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Co-Management as a Successful Strategy for Marine Conservation

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Abstract: Marine Protected Areas (MPAs) are a primary tool for conserving marine biodiversity. The literature presents a scattered picture regarding the extent to which co-management can be considered valuable. In this study we examine, what conditions are for co-management to make a contribution to conserving marine ecosystems (e.g., stopping coral bleaching and safeguarding fish populations). By combining data on MPA management practices with a novel source of global biodata collected by citizens (ReefCheck), we demonstrate that if co-management is part of a formal governmental strategy, coral reefs show up to 86% fewer bleached colonies and up to 12.2 times larger fish populations than co-managed MPAs lacking formalized governmental support.

Keywords: Marine Protected Areas; co-management; coral bleaching; fish population; citizen science

1. Introduction

Marine Protected Areas (MPAs) are one of the primary tools for conserving marine biodiversity [1]. MPA refers to "a clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values" [2]. The International Union for Conservation of Nature (IUCN) defines MPAs as delineated zones that involve "the protective management of natural areas so as to keep them in their natural state" [3]. According to the World Database on Protected Areas of IUCN, to date, 14,880 MPAs cover 7.4% of the entire ocean [4]. The effectiveness of MPAs is currently debated among scholars [5]. Evaluative studies show diverging results when it comes to the effectiveness of MPAs as a conservation tool, showing both promising as well as disappointing results in terms of conserving marine biodiversity or sustainably using marine resources [6–10].

1.1. Co-Management as Conservation Strategy

There is a growing body of literature exploring how stakeholders such as local communities or indigenous people can be involved in the management of MPAs, and how their involvement generates improved biodiversity outcomes [6,11–13]. As Christie [14] has argued, if these stakeholders are not part of the solution to enhance MPA-effectiveness, they may either strongly resist the imposition of the MPA or initially support the MPA but then lose interest. Subsequently, even more top-down efforts from government may be required to get the MPA management back on track, leading to further alienation of these stakeholders. Therefore, in order to generate biological success, MPAs need to create economic and social value [14] (p. 156), while in turn, social impacts and ecological effectiveness are also important for supporting MPA management [15]. Consideration of potential conflict among social subgroups that may jeopardize both social and biological goals therefore remains a key factor in designing effective MPA management strategies [16]. Scholars focusing on involvement of local communities in MPA-management have shown how these collaborations lead to a sense of trust among stakeholders, ownership among participants, socio-economic returns, and possibly improvements in wellbeing and ecosystem health trends [11,17]. In social sciences, such collaborative structures have been studied using concepts like collaborative governance [18], co-production [19], and co-creation [20]. Authors assessing these concepts have revealed underlying mechanisms for effective collaboration between government and other stakeholders, arguing that elements such as having a shared understanding of the mission, trust in each other's capabilities, and intermediate outcomes to maintain motivation and willingness (see also Supplementary Materials). As a result, if protected area management involves local communities it becomes co-management [21]. Co-management refers to "some kind of power-sharing arrangement between the State and a community of resource users" [22] (p. 65). That is "an arrangement where responsibility for resource management is shared between the government and user groups" [23] (p. 406). It is a relatively new concept, applying theories from management and political sciences to the natural domain [24]. As Blythe et al. [25] argue: "people who depend on marine resources are often the best informed about local resource contexts, the most committed to sustainable harvesting, and will thus develop more effective and appropriate management practices to address local objectives" (p. 50).

However, in the context of MPA management, the extent to which co-management leads to enhanced marine biodiversity or effectively addresses threats to marine life is up for debate. In their comprehensive study, Gill et al. [26] showed how forms of inclusive management, such as inclusive decision making, do not yield positive ecological impacts. They argue that in order to reach ecological effectiveness, management capacity needs to be increased (see also [27]). Hitherto, these studies have only considered the overall effect of co-management, and have failed to examine more specifically the different conditions required for successful co-management. This research specifically focuses on one of these conditions. As Emerson et al. [28] argue, for collaborative governance processes to lead to collaborative success (e.g., enforcing policy or management, implementation of policy, compliance to policy guidelines, maintenance) some procedural and institutional arrangements need to encompass interactions among stakeholders. These may refer to charters, by-laws, rules, and regulations. As they put it, "long-lived collaborative networks require more explicit structures and protocols for the administration and management of work" (p. 15). Whether such structures and protocols can also be considered conditional for management success in MPAs is the topic of this study.

