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Enhanced numbers of two temperate reef fishes in a small, partial-take marine protected area related to spearfisher exclusion

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ABSTRACT

Reviews of global studies suggest that even small no-take marine protected areas (MPAs) can have localized benefits on harvested organisms of varying mobility. The generality of this conclusion, however, has been questioned due to poor experimental designs of some studies included in reviews, and the relatively small proportion of studies which focused on very small MPAs ($\leqslant$1 km^2). Here we use a correlative approach to test for possible effects of a 0.1 km^2 partial-take MPA (closed to spearfishing for 12.5 years) on the abundance and size of key harvested fishes using an asymmetrical spatial comparison of the MPA vs. three unprotected control areas. Positive impacts were detected, despite our prediction that a small MPA would not provide protection to highly mobile taxa. Densities of legal-sized ($\geqslant$200 mm SL) *Cheilodactylus fuscus* (red morwong; relatively sedentary) were 2.8 times greater within the MPA than at the controls and densities of legal-sized *Acanthopagrus australis* (yellow-fin bream; relatively mobile) were 2.3 times greater on shallow ($\leqslant$3.5 m) but not deeper (4–12 m) areas of reef within the MPA. While benefits of protection were evident, the cost-benefit of implementing similar MPAs should be carefully considered as the partial protection status and small size of the MPA limit both the adequacy of the MPA for protecting a larger range of species, and the magnitude and thus detectability of effects.

1. Introduction

Marine protected areas (MPAs) are widely used as a tool in conservation and management of marine environments. Syntheses of global research provide strong evidence that site-specific reduction in harvesting can lead to significantly higher densities, mean size/age, and biomass of harvested species inside no-take MPAs relative to unprotected areas in tropical and temperate regions (Edgar and Stuart-Smith, 2009; Halpern, 2003; Lester et al., 2009; Russ and Alcala, 2010). Ecological interactions between strongly interactive species may also re-establish within no-take MPA boundaries, providing key insights into the extent of community-wide impacts caused by human extraction of marine species (Guidetti, 2006; Langlois et al., 2006; Micheli et al., 2004). Despite scientific evidence on the 'general' effects of MPAs, it is also recognised that individual species and community structures can exhibit broad variation in response to protection (Micheli et al., 2004). Theoretical effects and recovery rates depend on interactions among several factors including initial population size, intrinsic rate of population increase, recruitment variation, magnitude of reduction in fishing mortality, immigration and emigration rates, habitat quality, life history traits relative to MPA design (e.g. size, location), and levels of enforcement (Claudet et al., 2008; Jennings, 2001; Lester and Halpern, 2008). Given this, independent tests of the expected functions of individual MPAs remain important.

Consistent with global recommendations, Australia has sought to establish and manage a 'system of MPAs to contribute to the long-term ecological viability of marine and estuarine systems, maintain ecological processes and systems, and protect Australia's biological diversity at all levels' (ANZECC TFMPA, 1999). The terminology used to denote MPAs in Australia varies according to the specific purpose, level of protection, management regime and legislation used to declare them (Baelde, 2005). For example, in New South Wales (NSW), the system of MPAs includes marine parks, aquatic reserves, and marine extensions of national parks and nature reserves. Marine parks are large areas, typically covering 100s km^2, which are zoned for multiple-use (e.g. general use zones, habitat protection zones, sanctuary/no-take areas). In contrast, aquatic reserves are relatively small (100s m^2 km^2) with the types of protection varying among reserves from complete no-take, to partial-take MPAs which impose restrictions on specific activities, gear types, user groups, or extraction of particular species (Creese and Breen, 2003).

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The broad objective of this study was to investigate the effect of existing aquatic reserves in Sydney, NSW on reef fishes commonly targeted by anglers and spear-fishers. Although aquatic reserves have not been specifically designed to protect exploited species, they may still fulfill this role (Smith and Pollard, 1996) and there is significant public interest in this response, particularly from recreational fishers who are the main user-group affected by closures. From an ecological perspective, reef fishes often exhibit strong effects of protection via MPAs as many species are subject to intense fishing pressure for food, sport and bait (Kingsford, 1998; Lester et al., 2009). Changes in fish assemblages may also lead to 'trophic cascade' effects due to their influence on the dynamics of other reef organisms via herbivory, predation, feeding, excretion and their role as prey (Babcock et al., 2010; Kingsford, 1998).

Aquatic reserves within the Sydney region are generally small ($1.9 \pm 1.4\ km^2$, $n = 10$) and most offer only partial protection for marine organisms within their boundaries. Three of these reserves (Shiprock $0.02\ km^2$, Cabbage Tree Bay $0.20\ km^2$, and Bronte-Coogee Aquatic Reserve $0.43\ km^2$) impose additional restrictions (see Methods) on the harvesting of reef-associated finfish beyond state-wide regulation of legal lengths, daily bag limits, and taking of threatened and protected species. The dominance of small reserves may indicate that this is the most appropriate size to achieve ecological objectives or, more likely, that other non-ecological factors were considered more important at the time of declaration (e.g. effective administration and enforcement, acceptable to the public) (Smith and Pollard, 1996). Reviews of MPA research found that small no-take MPAs can lead to increases in abundance and size of target organisms; and the relative magnitude of these effects and rates of recovery tend to be independent of MPA size (Côté et al., 2001; Halpern, 2003). These generalizations, however, have been criticized as many studies included in meta-analyses were based on spatial comparisons of MPAs of different sizes and ages done at one time only, and were often confounded by variation in habitat type, levels of compliance, and the life history of target organisms (Barrett et al., 2007; Russ et al., 2005). A relatively small proportion of MPA studies has focused on the utility of very small partial-take and no-take MPAs ($\leqslant 1\ km^2$) (e.g. Afonso et al., 2011; Floeter et al., 2006; Roberts and Hawkins, 1997; Russ et al., 2005). In temperate Australia, changes in some macro-benthic invertebrates and fishes have been observed in very small no-take MPAs relative to unprotected areas in Tasmania (protecting $\leqslant 1$ km of shoreline), but changes took longer to manifest compared with larger no-take MPAs (2 & 7 km in length) within the same region (Barrett et al., 2009; Edgar and Barrett, 1999; Edgar et al., 2009).

