2016 Monitoring Report for Emergency Restoration following the T/V *Port Stewart* grounding in 2009 Yabucoa, Puerto Rico

Corals reattached during Emergency Restoration at the T/V Port Stewart grounding site.

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Introduction

The T/V *Port Stewart*, a 176-meter tanker, grounded in coral reef habitat near the entrance to Yabucoa Channel off the coast of southeastern Puerto Rico on October 27th, 2009. The hard bottom reef area affected was just over 500 square feet with approximately one quarter of the area severely damaged (Polaris 2010). Damage caused by the impact included the detachment and fragmentation of benthic organisms, including reef-building scleractinian corals (Figure 1). Restoration activities were described in detail by Polaris (2010) and by Hernández-Delgado et al. (2012). In short, in late 2009 scleractinian coral fragments and detached but intact octocorals were cached in an attempt to protect them until they could be permanently reattached. Restoration activities took place between February and September of 2010. The major goals of this restoration were to restore the area's rugosity and to stabilize coral fragments in order to prevent further damage to both coral tissue and the reef environment due to movement of fragments. Restoration efforts returned the site's rugosity to within 2% of the reference area. Over 1,000 corals were reattached, including 80 colonies of the threatened species *Acropora cervicornis* (Hernández-Delgado et al 2012). This report describes the results of monitoring activities to evaluate the success of the site restoration 6 years after the initial grounding.

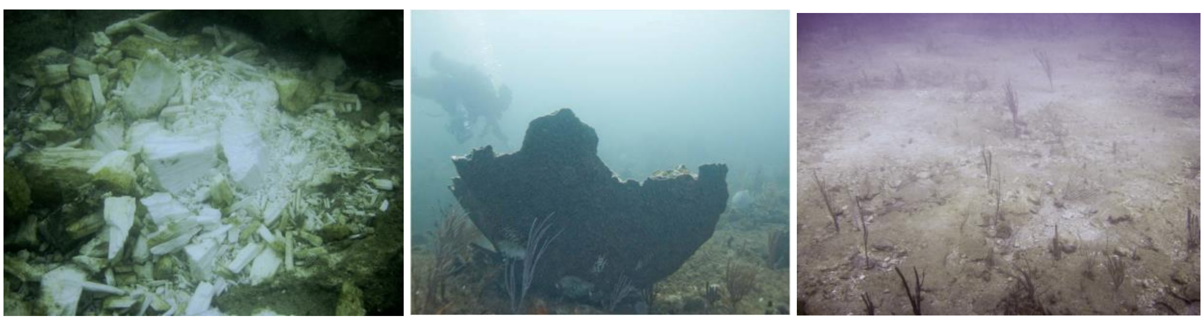

Figure 1: Photos of crushed and overturned corals and areas that were denuded of corals as a result of the T/V Port Stewart grounding**.**

Methods

In order to evaluate the long-term effects of the grounding and success of the site restoration, monitoring activities were performed in October 2010, March 2012, April 2013 and July 2016. Several parameters were compared between two areas: the Restoration Area, which was within the grounding area where corals were reattached, and the Reference Area, which was outside of the area impacted by the grounding where corals were naturally occurring and undamaged by the grounding. Permanent 1 m^2 quadrats (12 in the Reference Area in 10 in the Restoration Area) were used to locate and monitor the health of corals. Fifteen permanent 25 cm x 25 cm (0.0625 m^2) quadrats in each area (Reference and Restoration) were used to measure coral recruitment and benthic cover. (In 2012, data was collected from only 8 of the 15 smaller quadrats in the Reference Area. In 2016, data was collected from only 12 of the 15 smaller quadrats in the Restoration Area.)

Corals

In 2010, individual corals (scleractinian and octocoral) were selected for monitoring in both the Reference Area and the Restoration Area. (For n values, see Figure 2.) In the Restoration Area, all selected corals had been reattached during the site restoration. In the Reference Area, corals were naturally occurring and undamaged by the grounding. Percent survivorship of these corals was measured in 2016. Differences in coral survivorship between the two areas and between coral types (scleractinian, octocoral) were explored with Kruskal-Wallis ANOVAs.

