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20A Restoration of coral reefs

Coral Relocation: A mitigation tool for dredging works in Jamaica

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Abstract. A large-scale environmental mitigation plan was conducted to preserve benthic marine resources during the development of the Falmouth Cruise Ship Terminal in Trelawny, Jamaica. The magnitude of this project has made it potentially the largest reported coral relocation exercise in the world to date; between August 2009 and April 2010, 147,947 organisms (8,975 soft coral; 137,789 hard coral; and 1,183 sponges) were successfully relocated. An additional 2,807 sea urchins, mainly *Diadema sp.*, were relocated from the dredging area, as well as numerous sea cucumbers, hermit crabs, conchs, sea stars and lobsters. Time series photographs of sample colonies were taken on three occasions: October 2009, April 2010, and April/May 2011. Preliminary results indicate that 86% of the colonies relocated in 2009 were accounted for in 2011. Partial colony mortality and the occurrence of disease increased with each sampling event (from 38% to 43% and 9 to 20 cases respectively). By 2011, cases of total colony mortality accounted for 4% of the monitored colonies.

Key words: Coral Relocation, Dredging, Building with Nature.

Introduction

Sensitive ecosystems, such as coral reefs, seagrass meadows and mangroves, are being affected globally by large-scale processes, like climate change (Hughes *et al.*, 2003; Hoegh-Guldberg *et al.*, 2007; Hughes *et al.*, 2007) and locally by small-scale activities, such as coastal development (Ryan *et al.*, 2008). Dredging and land reclamation are oftentimes prerequisites for development of coastal infrastructure and they can result in increased sedimentation, increased turbidity, mechanical damage (Marsalek, 1981; TEMN Ltd., 2007) as well as loss of habitat and biodiversity, (TEMN Ltd., 2007). As a consequence, coastal development projects, which include dredging and land reclamation, usually come with severe environmental constraints and require mitigation measures ranging from silt screens, reflective shields and site specific dredge equipment to benthic relocation and restoration of mangroves and seagrass meadows.

Boskalis Westminister St. Lucia conducted the dredge and land reclamation required to develop the Falmouth Cruise Ship Terminal in Trelawny, Jamaica (Fig. 1) and Maritime and Transport Services Ltd. (MTS) conducted the benthic relocation exercise in accordance with the National Environmental and Planning Agency (NEPA) in Jamaica. The survival (relative health and attachment status) of a subset of colonies was monitored over an eighteen-month period and an independent assessment of coral cover and general benthic health was also conducted.

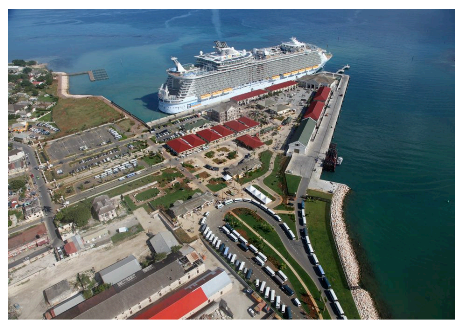

Figure 1: The Falmouth Cruise Ship Terminal, Trelawny, Jamaica.

Material and Methods

Site Description

The Falmouth Harbour is a shallow, natural harbour, ranging in depth from 1 – 12m and bounded to the north by an extensive fringing reef, to the east by Oyster Bay and to the west and south by the town of Falmouth and the mangrove system of the Martha Brae estuary.

The environmental impact assessment (EIA) indicated that there were sensitive benthic marine resources within and adjacent to the footprint of the proposed structure (Fig. 2), namely the reef system and Oyster Bay. Some 112 species were identified in the area (22 scleractinian corals, 29 algae, 8 sponges, 15 invertebrates and 45 fishes), coral cover was as high as 30% and *Diadema antillarum*, the keystone invertebrate herbivore (Lessios *et al.*, 2001), had densities of 8–13 individuals per m^2 (TEMN Ltd., 2007). Oyster Bay, also called Glistening Waters, is one of only four bioluminescent bays in the world (Seliger and McElroy, 1968). The bay's bioluminescence is due to densities of *Pyrodinium bahamense* ranging from 44,000 (Webber *et al.*, 1998) to 273,000 (Seliger *et al.*, 1970) individuals/L. The dominance of this bioluminescent plankton could be threatened by changes in water circulation and chemistry.

