Sink or Swim: Progress Evaluation of California's Marine Protected Area Network

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California calls itself home to some of the most stunning beaches and ecologically diverse habitats around the world. Over 130 million people flock to the state's waters[1] per year, in search of relaxation, recreation, and a reprieve from the modern world. But behind the scenes, the ocean is more than just a spiritual and aesthetic vessel for its visitors. 50% to 70% of the Earth's oxygen is produced by plants, algae, and cyanobacteria found in the ocean (UGC Berkeley). 25% of carbon dioxide emissions and 50% of the heat generated by these emissions are captured and absorbed by the ocean. And according to the Ocean Panel, ocean-based action can help close the emissions gap[2] by as much as 35 percentage points (Ocean Panel). In a world that is rapidly heating up—ostensibly close to a point of no-return—the ocean will undoubtedly play a major role in humanity's fate.

In 1999, the state of California made an effort to strengthen and expand the state's Marine Protected Area (MPA)[3] network to 16% of the state's waters after a string of collapsing fishing reserves and oil spills. More or less, MPAs protect the physical and biotic components of marine ecosystems from fishing and other anthropogenic activity. Today, pressure mounts on Governor Gavin Newsom to expand MPAs to 30% of California's waters. Many experts in the field contend that 16% is not enough protected territory to have a salient impact on the ocean or mitigate climate change. The purpose of this paper, then, is to evaluate the performance of California's MPAs in order to assess whether or not they merit expansion or need to be strengthened. Broadly, how effectively do MPAs restore marine ecosystems? Specifically, to what extent do MPAs along the California coast benefit marine life over time and how do they

[1] California's waters extend three nautical miles (around 3.5 miles) from its coast.
[2] Defined as the difference between where global greenhouse emissions are headed and where science indicates emissions should be in 2030 (UN Library, 2019).
[3] The World Conservation Union at its 17th General Assembly in 1988 defined MPAs as, "Any area of intertidal or subtidal terrain, together with its overlying water and associated flora, fauna, historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment" (McArdle, 2024).

compare to non-MPA reference points? To answer these questions, I compared the Catch Per Unit Effort (CPUE)[4], Biomass Per Unit Effort (BPUE)[5], count, and length of fish in MPAs to those of non-MPA reference points while tracking the Net Primary Productivity (NPP)[6] of the North, Central, and Southern MPA bioregions over the years. I found a positive relationship between all variables, but one that was more subtle than anticipated.

1. Context and Significance

The expansion of MPAs in California has its roots in the state of marine resource management from local to global levels in the late 20th century. At the time, anywhere from 20% to 60% of the world's fisheries were reportedly overfished.[7] The more extensive impacts of fishing on ecosystems were not well understood, and the knowledge that existed was not enough to incentivize action (Botsford et al., 1997). Meanwhile, California had its own setbacks: multiple fisheries were experiencing unprecedented collapses and studies showed the depletion of vital organisms, such as abalone and the Dungeness crab. A dramatic oil spill in 1969 in the Santa Barbara region amplified growing concerns among the public and scientists alike (Botsford et al., 2014). Increased awareness of the fragility of marine ecosystems, coupled with the alarm of the fishing industry and a growing affinity for conservation, paved the road to the Marine Life Protection Act (MLPA) of 1999. The MLPA was defined by six goals:

1. To protect the natural diversity and abundance of marine life, and the structure, function, and integrity of marine ecosystems.
2. To help sustain, conserve, and protect marine life populations, including those of economic value, and rebuild those that are depleted.

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[4] The indirect measure of the abundance of fish.
[5] The biomass (weight) of fish per unit of effort exerted.
[6] The amount of organic carbon that primary producers produce through photosynthesis after accounting for respiration.
[7] This range depends on whether fully exploited fisheries are included in the overfished category).

3. To improve recreational, educational, and study opportunities provided by marine ecosystems that are subject to minimal human disturbance,
   and to manage these uses in a manner consistent with protecting biodiversity.
4. To protect marine natural heritage, including protection of representative and unique marine life habitats in California waters for their intrinsic value.
5. To ensure that California's MPAs have clearly defined objectives, effective management measures, and adequate enforcement, and are based on
   sound scientific guidelines.
6. To ensure that the state's MPAs are designed and managed, to the extent possible, as a network.

Principally, the act instructed the California Department of Fish and Wildlife (CDFW) to strengthen and expand the state's MPA network.

California was no stranger[8] to MPAs before the MLPA of 1999. However, the MPAs that did exist were small and characterized by confusing, often lax, regulations. When the MLPA was enacted, a mere 2.7% (368 square kilometers) of the state's waters were protected to some degree in 63 MPAs (Gleason et al., 2012). For contrast, scientists recommended that 30-50% of the state's waters should be protected in order for MPAs to be effective on a broader scale (Botsford et al., 2014).

