California's Marine Protected Area Network
Long-Term Monitoring Reports Technical Memo
January 2023

Prepared by: Cyndi L. Dawson, Castalia Environmental

1. BACKGROUND

Between September 2007 and December 2012 California undertook a science-based and stakeholder driven process to designate a network of 124 Marine Protected Areas (MPAs). This globally significant effort was catalyzed by the passage of the Marine Life Protection Act (MLPA) in 1999. The MLPA required the state to redesign California's system of MPAs to function as a network to increase protection of marine life and habitats, marine ecosystems, and marine natural heritage; as well as to improve recreational, educational and study opportunities in marine areas subject to minimal human disturbance. Decades of scientific research have found that MPAs can increase the biomass, abundance, diversity, and size of marine species living within their borders[1,2]. However, MPAs are being increasingly designated worldwide with less of a singular focus on producing population level effects and a broader focus on maintaining the fullest suite of ecosystem services possible in a habitat or area under current and future environmental conditions[3,4]. The MLPA does not include numerical thresholds that define success but instead, includes goals that elevate the holistic benefits to humans and ecosystems provided by the habitats it protects from extractive uses. California's MPA Network has similar goals to national and state parks on land, which focus on providing opportunities for the public to interact with vibrant and thriving ecosystems while protecting these areas for future generations.

Research and monitoring are essential to tracking conditions and trends of marine populations, habitats, and ecosystems to understand how they change over time. The MLPA requires monitoring, research, and evaluation at selected sites to ensure that the Network meets its goals. A critical component of evaluating MPA performance is establishing a baseline of conditions in MPAs and at similar nearby sites that are not MPAs (i.e. reference site). California phased in the implementation of MPAs by region and deployed baseline monitoring to capture conditions at the start of protection.

The Marine Life Protection Act lays out ecological, design and management goals.

Goals (1) and (2) are ecologically focused and although they do not define thresholds, they do require the MPA Network to demonstrate positive trends related to: protecting the natural diversity and abundance of marine life, and the structure, function, and integrity of marine ecosystems; and helping sustain, conserve, and protect marine life populations, including those of economic value, and rebuild those that are depleted.

Goals (3) and (4) set out required elements that informed the creation of the scientific design guidelines and the design of the adopted MPA Network which: improve recreational, educational and study opportunities in ecosystems subject to minimal human disturbance that are managed in a way that protects biodiversity; and protect marine natural heritage, including representative and unique marine life habitats.

Goals (5) and (6) focus primarily on the management of the MPA Network ensuring California's MPAs have clearly defined objectives, effective management measures, and adequate enforcement, and are based on sound scientific guidelines; and the state's MPAs are designed and managed, to the extent possible, as a network.

