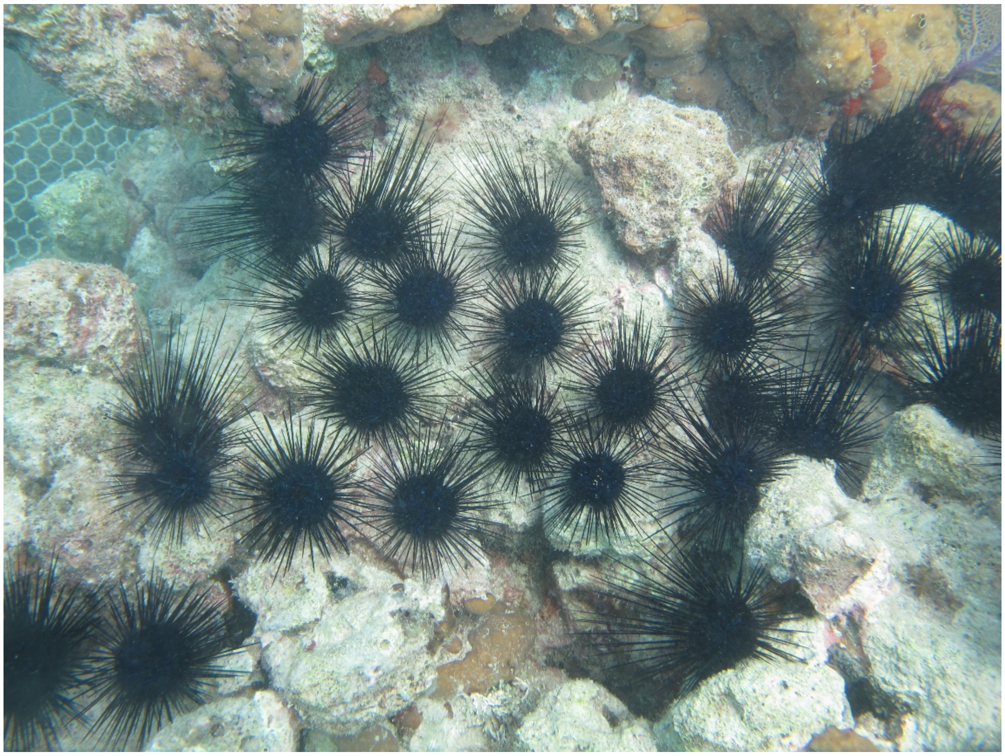
Seeding reefs with *Diadema antillarum* to enhance coral recovery in Puerto Rico

2015-2016

Final Report



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Introduction

Structure dynamics of coral reefs are intricate and continually changing, many times due to disturbances. Before the 1980's, Caribbean reefs were predominantly characterized by reef-building coral species, with a live coral cover of 55% (Gardner et al. 2003). Over the past three decades, coral reefs in the Caribbean have changed dramatically (Ginsburg 1994, Hughes 1994, Jackson 1997). The abundance of reef-associated organisms, especially corals, has suffered a massive decline due to cumulative factors such as, hurricanes, disease outbreaks, bleaching, pollution, and overfishing (Bythell and Sheppard 1993, Bythell et al. 1993, Littler et al. 1993, Hughes 1994, Kramer et al. 2003).

One of the most dramatic shifts in community structure occurred after the massive die-off of *Diadema antillarum*, a keystone herbivore. The 1983-1984 mass mortality of *D. antillarum* occurred throughout the Caribbean basin and was the most extensive and severe die-off ever recorded for a marine invertebrate (Lessios 1995). Before 1983, the presence of this organism was common (13-18 Ind m^{-2}) on coral reefs in the in Puerto Rico (Bauer 1980, Vicente and Goenaga 1984). Adult *D. antillarum* play an important role in structuring coral reef communities by controlling algal abundance (Carpenter 1981, Carpenter 1986, Carpenter 1990a, Carpenter 1990b, de Ruyter van Steveninck and Bak 1986, Odgen et al. 1973, Robertson 1987, Sammarco 1982), productivity (Williams 1990) and is one of the principal agents of bioerosion on reefs (Lidz and Hallock 2000, Bak et al. 1984, Scoffin et al. 1980). *D. antillarum* is a commensal for many organisms such as juvenile fish, crustaceans, and echinoderms (Randall 1964, Steiner and Williams 2005). After the massive die-off, populations were drastically reduced by 95-100% in many Caribbean locations (Lessios 1995) and at the same time fleshy macroalgal cover increased between 100% and 250% (Phinney et al. 2001). The absence of *D. antillarum* did not only influence the benthic algal productivity of coral reef communities, but it also impinged on the settlement of sessile recruits, such as corals and the growth of adult corals.

