High population density survival of the sea urchin *Diadema antillarum* (Philippi 1845) to a category 5 hurricane in southern Mexican Caribbean

Supervivencia de una alta densidad poblacional del erizo de mar *Diadema antillarum* (Philippi 1845) a un huracán categoría 5 en el sur del Caribe mexicano

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Jorgensen P., J. Espinoza-Ávalos and H. Bahena Basave. 2008. High population density survival of the sea urchin *Diadema antillarum* (Philippi 1845) to a category 5 hurricane in southern Mexican Caribbean. *Hidrobiológica 18* (3)**:** 257-260.

ABSTRACT. The vulnerability of the sea urchin *Diadema antillarum* to the impact of the category 5 hurricane "Dean" was assessed at a back-reef area of Mahahual (Southern Mexican Caribbean). Seventy days after Dean, there was a high mean *Diadema* population density of 12.6 ± 4.3 (*SD*; from here forward) ind m^{-2}, with a large mean individual test diameter of 59.2 ±9.8 mm. This population was comparable to a previous report for the same area, just before the landfall of Dean on 21 August 2007. Immigration of adults from deeper fore-reef sites after Dean across the reef-crest was unlikely, considering the homing behavior displayed by tagged urchins. The degree of physical alteration of the habitat indicated that *Diadema* may survive higher hurricane-generated disturbances than those reported in previous works. These results have strong implications on the conservation of the Mexican Caribbean coral reefs since the *Diadema* populations surveyed have a high grazing activity and are persistent against hurricanes impact.

Key words: *Diadema antillarum* urchin, herbivory, coral reef resilience, Caribbean Sea, hurricane Dean.

RESUMEN. La vulnerabilidad del erizo de mar *Diadema antillarum* al impacto del huracán categoría 5 "Dean" fue evaluada en el arrecife posterior de Mahahual, México. Setenta días después de la recalada de Dean fue estimada una alta densidad media poblacional de *Diadema* de 12.6 ind m^{-2} (DE = 4.3), con un elevado tamaño individual promedio de 59.2 mm de diámetro (DE = 9.8). Esta densidad fue comparable a la de un reporte previo para la misma zona, días antes del paso de Dean el 21 de agosto de 2007. Considerando la fidelidad al refugio mostrado por erizos marcados, la inmigración de adultos desde el arrecife anterior después del paso de Dean fue poco factible. El nivel de destrucción del hábitat indica que *Diadema* sería más persistente al impacto directo de huracanes que lo sugerido por estudios anteriores. Debido al elevado potencial de pastoreo de las poblaciones locales de *Diadema*, y a su persistencia al impacto de huracanes, los resultados de este estudio tienen fuertes implicaciones para la conservación de los arrecifes coralinos del Caribe mexicano.

Palabras clave: erizo de mar *Diadema antillarum*, herbivoría, arrecifes de coral, resiliencia, Mar Caribe, huracán Dean.

The long-spined sea urchin *Diadema antillarum* (Philippi 1845) strongly influences the Caribbean coral reefs dynamics by controlling the expansion of macroalgae through grazing. When an unknown pathogen decimated ~95% of *Diadema* from the Caribbean in 1983-1984, fleshy and filamentous macroalgae monopolized the substrate released after local and regional coral mortality events (Lessios 1988). Fortunately, the recent recovery of some *Diadema* populations has generated enthusiasm among researchers worried about the degradation of the Caribbean coral reefs (Knowlton 2001). The management of *Diadema* populations appears to be the most effective and relatively inexpensive approach to restore the Caribbean coral reefs (Aronson & Precht 2006).

Hurricanes are one of the most evident natural disturbances affecting coral reef populations (Woodley *et al.* 1981). Vulnerability of *Diadema* and other mobile fauna to storms is likely dependent on the presence of energy-dissipating structures that provide them refuge from disturbances (Aronson 1993; Williams 1984; Woodley *et al.* 1981). However, these three cited studies are the only published assessments of hurricane effects on sea urchins populations. Here, the impact of category 5 hurricane Dean on *Diadema* back-reef population at Mahahual is assessed by comparing pre- and post-hurricane data at the exact locality where the hurricane landfall with maximum power, on the 21st of August, 2007.

Pre-hurricane mean density of *Diadema* was estimated by Jordán-Garza *et al.* (2007) during the summer, within the shallow reef-lagoon of Mahahual (18º43´N, 87º42´W) (Fig. 1). The abundance of *Diadema* was quantified using one m^2 quadrates (n = 100) located randomly along 25 m transects (n = 10). Coral cover mean under the line-transects was 12.6% (SE = 3.5) and algal cover was low (macroalgae 0.9%, SE = 1.2; and filamentous algae 3.5%, SE = 2.9; (Jordán-Garza *et al.* 2007).

