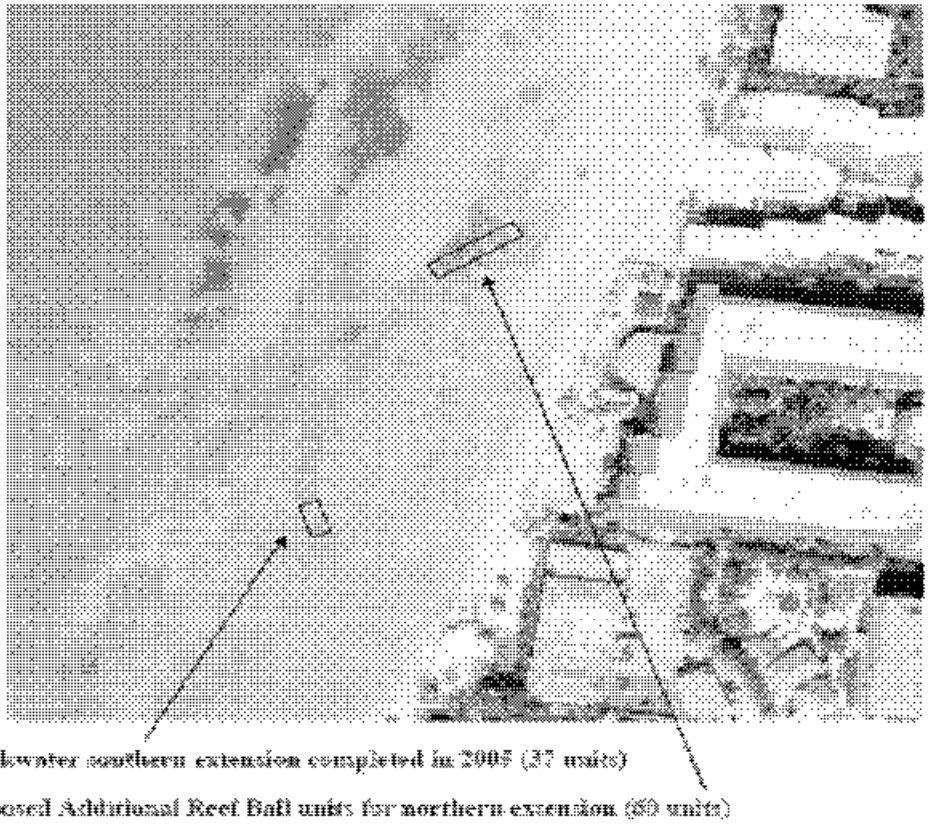
CAYMAN BIOLOGICAL MONITORING REPORT, JANUARY 2008

MONITORING OF MARRIOTT BREAKWATER AND CEMETERY REEF, GRAND CAYMAN

BACKGROUND

A submerged artificial reef breakwater was installed at the request of the Marriott Hotel on Seven Mile beach in 2002 to enhance the stability of the beach. Over 200 units were installed in autumn 2002 (see aerial below) and a further 37 units added at the south end in 2005 to increase wave protection from the SW. These units were



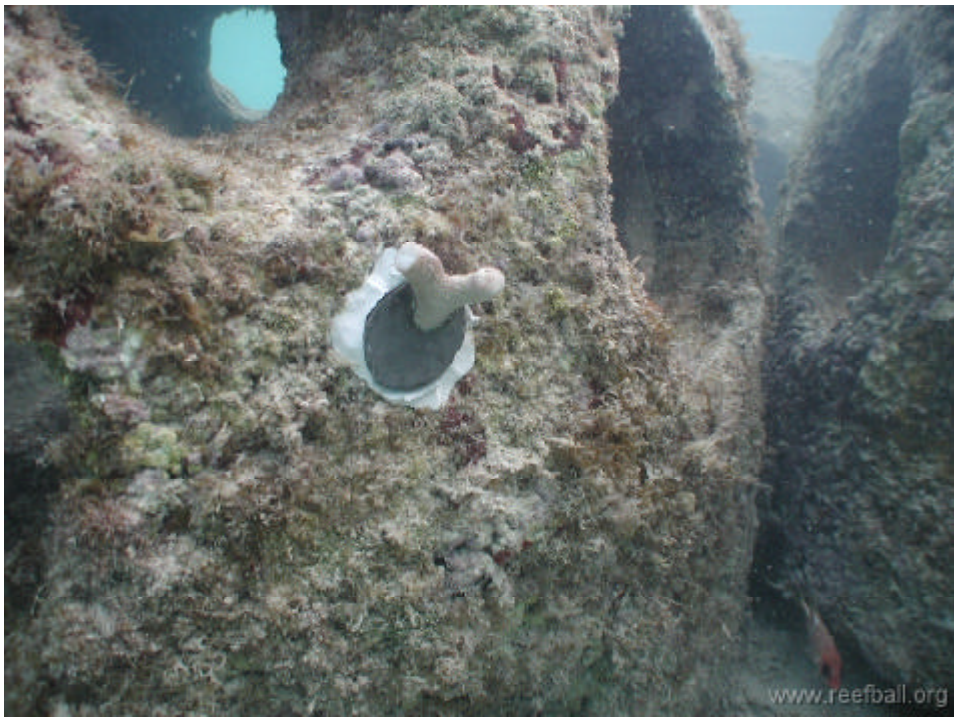
Southern extension 2005, 37 units. Photographs Dr. Lee Harris

stabilised with fibreglass rebar and withstood Hurricane Ivan in 2004. In 2005 two further units were added at a distance offshore in deeper water (c. 15 feet) for habitat creation purposes. At the same time, 4 units were deployed at Cemetery Reef, several miles further north for reef enhancement purposes and these were also in deeper water (15-20 feet). In 2007 a further 17 reefballs of various sizes were added to Cemetery Reef.