[8] Neither was the rest of the world. The first MPA can be traced all the way back to 1962 (Humphreys, 2018) and there are over 15,000 MPAs around the world (Marine Conservation Atlas).

In 2012, a network of 124 MPAs[9] that cover 16% of the state's waters was officially completed, consisting of four bioregions[10] (Gleason et al., 2012). The scale of marine life protection varies from MPA to MPA (no-take versus multiple-use)[11], but generally they all inhibit deleterious activity[12] to some degree (see Table 2.1). There are four important types of MPAs: coastal MPAs which protect coastal habitats, kelp forest MPAs which protect underwater forests, deep water habitats which safeguard deepwater environments, and offshore MPAs, like the Channel Islands, which protect both deepwater habitats and underwater canyons. Most MPAs—129 to be exact—are located on the coast. While many protected areas can resemble normal beaches, MPAs are typically differentiated by a sign or buoy that confers protected status.

California MPAs are managed as a statewide network, through the MPA Management Program, which is a collaboration between the CDFW, California Fish and Game Commission (FGC), California Ocean Protection Council (OPC), and the MPA Statewide Leadership Team. The CDFW, which works to ensure compliance with the rules set out by the FGC, primarily handles the enforcement of MPA regulations. This can involve patrolling MPAs, conducting inspections, and taking enforcement actions when necessary. Fishermen must follow MPA regulations upon obtaining fishing licenses and permits. Those that fail to follow protocol can face fines, revocation of their licenses, and in some cases, legal action (CDFW MPA Management Program).

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[9] The north which runs from the California/Oregon border to Alder Creek, the north central coast which spans Alder Creek to Pigeon Point, the central coast which encompasses Pigeon Point to Point Conception, and the south coast, which includes Point Conception to the California/Mexico border (see Figure 2.1).

[10] Technically there are 5, the fifth being the San Francisco Bay, but planning and implementation in this region may only occur following the completion of historic ecosystem restoration and water reliability planning efforts in the Sacramento-San Joaquin River Delta (CA MPA Decadal Management Review, 2022).

[11] A no-take zone is a highly-protected MPA where removing or destroying resources is strictly prohibited. A multiple-use, on the other hand, is a protected MPA that allows for some fishing and industrial use.

[12] Deleterious activity, in this case, is defined as any direct physical action that impedes the ocean's ability to function optimally when performed over an extended period of time (e.g., fishing, drilling and mining).

MPAs are not popular across the board—especially with commercial fishermen, who worry that MPAs dig into their profits by limiting or prohibiting extraction. After the network was completed, of the 85 commercial fishermen and 20 Commercial Passenger Fishing Vessel operators who participated in focus group meetings, most felt that MPAs have had a negative effect on marine resources as well as their own livelihoods (CA MPA Decadal Management Review, 2022). In addition, although most scientists view MPAs favorably, some argue that their effectiveness is largely limited by climate change and anthropogenic stressors (Monterey Bay Aquarium, 2023).

MPAs are designed to promote climate resilience by protecting marine ecosystems, “blue carbon” habitats, and coastal communities (MPA as Climate Solutions). California, which has direct access to the ocean and is reliant on it, has a lot to gain or lose depending on their effectiveness. But so does the rest of the world. The health of the human species is substantially reliant on the health of the ocean. By examining the performance of California’s MPAs, we can determine whether they are a meaningful asset to ocean life. These conclusions can then aid us in rolling back on or facilitating state-wide (and perhaps even country-wide) expansion.

Map Color	**Classification**	**Number**	**% of State Water**	**Summary**
Red	State Marine Reserve (SMR)	49	9.0	Prohibits damage or take of all marine resources, including recreational and commercial take.
Blue	State Marine Conservation Area (SMCA)	60	6.5	May allow some recreational and/or commercial take of marine resources.
Purple	State Marine Conservation Area (no-take)	10	0.6	Generally prohibits the taking of living, geologic, and cultural marine resources, but allows potentially affected and ongoing permitted activities such as dredging and maintenance to continue.

Green	State Marine Recreational Management Area (SMRMA)	5	0.1	Limits recreational and commercial take of marine resources while allowing for legal waterfowl hunting to occur.
Yellow	State Marine Park (SMP)	1	<0.1	Prohibits damage or taking of any marine resources for commercial purposes.
Pink	Special Closure	14	0.1	Prohibits access or restricts boating activities in waters adjacent to sea bird rookeries or marine mammal haul-out sites.

Table 1.1 Types of MPAs, marine managed areas, and special closures used in California's MPA Network, each of which has a designated color (Table from CA MPA Decadal Management Review).