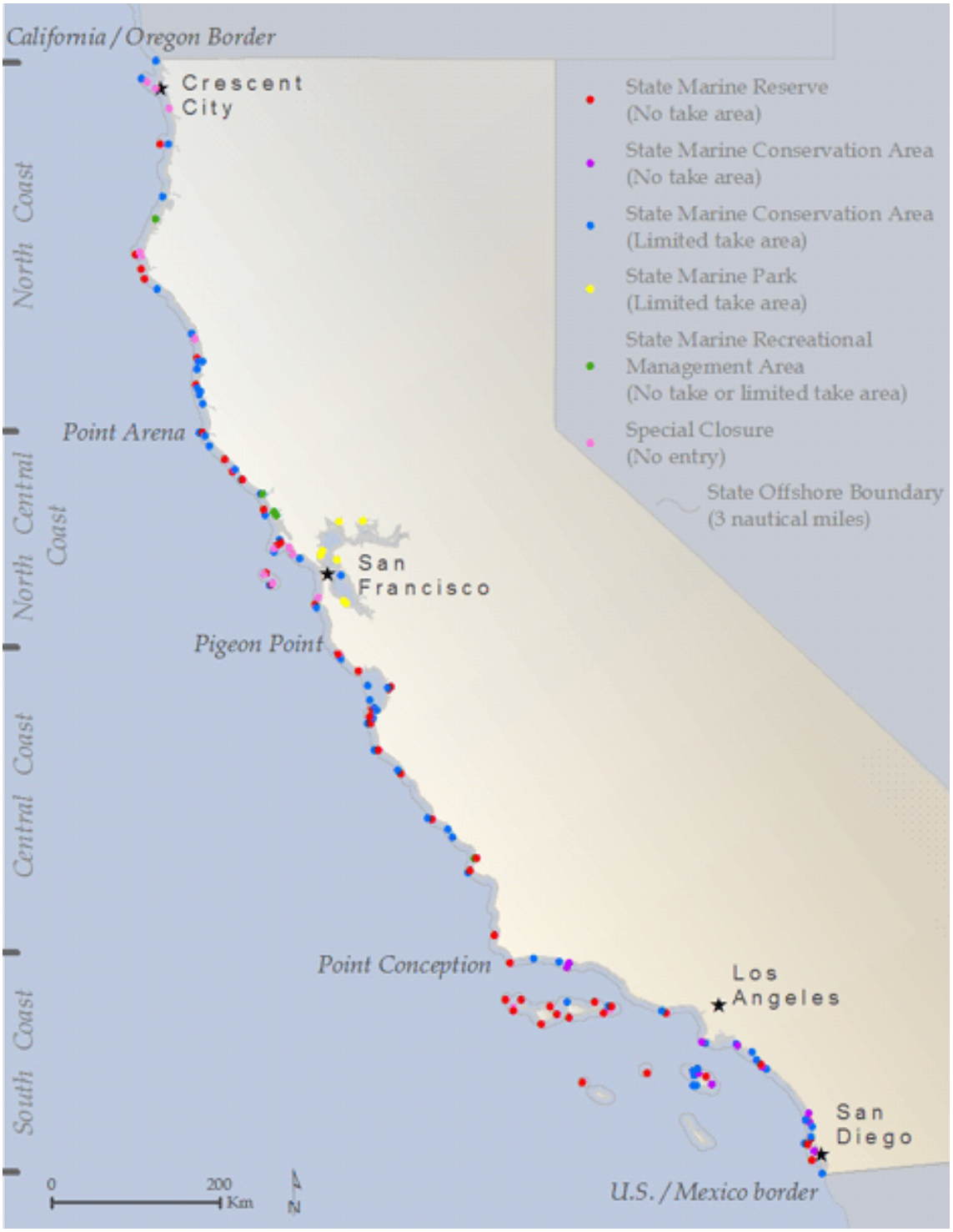

Figure 1. California Marine Protected Areas. The three main types of MPAs – state marine reserve (SMR), state marine park (SMP), and state marine conservation area (SMCA) – each have different rules about the activities that may or may not be undertaken within the MPA. In general, SMRs do not allow any type of extractive activities (including fishing or kelp harvesting) except for scientific collecting under a permit, SMPs do not allow any commercial extraction, and SMCAs restrict some types of commercial and/or recreational extraction. State Marine Recreational Management Areas prohibit performing any activity that would compromise the recreational values for which the area may be designated (e.g. waterfowl hunting). Special Closures prohibit access or restricts boating activities in waters adjacent to sea bird rookeries or marine mammal haul-out sites. Map by California Department of Fish and Wildlife.

Table 1. Timing of key milestones in California Marine Protected Area Monitoring Program Phase 1

COASTAL REGION/ DATE IMPLEMENTED	PHASE 1: BASELINE DATA COLLECTION PERIOD	ANALYZE, SYNTHESIZE, & SHARE BASELINE INFORMATION
CENTRAL/SEPTEMBER 2007 *(Pigeon Pt. to Pt. Conception)*	2007 - 2010	2010 - 2013
NORTH CENTRAL/MAY 2010 *(Alder Creek to Pigeon Pt.)*	2010 - 2012	2012 - 2016
SOUTH/JANUARY 2012 *(Pt. Conception to US/Mexico Border)*	2011 - 2013	2013 - 2017
NORTH/DECEMBER 2012 *(California/ Oregon border to Alder Creek)*	2013 - 2016	2016 - 2018

As the MPA Monitoring Program Phase 1 Baseline Monitoring was wrapping up in each region the state implemented Phase 2 which included Long-term Monitoring to detect changes over time. Long-term Monitoring is ongoing and provides information about MPA performance as environmental conditions and biological responses change over time. Based on the results of the Baseline Monitoring the four planning regions (Table 1) were compressed into three bioregions (north coast - California/ Oregon border to San Francisco Bay, including the Farallon Islands; the central coast - San Francisco Bay to Point Conception; south coast - Point Conception to the U.S./Mexico border, including the Channel Islands) to better reflect similar environmental conditions and simplify planning for future studies. All long-term monitoring projects currently underway were selected through a competitive process that incorporated lessons learned from the Baseline Monitoring. Projects focus on a range of species in different habitat types (e.g. rocky reef, mid-depth rock, sandy beaches) as well as monitoring effects on human behavior and coastal economies. The MPA Monitoring Program shared results throughout Phase 1 (Baseline) and 2 (Long-term) with stakeholders. All the results to date are now being combined through integrated analyses across habitats and species to inform the 2022 California MPA Network Decadal Management Review (DMR) to assess the progress of the MPA Network at meeting the goals of the MLPA[5]. The DMR Report is due in January 2023.

California's nearshore ecosystem is one of the most productive and dynamic in the world[6]. Nutrient-rich upwelling currents driven by wind support a wide variety of birds, marine mammals, invertebrates, and fishes. These ever-changing ocean conditions are a key driver of the survival and successful reproduction for these species. Nearshore species vary widely in their life history with some species like market squid growing quickly and living less than a year while others like rockfishes growing slowly living for decades. Species also vary widely in their movement patterns with some—like spiny lobster—moving very little, while others—like black rockfish—making periodic migrations over 30 miles[7].

California's MPA Network removes or reduces fishing pressure for a defined area, providing protection to species within their boundaries. The amount of fishing that occurred before protection and the length of time an area is protected combine with the physical and biological conditions to determine when we might see predicted positive effects from MPAs[8–10]. Climate change further complicates interpreting the

performance of California's MPA Network due to the impacts on currents, storms, water chemistry and water temperature.

Many of the marine species inside California's MPAs have a history of being targeted by commercial and recreational fisheries and are relatively long-lived and slow-growing. The MPA Network was established in phases with the final region implemented in 2012. However, even the oldest MPAs in California designed as a network in the Northern Channel Islands implemented in 2003 are still young in comparison to the life span of many of the species that live in them. Many nearshore rockfish live over twenty years and blue and black rockfish live to be near 50 years old. It is very early days in the life of California's MPA Network and the DMR is an opportunity to review the vast amounts of information and learning we have gained so far about our coastal ecosystem.