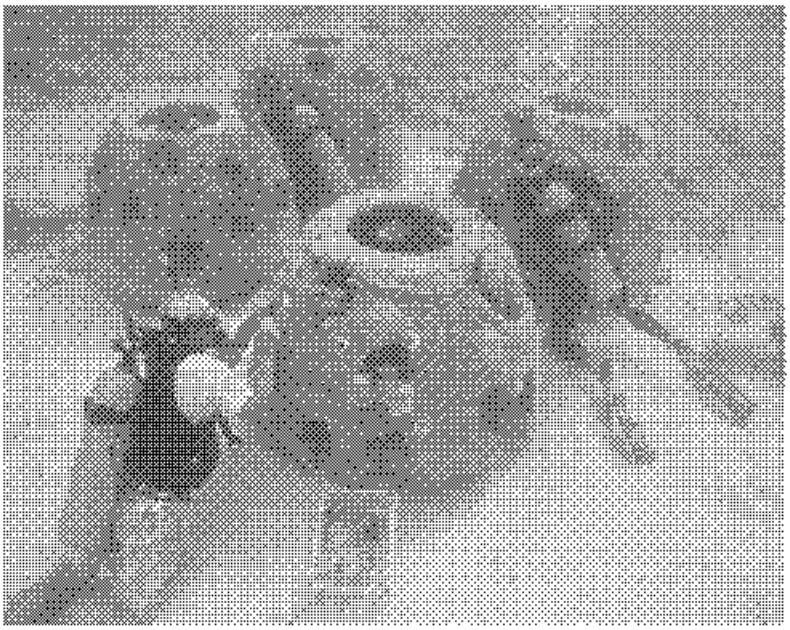
The nature of reefball breakwaters requires deployment in shallow water such that wave action is dissipated and the shore is protected from action by large waves. For these reasons, such structures are usually 1-2 feet below the surface of the water.

In 2005, 200+ coral plugs were transplanted on to the Marriott Breakwater and 30+ plugs onto the two balls offshore. A further 40+ plugs were placed onto the Cemetery Reef Balls. Exact records were not kept but species used included *Acropora cervicornis*, *Acropora palmata* and *Porites porites* (pictures below taken 2005). Additionally, some pieces of *Porites astreoides* were placed on the balls along with several plugs with gorgonians. In 2007 further plugs were added to the new balls at Cemetery Reef.

Coral plugs 'puttied' onto Marriott breakwater 2005



Porites porites **plug on Marriott Breakwater 2005**



Coral Plugs being puttied onto Reef Balls Cemetery Reef, 2005 (picture Dr Lee Harris)

Some photographic monitoring of the reef balls at both sites took place in 2006 and 2007 (see Reef Ball website link:

http://www.reefball.org/album/caymanislands/Caymanmarriottbreakwaterproject/reefballmonitoring/dec2006monitoring/index.html).

A detailed monitoring of both sites was made possible in January 11-16th 2008 through the assistance of Phoenix Biosystems. Methodology was developed based on the objectives defined below and within the constraints of time, equipment, personnel and site characteristics (including water depth).

Monitoring objectives were defined as:
1. Document success of transplanted coral plugs at all sites
2. Record colonisation of reefball surface by new coral colonies, algae etc.
3. Monitor fish and invertebrate populations in and around the reef balls.

METHODOLOGY

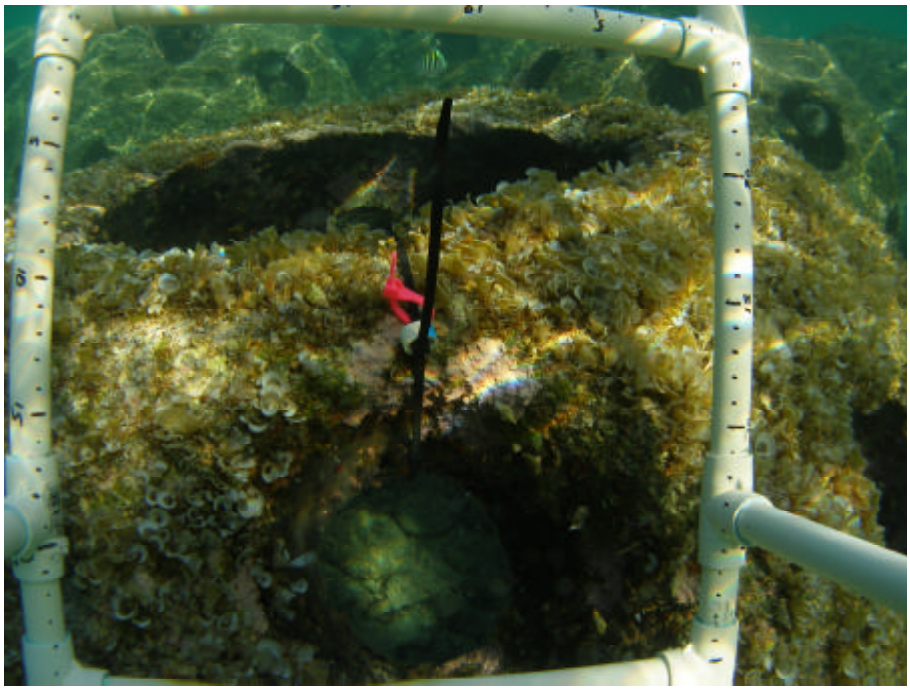
Coral Plugs and Benthic Cover (objectives 1 and 2)

A minimum of 10% of reef balls were selected for monitoring as a representative sample. These were randomly located throughout the sites as follows:

- Marriott Breakwater. 30 balls (12.6%) were selected as follows: The breakwater was divided into approx. ten separate sections from south to north, within each section 3 balls were selected, one on the inside of the breakwater, one in the middle and one on the outside. Criteria for selection was ease of 'tagging' (see below) in the water.
- Marriott Offshore. Both of these reef balls were selected for monitoring
- Cemetery Reef. 2 of the original 4 balls were selected and a further 4 throughout the remaining 16 balls (total of 6 out of 21 balls were selected i.e.28.5%).

These were marked with cable ties and marker rings. Each ball was marked at the top with black cable ties and was numbered consecutively as follows:

- Marriott Breakwater. Balls were numbered 1-10 inside, 1-10 middle or 1-10 outside. Inside balls were marked with a blue cable tie, middle with yellow and outside with pink. Balls were numbered with white ring counters (each representing one) and an orange tie to represent 5. Thus Ball number 8 in the middle of the breakwater is marked with a black cable tie with an orange cable loop and 3 white markers. Ball number one on outide of breakwater is pictured below.
- Marriott Offshore. The balls were numbered one and two as above.
- Cemetery Reef. Selected balls were numbered using the black cable ties and white ring counters.



Marriott Reef: Showing Marker on Reef Ball Number One on outside of Breakwater (Photo Paul Russell)

Documentation of Plugs.

