Restoration and monitoring of a vessel grounding on a shallow reef in the Florida Keys

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Abstract: This paper summarizes the results of a monitoring event designed to track the recovery of a repaired coral reef injured by the M/V *Alec Owen Maitland* vessel grounding incident of October 25, 1989. This grounding occurred within the Florida Keys National Marine Sanctuary. Pursuant to the National Marine Sanctuaries Act, NOAA recovers money for injury to Sanctuary resources, and uses it to restore those resources. A monitoring program tracks patterns of recovery, in order to determine the success of restoration measures. To evaluate success, reference habitats adjacent to the restoration site are concurrently monitored to compare the condition of restored areas with natural areas. Restoration of this site was completed in September 1995 by means of cement and limestone rock, and the monitoring results from summer 2007 are presented. Monitoring consisted of comparison of the biological conditions in the restored area with the reference area. Monitored corals are divided into the Orders: Gorgonians, Milleporans, and Scleractinians. Densities at the restored and reference areas are compared, and are shown to be greater in the restored. Size-class frequency distributions for the most abundant Scleractinians are examined, and reveal that the restoration is converging on the reference area. Also, for the Scleractinians, number and percentage of colonies by species, as well as several common biodiversity indices are provided; measures for the restored area approximate the reference area. A quantitative comparison of colony substrate settlement preference in the restored area is provided for all Orders, and for Scleractinians is further broken down for the two most frequent Genera. Rev. Biol. Trop. 58 (Suppl. 3): 151-161. Epub 2010 October 01.

Key words: coral restoration, vessel grounding, coral monitoring, coral density, coral biodiversity, coral size-class frequency distribution.

In 1989 a vessel known as the M/V *Alec Owen Maitland* ("*Maitland*") ran aground on a shallow coral reef within the boundaries of the Florida Keys National Marine Sanctuary. Pursuant to the National Marine Sanctuaries Act, the U.S. National Oceanic and Atmospheric Administration (NOAA) is the federal trustee for the resources of the Sanctuary. Under the Act, NOAA has the legal authority to recover monetary damages for injury to Sanctuary resources, and to use the recovered money to restore those resources. In the case of the *Maitland*, a lawsuit was filed, damages were obtained, and restoration accomplished.

Besides the restoration itself, the Act also provides that damages are to be collected to enable monitoring of the recovery of a restoration. The monitoring program tracks patterns of biological recovery and determines the success of restoration measures of the site over time. In this instance in order to evaluate success, reference habitat adjacent to the restoration site was concurrently monitored to compare the condition of restored and "natural" coral reef areas.

Restoration of this site was completed in the summer of 1995 with monitoring planned to begin in following years. The monitoring program at the *Maitland* site includes an

assessment of the structural stability of the restoration and an evaluation coral recruitment patterns. This paper presents the results of the third of the monitoring events that have been performed. That monitoring event took place in the summer of 2007 or approximately 12 years after restoration of the grounding site was completed. (For a more complete presentation of the restoration history and monitoring results arising from the M/V *Alec Owen Maitland* grounding site, please see: http://sanctuaries.noaa.gov/science/conservation/pdfs/schittone_new.pdf).

Reef Injury: On October 25, 1989, the M/V *Alec Owen Maitland*, a 47m oil field supply vessel, ran aground in a reef coral community south of Carysfort Reef, in 2-3m of water. Additional injury occurred as the result of initial attempts to "power off" the reef by putting the propellers in reverse, and then revving up the vessels' engines. The grounding totally destroyed $681m^2$ of living corals and partially destroyed $930m^2$ of coral reef framework (NOAA undated).

The grounding of the ship and subsequent attempts to free it resulted in significant injury to the reef substrate and resident marine organisms. Efforts by the vessel to extricate itself caused "blowholes" (gouges caused by high-revving propellers) in the reef's surface. Approximately 79% of the total stony coral cover, as well as numerous sponges and sea fans at the site, were destroyed by the grounding and/or removal attempts. The injuries ranged from superficial scraping of the reef surface and toppling of large coral heads, to complete crushing of coral and severe cracking of the reef framework structure.