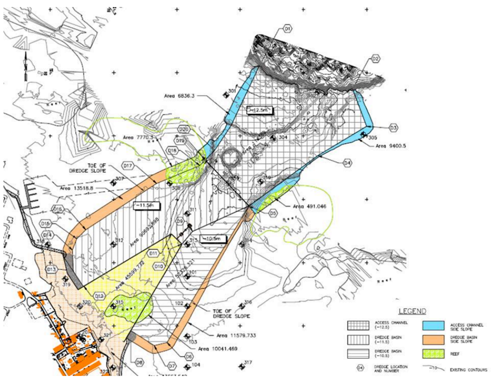

Figure 2: Layout of the Falmouth Cruise Ship Terminal, Jamaica.

Work Area Delineation

The work area (footprint of or area to be dredged and the relocation sites) was defined by an extensive, continuous 10m x 10m grid system.

Using a compass and basic geometry, parallel north-south lines were fixed to the substrate, using rebar stakes, hammers and rope and then the east-west lines were overlaid. The grid system facilitated the systematic removal and reattachment of organisms, by allowing divers to clear an area in visible units. The grid system was classified in a variation of the Cartesian coordinate (letter/number) system (both in theory and on the ground), in order to facilitate underwater navigation and reporting.

Coral Relocation

Divers, using both surface supply and scuba, were organized into four teams: harvesting, transporting, reattaching and monitoring.

Harvesting

NEPA specified that all hard and soft corals, with a colony diameter of 5cm or larger, should be harvested and transported to nearby reception sites (500m and 1,500m away). Colonies were detached at the point of attachment (using impact tools like hammers and chisels or pry bars) or with a 10-inch buffer (using hydraulic chain saws and disc saws – Fig. 3) to reduce fragmentation and facilitate handling. Where possible, colonies were detached in units (more than one colony or organism – Fig. 3) to maintain community structure at a micro level.

Transport

Detached colonies were packed, single layer, in mesh baskets, floated sub-surface using lift bags, and towed from the harvesting area to the reattachment area (Fig. 3).

Reattachment

Reattachment sites were predetermined based on similarities in water depth and movement; reef type (wall, patch or reef flat); and location (exposed or sheltered). Chipping hammers and wire brushes were first used to clean and prepare the substrate and the base of the colony; then epoxy or specialized cement, and in some cases, pins, pneumatic drills and compressors, were used as bonding agents. The specialized epoxy used was kneaded under water (Fig. 3), while the cement was premixed on deck (special amounts of sand and cement) and portioned into plastic bags. Both were lowered to the divers on demand. NEPA specified that colonies should be placed 0.5m apart and where possible, colonies were oriented based on shape; plates were fixed at an angle and the upper surface determined by the grooves and the potential for colony surface sand transport. Periodic checks were made to ensure that reattached colonies were stable.

Figure 3: Soft coral being detached with a chain saw (top left). Floated basket being attached to canoe (top right). Two hard coral species and sponge detached as a unit (bottom left). Diver on surface supply kneading epoxy to attach a colony (bottom right).

Monitoring

A total colony/organism count of harvesting area 1 (more than 300 grids – 29% of the gridded area) was conducted by December 2009 and the total number and species distribution of colonies to be relocated extrapolated. Each basket had a 'license plate' and for each tow, the license was recorded as well as descriptive data, such as the number of organisms. This along with the location of origin and destination was used to track the number of colonies reaped or planted per day. A record was also kept of the grids 'cleared' or 'planted' within the entire footprint each day; and the monitoring team verified grids, noted as cleared.