The MPA Network has already succeeded in providing better recreational, educational and study opportunities and the MPA Management Program, administered by the California Department of Fish Wildlife in collaboration with the MPA Statewide Leadership Team, is successfully managing the MPAs as a network[11]. The MPA Management Program encompasses the four pillars identified in the MLPA required for successful implementation of the Network and include outreach and education; research and monitoring; enforcement and compliance; and policy and permitting. The MPA Management Program is described in the MLPA and includes both the regulations that implement MPAs and the supporting components to comprehensively adaptively manage the Network. Adaptive management means a management policy that seeks to improve management of biological resources, particularly in areas of scientific uncertainty, by viewing program actions as tools for learning.

The International Union for the Conservation of Nature (IUCN) definition of an MPA network is exemplified in California's MPA Network. The IUCN defines an MPA network as a collection of individual MPAs or reserves operating cooperatively and synergistically, at various spatial scales, and with a range of protection levels that are designed to meet objectives that a single reserve cannot achieve[12]. The MPA Management Program has maintained the spatial design of California's MPA Network which was designed to maximize connectivity among individual MPAs across the Network. The unprecedented amount of data collected through the MPA Monitoring Program provides information on the biological and environmental conditions in selected areas across the MPA Network since implementation. Trends vary by species and by region but even at this very early stage, in general, California's MPA Network is supporting biodiversity, climate resilience and showing positive trends in biological responses, and is on track to meet the ambitious goals of the MLPA.

2. LONG TERM MONITORING REPORTS

Seven long-term monitoring reports have been submitted from the MPA Monitoring Program in preparation for the DMR. The south and central coast have the most robust monitoring with the longest time series and highest sampling intensity which result in an increased ability to detect change. The central and south coast also generally have higher fishing pressure making it more likely to detect an MPA response. Populations that are fished at a high level are expected to rebound more quickly and to a greater degree when MPAs are implemented and fishing is removed or reduced significantly. The Northern Channel Islands MPAs have been in state waters since 2003 and 11 of 13 MPAs have the highest level of protection—State Marine Reserves which prohibit all take. The length of protection and this high level of protection are key drivers influencing a positive MPA response.

Scientists can examine changes over time in several ways. They can look at different spatial scales (local vs regional trends), species or habitats. The study methods summarized next are focused on a particular habitat types and a range of species within each habitat. MPA performance monitoring studies require several species with varying life history characteristics (e.g. short-lived vs long-lived) and ecological niches (e.g. grazers vs predators) to be sampled. The MPA Monitoring Program Projects discussed here all take that approach and use a variety of sampling techniques (e.g. scuba, remotely-operated vehicles, nets, etc.) to collect information.

METHODS

A preferred sample design of a monitoring program to evaluate MPA performance is to evaluate a performance metric (e.g. fish density or biomass) inside the boundaries of an MPA and at an unprotected paired reference site with similar habitat and environmental conditions. This design was used for both the data collection and analyses for the MPA Long-term Monitoring Projects.

- *Surf zone/Sandy beaches*[13]
  Researchers used baited remote underwater video (BRUV) cameras (2-4 m depth), and beach seine nets (1-1.3 m depth) on sandy substrate to characterize surf zone fish communities in MPA and reference sites for the first time statewide since MPA implementation. Beach wrack (i.e. algae that washes ashore), beach features (zone widths and slopes, wave and swash climate), shorebird assemblages were characterized and observational human use data were also recorded. Not all types of data were collected at every site.

- *Rocky intertidal*[14]
  Photo plots, transects and environmental monitoring were deployed from the high to low intertidal zone, and detailed counts of invertebrates and algae were conducted. Information was also collected on the physical attributes of a site, such as elevation and temperature. The MARINe (Multi Agency Rocky Intertidal Network) program has been sampling for decades and has data from over 130 sites spanning the west coast from Alaska to Baja. The MLPA Monitoring Program supported this existing program to ensure coverage of key sites within the MPA Network.
- *Kelp forest/shallow rocky reef*[15]
  Scuba surveys inside and outside MPAs were conducted by divers who swam along 30 m transects recording the number, type and size of fishes, invertebrates and algae, along with the type of substrate and bottom-dwelling organisms at uniform points within the study area. Satellite data were used to monitor kelp canopy and physical and chemical metrics were collected at selected sites. The depth range for this work was 3 - 20 m.
- *Mid-depth rock*
  - California Collaborative Fisheries Research Program[16]
    Volunteer anglers fished regularly with researchers at selected locations inside and outside MPAs using standardized gear. Fish counts and lengths were recorded and fish in good condition were tagged. Researchers also collected data on angler perceptions of MPAs before and after participation in the project. The depth range for this work was 20 - 40 m.

  - ROV/HOV/Landers[17]
    ROV/HOV landers were used to survey depths beyond the limits of scuba to provide fishery independent data on fish and invertebrate communities. The depth range for this work was 20 -300 m.

- *Oceanographic*[18]
  A data clearinghouse for relevant oceanographic data were created and used to model connectivity, harmful algal bloom and climate risks to the MPA Network. The newly created visualization tool called the "California MPA Dashboard" is designed for accessing and visualizing information relevant to answering questions about the MPA Network https://mpa-dashboard.caloos.org/mpa-time-series/ . The tool includes models to visualize the risk for a key environmental stressor, such as harmful algal blooms (HABs), and the specific HAB risk to vulnerable species of interest (e.g. leatherback sea turtles, sea lions, and blue sharks) within individual MPAs throughout the California MPA network, as well as similar sites outside the network.
- *Socioeconomic*[19]
  Interviews of selected focus groups were used to collect commercial and CPFV fishery participant attitudes and perceptions towards MPAs and management with recommendations for the design of future human dimensions monitoring. Spatial analysis of fishing patterns was completed by using a combined dataset that included CDFW commercial fishing landing receipts and spatial layers of fishing areas developed by Ecotrust based on in-person interviews to support the MPA network development and implementation[20].