The company responsible for the grounding and NOAA agreed to a settlement in December 1991. Before a restoration could be implemented however, a very large hurricane, Hurricane Andrew, severely impacted the *Maitland* site. The storm passed less than 100km to the north of the site, with winds exceeding 200kph. After the hurricane's passage, it was found that the blowholes had been "excavated," i.e., expanded and merged together (CSA 1993).

NOAA believed the hurricane's effects exacerbated the grounding injuries and that additional storm-generated injuries would occur in the future absent restoration efforts. Thus, restoration was undertaken in 1995. Activities were planned by Office of National Marine Sanctuaries headquarters, and Florida Keys Sanctuary staff. The NOAA personnel collaborated with marine engineers from the firm of Olsen Associates, Inc.; work was implemented by Team Land and Development, Inc., along with Sanctuary staff.

MATERIALS AND METHODS

Reef Restoration: The objectives of the *Maitland* site restoration were to fill in the blowhole and to stabilize the damaged reef framework. Engineering design for the site was particularly challenging because of the scope of the damage, the site's shallow-water, high energy environment, and the proximity to sensitive resources. Structural repairs to the site included the placement of 40 pre-cast concrete and limestone boulder units to fill in the grounding crater, filling approximately $800m^2$ in total. After placement, they were sealed with approximately $45m^3$ of underwater pumped concrete. Before setting, the concrete was embedded with locally quarried limestone rocks.

The units were designed in six sizes to accommodate the crater's complex and varying geometry. Each unit weighed approximately 9.5-10tons above water. The units were designed to withstand wave and current forces anticipated in a once-in-25-year storm event. The structure has withstood the passage of several close hurricanes (Georges in 1998 and at least seven more recent storms). Overall, the restoration was intended to "re-create a stable foundation which closely emulates the adjacent natural seabed and which would foster future recruitment of the local biota" (Bodge 1996).

Restoration Monitoring: Between August 5 and 10, 2004, the *Maitland* restoration site

was monitored using SCUBA. Another monitoring event occurred on June 7 and July 26, 2005 and the latest monitoring visit occurred between July 27 and September 14, 2007. Between the August 2004 and the June 2005 monitoring evernts, the eyes of three powerful hurricanes passed within 250km of the restoration site. These were Charley in late August, and Jeanne and Frances in September 2004. Each sustained winds approximating 175-195kph at the time of closest approach to the restoration site.

In the 2005 season, hurricane Dennis made its closest approach in July, at similar distances and wind speeds as noted for the 2004 storms. In addition, in August and subsequently, hurricanes Katrina, Rita, and Wilma passed within 175km of the site. At the time of closest approach, Katrina and Rita had winds of about 130kph. Wilma had winds of approximately 205kph, but was over land (SW Florida) at the time. No monitoring of the site was conducted between the 2005 and the 2007 monitoring, and thus the possible confounding effects of these hurricanes, if any, are speculative. However, no visually perceptible damage of the restoration structures was observed.

Field Methods: In 2007, within both the restoration and adjacent Reference sampling area, 21 one m² quadrats were surveyed for variables of interest as described in the *Biological Classifications* section. Within each survey area, a random number generator corresponded to a digital grid of uniquely identified 1 m² cells overlaid on the grounding site map. Transect lines were used from landmarks to determine cell locations in the field as best as possible.

Biological Classifications: All information presented was generated by visual observation from the quadrat data. The majority of the benthos present was comprised of three coral Orders, and most of the comparisons presented are at the Order level. These include: Order Anthoathecata (specimens were of one Genus in the Family Milliporidae, henceforth referred to by the Genus name—*Millepora*);

and the Orders Gorgonacea and Scleractinia. Scleractinians were further divided into species for various analysis purposes.