Where plugs were still detectable they were recorded anticlockwise from the marker tie with each coral being recorded by species and condition (alive, dead, questionable), other notes were made such as whether encrusted by algae, whether 'basing out' onto substrate etc. Colony size was not recorded.

Benthic Cover

Photographic Record

A 25x25cm quadrat was constructed out of pvc pipe (using t-joints for corners to facilitate easy flooding) and the sides marked in cm. (see photo) The frame was extended to attach to an Olympus 350 camera (with wide angle lens) at the necessary focal distance.

Paul Russell taking photographs with quadrat fixed to camera, Cemetery Reef

A minimum of 6 photographs was taken on each reefball in the vicinity of the marker tie in the following sequence:

- a photo of the marker
- quadrat photo immediately below the marker
- quadrat photo below and to the left of the previous one
- quadrat photo to the immediate left of the marker
- quadrat photo to the immediate right of the marker
- photo of the whole ball

If it was not possible to follow this sequence (on at least 3 occasions) due to the proximity of other balls etc., the easiest progressive sequence was followed. Where possible and in particular if there was any danger of damage to corals or coral plugs, the quadrat was not placed directly on the ball surface.

Cover Estimates

Each ball was surveyed primarily to identify and count new coral colonies but also to estimate percentage of other benthic cover. Invertebrate species were also noted and urchins were counted. Access to the inside of the balls and to the balls in the middle section of the breakwater was difficult due to the shallowness of the water, however priority was paid to recording new coral colonies.

Fish and Invertebrate Populations

Fish Populations

These were recorded in 3 ways:

1. a swim route was identified (in the case of the Marriott breakwater) and a timed video taken along the route. This serves as a record but also will allow future analysis for fish species and numbers.
2. a modified 'roving fish count' was undertaken using video where as many fish species as possible were filmed, identified and given an abundance scale as follows:
    a. S- single
    b. F – Few (2-10 individuals)
    c. M - Many (11 – 100 individuals)
    d. A – Abundant (100+ individuals)
3. a modified Reef Check belt transect was conducted for the Marriott Reef where a 100m tape was laid alongside the breakwater (location shown below) and fish numbers of all species recorded as follows:
    Once the line had been deployed, the recorder waited 5 minutes for fish to settle (usual Reef check guidance is 15 minutes but at this site with heavy tourist use, 5 minutes was judged adequate). The recorder counted all fish species 2.5m either side of the line and up to the water surface (this would be up to 5m in deeper water). In practice this meant the width of one reef ball on one side (c. 2.5m) as it was impossible to record further than this. The recorder then swam slowly along the transect counting all fish species (Reefcheck only record indicator fish), stopping every 5m for one minute before proceeding to the next 5m stop. The inside of each Reef ball was checked. The fish were counted while swimming and while stopped along the entire length of each 20 m transect. This is a combined timed and area restricted survey: four segments x 20 m long x 5 m wide = 400m^2. As with Reef check there are four 5 m gaps where no data are collected.

    A Shannon-Weaver Diversity Index H (1984) was calculated as follows:

$$H = ? \ p_i \ln(p_i)$$

where p_i is the proportion of individuals in the i^{th} species (N_i), as a proportion of the total number of individuals:

$$p_i = N_i / ? \ N_i$$

Invertebrate Belt Transect

When the fish belt transect was complete, a second recorder carried out the same belt transect survey for invertebrates as above. Each belt transect was 5 m wide (2.5 m on either side of the transect line – again this approximated to one reefball width). In practice there were no invertebrates on the area adjacent to the reefballs thus the transect amounted to less than half a normal reefcheck transect i.e. 160 m^2 opposed to S400 m^2 for the complete transect. The recorder did not stop every 5m, but swam slowly along the transect counting the indicator invertebrates including all urchin species within the 20m transects. The recorder searched both inside and outside of the reefballs.

RESULTS

Film and still photography is not yet availab le for analysis but other results are given below.

Coral Plugs

Marriott Breakwater

On the main breakwater algae growth was prolific and very few surviving coral plugs were detected. A total of 9 living coral plugs were detected on the 30 monitored balls, 6 *Porites porites* and 3 *Acropora cervicornis*. This is mentioned further in the discussion section.

On the deepwater balls, detailed records of each plug recorded in sequence are given in Appendix 1 and a summary is given below (table 1). Survival here was also poor with 73% and 81% of plugs dead and one plug fallen out on each ball. 5 complete coral colonies were moved onto the balls and only one of these colonies survived.

	DW1	%	DW2	%
Year planted	2005		2005	
Live plugs	3	20.0	2	12.5
Dead p lugs	11	73.3	13	81.3
Plugs out	1	6.7	1	6.3
Live colonies	0	0	1	50
Dead colonies	3	100	1	50

Table 1. Condition of Transplanted Coral Plugs and Separate Colonies, Marriott Deep Water Reef Balls

Cemetery Reef

Survival of plugs was much better here and detailed records are shown in Appendix 2. A summary of results is shown in Table 2. 100% of the plugs survived on 3 of the balls (one of which was planted up in 2005) and the lowest survival rate was 68%. Average survival rate was 90.2%. 4 plugs looked to have barely any live polyps and

were not counted as 'live plugs', although they may recover. Some *Acropora cervicornis* plugs were planted 'upside down' but appeared to be 'basing out' and surviving. Those plugs that have started basing out are shown in Appendix 2.
It is worth noting that the second batch of reef balls that were deployed in 2007 had moved due to lack of staking and severe weather, despite this survival of the plugs is impressive.

Reefball no.	CR1	%	CR2	%	CR3	%	CR4	%	CR5	%	CR6	%
Year	2005		2005		2007		2007		2007		2007	
Live plugs	13	68.4	11	100.0	7	100.0	8	88.9	11	100.0	14	77.8
Dead plugs	3	15.8	0	0.0	0	0.0	1	11.1	0	0.0	3	16.7
Dead?	3	15.8									1	5.6
Live colonies	2	100										
Dead colonies	0	0										

Table 2. Condition of Transplanted Coral Plugs and Separate Colonies, Cemetery Reef Reef Balls.

Benthic Cover

Marriott Breakwater

The breakwater is extensively covered in algal growth and this was the case when the first coral plugs were transplanted in 2005. At least 10 species of algae were noted together with encrusting sponge that was not identified to species level. Estimates of percentage cover on the outside of the balls are shown in Table 3 and detailed estimates for each ball are shown in Appendix 3. Coral species were also noted and plugs were noted, where identifiable as such. Each colony was counted (results in Table 4).