1.2. Research Objectives

Our goal is to determine whether institutionalization of co-management can be considered a condition for marine conservation, i.e., protecting and preserving marine ecosystems. In order to accomplish this research goal, we employ a novel dataset that is based on the IUCN World Database on Protected Areas (https://www.iucn.org/theme/protected-areas/our-work/world-database-protected-areas) as well as data gathered by citizens for ReefCheck (http://data.reefcheck.us/). We analyze this cross-sectional data using the appropriate Bayesian mixed-effects models.

The remainder of this paper is structured as follows: In the next section we present our research methods and research approach, used to answer our research question. In Section 3 we present the results of our analyses. In Section 4 we elaborate on the implications of these results for our understanding of co-management as part of MPA-management. In Section 5 we discuss some limitations of our study and present a future research agenda. The last Section 6 is the conclusion of this research.

2. Methods

In order to measure marine conservation we focused on three outcome variables: coral bleaching, observed numbers of snappers and observed numbers of groupers. This resulted in three separate analyses of 61 (bleaching), 61 (snappers) and 68 (groupers) MPAs. To identify conditions for effective collaboration we drew on theories of collaborative governance in combination with theories on conservation and Commons management (see Supplementary Materials). We examined (1) whether co-management (MPA management as a collaboration between government and resource users) is an effective form for marine conservation in MPAs; (2) whether co-management is more or less effective under the condition of being part of a formalized governmental strategy; (3) whether co-management is more effective in *'No-Take'* MPAs (MPAs where access is heavily restricted or prohibited) than in '*Partially-Protected'* MPAs; (4) whether co-management in MPAs becomes more successful over time (see also Methods).

As mentioned above, co-management refers to a situation in which some form of decision-making power is shared with resource users (such as local communities or indigenous people) in MPA management. A formalized governmental strategy implies that the relevant government body has produced a Management Plan that details goals and means, thereby forming a proxy for better governance quality [21]. Examples of these management plans are available within the IUCN database [12]. The type of MPA refers to whether the MPA is considered a *'No-Take'* MPA, as opposed to a '*Partially-Protected'* MPA [29]. There are significant differences among partially protected areas as well [30], but for the sake of this paper we focus on the difference between *No-Take* and those MPAs that are not *No-Take.* Duration of the collaboration is captured by the *age* of the MPA. As Pope and Lewis [31] have argued, effective partnerships do not come out of the blue, but are built on existing and long-lasting social structures (see Supplementary Materials). Therefore, we may expect that the longer the collaboration is in place, the better its conservation success.

We relied on Bayesian mixed-effects mixture models to model the effects of management practices on biodiversity outcomes. The Bayesian specification of these models and their estimation and validation using Markov Chain Monte Carlo (MCMC) simulation is appropriate when fitting complex models to data with relatively few observations [32]. The proportion of bleached coral colonies per MPA was modeled using a beta regression, whereas fish counts were modeled using negative binomial regressions. All models include a zero-inflation correction and a random intercept to account for geographical non-independence. The estimates presented below are centered and standardized (see Supplementary Materials for details).

2.1. Data Reporting

The sample sizes were not based on power analysis but on the spatial matching of all available ecological data in the ReefCheck database with MPA geospatial and attribute data in the WDPA database (Supplementary Materials). The sample meets the requirements for the selected Bayesian modeling approaches employed.

