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Cozumel Island, México: A disturbance history

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Abstract. This study aims to determine the damage caused by the 2005 hurricanes "Emily" and "Wilma" on the landscape structure of the Parque Nacional Arrecifes de Cozumel (PNAC), México. We conducted samplings at six reefs located in the PNAC during May 2005 and May 2007. At each reef, six 30-m point-intercept transects were run parallel to the coast. The bottom elements that were quantified were coral, sponges, macro algae, coral with recent death, rock and sand. Landscape structure was quantified with the Pielou´s evenness index (J´), and changes were evaluated with non-metric multi-dimensional scaling (NMDS) and the Bray-Curtis similarity coefficient. The results show a significant decrease in the percentage of live cover, and an increase in the percentage of sand and rock. Corals were the most affected group decreasing from 24% to 10% in cover after the two hurricanes; fortunately, cover has increased to 16% by May 2007. Significant differences were found in the landscape evenness, being lower in July 2005($F_{5,210}$= 14.94, P=0.00),; the high similarity of J´ between May 2005 and May 2007 indicates a clear trend of recovery in the reefs. The NMDS show that the two hurricanes affected Cozumel reefs with varying intensity, with "Wilma" having an impact four times higher than "Emily".

Key words: Hurricanes, reefs, algae, Scleractinian coral, sponge, sand, rock.

Introduction

Tropical storms are usually seen as natural disturbances that modify the structure of biotic assemblages in short time periods on tropical reefs (Woodley et al. 1981). However, these phenomena also modify the abiotic components of the landscape and therefore their influence on biodiversity is not just immediate but can last for many years (Michener et al. 1997).

The most developed reefs in Mexico are in the Caribbean (Jordan-Dahlgren 1993). These reefs represent the northernmost part of the Mesoamerican Reef, recognized as one of the most important reef systems in the world (Almada-Villela et al. 2003). In this region, the island of Cozumel represents a key ecological reserve because of the high species richness and the complexity of the ecosystem (Jordán-Dahlgren and Rodríguez-Martínez 2003; Fig. 1). Cozumel reefs are also highly important for the socio-economics of the region, since they attract thousands of divers and snorkelers by its spectacular underwater spots (Spalding 2004).

During 2005, the island of Cozumel suffered the impact of two of the strongest hurricanes in record, "Emily" and "Wilma" (Alvarez - Filip 2007). The first one hit the coast of the Yucatan Peninsula on July 17, with sustained winds of 215 km/h and gusts up to 260 km/h. The eye of the hurricane passed about 5 km from the southern tip of Cozumel, moving in southeasterly direction, so the intensity of the winds diminished to the north of the island. A few months later (October 21 to 24), "Wilma" affected the island. This is the strongest hurricane recorded in the Atlantic Ocean (the tenth globally), with the lowest atmospheric pressure recorded historically in the Western Hemisphere (882 millibars at sea level, Nava-Alvarez 2005). The hurricane eye (63 km in diameter) moved across Cozumel with sustained winds of 220 km/h and gusts of more than 300 km/h, and moved very slowly, at a speed of less than 5 km/h, heading north-northwest (Alvarez-Filip 2007).
The hurricanes not only caused high mortality of benthic species but also moved away enormous volumes of sand and left large areas of bare rock, devoid of colonizers (Alvarez-Filip and Gil 2006).

Considering the strength and extent of the perturbation, the relevance of the reefs, and the need for a systematic evaluation of the effects on the entire ecosystem, our objective was to determine the effects of "Emily" and "Wilma" and the subsequent changes on the landscape structure of the reefs within the limits of the marine protected area of the Parque Nacional Arrecifes de Cozumel (PNAC). We observed a remarkable decline in all the biotic components and a considerably increase on bare rock after the hurricanes. During the 2 following years the reefs started to recovery, however, the general landscape may not be returning to its original state.

Material and Methods

Study area. Cozumel (Fig 1) covers an area of 647.33 km^2, is located approximately 22km from coast of Quintana Roo. The island is occasionally affected by hurricanes in summer and fall (June to November), although August and September are the months with more intense activity. The southwestern coast of the island has been under official protection since 1980; but was in 1996 when Natural Protected Area decree (INE 1998). The Parque Nacional Arrecifes de Cozumel (PNAC), which is the official name, goes from the north end of Paraiso reef (20º 35´ 22 N, 86º 43´ 46 W) to the southernmost tip of the island, and then continues north as far as Punta Chiqueros in the windward side (20º 16´ 11 N, 86º 59´ 26 W; Fig. 1).