AVERAGE %AGE COVER ALGAE AND SPONGE (OUTSIDE OF BALL)	Acetabularia sp.	Cladophora prolifera	Neomeris annulata	Ventricaria ventricosa	Padina sanctae-crucis	Lobophora variegata	Wrangelia argus	Coralline algae/reef cement	Derbesia sp.	Dictyota sp.	Encrusting Sponge
INSIDE BALLS	0.9	19.2	0.3	0.1	27.5	1.5	0.1	22.0	13.0	0.3	4.7
MIDDLE BALLS	0.8	10.0	0.0	0.1	22.0	0.6	0.0	39.5	10.0	3.5	7.5
OUTSIDE BALLS	1.0	15.5	0.3	0.1	11.5	0.9	0.1	25.0	17.6	3.4	6.0
ALL	0.9	14.9	0.2	0.1	20.3	1.0	0.1	28.8	13.5	2.4	6.1

Table 3. Average Percentage Cover of Algae and Sponge species on Monitored Reef Balls Marriott Breakwater (figures represent an estimate of cover on the outside of the ball).

Coralline algae/reef cement covered an average of 28.8% of the outer reefball surface with Padina sanctae-crucis and Cladophora prolifera covering on average between 14-21%. Balls in the middle of the breakwater showed higher cover of coralline algae and less green algae. It was difficult to gain percentage cover estimates for inside the

balls but algae cover was vastly reduced. An estimate of sponge cover was made and coral colonies counted. Results are shown in Table 5.

AVERAGE NUMBER OF CORAL COLONIES (OUTSIDE OF BALL)	Porites porites	Porites porites plug	Porites astreoides	Siderastrea radians	Favia fragum	Acropora cervicornis plug	Agaricia humilis	Millepora sp.
INSIDE BALLS	5.9	0.2	0.1	3.8	1.2	0.1	0.0	0.5
MIDDLE BALLS	6.6	0.2	0.1	2.2	0.5	0.0	0.1	0.0
OUTSIDE BALLS	6.0	0.3	0.2	2.4	0.6	0.1	0.3	0.5
ALL	6.2	0.2	0.1	2.8	0.8	0.1	0.1	0.3

Table 4. Average Number of Coral Colonies on Monitored Reef Balls Marriott Breakwater

It was apparent that there were many more new colonies of *Siderastrea radians* inside the balls than outside and in particular with the ultra balls which have a much wider open top than the slightly smaller reef balls. In one case (Y7), c.20% of the interior surface was covered by *S. radians*. *Porites porites* and *Favia fragrum* had also colonised the interior of the balls and there were some sizeable colonies of the former.

AVERAGE NUMBER OF CORAL COLONIES (INSIDE OF BALL)	Sponge (%age cover)	Porites porites	Porites astreoides	Siderastrea radians	Favia fragum
INSIDE BALLS	10.5	1	0	5.8	0
MIDDLE BALLS	10.2	1	0	7.7	1
OUTSIDE BALLS	2.6	1	2	11.9	1
ALL	7.77	1	1	8.47	1

Table 5. Average Number of Coral Colonies and %age cover of Sponge on interior of Monitored Reef Balls Marriott Reef

Marriott Deep Water Reef Balls

Detailed records for these balls are listed in Table 6 (this does not include coral plugs). Algal cover was 4-8% and large areas of the surface were still bare cement.

10 small new colonies of the purple coloured *Porites branneri* (unconfirmed) were noted on the top of Ball number 2. This was not recorded on any other reef ball during this survey.

Algae and Coral Species	Cladophora prolifera (%age cover)	Padina sanctae-crucis (%age cover)	Lobophora variegata (%age cover)	Porites porites (no. colonies)	Porites branneri (?) (no. colonies)	Siderastrea radians (no. colonies)	Millepora sp.(no. colonies)	
DEEP W 1		3	1			2	2	
DEEP W 2	2	5	1	1	10	1	1	

Table 6. Algal and Coral Species on Marriott Deep Water Reef Balls

Invertebrates

Marriott Breakwater

Table 7 shows the invertebrates recorded and an overall abundance rating. Lobsters were only noted in one ball (3 individuals) where there were parts of a broken reefball placed in the bottom. Stocky Ceriths (*Cerithium litteratum*) were common on most balls. 3 species of urchins were noted and were counted in the belt transect. All records were for the reef ball section of the transect which in effect was 2m width (one reef ball width).

The Rock-boring urchin is the most common urchin, favouring 'plugholes' in the reefball structure. The abundance of all urchins is indicative of the high algal cover on the balls. Table 8 shows the numbers of urchins per ball on the monitored balls.

Numbers suggest that Rock-boring urchins would appear to prefer the reefballs on the inside of the breakwater although this has not been proven.

Marriott Deep Water Balls

3 Rock-boring urchins were recorded on Ball number 2.

Cemetery Reef

Only one species was noted (Collector's Urchin *Tripneustes ventricosus*) of which one individual was noted on Ball number 6.

Belt Transect (4 x 20m transect, c. 2m wid	Overall Dominance Rating (=Abundant; F=frequent; O=Occasional; R=Rare)	0-20m	25-45m	50-70m	75-95m	Total	Av. Per 20m section	Av. Per sq.m.
Diadema antillarum (Long-spined Urchin)	O	3	6	1	4	14	3.5	0.09
Echinometra lacunter (Rock-boring Urchin)	A	105	60	128	120	413	103	2.58
Tripneustes ventricosus (West Indian Sea Egg/Collectors Urchin)	F	12	10	9	26	57	14.3	0.36
Cerithium litteratum (Stocky Cerith)	A							
Panulirus argus (Caribbean Spiny Lobster)	R							
Percnon gibbesi (Nimble Spray Crab)	R							

Table 7. Invertebrate Species recorded on Marriott Breakwater

AVERAGE NUMBER SEA URCHINS PER BALL	West Indian Sea Egg Tripneustes ventricosus	Long-spined Urchin Diadema antillarum	Rock-boring Urchin Echinometra lucunter
INSIDE BALLS	3.4	0.3	17.6
MIDDLE BALLS	2.5	0.7	10.4
OUTSIDE BALLS	4.4	0.4	6.2
ALL	3.4	0.5	11.4

Table 8. Sea Urchin species Recorded on Marriott Breakwater Monitored Reef Balls

FISH

Video records have not yet been analysed for any of the sites however a species list and abundance rating is given in Table 9. The detailed results of the belt transect carried out for the Marriott Breakwater are shown in Appendix 4.