2.2. MPA Geospatial and Attribute Data

MPA geospatial and attribute data (e.g., location, shape/boundaries, age, area and fishing regulations) were used as controls in the models and were taken from the September 2018 version of the World Database on Protected Areas (WDPA). Our *No take* variable indicates MPAs in which fishing is prohibited (as opposed to partially protected areas). *International* indicates MPAs that exceed the spatial borders of a single country. In the statistical models, a log-transformation was applied to the *Area* variable to reduce high-end outliers. Finally, we created a *Region* variable to account for the spatial clustering of MPAs across the globe.

2.3. MPA Management Data

We rely on two main indicators for MPA management practices from the WDPA. *Management plan* is an indicator for whether governments have a formalized strategy for the conservation of the MPA. Management plans involve assessments of conservation goals, how these goals should be accomplished, and what kind of resources are dedicated to these goals. *Co-management* is an indicator that captures whether user groups wield decision-making power over how MPAs are managed. It is a composite indicator consisting of all MPAs governed through government-delegated management, individual landowners, local communities, indigenous communities, joint governance, or non-profit organizations. For 20 MPAs in our samples, the WDPA database did not include information on their governing authority. In these cases, the authors used the websites of these MPAs to determine what kind of (co)management strategy is used to manage the MPA.

2.4. Ecological Impact Data

We capture our three ecological outcome variables, i.e., *coral bleaching*, *grouper count* and *snapper count*, using observational data from ReefCheck. Reef Check is a foundation that involves the general public in marine conservation. In order to do so they developed a monitoring protocol for collecting data by scuba divers. Scuba divers receive a 4-day training about marine biology, indicators and ecology. Data is examined by a 'smart filter' [33], thereby ensuring the data can be used for academic research. Reef Check staff, in collaboration with academic researchers, check the data and analysis and make it available for peer review [34].

For our *coral bleaching* variable, we gathered all ReefCheck observations on the percentage of coral colonies that exhibit bleaching relative to the entire surveyed population of colonies. This data was last gathered in September 2018. We then only kept observations that occurred since 2014 (N = 2133). As the youngest MPA in our sample was established in 2013, this cut-off point ensures our predictors precede the outcome. We used the same procedure for our *grouper count* (N = 2286) and *snapper count* (N = 2240) outcomes. In the next step, we used the geospatial functionalities of the 'R' software, most notably the 'sp' package, to match the reported coordinates of the bleaching observations to polygons of established MPAs in the WDPA. This step yielded a total of 921 observations in 61 MPAs for *coral bleaching*, 971 observations in 68 MPAs for *grouper count*, and 886 observations in 61 MPAs for *snapper count*, which were aggregated per MPA. Hence, *coral bleaching* measures the mean of the observed proportions of bleached colonies in a population per MPA over the period 2014–2018. *Grouper count* and *snapper count* measure the mean of the observed counts of these respective fish across ReefCheck surveys conducted in a given MPA over the period 2014–2018.

2.5. Analyzing MPA Management and Ecological Impacts

We employed three sets of Bayesian mixed-effects models to examine the effects of MPA management practices on our ecological impacts. The first set models *coral bleaching* using zero-inflated beta regression models. Beta regressions are more suitable models when modeling proportions that are bound between 0 and 1, and the zero-inflation correction controls for a larger-than-random proportion of zeroes in the distribution of the outcome variable [35]. Both *grouper count* and snapper *count* were modelled using zero-inflated negative-binomial regression models, which are count models that correct for excess zeroes as well as over-dispersion in non-zero observations [36,37]. The Bayesian specification and estimation of these models via Markov Chain Monte Carlo (MCMC) simulation enables the use of complex models with a relatively small number of observations [38].

All models include a random *Region* intercept, which accounts for the spatial clustering of MPAs and controls for unobserved ecological or managerial non-independence between MPAs situated in the same region. Moreover, we centered all predictors on their grand mean and standardized non-dichotomous predictors by two standard deviations to aid interpretability [39,40]. For all models, we specified diffuse, weakly informative priors to ensure regularization and therewith applied a more conservative test of the effects of our predictors on bleaching outcomes. We employed a number of posterior predictive checks to evaluate the fit and predictive accuracy of our models. More details on these models can be found in the Supplementary Materials.