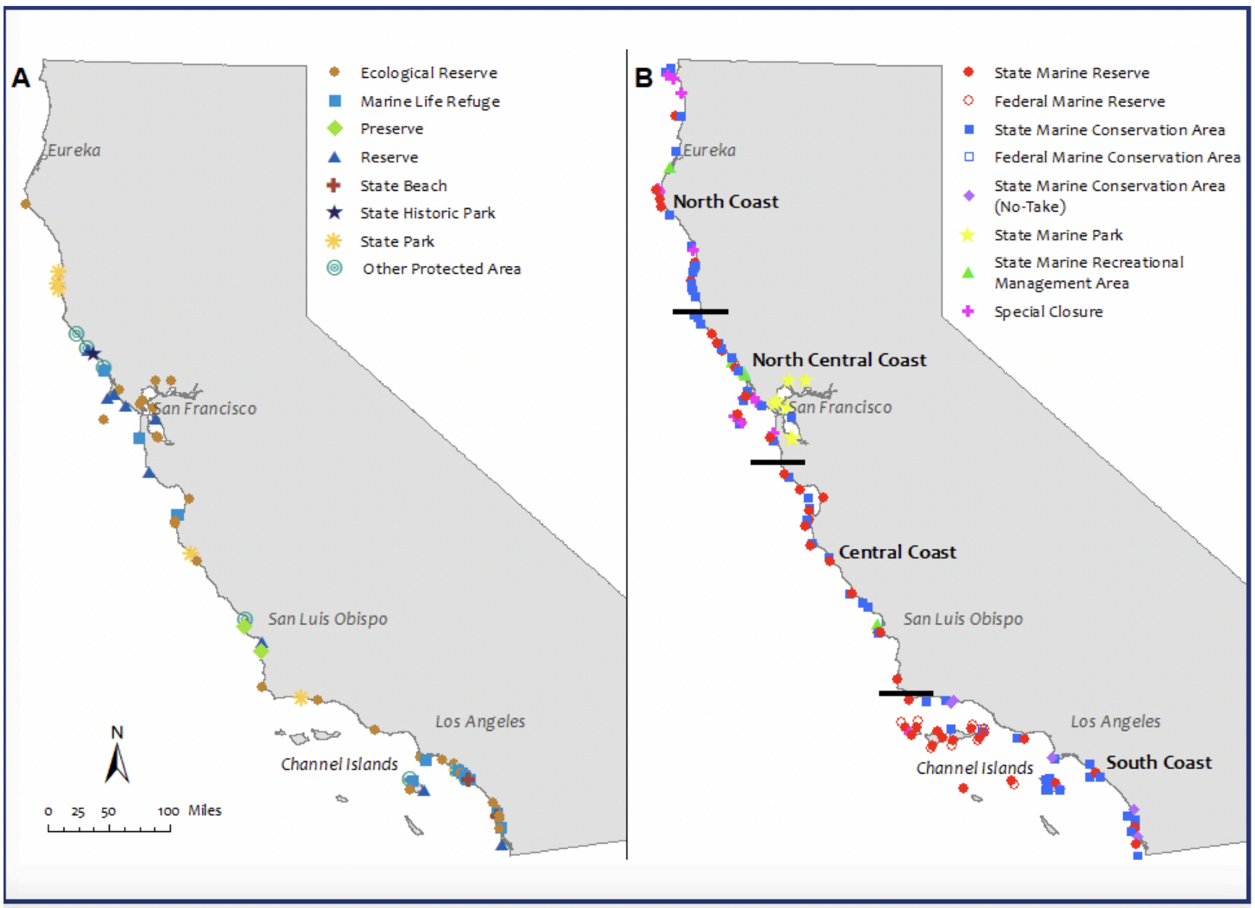

Figure 1.1 Map of California's MPAs before the MLPA of 1999 (A) and after the establishment of the statewide MPA network in 2012 (B). The black bars on Map B indicate the boundaries of the four MPA planning regions (Figure from CA MPA Decadal Management Review).

2. Literature Review

Monitoring and research are central to determining the effectiveness of MPAs and the course of future action. Fortunately, since the passing of the MLPA, scientists and researchers in the field have devoted their time and resources to gathering a plethora of data on the subject matter and deciphering results. The prevailing findings and conclusions are neatly summarized in the CDFW's first CA MPA Decadal Management Review (CA DMR/DMR), which set out to contrast the progress of MPAs relative to the objectives of the MLPA. The DMR delineates how each MPA bioregion has been faring since the completion of implementation using baseline and long-term monitoring data. The review finds that for some species and habitats, the state's MPAs support populations of bigger and/or more abundant fish and invertebrates by virtue of limiting or prohibiting extractive activities. Although the DMR by and large highlights the breakthroughs of MPAs, it also underscores significant limitations. For instance, the review notes that ecological changes resulting from MPAs may take years or decades to detect. In addition, species-level responses may vary by bioregion, habitat, and sampling method. And because the state's MPA network implementation took place incrementally and some MPAs existed prior to the MLPA initiative, not all MPAs are of similar age. Nevertheless, the DMR acknowledges that a well-managed MPA can support marine life within and outside its boundaries, provide natural laboratories for study, and meaningfully confront a changing climate (CA MPA DMR, 2022).