The breakwater lies parallel to an area of hardpan bottom with some corals (see aerial photo) and thus forms the eastern border of a somewhat sheltered corridor. This is reflected in the number of fish which is relatively high and diversity is higher than might be expected for a new breakwater of this age. Transect section 4 (75-95m) is located on the northern section of the breakwater and along the inside of the breakwater and shows lower fish numbers as might be expected (Appendix 4). Species of note include Green Moray Eel (c.5ft. individual), Ocean Triggerfish (feeding on rock-boring urchins) and Yellow Sting Ray.

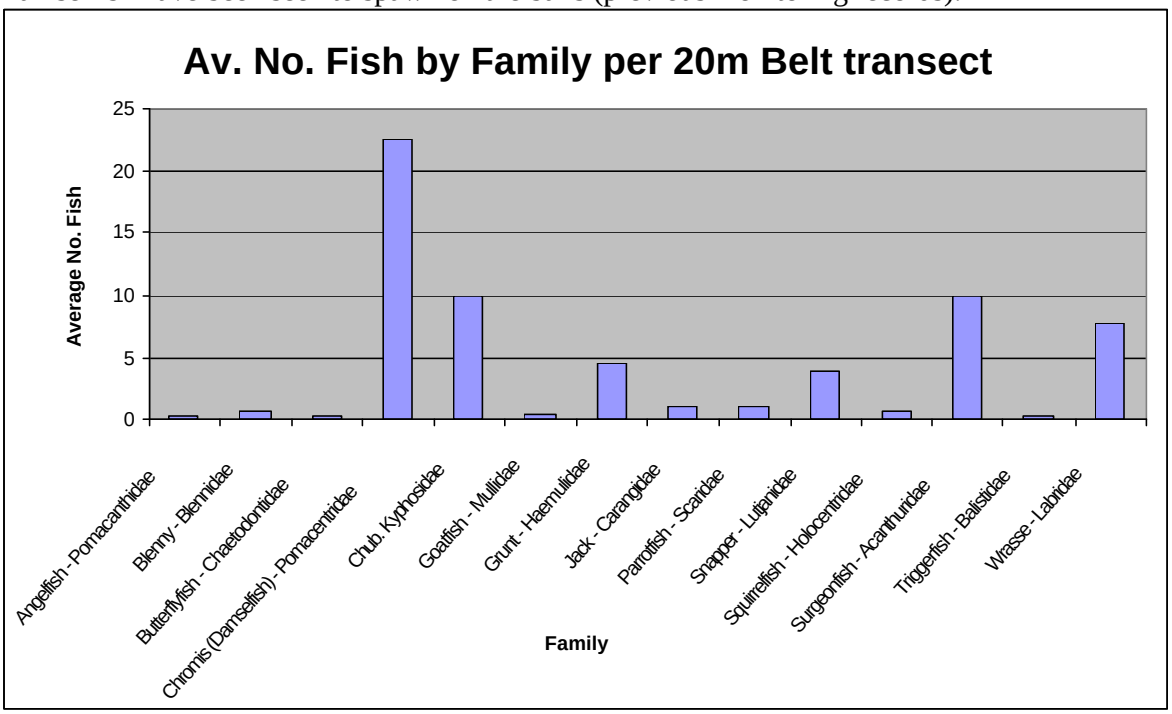
Species diversity was calculated using the Shannon-Weaner Diversity Index (calculations Appendix 5) and gives an index of 1.06 which reflects a wide range of species in fairly even numbers i.e. none are markedly more dominant than others.

Fish Species Presence/Absence P=1	Adults	Juveniles (where noted)	Abundance Rating (S=single; F=few 2-10 inds.; M=Many 11-100 inds.; A=Abundant >100 inds.)
Angelfish - Pomacanthidae			
Pomacanthus paru (French Angelfish)		1	F
Holcanthus ciliaris (Queen Angelfish)		1	S
Barracuda - Sphyraenidae			
Sphyraena barracuda (Great Barracuda)	1		S
Blenny - Blennidae			
Labrisomus nuchipinnis (Hairy Blenny)	1		S
Malacoctenus triangulatus (Saddled Blenny)(?)	1		F
Boxfish - Ostraciidae			
Lactophrys bicaudalis (Spotted Trunkfish)	1		S
Butterflyfish - Chaetodontidae			
Chaetodon striatus (Banded Butterflyfish)	1		F
Chaetodon ocellatus (Spotfin Butterflyfish)	1		F
Chromis (Damselfish) - Pomacentridae			
Stegastes variabilis (Cocoa Damselfish)	1		S
Stegastes leucostictus (Beaugregory)	1		M
Stegastes fuscus (Dusky Damselfish)	1	1	M/A
Abudefduf saxatilis (Sergeant Major)	1		M
Chub - Kyphosidae			
Kyphosus sectatrix	1		M
Moray - Muraenidae			
Gymnothorax funebris (Green Moray)	1		S
Flounder - Bothidae			
Bothus lunatus (Peacock Flounder)	1		S
Goatfish - Mullidae			
Pseudupeneus maculatus (Spotted Goatfish)	1		F
Mulloidichthys martinicus (Yellow Goatfish)	1		M
Grunt - Haemulidae			
Haemulon flavolineatum (French Grunt)	1		M
Haemulon sciurus (BluestripedGrunt)	1		F
Haemulon carbonarium (Caesar Grunt)	1		F/M
Anisotremus surinamensis (Black Margate)	1		S
Haemulon parra (Sailor's Choice)	1		S
Jack - Carangidae			
Caranx ruber (Bar Jack)	1		F
Caranx latus (Horse-eye Jack)	1		F
Mojarras - Gerreidae			
Gerres cinereus (Yellowfin Mojarra)	1		M
Needlefishes - Belonidae			
Tylosurus crocodilis (Houndfish) (?)	1		S
Parrotfish - Scaridae			
Scarus guacamaia (Rainbow Parrotfish) (?)		1	S
Sparisoma chrysopterum (Redtail Parrotfish) (?)		1	S

