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NOTE

Recruitment pattern of *Diadema antillarum* in La Parguera, Puerto Rico

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Abstract Recruitment success is one of the factors that may be influencing the slow population recovery of *Diadema antillarum* at many locations in the Caribbean. *D. antillarum* recruitment was measured with recruitment plates at monthly intervals from September 2005 to September 2006 at three reefs along an inshore-offshore gradient in La Parguera, Puerto Rico. A total of 275 recruits of *D. antillarum* were collected at the shelf-edge reef during this 13-month study. Two recruits were collected at the mid-shelf reef and no recruits were collected at the inner shelf reef. Recruitment varied among months at the shelf-edge, with the highest value (1,067 ind/m^2) occurring in July 2006. Previous benthic surveys in the La Parguera region have demonstrated higher densities of adult *D. antillarum* at inshore reefs. The higher recruitment at the shelf-edge suggests that recruitment is not a major determinant of the spatial distribution of the adult population. Recruitment occurring in this study is indicative that sources of larvae were available upstream and larval survival was occurring.

Keywords *Diadema antillarum* · Recruitment · Spatial and temporal variability · Puerto Rico · Caribbean

Introduction

Diadema antillarum populations declined by 95–100% in many Caribbean locations in 1983 (Lessios 1995). Karlson and Levitan (1990) suggested that since the mass mortality occurred over such a large scale it would be difficult for *D. antillarum* to recover to pre-mass mortality numbers. Since these predictions 20 years ago, signs of a slow recovery are apparent in Barbados (Hunte and Younglao 1988), St. Croix (Miller et al. 2003, 2007), Puerto Rico (Weil et al. 2005), Jamaica (Carpenter and Edmunds 2006) and Dominica (Steiner and Williams 2006). The present abundance of *D. antillarum* in Puerto Rico is still low compared to pre-die off densities (12 ind/m^2; Craft 1975). Adult *D. antillarum* populations are mostly confined to shallow reef habitats in La Parguera, Puerto Rico (Weil et al. 2005), and abundances at shelf-edge locations rarely exceed 0.01 ind/m^2 (Miller et al. 2009).

Larval mortality and/or recruitment have been suggested as the main factors regulating the adult population size of *D. antillarum* (Karlson and Levitan 1990). Balch and Scheibling (2001) defined recruitment as occurring some time after settlement when individuals can be reliably counted and some post-settlement mortality or migration may have occurred. Recruitment of *D. antillarum* has been recently measured in the Canary Islands (Hernández et al. 2006) and in the Florida Keys (Miller et al. 2009). Hernández et al. (2006) found a monthly maximum of 24–26 *D. antillarum* recruits/sampler with each sampler containing 100 pieces of experimental collectors (small plastic balls with a very high surface area, 0.04 m^2/ball). Also, Miller et al. (2009) found that the overall rates of recruitment in the Florida National Marine Sanctuary were variably low, with the highest rates being below 2 ind/m^2 and monthly counts of zero were common. The objective of this study was to examine spatial and temporal trends of *D. antillarum* recruitment in La Parguera, Puerto Rico, and to assess its relationship to the distribution of the adult populations.

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Materials and methods

We examined *D. antillarum* recruitment at three reefs in the vicinity of La Parguera on the southwest coast of Puerto Rico (Fig. 1): an inshore reef (Las Pelotas, 17°57.42′ N; 67°04.19′ W), a mid-shelf reef (Media Luna, 17°56.08′ N; 67°02.91′ W) and a shelf-edge reef (Old Buoy, 17°53.29′ N; 66°59.88′ W). Las Pelotas is an emergent reef with *D. antillarum* densities ≤0.15 ind/m^2 (Benavides 2006). Media Luna is also an emergent reef with *D. antillarum* densities ≤0.50 ind/m^2 (Benavides 2006). Old Buoy is a submerged reef on the edge of the continental shelf located about 9 km from the coastline. Coral cover (38%) is higher at Old Buoy than the two other reefs (Weil, pers. comm.), but adult *D. antillarum* are rare at this site (<0.01 ind/m^2, Miller et al. 2009).