RESULTS

There is a suite of ecological indicators used to evaluate an MPA effect or response, meaning an increase or upward trend inside an MPA after protection when compared to an adjacent similar reference area without protection. These metrics focus on density, abundance, size, biomass, and diversity of species and habitat types[21,22]. Physical and chemical indicators (e.g. temperature, oxygen levels) of environmental conditions and historical as well as current information about fishing pressure and compliance with MPA regulations provided critical context for interpreting results. For studies using standardized fishing gear, catch per unit effort and biomass per unit effort which records how many individuals or weight of fishes were caught over a designated period of time is collected. All studies that collected data for the long-term monitoring projects of California's MPA Network focused on collecting information that could help evaluate progress towards meeting the design, governance and broad ecological goals of the MLPA. The long-term monitoring studies summarized below primarily focus on evaluating the progress towards meeting the ecological goals.

Surf zone/Sandy beaches[13]

This 2019-2020 study represents the first statewide surveys of surf zone fishes. Results for fish metrics varied between the baited remote underwater video cameras (BRUVs) which sample the deep surf zone (2-4 m) and beach seines that survey the shallow inshore surf zone (1-1.3m). The deeper surf zone BRUVs detected positive MPA signals in fish richness and abundance, while biomass of all fish and targeted fish in MPAs was significantly higher in the shallow surf zone surveyed with beach seines. MPA effects varied across regions and site pairs, with more significant positive trends detected in the south. Surf zone and sandy beach habitat characteristics differed greatly among MPA sites. Wrack abundance did not differ in MPAs and reference sites, but kelp wrack was very low on the north coast when compared to other regions. Shorebirds were 30% more abundant in MPAs statewide but not significantly so, and the responses of individual species varied. Some MPA beaches are hotspots for wintering shorebirds, including the threatened Western Snowy Plover.

- NORTH COAST - Catch per unit effort (CPUE) of surf zone fish was higher in MPAs compared to reference sites in beach seines but was the lowest overall among the regions. No significant difference was observed in baited underwater video (BRUV) or seine abundance between MPAs

and reference sites. The abundance of beach wrack and shorebirds did not differ between MPA and reference sites.

- CENTRAL COAST - Catch per unit effort (CPUE) for beach seines was the highest overall among regions but generally lower in MPAs than reference sites. Results on abundance and richness from baited underwater video (BRUV) showed no difference between MPA and reference sites. The abundance of beach wrack of shorebirds was higher in MPA compared to reference sites but those differences were not significant.
- SOUTH COAST - Catch per unit effort (CPUE) for surf zone fish in BRUVs was three times higher in MPAs than reference sites, indicating significantly higher abundance of fish inside MPAs versus outside. No significant differences in fish abundance was detected in seine results. Species richness detected by BRUVs was also significantly greater in MPAs compared to reference sites. Also, significantly more elasmobranchs were observed using BRUV and seines in this region than in the north and central regions and there was a significant MPA signal in this group. Beach wrack abundance did not differ significantly between MPA and reference sites. Shorebird abundance was more than 30% greater in MPAs but that difference was not statistically significant.

Rocky intertidal[14]

MPA sites were more species rich and diverse than reference sites. A key finding with respect to marine community attributes was that stability, as measured by the same suite of species being present in the same proportions overtime, was enhanced in MPA's relative to reference sites, particularly in central and south regions. Community stability is indicated as a factor likely supporting more resilient community recovery after disturbance or climate change driven impacts like ocean acidification or non-native invasive species outbreaks[2]. The modeled results indicate that contribution of propagules from MPA's to other MPA's was greater than expected. Results suggest that MPA placement enhances both contributions from and settlement or larvae into MPA's. It is important to note that negative responses may be an artifact of natural variation between sites, biotic or environmental perturbations, or differences in recruitment.

- NORTH COAST - MPA and reference sites generally have similar site stability profiles. Common species were observed to show positive effects of protection on key metrics like abundance and biomass inside MPAs when compared to non-protected reference sites. Results are not biased in number of species (i.e., equal number of species represented between positive and negative MPA responses), the amount of positive change attributed to the MPA effect was substantially greater and had more positive than negative effects.
- CENTRAL COAST - MPA and reference sites have two very different thermal / stability profiles. The key distinguishing feature is that the impact of the marine heat wave (MHW) was much less severe in MPA sites than in reference sites. In the reference sites the MHW state was 10 points less than in the MPA sites indicating a buffering of community stability properties in MPA's. MPA effects across common species have positive values when associated with increased mean values for the species in MPA's relative to reference sites post-implementation of regulatory protection, results indicate a positive bias both in magnitude and number of species (indicating an overall positive MPA effect). In other words, more species responded positively to regulatory implementation relative to unprotected areas.
- SOUTH COAST - MPAs and reference site stability diverged during the recovery period from the marine heat wave, with MPA sites recovering to historical abundances and diversity from the marine heat waves much more rapidly than reference sites. Common species were observed to

show positive effects of protection on key metrics like abundance and biomass inside MPAs when compared to non-protected reference sites.MPA effects across common species have positive values when associated with increased mean values for the species in MPA's relative to reference sites post-implementation of regulatory protection, results indicate a slightly negative bias both in magnitude and number of species.

