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CORAL RELOCATION: A MITIGATION TOOL FOR DREDGING AND RECLAMATION WORKS AT THE CRUISE SHIP TERMINAL IN JAMAICA

ABSTRACT

To develop the Falmouth Cruise Ship Terminal in Trelawny, Jamaica, Boskalis Westminster St. Lucia Ltd. executed the dredging and reclamation works required. A large-scale environmental mitigation plan was conducted to preserve benthic marine resources and the magnitude of this project has made it potentially the largest coral relocation exercise in the world to date. Maritime and Transport Services Limited (MTS) executed this relocation project, which started in August 2009, and by April 2010, 147,947 items (8,975 soft coral; 137,789 hard coral and 1,183 sponges) were successfully relocated. An additional 2,807 sea urchins, mainly *Diadema* were relocated from the dredging area, as well as numerous sea cucumbers, hermit crabs, conchs, sea stars and lobsters.

To determine the biological success of the relocation exercise, time series photographs of 400 colonies were taken on three occasions: October 2009, April 2010 and April/May 2011. In April 2010, partial colony mortality and algal overgrowth were observed but no total colony mortality was found. In April 2011, cases of total colony mortality were observed, as well as new incidences of disease, but preliminary results indicate that

86% of the colonies relocated in 2009 were accounted for in 2011 and only 4% of the monitored colonies showed total colony mortality.

The authors wish to acknowledge the contributions of Peter Wilson Kelly and Timothy Burbury, both of Maritime and Transport Services Limited. The article was first published at the Proceedings of the 12th International Coral Reef Symposium (ICRS), Cairns, Australia, July 2012. It is published here with permission in an adapted version.

INTRODUCTION

In 2009, the Port Authority of Jamaica (PAJ) and Royal Caribbean Cruiselines (RCCL) received Permits and Beach licenses from the National Environment and Planning Agency (NEPA) for the development of a cruise ship terminal at the historical town of Falmouth in

Above: The newly expanded Falmouth Cruise Ship Terminal in Trelawny, Jamaica. To realise the dredging and reclamation works required for this port development project, a large-scale environmental mitigation plan was implemented, making it potentially the largest coral relocation exercise in the world to date.

Trelawny. The project was awarded to E. Pihl & Son A.S. (main contractor) and to Boskalis as a subcontractor for the marine works.

The intended marine works consisted of dredging an access channel to -12.5 m CD through an offshore reef system and two berthing pockets alongside the terminal to a depth of -11.5m CD (northwestern side) and -10.5 m CD (southeastern side) and land reclamation along the existing shoreline to improve berthing facilities. The Cruise Ship Terminal in Falmouth was designed to host the largest cruise ships in the world, "Oasis of the Seas" and the "Allure of the Seas" (Figure 1).

The Environmental Impact Assessment (EIA) conducted in 2007 indicated that there were seafloor-dwelling marine resources within the footprint of the proposed structure (TEMN and Mott McDonald 2007) (colored patches in Figure 2) and sensitive ecological features in the vicinity of the project location (mangroves and bioluminescent phytoplankton). However, initial surveys showed that the entire northern section of the dredge footprint was also colonised by corals.

Therefore, specific conditions of the permits and licenses spoke to the need for the development of mitigation plans for the

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



sensitive benthos, mangroves and the luminous lagoon that would be impacted by the construction and dredging works to be conducted. The sensitive benthos included mobile organisms (urchins, cucumbers and starfish) and sessile organisms (sea grass, sponges, hard and soft coral). Impacts included the loss of habitat and biodiversity, loss of coral cover, loss of fish habitat, loss of seagrass beds, loss of bioluminescent phytoplankton, turbidity and sediment dispersal.

ENVIRONMENTAL MANAGEMENT PLAN

Boskalis developed an Environmental Management Plan (EMP) to mitigate and monitor environmental impacts as a result of dredging and reclamation activities. The EMP consisted of:

- Water quality monitoring; parameters to be monitored were turbidity, dissolved oxygen and water temperature;
- Installation of silt screens;
- Relocation of benthic flora and fauna;
- Installation of a submerged pipeline for sediment laden excess water;
- Installation of reef havens and reef towers.

The magnitude of the coral relocation during this project is potentially the largest recorded

coral relocation exercise in the world to date. This article describes the applied work method and the results of the relocation.

