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Links between fish community structure and habitat complexity of a rocky reef in the Gulf of California threatened by development: Implications for mitigation measures

C.A. Sánchez-Caballero [a, b, *], J.M. Borges-Souza [a], G. De La Cruz-Agüero [a], S.C.A. Ferse [b]

[a] Department of Fisheries and Marine Biology, Interdisciplinary Center of Marine Sciences, Instituto Politécnico Nacional (CICIMAR-IPN), La Paz, Baja California Sur, Mexico
[b] Department of Ecology, Leibniz Center for Tropical Marine Ecology (ZMT) Bremen, Germany

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ABSTRACT

In reefs, fish distribution and community structure are strongly linked to habitat structure. The objective of this study was to develop a baseline of the attributes of a rocky reef fish community threatened by development and their possible relationship with habitat complexity in order to assess how predicted habitat modification would impact the fish community. In the study area, the construction of a tourist marina is planned as part of a residential area with a total size of 500 ha. The project includes the translocation of corals, infilling of reclamation areas by dredging, and floating docks, which is predicted to affect both benthic rugosity and the types of benthic cover. Using hierarchical clustering based on benthic substrate type and rugosity we defined three levels of habitat complexity (Low, Medium, High). The fish community at different levels of complexity was characterized in terms of species richness, abundance, diversity and dominance, and was classified into seven trophic groups. Transects with high habitat complexity featured the highest cover of dead coral with macroalgae (43.7% ± 2.3, mean ± SE) and live coral (21.0% ± 1.9). There were no significant differences in rugosity among the three levels of habitat complexity (ANOVA, $F = 0.145$, $df = 2$, $p = 0.87$). A total of 19,799 individuals belonging to 76 species were recorded over an area of 12,000 m^2. The greatest mean density and species richness occurred at high habitat complexity, with 1229.7 (±202.7) individuals per 500 m^2 and 64 species, respectively. Community structure was significantly different in richness and abundance between high and low levels of complexity ($p < 0.05$). It is expected that the benthic habitat will be modified mainly by dredging associated with the construction of reclamation areas and the translocation of benthic organisms (mostly corals), affecting the habitat variables associated with different levels of habitat complexity in our survey. Reducing habitat complexity as a result of development is predicted to lead to a loss of species richness and ecological functions. A better understanding of the influence of habitat complexity on reef organisms can help to predict the potential impacts of habitat degradation and develop appropriate mitigation measures. Based on the results, a number of measures are suggested to detect and mitigate the expected negative impacts of construction and operation of the marina.

1. Introduction

In reef environments, fish distribution is not uniform and tends to be aggregated (Adjeroud et al., 1998). The distributional heterogeneity can be attributed to multiple processes and factors such as competition, the availability of food and habitat complexity (Bohnsack, 1989; Buchheim and Hixon, 1992; Hixon and Beets, 1993).

It has been observed that habitats with high structural complexity have greater abundance and species diversity compared with less complex environments (Angel and Ojeda, 2001; Bell and Galzin, 1984). The effect is most pronounced for territorial species (Almany, 2004; Garpe, 2007; Gilligan, 1980; Roberts and Ormond, 1987; Sale and Douglas, 1984), for shallow

* Corresponding author. Department of Fisheries and Marine Biology, Interdisciplinary Center of Marine Sciences, Instituto Politécnico Nacional (CICIMAR-IPN), La Paz, Baja California Sur, Mexico.
E-mail address: cas_caballero@live.com.mx (C.A. Sánchez-Caballero).

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fish habitats (Angel and Ojeda, 2001; Chabanet et al., 1997; Steele, 1999), and for species of small sizes, including recruits and juveniles of bigger species that depend directly on structurally complex reef features to settle and feed (Alvarez-Filip et al., 2011; Garpe et al., 2006).

Coral and rocky reefs are among the ecosystems that have been altered intensely by increasing urban development (Jordan et al., 2009; Pratchett et al., 2011; Wen et al., 2010). The principal causes of concern are: habitat fragmentation, pollution from industrial and urban sources, sedimentation and physical impact by marine activities (Richmond, 1993), with subsequent impacts on the species associated with these ecosystems. In many cases there is insufficient information available to monitor changes in fish communities.