Presently, the recovery of *D. antillarum* has been slow and even absent at many locations in the Caribbean. In Puerto Rico, there has been a modest recovery in the population of *D. antillarum* (Mercado-Molina et al. 2014). However, densities are still far below pre-mass mortality numbers. Larval mortality and recruitment have been suggested as the main factors regulating the adult population size of *D. antillarum* (Karlson and Levitan 1990). In Puerto Rico, upstream sources of *D. antillarum* “settlement-ready” larvae are available (Williams et al. 2010), therefore larval supply and survival do not seem to be an inhibiting the recovery. Recruitment-limited processes, such as post-settler and/or recruit mortality may be regulating the population dynamics of *D. antillarum* in Puerto Rico.

Self-reinforcing negative feedbacks (no herbivores) will drive reefs towards a coral-depauperate stable equilibrium (Roff and Mumby 2012). Areas, especially in Jamaica have seen positive feedbacks from the recovery of *D. antillarum*. *D. antillarum* recovery has been coupled with the decrease of macroalgal cover on the shallow-water reefs of Jamaica (Woodley 1999, Aronson and Precht 2000, Cho and Woodley 2002, Bechtel et al. 2006, Carpenter and Edmunds 2006). Also, the survival of juvenile and adult corals has increased with *D. antillarum* recovery (Edmunds and Carpenter 2001, Idjadi et al. 2010).

Study Objectives

Short-term goals were to:

1) Increase survivorship of cultured settlers in a laboratory setting
2) Increase the populations of *D. antillarum* on the backreef of Media Luna in La Parguera, Puerto Rico.
3) Monitor and measure survivorship of restocked juveniles.
4) Measure the grazing effect of transplanted juveniles

The long-term goal of this project is to enhance coral reef resiliency, such as increasing (coral recruitment, survival, and growth and decreasing algal abundance by introducing herbivorous benthic organisms.

Materials and methods

I followed the same methodology outlined in Williams et al. (2010, 2011) settlement studies. Williams et al. (2010, 2011) observed a settlement hotspot at two shelf-edge sites Old Buoy and El Hoyo, with a max settlement of 1,064 Ind m^{-2}. The supply of *D. antillarum* settlers for this restoration experiment were collected at the Old Buoy (Fig. 1). The depth of the site ranges from 18-21 meters. The reef substrate is fairly flat with relatively low coral cover and diversity. Historically, there have been few adult *D. antillarum* recorded at both of these sites (<0.01 Ind m^{-2}). Williams et al.

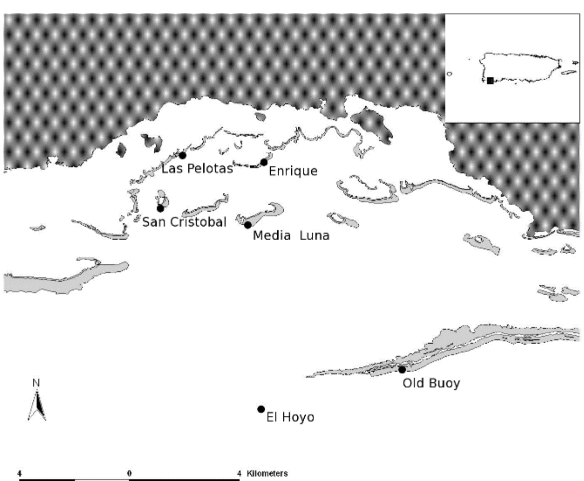

Figure 1 Settlement sites in La Parguera, Puerto Rico

(2010, 2011) observed the settlement of *D. antillarum* to peak during summer months, especially in July. Therefore, ten mooring lines were placed at Old Buoy on May 29, 2015. Two cement blocks anchored each of the mooring buoys. The cement blocks were placed in the middle of a sand channel, and not impacting the corals and reef on either side. The buoys were located at 6 m of depth and did not represent any navigational hazard. On each mooring line, a rope containing 20, 8 × 8 cm pieces of artificial turf (Fig. 2) was attached to the cement blocks and mooring buoy. Plates were positioned in 7 to 10 meters of depth in the water column. During collections, the rope was detached and placed in a dry bag and a new rope with clean plates was attached. Settlement plates were replaced every month until October 2015 (total of four samplings) and were brought back to the laboratory to analyze. The mooring lines were removed during our collection in October.

