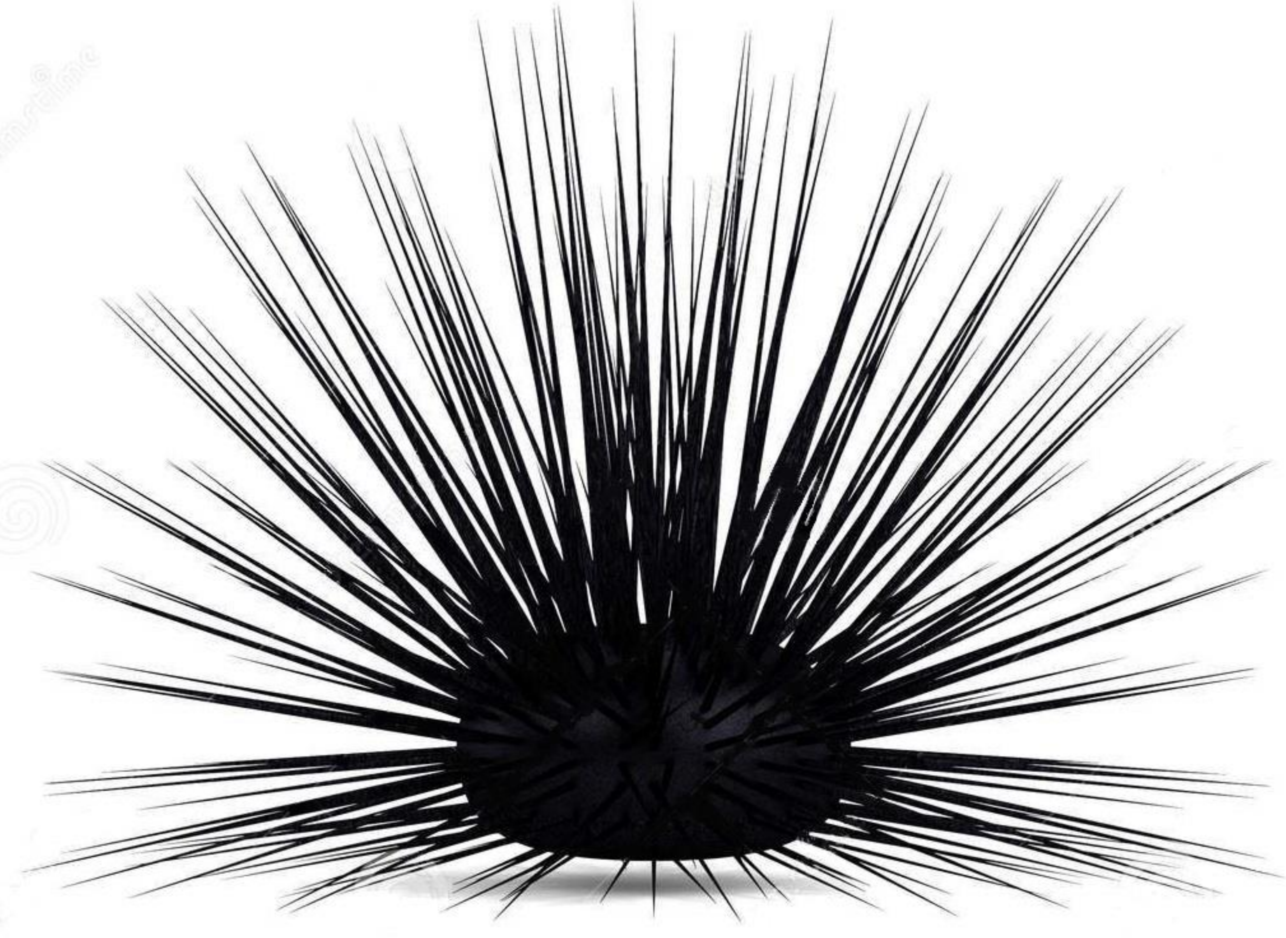
Diadema antillarum Translocation Study in Anguilla, British West Indies



