Inferring Marine Protected Areas Effectiveness Out of Temporal Patterns Alone: The Case of Two Marine Protected Areas of Puerto Rico

Inferencia Sobre la Efectividad de Áreas Protegidas Basadas en Patrones Temporales: El Caso de Dos Áreas Marinas Protegidas de Puerto Rico

Inférence sur l'Efficacité des Aires Protégées en Fonction des Schémas Temporels : Le Cas de Deux Aires Marines Protégées de Porto Rico

JUAN JOSE CRUZ-MOTTA[1], RICHARD APPELDOORN[1], MICHELLE SCHARER[2], JACK OLSON[1], ERIC APPELDOORN[1], and FERNANDO MELENDE[1]
[1]*Department of Marine Sciences — University of Puerto Rico*
PO Box 9000, Mayagüez, Puerto Rico 00681 USA.
juan.cruz13@upr.edu richard.appeldoorn@upr.edu eric.appeldoorn1@upr.edu
olson.jackc@gmail.com evan.tuohy@upr.edu fernando.melendez1@upr.edu
[2]*HJR Reefscaping*
P.O. Box 1442, Boquerón, Puerto Rico 00622 USA.
michelle.scharer@upr.edu

EXTENDED ABSTRACT

Introduction

Marine Protected Areas (MPAs) have been proposed as one of the main management tools to protect biodiversity (Wilhelm et al. 2014) against multiple stressors such as pollution, climate change, urbanization and overfishing (Mora et al. 2006). These MPAs, however, are not necessarily working as their success greatly depends largely upon its size, age, isolation from similar benthic habitats and degree of enforcement (Edgar et al. 2014). Consequently, it is of paramount importance to evaluate the effectiveness of MPAs on a case by case *basis*. Ideally, to assess the effectiveness of an MPA, it is important to have representative reference areas (inside vs. outside MPA) and temporal comparisons for each (before vs. after MPA declaration), in addition to the proper replication at several spatial (various areas and sites within each MPA and reference area) and temporal scales (several times before and after) (Osenberg et al. 2011, Willis et al. 2003). This optimal situation, however, is not commonly found; consequently, inferences about effectiveness must be made from alternatives such as descriptions of patterns of temporal variation alone. This is the case of Mona Island, a relatively isolated and unique notake zone within the Mona and Monito Islands Natural Reserve located west of Puerto Rico. To infer effectiveness of the Mona Island no take zone (MNTZ), closed to fishing since 2004 (Aguilar-Perera et al. 2006) and modified in 2010 (Schärer -Umpierre et al., 2014), temporal trends of the structure and composition of fish assemblages were assessed and compared to those of La Parguera Natural Reserve (LPNR), which had waters up to 9 nautical miles designated in 1998 and has always been open to fishing (Schärer-Umpierre et al. 2014). To evaluate effectiveness, the present study was aimed at describing patterns of spatial and temporal variation of fish assemblages associated with coral reefs within these two MPAs.

Materials and Methods

Structure and composition of fish assemblages associated with coral reefs in two MPAs of Puerto Rico (Figure 1), were assessed at three different periods during 2017 - 2018 and compared with previous data collected during 2004-2006 in LPNR and 2005-2006 in MNTZ (Schärer-Umpierre 2009). These two periods were comparable for each MPA as 17-18 surveyors were trained by the scientist that did the 2005 survey. In each MPA, different zones were considered to account for known habitat differences (LPNR) and/or management designations (MNTZ) (Figure 1). Several sites were haphazardly selected within each zone and between 8 to 10 nonoverlapping visual censuses of fish were done within each site. Visual survey methods consisted of a belt 30x2 m = 60 m^2 belt at Mona and 25x4 = 100 m^2 at LPNR. Direct comparison between MPAs was not attempted because:

