Diadema antillarum population status assessment in Dominican Republic 30 years after the mass mortality event

Laura Del Río Torres

Punta cana Ecological Foundation, La Altagracia, Dominican Republic

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Abstract:

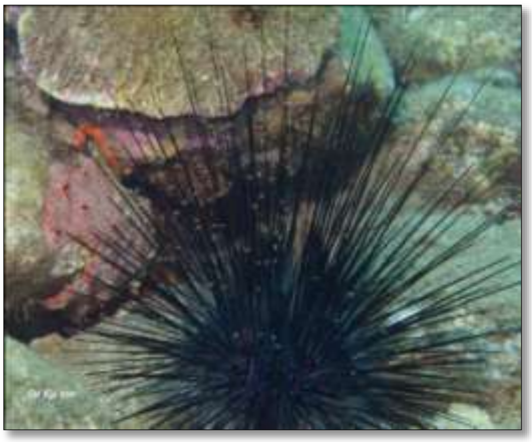
The long-spined sea urchin *Diadema antillarum* plays an important role in the coral reef community dynamics and geomorphology of the Caribbean. A dramatic die-off event in 1983-84 reduced its population in a 95-99% throughout the Caribbean resulting in dramatic changes in the benthic community. This study aims to report population density; bathymetric distribution and population size structure of this sea urchin in four localities of Dominican Republic: Bayahibe, Punta Cana, Samana and Sosua. For this study transects of 15 m^2 were conducted using a 0.5x0.5 (0.25) m^2 quadrants at *Acropora cervicornis* restored reef sites. Transects were laid in and out the restored plots. The benthic cover was also estimated and classified in 5 main categories: macroalgae, coralline algae, corals, sand/rock/rubble and sponges. The mean density of *Diadema antillarum* obtained for the entire study was 0.89±0.11 ind/m^2 (Mean ± SE, n=48). The distribution of this sea urchin was mostly limited to depths comprised from 1-10 m of the sublittoral; no significant differences were observed in the vertical distribution by age. The mean benthic cover found for the four localities was: Coral 6.75%, Macroalgae 22.66%, Coralline Algae 24.99%, Sand/Ruble/Rock 41.75% and Sponges 2.68%; although substrate communities vary significantly at different sites even at same localities, depending on multiple factors affecting the area.

1. INTRODUCTION

Coral reef ecosystems provide valuable social services and play an important role in the economy along the Caribbean. These ecosystems are of high complexity, understanding and assessing biodiversity is essential for coral reef communities and for future management improvements. The long spine sea urchin *Diadema antillarum* is a key species found in shallow waters of the Eastern and Western Atlantic Ocean and Caribbean Sea. Its feeding habits deeply influence the geomorphology and dynamics of the communities related to coral reef ecosystems such as algal cover or coral diversity. *D. antillarum* competes with other sea urchins and herbivorous fish and can be found grazing in coral reefs, rocky shores and sandy bottoms, and are often associated with causing bare areas in sea-grass beds (Lessios, 1984; Weil, 2004). Although *D. antillarum* feeds preferably on algae, is still considered an omnivore organism ingesting other sessile invertebrates (Randall, Schroeder & Starck, 1964; Carpenter, 1981; Weil, Losada & Bone, 1984; Soto-Santiago & Irizarry-Soto, 2013).

The long spines of *D. antillarum* also serve as refuge for larvae for a variety of species such as the Caribbean spiny lobster *Panulirus argus*, several species of fishes (Vicente & Goenaga, 1984), and invertebrates like copepods, mysids, shrimps and crabs (Randall et al, 1964; Soto-Santiago & Irizarry-Soto, 2013). (Figure 1).

Figure 1. Larvae and juveniles take refuge in the long spines of *Diadema antillarum*.



Before the 1980's *D. antillarum* was widely distributed throughout the Caribbean and West Atlantic, from the Gulf of Mexico and Bahamas to Surinam (Weil, 2005); however, from 1983-84 a mass mortality event occurred caused by a water-borne, highly specific and virulent pathogen transported by surface currents. This mass mortality event reduced *D.antillarum* population by as much as 99% (Lessios *et al*. 1984, Hughes *et al*. 1985, 1994, Hunte & Younglao, 1988).

In the Dominican Republic, studies to evaluate current *D. antillarum* population densities were only recently implemented and have been of limited scope and reach. As a result, information gaps still need to be addressed. Only 3 previous articles were found in the Dominican Republic referring to this echinoid reporting *Diadema antillarum* abundance dating from 2003, 2007 and 2013. Although these previous studies suggest a modest increase, 0.11 to 0.28 individuals/m^2, from 2003 to 2013 respectively (Brant 2007; Gloeckler 2013, unpublished), no literature previous to the die-off event has been found for a baseline comparison.

The main goals of this study are to continue monitoring, expand on previous studies and assess the current *Diadema antillarum* population density, size structure and bathymetric distribution along the Dominican Republic neritic zone, 30 years after the massive die-off. An additional objective was to obtain a brief characterization of the substrate and see if changes in the benthic cover can be related to *D. antillarum* population density increases.

2. MATERIALS AND METHODS

2.1. Study area

Since 2004 the Puntacana Ecological Foundation has a big on-going coral gardening and restoration project with over 9 coral nurseries in a similar number of coastal communities; these 9 nurseries are harvested for coral fragments and outplanted onto natural coral reefs. From these coastal communities, a total of four were selected based on logistical opportunities and included: Punta Cana, Bayahibe, Samana and Sosua. All sites selected included an *Acropora cervicornis* restoration project with at least 6 months of establishment.