Department of Fisheries and Marine Resources

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SUMMARY

The Long-Spined Sea Urchin (*Diadema antillarum*), known locally as the sea egg, is an ecological keystone species, meaning that its presence in a specific habitat shapes the integral nature of that habitat. *D. antillarum* are important grazers, cropping many different species of macroaglae that if left unchecked can smother coral reefs and inhibit the growth of hard coral. Hard corals are arguably the most important group of organisms in a coral reef ecosystem as they are responsible for the majority of its structural integrity. Without new hard coral growth Anguilla's reefs would slowly erode and eventually be unable to provide the services that the island currently relies upon them for.

During the early 1980s *D. antillarum* suffered a mass mortality event throughout the Caribbean that resulted in its almost complete disappearance from the region. During the subsequent quarter of a century it has slowly made a limited recovery, but today its distribution is still patchy with some areas exhibiting virtually no recovery at all. Although the reasons for such distributions are not fully understood, and the full extent of the influence that *D. antillarum* has on an ecosystem still in question, no doubts exist that healthy populations of the urchin can only benefit the ecological integrity of shallow reef habitats. Furthermore, because larvae of the urchin travel via ocean currents a healthy population will essentially 'seed' surrounding regions and thus benefit the regional recovery of this important species.

For these reasons the Department of Fisheries and Marine Resources believes that protecting healthy urchin populations should be a priority. When such a population was threatened at Shoal Bay West by a coastal development, a project was initiated that set out to translocate this population to an area in Shoal Bay – Island Harbour Marine Park that has yet to exhibit a substantial urchin recovery. This project served to develop a translocation methodology for similar future initiatives and to study the effects that such a translocation has on the receiving site.

A simple yet effective methodology was developed that allowed the relatively rapid translocation of *D. antillarum* from one site to another with no initial mortality effects. Overall densities did however drop over time with an almost 50% reduction recorded between surveys conducted six months and twelve months after translocation. Confoundingly, as individuals were recorded to migrate into the shallow reef zone (<3m) it is not clear whether these reductions were in fact caused by migrations out of the study site rather than mortality. Both scenarios could have been working in unison.

One cause of a lagging recovery phase in certain areas is likely poor larval supply caused by unfavourable ocean currents and/or an allee effect in recovering populations. Another possibility is some unknown mortality factor affecting *D. antillarum* and inhibiting an areas recovery and this opens up the possibility that the areas that have yet to recover may have had low urchin numbers prior to the 1980s mortality event. In this case macroalgae dominance that has occurred in these areas since the mortality event may be due to other factors such as over-fishing of herbivorous fish or increased nutrient levels in the water. A final consideration is the possibility that these areas have only recently become unfavourable to *D. antillarum* because of ecological alterations that may have taken place over recent years, for example increased nutrient loads.

The initial effect of *D. antillarum* on their surrounding habitat was a reduction in macroalgae, although over time these algae began to grow back as urchin numbers decreased, likely through migration into the shallow reef zone. Aspects of *D. antillarum* life history are known to be density dependant. Grazing competition is likely to be one of these and it is suspected that beyond a certain population density,

migrations into shallower depths will taper and deeper regions will begin to be populated. It can thus be concluded that future efforts should strive to concentrate urchins into the highest densities possible by estimating the number of *D. antillarum* available for translocation and selecting an isolated patch reef of suitable size to house them. It is not recommended that naturally occurring healthy populations of urchins be translocated unless they are threatened by coastal developments or other external anthropogenic factors.

INTRODUCTION

The long-spined sea-urchin *Diadema antillarum* has long been thought of as a key-stone species throughout Caribbean coral reefs, playing an important role in their structure and dynamics (Tuya *et al.* 2004). One of its main functions is as a grazer, and populations can reach such levels as top form 'urchin barrens', areas of rock or reef completely cleared of fleshy macroaglae. Tuya *et al* calculated that densities of 10 urchins per meter squared where sufficient to create such a barren, and experiments conducted by Morrison (1988) concluded that the removal of *D. antillarum* resulted in a pronounced change in the shallow algal community. After an absence of only two months erect and filamentous algae rapidly overgrew the area, although in contrast *D. antillarum* exclusion had little effect on the deeper algal community. The reason for this difference is likely due to differing algal composition on reefs deeper than 10m, and also probably the reason urchins favor shallower areas of natural systems. Increases in nutrient levels and/or decreasing densities of grazers can allow algae to out-compete corals and cause an ecological 'phase-shift' where algae is the dominant life form (Moe, 2003).

