<0.001
Gopher rockfish	17	1.00	0.99	0.008	1
Honeycomb rockfish	11	1.00	1.00	0	1
Kelp bass	22	0.99	0.98	0.01	1
Kelp rockfish	21	0.98	1.00	0.02	1
Ocean whitefish	31	0.82	0.50	0.31	<0.001
Vermilion rockfish	38	0.70	0.51	0.16	0.43

Table S7. Average catch per unit effort (CPUE; no. angler hr^{-1}) of the ten species most commonly caught during surveys along the Central California coast region for MPA and Reference (REF) sites for all years combined (2017-2020). Results from two-way ANCOVA.

Common name	Average CPUE (no. angler hr^{-1})		DF	F	p-value
	MPA	REF			
Black rockfish	0.75	1.60	1, 1647	46.94	<0.001
Blue/Deacon rockfish	6.75	3.65	1, 1647	80.5	<0.001
Canary rockfish	0.16	0.06	1, 1647	34.81	<0.001
Copper rockfish	0.24	0.08	1, 1647	123.13	<0.001
Gopher rockfish	2.73	1.62	1, 1647	159.22	<0.001
Kelp rockfish	0.22	0.20	1, 1647	0.484	0.49
Lingcod	0.44	0.23	1, 1647	99.72	<0.001
Olive rockfish	1.17	0.32	1, 1647	136.31	<0.001
Vermilion rockfish	0.52	0.19	1, 1647	1997.93	<0.001
Yellowtail rockfish	0.28	0.17	1, 1647	19.33	<0.001

Table S8. Average catch per unit effort (CPUE; no. angler hr^{-1}) of the ten species most commonly caught during surveys along the Northern California coast region for MPA and Reference (REF) sites for all years combined (2017-2020). Results from two-way ANCOVA.

Common name	**Average CPUE (no. angler hr^{-1})**		**DF**	**F**	**p-value**
	MPA	**REF**			
Black rockfish	1.41	1.35	1,337	0.081	0.78
Blue/Deacon rockfish	6.06	2.90	1,337	17.25	<0.001
Canary rockfish	1.11	0.74	1,337	3.82	0.05
China rockfish	0.28	0.31	1,337	0.21	0.65
Copper rockfish	0.58	0.38	1,337	7.95	0.005
Gopher rockfish	0.58	0.39	1,337	4.86	0.03
Lingcod	0.87	0.50	1,337	26.9	<0.001
Olive rockfish	0.48	0.20	1,337	10.62	0.001
Vermilion rockfish	0.41	0.22	1,337	13.99	<0.001
Yellowtail rockfish	0.64	0.76	1,337	0.43	0.51

Table S9. Average catch per unit effort (CPUE; no. angler hr^{-1}) of the ten species most commonly caught during surveys along the Southern California coast region for MPA and Reference (REF) sites for all years combined (2017-2020). Results from two-way ANCOVA.

Common name	Average CPUE (no. angler hr^{-1})		DF	F	p-value
	MPA	REF			
Blue/Deacon rockfish	0.49	0.78	1,301	2.33	0.13
California sheephead	0.31	0.07	1,301	55.78	<0.001
California scorpionfish	0.07	0.14	1,301	11.94	0.006
Copper rockfish	1.25	0.53	1,301	13.68	<0.001
Gopher rockfish	0.39	0.16	1,301	13.21	<0.001
Honeycomb rockfish	0.12	0.10	1,301	0.16	0.69
Kelp bass	0.95	0.19	1,301	40.56	<0.001
Kelp rockfish	0.23	0.13	1,301	5.52	0.02
Ocean whitefish	4.97	2.40	1,301	20.87	<0.001
Vermilion rockfish	0.17	0.09	1,301	5.6	0.02

Table S10. Average biomass per unit effort (BPUE; kg angler hr^{-1}) of the ten species most commonly caught during surveys along the Central California coast region for MPA and Reference (REF) sites for all years combined (2017-2020). Results from two-way ANCOVA.

Common name	Average BPUE (kg angler hr^{-1})		DF	F	p-value
	MPA	REF			
Black rockfish	0.43	0.73	1, 1647	23.93	<0.001
Blue/Deacon rockfish	2.35	1.14	1, 1647	96.1	<0.001
Canary rockfish	0.08	0.03	1, 1647	42.95	<0.001
Copper rockfish	0.31	0.06	1, 1647	165.94	<0.001
Gopher rockfish	1.00	0.58	1, 1647	77.89	<0.001
Kelp rockfish	0.11	0.10	1, 1647	0.96	0.33
Lingcod	1.10	0.49	1, 1647	127.91	<0.001
Olive rockfish	0.70	0.14	1, 1647	137.47	<0.001
Vermilion rockfish	0.59	0.17	1, 1647	256.17	<0.001
Yellowtail rockfish	0.09	0.05	1, 1647	26.28	<0.001

Table S11. Average biomass per unit effort (BPUE; kg angler hr $^{-1}$) of the ten species most commonly caught during surveys along the Northern California coast region for MPA and Reference (REF)sites for all years combined (2017-2020). Results from two-way ANCOVA.

Common name	Average BPUE (kg angler hr $^{-1}$)		DF	F	p-value
	MPA	REF			
Black rockfish	1.38	1.03	1,337	1.8	0.18
Blue/Deacon rockfish	2.05	0.91	1,337	21.12	<0.001
Canary rockfish	0.88	0.48	1,337	6.39	0.01
China rockfish	0.21	0.21	1,337	0.004	0.05
Copper rockfish	0.89	0.55	1,337	7.99	0.02
Gopher rockfish	0.29	0.15	1,337	12.66	<0.001
Lingcod	2.35	1.22	1,337	27.97	<0.001
Olive rockfish	0.40	0.15	1,337	13.44	<0.001
Vermilion rockfish	0.66	0.32	1,337	15.951	<0.001
Yellowtail rockfish	0.24	0.22	1,337	0.17	0.68

Table S12. Average biomass per unit effort (BPUE; kg angler hr^{-1}) of the ten species most commonly caught during surveys along the Southern California coast region for MPA and Reference (REF) sites for all years combined (2017-2020). Results from two-way ANCOVA.

Common name	Average BPUE (kg angler hr^{-1})		DF	F	p-value
	MPA	REF			
Blue/Deacon rockfish	0.22	0.25	1,301	0.123	0.73
California sheephead	0.63	0.11	1,301	37.9	<0.001
California scorpionfish	0.03	0.05	1,301	5.74	0.02
Copper rockfish	1.30	0.43	1,301	18.93	<0.001
Gopher rockfish	0.14	0.06	1,301	14.19	<0.001
Honeycomb rockfish	0.03	0.02	1,301	0.77	0.38
Kelp bass	0.54	0.09	1,301	41.88	<0.001
Kelp rockfish	0.10	0.05	1,301	5.827	0.02
Ocean whitefish	3.45	1.06	1,301	35.46	<0.001
Vermilion rockfish	0.20	0.07	1,301	9.26	0.003

Table S13. Average fecundity per unit effort (FPUE; no. eggs angler hr $^{-1}$) for 7 of the ten species most commonly caught during surveys along the Central California coast region for MPA and Reference (REF) sites for all years combined (2017-2020). Results from two-way ANCOVA. Shaded rows indicate insufficient data.

Common name	Average FPUE (no. eggs angler hr $^{-1}$)		DF	F	p-value
	MPA	REF			
Black rockfish					
Blue/Deacon rockfish	1174923.65	584817.32	1,104	16/27	<0.001
Canary rockfish					
Copper rockfish	75640.97	18393.92	1,88	20.27	<0.001
Gopher rockfish	215713.39	122750.75	1,104	27.4	<0.001
Kelp rockfish	50663.17	51072.41	1,80	0.3	0.86
Lingcod	25.198.96	11771.39	1,104	15.65	<0.001
Olive rockfish					
Vermilion rockfish	203813.87	66632.45	1,103	54.95	<0.001
Yellowtail rockfish	90249.01	51938.68	1,42	3.01	0.09

Table S14. Average fecundity per unit effort (FPUE; no. eggs angler hr $^{-1}$) for 7 of the ten species most commonly caught during surveys along the Northern California coast region for MPA and Reference (REF) sites for all years combined (2017-2020). Results from two-way ANCOVA. Shaded rows indicate insufficient data.

Common name	Average FPUE (no. eggs angler hr $^{-1}$)		DF	F	p-value
	MPA	REF			
Black rockfish					
Blue/Deacon rockfish	963937.04	444915.06	1,28	3.82	0.06
Canary rockfish	928704.87	563928.28	1,16	3.42	0.08
China rockfish					
Copper rockfish	197356.71	117625.67	1,27	3.07	0.01
Gopher rockfish	93651.24	52949.87	1,21	1.76	0.19
Lingcod	49449.20	27 008.89	1,28	9.56	0.15
Olive rockfish					
Vermilion rockfish	299908. I 67	113072.47	1,24	12.3	0.002
Yellowtail rockfish	413063.39	273845.44	1,9	0.45	0.52

Table S15. Average fecundity per unit effort (FPUE; no. eggs angler hr $^{-1}$) for 7 of the ten species most commonly caught during surveys along the Southern California coast region for MPA and Reference (REF) sites for all years combined (2017-2020). Results from two-way ANCOVA. Shaded rows indicate insufficient data.