Acropora cervicornis

Initially, several *Acropora cervicornis* outplants were tagged for monitoring. However, due to the life history of *A. cervicornis*, it becomes difficult to monitor individual colonies after more than 5 years. Colonies can move or fragment creating new additional colonies. In 2006, rather than monitoring only tagged colonies, all colonies in the Restoration Area were measured and percent tissue mortality was recorded. These numbers were then compared to the numbers and sizes of colonies originally reattached in 2010.

Recruitment

Recruitment rates in each area were calculated as new recruits/m^2 in the 25 cm x 25 cm quadrats and were measured in each of 4 sampling periods (2010, 2012, 2013 and 2016). A 3-way PERMANOVA based on Euclidian distance was used to evaluate differences in recruitment rates between areas, years and coral types.

New recruits from 2010, 2012 and 2013 were followed in order to determine recruit survivorship rates in 2016. Differences in recruit survivorship between the two areas and between coral types were explored with Kruskal-Wallis ANOVAs.

Benthic cover

Benthic cover was measured in the 25 x 25 cm quadrats. A 2-way PERMANOVA and SIMPER test were used to evaluate differences in benthic cover between areas and years.

Xestospongia muta

During the preliminary assessment of damage to the reef caused by the grounding, severe bleaching of surviving giant barrel sponges (*Xestospongia muta*) in the area of the grounding (primarily to the west of the impacted area) was observed. When bleaching of *X. muta* was first observed in 2009, permanent tags were used to mark 120 colonies (62 bleached and 58 not bleached). Both bleached and not bleached colonies were tagged to allow for comparison between bleached colonies and not bleached colonies as well as to monitor any potential spread of this bleaching episode. During monitoring surveys, condition (live/dead) of tagged sponges was evaluated. Mortality (% of tagged colonies that died between each sampling) was calculated in 2010, 2012, 2013 and 2016.

Desmapsamma anchorata

During monitoring in 2013 and 2016, significant amounts of the sponge *Desmapsamma anchorata* were observed in the Restoration Area. Presence of *D. anchorata* was noted in 1 m^2 quadrats that were used during the monitoring for locating corals in both the Reference (n=12) and Restoration (n=10) Areas.

Results

Coral survivorship

There was no significant difference in survivorship of adult corals between the Reference Area and the Restoration Area (Kruskal-Wallis: p=0.5948) (Figure 2).

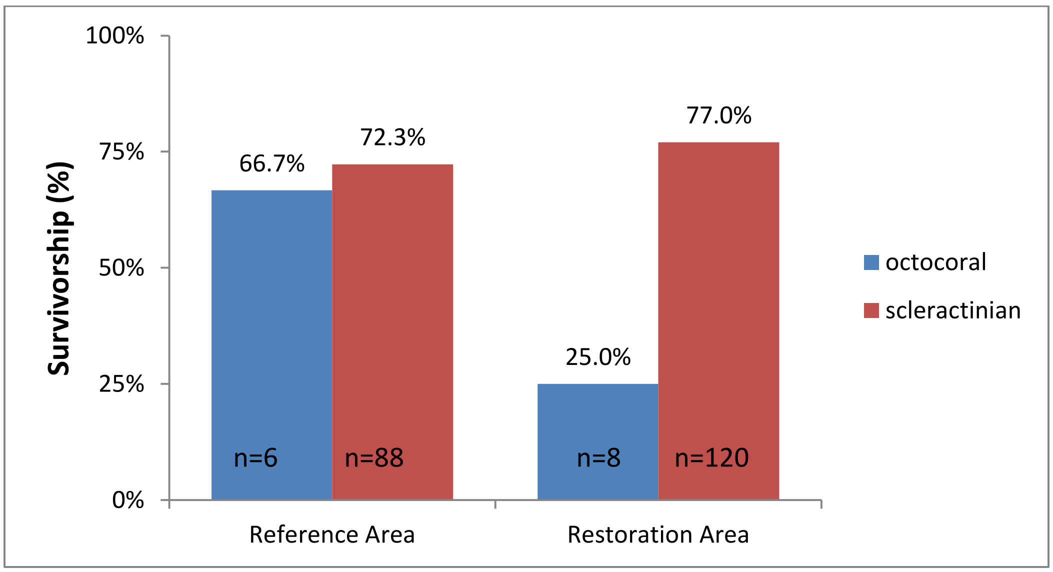

Figure 2: Survivorship (%) of corals (octocoral, scleractinian and all corals) from 2010 to 2016 in Reference and Restoration Areas. N values represent the number of corals tagged in 2010.