Field Work. We conducted seven visits to the area from May 2005 to May 2007. In each period we surveyed a total of six reef (Fig. 1), and a total of 36 transects were done per visit (six at each reef) using SCUBA equipment. and at a depth of 15 m.

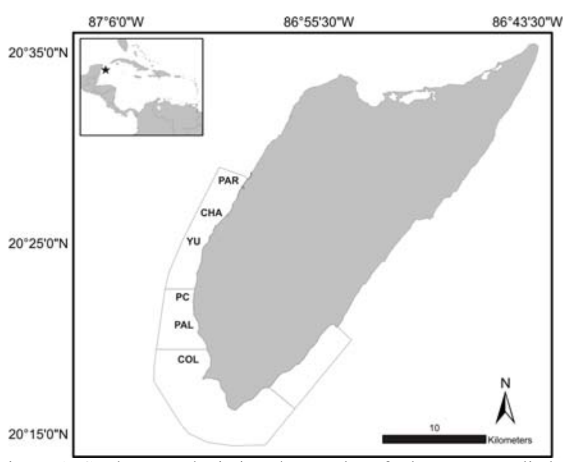

Figure 1: Study area, depicting the coral reefs that were studied at Cozumel Island. PA= Paraiso, CHA= Chanlana´ab, YU= Yucab, PC= Paso del Cedral, PAL= Palancar, COL= Colombia. Continuous line delimits the polygon of the Parque Nacional Arrecifes de Cozumel.

We used the point interception method to evaluate the components of the benthic substrate. The procedure consisted of placing a 30 m-long transect parallel to the coast and recording the type of bottom found directly below points signaled every 25 cm (120 sampling points in total per transect; Almada-Villela et al. 2003), and calculating percentage of bottom cover by each one. Then, the information was systematized and classified in ten major groups: bare rock, sand, dead coral, fleshy macroalgae, sponges, octocorals, hexacorals, turf algae, cyanophytes and coralline algae.

Statistical analysis. Using the percentage of cover of each bottom component, we calculated the Shannon-Wiener diversity index (base 10) and Pielou´s evenness index for each transect, reef and season. These indicators are recognized as among the best to characterize the complexity of the landscape (Jongman et al. 1995; Magurran 2003). Next, the level of change in the reef background among sampling dates was determined with analysis of variance, after confirming homoscedasticity and normality of the data (Zar 1999). Finally, we computed the similarity along landscape compositions in the different samplings with the Bray-Curtis similarity coefficient, and mapped the full information with a non-metric multidimensional scaling (NMDS; Martínez and Adarraga 2001).

Results

Abiotic components. In May 2005 the cover of sand and rock recorded together was 26% in the six sites. During July 2005, when the island received the impact of "Emily", the situation remained very similar, although the amount of rock increased as a result of sediment transport to deeper area. However, in the sampling after "Wilma" and the next one (May 2006) the bare rock was by far the dominant bottom type (~ 40% in average). In the last two visits, the rock decreased its percentage cover to about 25% and remained around that figure to the end of the study. Comparatively the amount of sand was much more stable; it actually decreased after "Wilma" but double its average by the following May (2006), and increased gradually since. Dead coral has been a minor component in the entire study, and had higher values after "Emily". By the last three censuses, dead coral cover was remarkably low, probably because most diseased or damaged colonies were broken and transported away from the reef by the hurricanes.

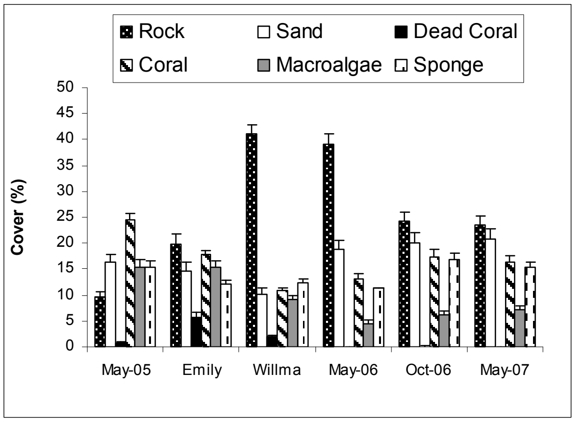

Figure 2: Average cover of the most common bottom types at Cozumel reefs, between May 2005 and May 2007.