To assess the *D. antillarum* population density, *in-situ* transect surveys were carried out expanding on the procedures from those described in the technical report presented to the Puntacana Ecological Foundation by Gloeckler and Galvan (2013). The transect surveys were conducted haphazardly in a combination of outplanted reef areas and natural reefs, to obtain a better understanding of the roles of different components of the reef ecosystem. Expansions to the established procedures included discriminating juvenile from mature individuals, categorizing individuals into class sizes and tracking individuals by depth (see data analysis section for detailed information).

The Punta Cana and Bayahibe sites were previously surveyed (2013) both inside and outside of the out-planted plots; here the same previous sites were surveyed using the reported coordinates as a follow up and incorporated the additional survey parameters. The present study was performed from August 2014 through January 2015.

The surveyed transects were registered by GPS (GPSmap 60Cx) and the coordinates used for mapping the surveyed areas with Google Earth.

The study area encompassed the seabed of the continental shelf from 0-15 m depth regardless of the nature of the substrate, as long spine sea urchins are also found in sandy bottoms and *Thalassia* mounds (Weil, 2004) where there is some shelter nearby (personal observation).

Figure 2. Dominican Republic map showing the selected study areas: Bayahibe, Punta Cana, Samana and Sosua).

- **Bayahibe**

Bayahibe is located in the Southeastern end of the Dominican Republic, in the province of La Altagracia, on the leeward side, protected by a land mass of Pleistocene and recent reef terraces (Geraldes, 2003). Located downstream of oceanic currents and receives minimal river influence. The reef orientation is east-west, perpendicular to the shore, with low relief and spur and groove communities. The Caribbean current dominates in the coastal waters of Bayahibe, which is also influenced by the action of NE trade winds, dominating most of the year.

The surveys were conducted at different localities from remote areas and low population to towns facing major resorts. (Map 1)

Map 1. Coordinates of the sites where the transects were conducted in Bayahibe: Magallan Deep (n=7), Magallan Shallow (n=4), Magallan Beach (n=3), PEPITO1 (n=2) and PEPITO2 (n=3).

Bayahibe	Latitude	Longitude
Magallan Shallow	N 18°22'6.24"	W 68°50'42.6"
Magallan Deep	N 18°21'39.5"	W 68°50'20.3"
Magallan Beach (MP1)	N 18°21'49.15"	W 68°50'29.32"
Magallan Beach (MP2)	N 18°21'48.87"	W 68°50'28.19"
Magallan Beach (MP3)	N 18°21'48.47"	W 68°50'27.03"
PEPITO1	N 18°20'44.304"	W 68°49'56.424"
PEPITO2	N 18°20'40.128"	W 68°49'50.988"

- **Punta Cana**

Punta Cana is located on the easternmost part of the Dominican Republic and influenced by the Mona Passage that connects the Atlantic Ocean with the Caribbean Sea. The coast is characterized by a fringing reef system with spur and groove reef formations; the reef rises up running perpendicular to shore. Breakers marking the reef crest are located 1-2 kilometers offshore. Depth in the lagoon between the breakers and shore varies from 0.5-4 meters. The shoreline is primarily formed by sandy beaches with occasional areas of rocky shore (Brandt, Cooper and Polsenberg, 2003).

This reef is exposed to high wave action, strong currents and heavy swells with a great dynamics of the fine sandy sediments.

Map 2. Transect surveyed **c**oordinates for Punta Cana.

Punta Cana	Latitude	Longitude	Reef Type
Aquarium	N 18˚32'20.7"	W 068˚20’50.6"	Back Reef
OP29	N 18°30'34.8"	W 068°21'36.8"	Fore Reef
OP30	N 18°32,06.0"	W 068°20'47.8"	Fore Reef
OP19	N 18°30’48.3”	W 068°21’28.4”	Fore Reef
OP4	N 18°27’44.6"	W 68°23’28.1”	Fore Reef
OP8	N 18°28'22.9"	W 068° 23'02.9"	Fore Reef
DR0102	N 18°31'46.0"	W 068° 21'30.0"	Back Reef
DRO501	N 18°33'19.0"	W 068°20'33.0"	Back Reef
OP35	N 18°31'04.9"	W 068°21'20.2"	Fore Reef
Ext OP21	N 18°32,01.2"	W 068°20'58.5"	Fore Reef

- **Samana**

The study area in Samana was “Los Cacaos”, located approximately 15 minutes east of the town of Samana. This region of the Dominican Republic is very humid. The Samana Bay is influenced by the discharge of several rivers, carrying an important amount of sediments creating a seabed composed of fine estuarine sediments of terrigenous origin, probably devoid of macro-vegetation. The Yuna river system discharges to the west in Samana bay, and together with the “Los Haitises” and the “Sabana de la Mar” watersheds, they form the largest estuarine system of the Caribbean islands. The waters in the entire region are generally murky due to the high loads of sediments, limiting coral growth. (Herrera-Moreno, 2005).

The physico-chemical characterization of this area shows significant fluctuations in all the physico-chemical water parameters, high percentages of silt and clay sediments and high concentrations of organic matter. The physical and chemical processes that occur when freshwater gets in contact with salt water, make a great amount of sediments associated with organic matter to precipitate (Herrera-Moreno, 2005). An extended area of red mangroove forests on the northern coast of the Bay has also been reported, characteristic of estuarine ecosystems (Sang y Lamelas, 1995).