Common name	Average FPUE (no. eggs angler hr $^{-1}$)		DF	F	p-value
	MPA	REF			
Blue/Deacon rockfish	161479.39	254221.82	1,15	0.37	0.55
California sheephead	510113.89	73640.93	1,26	6.77	0.02
California scorpionfish					
Copper rockfish	291245.58	153117.27	1,16	0.82	0.38
Gopher rockfish	36217.25	13882.12	1,25	4.94	0.04
Honeycomb rockfish					
Kelp bass	2102735.83	521567.17	1,24	7.47	0.01
Kelp rockfish	26500.94	28222.31	1,24	0.48	0.49
Ocean whitefish					
Vermilion rockfish	96309.16	43876.92	1,14	2.51	0.14

Table S16. Median, minimum, and maximum total length (cm) of the ten species most commonly caught during surveys along the Central California coast region for MPA and Reference (REF) sites for all years combined (2017-2020). Results from the Kruskall-Wallis test.

Common name	MPA			REF			Chi-squared	p-value
	Median total length (cm)	Minimum total length (cm)	Maximum total length (cm)	Median total length (cm)	Minimum total length (cm)	Maximum total length (cm)		
Black rockfish	32	18	47	30	11	50	1163.3	<0.001
Blue/Deacon rockfish	26	7	48	25	6	45	345.93	<0.001
Canary rockfish	30	10	51	29	11	56	22.58	<0.001
Copper rockfish	40	16	54	33	17	52	251.78	<0.001
Gopher rockfish	28	5	42	27	6	43	46.86	<0.001
Kelp rockfish	32	21	41	32	18	40	10.87	<0.001
Lingcod	59	16	102	55	15	99	119.79	<0.001
Olive rockfish	34	11	52	31	9	49	451.01	<0.001
Vermilion rockfish	41	12	56	37	10	58	255.26	<0.001
Yellowtail rockfish	27	9	45	26	8	42	9.48	0.002

Table S17. Median, minimum, and maximum total length (cm) of the ten species most commonly caught during surveys along the Northern California coast region for MPA and Reference (REF) sites for all years combined (2017-2020). Results from the Kruskall-Wallis test.

Common Name	MPA			REF			Chi-squared	p-value
	Median total length (cm)	Minimum total length (cm)	Maximum total length (cm)	Median total length (cm)	Minimum total length (cm)	Maximum total length (cm)		
Black rockfish	35	13	62	32	12	50	54.1	<0.001
Blue/Deacon rockfish	26	10	44	24	11	46	129.56	<0.001
Canary rockfish	34	17	58	32	12	54	30.83	<0.001
China rockfish	32	20	42	31	12	40	14.67	<0.001
Copper rockfish	42	21	55	39	14	59	16.93	<0.001
Gopher rockfish	31	18	47	28	14	44	147.9	<0.001
Lingcod	59	17	120	58	15	140	5.6	0.02
Olive rockfish	38	15	53	35	18	51	25.39	<0.001
Vermilion rockfish	47	25	59	44	19	57	12.29	<0.001
Yellowtail rockfish	27	13	53	25	12	51	59.5	<0.001

Table S18. Median, minimum, and maximum total length (cm) of the ten species most commonly caught during surveys along the Southern California coast region for MPA and Reference (REF) sites for all years combined (2017-2020). Results from the Kruskall-Wallis test.

Common Name	MPA			REF			Chi-squared	p-value
	Median total length (cm)	Minimum total length (cm)	Maximum total length (cm)	Median total length (cm)	Minimum total length (cm)	Maximum total length (cm)		
Blue/Deacon rockfish	30	14	46	25	11	47	90.1	<0.001
California sheephead	51	23	80	45	24	75	11.47	<0.001
California scorpionfish	28	13	40	27	13	40	0.24	0.62
Copper rockfish	37	15	58	35	15	46	235.79	<0.001
Gopher rockfish	27	14	38	27	16	45	2.36	0.12
Honeycomb rockfish	23	12	39	22	11	27	2.18	0.14
Kelp bass	33	15	57	32	15	50	9.08	0.003
Kelp rockfish	30	19	38	30	21	36	0.12	0.73
Ocean whitefish	37	19	69	33	17	70	741.62	<0.001
Vermilion rockfish	43	11	51	36	14	49	13.23	<0.001

Table S19. The rate of change in abundance (catch per unit effort; CPUE) of the 12 species most commonly caught during surveys along the Central coast region for MPA and Reference (REF) sites. Negative values indicate a decline in abundance, positive values indicate an increase in abundance, and values close to zero indicate no change.

Common Name	Slope	
	MPA	REF
Black rockfish	-0.25	-0.22
Blue/Deacon rockfish	-0.09	0.11
Canary rockfish	-0.015	-0.011
Copper rockfish	0.09	0.02
Gopher rockfish	0.58	0.23
Kelp rockfish	-0.05	-.0.05
Lingcod	-0.21	-0.05
Olive rockfish	0.51	0.09
Vermilion rockfish	0.18	0.01
Yellowtail rockfish	-0.07	-0.03
Brown rockfish	0.01	0.006
Rosy rockfish	0.01	0.009

Table S20. Generalized additive mixed model comparison table to determine the influence of fishing effort and environmental variables on fish biomass response ratios at four Central California MPAs.

Model	**df**	**AIC**
Sea surface temperature + s(1|Year)	8.01	49.22
Fishing effort + s(1|Year)	8.35	29.15
Fishing effort + Sea surface temperature + s(1|Year)	9.92	26.08
Fishing effort + Sea surface temperature + Primary production + s(1|Year)	11.12	24.90
Fishing effort + s(Sea surface temperature) + s(1|Year)	10.48	24.20
Fishing effort + Sea surface temperature + s(Primary production) + s(1|Year)	11.84	21.82
Fishing effort + s(Sea surface temperature) + s(Primary production) + s(1|Year)	17.72	10.54

Table S21. Output for the best fit model testing the influence of fishing effort and environmental variables on fish biomass response ratios at four Central California MPAs.

Model Output			
Predictors	***Estimates***	***CI***	***p-value***
Intercept	0.21	-0.17-0.60	0.25
Fishing effort	0.0078	0.0065-0.0091	<0.001
s(Sea surface temperature)			0.13
s(Primary production)			0.15
s(1|Year)			0.001
Observations	**31**		
R^2	**0.81**		

Table S22. Cross-correlation analysis of juvenile Blue rockfish (<21 cm) CPUE with MOCI values for MPA and Reference (REF) sites.

MPA Name	Designation	Season	Lag	Correlation	p-value
Ano Nuevo	MPA	Summer	2	0.893	0.0012**
Point Lobos	MPA	Summer	2	0.837	0.0025**
Piedras Blancas	MPA	Summer	2	0.748	0.0069**
Point Buchon	MPA	Summer	2	0.866	0.0018**
Ano Nuevo	REF	Summer	2	0.874	0.0016**
Point Lobos	REF	Summer	2	0.469	0.090*
Piedras Blancas	REF	Summer	2	0.803	0.0037**
Point Buchon	REF	Summer	2	0.829	0.0028**

Significance level: ** 0.05   * 0.1

Table S23. Cross-correlation analysis of adult Blue rockfish (>21 cm) CPUE with MOCI values for MPA and Reference (REF) sites.

MPA Name	Designation	Season	Lag	Correlation	p-value
Ano Nuevo	MPA	Summer	2	0.798	0.004 **
Point Lobos	MPA	Fall	3	0.660	0.017**
Piedras Blancas	MPA	Summer	3	0.776	0.005**
Point Buchon	MPA	Summer	2	0.792	0.004**
Ano Nuevo	REF	Fall	4	0.668	0.016**
Point Lobos	REF	Fall	3	0.621	0.025**
Piedras Blancas	REF	Summer	3	0.629	0.023**
Point Buchon	REF	Fall	3	0.707	0.011**

Significance level: ** 0.05   * 0.1

APPENDIX B

CCFRP Angler Survey 2021

This survey was designed to better understand CCFRP anglers' opinions and knowledge of ***ocean issues, conservation, and marine protected areas (MPAs)***. CCFRP science staff at Cal Poly, Moss Landing Marine Laboratories (MLML), Humboldt State, Bodega Marine Lab (UCD), the Marine Science Institute (UCSB), and Scripps Institution of Oceanography (UCSD) designed this survey; it builds on previous CCFRP-related surveys. The results generated from this survey will be used to inform CCFRP and the State of California about CCFRP anglers including their: experiences with MPAs, involvement with CCFRP, engagement in conservation, and basic demographic information. The survey is completely anonymous and voluntary.

This survey should take you ~15 minutes.

As a volunteer angler participating in this survey, we want to thank you for your time dedicated to our research! All of your time and input is very valuable to us – on and off the vessel!

Section 1: CCFRP Angler Involvement

The following are questions about your experience volunteering with CCFRP.