Three mooring lines were placed at each reef. Mooring lines were placed in sandy areas next to each reef, in a north to south pattern, perpendicular to the main reef axis, approximately 2 m apart. Pieces of artificial turf were used as the recruitment plates for this study. A 128 cm^2 piece of artificial turf was placed horizontally on the top of a cement block (Fig. 2a) that anchored each mooring line. Also, two 64 cm^2 pieces of artificial turf (Fig. 2b) were placed vertically back to back from each other at different depths on each mooring line. At Old Buoy, plates were placed at 19, 12 and 6 m, at Media Luna at 10, 8 and 5 m and at Las Pelotas at 3 and 2 m. Plate depths differed due to the different water depths at each reef. The purpose of the vertical plates was to determine if 'settlement ready' larvae were in the water column during this study. Buoys were placed 2.5 m below the water surface in order to reduce the movement of the mooring lines by surface waves.

Artificial turf plates were initially deployed during the first week of September 2005. The plates were collected and replaced with a new plate at monthly intervals until September 2006. Mooring lines were also cleaned each month with a knife. In the laboratory the retrieved plates were washed with seawater and inspected for *D. antillarum* recruits. Sea urchins with a test diameter ≤2.5 mm were counted as a recruit.

A one-way Analysis of Variance (ANOVA) test was applied to examine the temporal variance of *D. antillarum* recruitment at just the shelf-edge site, since there was a lack of recruitment at Media Luna and Las Pelotas. The Statistica 7 package was used for the statistical analysis.

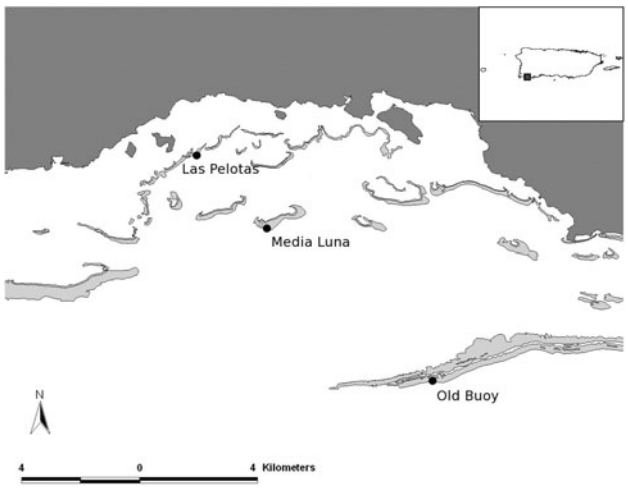

Fig. 1 Map of study sites for recruitment experiments in La Parguera, Puerto Rico

Results and discussion

The mean test size of recruits collected during this study was 0.90 ± 0.50 mm (mean ± SD). Recruits displayed a red test with long spines which were banded with colors of white and red. *D. antillarum* recruits were found during 12 out of the 13 mo (Fig. 3) as might be expected given the year-round reproduction in La Parguera, Puerto Rico (Lugo 2004; Williams et al. 2009). Significant temporal variation in recruitment was observed at the shelf-edge site (ANOVA, $F_{12,\ 38} = 9.94$, $P < 0.0001$), with peak recruitment occurring in July (Fig. 3).