Map 3. Transect surveyed **c**oordinates for Samana**.**

Samana	Latitude	Longitude
T1	N 19°10'09.6"	W 069° 16'17.7"
T2	N 19°10'11.4"	W 069° 16'12.96"
T3	N 19°10'3.02"	W 069° 16'17.35"
T4	N 19°10'5.68"	W 069° 16'15.73"
T5	N 19°11'0.22"	W 069° 15'23.81"
T6	N 19°11'44.92"	W 069° 19'43.60"
T7	N 19°11'42.89"	W 069° 19'45.17"

- **Sosua**

The Sosua region, located at northern coast of Dominican Republic, extends from east to west along 72 miles of the Atlantic coastline integrating a complex geosystem mosaic of plains and wetlands, fluviomarine valleys and river heights with erosive and erosive-denudation low mountains. The sublittoral geomorphology presents a rocky conglomerate similar to a coralline barrier 200 m away from the coastline, protecting the beach development. The sublittoral geomorphology is mainly formed by sandy bottoms with or without sea-grass and macroalgae with shallow coralline rocky patches with sandy channels (Betancourt & Herrera-Moreno, 2008). At low tide the average water flow matches with the wind westbound, but at high tide an eastward strong current can occur. This implies that under certain meteorological and oceanographic circumstances, the region may receive the influence of the Sosua River.

Recent studies showed a low biodiversity in the region, some of the impacts that can influence on the marine ecosystem are polluted waters coming from the river run off and overfishing (Betancourt & Herrera-Moreno, 2008).

Map 4. Transect surveyed coordinates for Sosua**.**

Sosua	Latitude	Longitude
T1 (3 Rocks)	N 19°46'23.44"	W 70°30'53.28"
T2 (3 Rocks)	N 19°46'22.56"	W 70°30'53.52"
T4(3 Rocks)	N 19°46'22.07"	W 70°30'54.39"
T5 (3 Rocks)	N 19°46'21.64"	W 70°30'54.78"
T3 (Sosua OP1)	N 19°45'28.40	W 70°31'8.40
T6 (Sosua OP1)		

2.2. Sampling and data analysis

- ***Diadema antillarum*** **Population Density and Size Structure**

The abundance and size of the individuals was estimated visually *in situ*, using the band transect method. A 15 m x 1 m (15 m^2) transect was laid haphazardly at each of the survey sites. The surveyor swam along the transect counting all the *D. antillarum* individuals in the 15 m^2 transect area, checking all the crevices and holes of the reef structure, and measuring their test size using a ruler. It was unavoidable that in some cases an estimation of the test diameter was taken due to de difficulty in approaching the organism, not only because of the long spines but also sometimes the inaccessibility of the crevices where they were hiding. At sites where *Acropora cervicornis* had been transplanted back onto the reef as part of a restoration project surveys were carried out inside and outside of the restored plots. At all other locations, only one survey per site was performed.

To assess the population size structure, individuals were quantified and classified into one of three different size ranges, based in previous literature (Bak, 1985; Casañas et al, 1998; Tuya et al, 2004; Lugo, 2004; Ortega Borges, 2006).

Class 1	<3 cm	Recruits: number of juveniles that succeeded the larval stage
Class 2	3-6 cm	number of individuals developing gonads
Class 3	>6 cm	Adults: ensuring gonad development (breeding population)

Size ranges were selected taking into account that most of the *Diadema antillarum* individuals develop gonads at a test diameter of approximately 4-5 cm (Lugo, 2004). This classification system allows for quantification of the number of individuals at each important sea urchin life stage and facilitates the work collecting data while diving.

A Mares Puk diving computer was used to record depth, with reef sites being divided into depth intervals of: 0-3 m, 4-6 m, 7-10 and > 10 m, to test if densities of *D. antillarum* vary along depth gradient (Carpenter, 1990; Lugo, 2004; Ortega Borges, 2010).

- **Benthic Composition Surveys**

Benthic composition was surveyed by placing a 0.5 m x 0.5 m (0.25 m^2) quadrant over every other half meter alternating to either the left or right of the 15 m long belt transects, and taking digital photographs of the quadrant. A total of 15 quadrant photos per transect were taken using a Canon PowerShot A620 camera. The images were uploaded into the computer and analyzed to estimate percentage cover of the substrate with Coral Point Count with Excel Extensions software (CPCe) with 100 randomly superimposed points; each of these points was then classified into one of six categories: coral, coralline algae, macroalgae, sponges, sediment or other. The substrate classified as “sediments” included rubble, sand and rocky substrates.

Locality	**Number Transects**	**Surveyed Area (m^2)**	**Processed Images**	**Benthic Cover Area analyzed (m^2)**
Bayahibe	19	285	194	48,5
Punta Cana	16	240	155	38,75
Sosua	6	90	79	19,75
Samana	7	105	88	22
Total DR	48	720	516	129

3. RESULTS

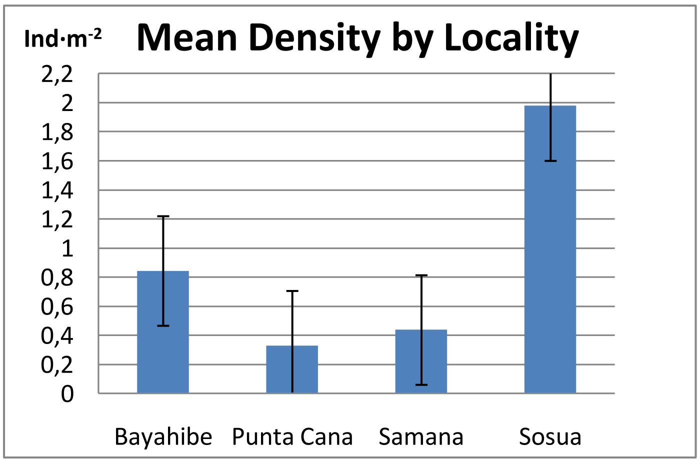
3.1. Population Density

The mean density of *Diadema antillarum* for the communities surveyed was 0.89±0.11 Ind·m^{-2} (Mean ± SE, n=48), ranging from 0 to 11.67 Ind·m^{-2}. The total mean density at each of the four surveyed localities was highest in Bayahibe with 0.82 Ind·m^{-2}, followed by Sosua (1.98 Ind·m^{-2}), Samana (0.44 ind·m^{-2}) and Punta Cana (0.30 ind·m^{-2}).