While in the Reference Area there was no significant difference in survivorship between coral types (Kruskal-Wallis: p=0.7175), in the Restoration Area octocorals had significantly lower survivorship than scleractinians (Kruskal-Wallis: H(1,N=58)=10.92899, p=0.0009) (Figure 2).

Acropora cervicornis

In 2016, 69 colonies of *A. cervicornis* were located in the restoration area. There were 47 live colonies and 22 dead colonies, 7 of which were covered by *Desmapsamma anchorata*. There was 58% as many live colonies in 2016 compared to the 80 that were reattached in 2010. Live tissue in 2016 was approximately 65% of what was outplanted in 2010 (Table 1). It is possible that some detached colonies or fragments have stabilized and survived elsewhere.

Table 1: Size classes of *Acropora cervicornis* colonies

	Total colonies	0 - 10 cm	10 - 20 cm	20 - 30 cm	30 - 40 cm	40 - 50 cm	50+ cm
Estimated # of colonies lost in 2009 based on Reference data	125	17	23	28	46	11	0
# of colonies reattached during Emergency Restoration	80	31	39	6	3	1	0
# of colonies located during 2016 monitoring - Total colony size	47	3	17	14	7	2	4
# of colonies located during 2016 monitoring - Live tissue	47	17	20	7	2	1	0

Recruitment dynamics

Overall, there were more recruits in the Reference Area than in the Restoration Area (3-way PERMANOVA: Pseudo-F=7.8526, P=0.006) and there were more octocoral recruits than scleractinians (3-way PERMANOVA: Pseudo-F=6.7243, P=0.014), but there was no significant difference in recruitment between years (P=0.736) (Figure 3).

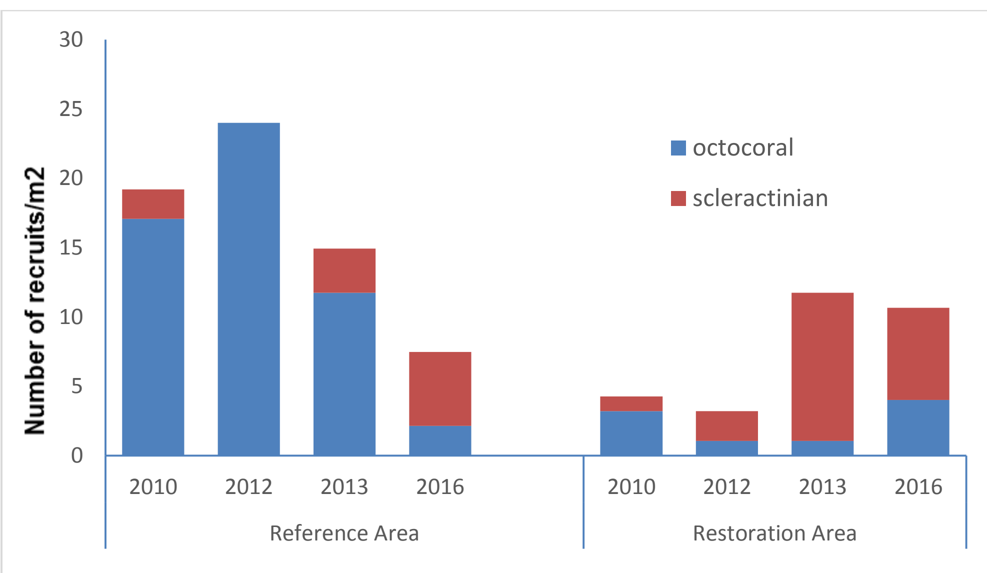

Figure 3: Number of octocoral and scleractinian recruits per m^2 in Reference and Restoration Areas.

There were significant interactions between area and coral type (PERMANOVA: Pseudo-F=18.921, P=0.001), between area and year (PERMANOVA: Pseudo-F=2.7709, P=0.043), and between year and coral type (PERMANOVA: Pseudo-F=4.5775, P=0.002). Although the three-way interaction between area, coral type and year was not significant (PERMANOVA: Pseudo-F=2.7125, P=0.058), pair-wise tests did return some significant results.

More octocorals recruited in the Reference Area than in the Restoration Area (PERMANOVA: t=4.2886, P=0.001). This difference was significant in 2010 (PERMANOVA: t=2.1753, P=0.048), 2012 (PERMANOVA: t=3.448, P=0.006) and 2013 (PERMANOVA: t=2.4254, P=0.037), but not in 2016 (PERMANOVA: t=0.61574, P=0.732).