Data Analysis: Regarding the density analyses: for the Gorgonians, square root transformation was necessary to enable *t* tests; for the *Millepora* and Scleractinians, no transformations were needed. All three Orders evidenced sufficient homogeneity of variance that no corrections were applied.

For all years, common biodiversity indices were calculated for the Scleractinian populations. Additionally, size-class frequency distributions are shown for *Porites astreoides*, the only species with a sample size sufficient for such calculations.

Additionally, data on substrate attachment in the restoration area was collected to permit Chi-square (χ^2) "Goodness of Fit" Test between actual and expected settlement occurrences. Due to the low proportion of *Millepora*, the test was conducted with Yates' continuity correction.

Inter-annual comparisons are made for Scleractinians and Gorgonians. For Scleractinians, no transformations were necessary; analysis proceeded by way of a single-factor ANOVA, followed by Bonferroni's Multiple Comparison Test. For the Gorgonians, normality could not be achieved after attempted transformation; analysis was by way of a Kruskal-Wallis Test, followed by Dunn's Multiple Comparison Test.

RESULTS

Density: Scleractinian densities in the Restored area greatly exceeded those in the Reference area. For the three Orders surveyed in 2007, the data yielded the densities shown in Fig. 1. For the Gorgonians, the statistical test used (see *Data Analysis*) indicated that the difference between the Restoration and the Reference populations were very significantly different (p=0.0015). The same test yielded non-significant results (p=0.8875) for *Millepora*. For Scleractinians, the statistical test

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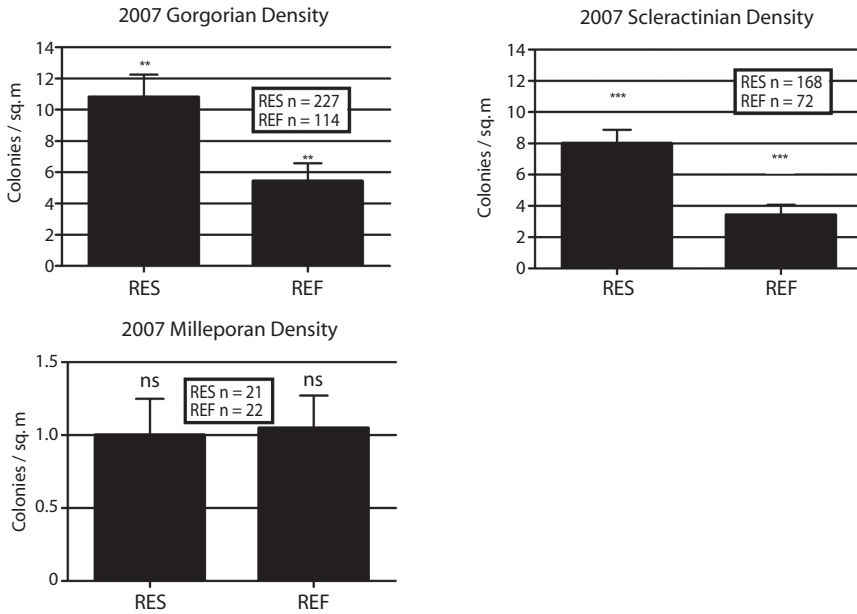
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Fig. 1. Densities of all three groups of corals. RES=Restoration; REF=Reference. Note different y-axis scale for Milleporans. Error bars equal SEM. * * notation indicates very significant difference; * * * indicates highly significant difference; ns indicates not significant.

utilized resulted in highly significant differences between the two areas (p<0.0001).

Biodiversity: Table 1 and Fig. 2 show a comparison of the biodiversity of Scleractinian colonies among the Restored and Reference sampling areas within the *Maitland* restoration site. Table 2 lists the results of a number of standard biodiversity indices performed for the Scleractinian colony populations.

