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Evaluating the effectiveness of coastal no-take zones of the Galapagos Marine Reserve for the red spiny lobster, *Panulirus penicillatus*

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ABSTRACT

Monitoring and assessing the effectiveness of no-take zones (NTZs) is critical, not just for the effective management of marine resources, but also for informing and gaining support from community stakeholders. The Galapagos Marine Reserve (GMR) established a network of coastal NTZs in 2001, yet, to date no study has investigated their effectiveness in protecting and enabling key species to recover. Using data from the Galapagos National Park Directorate annual Lobster Population Monitoring Program from 2012 to 2014, this study evaluated the recovery of the commercially valuable red spiny lobster (*Panulirus penicillatus*) inside NTZs in the GMR. It was hypothesized that NTZs would present higher lobster abundances or sizes when compared with adjacent fished zones. However, the study found no significant differences in these comparisons. Overall the findings indicate that > 11 years of protection has had no appreciable effect on lobster abundances or sizes inside the NTZs. This paper explores possible reasons for the lack of response in NTZs, and concluded that non-compliance and shortcomings within the enforcement framework of the GMR are the key factors limiting the functionality of these NTZs. Additionally, it also evaluates the limitations of the current monitoring program and highlights the need for a more comprehensive and long-term program to be implemented. As the new zoning scheme for NTZs in the GMR that began in 2016 is still to be determined, this information should be considered by decision makers to improve the effectiveness of NTZs and sustainable management of the GRM's coastal resources.

1. Introduction

In the last four decades governments worldwide have been creating marine protected areas (MPAs) with the main goal of preserving biodiversity and populations of ecologically and/or economically important species [1–5]. No-take zones (NTZs) are MPAs, or zones within an MPA, where all types of resource extraction are prohibited, and are regarded as key tools for conservation and fisheries management [5–7]. There is now an extensive body of empirical evidence confirming the benefits of NTZs for fisheries, which include increases in abundance, biomass, average size, and spawning potential, which in turn can ultimately lead to larval and adult spill-over into adjacent fishing areas [3,8–13]. This has especially been the case for commercially important lobsters species, which have been shown to respond rapidly to protection as they have rapid growth rates, reach sexual maturity at an early age, and tend to show high degrees of site fidelity [9,12,14–17].

However, not all MPAs deliver positive ecological outcomes, often referred to as “paper parks” [5,18–20]. Many MPAs fail to meet their management objectives due to inadequate human and financial resources, ineffective enforcement, and poor acceptance by local communities [4,21,22]. According to a recent global meta-analysis study on the response of exploited fish species in MPAs [5], the five key characteristics of effective MPAs that they are: no-take, enforced, old (> 10 years), large (> 100 km^2) and isolated (based on habitat discontinuities). The majority of MPAs assessed in the study that only had one or two of these five key features showed little to no response levels among populations of commercial fish species. Furthermore, another major problem MPAs feature is that they are often created to meet unspecified conservation goals, rather than verifiable management objectives, and lack targeted monitoring programs to evaluate their

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effectiveness [18,23,24].

Creating and managing MPAs, especially with NTZs, is costly and time-intensive [25], and often negatively perceived by local communities as they initially limit their resource extraction [26,27]. Thus, assessing the effectiveness of NTZs is critical [28,29], not only for supporting sound decision making for MPA management, but also for demonstrating long-term positive impacts on biodiversity and society [30]. For instance, evidence of positive responses of commercial fisheries can increase NTZ management legitimacy and improve stakeholder acceptance and compliance among local communities [21]. For a clearer understanding of whether protection measures work in practice, temporal trends in the recovery of exploited species should thus be evaluated [31]. Ideally, evaluation studies would use a before–after control-impact (BACI) design to obtain data from replicates in NTZs and control sites both before and after zonation [28,32].

The Galapagos Marine Reserve, created in 1998, is a multi-use MPA, covering an area of ~138,000 km^2 where industrial fishing is banned, while artisanal fishing remains permitted for ~1200 Galapagos residents [33,34]. To reduce ongoing conflict between the fishing, tourism, and conservation sectors at the time, a temporary zoning scheme, led by a consensus-based participatory process, was implemented in 2001 [35,36]. As a result of this process 22% of the coastline (that extends 2 nautical miles seawards) became designated as either conservation or tourism zones, while artisanal fishing remained permitted along the remaining coastline and open water (Fig. 1). In both the conservation and tourism zones, all types of extraction are prohibited, therefore in this study both are considered as NTZs. In total, there are 78 named NTZ sites across the GMR coastline, that range from 0.01 to 91 km^2 in size [33,34]. According to the Galapagos National Park Directorate (DPNG, initials for name in Spanish) management plan, the objective of the NTZs is to protect biodiversity, ecosystem services, and promote sustainable tourism and fishing [37]. Currently, the DPNGs management plan of the GMR has no evaluation framework in place to assess the effectiveness of its NTZs [36].