Overall scleractinian recruitment was higher in 2013 and 2016 than it was in 2010 and 2012 (PERMANOVA: 2010,2013 t=2.139, P=0.032; 2010,2016 t=2.093, P=0.037; 2012,2013 t=2.0409, P=0.047: 2012,2016 t=2.067, P=0.038). There was no difference in scleractinian recruitment between areas (PERMANOVA: t=1.4032, P=0.17). This held true for all individual years although Figure 3 shows that scleractinian recruitment was particularly high in the restoration area in 2013.

Overall recruit survivorship was higher in the Restoration Area than in the Reference Area (Table 2), although this difference was not significant (Kruskal-Wallis: p=0.1687).

Table 2: Survivorship of new scleractinian and octocoral recruits (from 2010, 2012 & 2013 combined) in Reference and Restoration Areas.

			# new recruits (2010, 2012, 2013)	# surviving recruits in 2016	% recruit survivorship in 2016
Reference Area			**44**	**12**	**27.3%**
	scleractinian		**5**	**4**	**80.0%**
		2010	2	2	100.0%
		2012	0	n/a	n/a
		2013	3	2	66.7%
	octocoral		**39**	**8**	**20.5%**
		2010	16	1	6.3%
		2012	12	3	25.0%
		2013	11	4	36.4%
Restoration Area			**15**	**7**	**46.7%**
	scleractinian		**11**	**6**	**54.5%**
		2010	0*	n/a	n/a
		2012	2	0	0.0%
		2013	9*	6	66.7%
	octocoral		**4**	**1**	**25.0%**
		2010	3	0	0.0%
		2012	0*	n/a	n/a
		2013	1	1	100.0%

* 1 additional recruit in this category was observed, but it was eliminated from the analysis because it was located in a quadrat that was not sampled in 2016.

Survivorship of scleractinians was significantly higher than survivorship of octocorals overall and in the Reference Area, but not in the Restoration Area (Kruskal-Wallis: overall H(1,N=59)=9.073149, p=0.0026; Reference Area H(1,N=44)=7.727137, p=0.0054; Restoration Area p=0.3271). This is likely due to higher recruitment of octocorals in the Reference Area paired with similar survivorship rates in the two areas (Table 2).

There was no significant difference between areas in survivorship of 2010, 2012 or 2013 recruits (Kruskal-Wallis: 2010 p=0.4561; 2012 p=0.4421; 2013 p=0.1977).

The majority of the scleractinian recruits in the Reference Area were broadcast spawners *(Dichocoenia stokesi, Stephanocoenia intersepta, Siderastrea siderea*) while the majority in the Restoration Area were brooders (*Porties astreoides, P. porites, Agaricia* spp.) (Table 3). Before 2016, 3 spawning corals recruited in the Restoration Area. Unfortunately, two of them (*Acropora cervicornis* from 2010, *Montastraea cavernosa* from 2013) were in quadrats that could not be located in 2016, so their fates are unknown. (The *A. cervicornis* was still alive in 2013.) The third (*Pseudodiploria strigosa* from 2013) did not survive to 2016.

Table 3: Scleractinian recruits in Reference and Restoration Areas divided between broadcast spawning and brooding species. Total number of recruits from the first three sampling periods (2010-2013), the number of those recruits that were alive in 2016, and the number of new recruits in 2016.

		2010-2013 recruits	2016 survivors	2016 recruits
Reference Area	Spawners	4	4	3
	Brooders	1	0	1
Restoration Area	Spawners	3	0 (condition of 2 unknown)	2
	Brooders	10	6	3

Benthic cover

Benthic cover was significantly different between areas (PERMANOVA: Pseudo-F=40.596, P=0.001) and years (PERMANOVA: Pseudo-F=3.8751, P=0.002) (Figure 4). The Reference Area was characterized mainly by turf and macroalgae which accounted for over 90% of the similarity of benthic cover within the Reference Area each year, while the Restoration Area was characterized by turf and CCA which accounted at least 90% of the similarity (SIMPER).