RELOCATION

Maritime and Transport Services Limited (MTS) developed a large-scale benthic relocation (hard and soft corals, gorgonians, starfish, lobsters, sea cucumbers and other marine life) programme including an initial survey, gridding and tagging activities, as well as relocation activities. The survival (relative health and attachment status) of a subset of coral colonies was monitored over an eighteen-month period and an independent assessment of coral cover and general benthic health (in relation to reference sites) was also conducted.

Site description

The entire Jamaican coastline is fringed by an extensive reef which drops to roughly 1,000 m off the Falmouth coastline. The Falmouth Harbour can be described as a shallow, natural harbour with a depth of 1 m (by the Old Wharf) to a maximum of 12 m (in the shipping access channel).

The Oyster Bay (located east of the Falmouth Harbour) can be described as very shallow owing to the continuous influx of river sediments. Globally this is well known as the Glistening Waters (bioluminescent bay); one of only four of its kind in the world, it is considered a sensitive ecosystem (Seliger and McElroy 1968). Its bioluminescence is caused by the densities of *Pyrodinium bahamense*



Figure 2. Layout of the Falmouth Cruise Ship Terminal, Jamaica and aerial view of the dredge site.





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studied Zoology at the University of the West Indies continued with a MPhil in Scleractinian Coral disease and since then has been studying coral disease and reef organisms. She has undertaken marine assessments and benthic relocations for an assortment of environmental companies like Maritime and Transport Services (MTS), including that of the Falmouth Cruise Ship Terminal, which involved potentially the largest relocation globally to date.

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. The worksite is bounded to the west and south by the town of Falmouth and the mangrove system of the



Figure 3. Work in progress at the Falmouth Cruise Terminal. Grab Dredger Packman was responsible for removing the soft dredged material during the first phase.

Martha Brae estuary. The impact assessment showed the presence of corals on the slopes of the existing access channel and nearby reef flats at depths which varied from less than 5 m up to 12 m (shown as reaping areas in Figure 4).

Some 112 animal species were identified on the reef in the footprint of the dredge area including 22 scleractinian corals, 29 algae, 8 sponges, 15 invertebrates and 45 fish species. Coral cover was as high as 30% in areas and *Diadema antillarum*, the keystone invertebrate herbivore (Lessios, *et al.*, 2001), had densities of 8–13 individuals per m² (TEMN Ltd., 2007). The NEPA permit required the harvesting of all hard and soft corals with a colony diameter of 5 cm or larger from the dredge footprint and

subsequent transporting of these colonies to nearby reception sites located between 500 m and 1,500 m from the donor area.

Work area delineation

The work area (footprint of or area to be dredged and the relocation sites) was defined by an extensive, continuous 10 x 10 m grid system. Using a compass and basic geometry, parallel north-south lines were fixed to the substrate, using rebar 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, both in theory and on the ground, in order to facilitate underwater navigation and reporting.

Owing to time constraints dredging (Figure 3) and relocation activities had to take place simultaneously. Consequently, the dredging and relocation activities were carefully planned. There were four gridded reaping areas within the dredge footprint (Figure 4) comprising 1,107 grids (over 11 hectares). Corals were relocated to areas with features identical to their originals. Aspects that were taken into account here were:

- Water depth and movement
- Angle (slope or reef flat)
- Location (exposed or sheltered)