In 2015, the DPNG initiated a re-zoning scheme for the NTZ network in the GMR. Yet no published study to date has investigated the effectiveness of the 2001 NTZs to conserve biodiversity and enable populations of valuable commercial species to recover. Over 70 marine species are exploited by artisanal fishermen in the GMR [38]. Among these fisheries, some have collapsed, like the sea cucumber fishery (*Isostichopus fuscus*) in 2002 [39], others have been on the edge of collapse, e.g. lobster fishery (*Panulirus gracillis,* and *P. penicillatus*) [40] and many are being unsustainably overexploited, in particular serranids such as the regionally endemic Galapagos sailfin grouper (*Mycteroperca olfax*) [41,42]. Increasing current understanding about whether the GMR zoning of NTZs is supporting the recovery of commercially valuable and fragile fisheries is thus paramount.

The only long-term species-specific population monitoring programs across the GMR have been carried under the Monitoring of Fisheries Resources Plan [37], which for now includes sea cucumber (*Isostichopus fuscus*) and the commercial lobster species *P. penicillatus, P. gracilis* and *Scyllarides astori* [42]. Using data collected from the DPNG's Lobster Population Monitoring Program, the aim of this study was to evaluate the efficacy of the GMR's NTZs by assessing the response of the populations of spiny lobsters *P. penicillatus* inside and outside NTZs.

2. Methods

2.1. Study area

The Galapagos Archipelago is located in the Eastern Tropical Pacific, ~1200 km west of mainland Ecuador, and constitutes 13 major islands and over 100 smaller islands and islets that altogether total 1667 km of predominantly rocky coastline [43]. The abundance and distribution of marine species and habitats is strongly influenced by the convergence of three major current systems: the Peru (from the southeast), the Cromwell (from the west), and the North Equatorial (from the northeast) as well as by natural environmental variability, such as “El Niño” [44]. The only inhabited islands are Baltra, Santa Cruz, San Cristóbal, Isabela, and Floreana, where approximately 25,000 people live permanently as of 2015 [45]. As of 2016 there were 1105 fishermen with fishing-licenses and 468 vessels actively registered by the DPNG, even though only ~40% of fishermen were active full-time or part-time [46,47].

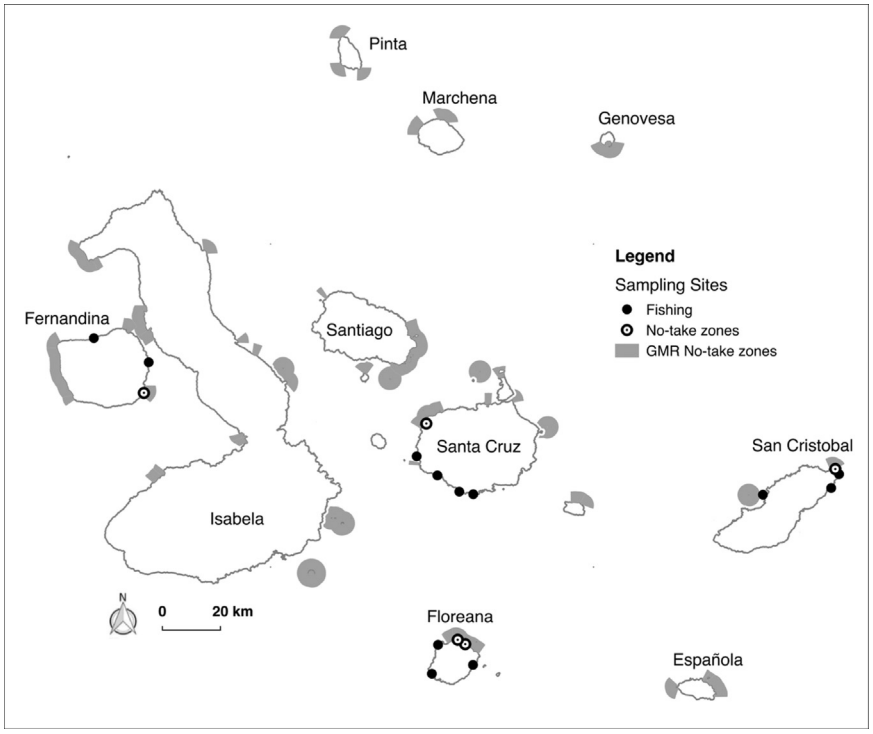

Fig. 1. Map of Galapagos Islands, excluding the far northern islands Darwin and Wolf, showing sampling sites and layer of no-take zone network implemented in 2001 (Moity, unpublished data).