1. What year did you first volunteer with CCFRP?

   ____

2. How often do you volunteer with CCFRP?
   - Every year
   - Every few years
   - Infrequently (1 – 2 years only)
   - Never

3. How many trips have you gone on with CCFRP? *Select only one.*
   - 1
   - 2-5
   - 6-10
   - 11-19
   - 20+

4. What institution have you volunteered with most?
    - Humboldt State University
    - Bodega Marine Laboratory
    - Moss Landing Marine Laboratories
    - Cal Poly SLO
    - UC Santa Barbara
    - Scripps Institution of Oceanography

5. Why did you volunteer to participate on your last CCFRP fishing trip? *Select all that apply.*
    - To enjoy fishing whenever I can
    - To fish inside the marine protected areas (MPAs)
    - To participate in citizen science
    - To give back to fisheries resources
    - To learn about rockfish, lingcod, and other species we catch on these trips
    - Other (specify) ____

6. Did you learn anything while volunteering with CCFRP that you found useful? *Select all that apply.*
    - I learned more about the wide range of fish species caught in this area
    - I learned what a marine protected area is
    - I learned where I am not allowed to go fishing
    - I learned how to identify nearshore fish species
    - I learned how fishing data can be used in fisheries management
    - I learned about techniques to descend groundfish
    - I learned how MPAs can be used to manage fisheries
    - I did not learn anything
    - Other (specify) ____

7. I use the following resources to learn about the data collected by CCFRP: *Select all that apply*.
    - CCFRP data briefings at the end of a trip
    - Reading the annual volunteer newsletter
    - Attending Volunteer Appreciation and Data Workshops if/when offered
    - am not interested in learning about the data that CCFRP collects

8. I have told my recreational fishing buddies about CCFRP.
    - Yes
    - No

Section 2) Marine Protected Areas

Marine protected areas (MPAs) are designated areas of the ocean where different types of activities such as fishing are monitored or prohibited. These marine protected areas are similar to designated areas on land such as national and state parks.

The following is split into three subsections: questions about your view of MPAs **before** volunteering with CCFRP, questions about your view of MPAs **after** volunteering with CCFRP, and then **general** questions about MPAs.

Before

9. **Before** volunteering with CCFRP, what was your general opinion of the creation of MPAs in California?

    My general opinion of MPA creation was …
    - Positive
    - Somewhat positive
    - Neither positive nor negative
    - Somewhat negative
    - Negative
    - No Opinion

10. **Before** volunteering with CCFRP, did you believe the creation of MPAs would affect the size/abundance of groundfish inside MPAs? *Select all that apply.*
    - Yes, I believed there would be an **increase** in the size of groundfish inside MPAs
    - Yes, I believed there would be an **increase** in the abundance of groundfish inside MPAs
    - Yes, I believed there would be a **decrease** in the size of groundfish inside MPAs
    - Yes, I believed there would be a **decrease** in the abundance of groundfish inside MPAs

- No, I believed there would be **no effect** on size of groundfish inside MPAs
- No, I believed there would be **no effect** on the abundance of groundfish inside MPAs
- I don’t know
- No opinion

<u>After</u>

11. **After** volunteering with CCFRP, what was your general opinion of the creation of MPAs in California?

    My general opinion of MPA creation was…

    - Positive
    - Somewhat positive
    - Neither positive nor negative
    - Somewhat negative
    - Negative
    - No Opinion

12. **After** volunteering with CCFRP, did you believe the creation of MPAs would affect the size/abundance of groundfish inside MPAs? *Select all that apply.*

    - Yes, I believed there would be an **increase** in the size of groundfish inside MPAs
    - Yes, I believed there would be an **increase** in the abundance of groundfish inside MPAs
    - Yes, I believed there would be a **decrease** in the size of groundfish inside MPAs
    - Yes, I believed there would be a **decrease** in the abundance of groundfish inside MPAs
    - No, I believed there would be **no effect** on size of groundfish inside MPAs
    - No, I believed there would be **no effect** on the abundance of groundfish inside MPAs
    - I don’t know
    - No opinion

<u>General</u>

13. If you believe that California MPA creation affected **groundfish abundance and/or size**, what aspect(s) of MPAs do you believe caused these changes? *Select all that apply.*

- Location of MPAs
- Size of MPAs
- Enforcement of MPA restrictions
- Planning of MPAs as a network
- MPA protection of a portion of fish populations
- Voluntary compliance with restrictions
- Other
- N/A, I do not believe there is an effect

14. In your **opinion**, what is the purpose of a Marine Protected Area? *Select all that apply*
    - To set aside areas of ocean to conserve, restore, and understand natural biodiversity and ecology of the area
    - To provide people the opportunity to experience these areas of the ocean now and into the future
    - To restrict industrial uses (seabed mining, oil and gas exploration or drilling, windmill or turbine construction, minerals extraction)
    - To prevent overfishing/ overuse/ degradation
    - MPAs do not have a purpose
    - I have no opinion on the purpose of MPAs

15. Have you ever fished in a Marine Protected Area before it was protected OR while volunteering with CCFRP? (If no, skip to section 3)
    - Yes
    - No

16. Think about this when answering a-c: Have you experienced a difference in fishing in an MPA versus outside of an MPA?

    a. I catch more fish when fishing inside….
    - MPAs
    - Areas open to fishing
    - I don’t know
    - No difference

    b. I catch a greater diversity of fish species when fishing inside….
    - MPAs
    - Areas open to fishing

- I don’t know
- No difference

c. I catch larger fish when I fish inside….

- MPAs
- Areas open to fishing
- I don’t know
- No difference

17. What is the ***primary*** reason you enjoy fishing with CCFRP in an MPA (select one):
    - I have no preference for CCFRP fishing sites (MPA or reference)
    - To catch a large fish
    - To catch a lot of fish
    - To catch a lot of species
    - To collect scientific fishing data

18. Hypothetically, how much would you be willing to pay for one day of catch and release fishing inside an MPA while **NOT** participating on a CCFRP trip?
    - $0
    - $1 - $20
    - $21 - $50
    - $51 - $100
    - $101 - $500
    - >$500

Section 3) Natural Resource Conservation

Now we would like to query you on your opinions about **conservation**. The Merriam-Webster dictionary definition of **Conservation** is: the careful preservation and protection of something, especially the planned management of a natural resource to prevent exploitation, destruction, or neglect.

Additionally, this section asks a few questions about potential ocean issues in their relation to California’s coastal waters.

19. In general, would you say you are more conservation-minded or less conservation-minded than others in the recreational angling community?

    Compared to the rest of the angling community, I am …

    - More conservation minded
    - Similarly conservation minded
    - Less conservation minded
    - I don't know

20. Do you participate in activities with conservation-oriented groups (separate from CCFRP)?

    - Yes
    - No

21. How informed do you consider yourself to be concerning ocean issues in California?

    - Not well
    - Somewhat
    - Well
    - Very Well
    - Unsure

22. In what ways do you currently obtain information about ocean related issues? S*elect all that apply.*

    - CCFRP related events (Volunteer Appreciation/ Data Workshops)
    - Newspaper
    - Magazine
    - Family/Friends
    - Radio
    - Internet
    - Social Media
    - Television
    - Other ____
    - I have not sought out information on ocean related issues

23. In your opinion, how well are California groundfish stocks managed?

I believe California groundfish stocks are:

- Very well managed
- Well managed
- Adequately managed
- Poorly managed
- Very poorly managed
- I don’t believe they are managed at all
- I don’t know

24. Please rank the following types of fishing gear or fishing practices(from 1 to 8) as having the greatest impact on the degradation of the marine environment or reduction in fish stocks. (1 is least impact and 8 is greatest impact).

Traps or pots ___________

Hook and line, recreational ___________

Bottom trawling ___________

Longline ___________

Gill nets ___________

Midwater trawling ___________

Hook and line, commercial ___________

Spearfishing ___________

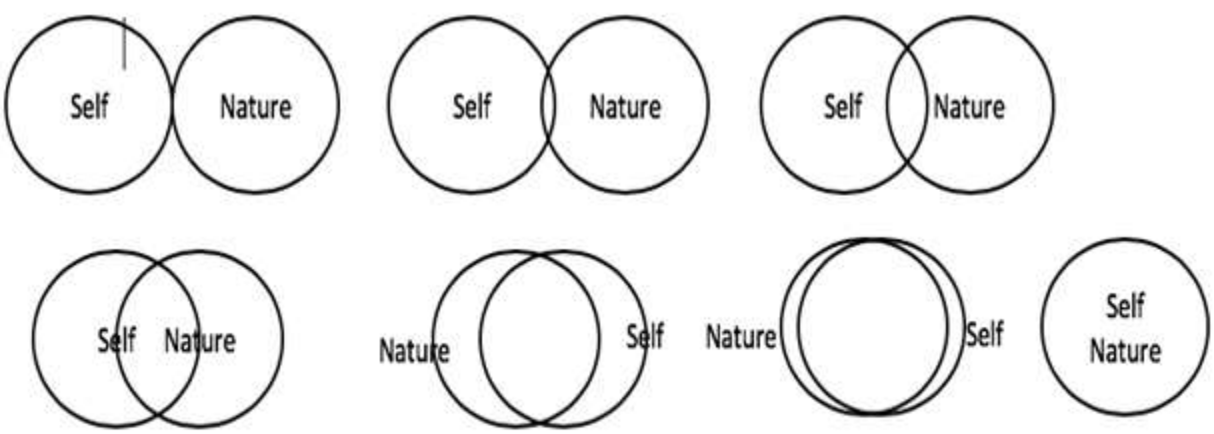
25. This question consists of a chart that queries you on your opinion of potential ocean issues. Statements are rated 1-7. An answer of ‘1’ indicates that you strongly disagree, ‘4’ indicates no opinion, and ‘7’ indicates you strongly agree with the statement.

