Session 42 B

# Propagation and active reef restoration – distribution, transplantation, monitoring and evaluation of restoration activities

**Session chairs**:

Anastazia T. Banaszak, banaszak@cmarl.unam.mx

Hajime Kayanne, kayanne@eps.s.u-tokyo.ac.jp

Peter Harrison, peter.harrison@scu.edu.au

Kaho Tisthammer, kahot@hawaii.edu

Dirk Petersen, d.petersen@secore.org

Makoto Omori, makomori@sk2.so-net.ne.jp

Andrew Heyward, a.heyward@aims.gov.au

Lauren Wetzell, lauren.wetzell@noaa.gov

Scott Countryman, scott@ree.ph

Zac Forsman, zac@hawaii.edu

# Monitoring and evaluation of coral transplantation to mitigate the impact of dredging works

**Remment ter Hofstede, Christine Finney, Andre Miller, Mark van Koningsveld, Tijmen Smolders**

**Abstract** To protect marine life from direct impact by dredging works for creating a port access channel in Coral Harbour, New Providence, Bahamas, over 1500 viable hard coral colonies and a broad range of associated invertebrates were relocated to recipients sites outside of the demarcated impact zone. Large coral boulders were transported on deck of a multipurpose vessel, smaller coral colonies and associated benthic invertebrates were relocated submerged in purpose-designed buoyant cages. Quantitative monitoring of survival, health condition, and size of all transplanted coral colonies was executed to allow for the evaluation of the success of the transplantation effort. One year after relocation the survival rate of the transplanted coral colonies was 91%, and 82% of these corals were without visible ailments. These numbers demonstrate that the transplantation operation has been an effective mitigation measure to reduce the ecological impact of the Coral Harbour's dredging project. The applied strategy for transplantation of small and large coral colonies may be recommended for future application to preserve corals that are threatened by permanent destruction, as well as in the establishment of thriving reef communities on new-build constructions like breakwaters and artificial reefs.

**Keywords:** mitigation, transplantation, relocation, monitoring, dredging

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Remment ter Hofstede, Mark van Koningsveld, Tijmen Smolders
Van Oord DMC, Schaardijk 211, 3063 NH Rotterdam, The Netherlands

Christine Finney, Andre Miller
Carib Marine Contracting & Research, Penrith, 11 Ave Belleville, St Michael, Barbados W.I.

Mark van Koningsveld
TU Delft, P.O. Box 5, 2600 AA Delft, The Netherlands

**Communicating author:** Remment ter Hofstede, remment.terhofstede@vanoord.com

## Introduction

Coral reef ecosystems have displayed globally a long-term degradation due to anthropogenic disturbances (Pandolfi et al. 2003; Bellwood et al. 2004), generally resulting in a loss of key ecosystem services such as fisheries productivity, coastal protection, and revenues from tourism (Salvat 1992; Hoegh-Guldberg et al. 2007). Human welfare depends on these services (Moberg and

Folke 1999) and substantial management measures are required to sustain en repair reef ecosystems to safeguard them for societal development and future generations (Pandolfi et al. 2003; Hughes et al. 2005).

The transplantation of corals has since the 1970s globally become a recognised measure to preserve, enhance and create coral reefs in degraded areas (Maragos 1974). Several types of source material have been applied for transplantation (Rinkevich 2005), including small or large whole coral colonies (e.g. Clark and Edwards 1995; Ortiz-Prosper et al. 2001), coral branches or fragments (e.g. Lindahl 2003; Soong and Chen 2003), nubbins (e.g. van Treeck and Schuhmacher 1997; Shafir et al. 2001), or sexually produced material by collecting and rearing larvae or gametes from reproductively mature colonies (e.g. Rinkevich 1995; Petersen and Tollrian 2001; Chamberland et al. 2015). Coral transplantation is commonly used in reef rehabilitation efforts, to re-establish coral cover on degraded reefs (Guest et al. 2014). When coral colonies are threatened from large infrastructural development projects such as port construction and expansion, or dredging and reclamation operations, the main incentive for transplantation is not rehabilitation, but the preservation of the whole coral colonies from permanent destruction. In Coral Harbour, New Providence, Bahamas, dredging works for creating a port access channel was anticipated to cause environmental impact on several patches of coral reef, in general primarily by destruction or exposure to increased turbidity and sedimentation (Erftemeijer et al. 2012). Contractual requirements prescribed the relocation of hard corals out of the direct zone of impact to unharmed areas. As a mitigation measure, transplantation of the viable coral colonies within the footprint of the channel was undertaken, to save them from destruction by caused the dredging activities. In addition, a variety of invertebrates were moved out of the zone of impact as these animals play a vital role in the healthiness of coral ecosystems (e.g. Bak 1994; Schneider et al. 2012), including octocorals, sponges, sea anemones, and echinoderms. A quantitative monitoring programme was executed to allow for the evaluation of the effectiveness of the coral transplantation effort. This so-called Coral Harbour Coral Transplantation Project represents one of the larger conservational mitigation projects in the region.