Kelp forest/nearshore rocky reef[15]

Aggregated results across regions showed no positive response for targeted fish species in reserves when compared to reference areas. This is likely due to the large variations in variables such as environmental conditions, length of time protected, sampling intensity and historical fishing pressure between regions. Analyses at the individual MPA or regional level proved more insightful than statewide analyses. Of the 20 MPAs analyzed that had a sufficient time series of data across the state, 16 showed a positive log mean biomass response ratio indicating an upward trend line that had a steeper slope for biomass inside the MPA for targeted species than what was observed in the paired reference area. Strong positive responses across indicators were observed in the Northern Channel Islands and Southern Region, which have been protected the longest and had moderate to high historical fishing pressure.

- NORTH COAST - Has the shortest time series, least number of replicates, and its MPAs are the youngest. Consequently, effects of the MPAs, if any existed, would be difficult to discern even under stable environmental conditions. The Marine Heatwave of 2014 – 2016 hit this area the hardest causing significant population level negative impacts to invertebrates, fishes and algae. Sonoma and Mendocino counties lost over 90% of their kelp canopy between 2013 – 2017[23]. As stated in the report, "North Coast sites had either short monitoring history and/or large gaps between baseline monitoring and present, so time series for these MPAs must be interpreted with caution." No differences were observed between MPAs and reference sites in fish densities. The extreme environmental disturbance driven by the marine heatwave 2014 – 2016 (aka "warm blob") during the monitoring period, low fishing pressure and limited monitoring likely decreased the ability to detect differences and likely swamped any MPA effects. Even so, some individual MPAs, such as Pt. Cabrillo SMR and Stewarts Pt SMR and species (lingcod and kelp greenling) showed positive trends in abundance and biomass. Point Cabrillo was designated a reserve in 1975 and has had a high level of protection with recreational fishing not being allowed within 1000 ft of shore which may explain the observed response, but this was not statistically tested. The diversity and species richness of fishes, invertebrates, algae and UPC (uniform point contact where information is taken at designated points along a transect laid on the bottom) organisms declined inside MPAs and reference areas likely reflecting a community-wide response to the marine heat wave.
- CENTRAL COAST - Has a monitoring data time series significantly longer than the north coast which allows for better detection of MPA responses, yet the region exhibited highly variable responses. The strongest responses were observed in the southernmost MPAs (Pt. Sur and Pt. Buchon). Of the five sites in the central coast analyzed, four showed a positive response ratio for targeted fishes. Targeted species (black, blue, gopher rockfish, kelp greenling and lingcod) showed positive temporal trends in MPAs when compared to reference sites across the region.
- SOUTH COAST - Results show generally the strongest positive trends in biomass and abundance across the targeted species (i.e. an aggregate of all fish targeted by anglers) with the biggest effects being seen in the Northern Channel Island MPAs. All MPAs in the Northern Channel Islands showed a positive trend in abundance and biomass for heavily fished species. Heavily fished species

including kelp bass, CA sheephead and lobster all showed significant positive responses to MPA protection.

Reef Check California, which is a data set collected by highly trained and tested community scientists, has comparable methods and data quality to academic researchers for a smaller group of species. RCCA has significant additional data across the state beginning in 2006, including in the north coast, that was not included in these analyses because there were data internal RCCA database issues that prevented sharing of the data on the timeline needed. RCCA has taken steps to address these issues and it is anticipated those data will be available for future analyses.

Mid-depth rock

Two different survey methods focusing on two depth zones 20 - 40 m (California Collaborative Fishing Research Project, CCFRP) and 30 - 100 m (ROV/HOV/Landers) were conducted in this habitat. The CCFRP project focused on both benthic and midwater fishes which the ROV/HOV/Lander primarily sampled benthic species.

California Collaborative Fisheries Research Program[16]

Monitoring results indicated that biomass indices were greater inside the MPA for species than those from the paired reference are positive at all sites in 2020 and were greater at all sites except South Cape Mendocino in all other years sampled (2017-2019), indicating that total fish biomass is consistently higher inside MPAs when compared to fished reference sites, statewide. Statewide fish are more abundant in MPAs compared to reference sites; 73% of observed species were more abundant in MPAs. Additionally, a statewide survey of anglers' positive perceptions towards MPAs increased 26% and negative perceptions decreased by 11% after participation in the CCFRP.

- 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. 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 (i.e. weight) inside MPAs compared to Reference sites; however mean lengths were not statistically different. 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.
- CENTRAL COAST - 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. Five of the 10 most common 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 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. 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. The average effect of fishing closure on total fish BPUE (i.e. biomass response ratio) indicating an upward trend line that had a steeper slope for biomass inside the MPA for species than what was observed in the paired reference was positive for all years.

- SOUTH COAST -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 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 (although only California sheephead lengths were statistically different. Two of the top ten 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.

ROV/HOV/Landers[17]

Structure-forming invertebrates, such as corals and sponges, were found at greater densities within MPAs than in associated Reference sites. Both Northern and Central California have more high-quality complex rock habitat than Southern California. The sampled State Marine Reserves (SMR) have more rock and more high-quality habitat than State Marine Conservation Areas (SMCAs) but there is no difference between inside MPAs and associated Reference sites. Across all regions and all the focal fish species analyzed, there was no statistical difference in the proportion of individuals greater than 50% maturity inside MPAs compared to associated Reference sites. Large differences in species diversity and species richness at the same MPAs and Reference sites in the same year between the HOV and ROV were observed. On average, more species and more diverse communities were observed with the HOV than the ROV in both MPAs and Reference sites. Additional analyses are being conducted based on recommendations in Perkins 2021[24] and will be available in early 2023.