Please indicate whether you think any of the following is a threat to California’s marine environment. Please circle ONE number for each.

Potential Ocean Issue	**Strongly Disagree**	**Somewhat Disagree**	**Disagree**	**No Opinion**	**Somewhat Agree**	**Agree**	**Strongly Agree**
Water Pollution	1	2	3	4	5	6	7
Marine Debris	1	2	3	4	5	6	7

Loss of Marine Biodiversity	1	2	3	4	5	6	7
Overfishing	1	2	3	4	5	6	7
Invasive/Exotic Species	1	2	3	4	5	6	7
Rising Sea Temperatures	1	2	3	4	5	6	7
Ocean Acidification and Hypoxia	1	2	3	4	5	6	7
Wave energy/Power development	1	2	3	4	5	6	7
Oil/gas exploitation or transport	1	2	3	4	5	6	7

26. The following diagram labels a series of circles overlapping. They are labeled 'Self' and 'Nature'. Please circle the picture below that best describes your relationship with the



natural environment. How interconnected are you with nature?

Section 4) Basic Demographics

27. What is the zip code of your primary residence?

    ____

28. I identify as
    - Male
    - Female
    - Non-binary
    - Prefer not to state
    - Other:___________ (specify)

29. What is your age?
    - 18-24
    - 25-34
    - 35-44
    - 45-54
    - 55-64
    - 65 years and older

30. What is the highest level of education you have completed?
    - Less than high school degree
    - High school degree or equivalent (e.g., GED)
    - Associate degree or completion of technical or professional school
    - Some college but no degree
    - Bachelor degree
    - Graduate degree (e.g., Master degree. PhD, JD, MD, etc.)

31. Which of the following categories best describes your household's total annual income before taxes in 2020?
    - Less than $25,000
    - $25,000 - $34,999
    - $35,000 - $49,999
    - $50,000 - $74,999
    - $75,000 - $99,999

- $100,000 - $149,999
- $150,000 - $199,999
- $200,000 or more
- Decline to state

32. Have you or anyone you know ever worked in marine resource management at the local, state, federal, or academic level. *Select all that apply*. (e.g., CA Department of Fish and Wildlife or NOAA)
    - Yes, self
    - Yes, family
    - Yes, friend
    - No

33. Have you ever worked in the recreational fishing industry? (e.g., a captain, boat crew, bait or tackle salesperson, etc.)
    - Yes
    - No

34. Have you ever worked in the commercial fishing industry? (e.g., a fisherman, captain, boat crew, buyer, etc.)
    - Yes
    - No

35. Additional space is provided below for any additional comments or concerns regarding this survey.

____
____
____
____
____

Thank you for your time and participation!

APPENDIX C

Informed Consent Form

INFORMED CONSENT TO PARTICIPATE IN A RESEARCH PROJECT:

"2021 California Collaborative Fisheries Research Program (CCFRP) Volunteer Angler Survey"

This form asks for your agreement to participate in a research project involving a survey about anglers' opinions and knowledge of ocean issues, conservation, and marine protected areas (MPAs). Your participation involves completing and submitting a survey taken through an online survey tool or a paper/pen version. It is expected that your participation will take approximately 15 minutes. There are no risks anticipated with your participation. If you are interested in participating, please review the following information.

The purpose of the study is to assess CCFRP volunteer angler opinions and knowledge of ocean issues, conservation, and MPAs. Potential benefits associated with the study include increased understanding of local anglers' attitudes towards scientific data collection and MPAs, increased collaboration between fishers and scientists, and provide a forum for angler opinions to be recorded. If you agree to participate, you will be asked to complete the 2021 CCFRP Volunteer Angler Survey and submit your answers anonymously through Qualtrics, an online survey tool or into a paper version. This survey contains questions about your experience with CCFRP, your opinions about MPAs, your opinions about natural resource conservation, and some questions regarding basic demographic information.

Please be aware that you are not required to participate in this research, refusal to participate will not involve any penalty or loss of benefits to which you are otherwise entitled, and you may discontinue your participation at any time. You may omit responses to any questions you choose not to answer. There are no risks anticipated with your participation in this study. Your responses will be provided anonymously to protect your privacy. We do not plan to destroy the data generated in this study and will store it on a Cal Poly server or other digital storage device secured through university firewalls. The data generated through this survey will be shared with our collaborators at the following CCFRP research institutions and be used to generate reports and manuscripts for publication: Humboldt State University, Bodega Marine Laboratories at UC Davis, Moss Landing Marine Laboratories, the Marine Science Institute at UCSB, and Scripps Institute of Oceanography at UCSD.

This research is being conducted by Grant Waltz (Senior Research Scientist) and Dean Wendt (Dean, College of Science and Mathematics) in the Biological Sciences Department at Cal Poly, San Luis Obispo. If you have questions regarding this study or would like to be informed of the results when the study is completed, please contact the researcher(s) at ccfrpslo@gmail.com

or gwaltz@calpoly.edu.

If you have concerns regarding the manner in which the study is conducted, you may contact Dr. Michael Black, Chair of the Cal Poly Institutional Review Board, at (805) 756-2894, mblack@calpoly.edu, or Ms. Trish Brock, Director of Research Compliance, at (805) 756-1450, pbrock@calpoly.edu.

If you are 18 years of age or older and agree to voluntarily participate in this research project as described, please indicate your agreement by clicking the survey link sent to your email and completing the 2021 CCFRP Volunteer Angler Survey. Please retain a copy of this form for your reference, and thank you for your participation in this research.

APPENDIX D

Recruitment Outreach Email

This is a reminder for the "CCFRP Volunteer Angler Survey". If you have already submitted the survey, thank you! You do not need to re-submit.

Dear CCFRP volunteer angler,

The California Collaborative Fisheries Research Program (CCFRP) has been running for 15 years along the central coast and 5 years statewide. With the help of volunteers like you, we have been able to successfully complete over a decade of data collection regarding the species compositions, sizes, and catch rates of nearshore fishes in and around California MPAs. Building off two separate surveys conducted along the central coast in 2018, we're interested in learning from the program's current and former statewide volunteers about their awareness, attitudes, and knowledge of MPAs, marine resource issues, and how volunteering with CCFRP has influenced their support for marine conservation.

If you choose to participate in the study, click on the "Begin CCFRP Volunteer Angler Survey" link below. You will be provided a Letter of Consent (a copy of which is attached to this email) followed by a series of questions about your experience with CCFRP, your opinions of MPAs, your opinions of marine resource issues, and some demographic/miscellaneous questions. The entire survey should take 15 minutes to complete.

Participation in this study is completely voluntary and any answers you provide will be anonymous. Additionally, participation in this survey, or the answers you provide, will in no way impact your standing as a volunteer angler with CCFRP. The survey collection period will be open from July 12 to December 31, 2021, so please complete and submit the survey as soon as you are able.

Begin CCFRP Volunteer Angler Survey

Please contact Grant Waltz at gwaltz@calpoly.edu or ccfrpslo@gmail.com, or leave a voicemail at 805-756-2950 with any questions or concerns you may have regarding the study.

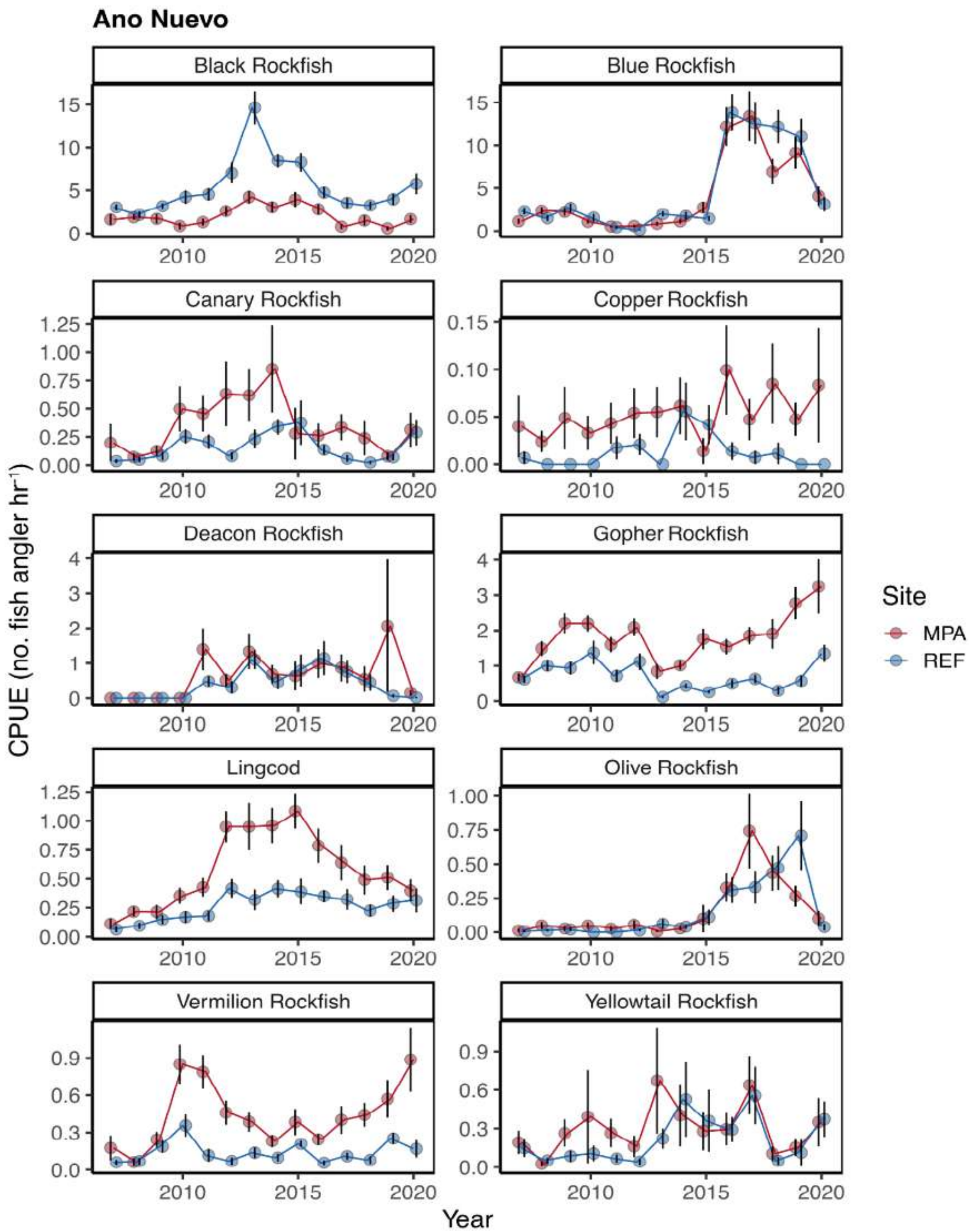
Thank you for your time and effort volunteering with CCFRP!