Unfortunately for the reefs of the Caribbean this is exactly what happened following the spread of an unidentified pathogen that decimated *Diadema* populations in the 1980's. This event was first observed at Galeta Point, Panama, in January 1983, and after fourteen months had ultimately affected urchin populations in over 3.5 million square kilometers of water (*Diadema* workshop 2004). Populations still have not returned to their previous levels with this slow recovery thought to be caused by asynchronous spawning behaviour that relies on dense populations for greatest success (Levitan 1988a) and equatable to an allee effect. Limited localized recovery has been reported in some areas however (Carpenter & Edmunds 2006), and it is hoped that as populations recover in these small pockets, overall rates of increase will improve through enhanced larval recruitment.

Consequently, even today, twenty-five years after their disappearance from the Caribbean's shallow reef environment, algae dominate many of Anguilla's reefs. Although it is recognized that this is not solely due to the paucity of *D. antillarum* (fishing of grazers and nutrification likely play an important role also), it is considered highly important to protect the recovering populations. Currently many of the complex algal covered reefs are still not supporting healthy populations of urchins, although a small number are present in many of the very shallow areas (<3m). The areas that have exhibited a recovery are surprisingly areas of low topological complexity which are not 'traditional' *D. antillarum* habitat as there is little refuge from predators. In these areas however (for example Pelican Point and Maundays Bay Point), populations are so dense that they are spilling off the rocks and forming aggregations on sand and rocky flats (see photograph 1 & 2). Reasons for these areas recovering before 'traditional' areas remain a mystery. Some once common and voracious urchin predators however are thought to be less abundant than prior to this mortality event (i.e. Queen Triggerifsh), which may offer an explanation as to why these aggregations survive, but not to their absence in more favorable areas close by. One possibility is that overall predator abundance is lower in these areas, even when taking into account invertebrates such as the Cushion Star (*Oreaster reticulates*).

Whatever the reason for the current distribution, these dense populations are an important natural resource for Anguilla as they represent biologically fit reproductive units of vital importance for *D. antillarum* overall recovery throughout the region. Because of this the Department of Fisheries and Marine Resources (DFMR) decided to undertake a translocation project when one of these populations was threatened by an approved marina development in Shoal Bay West[1]. This project served to not only save as great a percentage of the population as possible but also to test a methodology for such work that could serve as a template for future translocations should any subsequent populations become threatened. Furthermore, undertaking such work also tests the survivorship of translocated individuals using the methodology and adds to the limited but growing list of case studies published on similar experiments and their effects.

Photographs 1 & 2 – *D. antillarum* populations on sand and rocky flats at Maundays Bay Point, a short distance away from Pimms Restaurant

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[1] Due to the economic slow down in 2008 the marina project was shelved and as such only a small proportion of urchins were translocated. The number moved were sufficient for this project to be tested but likely not significant enough to damage the original populations spawning potential. If the development once again threatens the population, or indeed if any other developments do, the translocation work will be re-initiated, and this study expanded further.

METHODOLOGY

The donor site was chosen using sequential reasoning: Once permission had been granted to dig a marina access channel connecting a coastal salt pond to the ocean a rapid assessment was conducted that identified a healthy population of *D. antillarum*. The translocation site was chosen by rapidly assessing twelve sites in Shoal Bay – Island Harbour Marine Park, and making a choice based on high topological complexity and low resident sea urchin numbers.