Size Distribution: In 2007 size-class frequency distributions were ascertained for the only coral with sufficient numbers to make such calculations meaningful, *Porites astreoides*. The graphs depicting the Restored and Reference population distributions are shown in Fig. 3.

Settlement Preferences: A comparison was done of the number of colonies that had settled on the limestone rocks versus the number that had settled on the concrete matrix.

TABLE 1
Number of Scleractinian colonies by species in 2007

Species	Restored area	Reference area
Agaricia spp.	0	2
Diploria spp.	2	0
Favia fragum	0	1
Porites astreoides	119	53
Porites porites	17	9
Siderastrea radians	11	3
Siderastrea siderea	19	4
Total	168	72

TABLE 2
Biodiversity indices of Scleractinians in 2007

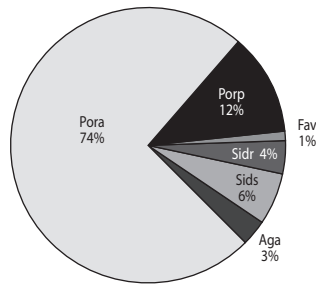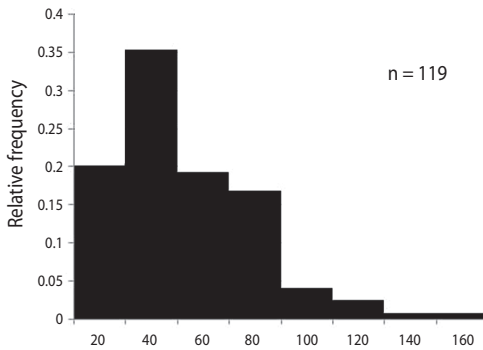| Index	Restored area	Reference area
Species richness:	5	6
Simpson's index:	0.529	0.563
Shannon-Weiner:	0.954	0.937
Evenness:	0.593	0.523
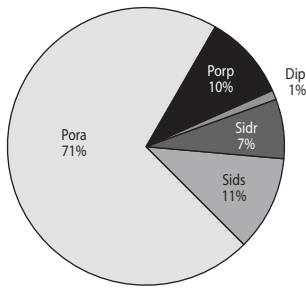
Fig. 2. Species (by percentage) of Scleractinian colonies. Abbreviations: Aga=*Agaricia* spp.; Dip=*Diploria* spp.; Fav=*Favia fragum*; Pora=*Porites astreoides*; Porp=*Porites porites*; Sidr=*Siderastrea radians*; Sids=*Siderastrea siderea*.
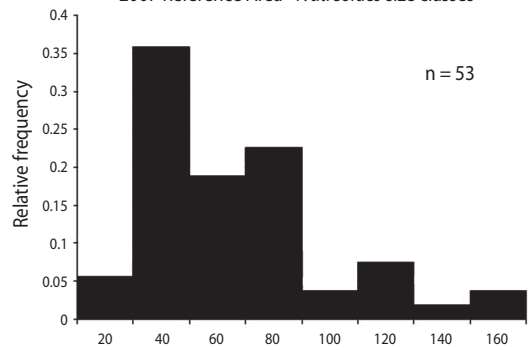

Fig. 3. 2007 size-class frequency distribution of *Porites astreoides* in the Restored and Reference areas.

The relative proportions of each surface are approximately 25% and 75% respectively (for methodology of how percentages calculated, see Miller & Barimo 2001). Totally random settlement events would be expected to yield above proportions of colonies on the two different surfaces. Observed numbers varied from this expectation. This variation was tested (see *Data Analysis*) and evaluation of observed versus expected settlement differences performed (results in Fig. 4).

The limestone rocks were preferentially settled by Scleractinians and Gorgonians. The differences from expectations were highly significant, p=0.0004, p<0.0001 and p=0.0003,

respectively. (Though detected difference was significant for Milleporans, the proportions involved were too low to enable meaningful evaluation.) For Scleractinians and Gorgonians, this perhaps indicates that active settlement preferences by larvae are implicated.