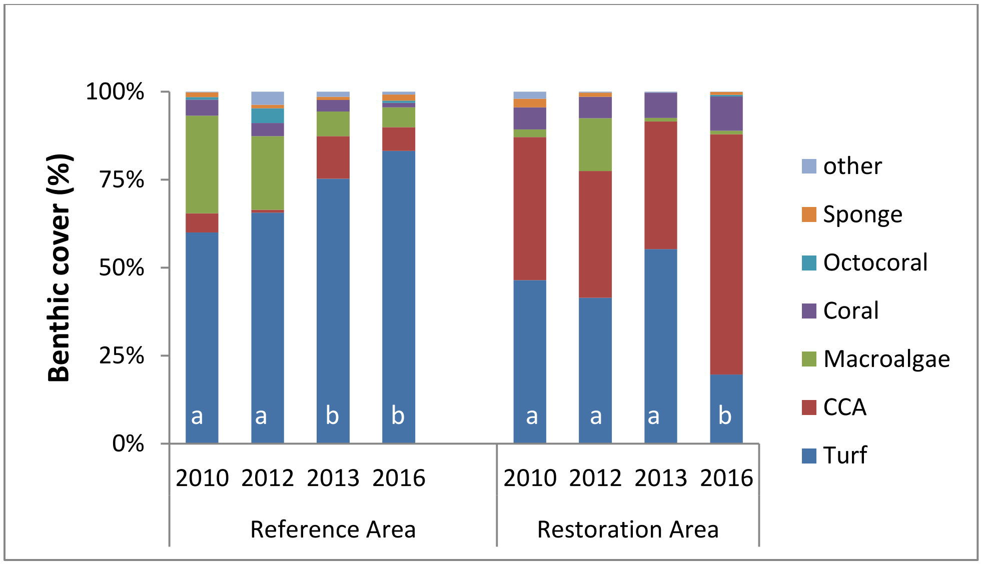

Figure 4: Percent cover of different benthic organism in Reference and Restoration Areas. Letters on bars indicate significant differences between years within each area.

There was also a significant interaction between area and year (PERMANOVA: Pseudo-F=4.3333, P=0.001). In the Reference Area, 2010 and 2012 were significantly different from 2013 and 2016 (PERMANOVA: 2010,2013 t=2.3111, P=0.005; 2010,2016 t=2.797, P=0.003; 2012,2013 t=1.9237, P=0.017: 2012,2016 t=2.2303, P=0.012). In 2013 and 2016 there was relatively more turf and CCA and less macroalgae than in the previous years (Figure 4). In the Restoration Area, 2010, 2012 and 2013 were significantly different from 2016 (PERMANOVA: 2010,2016 t=2.8683, P=0.001; 2012,2016 t=2.417, P=0.007; 2013,2016 t=3.1697, P=0.001). 2016 was characterized by more CCA and less turf and macroalgae than previous years (Figure 4).

Xestospongia muta

Between 2009 and October 2010, the *Xestospongia muta* colonies that had been bleached in 2009 suffered 11% mortality (Figure 5). Another 8% of these previously bleached colonies died by March 2012. There was no new colony mortality observed in 2013 and in 2016 there was 3% mortality. The *X. muta* colonies that had not bleached in 2009 suffered between 0 and 3% mortality during each sampling period. Actual mortality is probably higher than estimated due to the difficulty in locating tags after a colony dies. Once a sponge dies, it quickly decomposes and leaves no trace.