Reports for each individual bioregion go into more specific detail about the fruits and outcomes of MPAs. In the Central Coast, the California Ocean Science Trust, in collaboration with the CDFW and Central Coast MPA Baseline Program, found that MPAs are demonstrating promising results. The marine and coastal waters of the state's central coast are among the most biologically productive in the world and host a plethora of species. However, the increase of dissolved carbon dioxide and ocean acidity have posed a significant risk to the ocean's health and local economy. In 2007, this bioregion was the first to implement a network of 29 MPAs. The baseline monitoring, which ran until 2012, found that a range of economically important fishes, such as cabezon and black rockfish, increased in abundance in MPAs compared to comparable reference sites. In addition, both the numbers and sizes of protected black abalone and harvested owl limpets have increased over the monitoring period (State of the California Central Coast).

In 2010, the North Central Coast followed suit, implementing 31 MPAs that cover approximately 20% of the bioregion's waters. Like the Central Coast and the rest of the state, the North Central coast is home to productive fisheries, recreational activities, and tourism. Its persistent upwelling of cold, nutrient-rich water has earned it a position within the California Current Large Marine Ecosystem (CCLME). Long-term monitoring, particularly at Stornetta Ranch, revealed that the establishment of an MPA saw a sharp increase in red abalone numbers. Remotely operated vehicle surveys throughout the region found increased abundances of some rockfish and lingcod. However, the north central coast also witnessed shrunken kelp forests and mass sea star die off (State of the California North Central Coast).

Baseline monitoring for the southern bioregion’s 50s MPAs ran from 2011 to 2015. The results of the South Coast are considerably more ambiguous than those of the Central and North Central Coasts. For starters, older MPAs are unsurprisingly more successful than younger MPAs. But the bioregion also witnessed the simultaneous growth and decline of certain species both within and outside of MPAs. However, there were some noticeable breakthroughs, such as greater biomass for targeted species inside MPAs (State of the California South Coast).

The North Coast bioregion, consisting of 20 MPAs was completed in 2012 and marked the end of the network establishing process. Similarly, to the other bioregions, the North Coast witnessed increases in fish biomass, densities, and other metrics in MPAs, but the results did not always eclipse reference points, perhaps because this bioregion is the most recently implemented of the four networks (North Coast Baseline Program Final Report).

All in all, the four bioregions generally display promising results and similar limitations. The California Collaborative Fisheries Research Program combined MPAs across all four bioregions and compared them to suitable reference points to find that fish in MPAs are more abundant, have greater biomass, and are larger in size. Additionally, the report finds that fish increased more rapidly in the first bioregion, the Central Coast, suggesting that similar results await the other bioregions over time (CCFRP).

However, not every report is as optimistic about MPAs. For starters, several researchers (some from the aforementioned reports) are worried that the effectiveness of MPAs will be overshadowed and even overridden by climate change. Although MPAs are generally more resilient to climate stressors than reference points, they are not immune to them (Hamilton et al., 2023). The Monterey Bay Aquarium contends that MPAs are not a viable answer to climate change because they themselves are susceptible to it (2023). In addition, and perhaps less reputably, many fishermen claim that MPAs are negatively affecting marine life and their own livelihoods (CA MPA DMR, 2022). This paper settles the debate by comparing the CPUE, BPUE, count, and length of 11 MPAs and 11 reference points along the coast in order to evaluate the extent to which MPAs have been successful since the MLPA was passed in 1999. Moreover, I supply an additional analysis of the North, Central, and South coasts' NPP from 1999 to 2020 to uniquely evaluate how areas designated as MPAs have changed over time.

3. Theory and Hypotheses

I hypothesize that the marine life of California's MPAs have greater CPUEs, BPUEs, counts, and lengths over the years and as compared to non-MPA reference points. MPAs protect marine life from overfishing and human activity, which should naturally restore a resilient ocean. If we take eleven MPAs along the coast that have been established since the MLPA of 1999, and compare the aforementioned metrics over the years and to reference points along the coast, I expect that MPAs will not only perform better over time, but that they supersede reference points by most, if not all measurements. For my second hypothesis, I suspect that the NPP of the North, Central, and South coasts' MPAs will grow over time since 1999 for similar reasons.

MPAs allow fish numbers to rebound, repopulate, and grow to maturity because they limit or outlaw fishing and human activity which negatively affect fish species. The fishing industry has a vested interest in catching as many fish as possible, which disbalances marine ecosystems in the long term. When you remove the obstructions, you allow the ocean to naturally regenerate its resources. The combination of individual and comparative analyses hopefully provides a glimpse into the progress of MPAs and what they can mean for the future of marine life and ocean habitats.