D. antillarum were removed from the shallow donor site using two divers and a small dinghy. The two divers were equipped with a small hand trowel, thick leather gloves, and buckets with drainage holes. Urchins were flicked off the substrate with the trowels and guided into the bucket. Only *D. antillarum* that could be easily removed without damaging their spines were targeted (see photographs above at a different location). Once full the buckets were taken to the surface and passed up to the dinghy, where the number were recorded and transferred into a large container. Once this larger container was full it was transferred to the main vessel and filled with sea water, and when all large containers were full, they were transported around the island to the translocation site. At the translocation site the divers were passed one large container at a time and carefully submerged it, turning it upside down over the translocation site marker. A few gentle taps on the bottom of the container dislodged the urchins who then float down onto the substrate. Once all containers were empty, the translocated *D. antillarum* were observed for five to ten minutes to assess potential mortality. Two such translocation trips were conducted.

Prior to this translocation, the site and a nearby control site (both located on the same patch reef but separated by approximately 300m), were surveyed using randomly placed 50 cm x 50 cm quadrats. Physical and biological characteristics were recorded including depth, rugosity, algae cover (usually only down to genus level), turf algae cover, hard coral cover (species), and other invertebrates present. Separate *D. antillarum* belt transect (15m x 2m) counts were also conducted at different depths (3m, 4m, 5m, 6m, 8m & 10m). Subsequent visits repeated these survey parameters over the next twelve months. Each site was considered 15m x 15m, with the marker buoy situated centrally.

Logistical constraints: Although early surveys were planned bad weather and boat problems inhibited this and thus early survivorship data and ecological changes were not documented. Also, further translocations were planned to increase the number introduced to the site, but because the marina project was shelved due to the 2008 global financial slowdown, they were cancelled in order to preserve the integrity of the donor site population.

RESULTS

A total of 348 urchins were translocated with no initial fatalities observed. Some spine breakage was noted to have occurred.

Urchin Abundance

During baseline *D. antillarum* counts at the translocation site two individuals were counted along the 3m transect. Post translocation abundances are illustrated in figure 1a to 1c over the page.

Figure 1a, 1b & 1c – Abundance of *D. antillarum* across different depths during three survey visits subsequent to translocation. Below these results are presented as densities:

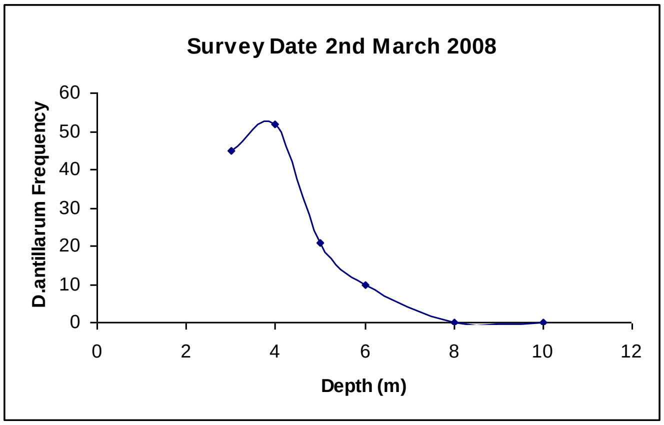

Figure 1a – 2nd March 2008

6m = 0.3 per m^2
5m = 0.7 per m^2
4m = 1.7 per m^2
3m = 1.5 per m^2

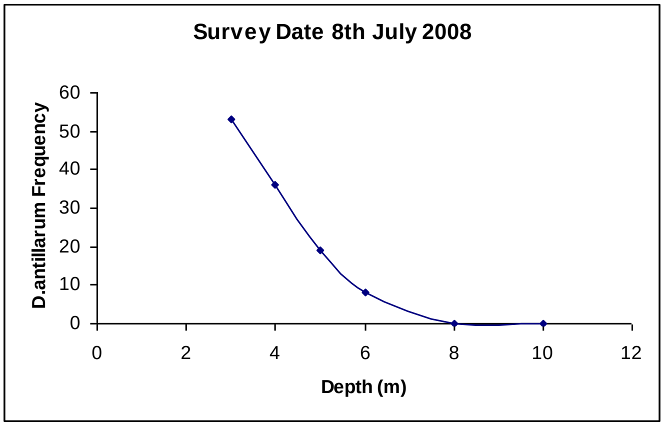

Figure 1b – 8th July 2008

6m = 0.3 per m^2
5m = 0.6 per m^2
4m = 1.2 per m^2
3m = 1.8 per m^2

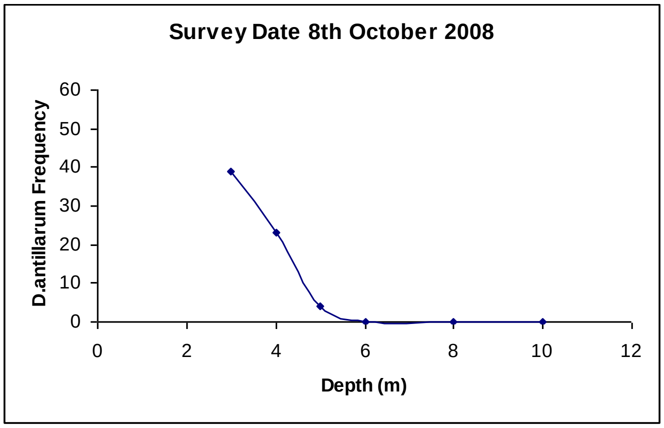

Figure 1b – 8th Oct 2008

6m = 0.0 per m^2
5m = 0.1 per m^2
4m = 0.8 per m^2
3m = 1.3 per m^2

During baseline *D. antillarum* counts at the control site one individual was counted along the 3m transect. No others were observed. The three subsequent surveys yielded total abundances of three individuals at 3m and one individual at 4m.

Habitat Characteristics

Data were analysed for normality and were found to deviate significantly so non-parametric statistical tests were performed only. Multivariate statistical software was not available, so only univariate analytical methods could be employed.

Baseline – Fleshy macroalgae and turf/sediment cover seemed to vary between the two sites, with fleshy macroalgae cover appearing higher and turf/sediment cover appearing lower at the translocation site. Analysis indicated however that although close there were no significant differences between these results, or indeed any of the other habitat characteristics collected.

Post Translocation – Mean results from subsequent survey visits to the translocation site revealed that turf/sediment significantly increased (Mann-Whitney $U_{30,90} = 577.5$, $p < 0.001$) at the translocation site and fleshy macroalgae significantly decreased (Mann-Whitney $U_{30,90} = 996.0$, $p = 0.032$), although this decrease was more noticeable in the first six months after translocation (Mann-Whitney $U_{30,30} = 291.5$, $p = 0.019$) and began to rise again in the latter six months (see figure 2). Although fleshy macroalgae was still lower during subsequent visits, the difference between the two sites became less as time progressed. After twelve months however, although not significant, macroalgae at the translocation site were still c.3.5% lower than the baseline results and those at the control site still c.5.5% higher. The increase in turf/sediment cover was inverse to this (see figure 3).

At the control site significance differences were also seen with increases in mean turf/sediment cover between baseline conditions and subsequent surveys (Mann-Whitney $U_{30,90} = 891.5$, $p = 0.005$) and also, a close but not significant increase in macroalgae during the first six months (Mann-Whitney $U_{30,30} = 320.0$, $p = 0.054$). The changes in turf/sediment cover followed the same pattern as the translocation site, and the differences between the two sites were not significant for any of the combinations. Similarly, at both sites calcareous algae and coralline algae significantly decreased after translocation: Calcareous algae, translocation site (Mann-Whitney $U_{30,90} = 324.5$, $p < 0.001$); coralline algae, translocation site (Mann-Whitney $U_{30,90} = 806.0$, $p = 0.001$); calcareous algae, control site (Mann-Whitney $U_{30,90} = 429.0$, $p < 0.001$); coralline algae, control site (Mann-Whitney $U_{30,90} = 618.0$, $p < 0.001$) - but the differences between sites were not significant.