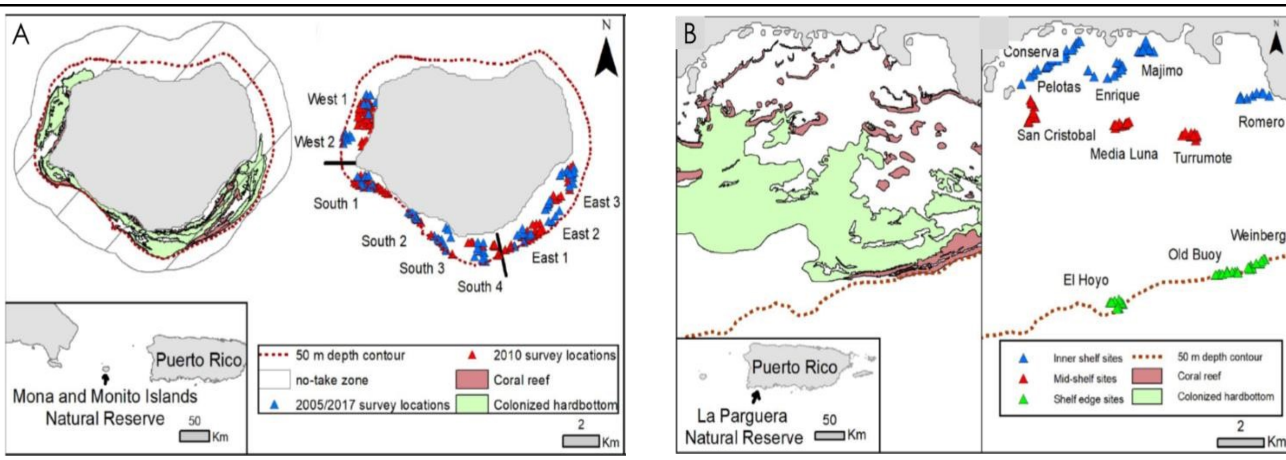
i) Different sampling units were used between MPAs through time, and
ii) Known sharp differences in habitats and fish assemblages found in these two MPAs (Schärer-Umpierre 2009).

Consequently, the strategy consisted of analyzing patterns of temporal variation in each MPA. It was hypothesized that these patterns would be different among MPAs, in terms of magnitude and direction of change in a multivariate space. It was also predicted that the type and magnitude of change would be consistent with the fact that MNTZ is a no-take area, whereas in LPNR fishing is allowed. To test these hypotheses, Permutational Multivariate Analyses of Variance (PERMANOVA) were done on the biomass data of the entire fish assemblage per MPA. The analysis accounted for five sources of variation: Periods (2004 - 2006 and 2017 - 2018), Times (Between 2 and 6 per period), Zones (two or three depending on MPA) and Sites (between 8 and 10 per site). Patterns of temporal and spatial variation were illustrated by means of multivariate ordinations of centroids per site and time.

Results and Discusion
(includes conclusion and recommendation)

Overall, 179 species were reported, of which 152 were found in LPNR and 146 in MNTZ with 68% of those species shared between the two MPAs. Standardized biomass per sampling unit ranged between 8-15 kg/100 m^2 and 8-13 kg/100m^2 in LPNR and MNTZ, respectively. Regardless of temporal variations described below, structure and composition of fish assemblages differed between MPAs and among zones in each MPA (Figure 2). This multivariate ordination shows that inner and mid shelf sites (blue and red symbols) were very different from sites in the outer shelf (green symbols) in LPNR. It is also evident that sites in MNTZ (pink and light blue symbols) were different from sites in LPNR, however fish assemblages in the outer shelf sites of LPNR seemed more similar to those sites in MNTZ than to sites located in the inner and mid shelf of LPNR itself (Figure 2). Similarities between the outer shelf of LPNR and MNTZ were characterized by speciose assemblages represented by small groupers, parrotfishes, angelfishes, and surgeon fishes.