4. Research Design Section

4.1. Independent variables: In this research project, 11 locations along the California Coast that each consist of one MPA and one complementary reference point for the years 2017 to 2020 act as my independent variables for my first hypothesis. The locations include Anacapa Island, Ano Nuevo, Swamis, Stewarts Point, South Cape Mendocino, Piedras Blancas, Point Buchon, South La Jolla, Carrington Point, Bodega Head, and Ten Mile. MPAs and reference points were already paired by the researchers who collected the data to reflect similar habitats and composition. According to the *State of the California Central Coast*, the composition and fish abundance between paired MPAs and reference points are more similar than among MPAs, indicating that reference sites and associated MPAs are well-suited for comparisons (2013). I chose these measurements rather than looking at all four bioregions at once because most of the reports I read during my preliminary research had already analyzed the performance of each bioregion since the MLPA was passed. Selecting 11 MPAs and reference points allowed me to craft a new and unique comparative combination while playing around with a plethora of data (over 200,000 observations). While this may be less comprehensive than looking at and comparing MPAs and reference points bioregion by bioregion, it provides a more close-up, individual inspection of the effects of MPAs.

For my second hypothesis, the North, Central, and South bioregions act as my independent variables. The data for these three areas from the passing of the MLPA in 1999 were conveniently stored in the California Ocean Observing Systems Data Portal (CALOOS), allowing me to easily examine all three regions from 1999 to 2020. Unfortunately, data for the fourth bioregion, the North Central Coast was unavailable on CALOOS and thus not observed in this report. The raw data I used for both hypotheses comes from DataOne and CALOOS. DataOne stored fish CPUE, BPUE, count, and length observations for 11 MPAs and 11 reference points while CALOOS stored NPP observations for the North, Central, and South bioregions. The data is collected annually for each MPA and bioregion in each raw data file. The DataOne file I used has data ranging from 2007 to 2020, and CALOOS has data ranging from 1996 to 2020.

4.2. Dependent Variables: My dependent variables, or measurements, for my first hypothesis are the average CPUE, BPUE in kilograms, count, and length in centimeters of fish within 11 MPAs and 11 reference points for each year from 2017 to 2020. Each year has multiple observations for each location. Anacapa Island, for instance, had close to 800 observations for its MPA and reference points in 2020. Data exists for other years as well, but was not included in my analysis to limit the scope of my research but also because not all years had data for the MPAs and reference points I examined. I chose CPUE, BPUE, count, and length of fish as my dependent variables because they are appropriate measurements for the health and abundance of fish: if fish are healthy, we expect them to be longer, heavier, and for there to be more of them overall. There are plenty of other ways to measure the health of fish—maturity for instance—but these four measurements were included in the data I was working with for the 11 MPAs and reference points I chose. The 22 areas combined do not track all fish present in their territory. Instead the researchers sampled around 100 fish species, likely because they were the most present in the areas they were collecting data for.

For my second hypothesis, NPP in the North, Central, and South bioregions serve as the dependent variable because the amount of organic matter available to marine life is the base of the food web and determines the productivity of a marine ecosystem. In addition, I did not see many NPP examinations in the papers I read during my preliminary research. Unlike data for my first hypothesis, NPP encapsulates each entire bioregion. Like for the independent variables, all of these variables can be found on DataOne and CALOOS.

4.3. Controlled variables: In this paper, I controlled for time and incomparable MPAs and reference points. To account for them, I discounted any data prior to 1999 when the MLPA was passed and examined the same amount of years for each MPA and reference point

(2017-2020). I also compared MPAs to suitable reference points based on what data reports deemed comparable (see section 5.1, paragraph one). I chose these specific variables because establishing a similar baseline between the MPAs and reference points is what allows us to analyze any glaring differences over time. Similarly, I limited MPA and reference point comparisons from 2017-2020 because data for all 22 locations was available for all four of those years. Data for NPP, or Net Primary Productivity, was available from 1996 for the North, Central, and South bioregions, but I chose to start with 1999 because that is when the MLPA was passed and I ended with 2020, because that was the most recent year with available data.

4.4. Unit of analysis: My unit of analysis for the first hypothesis is each individual MPA and its assigned reference point along the California coast. For my second hypothesis, my unit of analysis is the North, Central, and South MPA bioregions. In both cases, I look at multiple cases over time.

4.5. N-size and scopes of research: The n-size for my first hypothesis are all 11 MPAs along the coast and their associated non-MPA reference points. For my second hypothesis, it is the North, Central, and South bioregions. The geographic scope is the California coastline for both and the temporal scope is 2017-2020 for my first hypothesis and 1999-2020 for my second hypothesis.

4.6. Regressions: For this paper, I ran both a point-biserial and OLS regression for my first hypothesis in order to test for the strength of the relationship between MPAs and higher fish CPUEs, BPUEs, counts, and lengths. Rather than look at each individual year from 2017 to 2020, I grouped all the years together to look at the strength overall for each individual dependent variable.