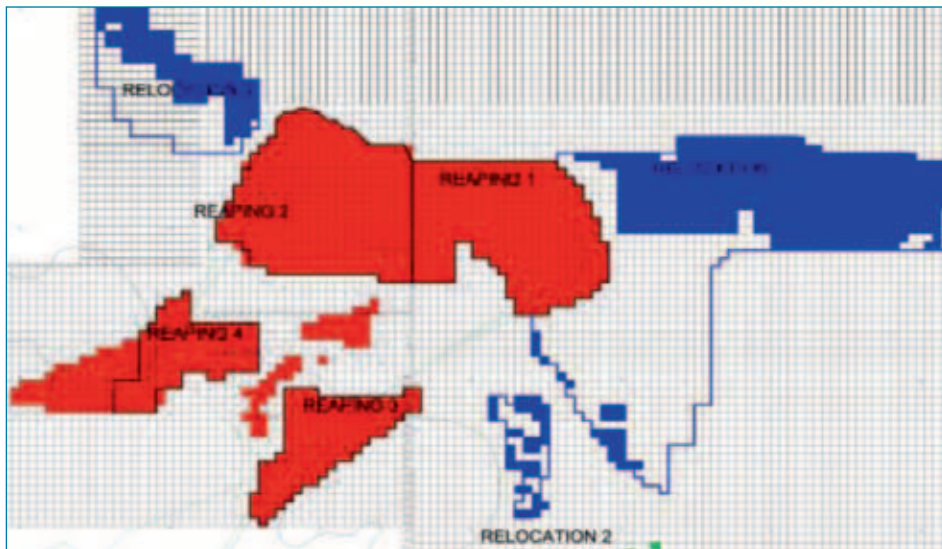


Figure 4. Layout of coral relocation programme with reaping areas in red (the access channel) and receiving area in blue.

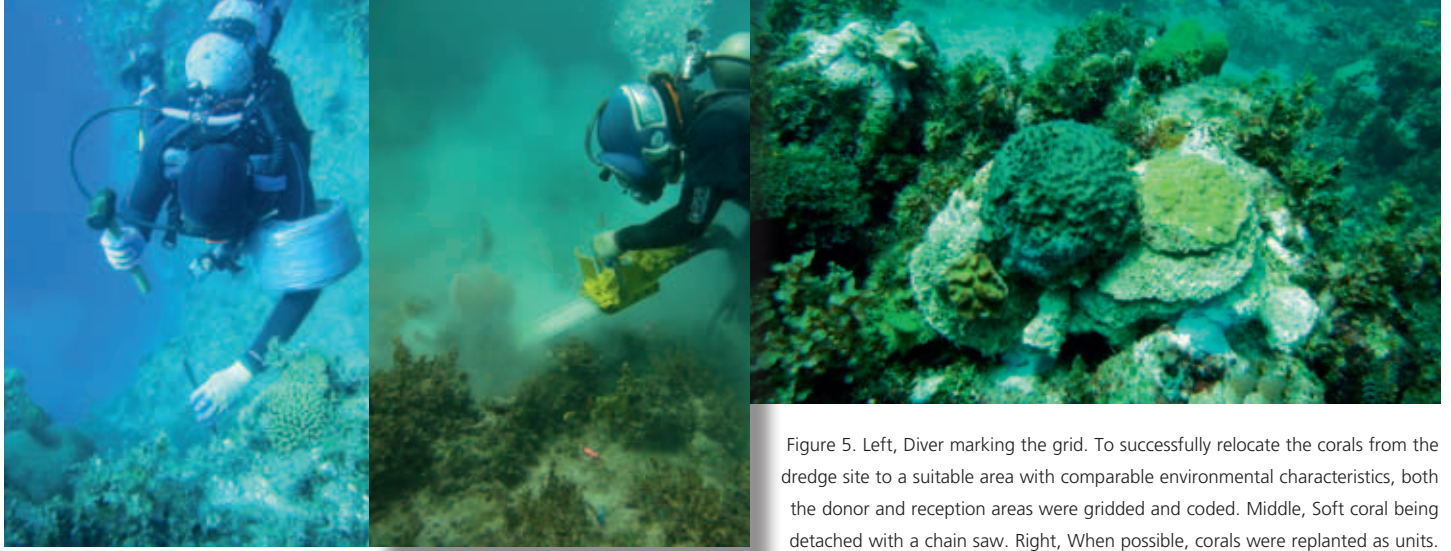


Figure 5. Left, Diver marking the grid. To successfully relocate the corals from the dredge site to a suitable area with comparable environmental characteristics, both the donor and reception areas were gridded and coded. Middle, Soft coral being detached with a chain saw. Right, When possible, corals were replanted as units.

Coral relocation

Divers, using both surface supply and scuba, were organised into four teams; harvesting, transporting, reattaching and monitoring. A topside support team was responsible for filling scuba tanks, and providing food, epoxy, cement and so on.

Harvesting

A reaping team responsible for the careful detachment of corals using hydraulic chain saws, disc saws, chipping hammers and wire brushes and the placement of the corals in transportation baskets (Figure 5).