In order to determine the biological success of the relocation exercise, a sample of colonies (15 grids) was photographed in October 2009. These grids were chosen based on the disparity in the conditions: depth, wave action, proximity to dredging, source of colonies, and time of planting. Upon the completion of the project, the representative sample size was determined according to Yamane (1967) and time series photographs were taken on two additional occasions: the end of the project (2010), and a year later (2011), thus monitoring the relative health over a period of nineteen months (October 2009 – April/May 2012).

An independent agency also monitored activities, before, during and after the relocation exercise.

Results and Discussion

Over an eight-month period, a team of 93 people successfully relocated 147,947 organisms, including 8,975 soft corals; 137,789 hard corals; and 1,183 sponges.

There were four gridded harvesting areas within the dredge footprint comprising 1,107 grids (over 11 hectares) and a variety of conditions – from dense sediment-laden channels, patch reefs, and walls to sparse reef flats. The relocated colonies come from 24 hard coral species and roughly 24% were *Siderastrea siderea,* 18% *Agaricia* spp., and 10% *Porites astreoides* (Fig. 4).

It was mandatory that all colonies, whether diseased, bleached, exhibiting partial mortality, branching or foliose, be relocated and colony size ranged in diameter from 5cm to >1m. Branching and foliose colonies proved difficult to harvest, especially large extensive colonies of *Madracis mirabilis* or *Agaricia* spp., while large colonies sometimes proved challenging to transport, and some had to be walked or floated individually (Fig. 5) from the harvesting site to the planting site.

Monitoring

A representative sample size of 398 organisms was determined using Yamane's sample size formula (Yamane, 1967). Consequently, 12 grids (containing 400 colonies – both hard and soft coral) were photographed on three occasions over a 19-month period: the initial set of photographs of 15 grids were taken just after the start of the project (October 2009); upon completion of the project, seven months later, another series of photographs (of the first 11 grids) were taken (April 2010); and the final set of photographs were taken a year later (April/ May 2011). Five of these grids (158 colonies) were located in an area called Spider Reef, a shallow (<10 ft.), reef flat, west of the dredge and fill footprint, while 7 grids (257 colonies) were from an area called Chub Castle, north-west of the main dredge and fill footprint in deeper water (<50 ft.). These 12 grids, which would have been exposed to the elements for the longest period, were planted by the commercial divers before they gained experience in the replanting exercise, and these grids would also have been differentially affected by sedimentation from the dredge activity due to their location. Colonies were not permanently tagged, instead they were tracked by photographs and the location of grids was mapped using 'landmarks'.

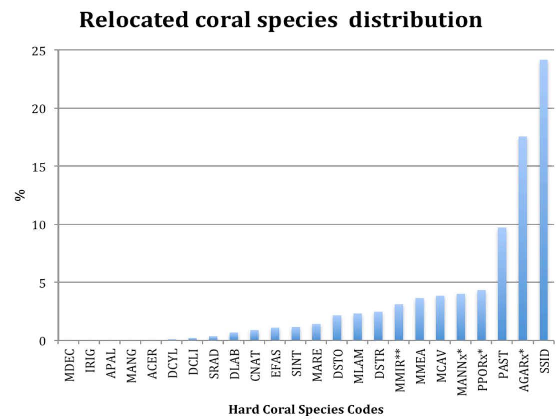

Figure 4: Distribution of coral species relocated in Falmouth, Jamaica. (CARICOMP based species codes, *more than one species of same genus and similar growth form recorded as one, ** extensive branching growth form thus underrepresented in counts).

Figure 5: Large colonies floated individually or walked to the relocation site. *M. cavernosa* on left estimated at >300 years old.