5. Results

With the data I collected from DataONE's Nearshore Fishes Abundance and Distribution, I calculated the average CPUE, BPUE, count, and length of fish for each 11 MPAs and their associated reference points for all years 2017-2020. Almost each MPA had a greater fish CPUE, BPUE, length, and count than their reference point for each of the four years examined, with a few minor exceptions where reference points had greater averages than MPAs. In other words, fish are generally healthier in MPAs than in reference points. Interestingly, while MPAs had greater measurements than reference points overall, some of these measurements dropped over the years. For instance, in Anacapa Island, the average count of sampled fish dropped from 1.212 in 2017 to 0.8584 in 2020.

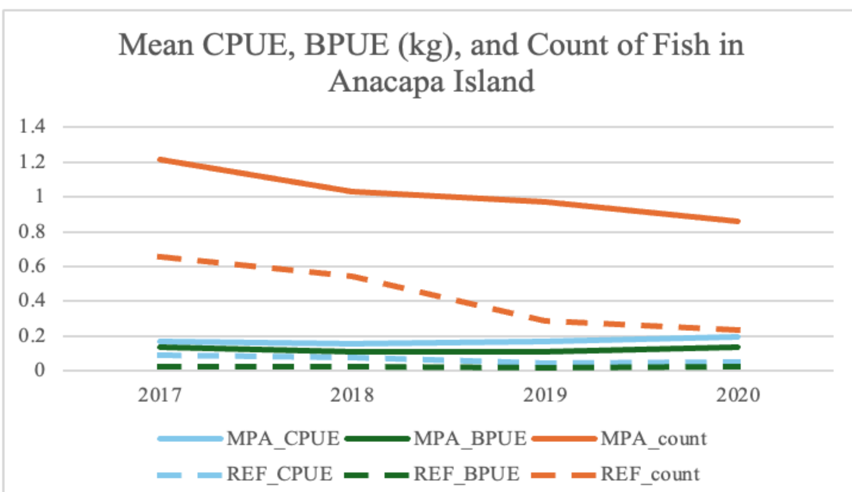

Figure 5.1 Mean CPUE, BPUE, and Count of Fish in Anacapa Island (Data Source: DataONE)

Figure 5.1 represents the mean CPUE, BPUE, and count of fish in Anacapa Island for the years 2017-2020. While I do not present graphs for all locations I analyzed, I felt Anacapa was an adequate representation of the patterns observed within my data, such as gaps between MPAs and reference points. In this figure, we can see that Anacapa Island's MPA had a greater CPUE, BPUE, and count for each year than did Anacapa Island's reference point. However, while the average CPUE and BPUE of fish in Anacapa's MPA slightly went up over time, the average count of fish decreased quite substantially from 2017. In addition, the gaps between the reference point and MPA are relatively small, with the exception of the count of fish, which remained significant from 2017 to 2020.

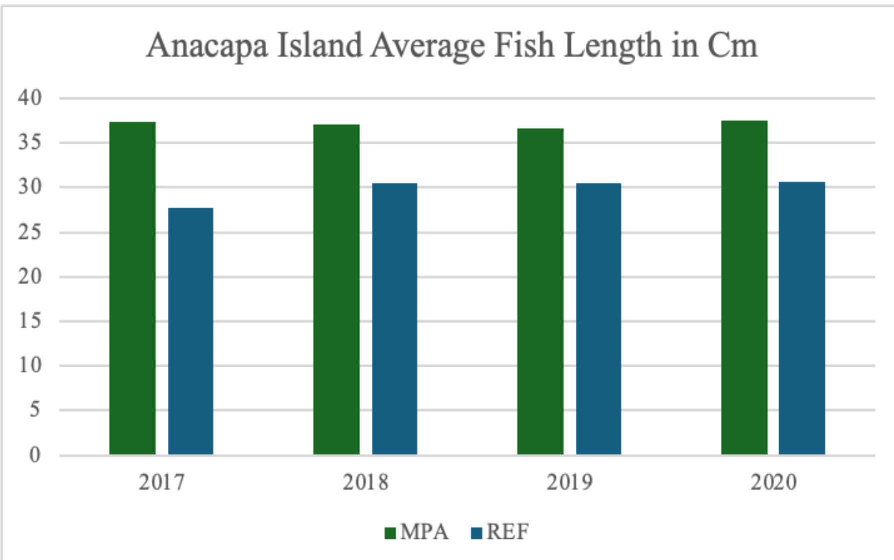

Figure 5.2 Average Fish Length in Cm in Anacapa (Data Source: DataONE)

Figure 5.2. compares the average length of sampled fish in Anacapa Island for the years 2017-2020. Like in Figure 5.1., fish in Ancapa's MPA were longer than those in its reference point. However, the average length of fish in Anacapa's MPA remained fairly stagnant from 2017-2020 while that of the reference point fluctuated slightly and even rose from 2017. In Anacapa, MPA status did not increase the length of fish for the years examined.