Biotic elements. In the case of sponges, their abundance first diminished because of the mass mortality caused by the hurricanes (Alvarez-Filip and Gil 2006), but there was a considerable rebound by May 2007 (Fig. 2). There were significant differences between seasons ($F_{5, 210}$= 41.456, p< 0.0001), caused by the low average found in May 2006, immediately after the hurricanes.

The behavior of the coral abundance at Cozumel was similar to that of the sponges, and we also depicted significant differences between seasons ($F_{5, 210}$= 16.86, p< 0.0001), although in this case were caused by the high cover in May and July 2006. Afterwards the average did not differ (fluctuating between 8% and 12%), an indication of a certain stability and long-term effects of the hurricanes on this group (Fig. 2).

The macroalgae behaved in the same way that corals ($F_{5, 210}$= 22,971, p< 0.0001) and the significative differences separated the higher values from May 2005 and July 2005 (after "Emily"), to the remainder. It is also apparent that the declining trend continued until spring 2006, and from then on the algal cover increased but still is much lower than the original.

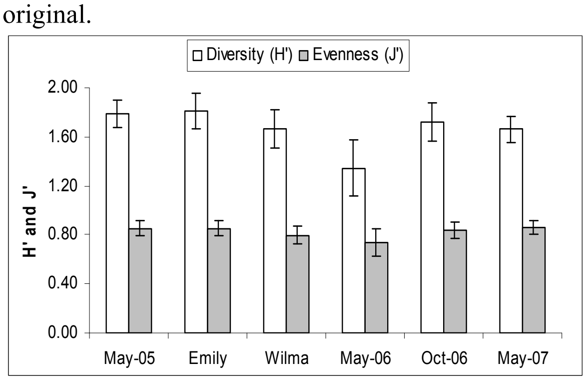

Figure 3: Diversity and evenness of the reef landscape at Cozumel Island between May 2005 and May 2007.

Landscape approach. Diversity and evenness of the landscape components was very stable at Cozumel (Fig. 3), although in both cases a clear and significant decrease occurred in May 2006 from the rest of samplings. Finally, the NMDS (Fig. 4) shows three stages in reef landscape composition between 2005 and 2007: first, the data from May 2005 and the first hurricane ("Emily"), then "Wilma" and the ensuing sampling in spring 2006, and finally the last visits (October 2006 and May 2007).

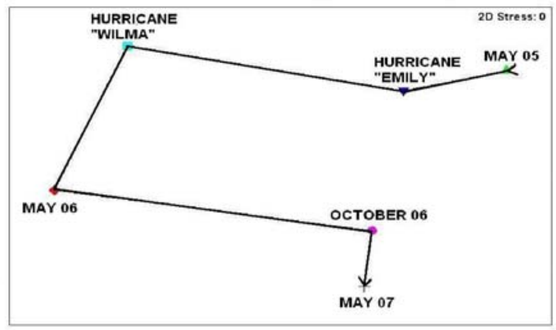

Figure 4: Non metric dimensional scaling comparing the bottom composition at the six sampling seasons (May 2005 to May 2007).

Discussion

This paper is one of the first to analyze the effects of hurricanes from a landscape perspective in México. We consider that this was the correct approach since the passage of hurricanes "Emily" and "Wilma" affected not only the live elements but also the abiotic ones. Then, by taking a more inclusive view we may have a better image of the long-lasting consequences to the composition and function of the system that if only we focus on specific taxa.

As shown by Fig. 2, during the study period we testified a major shift in the proportions of components of the substrate, directly caused by the incidence of two hurricanes in 2005. In general, there was a remarkable increase of the amount of bare rock and a decline in all biotic components, and probably both events were due to the movement of sand across the reef, and its eventual discharge to the slope (Alvarez-Filip and Gil 2006). A similar situation was faced by other locations along the Mexican Caribbean coast, and more specifically at Cancún (McField et al 2008), but the long term results differed remarkably. At Cancún the lack of reefs and limited generation of new sand caused a net deficit and the need to carry new sand to the beach, taken from deep areas, while at Cozumel the coral barrier naturally supported enough material so the amount of sand in the reef soon returned to normality (Fig. 2).