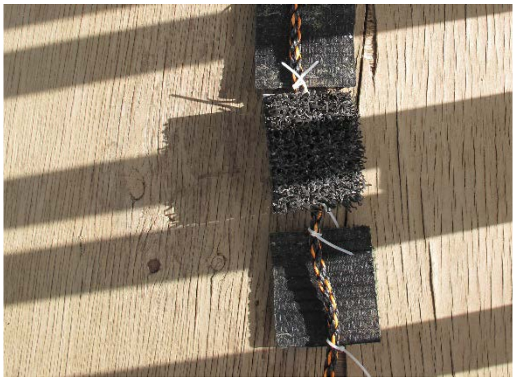

Figure 2 Astroturf or artificial turf used as settlement

Culturing Diadema antillarum settlers

Settlers (Fig. 3) were picked off each settlement plates, counted and transferred to 10-gallon tanks. A closed filtering system was installed in each tank, which helped reduce sediment and other larvae from entering and settling in the tanks. Tanks were cleaned once a week and one-third of the water was replaced with fresh seawater that was filtered. Water quality measurements were recorded every two weeks. These measurements included salinity, pH, temperature, nitrate, and ammonium. Brown and red algae (*Padina* and *Acanthomorpha* spp.)

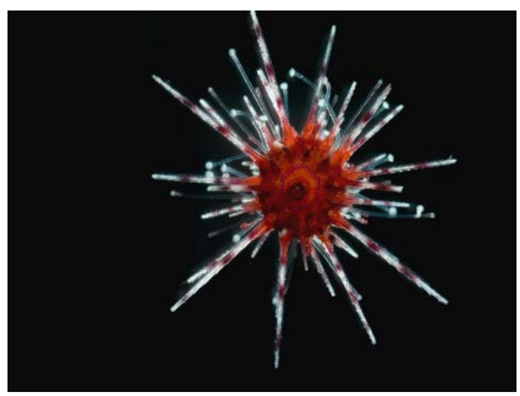

Figure. 3 Diadema antillarum settler

were collected, washed with freshwater, inspected for micropredators (worms and crabs), and placed in the tanks. Algae were collected once a week. Settlers were transferred to wet tables once they reached a size of 5 mm. We modified and expanded the flow through system for 2015 grow out (Fig. 5). Three new tanks were added and in the new design, wet tables were put on a semi-closed circulating system. This allowed water to flow through the tanks even if fresh seawater was not being supplied. A holding tank for fresh seawater and a filter sock were installed. The sock filtered out sediment and was replaced and cleaned once a week. Tables were cleaned once every two weeks, and algae were collected and placed in each table every three to four days. Algal species, *Acanthomorpha*, *Chaetomorpha*, *Padina*, *Stypopodium*, and *Dictyota* spp., were collected in the field once a week and kept in a holding tank. *D. antillarum* juveniles were transplanted to the reef once they reached a test size of at least 3-4 cm.

Figure 4 Wet tables at Marine Science Department

Reintroduction

D. antillarum juveniles were transplanted to the backreef of Media Luna (N°17.93948, W°-67.05070, Fig. 1) in La Parguera. The backreef of Media Luna (Fig. 5) is composed of series of patch reefs, which are structurally-complex, comprising of mostly dead *Orbicella annularis* colonies. This site was included as a permanent monitoring station for the Puerto Rico Coral Reef Monitoring Program (PRCRMP -DNER/NOAA). The dominant benthic substrate (ranging from 38% to 76%) on the backreef at Media Luna is a mixture of turf algae, growing intermixed with fleshy macroaglae, particularly *Dictyota* spp. and articulated calcareous algae, *Halimeda* spp (Garcia-Sais et al. 2015). The density of *D. antillarum* on this reef is less than 0.05 Ind m^{-1}. *D. antillarum* present on the reefs are large adults, no juveniles or recruits were recorded after a thorough search. A total of 53 fish species were identified during Garcia-Sais et al. (2015) surveys, with a total mean abundance of 61.8 Ind $30m^{-2}$ (range: 46-86 ind 30 m^{-2}). The numerically dominant species, were the bluehead wrasse (*Thalassoma bifasciatum*), princess parrotfish (*Scarus taeniopterus*) and french grunt (*Haemulon flavolineatum*).

