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Long-term changes in taxonomic distinctness and trophic structure of reef fishes at Cabo Pulmo reef, Gulf of California

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Abstract. Cabo Pulmo is the northernmost coral reef in the eastern Pacific, and has a remarkably high biodiversity. The Mexican government declared the area a National Park in 1995 and protection has been quite effective, resulting in increases in biomass and abundance of predator fish species. This study evaluates changes in average trophic level (indication of carnivory) and community structure of the 13 most important reef fish families, between 1987 to 2006. We performed censuses in observation cylinders (N=230), and calculated several ecological indices, as well as the taxonomic distinctness and average trophic level of the assemblages. The results show that fish community composition clearly differed in time as richness, diversity, evenness and taxonomic distinctness had higher values in the 1990s; at the same time the trophic level increased through the years, and its relation to most ecological indices was inverse and significant. The National Park had a positive influence on the fish community, at the same time carnivores seem to have depleted the abundance of many species and simplified the fish community. We conclude that conservation efforts have reached its goals but at the same time produced unexpected consequences in the composition and function of the area.

Key words: Community structure, Average trophic level, Marine protected area, México, Pacific Ocean

Introduction

The eastern Pacific region has many small and underdeveloped coral reefs, distributed from México to Colombia. The environmental conditions of this region are not adequate for zooxanthellate corals as the area presents relatively cold waters, large sandy tracts, a narrow continental shelf, and intense winter upwellings (Glynn and Ault 2000). However, the importance of those ecosystems in Latin America is high as they are characterized by an unusual mix of endemic taxa and immigrants from the central and western Pacific (Ketchum and Reyes-Bonilla 2001), and thus represent key areas for conservation (Aguilar et al. 2007; TNC 2008).

México is one of the countries that have paid substantial attention to research and protection of reefs, especially in the Gulf of California. In that inner sea there are only two areas where coral development is good enough that they can be considered as "functional reefs": San Gabriel Bay (24°N) and Cabo Pulmo (23°N; Reyes-Bonilla 2003). The latter has been recognized as a hotspot of marine species richness (Steinbeck and Ricketts 1941; Brusca and Thomson 1975; Robinson and Thomson 1992; Reyes-Bonilla 2003; Sagarin et al. 2008); the literature indicates more than 200 fish species and over 500 invertebrates reported for the area (Villarreal Cavazos et al. 2000; Hendrickx et al. 2005). The Mexican government recognized the relevance of the site and declared it a National Park in 1995, but the management plan was published until December 2006. According to the law of the country, all protected areas require at least some portion that should be open to extractive use (this means that the "no take zones" are not supported by the federal government, but nevertheless particulars or fishing cooperatives can exert its right to completely close any part of their own or concession areas; Lubchenco et al. 2007). However, at the same time the law establishes that no human use can be done in a reserve until the management plan is published (Aguilar et al. 2007). As a result of these regulations, we have witnessed the unusual case that *because of the lack* of a conservation program, the Cabo Pulmo residents, who were originally fishermen but changed their way of living to provide diving and sport fishing services, took the unilateral decision to avoid extractive uses in the park, and with help from NGOs and academic institutions, *de facto* managed efficiently the area for over a decade (Arizpe 2005).

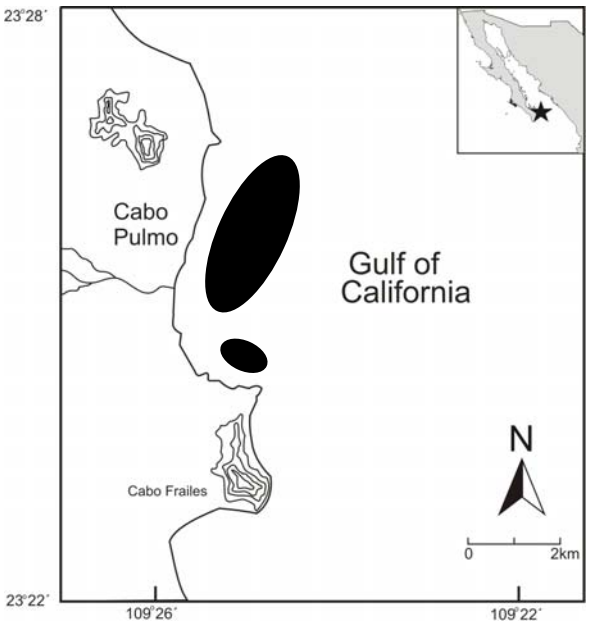

Figure 1: Study area, showing the approximate position of the coral reef.