NEPA specified that all hard and soft corals, with a colony diameter of 5 cm or larger, be harvested and transported to nearby reception sites (between 500 m and 1,500 m away). Colonies were detached with a 10-inch buffer using hydraulic chain saws and disc saws and eventually at the point of attachment (using impact tools like hammers and chisels or pry bars) to reduce fragmentation and facilitate

handling. Where possible, colonies were detached in units (more than one colony or organism) to maintain community structure at a micro level.

Transport

The transport team was responsible for the transport of corals from the reaping area to the planting area. They packed the detached colonies in single layers and floated them sub-surface in mesh baskets using lift bags. These baskets were then towed from the harvesting area to the reattachment areas.

Reattachment

The planting team was responsible for the attachment of corals using epoxy or cement and in some cases, pins as well as pneumatic drills and compressors. Chipping hammers and wire brushes were first used to clean and prepare the substrate and the base of the colony; then epoxy or specialised cement, and in some cases, pins, pneumatic drills and compressors were used as bonding agents.

The specialised epoxy used could be kneaded underwater and the cement was premixed on deck and portioned into plastic bags, both were lowered to the divers on demand.

NEPA specified that colonies should be placed 0.5 m 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 reattached colonies were stable.

Monitoring

The environmental team was responsible for data collection, gridding and tagging, addressing scientific issues as they presented themselves and assisting the three teams when necessary. A colony/organism count of harvesting area 1 (29% of the gridded area) was conducted 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, like 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. The monitoring team also verified whether grids were "cleared" by the reaping team or fully "planted" by the planting team.

In order to determine the biological success of the relocation exercise, a sample of colonies (15 grids) were 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. On 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

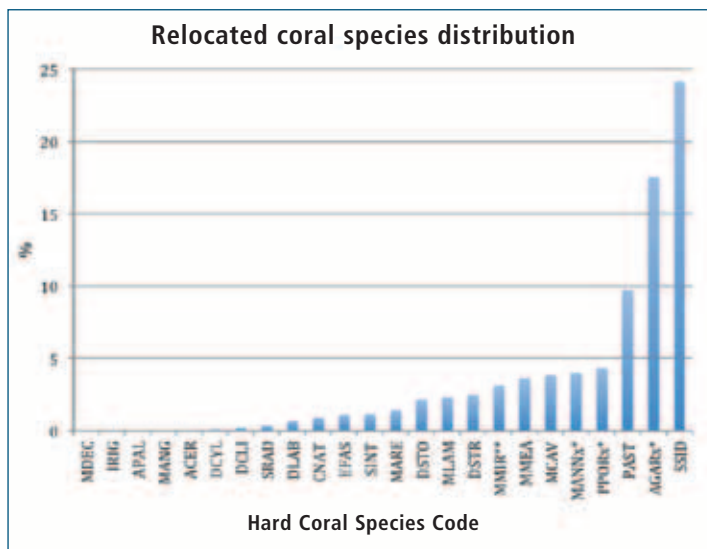


Figure 6. Distribution of coral species relocated in Falmouth, Jamaica. CARICOMP based species codes: *more than one species of same genus and similar growth form recorded as one; ** extensive branching growth form thus underrepresented in counts.



Figure 7. Left, A close up of a hard coral colony in a basket ready for transfer. Coral was transferred by being loaded into hanging baskets and then walked by divers to the designated reattachment area (middle) or towed by a boat when weather conditions allowed it. Right, Lowered basket being ready for planting.

end of the project (2010), and a year later (2011), eighteen months in total. The independent agency (TEMN) also monitored activities, before, during and after the relocation exercise.

RESULTS AND DISCUSSION

In eight months, a team of 93 people successfully relocated 147,947 organisms, including; 8,975 soft coral; 137,789 hard coral; 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.*, 10% *Porites astreoides* (Figure 6).

It was mandatory that all colonies, whether diseased, bleached, exhibiting partial mortality, branching or foliose were relocated and colony size ranged in diameter from 5 cm to >1 m.

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, some had to be walked or floated individually from harvesting site to planting site (Figure 7).

Monitoring

A representative sample size of 398 organisms was determined using Yamane’s sample size

formula (Yamane, 1967). Consequently 11 grids (containing 400 colonies – both hard and soft coral) of the 15 grids photographed at time zero (October 2009), were photographed upon completion of the project (April 2010 - 7 months) and a year later (April/ May 2011 - 18 months).