Sparisoma rubripinne (Yellowtail (Redfin) Parrotfish)	1		F
Sparisoma viride (Stoplight Parrotfish)	1		F
Round Stingrays - Urolophidae			
Urolophus jamaicensis (Yellow Stingray)	1		S
Snapper - Lutjanidae			
Lutjanus analis (Mutton Snapper)	1		F
Lutjanus griseus (Gray Snapper)	1		S
Lutjanus synagris (Lane Snapper)	1		F
Lutjanus apodus (Schoolmaster)	1		M
Ocyurus chrysurus (Yellowtail Snapper)	1		M
Squirrelfish - Holocentridae			
Holocentrus adscensionis (Squirrelfish)	1		S
Surgeonfish - Acanthuridae			
Acanthurus coeruleus (Blue Tang)	1		M
Acanthurus chirurgus (Doctorfish)	1		F
Acanthurus bahianus (Ocean Surgeonfish)	1		F
Triggerfish - Balistidae			
Canthidermis sufflamen (Ocean Triggerfish)	1		S
Wrasse - Labridae			
Halichoeres bivittatus (Slippery Dick)	1		M
Thalassoma bifasciatum (Bluehead)	1	1	M
Halichoeres radiatus(Puddingwife)	1		F
Wrasse spp.	1		F
Totals (species presence)			**45**

Table 9. Fish Species Recorded Marriott Breakwater

Fish data were also categorised into families and these results are shown in the figure below. Damsel fish are the most dominant family followed by surgeonfish, chub and wrasse. Chub are fed by the tourists and this would account for their prominance. Damselfish and surgeonfish are algae-eaters and this explains their abundance. Damselfish have been seen to spawn on the balls (previous monitoring records).



DISCUSSION

The Marriott Breakwater has created a significant area of new marine habitat which has been colonised by algae, new corals, numerous invertebrates and is frequented by large numbers and diverse species of fish. This breakwater has importantly given protection to the adjacent area of beach from wave surge but has made an important contribution to local marine biodiversity, and not least has created a noticeable tourist attraction. Similarly the reef balls located at Cemetery Reef have created a valuable additional habitat to the nearby reef and in time the growing coral transplants will add importantly to coral growth in the area.

The low success of the coral transplants on the Marriott breakwater could be the result of a number of factors:

- the breakwater receives a lot of tourist traffic. Swimmers and snorkellers sit and stand on the balls and this will no doubt have resulted in the dislodging of some plugs and physical damage to corals
- Coral plugs were transplanted onto balls already covered with algae (reef balls were in place 2 years previous to coral transplants), this presents difficult conditions for establishment
- Rock-boring urchins commonly burrow into reef structures, they tend to favour the plug holes and conceivably may have bored into the softer cement plugs
- For some species (*Acropora cervicornis* for example), the relatively high temperatures in this shallow water may have inhibited growth
- High nutrient levels (not confirmed) in the water (as compared to Cemetery Reef ?) may have encouraged algal growth to the detriment of coral establishment (they are unable to compete in these conditions).
- The 2005 Caribbean coral bleaching event will have been detrimental to coral survival especially in shallow water.

Any or all of the above reasons may explain the poor survival of plugs on the breakwater but do not explain similarly poor success on the deepwater balls. It is possible that the coral transplants may have suffered undue stress for some reason during the transplant process.

APPENDICES

APPENDIX 1. Detailed Records of Coral Plugs on Marriott Deep Water Reef Balls 13/1/08 (L=Live, D=Dead, B=Basing).

DW1	Position on ball	*Acropora cervicornis*	*Acopora palmata*	*Porites porites*	*Eusmilia fastigiata*	*Agaricia humilis*	species unknown
Plug 1	top	LB					
Plug 2	top				L		
Plug 3							D
Plug 4			D				
Plug 5							D
Plug 6		D					
Plug 7			D				
Plug 8							D
Plug 9							D
Plug 10							D
Plug 11							D
Plug 12			D				
Colony 1							D
Plug 13							D
Plug out							
Colony 2							D
Plug 14		LP					
Colony 3						D	
TOTAL LIVE		2			1		
TOTAL DEAD		1	3			1	9

DW2								Notes
Plug 1							D	
Plug 2							D	
Plug 3							D	
Plug 4							D	
Plug 5							D	
Plug 6							D	
Plug out								
Plug 7							D	
Plug 8							D	
Plug 9					L			
Colony 1						L		
Plug 10							D	
Plug 11							D	
Plug 12							D	
Plug 13							D	
Colony 2							D	
Plug 14		LP						Base of colony dead
Plug 15							D	

Appendix 2. Detailed Records of Coral Plugs on Cemetery Reef, 12/1/08 (L=Live, D=Dead, B=Basing)

CR1	Position on ball *Acropora cervicornis*	*Acopora palmata*	*Porites astreoides*	*Siderastrea radians*	Gorgonian	NOTES
Plug 1		L				
Plug 2	L					
Plug 3	L					
Colony 1				L		
Plug 4	Bot	L				
Plug 5	L					
Plug 6	L					
Plug 7	L					
STAKE						
Plug 8	D					
Plug 9		L				
Plug 10	L					
Plug 11	L					50% colony dead
Plug 12	Top	?				
Plug 13		D				
Plug 14	D?					
Plug 15		D?				
STAKE						
Plug 16 Colony 2		L	L			50% colony dead
Plug 17					D	
Plug 18	LB					
TOTAL	10	7	1	1	1	

CR2	Position on ball *Acropora cervicornis*	*Acopora palmata*	*Porites porites*	*Siderastrea radians*		NOTES
Plug 1		L				
Plug 2	Top L					
Plug 3			L			50% colony covered with algae
Plug 4	LB					
Plug 5		LB				
Plug 6	L					
Plug 7		L				50% colony dead
Plug 8		L				

Plug 9		L				
Plug 10	LB					
Plug 11		LB				
NEW				1		
TOTAL	4	6	1	1		

CR3	Position on ball *Acropora cervicornis*	*Acopora palmata*				NOTES
Plug 1		L				
Plug 2		L				
Plug 3	Top	L				
Plug 4	Top L					
Plug 5	L					
Plug 6		L				
Plug 7		L				
TOTAL	2	5				BALL algae covered

CR4	Position on ball *Acropora cervicornis*	*Acopora palmata*				NOTES
Plug 1	bot L					
Chain						
Plug 2	L					algae
Plug 3		L				
Plug 4	top	L				50% colony dead
Plug 5	top	LB				
Plug 6	D					planted upside down
Plug 7	L					
Plug 8		L				positioned inside hole
Plug 9	LB					
TOTAL	5	4				ball algae covered

