Using diversity in reef fish assemblages in determining recovery potential in marine protected areas

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Abstract Diversity is among the various aspects of reef fish assemblages that are expected to change with protective management. Reef fish diversity in terms of richness (number of species per 500 m²), abundance (ind/500 m²) and biomass (g/m²) were determined for six (6) reef sites in Tawi-Tawi, at the southwestern tip of the Sulu Archipelago, and in Danajon Bank, Bohol, in central Philippines in 2006 and 2008. At each reef site, reef fish within a 500 m² area were censused (identified, counted and their sizes estimated) in 6–12 stations following standard methods. Changes in reef fish assemblages in the two areas were examined and observed patterns were compared. The results are related to patterns in reef habitat structure and to local fisheries and are discussed in the context of recovery potential of reef fish assemblages in protected areas.

Keywords Philippines, reef fish, species richness, marine protected areas

Introduction

Marine protected areas are a popular tool in the management of coral reefs in the Philippines (Campos and Alino, 2008). The ultimate goal in establishing MPAs is to allow the environment to recover its productive potential by allowing natural processes such as settlement, growth and reproduction and the maintenance of habitat conditions to continue without disruption caused by fishing and other human-related activities. Recovery, however, depends on many factors. Among these are ecological considerations, such as habitat and resource conditions at the onset of protection, and habitat connectivity (e.g., between mangrove, seagrass beds and reefs) for the completion of life cycles (Roberts et al., 2003). There are also practical considerations including size of the MPA (Mora et al., 2006), duration of protective management, and effectiveness of implementation (Arceo et al., 2008). The relative importance of these factors to management oftentimes emerges after MPAs have already been established. Because not all areas will respond to protection in the same manner, determining which ones would most likely show positive changes in the shortest time would improve or enhance the effectiveness of MPA management efforts on the whole.

This study examines changes in the abundance, biomass and diversity (=richness) of reef fish assemblages in two reef areas over a two-year period, three years after the establishment of MPAs, to determine which characteristics are most indicative of recovery potential.
Materials and methods

The two coral reef areas investigated in this study are located in the municipality of Talibon in the eastern part of Danajon Bank, Bohol and in western Tawi-Tawi Bay in the southernmost tip of the Sulu Archipelago (Fig. 1). Danajon Bank is a double barrier reef system located within internal waters of Central Philippines. The MPA sites in this area are all located within the inner portion of the Bank and are somewhat protected by the outer Bank. The MPA sites in Tawi-Tawi, on the other hand, are all within the Bay, but are more accessible to water exchange with the open ocean (i.e., Sulu Sea to the north and Celebes Sea to the south). In both areas, six (6) MPA sites were monitored during the SW monsoon (Jul-Oct) in 2006 and 2008 for one and three years respectively, after protective management was initiated in the various sites. At each MPA site, ten (10) dive stations were surveyed, five inside and five outside the MPA boundaries. Fish species composition and abundance were determined by means of visual census covering an area 5m on both sides of a 50 m transect (i.e., 50 m × 5 m belt × 2 sides = 500 m²) in each station (English et al., 1997). Transects were laid along the reef crest, generally parallel to the shore, with depths ranging from 2–10 m. Fish biomass was derived using size estimates (FL) from the census and species-specific length-weight relationships reported in the literature.

Three-way ANOVA was employed to examine variation in the abundance (ind/500 m²) and biomass (g/m²) of all fish, as well as number of species recorded per 500 m² area surveyed, across MPA sites (Sites), locations in and outside of MPA boundaries (Loc), and between years (Years) in both Danajon Bank and Tawi-Tawi Bay. Abundance and biomass values were transformed to logₑ (x + 1) before the analysis. Homogeneity of variances was tested using either the Bartlett’s or F-max tests.

Results and discussion

The results of the factorial ANOVAs for each of the study areas are shown in Table 1. Variability in the data is

![Fig. 1](image-url) Map showing the location of the two areas (inset) included in this study and the six MPA sites in each of these areas. Dive sites in the vicinity of each MPA site are marked as red crosses.
high in both areas, especially in Danajon Bank where variances remained non-homogeneous in spite of transformation. Similarly, both areas showed significant differences in abundance and biomass between MPA sites (Sites) and between transects inside and outside of MPA boundaries (Loc). The lack of a significant main or interaction effect of years for these two variables indicates the absence of changes in abundance and biomass from one year to the other.

This pattern of results may be attributed to differences in structure and condition of individual reef habitats in each area or to insufficient time for protection to have an effect on fish assemblage structure and abundance. Hence, significant differences between locations within MPAs are not necessarily due to protection, but may be due to habitat differences existing even before the establishment of MPA boundaries in 2005. Alternatively, the observed pattern in differences might be simply due to high natural variability in habitats and their fish assemblages at the spatial scale addressed by the surveys. Villarta et al. (2010) show that the relationship between variability in reef habitat conditions (e.g., live hard coral cover) and distance between survey stations differs between reef systems (areas) and is likely determined by hydrography and physical landscape of specific reef systems.