- NORTH COAST- ROV/HOV/Landers -There were differences in body size for 2 of the 11 focal species (kelp greenling and quillback rockfish) between MPA and Reference sites and across years. For all 11 focal species there was no difference in the trajectory of densities among MPA and Reference sites through time.
- CENTRAL COAST - ROV/HOV/Landers - Statistical differences in mean lengths among MPA and Reference sites across sampling years were apparent for 6 of 11 focal species (Blue/Deacon Rockfish, Gopher Rockfish, Lingcod, Painted Greenling, Pink Seaperch, and Vermilion Rockfish). Nine of 11 species showed increasing densities through time however,

there were no statistical differences among MPAs and Reference sites with the exception of higher densities in the Reference sites for Pink Seaperch.

- SOUTH COAST - ROV/HOV/Landers - Copper Rockfish densities were consistently higher inside MPAs relative to outside MPAs in all years surveyed. Five of 13 species (Blacksmith, Blue/Deacon Rockfish, California sheephead, Kelp Greenling, and Vermilion Rockfish) showed differences in mean body size among MPAs and Reference sites across years. Between 2005 and 2020, 9 out of 13 species showed increasing densities through time, 3 species (Bocaccio, Kelp Greenling, Lingcod) showed little change in density between 2005 and 2020, and 1 species (Pile Perch) experienced a decline in density through time (Fig. 15; App. Table B7). For both Copper Rockfish and California sheephead, the difference in densities between MPA and Reference sites increased through time with statistically higher densities in the MPAs in 2020. Sea cucumber numbers were significantly lower in Reference sites in Southern California where there is an active commercial fishery compared to within MPAs. Carrington Pt. and Anacapa MPAs are subject to different oceanographic conditions and previous work in shallow water has documented strong geographic variation in fish community structure at the islands as well as differences in and out of MPAs

Oceanographic[18]

A massive and extended Marine Heat Wave had extensive impacts to ocean communities across the state centered around 2015/16. This included the largest recorded harmful algal bloom event that had impacts across fish, marine mammals and seabirds. However, the unusual conditions that dominated that period, even into 2018, have since dissipated. This is evident in the time series of the California Multivariate Ocean Climate Indicator (MOCI) and many other datasets. Generally, high-resolution modeling of connectivity in Central California, ability to transport and receive larvae/spores, showed connectivity and spillover across the network. The data supports that bioregions are projected to show distinct, coherent change over time out to 2100 and remain as distinct bioregions. However, change is expected to be substantial enough that direct environmental analogs of current MPA conditions will become increasingly rare and may not exist in California by the end of the century. California MPAs protected higher percentages of potential 'climate refugia', areas that remain buffered from climate impacts and are more similar to past environmental conditions, from 1980-2099 compared to overall state waters, but refugia were often not spatially persistent.

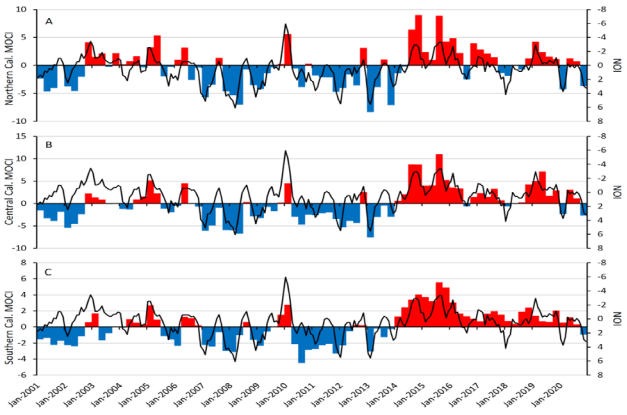

Figure 2. From Ruhl et al. 2021 Figure 5-2. Time series of the California Multivariate Ocean Climate Indicator (MOCI), which is calculated as seasonal values across the A) Northern (38-42°N), B) Central (34.5-38°N), and C) Southern (32-34.5°N) bioregions (red and blue bars). Also shown with each is the Northern Oscillation Index (NOI) with a 3-month seasonal running mean (black line).

- NORTH COAST- Oceanographic- Modeling future conditions in the MPA Network, the probability of harmful algal blooms (HAB) events is more frequent and has a larger spatial extent. Sea Lion SMR had consistently different environmental conditions than the rest of the MPAs in the region due to the persistence of kelp cover at this site in 2016.
- CENTRAL COAST -Oceanographic- Point Sur SMR had consistently different environmental conditions than the rest of the MPAs in the region. On a monthly basis, the project team calculated connectivity of virtual larvae between MPAs in Monterey Bay. Most MPAs in the region were well-connected during the study period, especially when moving from southern to northern MPAs. Modeled adult fish spillover from MPAs to other non-MPA nearshore regions was also high.
- SOUTH COAST - Oceanographic- The South Coast bioregion was projected to experience the greatest multivariate change (Sea Surface Temperature, Chlorophyll a, Dissolved Oxygen, Buoyancy Frequency, and the Coastal Upwelling Transport Index) in environmental conditions over time. Particulate domoic acid (pDA) has the opposite geographic trend than cDA and PN with larger areas and more long lasting events when compared to southern and northern California.