There is a growing body of scientific evidence pointing out that no take areas bring noticeable advantages for conservation and fisheries, particularly higher biomass and larger fish sizes, an increase in abundance of carnivores (this is, a higher trophic level of the assemblages), and economic benefits for residents (Halpern 2003; Gell and Roberts 2003; Lester and Halpern 2008). Cabo Pulmo National Park is no exception and in the last decade there has been a noteworthy improvement in the general state of the reef and also in the living standard of the people (Angeles-Villa et al. 2008). Considering this background, the objective of this paper was to assess the effects of the conservation of the reef, taking as a measure the changes in trophic level and in several ecological indices of the fish assemblages at Cabo Pulmo. We noticed that as anticipated, a steady increase in abundance and size of carnivores has been occurring after the park was established, but interestingly, this also brought an unexpected reduction in the complexity of community structure. Our results call attention to responses at species and community level which were not anticipated when management efforts focused on specific targets (higher level predators), and resulted in an "ecological surprise" (Doak et al. 2008).

Material and Methods

Study area. Cabo Pulmo reef (Fig. 1) is located in the southeastern portion of the Baja California Peninsula, México. The area has a warm, tropical climate, and the sea temperature yearly fluctuates between 18° and 30° C (Arizpe-Covarrubias 2008). Photosynthetic pigment concentration is only 0.24 mg/m^3, with an annual range of 0.06 to 1.44 (NASA 2008), and correspondingly, nutrient concentrations are among the lowest in the Gulf of California, (WOA05 2008).

The coral community grows on basaltic outcrops and is composed of 12 species of five genera, with *Pocillopora* as the dominant one, followed by *Porites* and *Pavona*. (Alvarez-Filip et al. 2006). Coral cover was high in the 1980s and 1990s (over 30%; Reyes-Bonilla and Calderón-Aguilera 1999; Arizpe 2005) but decreased drastically after the 1997 ENSO event (Reyes-Bonilla 2001). To date recovery has been limited as the reef was impacted by several hurricanes and tropical storms, especially in 2003 (Alvarez-Filip et al. 2006). As a result, the coral cover in 2007 was 21%, a very small step up from the late 1990s.

Field Work. For this study we conducted censuses at Cabo Pulmo in nine different years during the interval 1987 to 2006. The counts were done at depths from 1 to 15 m (base of the reef), inside observation cylinders of 7.5 m radius in 1987 and 1994 (176 m^2 in area), and of 5 m radius in the remainder years (76 m^2). Because of the difference in sampling area and to make adequate comparisons, the number of individuals per census was scaled using density (ind/m^2) before any calculation.

For the analysis we included density data of the 13 "typical" reef fish families: Acanthuridae, Apogonidae, Blennidae, Chatodontidae, Haemulidae, Holocentridae, Labridae, Lutjanidae, Pomacanthidae, Pomacentridae, Scaridae, Scorpaenidae and Serranidae (Bellwood 1998; Robertson 1998), which are also the most abundant at Pulmo reef (Villarreal Cavazos et al. 2000). From that information we calculated the following community indices: species richness (S), Shannon-Wiener diversity (H´), Pielou´s evenness (J´), average taxonomic distinctness (Δ*) and taxonomic distinctness (Δ+). Finally, we estimated the average trophic level of the fish assemblages at each cylinder using the method of Pauly et al. (1998), and information of diet for each species from FishBase (2008).

Statistical analyses. We performed several statistical procedures. First, parametric analysis of variance and Tukey *a posteriori* tests were used to determine differences in each index among years in the sampling span. Then, the Pearson correlation coefficient was applied to evaluate the relation between trophic level and each ecological index, and simple linear regressions were conducted between trophic levels and those indices that were significantly related to the factor; in this case the idea was to depict the rate of change in the community structure using the slope of the regression (Zar 1999).

Results

The analysis of variance evidenced statistical differences in most indices (in all cases, degrees of freedom were 8,221). For richness, the year 1987 (19.8 ± 0.9 sp/census) differed from the rest (10.9 ± 0.8 sp/census general mean from 1994-2006; F=20.1, P< 0.01). In the case of density, again 1987 had the highest figure (2.7 ± 0.7 ind/m^2), but in addition, 2003, 2004, 2005 and 2006 had more individuals per census (in all cases over 1.0 ind/m^2) than years between 1994 and 2001 (less than 0.8 ind/m^2).

Diversity was highest in 1987 (1.77 ± 0.03 decits/ind), but the ANOVA and Tukey test determined that the difference among years was actually caused by the low values observed in 1994, 2002 and 2003, related to the rest (F= 4.1, P= 0.0001). Finally, evenness was significantly lower in 1994, very high in 1999, and remained statistically similar in the remainder years (F= 3.2, P= 0.001).

When the analysis covered taxonomic diversity (Δ+) there were no statistical difference (F= 1.7, P= 0.09) but in contrast, for Δ* (taxonomic distinctness) all years before 2000 had higher values than those of ensuing ones (F= 3.5, P= 0.001). The trophic level also differed among years (F= 3.1, P= 0.002), and 2002 and 2006 showed higher figures than all others (Fig. 2); furthermore, as a group the values of between 1994 and 1999 were significantly lower than those of the 2000s (t 228= 2.18, P= 0.03).