Five of these grids (158 colonies) were in an area called Spider Reef, a shallow (<10 ft.), reef flat west of the dredge and fill footprint; 7 grids (257 colonies) in an area called Chub Castle, north-west of the main dredge and fill footprint in deeper water (<50 ft.). These grids were chosen because they used both epoxy and cement to fix colonies, would have been exposed to the elements for longest, were planted by the divers before they became

experienced and would be differentially affected by sedimentation from the dredge activity owing to location. Colonies were not permanently tagged, instead they were tracked by photograph and the location of grids was mapped using “landmarks”.

The photographs were catalogued based on the area, grid and colony, i.e the first colony in grid 1 was called 1A and that of grid 2 called 2A and so on. In April 2010, of the photographs taken, 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 (Figure 8). The 14% of colonies not identified could be because of detachment or changes in morphology. Coral

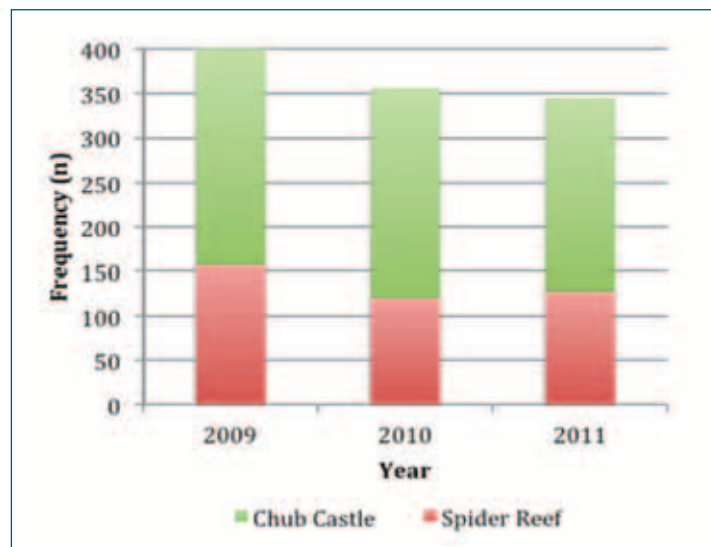


Figure 8. Number of relocated colonies identified per year.

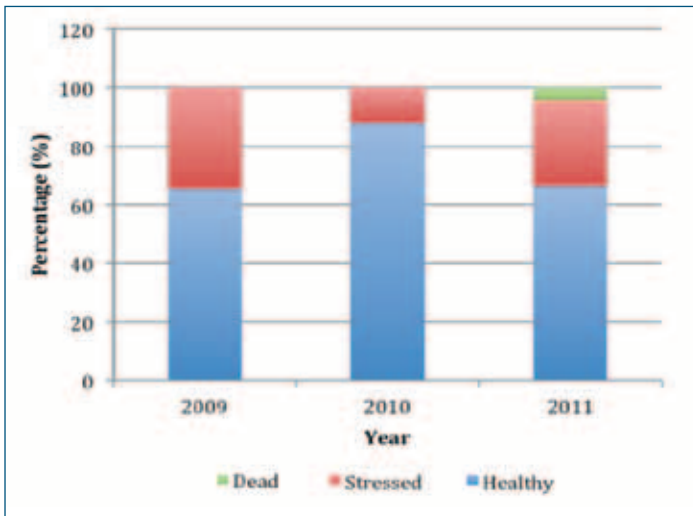


Figure 9. Relative health of relocated colonies.

