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Prof. Pellaton
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Primary Concerns: Investigating the Productivity of Marine Protected Areas

California's Marine Protected Area (MPA) network is made up of 149 individual MPAs within four bioregions. While the goal of these protections is to preserve and conserve the state's marine health and biodiversity, the variations in restrictions and protection levels begs the question: do these differences impact how effective the MPAs are? Specifically, do MPAs with stronger restrictions have a more productive marine ecosystem, as identified by the net primary productivity, compared to MPAs that are more lenient in their restrictions and protections? To answer this question, I compare the net primary productivity of California's four coastal bioregions from 2015 to 2020 and analyze the distribution of different MPA restriction levels and types within each of the bioregions.

Context and Significance

Marine protected areas were established because of the threats facing the ocean and its inhabitants. The network of MPAs in use now was created on paper in 1999 by the California Department of Fish and Wildlife (CDFW) as a result of the Marine Life Protection Act (MLPA). Due to the expanse of range the network was aiming to include in its protections, it was not until 13 years later in 2012 that the MPAs were officially finalized and implemented [13]. While some have different goals and purposes, the "main focus of many MPAs is to protect marine habitats and the variety of life that they support" [1]. This means that the priority for most MPAs is the protection and the continued maintenance of the habitat to ensure success for the now and the

future. One way to measure a marine ecosystem's health and success is by measuring the net primary productivity of the area. Net primary productivity (NPP) is "the uptake of inorganic carbon through photosynthesis, support[ing] marine life and affect[ing] carbon exchange with the atmosphere" [2]. The reason NPP is informative of the health of an ecosystem is because it explains how the primary producers are doing in that ecosystem and because every trophic level of an ecosystem's food web is built off the primary producers, their success is crucial to health and success of the rest of the ecosystem. California's status as a coastal state means that the threats facing the ocean are threats facing the state. This is why it is important that actions such as the implementation of MPAs are undertaken, but more than that, they must be maintained. In 2023, in an effort to maintain the efficiency of the network, the California Department of Fish and Wildlife released the Decadal Management Review of the MPA network, where the ultimate conclusion was that while the MPAs are working and do matter, more could be done to increase the safety and conservation of the state's oceans and marine life [3].

More specifically, it is important to understand how the MPA type and protection level affect a bioregion's NPP because of the impacts it has on the state's economy. Due to California's 800+ miles of coast, coastal counties generate more than 80% of the state's GDP [4], and the ocean economy including recreational and commercial fishing, as well as tourism and even aquaculture [5], are all dependent on the continuing health and success of the ocean and marine life.

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Literature Review

My literature review will be organized by the concept of the external literature I have found to be relevant and useful to my research project. First I will discuss the research that exists around marine protected areas and their relative efficacy and what affects these designations of "efficiency." In the article "Debating the effectiveness of marine protected areas" [8] authors asked various questions about how to determine if an MPA is effective and what it means for an MPA to be effective. The ultimate results were slightly vague and intentionally left open ended. This is because they describe how the various purposes and goals of different MPAs makes it difficult to determine if they are truly effective [1]. The authors explain how, depending on which variables one is looking at, a single MPA could be found efficient by some and inefficient by others. The article concludes by emphasizing the need for a continuing discourse on the topic and a reminder that efficiency is relatively subjective and can vary and change.

Alternatively, a journal article titled "Collaborative fisheries research reveals reserve size and age determine efficacy across a network of marine protected areas" published to Conservation Letters [9] was a study done with a specific variable in mind used to determine how efficient the MPAs were in California. As the title suggests, the authors ultimately concluded that the size and age of an MPA influences how effective, by the authors' terms, it would be. This study focused on fish catch size (biomass) and rate to determine how successful

[1] There are many "multiple use" types of MPAs, which makes it difficult to interpret if loss of biodiversity or biomass is a result of the allowed fishing (or other activities) or a result of ineffective protective measures. There are also MPAs that are classified as "not strongly protected", meaning that they will inherently be seemingly less effective than the most protected types of MPA.

and therefore efficient the MPAs were. This research does a good job of identifying where the MPAs are strong and how they protect certain fish and wildlife, but they study along the coast as a whole, as opposed to my research where I am looking at the four different bioregions along the coast to see if there are variations and differences. Ultimately the researchers found that most of the larger and older MPAs were more effective at protecting the fish and wildlife within the boundaries..