3. Results

3.1. Coral Bleaching

Our first dependent variable is coral bleaching. Coral bleaching can have five causes: (1) changes in sea temperature (either elevated or decreased); (2) solar radiation; (3) reduced salinity; (4) bacterial and other infections; (5) combination of elevated temperature and solar radiation [41]. We were able to match management and conservation data for 61 MPAs (Figure 1). The MPAs with the largest proportions of bleached coral colonies are found in the Caribbean and around Australia; the highest proportion of bleached colonies in our sample is located in an MPA off the shore of Honduras (49%). A relatively large share of MPAs (28.3%) reported no bleaching of any coral colonies in the population.

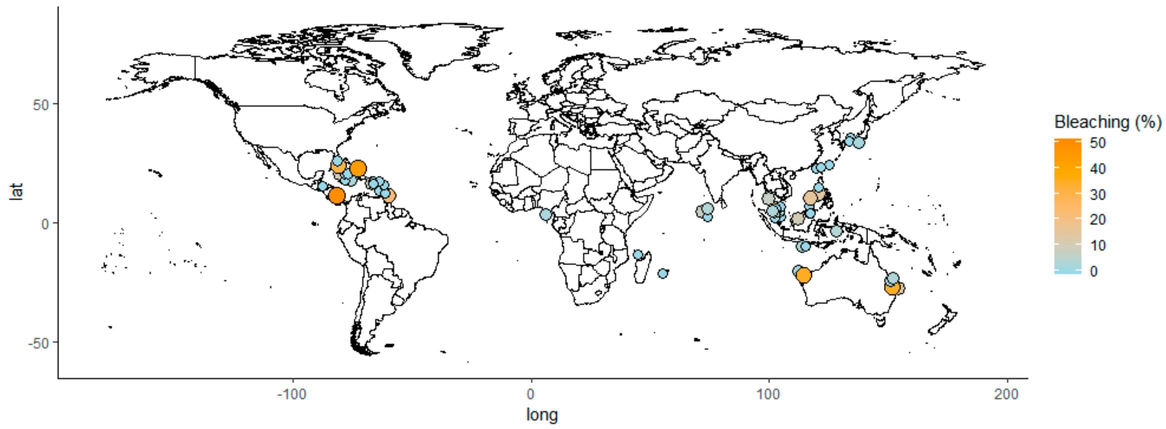

Figure 1. Aggregates of coral bleaching observations by MPA.

Figure 2 shows the point estimates and 95% credible intervals of interest for the model predicting coral bleaching. In accordance with the results of Gill et al. [26], MPAs that employ a formal governmental strategy (i.e., management plan) thereby indicating enhanced governmental efforts, show slightly lower levels of bleaching than MPAs which do not employ such strategies ($\beta = -0.371$).

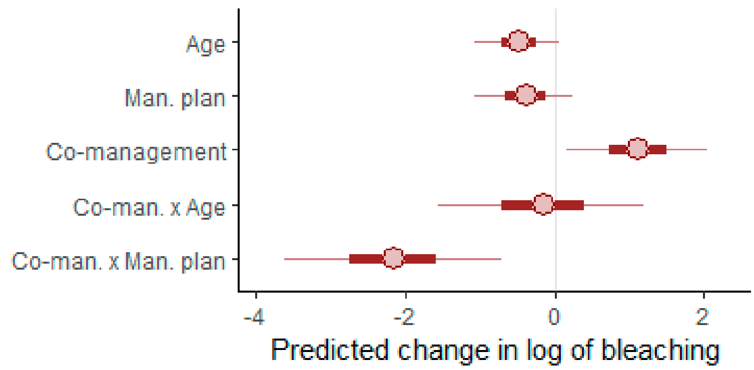

Figure 2. Posterior estimates for coral bleaching.