For Scleractinians, the evaluation was broken down (Fig. 5) into the Genera that comprised the majority of colonies, those being *Siderastrea* and *Porites*. (Note: this included virtually all Scleractinians; one *P. astreoides* settlement wasn't categorized, and two *Diploria* spp. that settled on cement. *P. astreoides* made up 87% of total *Porites*, and *S. siderea* made up 63% of total *Siderastrea*).

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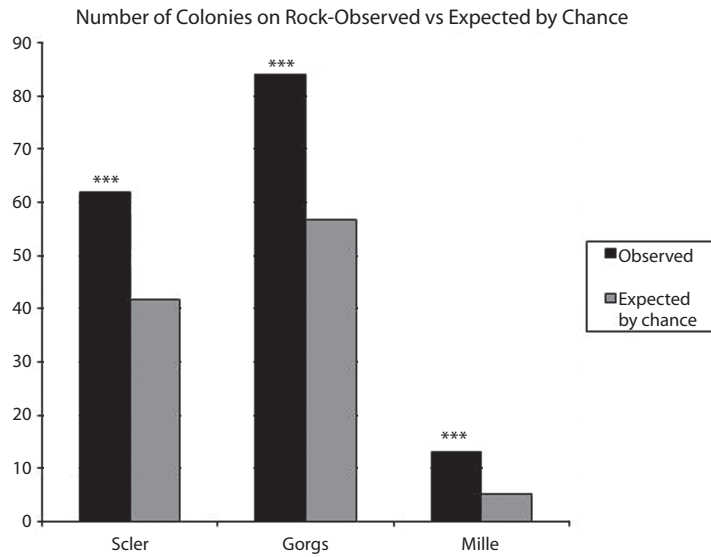## Number of Colonies on Rock-Observed vs Expected by Chance

Fig. 4. Evaluation of substrate settlement preference for all 3 groups of corals; Scler=Scleractinians; Gorgs=Gorgonians; Mille=Milleporans; ***indicates highly significant differences detected.

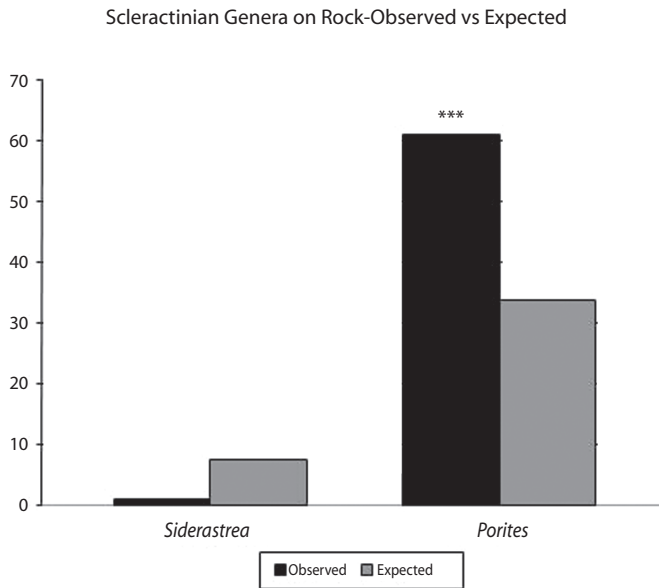## Scleractinian Genera on Rock-Observed vs Expected