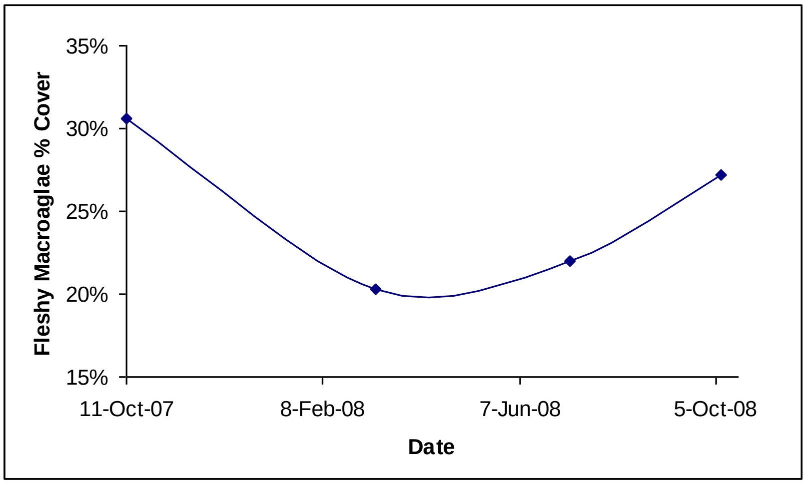

Figure 2 – Mean fleshy macroalgae cover for the different survey dates at the translocation site before (11th Oct 07) and after translocation.

No significant results were obtained relating to the presence of *D. antillarum* in a quadrat and the amount of fleshy macroalgae or turf/sediment cover also within it. Similarly, no such significant relationships were found between urchin presence in a quadrat and its depth, depth and fleshy macroalgae, or depth and turf/sediment.

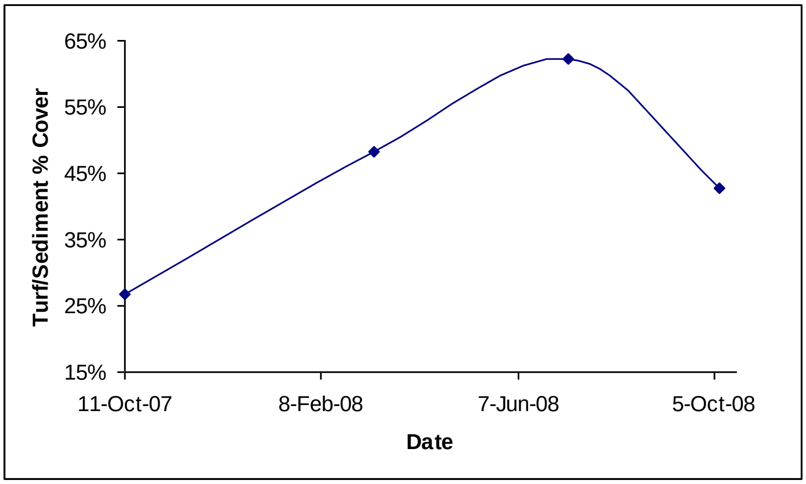

Figure 3 – Mean turf/sediment cover for the different survey dates at the translocation site before (11th Oct 07) and after translocation.

DISCUSSION

Although both the translocation site and control site appeared similar on first inspection and showed no significant differences between baseline habitat characteristics, a few aspects did vary slightly and these differences are interesting to use when highlighting other results in this section.

As no fatalities were observed during translocation, and no injuries received by the field staff, the methodology used can be viewed as a success. However, it was noted that a number of the urchins' spines broke during transport, which although not initially fatal may reduce the individual's ability to resist predation. It is not clear how the methodology could be improved to reduce such breakages, unless urchins were transported in less crowded conditions. Modifying the methodology like this would make translocation work more labour intensive and thus expensive, possibly rendering it impractical. It is therefore not recommended until any increase risk from predation has been substantiated. As survivorship appeared reasonably high over the first six months it is assumed that such breakages are of minimal impact as replacements would be grown by those individuals affected.