In Punta Cana, previous studies by Brant (2007) and Gloeckler (2013, unpublished) obtained *D. antillarum* densities of 0.11 and 0.28 ind·m^{-2} respectively; 2014 surveys show a slow but steady increase of the population of approximately 7% to 0.30 ind·m^{-2}, compared to previous years. In Bayahibe, density increased 1.8 fold this past year from 0.45 Ind·m^{-2} (Gloeckler, 2013) to 0.82 Ind·m^{-2} in 2014.

One of the transects at Sosua was conducted on an isolated rock surrounded by sand that resulted in a significant number of urchins with a density of 11.67 Ind·m^{-2}, this increased the overall density for the Sosua locality. The rest of the transects at this locality had a density ranging from 0 to 0.20 Ind·m^{-2}, and the substrate was composed of sandy bottoms devoid of refuge structures.

Figure A. Total *Diadema antillarum* abundance in each of the 4 localities sampled showing Standard Error bars (±SE). Density values corresponding to the graph shown on the annexed table.



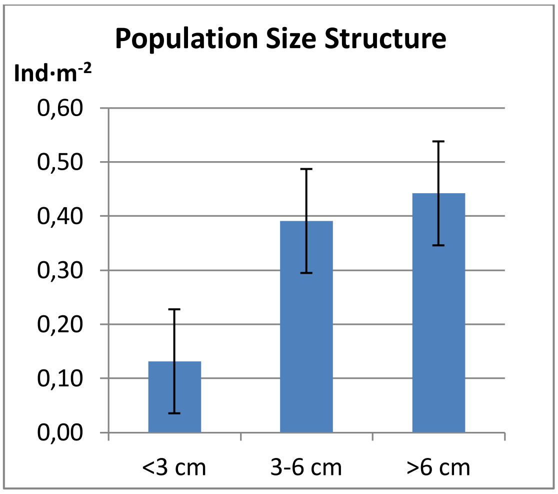
3.2 Population Size Structure

In general the larger size classes (Class 2 and 3) are present and dominate in terms of total abundance (Fig. B).For Sosua the average population density of adult *D. antillarum* was 5 times greater than the average for the rest of the localities. Sosua also had the highest number of recruits (0.20 Ind·m^{-2}) and a maximum density value for the adult group (breeding population) of 1.56 Ind·m^{-2} compared with the other locations. The lower class size range (Class 1) is also present in all locations, but to a lesser extent, with the lowest recruitment found in Punta Cana (0.05 Ind·m^{-2}). Punta Cana has the lowest density values for all three class sizes from all locations surveyed. Bayahibe has the highest abundance of individuals in class 2 (3-6 cm) with a density of 0.42 Ind·m^{-2}, a low recruit class 1, with a 0.08 Ind·m^{-2}, and a 0.34 Ind·m^{-2} size Class 3. At

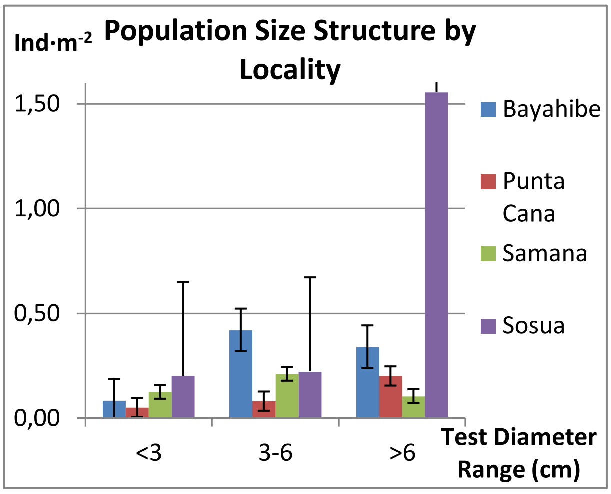
Samana, in general, the abundance of *Diadema antillarum* population is low, possibly due to the high sedimentation on that area, but has a higher density of recruits compared to Bayahibe and Punta Cana.

Figure B. Average values of *Diadema antillarum* abundance (Ind·m^{-2}) for the different size ranges (cm): Class 1: <3 cm, Class 2: 3-6 cm, Class 3: >6 cm

B.1) Total Mean Density by Size



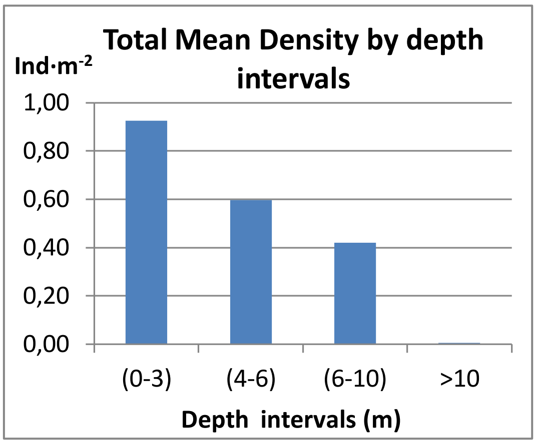
B.2) Mean density at each locality.