However, when co-management is part of a formal governmental strategy (*co-management* and *management plan* combined), this effect is much stronger: MPAs in this category on average report far fewer (up to 86%) bleached colonies per coral population than co-managed MPAs without explicit strategies ($\beta = -2.165$). This is the strongest effect produced by any of the included predictors. It is unlikely that co-management affects non-local factors such as changes in water temperature, decreased solar radiation and reduced salinity [42]. Therefore, this finding suggests that co-management as part of a formal governmental strategy seems to contribute to more *adaptive* corals (for example, corals that are better able to survive elevated sea temperatures), compared to corals in MPAs where such institutionalized collaboration is not in place. In order to understand this relationship we need to point out that (co-)management can contribute either *directly* or *indirectly* to the well-being of coral. To start with the former, direct effects that can be generated through (co-) management include mitigating pollution, and banning the use of sunscreen [43,44]. Or as Brown [41] has shown: reducing bacterial and other infections. Indirect effects may come about through a reduction in local anthropogenic pressures that are directly affected by co-management, but with an indirect effect on coral well-being in general and bleaching in particular. To give an example of such an indirect effect we refer to Ruppert et al. [45] who show that the absence of sharks ultimately leads to poorer coral health. This is because sharks hunt mesopredators (such as grunts). That influences the number of herbivores (e.g., parrotfishes), that are hunted by these mesopredators. The number of herbivores affects the influx of green algae, which may cover corals and cause coral suffocation. All corals in the world are fighting increased oceanic heating, but the corals that also have to fight pollution and/or algae coverage will suffer the most. Hence, the overfishing or killing of sharks has a negative effect on coral health. Other explanations of this effect are that co-management induces the effective enforcement of bans on coral-damaging fishing methods; no-take zones; or the prevention of water pollution. As a consequence, marine ecosystems may be healthier and therefore more resistant to reduced salinity or changes in water temperature.

Finally, the estimate for *Age* suggests there is less coral bleaching occurring in older MPAs. This implies that the longer an MPA is established, the more successful it is in safeguarding ecological outcomes. In this regard, there does not appear to be a clear difference in this temporal effect across MPAs that do or do not involve other stakeholders than government.

3.2. Fish Populations

Both snappers (*Lutjanidae*) and groupers (*Epinephelinae*) are very much at risk to become overfished [46–48]. As such, their prevalence is a useful indicator for the well-being of the marine ecosystem in general and overfishing in particular. Figures 3 and 4 map the 68 MPAs for which we were able to match management and conservation data.

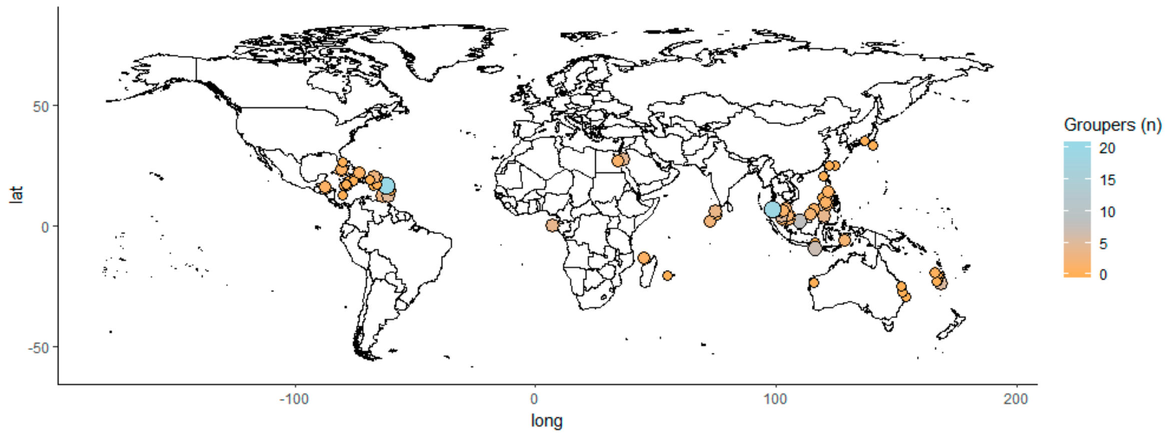

Figure 3. Aggregates of grouper observations in MPAs.