After translocation the fleshy macroalgae percentage cover dropped significantly at the translocation site. During the same period the cover of fleshy macroalgae at the control site increased markedly. The most common genus' of fleshy macroalgae present at both sites (*Dictyota sp.* and *Lobophora sp.*) are known to be associated with moderate to high nutrient levels (Goreau *et al.* 2008) and such levels are known to exist in the area (Wynne 2009) and can be considered eutrophic (Goreau & Thacker 1994). Consequently, it is quite possible that the increase at the control site was due to nutrient levels and potential seasonal fluctuations in the area and because the two sites are so close to each other it can be assumed such factors would be uniform across both. The significant change at the translocation site can therefore be inferred as a direct result of increased urchin numbers. It also shows how the presence of urchins can influence macroaglae composition even in high nutrient levels. This effect can be further highlighted by appreciating that fleshy macroalgae cover was initially higher at the translocation site than the control site by 8%, but after urchins had been introduced it dropped to below 17% that of the control site.

Other changes that could be attributed to *D. antillarum* introduction were also recorded at the translocation site. For example, cover of calcareous algae dropped and cover of turf algae/sediment increased. However, because these changes were also noted at the control site it is almost certain that other factors influenced the change, for example seasonal variations in algal species composition caused by nutrient fluctuations or removal of flora by wave action (heavy seas occurred between translocation and the first set of surveys). If this latter factor is indeed the cause, then it is even more significant that fleshy macroalgae increased in cover at the control site because it did so even when faced with destructive wave action. This could point to nutrient fluctuations that were sufficient to promote algae growth even during such conditions, and again increases the significance of the potential influence *D. antillarum* had on fleshy macroalgae at the translocation site. Such fluctuations will be investigated by DFMR's current water monitoring programme.

After six months, the amount of macroalgae at the translocation site began to increase again. During this time *D. antillarum* populations appeared to slowly migrate into shallower regions. This led to a 'muddying' of the data where shallow regions were low in algae cover, but deeper regions with high cover blurs any significance. It was attempted to tease these variables apart by looking for associations between depth, urchin presence, macroalgae and turf algae/sediment. No significant results were found however, probably due to replicate limitations and the low sample size of urchins that actually fell under a quadrat. This could be addressed by actively targeting urchins and comparing their immediate surroundings with areas where no urchins were present, although it was not felt necessary to do this as there is much literature describing such associations (*Diadema* workshop 2004). Another method would be to restrict quadrat surveys to depths where urchins were seen to be present following the counts made using belt transects, thus mitigating the effect of migration.

Also adding to this increase in macroalgae will be the fact that *D. antillarum* dropped in overall density during this same period, thus the effect of urchin presence was reduced. As stated by Tuya *et al*. (2004), densities need to be in excess of 10 individuals per m^2 to effectively control macroalgae and these levels were far from achieved. It is likely that this drop in number is due to: Mortality, either 'natural' or through predation; or because of migration, either to shallower regions or out of the study site. Migrations into shallower regions were confirmed not only by the results but also by unquantified visual assessments in areas less than 2m deep. Due to wave action and the shallow depths, surveys were unable to take place.

Although migration is potentially more encouraging than mortality and even though mortality can't be ruled out, migrations still represent a drop in density on the study site. Many aspects of an urchin's life history are density dependent (Levitan 1988b), and as such the reduced densities seen in effect represents a drop in spawning and recruitment potential (Levitan 1991) through an allee effect (Gascoigne & Lipcius 2004). Urchin populations are open however, thus providing surrounding regions are spawning successfully and currents permit, a supply of recruits should be brought into the area. It has been suggested that recruitment is aided by more dense populations as adults provide shelter and protection (Karlson & Levitan 1990), as are overall mortality rates, hence pointing to more complex reasons for a potential allee effect. It is hoped that the translocated population will mitigate this allee effect somewhat and enable a population to establish itself in the area.