## Materials and methods

### Donor sites

A survey was conducted prior to dredging activities, indicating five thriving patch coral reefs and about 30 isolated coral mounds within the footprint of the new channel and the zone of direct

impact (Fig. 1). All hard coral colonies present within the footprint of the works of sizes > 10 cm (diameter) and in a fully healthy condition (i.e. without visible ailments) were contractually

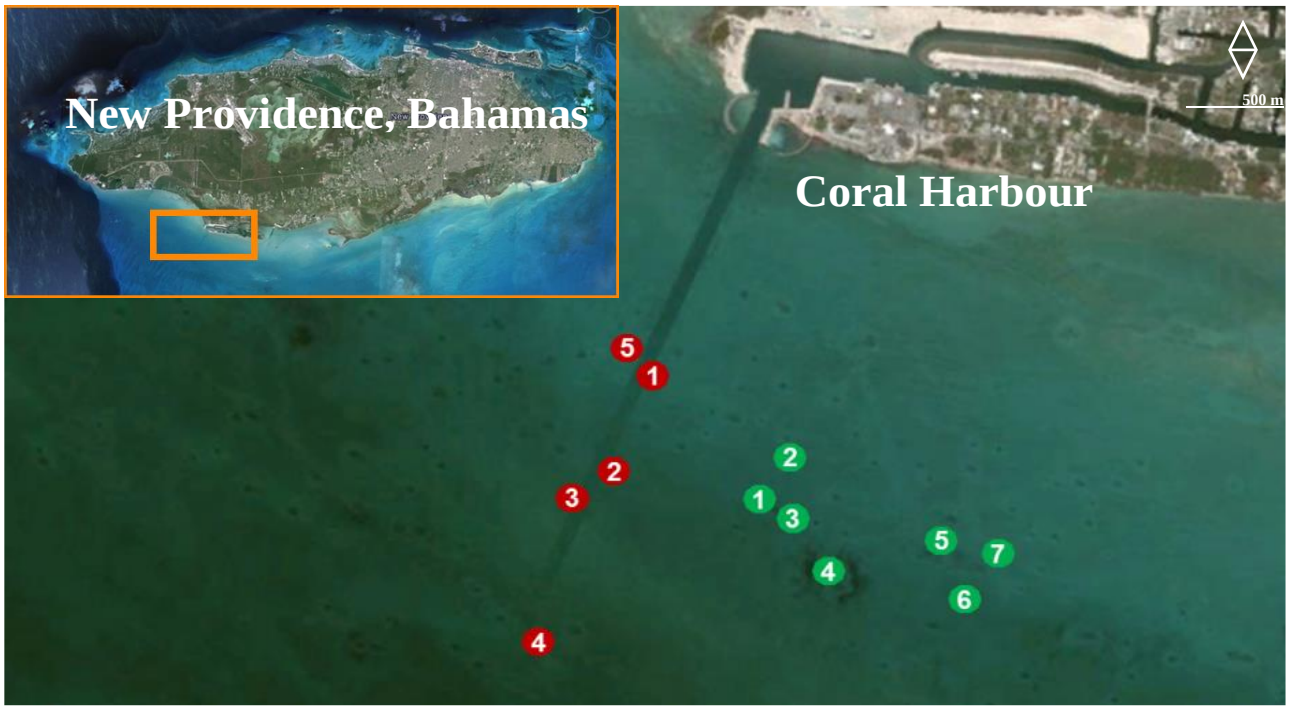


**Fig. 1** Satellite image of the project area, showing the new channel to Coral Harbour after dredging, the five coral donor sites (in red) and the 7 coral recipient sites (in green). Image from Google Earth (d.d. 22/07/2015)

required to be transplanted. A total of 1523 hard corals were selected for transplantation, comprising ten different species. Dominant species were *Porites astreoides* (60%), *Orbicella* spp. (22%) and *Diploria labyrinthiformis* (9%). Sizes of the transplanted coral colonies ranged between 5 and 61 cm, measured as the maximum diameter of the coral colony on a horizontal plane. In addition, hundreds of invertebrates were moved out of the zone of impact, including sponges, octocorals, sea anemones, sea cucumbers, long spine and rock boring sea urchins, molluscs, sea stars, and brittle stars.

**Selection of recipient sites**

Critical to successful coral transplantation is to select a recipient site with similar environmental conditions as the donor site and that it can support a viable coral community (Edwards and Gomez 2007). There is inevitably a paradox in the selection of the recipient sites, as it needs to provide conditions under which coral transplants will thrive, yet it must be an area that is not already so densely populated that there remains insufficient substrate for new growth and re-attachment. More

specifically, recipient sites should have good light conditions and water quality which are comparable to the donor site, i.e. a minimum of nutrients, sediments, and sewage, and similar temperature, depth and currents (Edwards and Gomez 2007). Furthermore, recipient sites should preferably have barren and stable reef rock areas or artificial structures that lack excessive algal growth in order to reattach the corals, although corals could also be placed directly onto sand if the colony is large enough to survive potential smothering from the movement of itself or the sand.