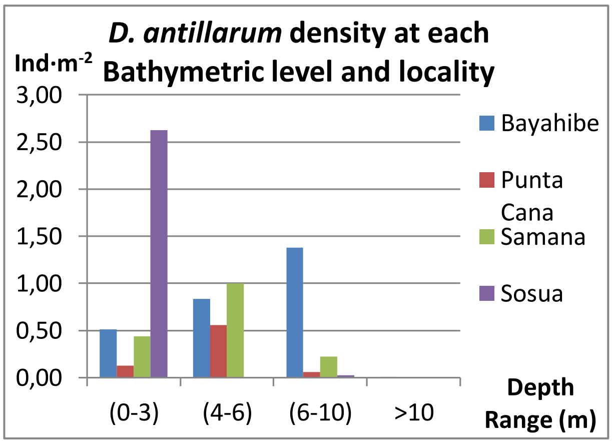


3.3 Bathymetric Segregation

A clear vertical pattern distribution was observed for most sites, with a notably increase of *Diadema antillarum* density with increasing depth up to 7 m; most of the *D. antillarum* population were found in the sublittoral environment at depths ranging from 2 to 7 m. At depths >7 m *D. antillarum* presence decreased and was almost absent for depths >10 m. Sosua exhibited a contrasting distribution pattern compared to all other sites with the highest density of *D. antillarum* (2.62 Ind·m^{-2}) occurring at shallow depths (0-3 m). Minimum values were observed for the rest of the depth intervals at this locality, 0-0.02 Ind·m^{-2} for size class 2 and 3 respectively. Bayahibe *D. antillarum* population increased with depth from 0.51 Ind·m^{-2} in shallow waters (0-3 m) to 1.38 Ind·m^{-2} at (6-10 m) depth, for depths >10 m significantly decreased to 0.01 Ind·m^{-2}.

Figure C. *Diadema antillarum* frequency distribution (Ind·m^{-2}) for the different bathymetric levels: Total mean densities (left) and at the 4 different localities surveyed (right).





3.4 Bathymetric distribution for the different Size Ranges

In the bathymetric segregation by size, the results were analyzed taking into consideration the following: i) all locations sampled, since no error was committed in the methodology and all transects were laid randomly (Fig. D) and ii) on the other hand, Sosua was excluded (Fig. E) by the exceptional results detected, possibly due to the unique characteristics of the area. Depth range > 10 m, was also excluded to present this results in both cases (Figs. E & D), as *D. antillarum* individuals were almost absent for depths >10m, and the main objective of this section was to detect if there was a bathymetric segregation pattern by size (age).

In Fig. D where all localities were considered, the high density found in the transect conducted on the isolated rock resulted on average values, for all size classes (1-3 m), much higher in the shallower depth interval (0-3 m): Class 1 (0.39 Ind·m^{-2}), Class 2 (0.59 Ind·m^{-2}) and Class 3 (1.58 Ind·m^{-2}).

In Fig. E. where Sosua was excluded, the results obtained for the shallowest bathymetric level (0-3 m) was: Class 1 (0.12 Ind·m^{-2}), Class 2 (0.76 Ind·m^{-2}) and Class 3 (0.13 Ind·m^{-2}). *D. antillarum* showed a clear pattern for size Class 1 and 3 (juveniles and adults) being more abundant at intermediate depths and size Class 2 (pre-adults) density increased with increasing depth.

Figure D. *Diadema antillarum* density (Ind·m^{-2}) (average values±SE) for the different bathymetric levels (m) and size ranges: Class 1: <3 cm, Class 2: 3-6 cm, Class 3: >6 cm of test diameter (spines not measured). Bathymetric level >10 m was excluded.

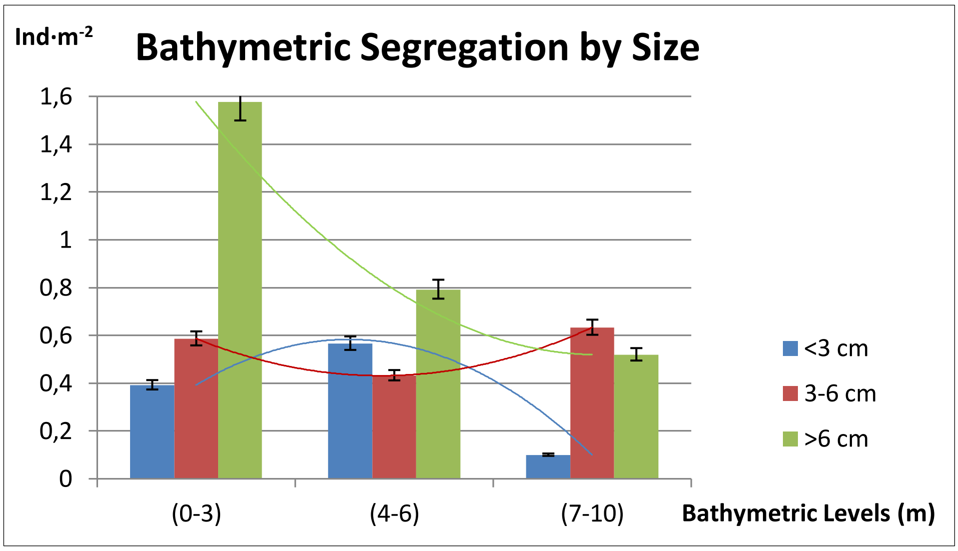


Fig E. Bathymetric Segregation excluding depth interval > 10 m and Sosua Locality (average values ± SE).