Spatial variations of recruitment by *D. antillarum* were evident. Recruitment was greater at Old Buoy than at Media Luna or Las Pelotas. A total of 275 recruits were found at the shelf-edge site, 14 recruits were collected at

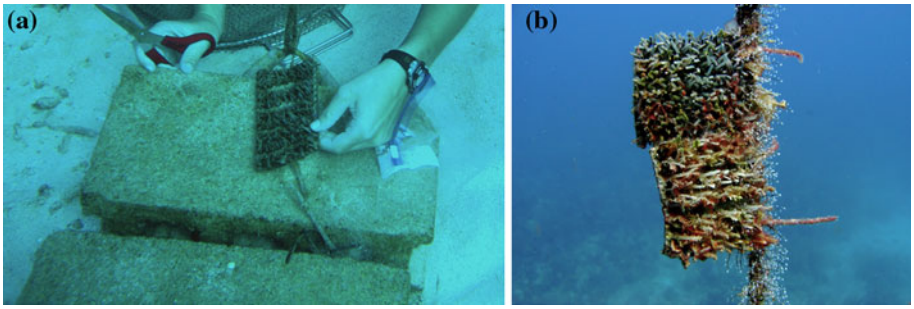

Fig. 2 Horizontal (**a**) and vertical (**b**) recruitment plates made out of artificial turf at the shelf-edge site in La Parguera, Puerto Rico

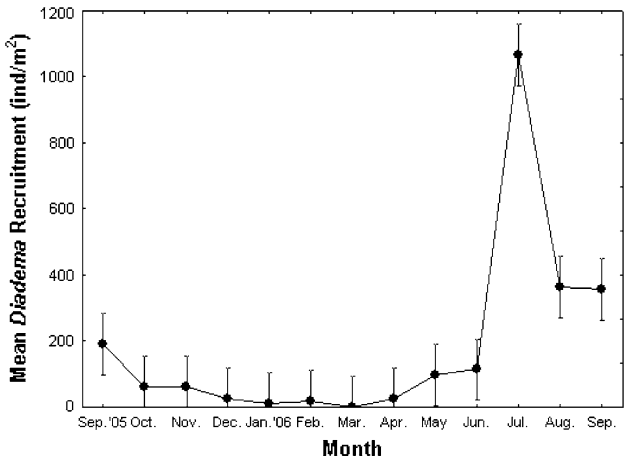

Fig. 3 Mean monthly recruitment of *Diadema antillarum* per m^2 at Old Buoy. Vertical bars denote standard errors ($n = 9$)

19 m, 122 at 12 m and 139 at 6 m plates. Two recruits were found at the mid-shelf reef and no recruits were collected at the inner shelf reef, La Pelotas. Three non-mutually exclusive explanations for the low recruitment at the inner and mid-shelf reefs compared to the shelf-edge site include (1) stochastic variation, (2) a shelf-edge reef larval 'filtering effect' (Gaines et al. 1985), 3) that high abundance of fleshy macroalgae colonizing the artificial turf plates precluded recruitment at inshore reefs. Bak (1985) noted that *D. antillarum* recruitment was enhanced when the settlement plates were un-fouled. At the inner and mid-shelf reefs the artificial turf plates were difficult to locate due to the fleshy algae, compared to the relatively clean plates at the shelf-edge where the original color of the artificial turf was still visible.

If mortality of recruits is constant in space and time, the adult distribution should match the distribution of recruits (Gotelli 1988), but in this study the greatest recruitment of *D. antillarum* in Puerto Rico was concentrated at the shelf-edge, where adult urchins are rare. Therefore, *D. antillarum* recruitment in La Parguera may be independent of local adult density (Lessios 1988). Assuming that recruitment on the plates is representative of recruitment on the reefs themselves, the inverse relationship between recruitment and adult densities raises an important issue about the population dynamics of this species. Post-settlement mortality on *D. antillarum* at the shelf-edge may be high, explaining the absence of these adult urchins at this location.

Lessios (2005) and Miller et al. (2009) argued that low larval supply was the limiting factor inhibiting the recovery of *D. antillarum* in Panama and the Florida Keys. The high recruitment reported at the shelf-edge in this study is indicative that upstream sources of *D. antillarum* 'settlement ready' larvae are available and these larvae were capable of surviving through the planktonic stage. The shelf-edge may act as a 'sink' for settling larvae and the habitat dynamics of this reef may play an important function in understanding the recovery and future reef restoration efforts of *D. antillarum* populations.

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