To explain more about why the food web and trophic levels matter when attempting to determine health and success of an ecosystem or environment, the study by House and Allen [12] focuses again on the various fish species in and around the MPAs in Southern California. They aimed to discover what effect MPAs had on trophic levels within and beyond the MPA boundary. They found that predators and prey alike were affected by the restrictions put in place against fishing and removal of wildlife from the MPA in a way that influenced the trophic level system in a top-down way. This research is important to my study because I am studying the health of primary producers and seeking to determine if the MPAs are having enough of a top-down influence that primary productivity becomes significantly affected. While House and Allen looked at the top-down impacts on health and biodiversity, I am now looking at the bottom-up impacts, especially on biodiversity.

One study that explains why biodiversity, especially in lower trophic levels, is crucial to ecosystem health is “The functional role of producer diversity in ecosystems” in the American Journal of Botany [11]. This paper immediately explains that “[producer] biodiversity does

indeed regulate several processes that are essential to the functioning of ecosystems..." suggesting that a more diverse producer trophic level is key to a healthier and more successful ecosystem. Because of the producer's role at the bottom of the trophic pyramid, when it increases, so too can all the upper levels of the pyramid. This paper specifically is focused on terrestrial ecosystems and terrestrial producers, so my use of these ideas in my research is novel because I am applying these concepts to the ocean environments and looking at how the protection and preservation of species in higher trophic levels impacts the diversity and health of the primary producers and their ability to produce.

Finally, the research article published on Frontiers in Marine Science, "Vulnerability to climate change of managed stocks in the California Current large marine ecosystem" [10] explains how certain marine species in California are faring with regards to climate change, specifically sea level rise. The biggest takeaway from this research is that "two-thirds of the species evaluated had moderate or greater vulnerability to climate change" as defined throughout the paper. This is a huge deal and is cause for concern when considering the preservation and conservation of marine wildlife. This becomes relevant to my research project because, while it does not address MPAs or NPP explicitly, it calls attention to the damage that climate change can cause and the threats that it poses to the marine ecosystem.

It is clear from this compilation of previous research and studies that there is not a complete and coherent consensus on whether marine protected areas are efficient and effective, or how to tell whether they are or not. I believe this issue is a result of the many variables that are

at play in a policy such as the MPAs; the level of protection it has, the various activities allowed under that type of protection, the ecosystem composition (both human and animal), the demand of outside industries such as fishing and recreation, and ultimately climate change and those effects on the global environment as a whole. It is also worth noting that politics play a role in this issue as well, with different groups wanting different things and having scientific research that backs up both sides it becomes hard to tell what is real and even harder to determine what to do with all the information. Because of this lack of agreement around the performance of marine protected areas, research like mine is even more important than if all the players were on the same page. With my study I hope to find at least one link between effectiveness (as NPP) and MPA designation and protection level. Depending on the results of this research, those who come after me asking similar questions can potentially have a groundwork from which to start.

There are some gaps in the pre existing literature that I am to at least partially fill in. For one, instead of looking at fish biomass and catch rate (Ziegler, et al) to measure the efficiency and effectiveness of the MPAs, I am choosing to use net primary productivity which is a more commonly used measure of general whole ecosystem effectiveness and efficiency. This is because the NPP measures the rate at which the primary producers are photosynthesizing which is essentially telling us if the primary producers are healthy and functioning efficiently. As mentioned before, when the primary producers are functioning successfully, because they are the base of every food web, the rest of the ecosystem will have a higher chance at functioning successfully and being healthy. Similarly, Pendelton, et. al. explains that when looking at a single

specific variable a researcher may be able to determine and rank effectiveness of MPAs, as opposed to what they did in their study which was to look at the MPA as a whole. I plan to do as they suggest and focus on the singular NPP variable. Depending on the results of my study, I will either contribute to the debate and conversation around determining effectiveness (if we can, how, etc.) of MPAs, or I will provide future researchers with at least one example of a method in which effectiveness was found and ranked by looking at one singular variable.