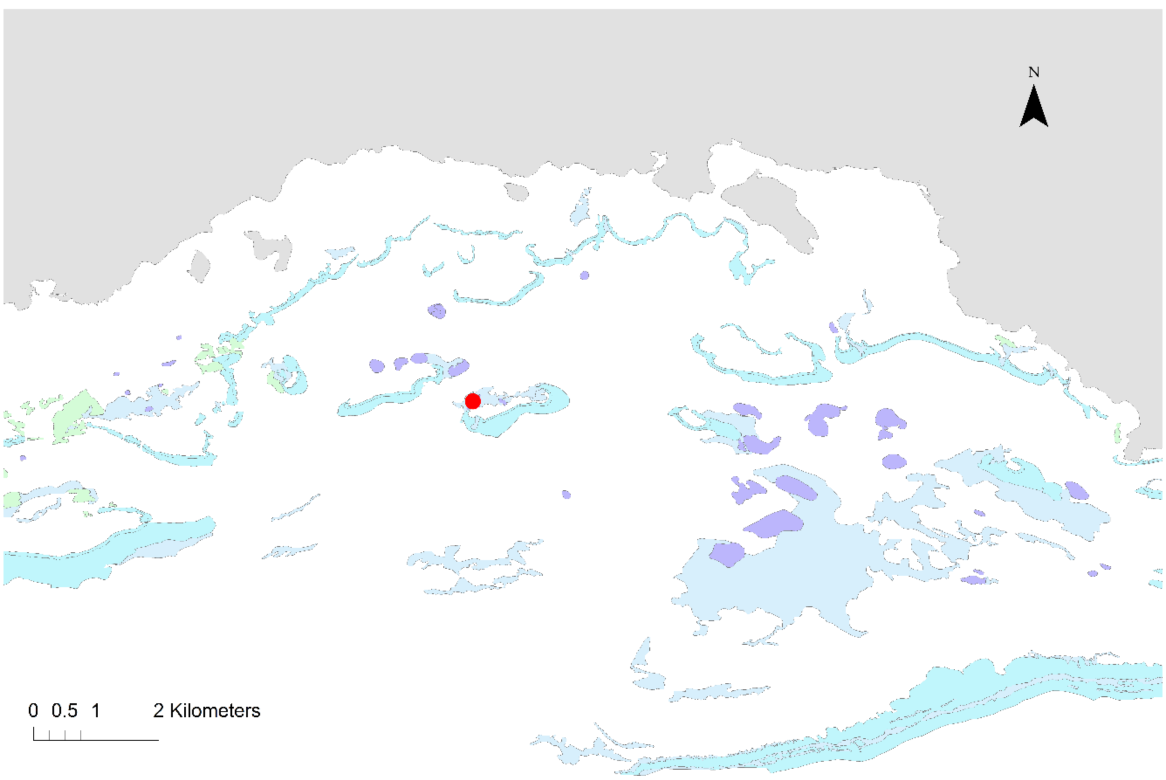

Figure 5 Diadema antillarum were reintroduced to a backreef at Media Luna (red dot) in La Parguera, Puerto Rico.

Six corrals were installed at the backreef of Media Luna (5m of depth) and held into place with rebar. The area of each corral was approximately $4m^2$. Corrals were made of galvanized chicken wire with a 1 inch diameter mesh size. Plastic chicken wire was attached to the bottom of the corral to mold to the reef and fully enclose the corrals. Corrals were placed around isolated *O. annularis* colonies.

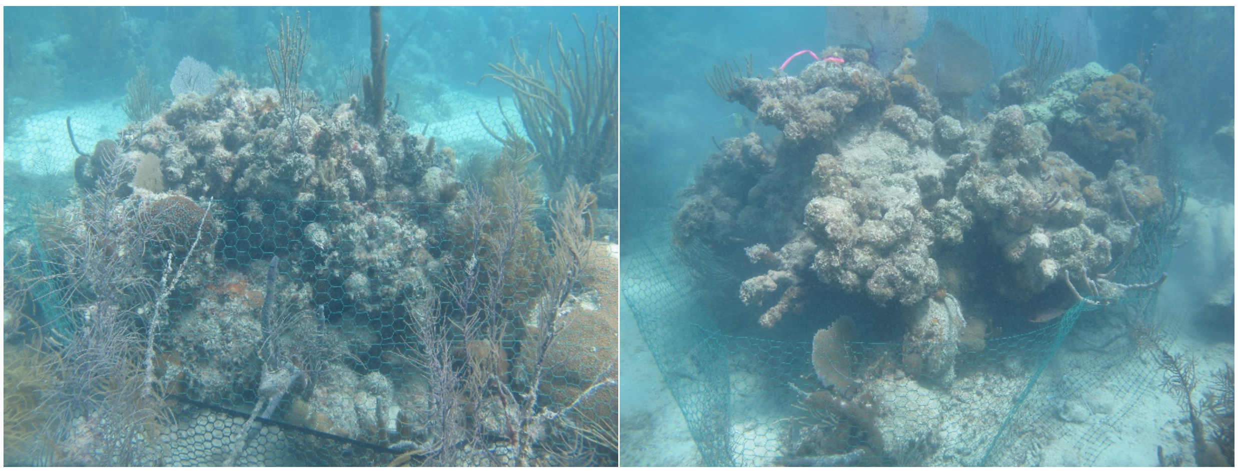

Figure 6 Photographs of two corrals taken before reintroduction.