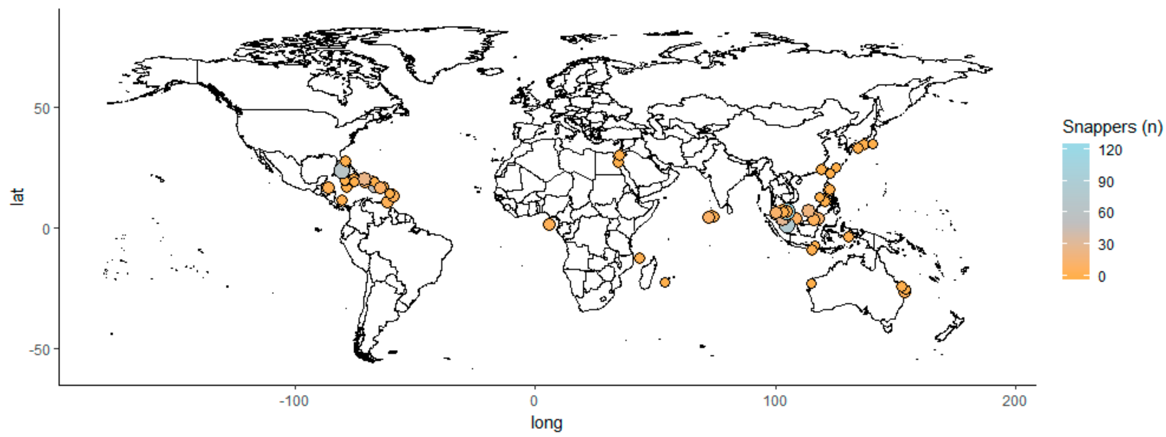

Figure 4. Aggregates of snapper observations in MPAs.

Gill et al. [26] conclude that adequate staff capacity is the most important factor in explaining fish responses to MPA protection. Gill et al. [26] also conclude that budget capacity has a similar effect, indicating that biodiversity conservation is also heavily dependent on available capacity. Our analysis confirms this result, as illustrated in Figure 5. Both for groupers and snappers, an official governmental strategy has a positive effect on grouper and snapper counts, although the effect for the latter is much weaker, less credible, and close to zero.

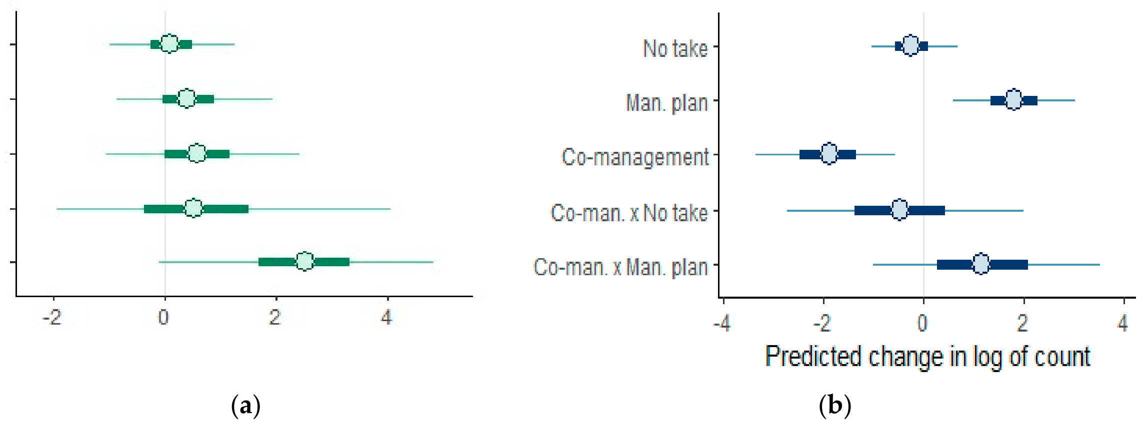

Figure 5. Posterior estimates for grouper (**a**) and snapper counts (**b**).