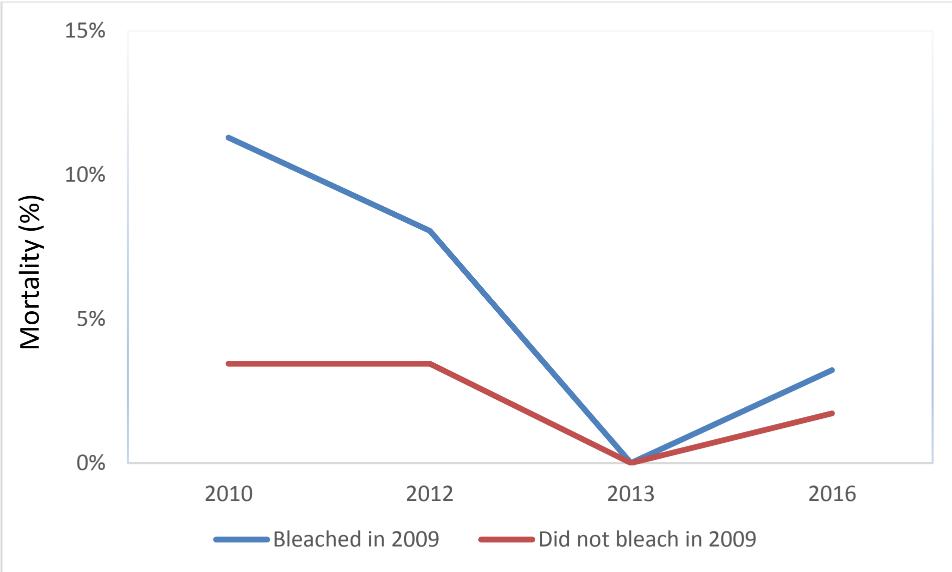

Figure 5: Mortality rates for colonies of *X. muta* that were bleached and not bleached in 2009.

Desmapsamma anchorata

Although *Desmapsamma anchorata* was present during earlier monitoring periods, its high densities in 2013 and the effects it was having on the restored areas was apparent to researchers. *D. anchorata* was observed overgrowing dead *A. cervicornis* skeletons and in some cases was observed overgrowing live coral tissue (Figure 6). In 2013, *D. anchorata* was present in 80% of Restoration Area quadrats and only 8.3% of Reference Area quadrats. In 2016, the sponge was present in 100% of Restoration Area quadrats and in 20% of Reference Area quadrats. Immediately following 2013 data collection, three bags (approximately 0.1 m^3) of the sponge were removed from the Restoration Area. In 2016, 1.5 bags (approximately 0.05 m^3) were removed.

Figure 6: *Desmapsamma anchorata* overgrowing *Porites astreoides* on left and *Acropora cervicornis* on right within the restoration area.

Discussion

Coral survivorship

Coral survivorship rates were statistically the same inside and outside of the grounding area, indicating that the restoration of the grounding site with corals was successful. Reattachment of octocorals, however, was not as successful as reattachment of scleractinians. While octocorals do not secrete calcium carbonate skeletons and are not reef builders, they provide vertical relief on a reef and important habitat for reef organisms. Both delays in reattachment and storm waves may play a role in low octocoral survivorship. Since few octocorals were attached during the restoration (small sample size), this could be researched further in future restoration projects.

Acropora cervicornis

Although many reattached *Acropora cervicornis* colonies are still present in the Restoration Area, neither the number of colonies nor the amount of live tissue equals that which was originally reattached. One of the major reasons seems to be colony detachment. Another problem that the reattached corals have faced is overgrowth by *Desmapsamma anchorata*. The sponge was observed overgrowing both live and dead skeletons of *A. cervicornis* and other corals.

Recruitment dynamics

During the first two sampling periods after restoration activities, recruitment was much higher in the Reference Area than in the Restoration Area but in 2016 recruitment rates were higher in the Restoration Area. The large majority of the recruits in the Reference Area were octocorals which had lower survivorship than scleractinian recruits. The high number of scleractinian recruits in the Restoration Area in 2013 and 2016 paired with higher survivorship or scleractinian recruits, is a good sign for the Restoration Area. Small sample size (due to low recruitment rates) may have masked variability, making it impossible to find statistical differences. Future monitoring will determine whether this trend continues. Monitoring at other sites should consider using larger quadrats (50cm x 50cm) to increase the number of recruits that are being monitored.

Although continued monitoring in necessary to confirm the trend, the increase in recruitment in the Restoration Area in 2013 and 2016 is promising for the recovery of the grounding site. Because of their reef-building capabilities, it is interesting to note that most of these recruits are scleractinian corals and that overall, 67% of scleractinian recruits were found in the Restoration Area (Tables 1&2).

Most of the recruits in the Restoration have been *Porites astreoides*. *P. astreoides* was the most commonly transplanted brooding coral. If these recruits are from the reattached colonies, it is possible that the colonies needed time, but have now recovered reproductive abilities after the stress of being damaged by the grounding and reattachment.

Benthic cover

There were differences in benthic cover between the Reference Area and the Restoration Area. CCA was the greatest contributor to this difference, followed by turf and macroalgae. CCA cover was higher in the Restoration Area which is important because there is a known association between CCA and scleractinian coral settlement (Erwin et al. 2008). CCA cover in the Restoration Area was even higher in 2016 than in previous years. The high CCA cover may have contributed to the higher rates of scleractinian recruitment in the Restoration Area than in the Reference Area.