Post-hurricane mean density of *Diadema* was estimated using one m^2 quadrates (n = 16), located within three haphazardly selected areas across a 36 m long reef section (18º43´13.51´´N, 87º42´12.66´´W) (Fig. 1). Two of these areas were in shallow (< 1 m depth) leeward crest margin, dominated by a matrix of dead corals, crustose coralline algae and abundant coral rubble. The third area was located in a deeper back-reef area (~3 m depth) dominated by *Montastraea annularis* colonies, and delimited leeward by short, sparse *Thalassia testudinum* meadows.

To assess the likelihood of immigration to our study area after Dean landfall, nightly mobility of *Diadema* individuals from Mahahual and Xcalak (Fig. 1) was monitored. To allow identification of individuals was followed an *in situ* tagging procedure described in Tuya *et al.* (2004). A fishing hook was introduced into the periproct of each *Diadema*, fastened to a fishing line with a small buoy to facilitate localization of tagged individuals. A total of 20 *Diadema* were tagged in the back-reef of Mahahual, while 12 *Diadema* were tagged on a patch-reef at Xcalak. At Xcalak, the distance from the original tagging location (i.e. crevice) and the position of each individual was recorded every 3 h. The measurements were performed between 19:00 h and 07:00 h.

With maximum sustained winds of ~270 km h^{-1} and gusts of 320 km h^{-1}, Dean was the third most intense Atlantic hurricane ever at landfall. Physical damage to the coral reef community was more severe in the shallow fore-reef than in back-reef areas, sheltered by the reef-crest. However, local reports of ~6 m waves in Mahahual had visible effects on the back-reef. The hurricane damaged colonies of *Agaricia* spp. and *Porites* spp., overturned some *Diploria strigosa* (Dana 1848) coral heads, remove sponges and gorgonians, and literally washed out sand from beaches fringing the reef-lagoon.

Seventy days after the hurricane landfall, Mahahual populations of *Diadema* were very dense despite the physical evidence of disturbance in the back-reef area (Fig. 2). A mean density of

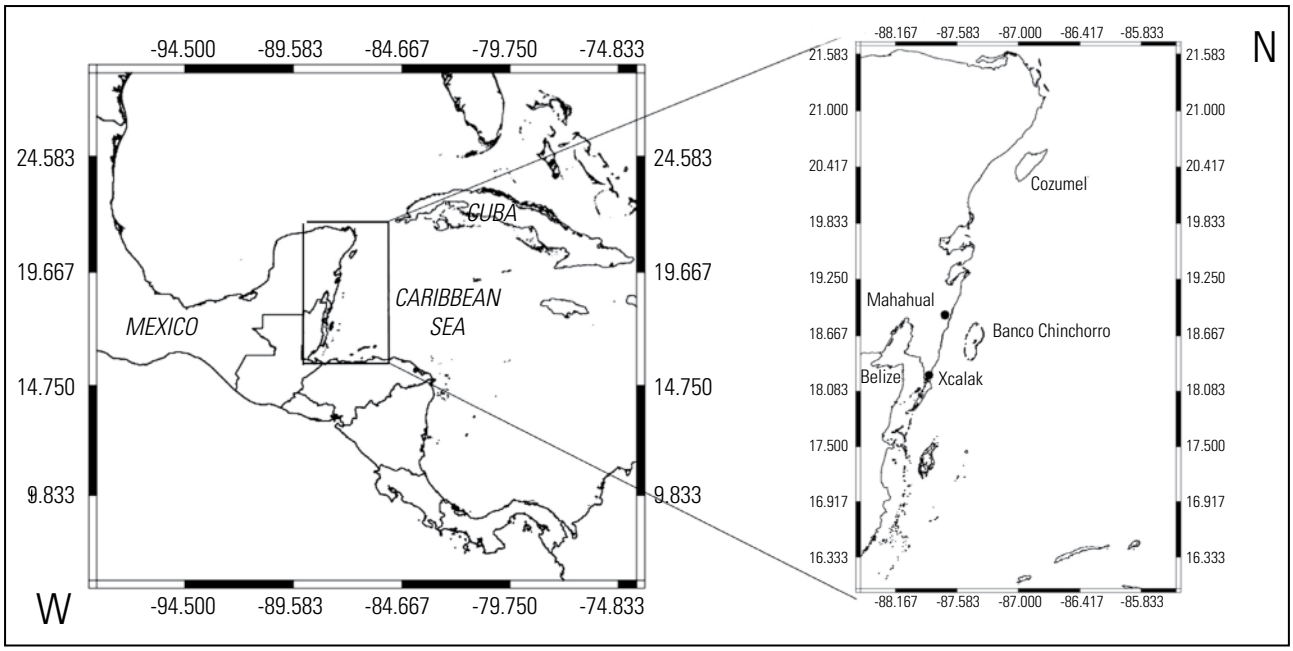

Figure 1. Geographic location of Mahahual and Xcalak in Yucatan Peninsula (Mexico)