The loss of sand can have important consequences at Cozumel; water clarity diminished a lot after the hurricanes because of the floating sand grains (LAF personal observations), and that may have altered the metabolism of the zooxanthellae, decreasing in turn the amount of food for corals and the rest of the community, and probably affecting the reproductive success of scleractinians (Chavez et al. 2003; Fabricius 2005). In addition, Alvarez-Filip (2007) indicated that as the large amount of sand moved to the barrier reef and surrounding areas in 2005 left a sizeable area of new substrate, it was to be expected that many new areas were available for colonization. If this is the case, we can expect a high incidence or benthic recruitment in years to come. As the data in Figure 2 show, sponges and corals may have been responding to this opportunity, but nevertheless their slow growth rate forces that the process should take many years (McMurray et al. 2008). This hypothesis checks well with Fenner (1991) observation that after Hurricane “Gilbert”, it was expected at least 10 years for recovery of Cozumel reefs.

Many studies have documented changes severe damage to coral colonies and populations due to the behavior of the waves and sea currents during a hurricane (Woodley et al. 1981; Rogers 1993; Kjerfve et al. 1996), and a consequent change in the composition of the biotic components (Done 1992; Bythell et al. 1993; Bahena et al. 2000). At Cozumel, before 2005 were clear differences in coral cover among reefs, but after 2005 we noticed an homogenization of abundance all over the national park (Millet-Encalada et al. 2007). In general this took place because differential mortality concentrated in the two main genres (*Agaricia* and *Porites*), which because of its morphology are much more prone to mechanical damage.

The general trend in the coverage of the sponge was a reduction after 2006 (Fig. 2). This was expected considering fragile structure of these animals that can be easily damaged by the abrasion caused by sediment movement, and to excessively high speeds in water flow (Done 1992; Fenner 1991). However it is important to note that many broken colonies are recovering its size using cellular growth (Stoddart 1974), and probably the cover will increase faster that anticipated by asexual recruitment.

As for the percentage of macroalgae found, this was very variable during the study but fortunately cover was never too high; this means that there is no indication of a phase shift due to the opening of colonization spaces in the reef. Very probably the control of algal proliferation was exerted by urchins but mostly, by herbivorous fishes, which numbers are higher than 2 fishes/m^2 (Díaz-Ruiz and Aguirre León 1993; Lozano Alvarez et al. 2007). Considering this information we support the idea that Cozumel reefs can still be considered as healthy, even when human use is very high (Rioja-Nieto and Sheppard 2008).

In this study we applied diversity and evenness indices (H' and J') to describe the complexity of the reef landscape in the study region. The data showed a clear decrease in May 2006 which reflects the post-hurricane response to two major perturbations, however, both indices rapidly return to the original figure and by the end of the study there was no statistical difference in the indicators. This result may be the best indication of the reef resilience.

Although our data show that Cozumel reefs resisted well the effect of the hurricanes, there are still changes of notice. The NMDS clearly shows that between 2005 and 2007 there have been three distinct stages in reef succession: May to July 2005, late 2005 and early 2006, and the last two samplings (Fig, 3). The fact that the arrow did not return to the original position in the graph remarks that the reefs are showing signs of recovery, but are not “returning” to its original condition; a more accurate view is that the landscape is in dynamic equilibrium, and we need more years to actually confirm what direction is taking.

In conclusion, the effects of two major hurricanes on the landscape diversity of Cozumel reefs were clear, but in a very short time span the animal and plant communities as well as the abiotic environment, seem to be regaining their position. It is probable that if no other perturbation of this caliber occurs, we can assess a complete recovery of the ecosystem. However, the situation may not be so adequate in the near future considering the projected increase in anthropogenic pressures (especially coastal development) for the entire Mexican Caribbean. It is vital to keep a proactive position for management and preview what problems can occur if the number of visitor keeps increasing, and also to continue monitoring and Before –After studies (Michener et al. 1997), fundamental to assess the long-term effects of these perturbations.

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