Sincerely,

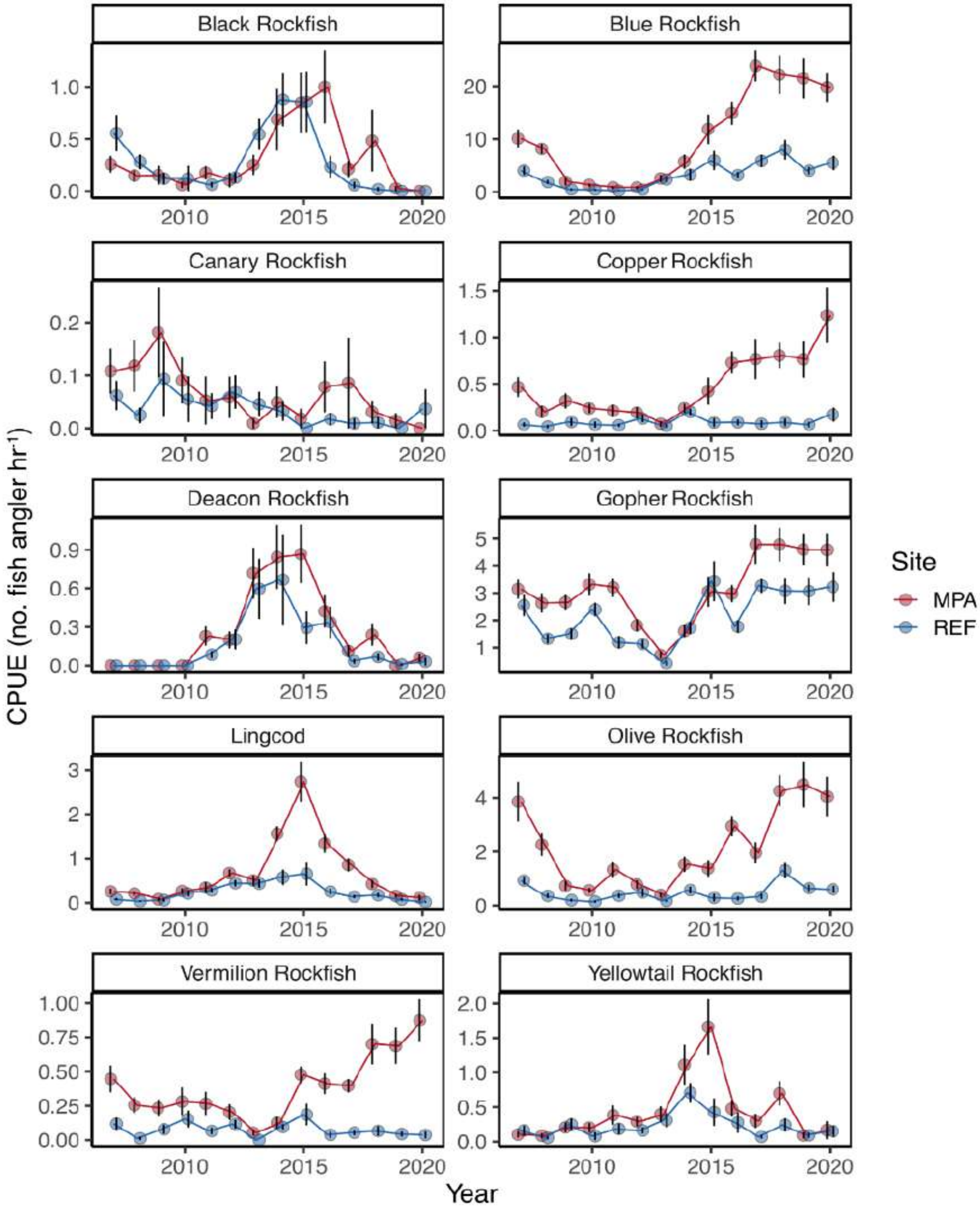
California Collaborative Fisheries Research Program

APPENDIX E

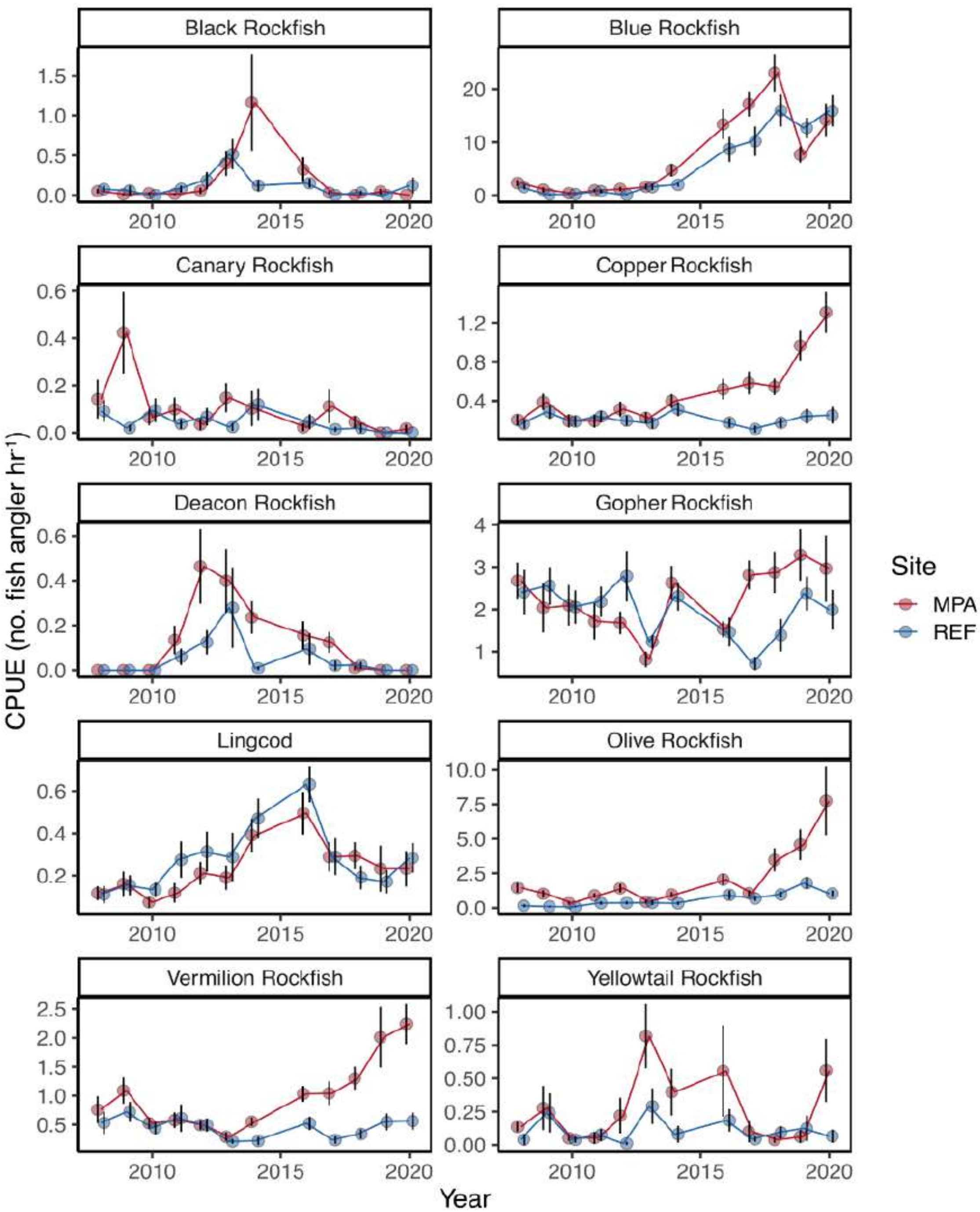
Mean CPUE for the top 10 most commonly caught species from 2007-2020 for the four Central coast MPAs, respectively. Red points denote mean CPUE inside the MPA, and blue points denote mean CPUE in the Reference sites. Error bars are ± standard error.