The photographs were catalogued based on the area, grid and colony, i.e., the first colony in grid 1 was called 1A and the first colony in grid 2 called 2A and so on. Of the photographs taken in April 2010, 357 colonies were identified and catalogued as colonies photographed in 2009, and in April/May 2011, 345 colonies were identified and catalogued as colonies photographed in 2009 (Fig. 6). Fourteen percent of colonies were not identified and this could be due to detachment or changes in morphology. The greatest difference was observed at Spider Reef in 2010. Spider Reef, the first shallow location planted, was discontinued due to severe wave action during storms. Some 39 colonies, both relocated and native colonies, were detached following a 'north-wester' (storm event) and they were subsequently relocated. Initially, the relocated colonies were easily differentiated due to the removal of macro algae, the visible epoxy or cement used to fix colonies, and the flagged nail marking the location. However, over time natural processes made this more difficult; macro algae overgrew nails and colonies, while disease, bleaching and partial mortality changed the appearance of the colonies. Consequently, some photographs identified as relocated colonies could not be matched to any specific colony photographed in 2009.

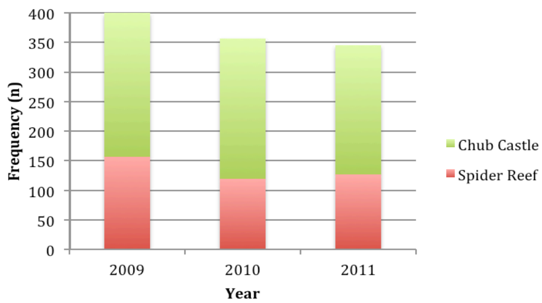

Figure 6: Number of relocated colonies identified per year.

Relative Health

The relative health of the relocated colonies was also assessed. Colonies were classified as healthy (no obvious signs of ill-health – hyperpigmentation, hypopigmentation, new partial mortality), stressed (diseased, bleached, exhibiting partial mortality) or dead. The number of healthy colonies increased in 2010 moving from 66% to 88%, but this number declined to 67% in 2011 and in addition, 4% of the colonies identified in 2011 were dead (Fig. 7). Percentage partial mortality and the occurrence of disease also increased over time. At Spider Reef the percentage of colonies that exhibited partial mortality increased from 27% in 2009, to 30% in 2010 and 43% in 2011, while at Chub Castle partial mortality increased from 22% in 2009 and 2010 to 38% in 2011 (Fig. 8). Four disease types were identified on the monitored colonies and an additional category, called disease (D), included diseases that could not be identified (dormant). White plague was by far the most dominant in all sample events, and black band was only observed during the 2011 sampling event, where it was the second most dominant disease (Fig. 9). Note that only the occurrence of diseased colonies was noted, consequently, colonies which were previously diseased, but which were now dead, were not recorded. The initial improvement in colony health (2010) is expected as the process of harvesting, transporting and planting can be stressful on a colony, resulting in changes in pigmentation and increased susceptibility. Additionally, the conditions of the

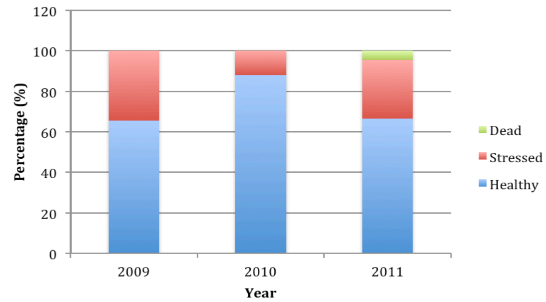

Figure 7: Relative health of relocated colonies.

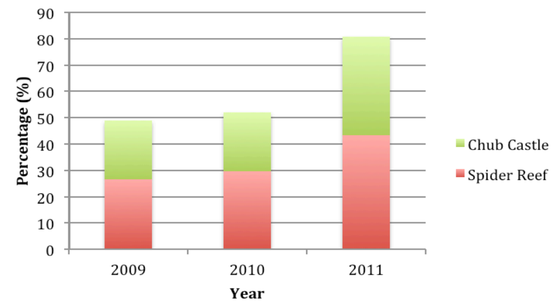

Figure 8: Partial mortality as a percentage of relocated colonies identified.

