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Effects of marine protected areas on coastal fishes across the Azores archipelago, mid-North Atlantic

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ABSTRACT

Marine reserves across different eco-regions and habitats have proven to benefit exploited fish populations within their borders. There is also mounting evidence, mostly from continental shelf regions, that such positive effects will depend on the species ecological traits (e.g. mobility) and on the characteristics of the reserves (e.g. design, age and enforcement). This study examines the effects of protection on commercial coastal fishes with different ecological traits from three marine reserves with distinct habitats (coastal vs. offshore reefs), protection regime (legal vs. voluntary, partial vs. total protection) and age (8, 15 and 26 years old) across the oceanic archipelago of the Azores, mid North Atlantic. Overall, positive effects of protection on fish abundance or individual size were limited to species of larger maximum size and lower mobility in reserves with higher compliance levels. This result agrees with many studies elsewhere showing that reserves of small size and/or insufficient compliance do not provide adequate protection to the entire fish community, limiting their contribution to manage fisheries and conserve biodiversity. That might very well be the case of Azorean marine reserves but a more conclusive result will require testing the effects of protection on larger, well enforced reserves, which still do not exist in the region. There was also a clear influence of depth in commercial fish distribution and a common preference for substrates of higher complexity across ecological traits. Combined, these results highlight the need to include complex reef structures, diverse coastal habitats and larger areas when designing multispecies marine reserves and stress that an appropriate management regime is crucial for the success of the reserve, in particular to promote compliance.

1. Introduction

Research over the last two decades on marine protected areas (MPAs, areas with some level of restriction) and specifically on marine reserves (areas closed to fishing) has provided much evidence of the positive effects of protection on marine communities. These so-called "reserve effects" include an increase in abundance, individual size and reproductive potential of previously exploited species inside the reserves (Roberts et al., 2001; Halpern, 2003). Yet, recent global studies estimate that the proportion of underperforming MPAs can be as high as 90% (Edgar et al., 2014). These underperforming cases cast legitimate doubts on the usefulness of marine reserves as tools for fishery management and biodiversity conservation, given that both objectives directly rely on achieving the positive reserve effects. Moreover, they fuel arguments that spatial restrictions bear the 'burden of proof' as to their effectiveness (Nowlis, 2000; Lubchenco et al., 2003; Palumbi et al., 2003; Sale et al., 2005). It is therefore worth asking: what are the characteristics of marine reserves that may offer higher probability of success, and what are the pitfalls to avoid?

Edgar et al. (2014) recently reviewed the reserve effects of 87 MPAs from 76 different eco-regions of the world. They concluded that the response of fish communities within MPAs is affected by the cumulative effects of five key planning and management features: the NEOLI criteria. Under the acronym lie the notions of No-take, Enforced, Old, Large and Isolation, which respectively gauge: (1) the degree of fishing allowed within the MPA, (2) the level of enforcement, (3) the age of the MPA, (4) the size of the MPA, and (5) the presence of continuous habitat allowing unconstrained fish movement across MPA boundaries. In general, the effects of protection are more likely in no-take (as opposed to partially protected), well enforced, older, larger, isolated but continuous MPAs. It is also necessary to take into account the exploitation levels prior to the establishment of the MPAs when assessing their

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effectiveness, given that recovery rates will differ between mildly and heavily exploited communities (Claudet et al., 2008). Natural factors can also strongly mediate the effects of protection on exploited species, namely the ecological traits of the species to protect and their habitat preferences, and even stochastic (environmental) factors. This study deals with all of these apart from the stochastic factors.

The influence of habitat in shaping the structure of marine populations and their recovery trajectories inside reserves has been widely addressed since the early MPA studies (reviewed in Russ, 2002). For example, the quality of reef habitat in terms of depth and bottom complexity (i.e. relief and rugosity) is known to influence the distribution of many fish species, as it can be a key factor for predator avoidance and access to food (e.g. Friedlander and Parrish, 1998; Claudet et al., 2011). These patterns of habitat selection are, in turn, intricately linked to the species ecological traits. Many reef fishes show either ontogenetic or reproductive changes in habitat preferences, and the size and location of their activity areas, or home ranges, can vary substantially across species, life stages and even across individuals within a population (e.g Afonso et al., 2009; Afonso et al., 2011; Meyer et al., 2010). The selection of sites to implement MPAs thus needs to consider these factors in order to effectively protect individuals within borders. Since protecting areas of low quality habitat is unlikely to contribute to the success of the reserves, the observation of positive effects within some MPA boundaries may also reflect a biased choice of high quality areas in the first place. This misperception can lead to unrealistic expectations, in particular the long-term performance of the reserves and their benefits to adjacent exploited areas (Russ, 2002; Sale et al., 2005).

MPA studies have focused essentially on continental shelves (e.g. Claudet et al., 2006; Goni et al., 2008; Molloy et al., 2009). Less is known about the effects of protection in oceanic islands where marine populations are subject to different environmental constraints. These habitats are frequently of recent geological age with fragmented and restricted shelf habitats, especially in the case of the many volcanic archipelagos scattered around the world's oceans. Moreover, they are largely isolated by distance and/or stretches of unfavourable habitat that are often at odds with the species' dispersal capabilities, and naturally limit connectivity among populations. In warm temperate to subtropical regions they are also subject to oligotrophic and highly hydrodynamic environments. These conditions could impact individual survival and the stability and resilience of local marine populations. A broad understanding of the effectiveness of marine reserves in these regions thus requires studying the recovery trajectories of marine populations after protection across habitats and reference (baseline) situations.