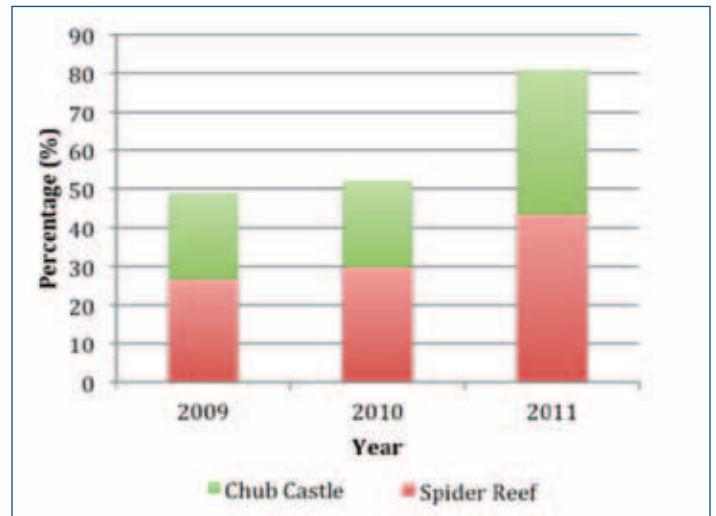


Figure 10. Partial mortality as a percentage of relocated colonies identified.

colonies did not have permanent tags and sometimes colonies could not be recognised as a result of changes in appearance and attachment marks being overgrown.

The greatest difference was observed at Spider Reef in 2010. Spider Reef, the first shallow location planted, was discontinued because of severe wave action during storms. Some 39 colonies, both relocated and native colonies, were detached following a “north-wester” storm event and were relocated.

Initially the relocated colonies are easily differentiated owing to the removal of macro algae, the visible epoxy or cement used to fix colonies and the flagged nail marking the location. Over time, however, natural

processes made this more difficult: Macro algae overgrew nails and colonies, while disease, bleaching and thus partial mortality changed the appearance. Consequently, some photographs were identified as relocated but could not be matched to a particular colony photographed in 2009.

Relative health

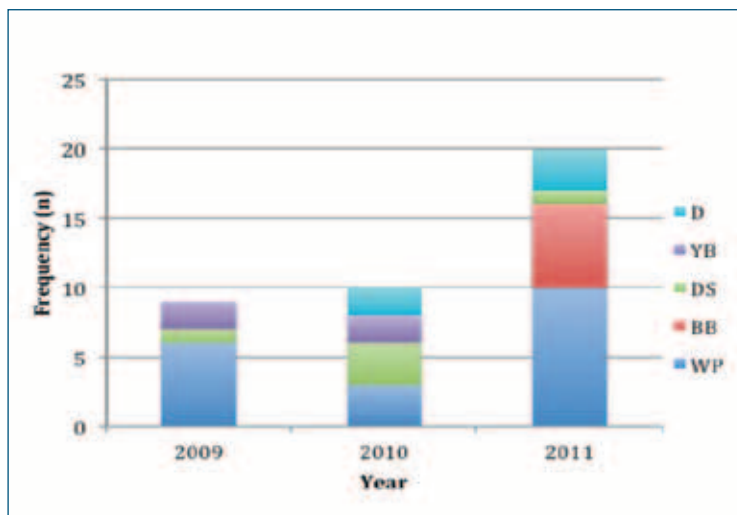
The relative health of the relocated colonies was also assessed. Colonies were classified as healthy (no obvious signs of ill-health – hyperpigmentation, hypopigmentation, new partial mortality), stressed (diseased, bleached, exhibiting partial mortality) or dead. Health increased in 2010 from 66% to 88%, but decreased in 2011 to 67% back to original levels (Figure 9).

The percentage of partial mortality and the occurrence of disease 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 (Figure 10). 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 (WP) was by far the most dominant in all sample. Black band (BB) was only observed during the 2011 sampling event, where it was the second most dominant disease (Figure 11). Note that only the occurrence of diseased colonies was noted, consequently, colonies which were previously diseased, but now dead were not counted. 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 from which the colonies came were also variable; two source sites were very turbid (no visibility), because of 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 initial assessments (2009) would reflect this.

Figure 11. Occurrence of coral disease post-relocation.



D = dormant diseases
 YB = yellow band
 DS = dark spot
 BB = black band
 WP = white plague



Figure 12. Aerial view of the coral reefs, red mangrove and the luminous lagoon which are located in close vicinity of the project footprint at Falmouth, Jamaica. In the background the luminous lagoon and the Martha Brae River mouth.

The subsequent decline in health (2011) could possibly be attributed to seasonal outbreaks of diseases (colonies which contained diseases were relocated), which could have spread to other colonies, increased sedimentation as a result of started dredging activities or temporal increased sedimentation deriving from the Martha Brae River and land use in the upper watershed. Even though relative health, partial mortality and occurrence of coral disease has increased during the 18 months of monitoring, only 4% of the relocated colonies identified was observed dead (Figure 9). 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.