Theory, Hypotheses, and Mechanisms

My conceptual hypothesis is that areas with more strictly regulated MPAs will see higher NPP. I hypothesize that higher numbers of MPAs designated State Marine Reserve (SMR) and State Marine Conservation Area (SMCA) within a bioregion will lead to a higher NPP in that bioregion. Because the regulations placed on the MPA are meant to protect and conserve habitat and wildlife, the stricter they are, the fewer disturbances the ecosystem will be faced with, allowing the environment to become healthier, thus leading to higher productivity. State marine reserves are the most restrictive and protective of types of MPA with a definition describing that "no take, damage, injury, or possession of any living, geologic, or cultural marine resource is allowed" [13]. This means that there is no fishing (recreational or commercial) allowed, no harm (death, injury, introduction of germs or diseases, etc.) to any animals or wildlife is allowed, no removal of shells or rocks or sand or other "geologic resources" is allowed at all. State marine conservation areas are the second most restrictive, but offer some leniencies that SMRs do not.

The broader definition of an SMCA is "some recreational and/or commercial take of marine resources may be allowed (restrictions vary)" and the slightly more explanatory definition is "no take of any living, geologic, or cultural resource is allowed, EXCEPT for take incidental to specified activities permitted by other agencies". This designation allows for certain *permitted* individuals to remove (via fishing, netting, etc.) resources within the terms of their permit. One thing to note about this is that permits vary depending on who is issuing them, who they are being issued to, and under what circumstances. Regardless, these two designations are significantly more protective than the remaining three [2], and it is because of these differences that I hypothesized that bioregions containing higher numbers of SMR and SMCA designations will see a higher annual mean NPP. My theory is that the more protected the area is, the better it will do in terms of primary producer health and subsequently annual mean net primary productivity.

Research Design

The independent variable in my study is the MPA type within the bioregion, also referred to as level of protection. This is a categorical variable with five options for what it could be. These levels and types are defined and designated by the California Department of Fish and Wildlife [6]. As mentioned above, in order from most to least restrictive and protected they are: State Marine Reserve (SMR), State Marine Conservation Area (SMCA), State Marine Park

[2] The remaining order from most the least protective is: State Marine Park (SMP) which allows some recreational take but does not allow commercial take, State Marine Recreational Management Plan (SMRMA) where some take of marine resources may be allowed and legal waterfowl hunting is allowed (restrictions vary), and Special Closure (SC) which prohibits or restricts access in waters adjacent to seabird rookeries or marine mammal haul-out sites.

(SMP), State Marine Recreational Management Area (SMRMA), and Special Closure (SC). All MPAs are predesignated, and each level has its own set of restrictions and what activities are or are not allowed within their boundaries. As described, the main difference in restrictions comes from allowed fishing; as the protections become less severe, more fishing becomes allowed. Take of geologic resources such as rocks, sand, and shells is another factor in protection levels. I chose to use this as my independent variable because of the clear categorization and emphasis on different levels of restrictions. I gathered the data for each of the 149 MPAs in California from the National Oceanic and Atmospheric Administration (NOAA) MPA Inventory.

My dependent variable in this project is the annual net primary productivity mean of each of the four bioregions from 2015 until 2020. The NPP data comes from a partnership between the Central and Northern California Ocean Observing System (CeNCOOS) and the Southern California Ocean Observing System (SCOOS) where they have compiled data on numerous ecosystem health measurements, one of which being the NPP [7]. As stated before, NPP is a good measure of ecosystem health because of the implications of primary producers on the rest of the food web and surrounding environment, this is why I chose to use NPP as my dependent variable. I also chose to look at annual mean as opposed to monthly mean or annual maximum because it is the most telling without too many data points for the duration of the time that I chose to study.

The control variables of this project are the number of MPAs within a bioregion, temporary MPAs and closures, and environmental factors. The bioregions are divided by range,

not by dividing the MPAs equally across the coast. Because of this, the north coast bioregion has 67 total MPAs, where the other three bioregions, central coast, south coast, and the channel islands, have 29, 27, and 26, respectively. This difference in the number of protected areas will have an impact on the NPP because in the north coast it will be taking into account significantly more area than the other regions. The other thing to consider a variable needing to be controlled for is temporary MPAs that had been a part of the bioregion during the 2015-2020 years and thus contributed to the annual mean NPP data, but were not included in the most recent data of California's MPA network, because it was only temporary [3]. This would influence the significance of the contribution of the included MPAs..

My project looks at the four bioregions of California's coast as the unit of analysis and looks at the annual mean NPP of each of these four bioregions over the course of five years (2015-2020). I chose this period of time to study because 2020 is as recent as the data went, and since the MPAs have only been in practice for the last ten years, I believe five years to be enough time for the areas to become accustomed to their regulations and restrictions that were implemented the ten years prior. So I will be studying the four bioregions along the California coast (149 individual MPAs) and their annual mean net primary productivity for the most recent five years the data has available.