For both types of fish counts, we find that the coupling of co-management as part of a formal governmental strategy show a positive effect (for groupers: β = 1.17 or 3.2 times more, for snappers: β = 2.50 or 12.2 times more) on the population of both species. This strongly corroborates our earlier findings on the success of the coupling of co-management and management plans in on coral bleaching, and suggests these findings hold regardless of unobserved species-specific confounding effects. Therefore, we conclude that although we can raise serious questions about whether leaving marine conservation to other stakeholders than government is an effective strategy, our data generates a strong indication that if a form of co-management is supported by government, this may lead to positive results in terms of marine conservation.

Importantly, we did not find any clear differences between the effects of co-managed MPAs that prohibit fishing (*No Take*) and those that do not. Figure 5 shows the results of interest for both models predicting fish counts.

4. Discussion: Assessing Co-Management for Marine Conservation

This study shows that co-management by itself should not be considered as an effective strategy for marine conservation. Co-management must be part of a formal government-supported management plan, supported by *governing institutions* [49]. Therefore, our analysis indicates that theories and concepts that deal with this relationship between civil communities and governmental organizations [50], such as collaborative governance, co-production and co-creation, can have added-value in thinking about addressing anthropogenic pressures on MPAs. This literature may provide stepping stones for creating and maintaining legislative and institutional support and other prerequisites for effective collaboration between government and other stakeholders (see for instance [18,51]).

The results of this study indicate that co-management can have beneficial effects on fish populations, which is in agreement with conclusions from other studies [52,53]. In addition, this study shows that the same positive effect may also apply to healthier coral populations. Although this positive relation has yet to be substantiated, authors have suggested that *a lack* of co-management will also affect the wellbeing of coral populations [54].

Our main addition to the literature on MPA management is that if co-management is supported by governmental structures and plans, this may contribute to healthier marine ecosystems. Our analysis shows that, in line with Gill et al.'s conclusion that inclusive management practices do not yield positive ecological impacts [26], co-management *by itself* cannot be considered an effective instrument to address the decline of fish populations or coral bleaching. Just leaving MPA-management to other stakeholders is not effective for marine conservation and can even be detrimental for coral bleaching and fish populations. However, our results indicate that if MPAs are co-managed and that if co-management is part of a broader, institutionalized management scheme (i.e., part of an official management plan), marine ecosystems are more adaptive, as demonstrated by the ecological indicators used in this study: less bleached coral populations and more groupers and snappers. This result is very much in line with the conclusions of Gurney et al. [55], who argue that the participation of local people in MPA management is much more extensive if they receive external support from NGOs or other *nested* governance institutions. This 'nestedness' may prevent civic volunteerism from being *crowded-out* by government services [56]. This research empirically underpins the necessity of institutions for effective MPA-management, i.e., (the harmonization of) legal frameworks, policies, and mandates [57]. In doing so, this research reveals another condition for MPA management, next to the already known importance of prominent community leaders and social capital [58]. We emphasize again, that it is unlikely that the enhanced resilience of the marine ecosystems is related to more stable water temperatures, decreased acidification or salinity levels, but rather that direct (and local) anthropogenic pressures (e.g., water pollution; extinction of species on higher trophy levels, such as sharks; and coral-damaging fishing methods) that have an indirect effect on coral bleaching can be more effectively managed by formalized co-management. This possibly induces an indirect positive effect on the resilience of coral reefs and fish populations. Lastly, our analysis also shows that citizen science can make valuable scientific contributions when combined with an established database such as the WDPA. As Hyder et al. [59] argue, it is very unlikely that citizen science will replace traditional marine monitoring efforts, but it may assist tremendously in collecting data. Therefore, we underline the argument of Hyder et al. that citizen science should be "an integral part of the solution for evidence provision as long as formal statements of data quality and accessibility are resolved, and selection of data for inclusion in the evidence-base is made on the basis of quality rather than simply the methodology" (p. 118).