In addition to these spatial patterns, important temporal changes (49% of total variation) were observed in all zones in both MPAs. These temporal changes, however, had different magnitudes and directions in different zones and MPAs (Figure 2). It can be noted that differences between the period 20042006 (filled symbols) and 2017 - 2018 (empty symbols) were greater for sites in LPNR than those in MNTZ, indicating that the species responsible for changes were not the same in all zones and MPAs. Changes in the inner and mid shelf of LPNR corresponded to a 30% reduction in the average number of species observed per sampling unit. In the inner and mid shelf, number of species observed per sampling unit ranged between 16 and 19 during the period 2004-2006, but dropped to 8 and 14, respectively, in 2007 - 2018. Importantly, despite the reduction in α-diversity (i.e., number of species per sampling unit), γ-diversity (i.e., total number of species per zone) only showed a non-significant reduction of 9%. In the outer shelf of LPNR, changes were more complex because it involved a substitution of species in the assemblage rather than the disappearance of species. During the period 2004 - 2006, assemblages in the outer shelf were very variable at the scale of sites (i.e., different sites along the outer shelf were very different) and were characterized by mid-size groupers, parrotfishes, and surgeon fishes. During the period 2017 - 2018, sites in the outer shelf were more homogeneous since all sites along the outer shelf were very similar. These new assemblages were characterized by species that were normally found in the inner and outer shelf, such as the lutjanid *Osyurus chrysurus,* damselfishes and squirrelfishes, as well as by species of triggerfishes that were normally found in the outer shelf during the period 2004- - 006. In the outer shelf, α-diversity (12 to 24 species per sampling unit) and γ-diversity (78 to 81 species) remained constant between periods, however there was a significant reduction in β-diversity at the spatial scale of sites (average Bray-Curtis dissimilarity among sites decreased from 67.78 % +/- 5.02 to 44.25% +/- 10.42). Finally, temporal changes in MNTZ were not as big as those observed in LPNR and were not reflected in loss of diversity at any of its components (α, β or γ diversity). Conclusions about temporal changes in MNTZ, however, must be handled with care as only one sampling time was considered during the period



- No Take Zone since 2004, 2010	- Multipurpose (fishing allowed) since 1998
- Management Plan	- NO Management Plan
- Isolated	- Connected
- Oceanic Island	- Terrestrial influence
- No mangroves	- Mangroves

Figure 1. Sampling sites and MPAs characteristics: A) MNTZ and B) LPNR. Taken and modified from (Olson, Appeldoorn, Schärer-Umpierre, and Cruz-Motta, 2019)

2005-2006. Assemblages of fish in MNTZ showed a slight increase in the total biomass of a wide array of species that include several species of lutjanids, some grunts, triggerfishes, trunk fishes, rays, angelfishes, porgies, small sized groupers (*Cephalopholis fulva*) and barracudas. These increases, however, were mostly related to increases in numbers (i.e., abundances) and not in sizes.

In conclusion, fish assemblages showed important spatial differences among MPAs and zones within these two MPAs. In addition, fish assemblages showed significant temporal changes in both MPAs. The magnitude and direction of change, however, differed between LPNR and MTZ indicating that different ecological processes and or anthropogenic disturbances (e.g., overfishing) might have been operating in each MPAs. Even though, ecological processes cannot directly be inferred from descriptions of patterns alone (Underwood et al., 2000), such as the ones reported here; some inferences can be done based on the type of changes that were described. In particular, the loss of α-diversity in the inner and mid shelf, and loss of β-diversity in the outer shelf indicate that LPNR is not performing well in terms of maintaining biodiversity. On the other hand, and even though increases of commercially important species (e.g., large groupers and snappers) have not been observed in MNTZ, biodiversity has not significantly changed. In addition, several species have shown a slight increase a total biomass, which lead us to propose that in MNTZ fish assemblages have not deteriorated as much as those in LPNR, likely as a benefit of notake protection.