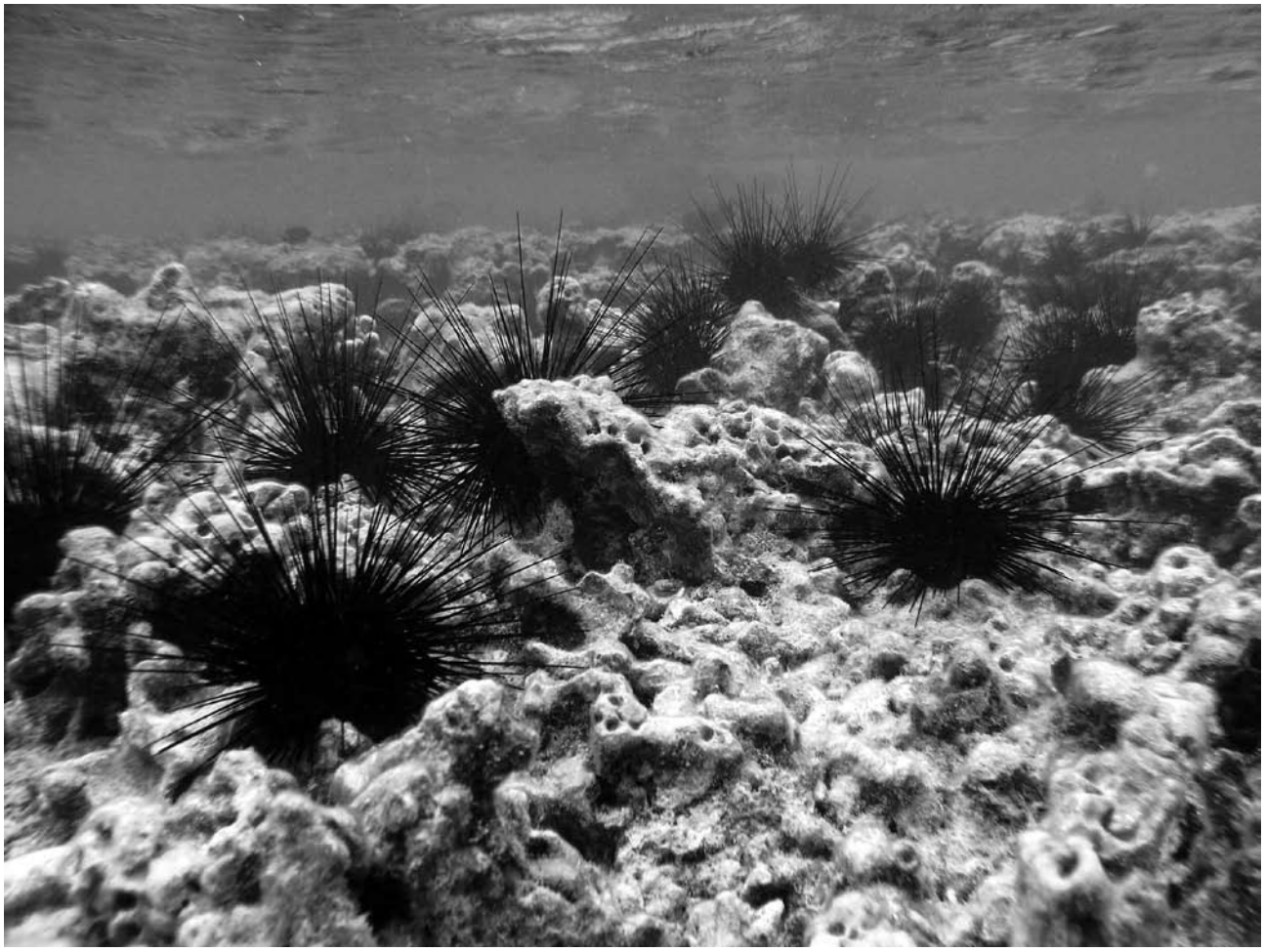

Figure 2. Long-spined urchins, *Diadema antillarum*, in a shallow area (< 1 m depth) covered by a matrix of dead corals and crustose coralline algae in the leeward crest at Mahahual (Photo: H. Bahena-Basave).