CR5	Position on ball	*Acropora cervicornis*	*Acopora palmata*				NOTES
Plug 1	L						
Plug 2	L						large
Plug 3	LB						
Plug 4	L						
Plug 5		LB					
Plug 6		LB					
Plug 7		LB					algae
Plug 8	L						
Plug 9	L						
Plug 10	top	LB					
Plug 11	L						algae
TOTAL	7	4					*Acetabularia* common
							ball algae covered

CR6	Position on ball	*Acropora cervicornis*	*Acopora palmata*	species unknown			NOTES
Plug 1				D			
Plug 2	LB						
Plug 3		LB					
Plug 4	LB						
Plug 5	L						
Plug 6	L						
Plug 7	top L						
Plug 8	L						
Plug 9	L						
Plug 10	D						
Plug 11	L						
Plug 12	D						
Plug 13	top	L					
Plug 14	top	L					
Plug 15	LB						
Plug 16	LB						
Chain							
Plug 17	top	?					
Plug 18		L					
TOTAL	12	5		1			Ball algae covered, no new coral colonies
							1 Purple sponge, 1 *Tripneustes*.

Appendix 3. Benthic Cover of Monitored Reefballs Marriott Breakwater including New Coral Colonies and Numbers of Sea Urchins

LOCATION OF MONITORED BALLS	*Acetabularia sp.*	*Cladophora prolifera*	*Neomeris annulata*	*Ventricaria ventricosa*	*Padina sanctae-crucis*	*Lobophora variegata*	*Wrangelia argus*	Coralline algae/reef cement	*Derbesia sp.*	*Dictyota sp.*	Sponge	West Indian Sea Egg *Tripneustes ventricosus*	Long-spined Urchin *Diadema antillarum*	Rock-boring Urchin *Echinometra lucunter*
	Percentage cover algal species and sponge											Number of urchins		
INSIDE														
B1				1	50	2		5	20	1		1		6
B2		5			50			10	10			4		3
B3	2	2	1		15	2		10	30		2			1
B4		5			10			10	15			3	1	3
B5		20			30	2	1	30			5	2	1	55
B6	5	30	1		25	2		30	5		10	2		70
B7		30			30			50	20	1	10	2	1	15
B8	1	50			10	1		30	15		5	4		15
B9	1	20			25	5		30	5		5	5		3
B10		30	1		30	1		15	10	1	10	11		5
AVERAGE	0.9	19.2	0.3	0.1	27.5	1.5	0.1	22.0	13.0	0.3	4.7	3.4	0.3	17.6
MIDDLE														
Y1					50			50	30			3		3
Y2		5			5			50					1	3
Y3		5			25	2		30	10	2	20	2		5
Y4		5			10			20	15		20	2		11
Y5		5			10	2		50	10	5				51
Y6	2	10		1	5			30	10	10	5	1		9
Y7	2				10			70	5	3	15	7	3	7
Y8	2	10			5			70	5		5	4	3	3
Y9	2	30			50	2		5	10	10	5	1		5
Y10		30			50			20	5	5	5	5		7
AVERAGE	0.8	10.0	0.0	0.1	22.0	0.6	0.0	39.5	10.0	3.5	7.5	2.5	0.7	10.4
OUTSIDE														
P1			1		50			10	20	2	2	2		
P2					10			40	50	5		10		1
P3	5	10			10			20	5			7		
P4				1	5	2		30	5		30	1	2	
P5					10			20	30	3	5	15	1	1
P6	2	30			5			30	10	10	5	1		11
P7		5	2		5	1		50	5	5		2	1	4
P8	1	30			5				30	5	10	2		6
P9	1	40				3	1	30	16	2	3	2		22
P10	1	40			15	3		20	5	2	5	2		17
AVERAGE	1.0	15.5	0.3	0.1	11.5	0.9	0.1	25.0	17.6	3.4	6.0	4.4	0.4	6.2
OVERALL AVERAGE	0.9	14.9	0.2	0.1	20.3	1.0	0.1	28.8	13.5	2.4	6.1	3.4	0.5	11.4

LOCATION OF MONITORED BALLS	Porites porites	Porites porites plug	Porites astreoides	Siderastrea radians	Favia fragum	Acropora cervicornis plug	Agaricia humilis	Millepora sp.	Porites porites	Porites astreoides	Siderastrea radians	Favia fragum	TOTAL COLONIES	Sponge	COMMENTS
	No. coral colonies OUTSIDE OF BALL								No. of coral colonies INSIDE OF BALL					%age cover	
INSIDE															
B1	2												2		
B2	7												7	10	
B3	3			5		1			3		16		28		2 big colonies Pp inside
B4	7			2					1		14		24	10	Some big colonies Pp (5x5cm)
B5	4				1								5		
B6	6	1		7	3				4		28	3	52	30	
B7	10	1		8									19	30	1 big Pp, Dictyopteris sp.?
B8	3			8	1				1				13	5	Blackball sponge
B9	3			4	7							1	15	20	
B10	14		1	4				5	4				28		Hydroid growth, Pp colonies inside big
AVERAGE	5.9	0.2	0.1	3.8	1.2	0.1	0.0	0.5	1.3	0.0	5.8	0.4	19.3	10.5	
MIDDLE															
Y1											1		1	2	
Y2	13												13		Little growth
Y3	6												6		
Y4	5				1								6		
Y5				1									1		
Y6	12	1							11		3	2	29	5	
Y7	2		1	3	1				1		50		58	30	1 big Pp, 20%Sr cover inside
Y8	11	1		3	3		1		2		23	3	47	5	
Y9	2			5									7	30	Pp plug?
Y10	15			10									25	30	Blackball sponge 1
AVERAGE	6.6	0.2	0.1	2.2	0.5	0.0	0.1	0.0	1.4	0.0	7.7	0.5	19.3	10.2	
OUTSIDE															
P1	2					1					4		7		
P2				8									8	10	
P3	4			1									5		
P4	7			5	1				2		50		65		50+ Sr inside
P5	3			2	1				1		20	4	31		20+ Sr inside, Pp large inside
P6	3	1							2		3	2	11	5	plug on top
P7	7	2			3		1	3	1	15	34	2	68	1	
P8	22		2	6	1								31		
P9	5			2			1		3		8		19	5	
P10	7				1		1	2					11	5	Blackball sponge inside
AVERAGE	6.0	0.3	0.2	2.4	0.7	0.1	0.3	0.5	0.9	1.5	11.9	0.8	25.6	2.6	
OVERALL AV	6.2	0.2	0.1	2.8	0.8	0.1	0.1	0.3	1.2	0.5	8.47	0.57	23.54	7.8	