KEYWORDS: Marine protected Areas, effectiveness, temporal trends, Puerto Rico

LITERATURE CITED

Aguilar-Perera, A., M.T. Schärer, and M. Valdés-Pizzini. 2006. Marine protected areas in Puerto Rico: Historical and current perspectives. *Ocean & Coastal Management* **49**(12):961 - 975. https://doi.org/10.1016/j.ocecoaman.2006.08.011

Edgar, G.J., R.D. Stuart-Smith, T.J. Willis, et al. 2014. Global conservation outcomes depend on marine protected areas with five key features. *Nature* **506**(7487):216 - 220. https://doi.org/10.1038/nature13022

Mora, C., S. Andréfouët, M.J. Costello, et al. 2006. Coral reefs and the global network of marine protected areas. *Science* **312**(5781):1750 - 1751. https://doi.org/10.1126/science.1125295

Olson, J.C., R.S. Appeldoorn, M.T. Schärer-Umpierre, and J.J. Cruz-Motta. 2019. Recovery when you are on your own: Slow population responses in an isolated marine reserve. *PLoSONE* **14**(10):1 - 22. https://doi.org/10.1371/journal.pone.0223102

Osenberg, C.W., J.S. Shima, S.L. Miller, and A.C. Stier. 2011. Ecology - Assessing effects of marine protected areas: Confounding in space and possible solutions. *Marine Protected Areas: A Multidisciplinary Approach*, 143 - 167. https://doi.org/10.1017/CBO9781139049382.010

Schärer-umpierre, M.T. 2009. *Using Landscape Ecology to Describe Habitat Connectivity for Coral Reef Fishes*. Ph.D. Thesis. University of Puerto Rico, Mayaguez, Puerto Rico USA.

Schärer-Umpierre, M.T., D. Mateos-Molina, R. Appeldoorn, et al. 2014. Marine managed areas and associated fisheries in the US Caribbean. *Advances in Marine Biology* **69**:129 - 152. https://doi.org/10.1016/B978-0-12-800214-8.00004-9

Underwood, A.J., M.G. Chapman, and S.D. Connell. 2000. Observations in ecology: you can't make progress on processes without understanding the patterns. *Journal of Experimental Marine Biology and Ecology* **250**(1 - 2):97 - 115. https://doi.org/http://dx.doi.org/10.1016/S0022-0981(00)00181-7

Wilhelm, T.A., C.R.C. Sheppard, A.L.S. Sheppard, C.F. Gaymer, J. Parks, D. Wagner, and N. Lewis. 2014. Large marine protected areas - advantages and challenges of going big. *Aquatic Conservation: Marine and Freshwater Ecosystems* **24**(S2):24 - 30. https://doi.org/10.1002/aqc.2499

Willis, T.J., R.B. Millar, R.C., Babcock, and N. Tolimieri. 2003. Burdens of evidence and the benefits of marine reserves: Putting Descartes before des horse? *Environmental Conservation* **30**(2):97 - 103. https://doi.org/10.1017/S0376892903000092

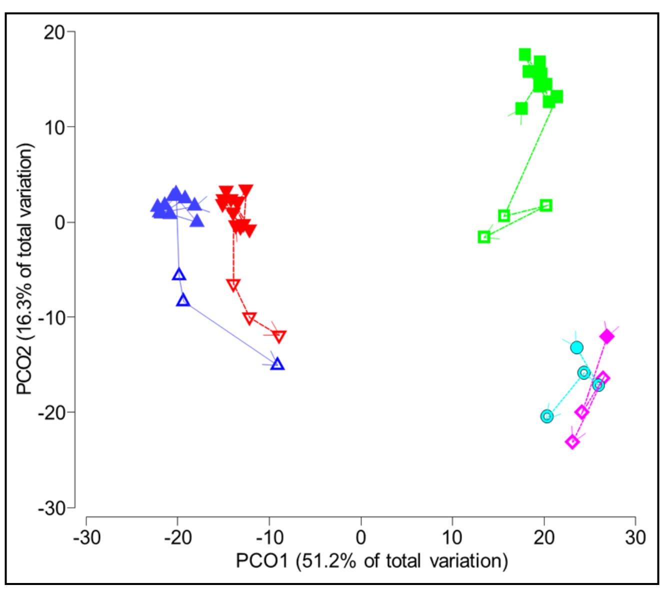


Figure 2. Principal Coordinate analyses showing patterns of spatial and temporal variation of centroids per site, zone, MPA and Time. LPNR = ▲ inner, ▼ mid, ■ shelf; MNTZ = E/W ● South. Filled Symbols = period 2004-2006, Empty symbols = 2017-2018.