SUMMARY OUTPUT 2017-2020				
Statistics	CPUE	BPUE	Count	Length
Multiple R	0.29732942	0.488828614	0.25225737	0.36347991
R Square	0.08840478	0.238953414	0.06363378	0.13211765
Adjusted R Square	0.07728777	0.229672358	0.05221468	0.12153371
Standard Error	0.08598639	0.047511335	0.6748588	4.43690378
P-value	0.00602077	2.38367E-06	0.02061804	0.00067766
Point-biserial	0.3014854	0.49025882	0.28089603	0.34616473

Table 6.1 Summary Statistics for CPUE, BPUE, Count, and Length of All MPAs

The table above demonstrates the strength of the relationship between MPAs and the dependent variables for my first hypothesis. For these results, I grouped all MPAs for 2017-2020 together and analyzed the CPUE, BPUE, count, and length regression statistics individually. Across the board, the R square value is extremely small while the P-value is statistically significant, indicating that there is a relationship between MPAs and the health and abundance of fish, but that other factors must be influencing the strength and existence of this relationship in the first place. This is corroborated by small but positive point-biserial values. According to these values, the strongest relationship exists between MPA establishment and BPUE (weight), followed by length, then CPUE, and finally count.

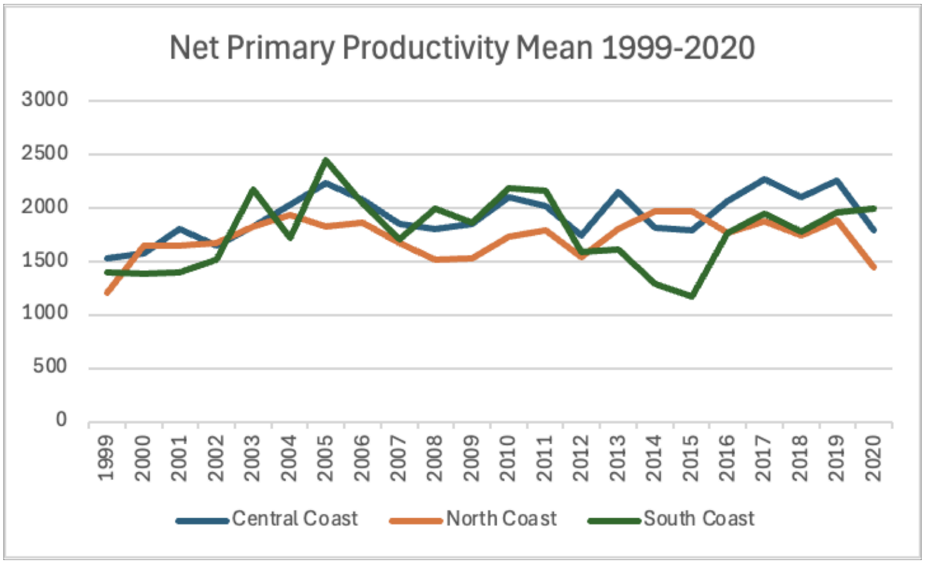

Figure 5.3 Mean NPP in North, Central, and South Bioregions 1999-2020 (Data Source: CALOOS)

Figure 5.3 tests the strength of my second hypothesis. From 1999 to 2020, the mean NPP of the North, Central, and South bioregions have fluctuated greatly but have ultimately slightly risen since 1999. According to this figure, the South Coast currently has the highest NPP, meaning it has the most productive waters out of the three bioregions and the most available organic matter for marine life. The South Coast is followed by the Central Coast and finally the North Coast. The overall NPP has not risen much since 1999 and even dropped dramatically in some years (e.g., South Coast 2015), indicating that if MPAs do influence NPP, significant results may take a long time to develop. Due to the nature of the fluctuations, there are certainly other factors influencing NPP levels that MPAs alone cannot fully account for.

6. Discussion and Research Implications

The purpose of this paper was to evaluate the extent to which MPAs along the California coast benefit marine life over time and compared to non-MPA reference points. While both my hypotheses were correct in the sense that MPAs tended to have more and healthier fish than reference points and NPP did go up slightly since 1999, the results were much more subtle and nuanced than I anticipated.

For starters, while the CPUE, BPUE, count, and length of fish in MPAs were greater than those of reference points for the most part, this was not true across the board. In some cases, non-MPA reference points had fish that were either more abundant, weighed more, or were longer than their MPA counterparts. While these were in large part aberrations, even for the MPAs that performed better, the gaps between them and reference points were often small and sometimes insignificant. The existence of a gap is important: it suggests that MPAs are in one way or another better at supporting marine life than reference points. However, because the gaps are often small, it calls into question whether there are factors that are influencing the effectiveness of MPAs or whether there is something inherent about MPAs that are limiting progress.