Habitat degradation in coral reefs is usually understood as the decline in habitat formed by corals and their replacement by any other organism or structure (Hughes et al., 2003). Construction activities in coral reef areas in particular frequently entail removal of material from the seafloor, reducing coral cover and structural complexity, and the creation of new artificial structures such as breakwaters (PIANC, 2010). In places where habitat complexity has decreased as a result of anthropogenic disturbances, fish diversity and abundance is usually low (Jones et al., 2004; Graham et al., 2007; Pratchett et al., 2011). For fish in rocky reefs, where corals are not a major habitat feature, the effect of loss of live coral cover itself is expected to be less than the effect of a decrease in structural complexity (Graham et al., 2007; Lindahl et al., 2001). It is possible that some generalist fish could even benefit from changes in habitat structure and the disappearance of coral cover (Bellwood et al., 2006; Wen et al., 2010). Several studies have described that the presence of artificial structures contributes to increased fish biomass (Bohnsack, 1989; Clynick, 2008; Fabi et al., 2004; Wen et al., 2010). This is possible because the artificial structures are creating new habitats that support a different set of plants and animals compared to natural habitats (Clynick, 2008). Dredging and land reclamation activities furthermore frequently lead to significantly increased sediment loads to the surrounding areas, which lead to lethal and sublethal effects on corals and other benthic biota (Jones et al., 2016; McCook et al., 2015). Sedimentation varies in its impacts on coral species, which differ in their susceptibility depending e.g. on their morphology. Massive, branching and foliose species appear most susceptible to sedimentation impacts (Erftemeijer et al., 2012). Creation or modification of habitat has the potential to alter the distribution, diversity and abundance of organisms in such environments (Connell and Glasby, 1999; McDonnell and Pickett, 1990). In order to understand the effects of habitat modification and altered habitat complexity on fish communities, the relationship between the fish community and specific habitat attributes in an area prior to its modification needs to be known.

In the study area, the construction of a tourist marina is planned as part of a residential area with a total size of 500 ha. The tourist marina construction will last for 5 years, with about 80% of the construction work and development activities located in a rocky reef area featuring numerous colonies of live corals. The principal construction structures are two main breakwaters and floating docks in addition to other shipping infrastructure, such as a boat ramp, navigational features, a fuel terminal, warehouses and stores (SEMARNAT/DGIRA, 2014).

The first two years of construction have the highest potential of causing damage to the marine environment because the construction area will be cleared, both breakwaters will be embedded, and land reclamation carried out. In the third year of the project, construction of the first part of floating docks (50%) along the boat ramp, of the fuel station and of the boardwalk is planned. In the fourth year, the construction of the second part of the floating docks (the remaining 50%) is planned. Finally in the fifth year, operation of the tourist marina with all services is slated to begin (SEMARNAT/DGIRA, 2014). It is expected that benthic habitat will be modified mainly by dredging associated with the construction of reclamation areas and the translocation of benthic organisms, mostly corals (SEMARNAT/DGIRA, 2014), as has happened in others reefs, for example in the Caribbean region (Alvarez-Filip et al., 2011). This will likely affect the benthic habitat by a reduction of live coral cover, increase in sand, and reduction of structural complexity. Furthermore, construction activities and the operation of tourism facilities run the risk of increased nutrient release and terrestrial runoff, noise pollution, as well as recreational fishing impacts on the reef environment.

The aim of the current study was to develop a baseline of the distribution, diversity and abundance of reef fishes at the study site before the onset of construction activities and to assess their link to habitat complexity, in order to predict the potential impacts of habitat degradation from construction and to inform potential mitigation measures. It was hypothesized that areas with high habitat complexity would feature the highest fish abundance, biomass and species richness.

2. Methodology

2.1. Study area

The study was carried out between 2010 and 2012 on the rocky reef in front of “La Sorpresa” (Surprise) beach located in the southern Gulf of California, Mexico, at 24°15′06.16″ N, 110°09′18.17″W (Fig. 1). The Sorpresa reef is comprised of rocky areas of various sizes from small pebbles to giant rock masses forming small islets, sand and coral patches mainly dominated by species of the genera *Pocillopora* and *Porites* and, to a lesser extent, *Psammocora* and *Pavona*. No previous monitoring studies on the area exist, but anecdotal information from local inhabitants indicates that fishing pressure at the Sorpresa reef is low.

A two-step approach was used to relate habitat complexity with rocky reef fish community structure: first, characterization of habitat complexity; second, assessment of relationships between rocky reef fish and levels of habitat complexity.

2.2. Characterization of habitat complexity

Both benthic community composition and structural complexity are important factors in structuring the associated fish community (e.g., Bell and Galzin, 1984; Friedlander and Parrish, 1998; Risk, 1972). With the objective to capture the anticipated impacts of coastal development in the study area, we thus used a combination of habitat variables to describe habitat complexity: benthic substrate types and structural complexity (Bell et al., 1991; Ferreira et al., 2001; Roberts and Ormond, 1987). Habitat complexity was derived from benthic cover based on the following types of substrate: sand (S), macroalgae (MA), coral (C), dead coral with macroalgae (DC) which includes remnants of live coral, hardpan (H; defined as a cemented and compacted layer of soil at the surface), rock (R), as well as a measure of rugosity. Cover by substrate types was evaluated from 15 photographic transects of 50 m length placed haphazardly throughout the study area (Fig. 1), each comprising 20 pictures (drawing an outline around each substrate type on the photo). Digital photographs were taken parallel to the substrate at a height of 1.20 m, with approximately 1.5 m of distance between each photo. The distance from the substrate to the camera was controlled using a stick attached to the camera. The digital picture recorded an area of 1 m^2. The analysis of each photo