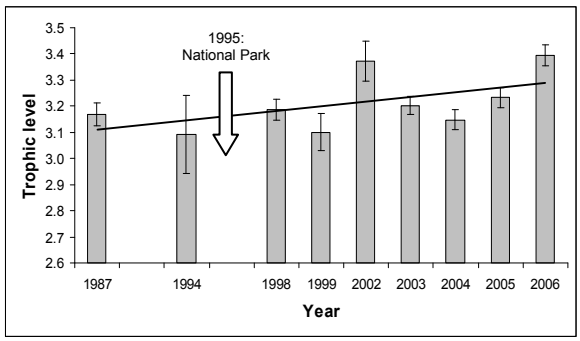

Figure 2. Trophic level of the icthyofauna at Cabo Pulmo reef, western México (average ± SE), and regression line of the values (slope: 0.008, ordinate: -14.65. r^2= 0.15, p= 0.16).

The data (Fig. 2) show that the trophic level has increased steadily from 1994 to 2006 (annual change of 0.008 units, according to the regression slope), and especially after the declaration of the National Park (annual change in 1999-2006 was 0.019); however, in both cases the relation was not significant, indicating that although the change seems to exist it is still not statistically relevant.

The correlation analysis between trophic level and the ecological indices (Table 1, Fig. 4) showed that the latter (including those with a taxonomic component), behaved similarly and were significantly linked. At the same time, it depicted that the trophic level was related negatively with all indicators, except fish density (positive relation) and Δ+ (not significant).

Table 1. Pearson correlation coefficients for ecological indices and trophic level of the reef fish community at Cabo Pulmo reef (1987-2006). All values are significant, except when noted (*). Key: S= species richness; N= density; H´= Shannon-Wiener diversity; J´= Pielou evenness; Δ*= Average taxonomic distinctness; Δ+= Taxonomic distinctness.

	S	N	H´	J´	Δ*	Δ+
N	0.33					
H´	0.63	- 0.21				
J´	0.06 *	- 0.49	0.79			
Δ*	0.18	- 0.05 *	0.29	0.22		
Δ+	0.30	- 0.01 *	0.28	0.13	0.53	
TL	- 0.15	0.19	- 0.35	- 0.35	- 0.14	- 0.05 *

The NMDS showed that community changed noticeably between 1987 and the 1990s, but afterwards (between 2003 and 2006), the composition of the assemblages became quite similar to what it was before artisanal fisheries were important.

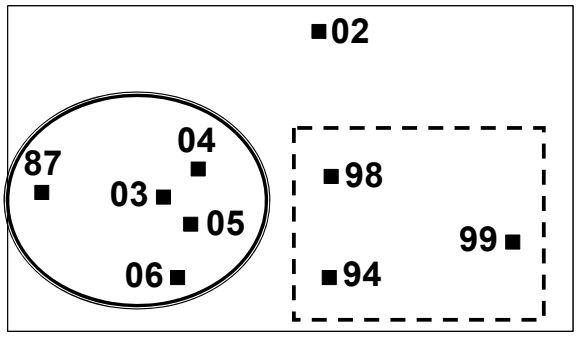

Figure 3. Nonmetric multidimensional scaling plot of the fish assemblages at Cabo Pulmo (1987-2006).

Discussion

This paper shows that as observed elsewhere, the establishment of Cabo Pulmo Marine Park led to fast changes (Polunin and Roberts 1993; Russ and Alcala 2004), and also modifications in the fish community. Practically all ecological indices showed a reduction in value with time (they were especially low in the early years of this decade), while at the same time the average trophic level of the community ascended gradually. These trends were clearly pointed out by the correlation analyses (Table 1) in which practically all coefficients had a negative sign, meaning an inverse relationship.

The effects of the increase in carnivore are better shown in Fig. 4, where simple linear regressions evidenced how a rise in trophic level is followed by a decrease in richness, diversity and taxonomic distinctness of the fish fauna, this is, by a simplification of the general community structure.