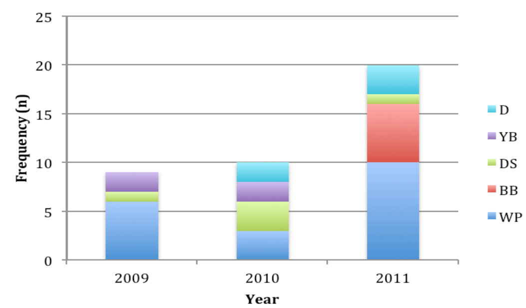

Figure 9: Occurrence of coral disease post relocation.

harvesting sites were also variable; two source sites were very turbid (no visibility), due to the riverine input of the Martha Brae. Consequently, changes in turbidity (light attenuation) led to changes in the clade and density of zooxanthellae and thus changes in pigmentation and the initial assessments (2009) would reflect this.

The subsequent decline in health (2011) could be attributed to the onset of dredging and thus increased sedimentation; turbidity ranged from 2 NTU to 44 NTU and TSS ranged from <1 mg/l to 27 mg/l (TEMN Ltd., 2011) across the study area throughout the duration of dredging and monitoring. Sedimentation is linked to changes in algal cover and type, as well as to the incidence of partial mortality (Nugues and Roberts, 2003), disease (Voss and Richardson, 2006), and general decline in coral health, growth, reproduction and so on (Rogers, 1977).

The independent monitoring exercise conducted by TEMN Ltd. (2011) indicated that at both relocation and reference sites no significant change in coral or macroalgal cover was observed between July 2010 and February 2011.

Building With Nature (BWN)

Worldwide, benthic relocations and mangrove restorations have become common mitigating measures required by governance bodies. However, large-scale relocations, as demonstrated in Falmouth, Jamaica, are logistically and financially complex and may have an uncertain survival success.

Dredging contractors, stimulated by the tightening of environmental requirements and the growing awareness of the role of these ecosystems, are presently developing innovative approaches, like the Building with Nature programme utilized in Falmouth, Jamaica. The aim is to adopt the ecosystem as a starting point to design alternative work methods and mitigation measures that are effective and efficient and reduce project risks, thus fostering greater levels of sustainable development. This includes the increasing collaboration among governments, dredging contractors and scientists, who together have the capability and authority to monitor and adjust work methods to suit the dynamic external influences.

Conclusion

The coral relocation programme executed during the development of the Falmouth Cruise Ship Terminal is potentially the largest coral relocation project known to date. In eight months, a team of 93 people successfully relocated 147,947 organisms. Based on colonies monitored, 86% of these colonies still remained attached eighteen months later, and only 4% died. Although relative health increased within six months of relocation (2010), partial colony mortality, disease and algal overgrowth increased with each sampling event. By 2011 (nineteen months after the start of the project), relative health returned to 2009 levels, with cases of total colony mortality observed, as well as new incidences of disease. This success rate may be linked to the lack of selection pressure, as due to the permit specifications, colonies were transplanted with > 50% partial mortality, active disease, and evidence of bleaching, all of which limit the long-term viability of colonies. The success rate may also be linked to the lack of permanent tags and the inability to identify and match colonies due to changes in appearance. Although, no reference site or colonies were monitored in this survey, the independent monitoring report, including both reference and relocated colonies, reported no significant change in coral or algal cover at reference and relocation sites assessed.

This relocation was conducted in an effort to adapt the 'Building with Nature' principles initiated by the Dutch dredging companies, and as Yap (2004) indicates a single year is sufficient to evaluate the success of a coral relocation. It is indeed significant that two entirely different monitoring agents have arrived at the same conclusion.

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