Fig. 5. Evaluation of coral substrate settlement preference for selected Scleractinian Genera; *** indicates highly significant differences detected.
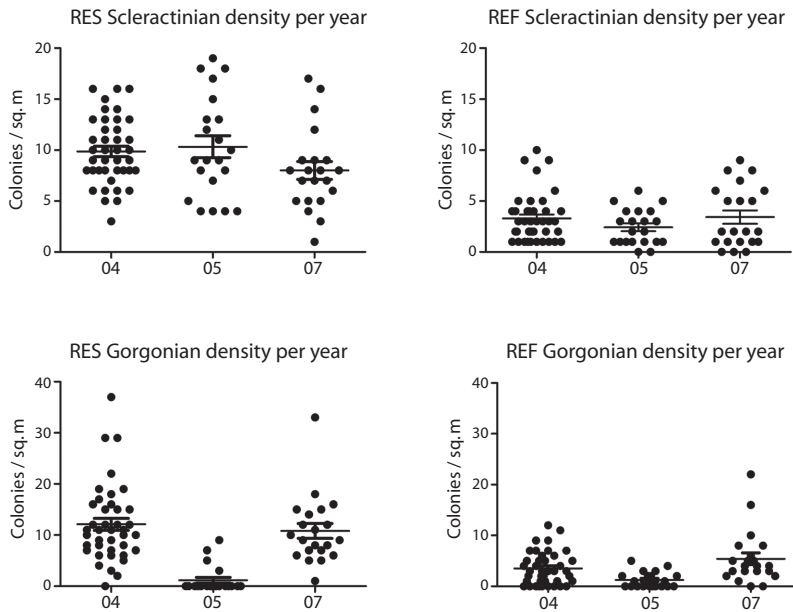
Fig. 6. Scatterplots of the densities of Restored (RES) area and Reference (REF) area Scleractians and Gorgonians in 2004, 2005 and 2007. The longest horizontal bar in each year's group represents the mean; the shorter bars above and below represent +/- SEM.

As one would anticipate from Fig. 4, since the percentage of their contribution to the overall Scleractinian population was so high, *Porites* preferentially settled on rock (p≤0.0001). *Siderastrea* showed an equally highly significant trend to settle on cement, though once again low proportions did not permit robust conclusions to be drawn. (Although all 19 *S. siderea* present settled on cement; the sole settler on rock was a *S. radians*).

Inter-annual Comparisons: In addition to examining data for 2007, some inter-annual comparisons with previous years' monitoring were made. In the analysis which follows, only Scleractinian and Gorgonian data will be presented (Fig. 6), as *Millepora* populations were too low for meaningful analysis.

For Scleractinains in the Restored area, densities were very similar for 2004 and 2005. While they appeared to slightly decrease in 2007, overall ANOVA revealed no significant differences, (p=0.1228). Likewise, in the Reference area differences were also non-significant (p=0.3226).

Regarding the Gorgonians, a different statistical test was used (see *Data Analysis*), and yielded the following results. For the Restored area, densities varied considerably among years, falling greatly in 2005; the analysis evidenced highly significant differences (p<0.0001). Further tests revealed a highly significant difference between 2005 and either other year. For the Reference area, the same tests yielded the same initial (p=0.0006), and among year differences.

DISCUSSION

The results of the 2007 *Maitland* restoration monitoring survey indicates a gradual but definite development of a healthy coral community on the restoration structures. However, several points should be kept in mind while

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reviewing results and this discussion, primarily the duration and scope of the monitoring program. Regarding duration, it is important to remember that this report reflects the first stages of a longer term monitoring program.

The development of coral communities is well-known to be a long-term process, so NOAA cannot make definite conclusions about the success of the *Maitland* restoration at this stage. Additionally, coral recruitment in the Florida Keys is well-known to be comparatively low (Shearer and Coffroth 2006). Taking these locally limited circumstances into account, in general the results of this monitoring program are comparable with the results reported by other researchers (Moulding 2005).

Further, the density and composition of coral recruits at this stage provides a good indication that the stability offered by the restoration is providing suitable substrate. However, the scope of the monitoring program is somewhat limited. It tracks only certain aspects of coral restoration, namely: density, biodiversity, settlement preference, and size distribution. The effort is circumscribed by the amount of damages collected from the party responsible for the grounding. Given this inherent limitation, it was thought more important to focus on coral recovery than overall community structure (Miller *et al*. 2009).