As Yap (2004) indicates: One year is sufficient to evaluate the success of a coral relocation and two distinct monitoring agents have reached the same conclusion. This confirms that the relocation has been successful and resulted in the survival of thousands of corals where as in the past these were usually sacrificed for coastal development (Figure 12).

BUILDING WITH NATURE

Sensitive ecosystems such as coral reefs, seagrass meadows and mangroves are being affected worldwide by the effects of large-scale processes like climate change. However, small-scale man-induced activities such as dredging can also have a serious impact. For this reason, dredging projects in sensitive environments usually come with severe environmental constraints, even though the underlying relationships between dredging impacts and ecosystem responses are only poorly understood.

Dredging is often a pre-requisite for sustainable development of coastal safety against flooding, marine and inland infrastructure and land reclamation.

Historically, the role of dredging contractors in these projects concerning the protection of sensitive ecosystems can be characterized as "passive". Dredging contractors traditionally used to comply with these constraints and their role was focussed solely on carrying out appointed mitigation or compensation measures covering project impacts.

Understanding of the relation between dredging and ecosystem health was somewhat limited. The latter often resulted from the lack of available tools and knowledge to predict the behaviour of sensitive ecosystems as a function of dredging operations. However, stimulated by the tightening of environmental requirements and a growing awareness of the role of coral reefs, seagrasses and mangroves in biodiversity, the contractor's perspective towards dredging near sensitive receptor sites has changed and they presently develop innovative approaches, which adopt the ecosystem as a starting point for the design and realisation of marine infrastructure projects.

The aim is to develop alternative work methods and mitigation measures that are effective, efficient, allow projects to be carried out in a responsible manner and reduce project risks. This perspective is illustrated by the strong collaboration between ecologists, biologists and Boskalis during the development of the Falmouth Cruise Ship terminal.

Worldwide, coral relocation, seagrass relocation and mangrove restoration have become a more common mitigating measure proposed or required by governance bodies. Large-scale relocations as demonstrated in the Jamaican project are logistically and financially complex and may have an uncertain survival success. Thorough understanding of the ecology and physical parameters of both the donor and the receiving reef is essential if corals are to be properly relocated and kept alive. Additionally there are many risks which can hardly be controlled such as the weather, ship groundings, and diseases. Direct cooperation with recognised coral scientists, capable of monitoring and adjusting the work method as required are therefore essential aspects of a relocation programme.

The new approach allows all “stakeholders”, including the natural eco-system, to benefit and aims to eventually develop a complete ecosystem-based approach where the ecosystem has shifted from being a side issue to becoming the focal point of a project. Coral relocation is already a step in this direction, but the focus is still on mitigation as the coral reef system has still not been placed at the centre of the design. Clearly more time will be required to collect all the necessary data on the functioning of the ecosystems before work can begin with a fully ecosystem-based design. This comprehensive approach will require several key elements:

- A thorough understanding of the resilience of key species to dredging-related impacts;
- Inventory of information on size and nature of dredging impact;
- Validated tool to translate the impact of the dredging works on the key species and ecosystem as a whole.

The research and innovation programme “Building With Nature” of the EcoShape Foundation (www.ecoshape.nl) focusses on this approach by developing adaptive monitoring strategies that link impact measurements near sensitive habitats directly to dredging operations and aims to create useful tools to design dredging projects in a more sustainable way. The further development of the Building With Nature approach will contribute to the sustainable realisation of marine infrastructures near sensitive areas in the near future.

CONCLUSIONS

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 remained attached eighteen months later, and only 4% died. Although relative health increased within 6 months of relocation (2010), partial colony mortality, disease and algal overgrowth increased with each sampling event and by 2011 (eighteen months) 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 in compliance with governance requirements, colonies were transplanted with > 50% partial mortality, active disease, and evidence of bleaching, all of which limit the long-term viability of colonies. It may also be linked to lack of permanent identification tags and thus the inability to identify and match colonies resulting from changes in appearance.

Although, no reference site or colonies were monitored in this survey, the independent monitoring report, which included both reference and relocated colonies, reported no significant change in coral or algal cover at reference and relocation sites assessed.

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