[3] A temporary MPA can be implemented in the short term to address an urgent conservation or management matter (e.g. rapidly decreasing populations). Key thing here: no expectation of renewal after the defined time specification.

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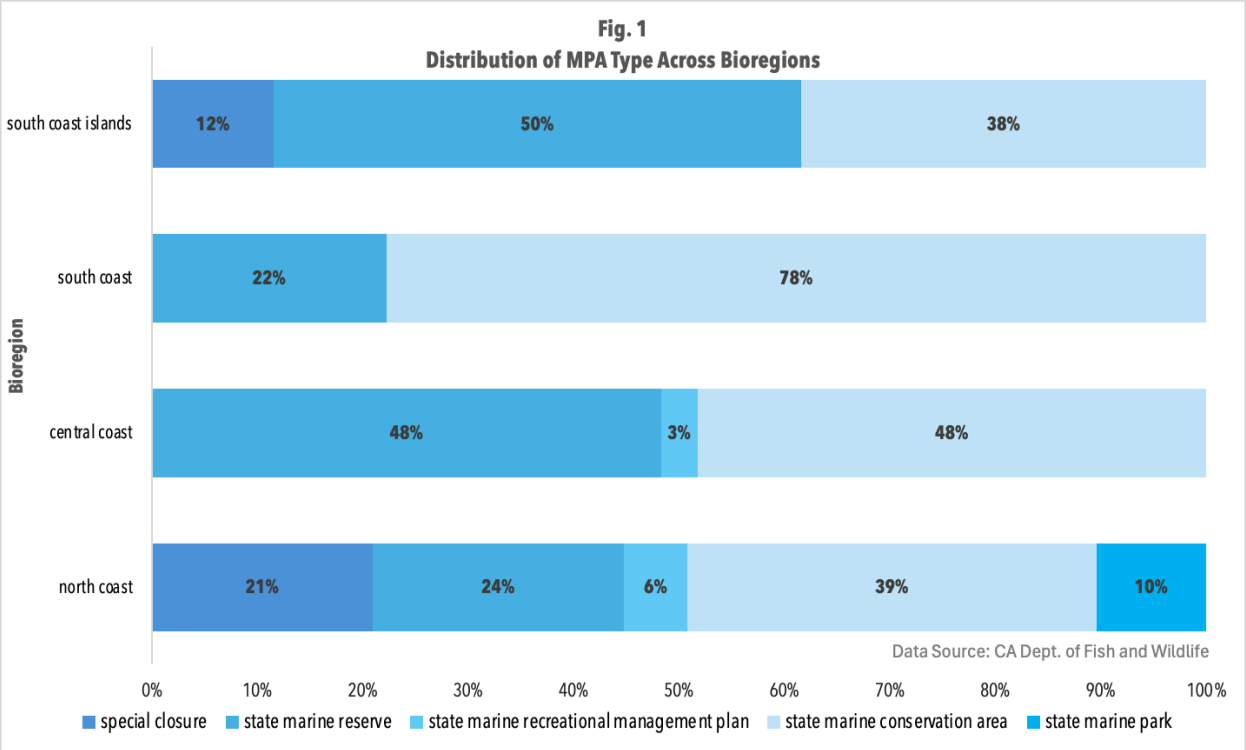
Research Methods

After collecting the annual mean NPP for each of the four bioregions for each of the six year points from the CeNOOS and SCOOS [7], I plotted them in a graph (figure 1). Once the data was graphed, I could visually see a clear difference between the annual mean NPPs for each bioregion, but to determine if this difference was statistically significant I ran an ANOVA (analysis of variance) test on the data. What I found after running the test was that the p-value was less than 0.05, meaning that the difference in bioregion annual mean NPP is, in fact, statistically significant. The significance of this test is that it demonstrates that the differences in annual mean NPP of each bioregion is important and has a driving force behind it.