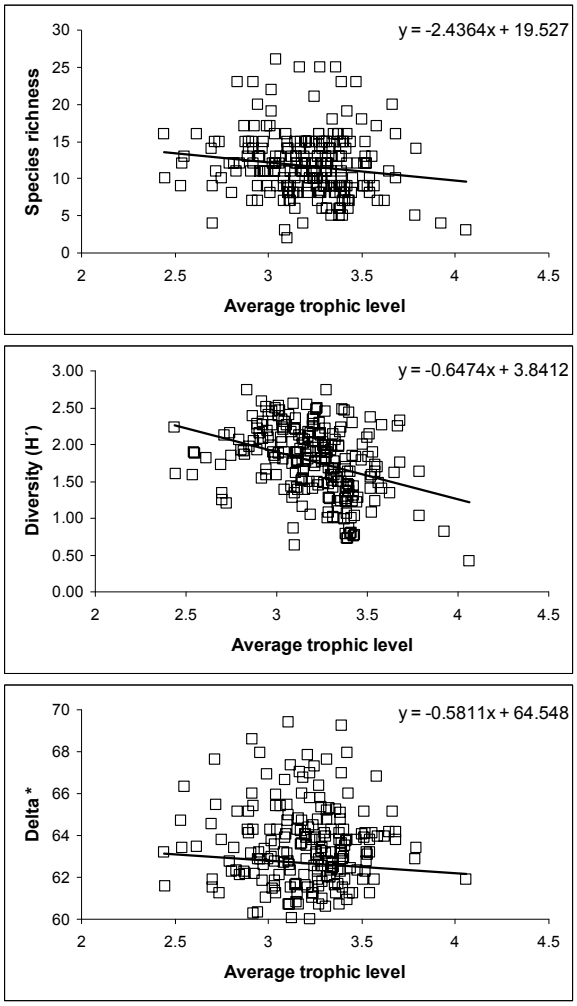

Figure 4. Regression analyses of trophic level and selected ecological indices of the icthyofauna at Cabo Pulmo reef.

Of those indices analyzed in Fig. 4, Shannon-Wiener diversity and species richness were most affected, as shown by the regressions slope. These measures depend on the number of fish taxa seen per transect and the relative abundance of the species (Magurran 2003), and consequently we suggest that the action of predators has been gradually diminishing the variety of fish types, and also the dominance of pomacentrids and labrids, the best-represented families in the reef (Alvarez-Filip and Reyes-Bonilla 2006).

In addition to the increase in trophic level, there are other indications of the good state of the assemblages. For example, the length of commercial species like the bumphead parrotfish *Scarus ghobban* Forskaal 1775, and the leopard groper *Mycteroperca rosacea* (Streets 1877), have augmented in the last years as a consequence of the lack of fishing (Fig. 5). Also, the larger size of fish aggregations is apparent, and finally the sightings of tiger and bull sharks in the reef have become common. All these observations point out the fact that large predators have returned to the reef.

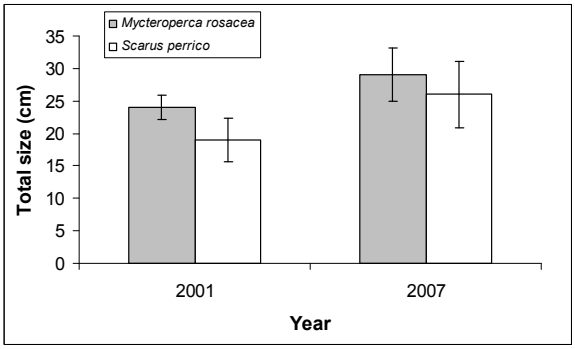

Figure 5. Differential in size (total length) of two key commercial species at Cabo Pulmo reef in the last decade.

The cited changes in fish assemblages are not a response to the local reef condition; to the contrary, coral cover has had small variations in the aftermath of the 1997 ENSO (average from 20% to 23%; Reyes-Bonilla 2001, 2003), especially because of repeated hurricane-caused damage (Alvarez-Filip et al. 2006). In addition, preliminary data shows that other faunas have been also influenced by the presence of higher level fish carnivores; for example, predatory damage is increasing on sea stars, and the abundance of certain species such as the urchin *Diadema mexicanum* Agassiz 1863, in 2006 was much reduced from the one in 1987. We suggest that the increase in fish predators is causing a substantial modification of the composition (and probably the function) of the entire reef ecosystem.

The response of the fish community of Cabo Pulmo to the increase in trophic level coincides with Barrett et al. (2007) remarks that predation is causing species specific and complex responses in Tasmanian reefs; however there is a key difference among regions because richness shifted in opposite directions as a consequence of the presence of large predators (down in México, up in Australia). In short, the divergent results advice of the need of more studies in different geographic realms before the trends of the ichtyofauna can be established with confidence.

We conclude that the establishment of Cabo Pulmo National Park has been a success from the perspective of the increase in abundance of carnivore species and sizes, and in general it can be said that the fish fauna shows an excellent conservation status. However,

there has been a simultaneous decrease in several ecological indices such as richness, diversity and taxonomic distinctness, an evidence of a simplification of the community, probably due to the depletion of specific kind of prey. Undoubtedly the conservation efforts have reached its goal, but nevertheless they brought upon unexpected changes in the ecological complexity and probably diminished the range of functions of reef fishes in this protected area.

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