12.6 ± 4.3 m^{-2} long-spined sea urchins with a mean test diameter of 59.2 mm (SD = 9.5. N = 50) was estimated across the 36 m long reef section. According to the ANOVA test (α = 0.05), *Diadema* mean densities has not a statistically significant variation (p = 0.36) among the three areas surveyed within the reef section, despite the marked differences on their reef structures.

Both pre- and post-hurricane *Diadema* population at Mahahual where characterized by the low occurrence of *Diadema* juveniles. Jordán-Garza *et al.* (2007) reported that 95% of the recorded individuals featured a 7-10 cm test diameter, while was measured only one *Diadema* < 30 mm test diameter.

Post-hurricane mean density estimation of *Diadema* in this study is one of the highest reported for Caribbean populations of the species since the 1983-1984 mass mortality event (see Carpenter & Edmunds 2006). This estimation was slightly higher than the pre-hurricane report of Jordán-Garza *et al.* (2007) for the same area. Jordán-Garza *et al.* (2007) reported 7.29 ind m^{-2} (SE = 4.2), with a range 0–19 *Diadema* m^{-2}. Enhancement of back-reef *Diadema* densities after hurricane impacts was previously reported (see Williams 1984). These increases were in part attributed to increasing food availability in the form of live coral fragments after the disturbance (Williams 1984).

The apparent enhancement of *Diadema* density after Dean may be alternatively explained by differences in the sampling design between this study and that of Jordán-Garza *et al.* (2007). While Jordán-Garza *et al.* (2007) randomly located their sampling units for *Diadema* quantification, in this study sampling was limited to hard substrate areas that provide refuge to *Diadema* during the day. However, whatever the causes of the differences, overcrowded post-hurricane *Diadema* populations recorded at Mahahual are indicative of a high survival to Dean impact.

Post-hurricane immigration of adults from deeper fore-reef sites across the reef-crest was unlikely for two reasons. First, *Diadema* was reported to be absent in the fore-reef of Mahahual

(Jordán-Garza *et al.* 2007). Second, displacement of adults is restricted, considering the homing behavior displayed by tagged *Diadema*. Eighteen of 20 tagged *Diadema* in the back-reef of Mahahual on October 30 evening returned to their refuge on October 31 at dawn. The maximum distance between the position of tagged *Diadema* and its refuge was 2.04 m (n = 20). Homing behavior was previously described for central East Atlantic Ocean and Caribbean *D. antillarum* populations (Carpenter 1984, Tuya *et al.* 2004).

The survival of high densities of adult *Diadema* in the reef-lagoon following Dean at Mahahual contrasted with the extremely low survival of Jamaican *Diadema* populations in the shallow water fore-reef to hurricane Allen in 1980 (Woodley *et al.* 1981). This contrast may partially be explained by differences in the exposure to hurricanes between locations, as urchin mortality related to wave impact may be much less severe in back-reef areas sheltered by the reef-crest (Aronson 1993, Williams 1984). Similarly, reports of reductions in Dominica's *Diadema* populations by storms where related to the lack of energy-dissipating structures, such as wide fringing or barrier reefs, in the island narrow shelf (Steiner & Williams 2006).

The present study indicates that the causal relationship between the degree of physical alteration of the habitat on *Diadema* mortality is not always straightforward. Although the reef-crest provided protection against Dean to the Mahahual reef-lagoon habitat, it did not impeded visible physical disturbance effects generated by the hurricane. Dense *Diadema* populations occurred even at very shallow areas within, and close, to the reef-crest. Thus, *Diadema* populations may survive higher levels of hurricane-generated disturbance than previously thought.

Observations reported in this study have strong implications for the conservation of Mexican Caribbean coral reefs due to the potential grazing pressure associated to high densities of *Diadema* adults and their persistence against the impact of hurricanes.

ACKNOWLEDGMENTS.

Steve Box, M. A. Ruiz-Zárate and 2 anonymous reviewers improved a previous version of this manuscript. This study is part of a monitoring program financed by CONABIO Convenio FB1215/DM015/06 and FOMIX Convenio MOD-ORD-29-02. P. J. was supported by posdoctoral scholarship from ECOSUR and CONACYT (Convenio 290523).

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Recibido: 1 de abril de 2008.

Aceptado: 15 de diciembre de 2008.