As the above density data reveals, either very or highly significant differences were shown for Gorgonian and Scleractinian densities respectively (Fig. 1). The much greater densities in the Restored area give rise to some interesting questions. Are the restoration units really such great recruitment attractors, or do the densities only appear high in relation to mature, stable areas? Or, has young-adult colony mortality not yet had a chance to play a role as a structuring factor? (Recall that the monitoring protocol does not track actual recruitment and mortality, only resultant overall density. As noted, the monitoring permitted by available recovered funds does not permit tracking individual colonies, and the discrimination of population structure that might result.).

Regarding biodiversity, Tables 1, 2 and Fig. 2 reveal only slight differences by 2007 and the two areas may be fairly said to have converged by this time, at least as regards common biodiversity indicators. As the mentioned tables and charts show, large broadcasting corals (*Siderastrea siderea*) were disproportionately present on the restoration site.

Just why this should be so remains somewhat of a mystery; as mentioned, the issue of generally low recruitment for these corals in the Florida Keys is well known. Why then does it appear much higher in the Restored area? Certainly, one should be conservative when it comes to making predictions based upon demographics of these corals, based upon the relatively low numbers involved. However, if any reader has any thoughts or insights regarding this issue, contact with the author would be appreciated.

With respect to the 2007 *P. astreoides* size-class frequency distribution (Fig. 3), percentage of small colonies (≤40mm) in the Reference area was 42%. However in the Restored area, the proportion of those size colonies was 55%, while the proportion in the 60, 80 and 100mm classes experienced an increase from prior years, and was approximately 40%.

Thus, with the exception of the very smallest class (≤20mm), where the Restored area still had a 3.5-fold advantage (20.2 vs 5.7%), the distribution in the two zones almost mirrored each other. Besides the smallest class, the only notable exception was in the very largest (≥120mm) classes where—unsurprisingly—the Reference area retained a large advantage. Future monitoring could reveal whether the two areas eventually totally converge in this regard.

The inter-annual comparisons among the Scleractinian and Gorgonian densities (Fig. 6) were revealing. For the Scleractinians, very little difference in the Restored and Reference areas across years was apparent. There was some slight (though non-significant) decrease in density in 2007 as compared to either of two previous years. The real story to be told is that, considering the respective zones across years,

the Restored area maintained approximately a three-fold advantage in population over the Reference area. Does this provide any inference regarding the most oft-cited coral health metric, percent cover? It must be remembered that the individual colonies (at least of *P. astreoides*, as well as certain other species[1]) were growing during this period (see above discussion re size-class distribution). While percent cover was not evaluated, it is likely that it would have increased.

The Gorgonians proved equally interesting. From 2004 to 2005 they suffered a precipitous decrease. As a first suspicion, one might implicate disease brought about by *Aspergillosis sydowii* as the cause of the rapid Gorgonian decline. *Aspergillosis* is a fungal pathogen responsible for considerable Gorgonian decline in the Florida Keys in the last two decades. However, at least in this case, physical ablation appears a more probable cause. The passage of the three violent hurricanes in the near vicinity between the 2004 and 2005 monitoring events has already been noted.

Further support for the proposition of a physically destructive causative factor is provided by the fact that colony densities experienced complete recovery to 2004 levels by the time of the 2007 monitoring event. Perhaps most noteworthy is that both before and after the population crash, the Restored area Gorgonians evidenced a 2.5 to 3-fold population advantage over the Reference area, proving similar to the Scleractinians is this regard.

Lastly, among the most interesting findings, the data provide some evidence that brooder-spawning *Porites* larvae exhibit an active settlement preference for the limestone rock substrate. This is as opposed to the cement matrix in which the rock is embedded; see Figs. 4 and 5, and the accompanying text. This finding is generally consistent with the work of Miller and Barimo (2001) regarding early settlement preference results (obtained 3 years post-settlement) conducted at this site.