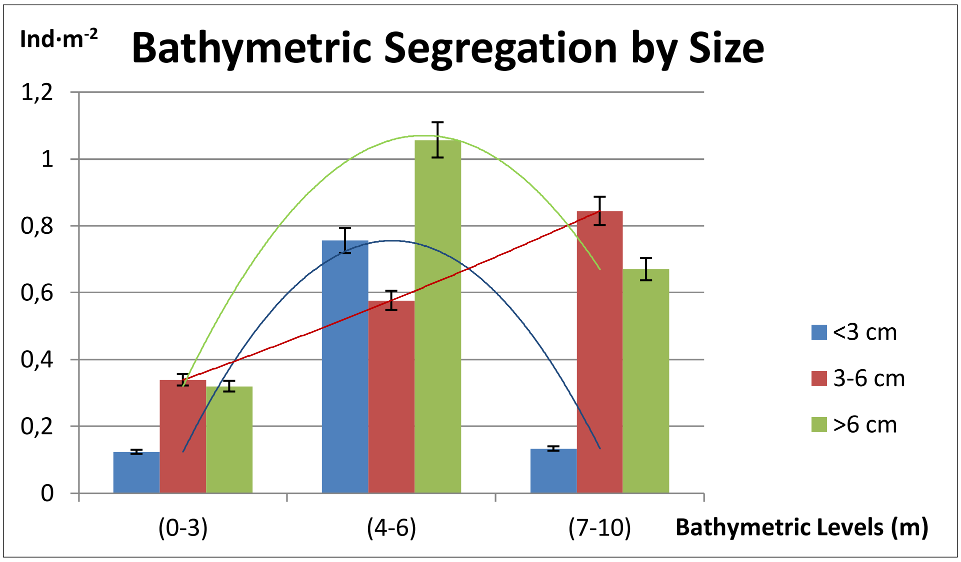
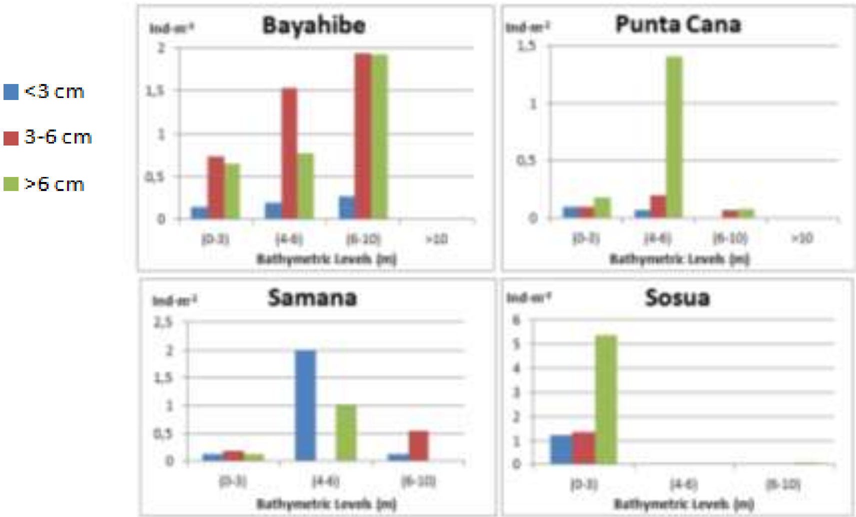


Figure F. *Diadema antillarum* total mean densities (Ind·m^{-2}) for the different bathymetric levels (m) and size ranges: Class 1: <3 cm, Class 2: 3-6 cm, Class 3: >6 cm (test diameter without spines: legend to the left) at each locality.



Bayahibe showed a clear pattern for all three size classes, increasing abundance with increasing depth up to 10 m, no individuals for depths deeper than 10 m. Class 2 and 3 are significantly more abundant than Class 1.The density values for Class 2 increased from 0.73-1.93 ind·m^{-2} and then dropped to 0.01 ind·m^{-2} below 10 m of depth; Class 3 densities increased from 0.65-0.93 ind·m^{-2} and was absent below 10 m.

The results observed on the rest of localities do not show a clear pattern. Punta Cana shows a low abundance in general for the three size classes with highlighting peak (1.40 Ind·m^{-2}) of Class 2 individuals at intermediate depths (4-6 m).

Samana had a greater density of juveniles (2 Ind·m^{-2}) at the intermediate depth interval (4-6 m) than all other sites.

At Sosua the mean density of *Diadema* was found to be high at shallow waters due to the concentration of this sea urchin at an island-rock. *Diadema* sea urchins at Sosua presented the maximum density of adult population (5.35 Ind·m^{-2}) at the shallowest depth interval (0-3 m).

3.5 Benthic Composition

To determine benthic composition 48 transects were performed; a total of 516 photos were processed with the Coral Point Count with Excel Extensions software including: 194 images for Bayahibe, 155 for Punta Cana, 88 for Samana and 79 for Sosua.