Results

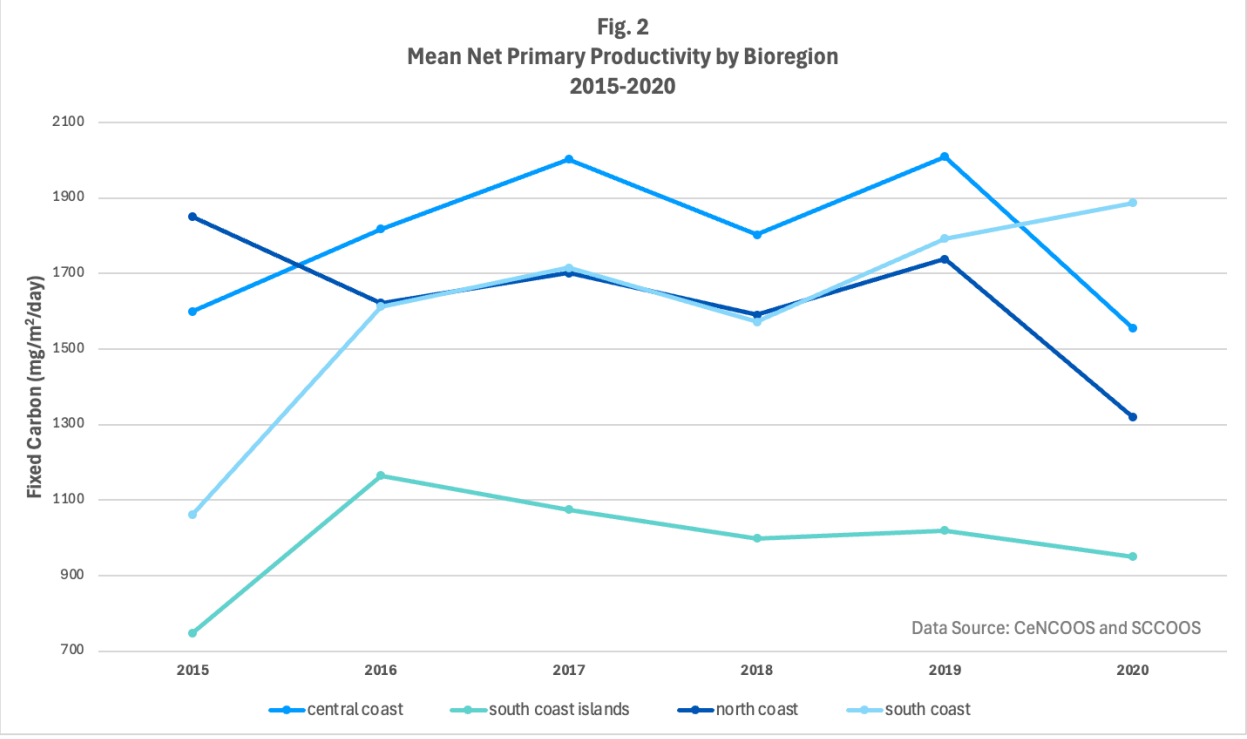
My study found that the annual mean NPP differences are statistically significant between the four bioregions, and these findings support my hypothesis that the more strictly protected bioregions will have higher net primary productivity. As shown in figure 1, the north coast bioregion has the widest spread of MPA type designation; there is at least one MPA in the bioregion that is classified in all of the five categories. Meanwhile the south coast bioregion is made up entirely of SMR and SMCA designated MPAs, meaning that 100% of the south coast bioregion is under the strictest regulations possible as an MPA. The central coast is made almost entirely of SMRs and SMCAs, except for 3% of the total MPAs which are in the SMRMA classification which, again, is the third most restrictive. Meaning that even though this bioregion

has a wider variety than the south coast, it is still strongly protective. Finally, the south coast islands bioregion is half composed of SMRs, the other half being a mix of SMCA and SC. Different from the central coast, while 50% of this region is protected under the most strict regulations, the 12% of special closure regulations make it less protected than the central and south coast bioregions.



When looking at the data laid out in this way, I imagined the south coast would have the highest annual mean NPP because it is more protected than the other bioregions. However, figure 2 reveals that the south coast bioregion only has the highest annual NPP most recently, in 2020. From 2016 to 2019, which spans nearly the entire period studied, the central coast bioregion

shows the highest annual mean NPP. The north coast bioregion produced the highest NPP only in 2015. Considering that the central coast bioregion is made up of the top three most restrictive MPA designations, and has more than double the amount of SMR (top most restrictive) designations than the south coast, it makes sense, following my hypothesis that these more protected areas will be more productive. However, one thing worth noting is that the south coast islands bioregion, 50% of which is under the SMR restrictions consistently, throughout the entire study period, has the lowest annual mean NPP. This piece of data, along with the fact that the north and south coast bioregions are eerily similar in their NPP throughout the years contributes to the lack of strength that my findings have because how can two opposite things be true at the same time.