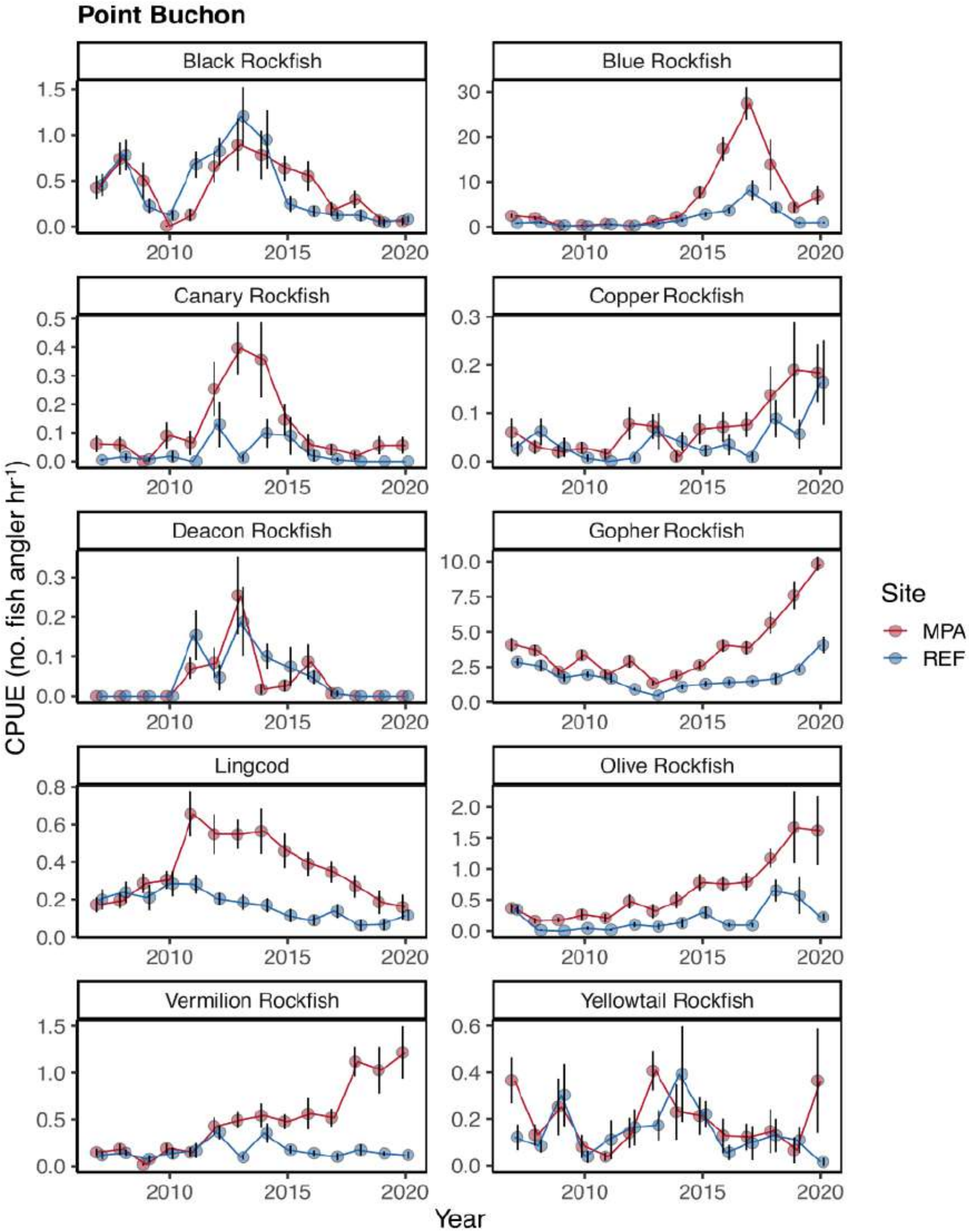


Point Lobos


Black Rockfish
Blue Rockfish
Canary Rockfish
Copper Rockfish
Deacon Rockfish
Gopher Rockfish
Lingcod
Olive Rockfish
Vermilion Rockfish
Yellowtail Rockfish
CPUE (no. fish angler hr-1)
Year
Site
MPA
REF