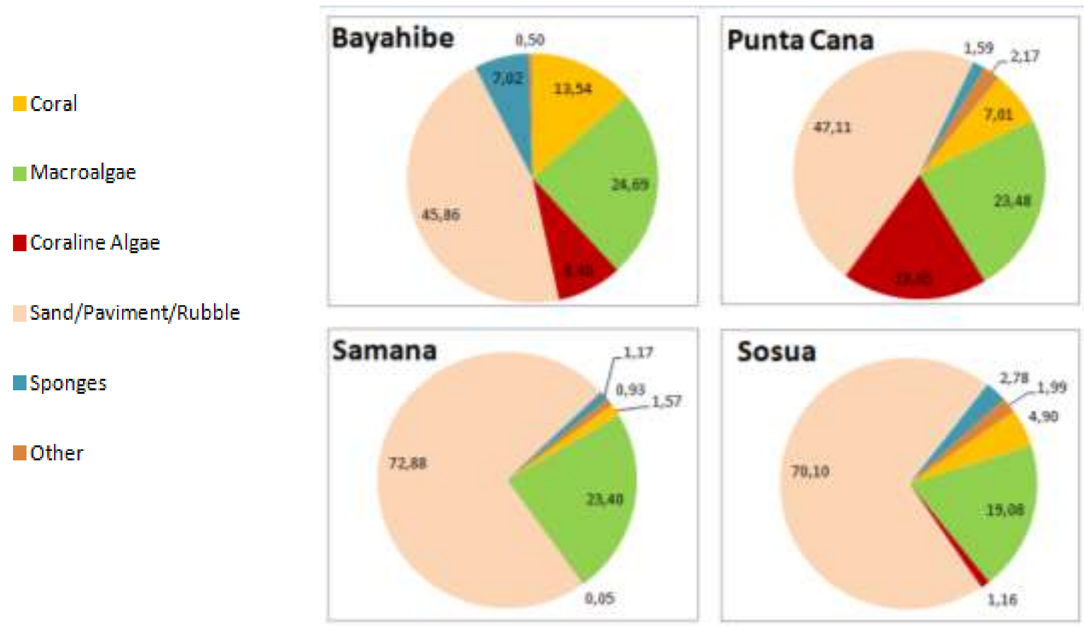
The results obtained showed similar values for macroalgal cover amongst all four sites with Sosua having the lowest macroalgal cover (19.08%), followed by Punta Cana (23.48%), Samana (23.4%) and Bayahibe (24.69%). Corals and sponges were notably more abundant at Bayahibe and Punta Cana with values of 13.54% and 7.02% respectively.

The northern regions (Samana and Sosua) presented higher percentage of sediments, 72.88% and 70.10% respectively; while Bayahibe and Punta Cana had 45.86% and 47.11%. The Sponge coverage found at Samana (1.17%), Sosua (2.78%) and Punta Cana (1.59%) was very low.

Coralline algae cover was much lower at the northern localities; it was completely absent in Samana, while Sosua had a value of 1.16%. Greater values were observed at Bayahibe 8.4% and Punta Cana 18.65%.

The mean benthic cover for the Dominican Republic, based on these four localities was: 6.75% Coral; 22.66% Algae; 7.06% Coralline Algae; 58.99% Sediments and 3.14% Sponges.

Figure G . Percentage values (%) for Benthic composition (Coral, Macroalgae, Coralline Algae, Sediments, Sponges and Other) estimated for the different localities.



4. DISCUSSION

- Population Density

The long spine sea urchin *Diadema antillarum* was present at all the locations surveyed in the Dominican Republic. The average value for the *Diadema antillarum* density, based on the 4 localities surveyed (Bayahibe, Punta Cana, Samana and Sosua) was 0.89±0.11 Ind·m^{-2} (Mean ± SE). Although densities of *D. antillarum* prior to mass mortality are unknown for the Dominican Republic; overall, the population densities were low across the DR, compared to earlier studies from neighboring islands where densities ranged from 0.83-1.55 Ind·m^{-2} in Puerto Rico in 2004 (Weil, Torres & Ashton, 2004), to 1.50 and 2 Ind·m^{-2} in Dominica, 2001 and 2004 respectively (Steiner and Williams, 2006), to 5-12 Ind·m^{-2} in 2000 (Edmunds & Carpenter,2001) and 2.77 Ind·m^{-2} (2010) in Jamaica (J. Keller, 2010). The lack of historical density values makes it difficult to evaluate the status of the current population but an apparent yet slow recovery over the last 11 years continues to be observed.

At the individual community level Punta Cana *D. antillarum* populations continue to increase but at a much slow pace than Bayahibe. The faster increase of *D. antillarum* in this area could be explained by the more favorable conditions: less surge action, weaker currents, higher macroalgae cover and less predatory pressure (removal of sea urchin predators due to overfishing), as previously speculated by Ogden *et al*. (1973), Hay (1984) and Carpenter (1990).

No previous data has been reported for Samana and Sosua making their continued monitoring as part of an integral species recovery monitoring is recommended. Furthermore, expanding the number of localities with different habitat conditions can broaden our understanding of the factors affecting the population growth and its impact on the coral reef communities.

All the surveys were conducted during daylight, and although extra effort was put on to check all holes and crevices in complex substrate transects the results obtained can be conservative values, adding some night dives could increase these results, as some individuals hide deeply in the reef structure (Weil, 2004).

- Population Size Structure

In the surveyed regions from the Dominican Republic, populations of *Diadema antillarum* showed a size distribution with predominant medium to large sizes (4 to 9 cm of test diameter) and very few small (<3 cm) individuals. No previous data was found for size frequency distribution for the Dominican Republic, although previous studies in Puerto Rico report a similar size distribution (Vicente *et al*, 1984; Torres *et al*, 2001; Weil, 2004 and Lugo, 2004).

The low densities observed for size Class 1 (<3 cm) might be an indicative of a low level of recruitment or juvenile survival or either a high mortality of juveniles (Lugo, 2004). Their natural cryptic behavior hiding in holes and crevices also could have lead to an under estimation by missing some individuals. Furthermore, when talking about urchin predation the urchin test size should be taken into account, as it will determine which species can attack them. In this sense, and as a conclusion to the observed results, it suggests the existence of a escaping size, above which no natural predator has the possibility of opening the skeleton. Consequently, the pressure of predation on these urchins should focus on smaller individuals (Tuya *et al*, 2004).