Secondly, the slight rise in NPP for the North, Central, and South bioregions indicates that while NPP is marginally doing better since 1999, the change is so slight, that it can be difficult to attribute it to MPA designation. However, many researchers have pointed out that MPAs tend to exhibit better results over a longer time-frame. The slight shift in NPP can be imputed to MPAs, but also suggests that MPAs take a long time before results become significant.

A small R square but statistically significant P-value for CPUE, BPUE, count, and length suggests that there is a weak but existing relationship between MPAs and the dependent variables measured. This is further corroborated by small but positive point-biserial values. While MPAs are linked to healthier and more abundant fish species, other factors may be influencing this relationship. What these factors are can be difficult to extrapolate, but many researchers, as noted in the literature review, have suggested that a warming climate impedes MPAs' ability to function optimally. In this case, MPAs are not so much inherently flawed, but rather struggling to offset the negative consequences of a changing climate and anthropogenic stressors. This would explain why the gap between MPAs and reference points exists, but why it is limited for some locations and why there are even some declines in fish abundance, weight, and length over time in MPAs.

A different explanation for the limited effectiveness of observed MPAs may be owed to time. As researchers have noted, MPAs tend to be more effective, in the sense that they produce healthier, longer, more abundant fish, the longer they have been instituted. The MPA network was completed in 2012, less than 13 years ago. Of the MPAs that have been around for longer, regulations were lax and confusing prior to the MLPA of 1999. The slight increases overall observed in CPUE, BPUE, count, length, and NPP suggest that MPAs are having an effect on the ocean, but these successes will take some time to materialize. Given these findings, it is necessary to continue monitoring MPAs over time, with an eye towards reducing costs and controlling for confounding variables, such as rising temperatures, whenever possible. The nature of these findings can direct whether or not MPAs should be expanded, strengthened, or both.

7. Research Limitations and Research Extensions

This paper looked at 11 MPAs, 11 reference points, and three bioregions in order to assess the overall strength of the MPA network. While the MPAs I chose provide a glimpse into the overall look and function of the network, they comprise only a small fraction of the total 124

MPAs. As such, the results I obtained for these areas may be vastly different for other MPAs and reference points. In addition, for my first hypothesis, I looked at the MPAs and reference points on a limited time scale: from 2017-2020. These years do not provide information about what the gaps between MPAs and their associated reference points looked like from the beginning and how they have changed over time.

Although I examined all the species that I had data on for my first hypothesis, these species are not necessarily representative of all the marine life within an MPA or reference point, nor do they encapsulate all the species in a certain site. As regeneration takes different times for different species, by grouping together all the species sampled for each MPA and reference point, my research did not examine the nuances of recovery on a species level. For future research, it may be useful to compartmentalize and examine different fish species on an individual level for both MPA and non-MPA sites.

Finally, while I controlled for time and the compatibility between MPAs and non-MPAs, the fluctuations in data as well as some declines among measurements in MPAs suggest the existence of other confounding variables. In the future, scientists and researchers should note what factors most prominently influence MPAs and control for them in analyses involving non-MPA reference points. Rising temperatures, for instance, might be a valuable variable to control for.

In addition to these limitations and suggestions, it might be useful to compare the successes of California's MPAs to those of other coastal states and even coastal countries. Potential differences in performance can guide California to new policy objectives when it comes to marine life protection as well as measures that can improve the effectiveness of its own MPAs.

To be impactful, MPAs must be constantly monitored, assessed, and improved upon as global temperatures continue to rise and more threats to wildlife emerge. These efforts can be pricey and time-consuming, but they are crucial to maintaining and improving an already expensive network.

7. Conclusion

California's MPAs have long been a beacon of hope to scientists and researchers who hope that they present a viable solution to restoring the ocean's health and that of marine life. The MLPA of 1999 and the completed MPA network of 2012 were an accumulation of various varying efforts to protect the ocean and limit anthropogenic stressors that compromise marine life and ocean habitats. The positive, albeit tenuous, relationship between MPAs and healthier, more abundant fish found in this paper suggests that MPAs may indeed be on track to fulfill the objectives of the MLPA and the wishes of its stakeholders. In addition, a slight rise in NPP since 1999 across the North, Central, and South bioregions can be interpreted as a positive sign for the productivity of these protected areas. While the relationship between MPAs and dependent variables was not as strong as I anticipated, that is not to say that MPAs are necessarily only marginally effective. The network has only been recently completed and significant progress can take time. Meanwhile, these results suggest that monitoring and strengthening efforts of MPAs by relevant organizations such as the CDFW are important to understand MPAs and increase the likelihood of their success. As time goes on, we can evaluate how MPAs impact the ocean and climate over the long-run and what that can mean for future policy and implementation.

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