On June 28, 2016, at 4:00 PM, 152 young adults (3-4cm) were transferred and placed in the corrals (Fig. 7). Reintroducing *D. antillarum* during late afternoon hours allows for adaption to reef conditions overnight. Densities of reintroduced individuals varied among corrals to assess density-dependent survivorship. Fifty-two individuals were placed in two corrals (13 Ind m^{-2}), mocking pre-mass mortalities of 13 Ind m^{-2}. While 16 individuals were placed in two other corrals (4 Ind m^{-2}) and four individuals were placed in the last two corrals (1 Ind m^{-2}). Monitoring took place one and two days, one week and two weeks, one month after the reintroduction. Individuals were counted inside and outside the corrals.

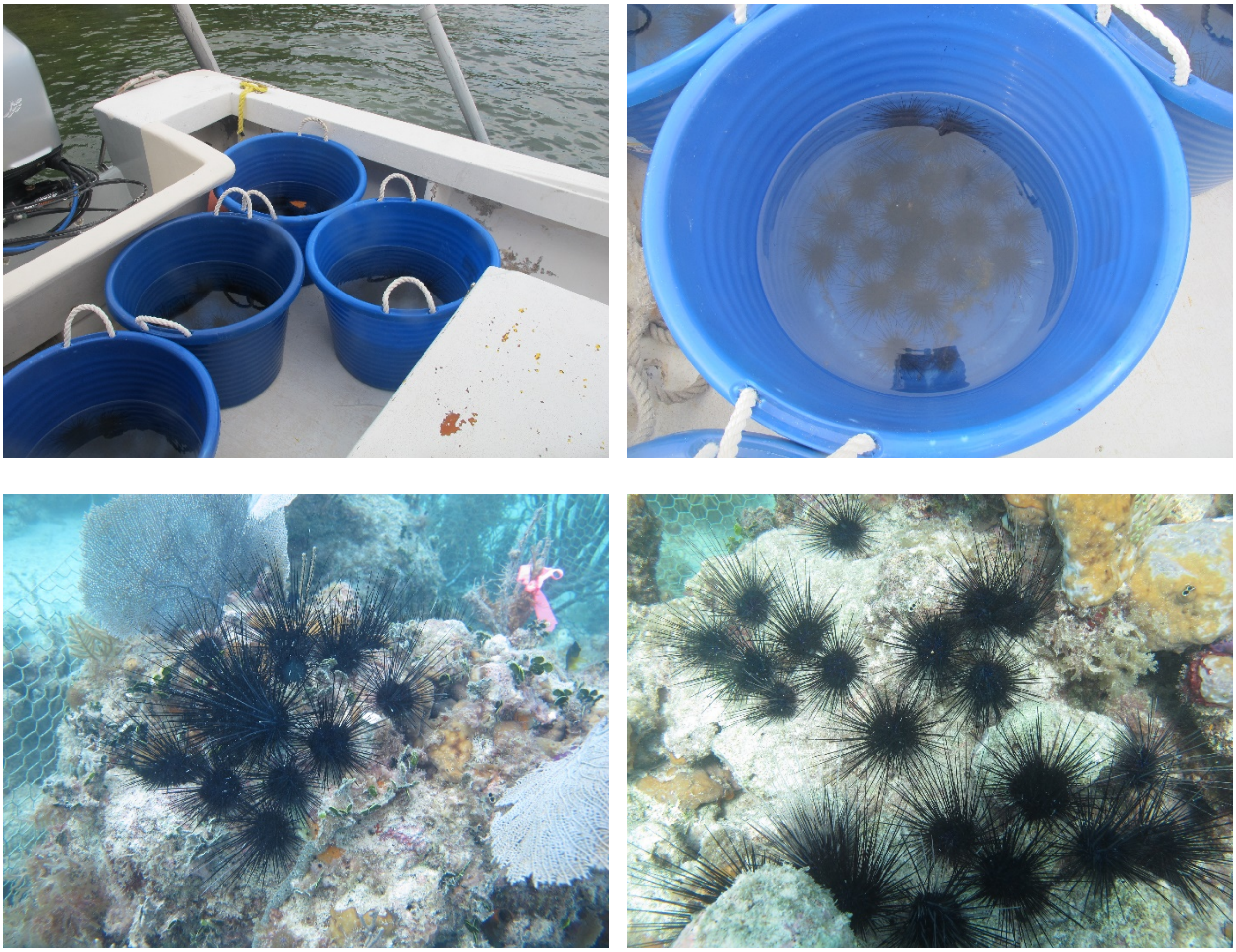

Figure 7 Photographs of the transfer and reintroduction of lab-reared Diadema antillarum at a patch reef in the backreef of Media Luna, La Parguera.