Socioeconomic/Human Dimensions[19]

Detailed results were not presented on a regional scale in the report, however, the website http://www.mpahumanuses.com developed can give port by port results and details by selecting data filters. Data were not collected from non-extractive users and no quantitative economic analyses were completed for this study. The commercial fishing focus groups consisted of three to eight participants and were between two hours, forty minutes and four hours, twenty minutes in length, inclusive of a break in the middle. A total of 85 individuals from 19 ports participated in the commercial fishing focus groups. No fisherman from Monterey wanted to participate in the focus group.

Focus group responses indicated ports across California experienced many challenges related to their well-being; however, there were some bright spots. Perceived well-being varied fairly extensively across the state, indicating that not all ports may be experiencing the same type or extent of challenges. Participants highlighted the disparity of available funding for researchers, managers, and planners relative to how fishermen are compensated for their time and expertise. Using a modeled dataset, proportion of catch in areas adjacent to MPAs increased from pre-MPA implementation years compared to post implementation.

Focus group responses indicate commercial fishermen across California are both dissatisfied with and have experienced negative effects from the MPA network. A majority of participants' perceptions about MPA effects on marine resource health fell below positive, with 43% reporting strongly negative or negative and 50% reporting no effect/neutral. Reported impacts tended to be more acute for ports in Central and Southern California compared to Northern California, where participants indicated that MPAs are located further from ports. Overall, participants expressed dissatisfaction with MPA management (including the MPA planning process), MPA monitoring, and MPA enforcement with many emphasizing this dissatisfaction related to a lack of communication from the state.

Modeled spatial analyses of fishing effort found that fishing in areas adjacent to MPAs increased. Data supports a "fishing the line" effect with increased fishing effort in areas along the boundaries of MPAs from commercial fisheries for lobster (+3%), urchin (+3%) and nearshore finfish (+8%). Nearshore finfish saw a greater increase in modeled landings compared to urchin and lobster: the proportion of catch of finfish in adjacent areas was 7% in pre-MPA years (2005-2009) and increased to 15% in post-MPA years (2010-2020).

3. ADAPTIVE MANAGEMENT RECOMMENDATIONS

Based on recommendations from the long-term monitoring reports and a review of the literature it is imperative that California continues its robust commitment to the MPA Management Program ensuring it has dedicated funding to support the four key pillars of the program that include research and monitoring, outreach and education, policy and permitting and enforcement and compliance. The MPA Statewide Leadership develops a detailed Work Plan[25] that outlines required tasks and actions needed to ensure the MPA Network is well-supported and set up to continue progress towards meeting the goals of the MLPA. All elements of the Work Plan should be fully implemented.

A consensus from the scientists involved in the MPA Monitoring Program and DMR integrated analyses as well as many environmental non-governmental organizations is that CDFW needs to develop a data use and sharing agreement for the different data sources it manages that is more stream-lined and responsive. The data use agreements should meet CDFWs legal requirements and allow for raw or anonymized data to be released to researchers when requested in a timely manner. Data collected by CDFW staff on species and habitats sometimes include datasets that go back for decades and can further a more comprehensive understanding of the MPA Network by leveraging the increased capacity available from outside researchers.

Data that are more spatially explicit on fishing effort, catches and enforcement needs to be made a priority by the California Natural Resource agency and staffing and funding needed to accomplish this needs to be secured.

CDFW needs to develop a program and seek funding to process satellite imagery in near real time of kelp canopy across the state. This is achievable if a sustained funding source can be found and will be informative in identifying large- and small-scale environmental changes that not only affect the MPA Network but many other state managed fisheries.

The State Water Resources Control Board adopted Resolution 2010-0057[26] and 2011-0013[27] directing staff to develop recommendations for new Water Quality Protection Areas to co-locate with MPAs. This work was never completed. The update 2019 Ocean Plan[28] provides specific implementation guidance for WQPAs and this should be used to develop a plan to implement the adopted resolutions.

The state should undertake an evaluation of the opportunities to increase the level of protection and spatial extent of California's MPA Network. Executive Order N-82-20[29] and the Climate Resilience and California's MPA Network Report[30] highlight increasing climate impacts to our ocean ecosystem. Current and emerging scientific information from California's MPA Network and MPAs around the world support increases in the size, number and level of protection in MPAs are likely to provide additional benefits to mitigate climate impacts and protect biodiversity[2,31].

REFERENCES

1. Caselle, J. E., Rassweiler, A., Hamilton, S. L. & Warner, R. R. Recovery trajectories of kelp forest animals are rapid yet spatially variable across a network of temperate marine protected areas. *Sci Rep* **5**, 1–15 (2015).

2. Marcos, C. *et al.* Reviewing the Ecosystem Services, Societal Goods, and Benefits of Marine Protected Areas. *Front Mar Sci* **8**, 504 (2021).

3. Maestro, M., Pérez-Cayeiro, M. L., Chica-Ruiz, J. A. & Reyes, H. Marine protected areas in the 21st century: Current situation and trends. *Ocean Coast Manag* **171**, 28–36 (2019).

4. Ziegler, S. L. *et al.* Marine protected areas, marine heatwaves, and the resilience of nearshore fish communities. *Sci Rep* **13**, 1405 (2023).

5. California Department of Fish and Wildlife. MPA Decadal Management Review. https://wildlife.ca.gov/Conservation/Marine/MPAs/Management/Decadal-Review#566381056-information-sources (2019).

6. National Science Foundation. California Current Ecosystem - Long term Ecological Research. https://lternet.edu/site/california-current-ecosystem-lter/ (2019).

7. Green, K. M. & Starr, R. M. Movements of small adult black rockfish: implications for the design of MPAs. *Mar Ecol Prog Ser* **436**, 219–230 (2011).