Appendix 4. Fish Counts Belt Transect Marriott Breakwater

Fish Counts Marriott Breakwater (80m transect - 4sections 5x20m)	0-20m	25-45m	50-70m	75-95m	Total/20m transect (100 sq. m.)	Average/20m transect (100 sq.m.)
Angelfish - Pomacanthidae						
Pomacentrus paru (French Angelfish)		1			1	0.25
Blenny - Blennidae						
Labrisomus nuchipinnis (Hairy Blenny)	1				1	0.25
Blenny sp	1		1		2	0.5
Butterflyfish - Chaetodontidae					0	
Chaetodon striatus (Banded Butterflyfish)	1				1	0.25
Chromis (Damselfish) - Pomacentridae						
Stegastes leucostictus (Beaugregory)	1				1	0.25
Stegastes fuscus (Dusky Damselfish)	7	4	7	4	22	5.5
Abudefduf saxatilis (Sergeant Major)	13	25	24	5	67	16.75
Chub - Kyphosidae						
Chub (Kyphosus sectatrix)	1	37	2		40	10
Goatfish - Mullidae						
Mulloidichthys martinicus (Yellow Goatfish)	2				2	0.5
Grunt - Haemulidae						
Haemulon flavolineatum (French Grunt)	3	4	10		17	4.25
Haemulon carbonarium (Caesar Grunt)	1				1	0.25
Jack - Carangidae						
Caranx ruber (Bar Jack)			1		1	0.25
Caranx latus (Horse-eye Jack)		3			3	0.75
Parrotfish - Scaridae						
Sparisoma rubripinne (Yellowtail (Redfin) Parrotfish)		2			2	0.5
Sparisoma viride (Stoplight Parrotfish)		2			2	0.5
Snapper - Lutjanidae						
Lutjanus apodus (Schoolmaster)	1	3	1		5	1.25
Ocyurus chrysurus (Yellowtail Snapper)		11			11	2.75
Squirrelfish - Holocentridae						
Holocentrus adscensionis (Squirrelfish)			1	2	3	0.75
Surgeonfish - Acanthuridae						
Acanthurus coeruleus (Blue Tang)	13	9	1	2	25	6.25
Acanthurus chirurgus (Doctorfish)		2			2	0.5
Acanthurus bahianus (Ocean Surgeonfish)	2	1	8	2	13	3.25
Triggerfish - Balistidae						
Canthidermis sufflamen (Ocean Triggerfish)			1		1	0.25
Wrasse - Labridae						
Wrasse spp.	1	2			3	0.75
Thalassoma bifasciatum (Bluehead)		3	11	1	15	3.75
Halichoeres bivittatus(Slippery Dick)	4	6	3		13	3.25
TOTAL	52	115	71	16	254	63.5

Appendix 5. Shannon-Weaner Diversity Index Calculation Fish Counts Belt Transect Marriott Breakwater

Calculation of Shannon-Weaver Index for Diversity of Fish Species	Count	Proportion	ln (pi)	[(pi)(ln pi)]
Angelfish - Pomacanthidae				
Pomacentrus paru (French Angelfish)	1	0.00394	-2.4048	0.0095
Blenny - Blennidae				
Labrisomus nuchipinnis (Hairy Blenny)	1	0.00394	-2.4048	0.0095
Blenny sp	2	0.00787	-2.1038	0.0166
Butterflyfish - Chaetodontidae	0			
Chaetodon striatus (Banded Butterflyfish)	1	0.00394	-2.4048	0.0095
Chromis (Damselfish) - Pomacentridae				
Stegastes leucostictus (Beaugregory)	1	0.00394	-2.4048	0.0095
Stegastes fuscus (Dusky Damselfish)	22	0.08661	-1.0624	0.0920
Abudefduf saxatilis (Sergeant Major)	67	0.26378	-0.5788	0.1527
Chub - Kyphosidae				
Chub (Kyphosus sectatrix)	40	0.15748	-0.8028	0.1264
Goatfish - Mullidae				
Mulloidichthys martinicus (Yellow Goatfish)	2	0.00787	-2.1038	0.0166
Grunt - Haemulidae				
Haemulon flavolineatum (French Grunt)	17	0.06693	-1.1744	0.0786
Haemulon carbonarium (Caesar Grunt)	1	0.00394	-2.4048	0.0095
Jack - Carangidae				
Caranx ruber (Bar Jack)	1	0.00394	-2.4048	0.0095
Caranx latus (Horse-eye Jack)	3	0.01181	-1.9277	0.0228
Parrotfish - Scaridae				
Sparisoma rubripinne (Yellowtail (Redfin) Parrotfish)	2	0.00787	-2.1038	0.0166
Sparisoma viride (Stoplight Parrotfish)	2	0.00787	-2.1038	0.0166
Snapper - Lutjanidae				
Lutjanus apodus (Schoolmaster)	5	0.01969	-1.7059	0.0336
Ocyurus chrysurus (Yellowtail Snapper)	11	0.04331	-1.3634	0.0590
Squirrelfish - Holocentridae				
Holocentrus adscensionis (Squirrelfish)	3	0.01181	-1.9277	0.0228
Surgeonfish - Acanthuridae				
Acanthurus cœruleus (Blue Tang)	25	0.09843	-1.0069	0.0991
Acanthurus chirurgus (Doctorfish)	2	0.00787	-2.1038	0.0166
Acanthurus bahianus (Ocean Surgeonfish)	13	0.05118	-1.2909	0.0661
Triggerfish - Balistidae				
Canthidermis sufflamen (Ocean Triggerfish)	1	0.00394	-2.4048	0.0095
Wrasse - Labridae				
Wrasse spp.	3	0.01181	-1.9277	0.0228
Thalassoma bifasciatum (Bluehead)	15	0.05906	-1.2287	0.0726
Halichoeres bivittatus(Slippery Dick)	13	0.05118	-1.2909	0.0661
TOTAL/Diversity Index	254			1.0635