These factors interacting with each other may offer insights into why the recovery of urchins has been patchy, also happening in areas not historically associated with them. For example, it has been suggested that one factor influencing recovery is the absence of their natural predators (for example – triggerfish and nurse sharks). Although fishing occurs more heavily in the traditional yet un-recovered urchin grounds, the habitat is more suitable for such predators and so they still likely occur in higher numbers than in the areas where recovery is occurring. The lack of complexity in these latter areas mean they do not house noticeable predator populations and thus urchin numbers can flourish. Furthermore, because these areas are somewhat limited in size (i.e. scattered rocks or small coastal overhangs), dense numbers soon form small patches which then aids juvenile settlement, survival, and thus increases numbers. With no habitat to migrate to, they begin to spill over onto sandy/rocky flats, aggregate and again aid density dependant life history traits. The 'traditional' areas with little or no recovery are large regions of complex structures that offer plenty of space for migrating urchins to move to. It is speculated that although urchins will aggregate, especially if complex habitat that provides protection is lacking, they have the tendency to seek out new patches that they can graze unhindered by other individuals. Migration of a type at least is a certainty, as was seen with their selection of shallower regions.

These factors alone could well explain the patchy recovery in unexpected places, but they may also be influenced by as yet un-quantified variations in larval recruits, in which currents and the locations of successfully spawning populations are responsible for. Certainly, on a macro-ecological scale it does seem unlikely that recruits would be distributed evenly and those areas where recovery is apparent do appear to have better water circulation. Indeed, these are precisely the findings of Miller *et al.* (2003) who reports that in St Croix recovery seemed to follow the same pattern of the 1980's die-off which suggests the same oceanographic features that spread the pathogen are now carrying urchin larvae.

What is clear however is that it is imperative when considering the restoration of *D. antillarum* to areas yet to recover, that sufficient quantities are translocated in order to give the new population the greatest chance of survival. Such translocations should not be made to areas where habitats are so vast that migrations will allow dispersal of *D. antillarum* and produce populations of minimal density. For example, this study took place on a relatively large patch reef, which although useful in terms of this study and its conclusions, in retrospect potentially reduces the likelihood of a long-term positive impact with the number of urchins translocated. Subsequent studies must allow for this.

Reportedly 10 individuals per m^2 are required to control fleshy macroalgae, although such densities can also cause damage to coral recruits through scraping, which is undesirable (Goreau 2008). Accordingly, a density less than 10 per m^2 is suggested to still reduce macroalgae, establish a viable urchin population, while at the same time reducing the likelihood of scraping, therefore promoting coral recruitment. To achieve 5 urchins per m^2, 1000 urchins would be needed to populate a site 15m x 15m - almost three times the number translocated. In fact, at the levels translocated, assuming equal distribution, no mortality, and no migration, there were less than 1.6 individuals per m^2. Thus, for a translocation to be successful it is imperative that an isolated habitat be chosen, its size quantified, and a minimum urchin number to be translocated established. Ideally a small patch reef surrounded by sand would be used that can potentially produce a successfully spawning and recruiting population.

As a final note, the latter part of this discussion highlights the importance of not translocating a healthy *D. antillarum* population from a habitat for restoration purposes unless it is threatened. A healthy population is spawning and producing larval recruits that will help populate other areas. Regional recovery, although slow, does seem to be happening, so protecting healthy populations is likely the most effective form of habitat restoration in terms of restoring *D. antillarum* to their pre-1980 levels.

CONCLUSIONS

The methodology used to translocate *D. antillarum* was successful with no fatalities observed during translocation. It is therefore recommended for use if subsequent work is conducted. The survey methodology following the translocation could be modified slightly to illustrate significant results relating to depth and potential migrations. To increase chances of success a translocation site should be chosen based on its size and the number of *D. antillarum* available for translocation. The site should also be isolated in order to mitigate any effect of migration. This increases the potential for high densities to be achieved and thus increase survivorship, spawning success and recruitment; all of which are known to be density dependant life history traits. It is not recommended to translocate urchins from a healthy population unless the population is threatened, as it is recognised that these healthy populations are likely important sources of new recruits and likely facilitate higher rates of larval urchin settlement. As such damaging a naturally occurring healthy population, combined with the uncertain long-term survival and viability of an artificial daughter population, may produce a net loss in regional urchin fecundity.

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