Mobility is important in determining the response of reef fishes to MPAs (Gerber et al., 2002; Halpern, 2003; Palumbi, 2004). Localised effects on populations residing within MPAs, and potential spill-over and recruitment subsidies to unprotected regions will be influenced by the rates and patterns of exchange of all life history stages relative to the size and location of MPAs (Kramer and Chapman, 1999; Palumbi, 2004; Sale et al., 2005). Movement of reef fishes can vary from metres to hundreds of kilometres (Annese and Kingsford, 2005; Griffiths and Wilke, 2002; Kingsford and Carlson, 2010; Popple and Hunte, 2005; Samoilys, 1997; Starr et al., 2002). Fishes may be site-attached, or move among habitats within a reef, among reefs, between estuaries and the open coast, and movements may vary diurnally, seasonally, and with size and age (Edgar et al., 2004b; Gillanders, 1997; Gillanders and Kingsford, 1996; Lowry and Suthers, 1998; Morrison, 1990). A lack of precise information on the movement of marine species often makes the effect of MPAs difficult to predict. For example, species considered to be highly mobile have responded to protection by small MPAs. This has been attributed to intraspecific variation in mobility whereby a portion of the population is more sedentary and resides within the MPA, and the incorporation of aggregation sites which were previously subject to high levels of fishing pressure (Grüss et al., 2011; Roberts et al., 2001; Roberts and Hawkins, 1997; Willis et al., 2003).

Similar to very small no-take MPAs, there is a need to assess the conservation role and cost-benefit of partial-take MPAs. Partial protection can be viewed as a compromise between conservation goals and socio-economic and political constraints (Lester and Halpern, 2008) and may result in ecological benefits such as reduction in overall and incidental mortality (Denny and Babcock, 2004). However, partial protection may also encourage fishing pressure within MPAs due to their unique locations and the perception that there will be more fish inside MPAs relative to unprotected areas (Denny and Babcock, 2004; Shears et al., 2006; Westera et al., 2003). In contrast to no-take areas, there have been relatively few studies on partial-take MPAs and generalizations regarding effects are difficult to make (Lester and Halpern, 2008 and references therein). Most studies report that partial-take MPAs do not produce significant differences in fish assemblage structures, and in density, size and biomass of harvested fishes and lobsters relative to unprotected areas (e.g. Di Franco et al., 2009; Sala et al., 2012; Shears et al., 2006) while others report some positive responses for heavily fished, carnivorous species (e.g. Serranidae, tribe Epinephelini; Floeter et al., 2006). This is not surprising given the broad variability in types of restrictions that can be applied (e.g. gear type, recreational vs. commercial fishing). From a scientific perspective, partial-take MPAs offer a unique opportunity to understand the impact of specific activities (e.g. spearfishing) on marine assemblages.

The specific objective of this study was to investigate the response of targeted reef fishes to a very small ($0.1\ km^2$), partial-take MPA in Sydney, relative to current knowledge of their mobility. The study focused on the Gordons Bay component of the Bronte-Coogee Aquatic Reserve where spearfishing has been banned for over a decade. Spearfishing is a popular recreational activity in NSW, Australia, yet there are no empirical data on potential impacts on local fish populations. The activity of spearfishers in the Sydney region is patchy, but can be intense, particularly in shallow, sheltered areas like Gordons Bay, which allow good year round access for spearfishers of all skill levels (Kingsford et al., 1991; Lincoln Smith et al., 1989). Previous studies have shown that the catch composition of spearfishers is often dominated by species that are reef-attached, relatively sedentary, and docile in nature (e.g. aplodactylids, monacanthids, cheilodactylids; Kingsford et al., 1991). Given this, it was hypothesized that the density and size of legal-sized fishes, assumed to be relatively sedentary (move at scales of metres to kilometres), would be greater inside Gordons Bay than in fished areas in the region which have similar types of fish assemblages, reef habitats, depths, and wave exposures. In contrast, densities and size of legal-sized species which move across larger spatial scales should not be influenced by protection, unless Gordons Bay represents an aggregation site which was previously subject to high levels of fishing pressure and/or the species exhibits interspecific variation in mobility. Other reserves located in Sydney (Shiprock, Cabbage Tree Bay and the recent extension of Gordons Bay into Bronte-Coogee reserve) were not included in the current study as robust comparisons were not considered viable, using the same methodology, given differences in habitats, depths, and fishing restrictions, and the size and age of the MPAs.

2. Methods

2.1. Study area and experimental design

Gordons Bay (lat 33°54′59.66″S, long 151°15′49.50″E) is a partial-take MPA located in Sydney, NSW, Australia (Fig. 1a). The