5. Study Limitations and Future Research

This study has its limitations. First, we focused on the effect of co-management on MPA effectiveness in terms of opposing coral bleaching and conserving grouper and snapper populations. We did not have sufficient data on other ecological indicators. Hopefully, future research will enrich this understanding by testing this effect for other components of the marine ecosystem. Second, we were unable to reveal other, more detailed conditions that are relevant for marine conservation (such as the proximity of local communities who can enforce the law [60]). This data allowed us only to highlight two conditions of the Ansell and Gash collaborative governance framework (institutional design and pre-history of cooperation). Our research indicates that a more inter-disciplinary approach is needed to develop authoritative frameworks for (marine) conservation. Using the body of knowledge built around other concepts can be useful for developing this framework. Future research will hopefully address what kind of configurations of influential factors are necessary for achieving marine conservation success. Third, our study indicates a positive effect on the well-being of marine ecosystems, of nested co-management. Our data cannot show us what mechanisms explain this effect in more detail (for instance, the presence of sharks; the absence of sea urchins; or water quality). Hopefully future research will reveal these mechanisms, thereby not only showing how co-management efforts can create a positive impact, but also enhancing our understanding of the interrelatedness of several aspects within the marine ecosystem. Last, as co-management can have many faces and many different objectives [24], it is useful to consider what forms of co-management yield what kind of outcomes. As our data suggests, co-management can be useful to manage direct and local anthropogenic factors, but a more elaborate understanding is required to grasp what features of these co-management relations can indeed effectively manage these factors.

6. Conclusions

The role of involvement of local communities in the effectiveness of Marine Protected Areas has sparked debate in recent academic literature. By combining the IUCN database on Protected Areas with the database of Reef Check, we were able to examine the relationship between co-management ("some kind of power-sharing arrangement between the State and a community of resource users") [22] (p. 65) and the level of coral bleaching, and abundance of snappers and groupers. In doing so, we sought an answer to the question: To what extent can co-management be considered an important factor for marine conservation in Marine Protected Areas? Our analysis showed that if co-management is part of a formalized strategy (i.e., supported by institutionalized governmental organizations), there is significantly less coral bleaching and significantly larger numbers of snappers and groupers are reported. Hence, we conclude that there is a positive relationship between formalized co-management and marine ecosystem well-being.

Data availability. The authors declare that the source data supporting the findings of this study are available within the paper and its Supplementary Materials. All other data and R code are available from the corresponding author upon reasonable request.

Supplementary Materials: The following are available online at http://www.mdpi.com/2077-1312/8/7/491/s1, Section 1, Analytical framework and indicators; Section 2, Data sources; Section 3, Model priors; Section 4, Estimation procedure; Section 5, Posterior predictive checks; Section 6, Data limitations; Section 7, Supplemental tables and figures; TableS1, Descriptive statistics of sample MPAs per outcome variable; Table S2, Model 1-Outcome: Coral bleaching; Table S3, Model 2-Outcome: Grouper count; Table S4, Model 3-Outcome: Snapper count; Figure S1, Posterior predictive check 1 for Model 1 (coral bleaching); Figure S2, Posterior predictive check 2 for Model 1 (coral bleaching); Figure S3, Posterior predictive check 1 for Model 2 (grouper count); Figure S4, Posterior predictive check 2 for Model 2 (grouper count); Figure S5, Posterior predictive check 1 for Model 3 (snapper count); Figure S6, Posterior predictive check 2 for Model 3 (snapper count).

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