Significant differences between years were detected only in Tawi-Tawi Bay, and only for number of species recorded per 500 m$^2$ area surveyed (richness) (Table 1). Species richness by MPA site were pooled and compared between years for Danajon Bank (Fig. 2) and Tawi-Tawi Bay (Fig. 3). In the former area, richness increased from 2006–08 in only one of the 6 sites (Bilang-Bilangan), with slight reductions in 3 other sites (Pinamgo, Cataban and Hingutanan). In contrast, changes in species richness in Tawi-Tawi Bay seemed to be more consistent (Fig. 3), with slight increases in 5 of the sites, except in Ungos-Ungos. The mean change in species richness across all sites was 7.6% (range: 0–16%), although none of these were statistically significant because of considerable differences inside and outside of MPA boundaries (Table 1). A comparison of species-area curves between 2006 and 2008 is shown Figure 4. In spite of substantial overlap in the curves for both years, overall log-linear species-area curves were significantly different. A comparison of regression slopes (t-test: $t=2.528$, df=101, $p<0.01$) showed that the increase in species richness per unit area is about 13.1% higher in 2008. This indicates that, on average, the number of species recorded within 500m$^2$ increased in 2008. Whether this is due to increased productivity, enhanced habitat complexity or a positive effect of protective management in 2008 is not yet known. Monitoring in these sites should be continued to provide a clearer explanation of this observation.

In the case of MPA management, blast-fishing has always been common in Tawi-Tawi. The number of blasts per hour observed (=heard) during daytime underwater surveys in the area from 2004 to 2008 are shown in Fig. 5. There appears to be considerable reductions in some areas, like Pababag and Ungos-Ungos, which are closest to the town center (see Fig. 1) and are therefore more accessible to the authorities, as well as in Tonggosong. On the other hand, there seems to be equally considerable increases in Doh-Tong and Tundol, both of which are far less accessible from the town center (see Fig. 1).

Blasts were recorded while divers were working underwater on the transect. From previous experience in the Bolinao reef flat in northern Philippines (Campos et al., 1994), blasts from within about a 1km radius can be heard under water. Since the MPAs in Tawi-Tawi do not generally exceed 50 has, it is likely that at least some of the blasts recorded underwater are outside of the immediate vicinity of the protected areas. Hence, while protective management may have truly eliminated blastfishing within and just outside the MPA boundaries since 2005, such practices may still have continued some distance from the protected areas where policing is usually absent. This may explain what appears to be a continuing increase in the frequency of blasts in at least 2 of the MPAs surveyed during the study. The decreasing trends in the other MPA sites, with an average reduction in blasts per hour of about 50% from 2006 (range: 32–84%) indicates that strict enforcement against blasting and other illegal fishing practices seemed to have worked in at least a few MPA sites.

Enhancement of natural productivity through protection need not necessarily lead to increased overall abundance of fish. An increase in species richness may ensue without an overall increase in abundance, especially if
fishing remains heavy in the vicinity of the MPAs or if conditions like food and habitat availability do not increase considerably as a result of protection. It is such subtle changes in fish and perhaps other reef assemblages that may be the initial effects of protection under conditions of continued heavy fishing in the vicinity.

A comparison of species-area curves in Tawi-Tawi Bay and Danajon Bank for 2008 provides additional insights (Fig. 6). In terms of species richness, the 6 MPA sites in Bohol can be further subdivided into a group with low diversity and another with high diversity (Bilang-Bilangan and Hingutanan, those closest to the outer bank) (see Fig. 1), but the overall change in richness per unit area is about 30% less than what was observed in Tawi-Tawi (t-test for comparison of slopes: t = 2.88; df = 107; p < 0.005). Blast records from Bohol during the period of study show only few occurrences, so that when averaged over actual time underwater during surveys in 2006 and 2008, the overall averages would be just above zero. Anecdotal accounts go back to previous decades of much more frequent blasting in the area, as evidenced by extensive areas of rubble and eroded substrate that can still be observed at the present. The central location of Danajon Bank reflects its ready accessibility to fishers from the numerous municipalities bordering it as well as from neighboring islands and provinces in Central Visayas.
heavily-fished even with its rather limited accessibility, the Danajon Bank area would then be much more intensely exploited and would’ve been so for a longer period of time. While this notion is anecdotal, this is nevertheless consistent with contentions of heavy losses in reef fish biodiversity in the Visayas region due to extensive heavy and oftentimes destructive fishing that has been practiced in the region for many years in the past (Nanola et al., 2011). Hence, it can be expected that reefs in Danajon Bank will generally take more time before signs of recovery can be observed.

In this context, we believe that relatively high levels of species richness are good indicators of the health and integrity of reef areas, and under conditions of intense fishing pressure, reefs with higher fish species richness are likely to recover faster. Thus reefs in Tawi-Tawi have a generally higher potential for recovery than similar reefs with lower fish diversity in other regions of the country.
Whether this is due to the natural richness of the species pool in the Sulu Sea (Nanola et al., 2011) or to the limited accessibility of these reefs which translates to protecting areas from less potential stress and disturbances, or both is not certain. Following similar arguments, the two MPA sites closest to the outer portion of Danajon Bank (Bilangbilangan and Hingutan) are likely to show recovery from protection sooner than the other four MPA sites.

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