Nonetheless, it should be prominently noted that nothing can be said regarding the *mechanism* of the preference. Are the larvae drawn to the rock because of chemotaxis due to something in the limestone, or simply because it presents more rugosity in its surface area, providing more cryptic settlement opportunities (Babcock & Mundy 1996)? (Elevation may also play a role, as the rocks project surface area above the surrounding flat, horizontal concrete.) Or, are they "put off" by chemicals leaching out of the cement, differences in pH, etc.? Most intriguing is the fact that the pattern seems to be exactly reversed for the broadcaster-spawning *Siderastrea*. There would appear to be something about cement that is attractive to that Genus.

Certainly it is well known that restoration substrate differences can result in variation of density of coral recruitment (Burt *et al*. 2009). One possible answer in this case is may be that one surface or the other is subject to greater colonization by macroalgae and/or cyanobacteria. If so, perhaps settlement by one Genus is more inhibited by the presence of such organisms (Kuffner *et al* 2006). Even if coral settlement takes place, it is conceivable that the mortality rate of relatively new settlers is differentially affected by the inhibiting taxa (Vermeji *et al*.

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1. An interesting, though far from statistically meaningful footnote: To evaluate the growth of a coral with a different life history strategy than *P. astreoides*, size-class frequency distributions were constructed for *Siderastrea siderea*, a framework-building, broadcasting coral. *S. siderea* also proved to be the second most abundant coral during each of the three monitoring years, and as a proportion of total Scleractinians, was consistent at about 9.5% of restoration area colonies. Absolute numbers of colonies were so low as to make a frequency distribution less than robust, and it is for this reason that graphs of same are not depicted. Nonetheless, the story told by the coral's progression through size classes is much the same as that of *P. astreoides*, though the size classes utilized for *S. siderea* were smaller (10, 20, 30, 40, & 50mm). The smallest two size classes started out as 62% in 2004, but by 2007 had dropped to 37%, with the larger classes gaining reciprocally. Since the density of the species was almost exactly the same across years (at approx. 0.9col./m^2) the colonies' growth represents an absolute increase in their percentage benthic cover.

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2009). Again, if any reader has any thoughts along these lines, contact and communication would be appreciated. This phenomenon is suggestive of future research possibilities.

ACKNOWLEDGMENTS

RESUMEN

Este artículo sintetiza los resultados del seguimiento diseñado para medir la recuperación de un arrecife restaurado que fue impactado por el encallamiento del *M/V Alec Owen Maitland* el 25 de octubre de 1989. Este encallamiento ocurrió en el área que comprende el Santuario Marino Nacional de los Cayos de Florida. De acuerdo con la Ley de los Santuarios Marinos Nacionales, la NOAA cobra dinero por daños a los recursos del Santuario y los usa para restaurar dichos recursos. Un programa de seguimiento o monitoreo mide los patrones de recuperación para determinar el éxito de las medidas de restauración. Para evaluar el éxito, hábitats de referencia adyacentes al sitio de restauración son examinados para comparar las condiciones de las áreas restauradas con las naturales. La restauración de este lugar se completó en septiembre de 1995 utilizando roca de cemento y caliza y los resultados del seguimiento desde el verano del 2007 son presentados. Se compararon las condiciones biológicas entre el área restaurada y la de referencia. Los corales evaluados se dividieron en tres Órdenes: Gorgonios, Milleporinos y Escleractinios. Se compararon las densidades en las áreas de restauración y de referencia, siendo la densidad más grande en las áreas restauradas. Se examinaron las distribuciones de frecuencia de tamaño y clase para los Escleractinios más abundantes, lo que mostró que las áreas restauradas están convergiendo con las de referencia. Para los Escleractinios, también se presentan números y porcentajes de colonias por especie al igual que varios índices comunes de biodiversidad. Las medidas para el área restaurada se aproximan al área de referencia. Una comparación cuantitativa del sustrato preferido para el asentamiento de las colonias en el área de restauración se presenta para todos los Órdenes; para el caso de Escleractinios se presenta más detalle de los dos géneros más frecuentes.

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