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Discussion and Implications

I began my research wanting to determine if the different levels of protections that MPAs have, which dictate the different activities allowed, or not allowed, within the MPA boundaries have an effect on how productive that ecosystem is and subsequently, how effective those MPAs are. I used the annual mean net primary productivity of each of the four bioregions on California's coast to qualify that "effectiveness" because it is essentially a measure of the health of the primary producers in the ecosystem and when the primary producers are functioning efficiently and effectively, the rest of the ecosystem will have higher chances of health and success. Ultimately, the findings of my research are inconclusive and not strong enough to make a determinate conclusion. While on one hand, the central coast bioregion which is very strongly protected by the top three most restrictive MPA designations does indeed have the generally highest annual mean NPP, the south coast islands bioregion which is a full 50% protected under SMR, has the lowest annual mean NPP every year of the study. These two contradicting facts make it difficult to extract a confident answer as to whether the protectiveness and strictness of the MPA restrictions actually has an effect on the productivity in the relevant bioregion. Due to this inconclusive result, I would recommend to future researchers utilizing a different variable when attempting to determine effectiveness of MPAs. I would also suggest considering multiple variables, because, as I mentioned before, there are many parts of an MPA and in a bioregion in general that it is hard to look at just one and consider that to be telling of the whole system. I would urge future researchers to look into the make up and composition of the bioregions, for

example: types of animals and wildlife present, what percent of the region is a primary producer, what state (in terms of health) was the region in before the study period or even before it was designated an MPA and how does it compare to now.

Given what I learned and found through this study, I would recommend (and I will recommend at the CDFW Fish and Game Commission meeting on Wednesday) to continue to expand and increase protections and restrictions to the MPA network. In an effort to achieve the main goals set out by the CDFW in the MLPA back in 1999, these actions would maintain the protection and conservation of the wildlife and biodiversity in the marine environment.

Limitations and Extensions

As I have mentioned a few times before, the presence of multiple variables included in the nature of an MPA and of a bioregion and primary producer ecosystem suggests that there must be multiple variables in a study about these things. I do believe my lack of additional variables contributed to the lack of strength behind my conclusion to the study. I also believe that there were so many control variables that could have an effect on the project, that including some but not all of them results in the study being inconclusive or incomplete. Especially a project that deals in the natural environment where a variable such as climate change is relevant, it is necessary to take that into consideration and include it as part of the study. I did not have that, and as a result, my findings are not what they could have been. One other piece of the project I could have done differently is the time period of study. After looking at the results and being left

wanting more I think that adding another five-year time period, perhaps from the beginning of when the MPAs were enacted, so as to compare it to the current data, could be telling in terms of how the MPA and its protections have helped the ecosystem over time, as opposed to just the most recent five years. It would also be interesting to see how certain historical events impacted the health and productivity of the ocean ecosystems.

Conclusion

The biggest takeaway from this study is the realization that the network of marine protected areas along California's coast is incredibly complex and challenging to evaluate. These MPAs are shaped by a variety of factors, including ecological variability, shifting species distributions, and human activity. It is clear to me why the previous literature and research on this topic has often yielded inconclusive or conflicting results. Assessing the effectiveness of such a vast policy is not a small or easy task, especially when it involves moving parts such as wildlife, evolving boundaries, and the unpredictable, inevitable impacts of climate change. This project has underscored the difficulties in quantifying success when it comes to conservation efforts of this scale. The constantly changing conditions within MPAs, combined with the challenges of monitoring them over time, make it difficult to draw definitive conclusions. Especially with the overwhelming lack of a definitive measure of "effectiveness". My findings highlight the critical need for ongoing research in this area, particularly as climate change intensifies and accelerates changes in marine environments. There is a pressing need for new,

science based approaches to evaluating MPAs, ones that account for ecological, social, and environmental dimensions. These are just a few of the reasons why it is so important to have educated people in positions of responsibility so as to make the most informed decisions possible. While I may not have arrived at the exact answers I was hoping for or expecting, this project has demonstrated to me that not finding a definitive answer is still incredibly valuable. It is just as informative to understand what the answer is not, as it helps refine future studies and directs researchers towards more focused areas of study. My research, even if it doesn't provide all the answers (or any distinct answer), can hopefully serve as a foundation for future work, offering insights that may help bridge gaps in knowledge about MPAs.

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