Results

Settlement

During 2015, a total of 795 settlers were collected during the four-month collection. Settler collection was considerably low during 2015 compared to 2014 collection, where a total of 1,342 settlers were collected. As seen in Figure 6, the pattern of settlement was similar between the two years. Settlement varied between months and peaked in July during 2014 and 2015. It is important to note that El Niño was occurring during the summer of 2015, causing the seawater temperature to be warmer earlier in the summer and there was high abundance of *Sargassum* sp. floating in the water. Possibly, *D. antillarum* spawned earlier in the year and/or there was a low larval survivorship. Garcia-Sais observed atypical high abundance of fish larvae in plankton surveys in Salinas, Puerto Rico during the summer, possibly due to the high amount of floating *Sargassum*. The size of the settlers ranged from 0.4 mm to 1.0 mm. The majority of settlers were smaller than 0.6 mm in test size. Approximately, 8 to 10 percent of the settlers died either during transporting them back to lab and/or when sampling through settlement plates.

Survivorship

It was hard to measure survivorship during the early stages of culturing because of the size of the settler. Settlers are the very sensitive to water quality and sediments when they are <1mm, and ideally, water used for culturing in the 10-gallon tanks should be filtered and sterilized. Water was filtered for larger sediments, but there was not the necessary equipment to sterilize the water and filter for finer sediments and organisms. There was high settler mortality (20% survivorship) during the first month of culturing (July). High settler mortality could be due to water quality and/or micropredators. All live rock and algae were cleaned before putting them in the tank. Nitrate, phosphate, calcium and ammonia were normal throughout the grow-out period. Salinity fluctuated from 35‰ to 36‰. All recruits were transferred to the large wet tables by the beginning of November 2015. The overall survivorship of settlers/recruits in the 10-gallon tanks was 44%, which was greater than 2014 culturing (by 17%).