8. Kaplan, K. A. *et al.* Setting expected timelines of fished population recovery for the adaptive management of a marine protected area network. *Ecological Applications* **29**, e01949 (2019).

9. Ziegler, S. L. *et al.* External fishing effort regulates positive effects of no-take marine protected areas. *Biol Conserv* **269**, (2022).

10. Starr, R. M. *et al.* Variation in Responses of Fishes across Multiple Reserves within a Network of Marine Protected Areas in Temperate Waters. *PLoS One* **10**, e0118502 (2015).

11. NOAA National MPA Center & World Commission on Protected Areas. Ecological Connectivity for Marine Protected Areas. (2020).

12. IUCN World Commission on Protected Areas (IUCN-WCPA). *Establishing Resilient Marine Protected Area Networks-Making It Happen*. https://www.iucn.org/content/establishing-resilient-marine-protected-area-networks-making-it-happen (2001).

13. Dugan, J. E. *et al. Evaluating performance of California's MPA network through the lens of sandy beach and surf zone ecosystems*. https://caseagrant.ucsd.edu/our-work/research-projects/evaluating-performance-californias-mpa-network-through-lens-sandy-beach (2022).

14. Raimondi, P. *et al. Assessment of Rocky Intertidal habitats for the California Marine Protected Area Monitoring Program: Decadal report*. https://caseagrant.ucsd.edu/sites/default/files/MPA_Rocky_Intertidal_decadal_report_FINAL_1_12_2022.pdf (2022).

15. Carr, M. H. *et al. Monitoring and Evaluation of Kelp Forest Ecosystems in the MLPA Marine Protected Area Network*. https://caseagrant.ucsd.edu/system/files/2022-06/Kelp%20Forest%20Technical%20Report%20Narrative_v2.pdf (2021).

16. Hamilton, S. *et al. California Collaborative Fisheries Research Program (CCFRP) – Monitoring and Evaluation of California Marine Protected Areas*. https://caseagrant.ucsd.edu/sites/default/files/CCFRP_Final_Report.pdf (2021).

17. Starr, R. *et al. Monitoring and Evaluation of Mid-Depth Rock Ecosystems in the California MLPA Marine Protected Area Network*. https://caseagrant.ucsd.edu/sites/default/files/MidDepth_MPA_Report_1_25_2022.pdf (2022).

18. Ruhl, A. H. *et al. Integrated ocean observing systems for assessing marine protected areas across California*. https://caseagrant.ucsd.edu/sites/default/files/CA%20IOOS%20MPA%20Final%20Technical%20Report%20ruhl_20220119.pdf (2021).

19. Bonkoski, J. *et al. Establishing a Statewide Baseline and Long-Term MPA Monitoring Program for Commercial and Commercial Passenger Fishing Vessel Fisheries in the State of California*. https://caseagrant.ucsd.edu/our-work/research-projects/establishing-statewide-baseline-and-long-term-mpa-monitoring-program (2021).

20. Scholz, A. J., Steinback, C., Kruse, S. A., Mertens, M. & Silverman, H. Incorporation of spatial and economic analyses of human-use data in the design of marine protected areas. *Conserv Biol* **25**, 485–492 (2011).

21. Roberts, K. E., Valkan, R. S. & Cook, C. N. Measuring progress in marine protection: A new set of metrics to evaluate the strength of marine protected area networks. *Biol Conserv* **219**, 20–27 (2018).

22. Cardoso-Andrade, M. *et al.* Setting Performance Indicators for Coastal Marine Protected Areas: An Expert-Based Methodology. *Front Mar Sci* **9**, 907 (2022).

23. McPherson, M. L. *et al.* Large-scale shift in the structure of a kelp forest ecosystem co-occurs with an epizootic and marine heatwave. *Communications Biology 2021 4:1* **4**, 1–9 (2021).

24. Perkins, N. R. *et al.* Quantifying the statistical power of monitoring programs for marine protected areas. *Ecological Applications* **31**, (2021).

25. California Ocean Protection Council. *Marine Protected Area Statewide Leadership Team Work Plan Fiscal Year 21/22-24/25*. https://www.opc.ca.gov/webmaster/_media_library/2022/02/MSLT_WorkPlan_FINAL_02.04.22-1.pdf (2021).

26. State Water Resources Control Board. *RESOLUTION NO. 2010-0057 MARINE PROTECTED AREAS AND STATE WATER QUALITY PROTECTION AREAS*. (2010).

27. State Water Resources Control Board. *RESOLUTION NO. 2011-0013 ADOPTING THE CALIFORNIA OCEAN PLAN (OCEAN PLAN) TRIENNIAL REVIEW AND WORKPLAN 2011-2013*. (2011).

28. State Water Resources Control Board. *WATER QUALITY CONTROL PLAN OCEAN WATERS OF CALIFORNIA*. https://www.waterboards.ca.gov/water_issues/programs/ocean/docs/oceanplan2019.pdf (2019).

29. California Natural Resources Agency. 30x30 | California Nature. https://www.californianature.ca.gov/pages/30x30 (2021).

30. Hofmann, G. E. *et al. Climate Resilience and California's Marine Protected Area Network: A Report by the Ocean Protection Council Science Advisory Team and California Ocean Science Trust*. https://www.opc.ca.gov/webmaster/ftp/pdf/agenda_items/20210615/Item3_Climate_Resilience_and_Californias_MPA_Network_2021.pdf (2021).

31. Edgar, G. J. *et al.* Global conservation outcomes depend on marine protected areas with five key features. *Nature* **506**, 216–220 (2014).