Xestospongia muta

Bleaching is a general sign of stress in marine organisms. Although the cause of the stress is usually very difficult to pinpoint, the timing, location and isolated-nature of this event indicate that, in this case, the stress was due to activities associated with the grounding and/or removal of the vessel. One possibility is that the stress was due to the release of ballast water from the Port Stewart during recovery operations. While it is impossible to prove that this is the case, it is something to watch for in the future when ballast water is released in coral reef areas.

After six years, the bleached sponges seem to have stabilized. After 2012, only a few of the colonies that had bleached died. This is in line with the rate of mortality of the sponges that never bleached. Although monitoring will continue, it is possible that the mortality has run its course.

Desmapsamma anchorata

Desmapsamma anchorata is known to be a weedy sponge species which grows and reattaches faster than other sponge species, but also has a high mortality rate (Wulff 2008). The sponge seems to have taken advantage of the uncolonized substrate in the Restoration Area.

In both 2013 and 2016, it was considerably more abundant in the Restoration Area than in the Restoration Area. The only colony that fell within one of the quadrats in the Reference Area in 2013 was growing on a rebar that was placed in 2010 as part of monitoring activities. In 2016, all observed colonies in the Reference Area were again growing on the rebar and in only one instance was it spreading from the rebar to the substrate. *D. anchorata* has been observed overgrowing live coral tissue as well as dead coral skeletons. Only half as much of the sponge was removed from the site in 2016 as in 2013 indicating that in might be in decline, but only further monitoring will tell.

The presence of this species will be followed in future monitoring activities at this site and would be a good species to follow from the beginning of monitoring activities at future reef restoration sites. Because the sponge quickly covers substrate, it is potentially a threat to coral growth and coral recruitment which both require hard substrate. Whether the presence of the sponge will be significantly detrimental to the restored grounding site and whether removal of the sponge is effective in the long term remains to be seen. It would be good to return annually to the site to monitor and remove any *D. anchorata.*

Conclusions

Overall, the restoration of the site of the grounding of the T/V Port Stewart has been successful. Survivorship of reattached corals has been comparable to that of naturally occurring corals in the area. While reattachment of corals to restore the site was successful, survival rates of octocorals and *A. cervicornis* in the Restoration Area were lower, but not statistically different from the Reference Area. Both octocorals and *A. cervicornis* provide vertical relief and habitat for a variety of reef organisms. Their vertical structure may also make them more susceptible to detachment due to storm waves.

A. cervicornis monitoring can be a challenge because it is a branching species which fragments and reattaches easily. Monitoring tagged colonies is limited in its ability to track the success of outplanting because it doesn't take into account reattachment of loose fragments. After 5 years it is better to monitor whole areas through photomosaics, transects or censuses. In this case, we chose a census because of the small size of the impact area. In larger areas, photomosaics, including an initial photomosaic of outplanting efforts, could be extremely useful for long-term monitoring of outplanting success.

Although overall there was more recruitment in the Reference Area than the Restoration Area, the majority of the recruits in the Reference Area were octocorals. Scleractinian recruitment was higher in the Restoration area and overall scleractinian recruits had higher survivorship. Scleractinians are the reef-building corals so their recruitment is a good sign and may be more important at least initially in restoring the site. Higher scleractinian recruitment may be due to the high cover of CCA in the Restoration Area compared to the Reference Area. Although recruitment rates were initially lower in 2010 and 2012 in the Restoration Area, in 2013 the rate increased dramatically and remained relatively high in 2016. Future monitoring will determine whether this is a positive new trend. Larger 50 x 50 cm quadrats would be useful in collecting recruitment data in order to increase the numbers of recruits observed.

Bleaching of giant barrel sponge, *Xestospongia muta*, cannot be unequivocally attributed to the release of ballast water during the recovery of the vessel after the grounding; however, the timing, location and isolated-nature of the event indicate that is was related to the grounding and or removal of the vessel. Similar signs in *X. muta* and other species should be noted at grounding sites in the future. The local population of *X. muta* suffered considerable mortality after the bleaching

Desmapsamma anchorata should be monitored in future restoration sites. It covers a considerable amount of hard bottom in the Restoration Area and may have been partially responsible for the *A. cervicornis* mortality.

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