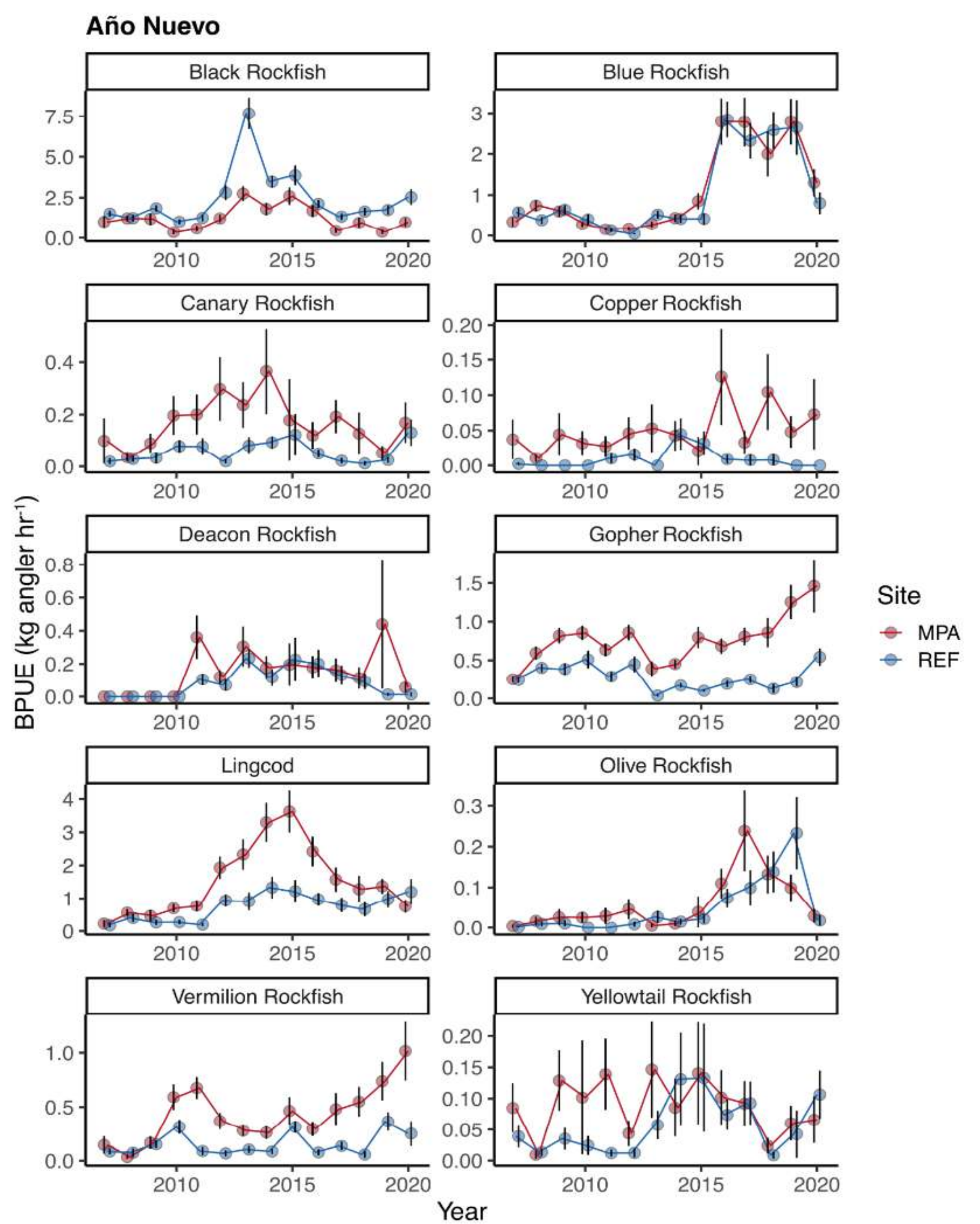
Piedras Blancas

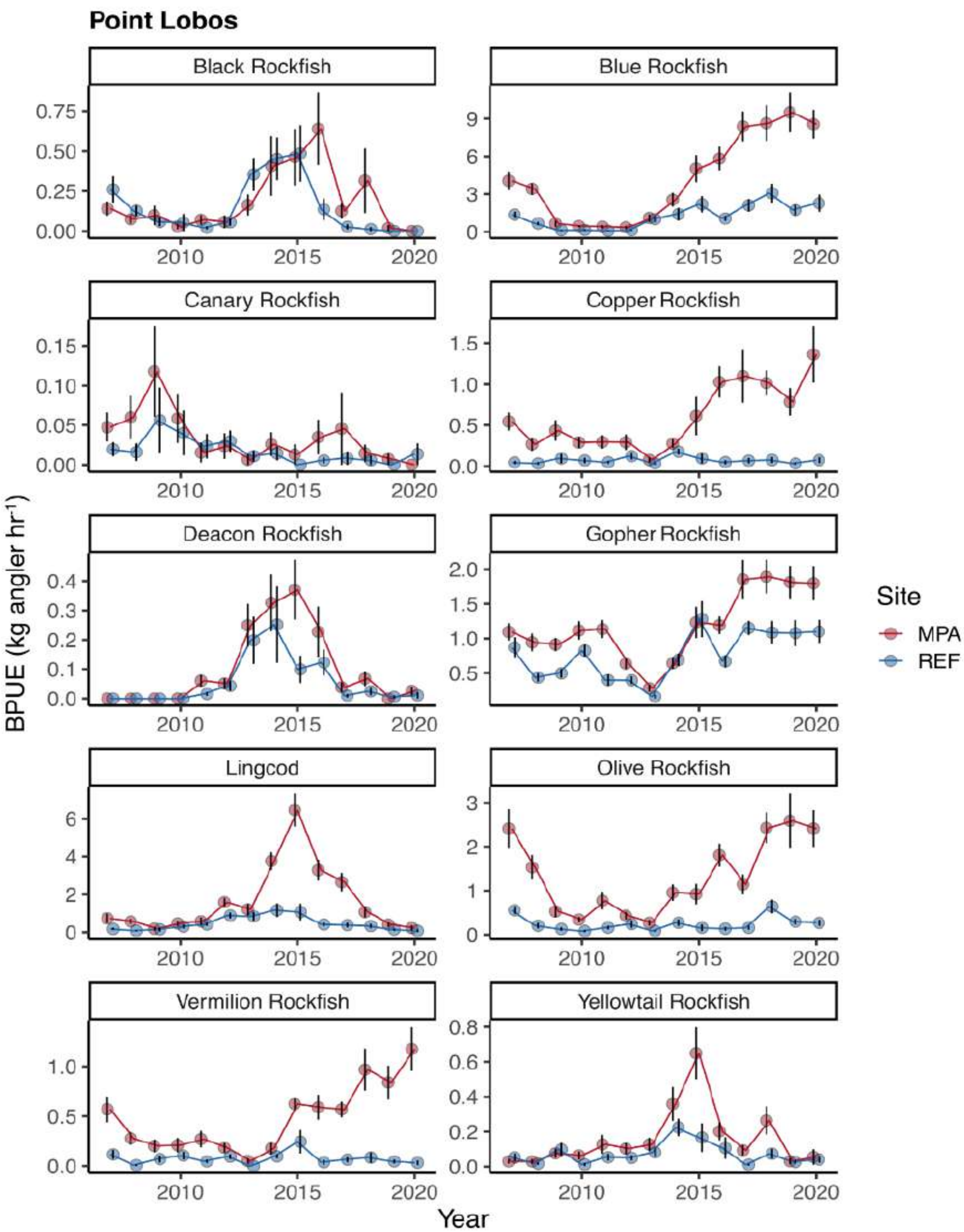


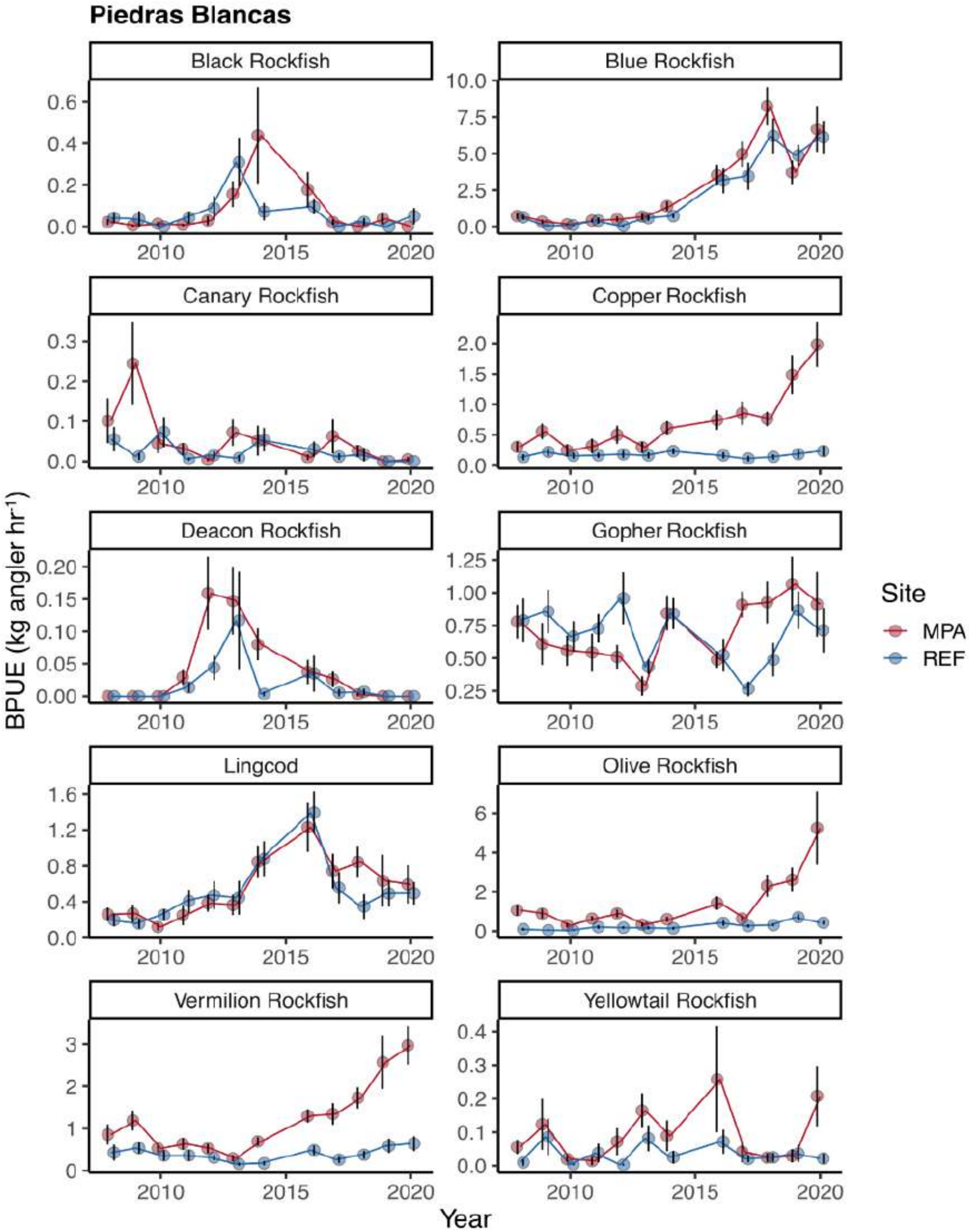

Point Buchon
Black Rockfish
Blue Rockfish
Canary Rockfish
Copper Rockfish
Deacon Rockfish
Gopher Rockfish
Lingcod
Olive Rockfish
Vermilion Rockfish
Yellowtail Rockfish
CPUE (no. fish angler hr-1)
Year
Site
MPA
REF