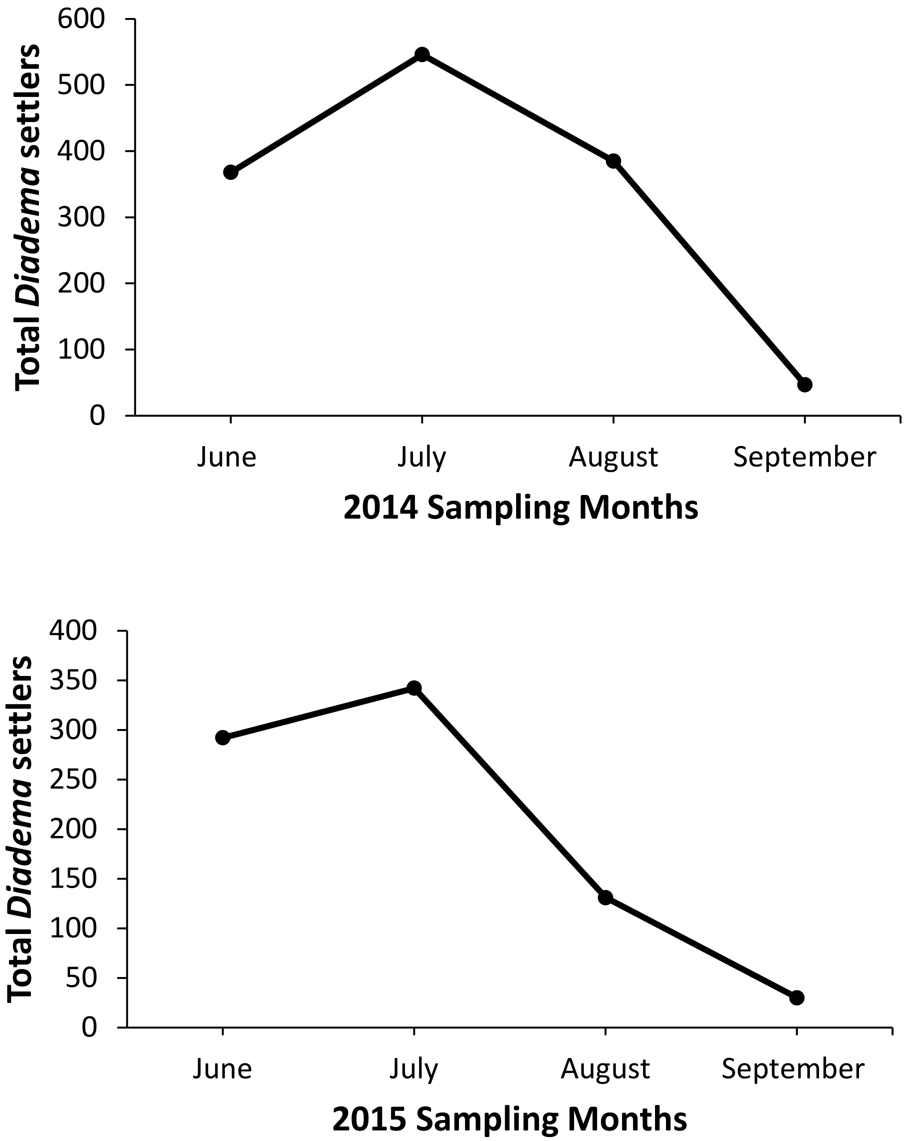

Figure 8 Total amount of Diadema antillarum settles collected during each month in 2014 and 2015.

The last set of recruits transferred from the 10-gallon aquariums to the wet tables was on November 6, 2015, and the total amount of recruits/juveniles in the wet tables at this time was 352 individuals. Only two individuals died from November 2015 to June 2016. Therefore, 2015-16 survivorship (99%) was greater than 2014-15 survivorship (92%).

Reintroduction

The amount of confined individuals varied between the corrals throughout the monitoring. Benthic characteristics (amount of food, shelter, etc.) of the *O. annularis* colonies inside the corrals did not vary between corrals. Thus, the amount of escaped individuals of each corral did not depend on the benthic characteristics inside the corral. Individuals escaped in groups and usually aggregated in coral heads surrounding the corrals. They were well hidden and many times hard to find. Some young adults moved far (20-30 meters) and did not display homing behavior until they found a particular coral head. There were no broken spines and/or skeletons observed in the restoration area throughout the monitoring.

The majority of the urchins escaped during the first two days of monitoring. Fourteen (14) individuals escaped the corrals a day after the reintroduction; eight were not identified in the surrounding area, and six individuals were returned to their respective corrals. I observed more escaped urchins (30 individuals) during day two of the monitoring. The number of individuals recorded stabilized one week after the reintroduction (Fig. 9) and was consistent throughout the month. Seventy-nine (79) percent of young adults were recorded a month after the reintroduction. During the last day of monitoring a number (nine individuals) of escaped individuals were observed on an adjacent patch reef. These individuals were about 20 to 30 meters from the corrals.

Survivorship of reintroduced *D. antillarum* appeared to be influenced by their densities and shelter availability. As mentioned before, the reintroduced individuals preferred to display aggregate behavior. Aggregated urchins were usually out on top of the reef and solitary individuals were hidden within the reef substrate. In the future, restoration efforts may want to focus on reintroducing many individuals (~100) at one time.

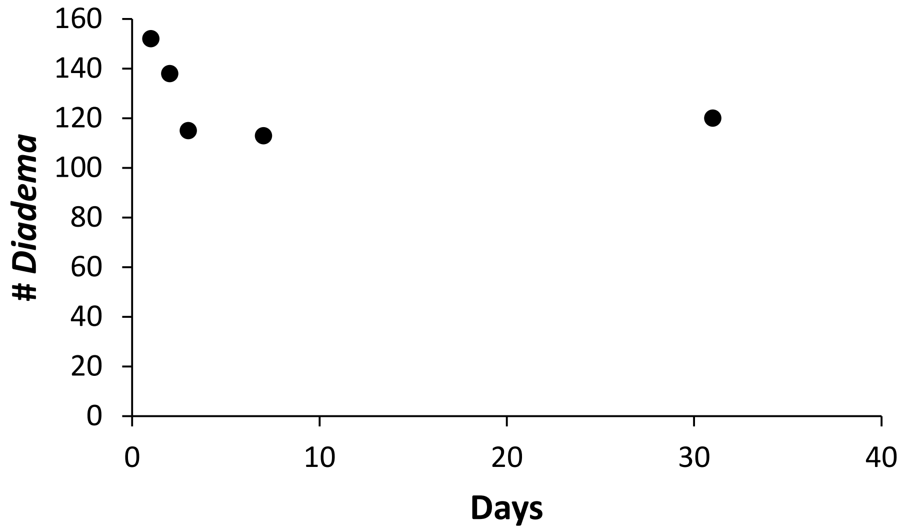

Figure 9. Amount of transferred Diadema antillarum recorded days after reintroduction.