The volcanic archipelago of the Azores is one of such cases. Located on the mid-Atlantic ridge, it harbours the most isolated coastal marine communities in the North Atlantic, which are of high ecological and evolutionary interest (Santos et al., 1995; Afonso and Santos, 2004). The first experiences with MPAs in the region date back to the 1980's when a few dispersed, small and poorly-enforced MPAs were established in the archipelago with the rather broad objective to manage marine resources and conserve biodiversity (Santos et al., 1995; Costa Abecasis et al., 2015). This network included the minuscule coastal MPA of Monte da Guia in Faial Island, encompassing a reserve area covering a mere 8 ha, as well as the offshore MPA of the Formigas Bank, originally covering a sizeable 37.695 ha. In the 2000's, the surge of nature tourism and diving in Corvo Island prompted the creation by local stakeholders of a small voluntary MPA (18 ha) where no fishing occurs, thus in practice becoming a marine reserve. The three areas are considered of high biodiversity value, integrating both the Natura 2000 and the OSPAR (Oslo-Paris Convention) MPA networks. Altogether, they typify the breadth of shallow habitats and marine communities present in the region, quite different from those of continental shelves, and represent the variety of social and operational challenges in broader marine conservation contexts.

This is the first study to assess the effects of protection on fish communities in the Azores archipelago. We used a 15-year dataset from the Azorean coastal fish monitoring program to test for "reserve effects" (increase in abundance and individual size) in three MPAs. We tested MPAs against age, levels of protection, as well as their contrasting ecological and design characteristics. The two objectives of this study are 1) to test whether there is an effect of protection inside Azorean reserves and, if so, to evaluate its magnitude across time, and 2) to evaluate the influence of design and management characteristics on MPA performance. We used exploited fish species as indicators of protection inside of MPAs and their responses across various life history and ecological traits (LHTs) to determine how protection, design and management are affecting the success of the three MPAs.

2. Material and methods

2.1. Study areas

We studied three Azorean MPAs with different degrees of protection and associated zoning schemes, including (no-take) reserve areas and areas with partial protection.

The Caneiro dos Meros (literally the "grouper gully") MPA was voluntarily established in 1999 and named after the large dusky groupers that reside in the area and attract many divers to Corvo Island. It is a small (ca. 0.2 Km^2) no-take area located in the south end of the island (Fig. 1, Table 1), covering the exposed rocky reef formed by parallel lava ridges interspersed with sand that stretches from the shallow shoreline down to approximately 40 m depth. It benefits from the voluntary compliance and surveillance of the small local population (400 people), including the handful of local artisanal fishermen. In this study, it is considered a fully protected MPA.

The Monte da Guia MPA was legally established in 1980 and regulated in 1984 in Faial Island to protect the marine biodiversity and landscape of the Monte da Guia volcano, just next to the town of Horta (8000 people). It harbours a very small fully protected reserve (the Caldeirinhas twin craters, 0.08 Km^2, max. depth 25 m) surrounded by a partially-protected buffer of ca. 0.2 Km^2 around the perimeter of the volcanic cone, where spearfishing, gillnetting and trapping is not allowed (Fig. 1, Table 1). Altogether, it encompasses a variety of coastal reef habitats (exposed to sheltered, shallow to deeper - 80 m), including two shallow bays located either side of an isthmus. The coastal communities near the Monte da Guia MPA are historically populous and with relatively intensive fishing activity. Stakeholder conflict is potentially high and enforcement is somewhat problematic (Afonso and Santos, 2004). In this study, it is considered a multizoning MPA with both partial and fully-protected zones.

In contrast, the Formigas MPA (established in 1988) is substantially larger (57.4 Km^2) and harbours a broad range of habitats from the bathyal plains (ca. 2300 m) at the base of the seamount to the rocky outcrops emerging in its shallowest portion (Fig. 1, Table 1). The shallow reefs (< 50 m) of the seamount alone occupy an area of 3.26 Km^2. It differs from the two small coastal MPAs by possessing both a coastal marine community and an exuberant population of oceanic visitors, including marine turtles, cetaceans, tunas, as well as pelagic sharks and rays. Initially, Formigas was an MPA offering only partial protection to its coastal habitats (< 200 m), as fishing was still allowed to vessels smaller than 11 m inside the smaller MPA. A regulation review in 2003 considerably extended the limits of the reserve to encompass the whole seamount down to its base, and strengthened the protection status by allowing only pelagic pole-and-line fishing for tunas inside the MPA. Thus, Formigas became a larger MPA with a quasi-reserve status in 2003. Given that tunas are strictly pelagic species that feed on small pelagic prey, both of which are not accounted for in this study, we considered the Formigas as a fully-protected MPA for the purpose of this study.

A detailed description of these MPAs can be found in Abecasis et al.