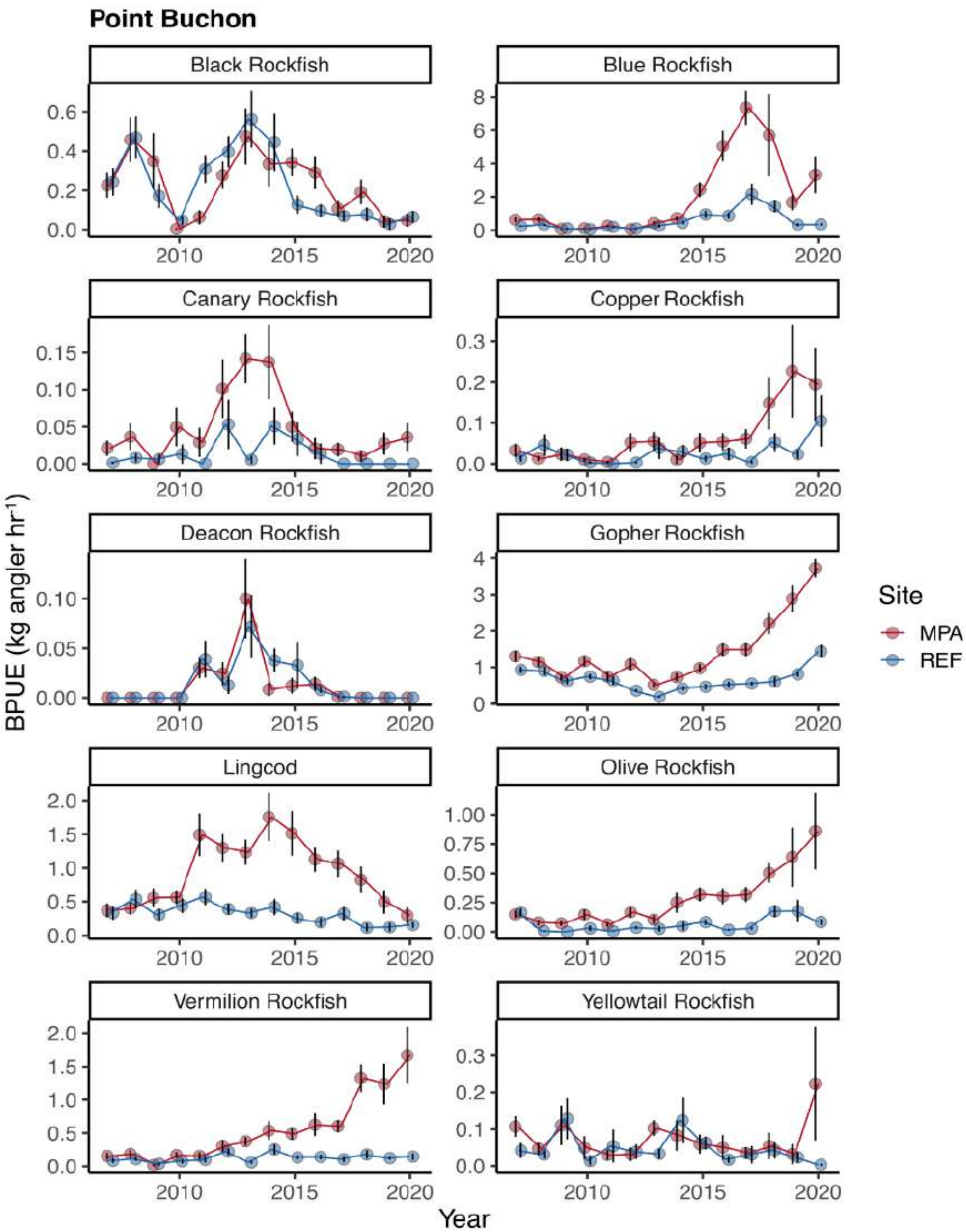
APPENDIX F

Mean BPUE for the top 10 most commonly caught species from 2007-2020 for the four Central coast MPAs, respectively. Red points denote mean BPUE inside the MPA, and blue points denote mean BPUE in the Reference sites. Error bars are ± standard error.




Point Lobos
Black Rockfish
Blue Rockfish
Canary Rockfish
Copper Rockfish
Deacon Rockfish
Gopher Rockfish
Lingcod
Olive Rockfish
Vermilion Rockfish
Yellowtail Rockfish
BPUE (kg angler hr-1)
Year
Site
MPA
REF


Piedras Blancas
Black Rockfish
Blue Rockfish
Canary Rockfish
Copper Rockfish
Deacon Rockfish
Gopher Rockfish
Lingcod
Olive Rockfish
Vermilion Rockfish
Yellowtail Rockfish
BPUE (kg angler hr-1)
Year
Site
MPA
REF



Point Buchon
Black Rockfish
Blue Rockfish
Canary Rockfish
Copper Rockfish
Deacon Rockfish
Gopher Rockfish
Lingcod
Olive Rockfish
Vermilion Rockfish
Yellowtail Rockfish
BPUE (kg angler hr-1)
Year
Site
MPA
REF

APPENDIX G

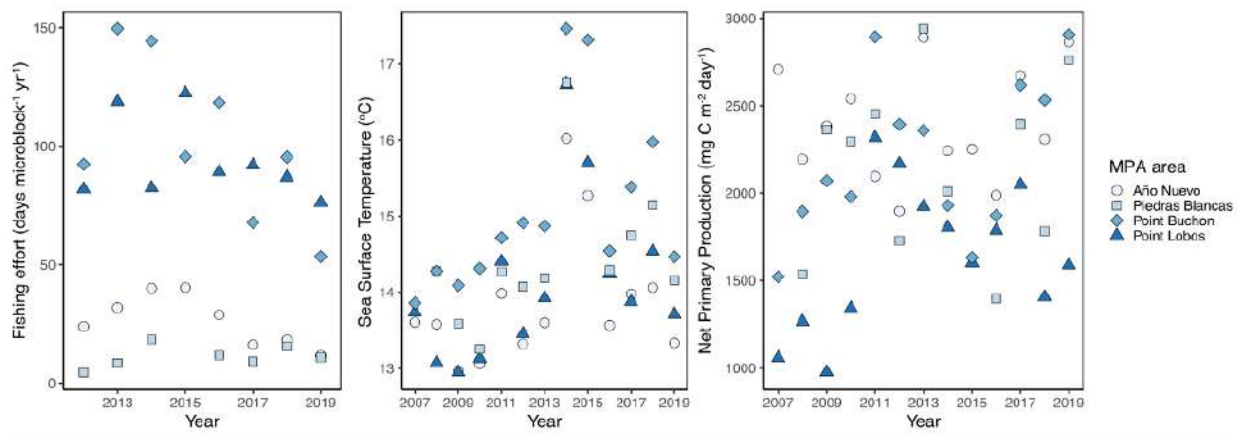


Figure S1. Fishing effort (A) and environmental variables [SST (B) and NPP(C)] by year for the 4 MPAs along the Central coast for years with sufficient data of between 2007 and 2019.

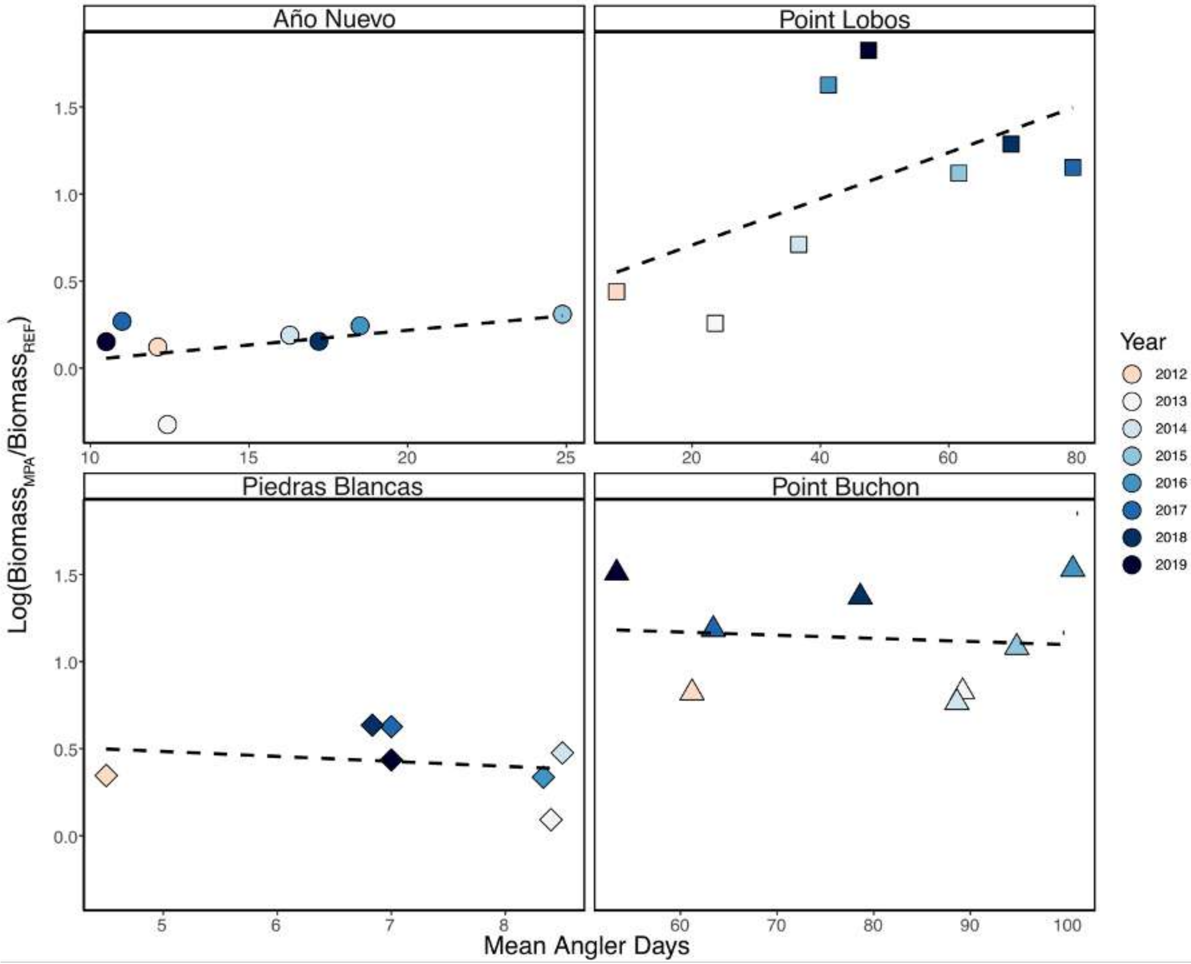


Figure S2. BPUE response ratios by site and the mean angler days per year for each site sampled.

APPENDIX H

Demographic information from CCFRP survey participants. (A) Percentage distribution of respondents' gender identity (n = 262). (B) Percentage distribution of respondents' age (n = 260). (C) Percentage distribution of respondents' highest level of education (n = 259). (D) Percentage distribution of respondents' household's total annual income before taxes in 2020 (n = 256).