Changes in benthic composition were evident in corrals one week after the reintroduction (Fig. 10). *D. antillarum* in the corrals were efficient in grazing the benthos of algae, especially turf and *Dictyota* spp. The area of grazing was bare of algae and sediment after one week of reintroduction. In the corral, 50% of the reef substrate was effectively grazed after one month of the reintroduction. The benthos was noticeably cleaner inside the corrals compared to benthos outside (Fig. 11).

Figure 10. Photographs of a corral before (left) and after (right) after the reintroduction of Diadema antillarum.

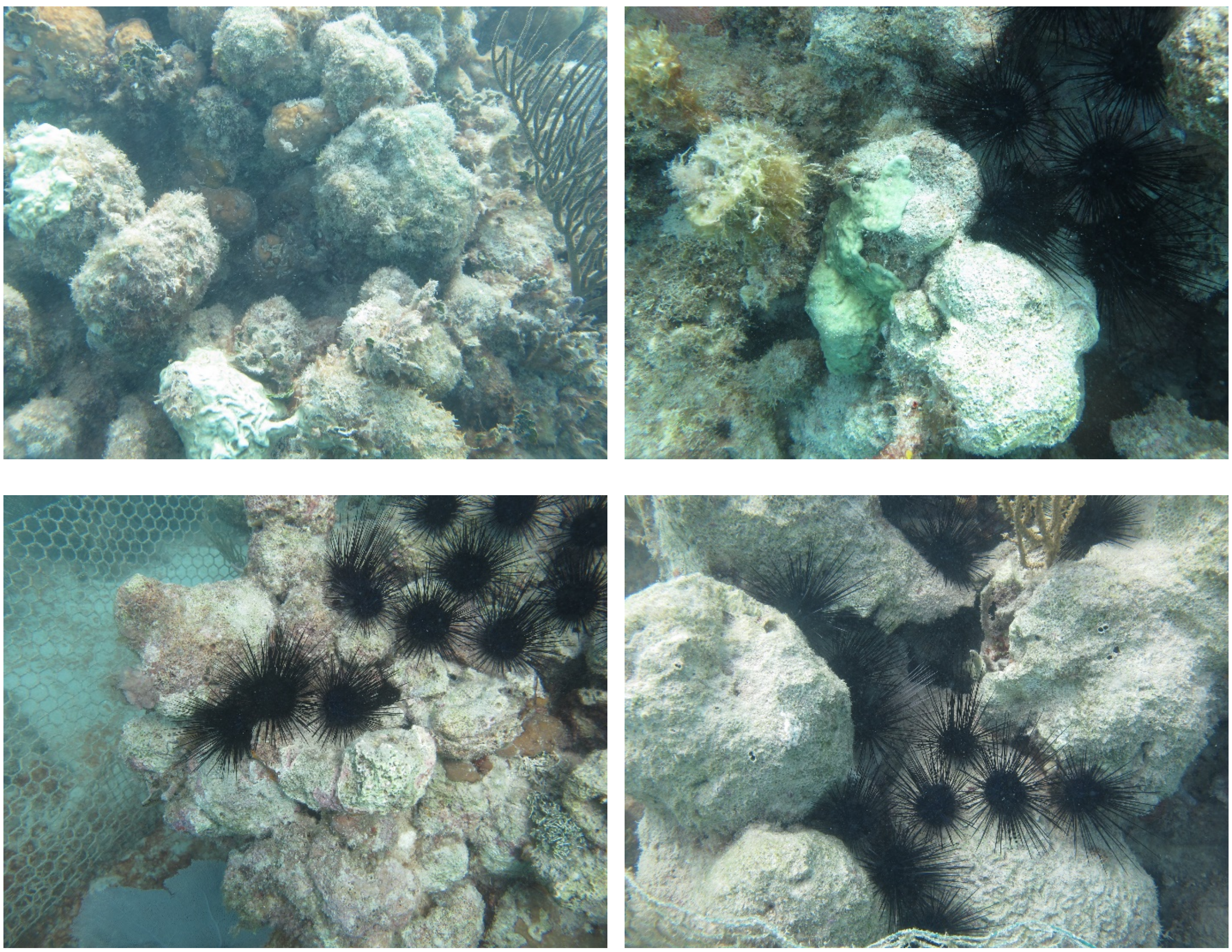

Figure 11. Photographs (clockwise) of the benthos before Diadema antillarum reintroduction, interface of Diadema antillarum grazing, substrate of grazed substrate.

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