Additional information to better understand the low recruit numbers is needed as this pattern was observed at all sites surveyed. The lack of or reduced recruitment of *D. antillarum* can potentially threaten the recovery of the species and can leave them susceptible to a potential localized extinction from a possible disease outbreak or severe weather event resulting from climate change.

- **Bathymetric Segregation**

In general, the *Diadema antillarum* densities presented higher values at shallower depths. Its abundance increased from the 0-4 m to the intermediate 4-6 m depth intervals and was almost absent for depths below 10 m. Although, some inconsistencies were detected in the vertical distribution patterns amongst localities.

An exception was encountered for the Sosua locality where the highest values were found at a transect undertaken on a shallow isolated rocky island and performed at 1.3 m depth. The high densities found at this one transect could be explained by the distance to reach another source of food, and the protection of the assemblages against predators. Aggregations of this echinoid are found in less complex habitats, juveniles can be found inside the aggregates where they provide mutual protection between closely spaced urchins in open areas (Hunte and Younglao, 1988).

The low densities of *Diadema* observed in Punta Cana can also be explained by the highest wave action and strong currents at that locality; its long spines conveniently designed to minimize the risk of being attacked by potential predators are at the same time an inadequate mechanical design for turbulent environments (Ogden and Carpenter, 1987; Tuya *et al*., 2007).

- **Bathymetric Distribution for the different Size Ranges**

The size-frequency distribution of *Diadema* in the "urchin zone" varied amongst the 4 localities as the habitat characteristics also differed in some parameters that may be influencing in the spatial distribution of *D. antillarum* populations.

The *D. antillarum* size class 2 (pre-adults: 3-6 cm test diameter) was more evenly distributed along the "*Diadema* zones" (2-7 m) (Edmunds and Carpenter, 2001; Keller, 2010). The juveniles (<3 cm) and adults (>6 cm) were more abundant at intermediate depths (4-6 m), increasing from the shallowest depth range (0-3 m) to a maximum abundance in the intermediate depth interval (4-6 m) and significantly decreased at depths from 7-10 m and deeper. Each community surveyed showed different patterns for the *Diadema* distribution, hence supporting the hypothesis that factors affecting their distribution appear to be more related to the turbulence of water, availability of shelter structures and the number of predators or competitors for resources in the area (overfishing pressure) (Weil, 2004; Tuya *et al*, 2004).

The pattern detected at Bayahibe, with lower densities of this echinoid at shallower depths (0-3 m), and increasing abundance with increasing depth up to 8 m, matched with the recent study by Soto & Irizarry (2013) at Puerto Rico, although the registered *Diadema* densities were higher (1.75-2.35 ind·m^{-2}).

Despite results showing an absence of *D. antillarum* deeper than 10 m, a few adult individuals were observed while diving at Bayahibe and Punta Cana localities near the transects laid. The observed distribution of *Diadema* while diving matched with previous studies (Tuya, 2005).

Punta Cana *D. antillarum* abundance was lower compared to the other localities with an apparent recruitment failure, indicating the need to continue monitoring their populations along with other parameters that may be hindering the recovery of this species in this area. It is important to estimate the influence of oceanographic factors such as water temperature, nutrient availability, water turbulence, etc. that influence the photophilic algae dynamics and therefore its distribution and abundance (Tuya, 2005). A more specific research is suggested for a better knowledge of the *Diadema* ecology, thus enabling a proper management of their populations and indirectly, of coastal resources in Dominican Republic.

- **Benthic Cover**

Localities surveyed presented similarities between Samana and Sosua, with predominant sediment coverage and low coral percentage values. High sedimentation rates impede coral recruitment and growth (Stokes, Leichter, Salvatore, 2010). All localities presented values close to a 20% macroalgal cover. No significant differences were found to relate with the echinoid abundance. *Diadema* population density is independent from local resources (Karlson & Levitan, 1990).

The highest abundance of macroalgae and corals was found at Bayahibe coinciding with a higher density of *Diadema* observed at this locality, but also to have in consideration that Bayahibe is a fishermen town where sea urchin predator populations might be under fishing pressure. The rapid increase of this echinoid in Bayahibe could indicate the absence of main predators, 15 species of fish including ballistids, sparids, batrachoidids, *Cassis* helmet gastropod and spiny lobster *Palinurus argus,* and other fish that strongly compete with *Diadema* for algal resources as some species of scarids and acanthurids (Randall *et al*, 1964; Carpenter, 1990; Weil *et al*, 2005). Furthermore, Gloeckler reported benthic cover values of 39.9% macroalgae and 11.1% coralline algae in Bayahibe, compared to the 24.69% and 8.40%, respectively, observed in the actual study. The decrease in photophilic macroalgal bed could be related to the *Diadema* increase, although an increase in crustose algae would be expected. Bayahibe has a developed coastline full of Touristic Hotels and Resorts that grew without territorial planning; tourism overloads this location and consequently deteriorates water quality. Bayahibe subsoil consists mainly of extremely porous limestone, full of holes with dead coral and other fossilized organisms; drainage is excessive, making most of the rainfall quickly seep into deeper strata, with the poorly treated sewage possibly infiltrating the subsoil and ending in the marine environment. The latest Environmental Protection Program report (2014) denounced the organic pollution from the underground waters from Bayahibe (Herrera *et al*, 2014).

The same Gloeckler previous study reports a 15.3% coral cover that has slightly decreased to 13.54% on the actual study. For this study a more accurate classification of the algal communities was not performed, but a surprisingly high abundance of cyanobacteria was found in both Bayahibe and Punta Cana. For statistical analysis cyanobacteria was classified as macroalgae. A more detailed study is recommended of the benthos cover to see if there are shifts in algal communities and their functional structure to better understand the multifactorial distribution of *Diadema* populations.

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