Also, it has been shown that survivorship of coral transplants increases when they are relocated to reef areas with some degree of pre-existing healthy coral cover, and which are protected from anthropogenic pressures such as recreational activities and fisheries (Edwards 2010). Based on all these conditions, seven locations were selected to serve as recipient sites for the relocation of the coral colonies that would face impact due to the dredging operations near Coral Harbour. All seven recipient sites were isolated elongated reefs parallel to the shore surrounded by flat sandy bottom. Depth ranged from 4.0 m CD (Chart Datum to mean lower low water) (edge) to 0.5 m CD (crest). A total of 24 benthic monitoring 10-m long transects were conducted on the reefs following AGGRA protocols version 5.4 (Atlantic and Gulf Rapid Reef Assessment; Lang 2003), with a minimum of three transects per reef (one 3 m from the western edge, one in the centre, and one 3 m from the eastern edge). Transects were set into a northern direction (towards shore), starting at the edge of the reef. The general reef composition of the recipient sites based on the AGRRA benthic surveys is provided in Table 1.

**Table 1** Reef composition of recipient sites (RS) in percentages (mean ± SD), based on AGRRA benthic surveys

| **Category** | **RS1** n=1 | **RS2** n=3 | **RS3** n=3 | **RS4** n=3 | **RS5** n=4 | **RS6** n=3 | **RS7** n=3 | **mean** |
|---|---|---|---|---|---|---|---|---|
| **hard corals** | 27.2 | 17.0±12.7 | 24.8±5.7 | 32.8±16.7 | 12.4±5.6 | 29.0±14.8 | 24.3±19.7 | **23.2±14.2** |
| **soft corals** | 0 | 0 | 0 | 3.3±5.8 | 4.1±5.9 | 0.2±0.3 | 0.1±0.2 | **1.2±3.3** |
| **Sponges** *(x = no records)* | x | x | x | 6.7±3.5 | 12.0±2.2 | 13.5±3.0 | 11.5±5.2 | **11.1±4.3** |
| **crustose coralline algae** | 7.2 | 5.3±2.6 | 11.2±5.9 | 14.7±3.0 | 7.4±4.2 | 11.8±6.4 | 8.7±7.1 | **9.5±5.5** |
| **macroalgae** | 11.1 | 3.7±2.5 | 11.8±4.3 | 9.2±5.8 | 2.6±1.3 | 4.3±5.3 | 1.8±2.4 | **5.2±4.9** |
| **sand** | 11.1 | 7.5±12.6 | 8.2±7.4 | 3.7±3.8 | 22.4±9.0 | 5.0±4.6 | 17.8±16.3 | **12.2±12.0** |
| **rock** | 16.7 | 4.0±1.3 | 0.3±0.3 | 1.7±1.5 | 2.3±1.7 | 0.3±0.6 | 3.8±3.9 | **2.9±3.9** |
| **other** *(mean based on RS4-RS7)* | 27.2 | 62.5±13.9 | 44.0±9.8 | 28.0±4.0 | 36.9±5.8 | 35.8±9.6 | 32.1±9.7 | **33.2±8.0** |

## Coral transplantation method

A team of biologists, assisting divers, and surface support executed the coral transplantation work during a period of 6 weeks in January-February 2015. Coral colonies were detached from the reef as

intact units by cutting with a hammer and chisel the coral at its base where it is attached to the substratum. If a particular coral began to display stress symptoms by secreting mucus during detachment, the process was delayed for several hours. Whenever possible, the colonies were removed as one unit with their associated biota such as anemones or sponges included, to preserve their microhabitat. Once detached from the reef, handling was minimised and the colonies were held by their rock base to avoid touching the live and delicate surfaces.

Large coral boulders were transported using a multipurpose vessel equipped with a crane. Corals were placed on deck for a short period and constantly soaked with seawater using deck hoses (Fig. 2). Smaller coral mounds and associated benthic invertebrates were placed in aluminium underwater cages of 3x3 $m^2$ with a mesh size of approximately 5 $cm^2$. Once filled, the square cages were made buoyant with lifting bags attached at the four corners of each cage, and towed while remaining submerged to the appropriate destination site (Fig. 2). During transportation, divers ensured that no corals were toppled or damaged.

**Fig. 2** Coral transplantation techniques used. Small colonies were relocated submerged using buoyant cages (left), and large boulders were brought on deck of a vessel and constantly soaked with seawater (right)

The transplanted coral colonies were affixed to the recipient reef substrate using cement adhesives at the same day of removal. No standardised recipe was used due to variability in the availability of material, weather conditions, and travel time from the preparation base on land to the recipient sites, but the consistency of the mixed cement balls was always perfected such to ensure fast re-attachment and to minimise spill. Clusters of transplants and individual colonies were marked by attaching numbered aluminium tags on barren sections next to the corals.

**Monitoring**

Monitoring was executed 2, 6 and 14 months after transplantation to assess whether the transplantation effort had been effective and is worth repeating in the future. All monitoring surveys entailed recording the detachment of the coral colonies and their health condition based upon the presence (in % surface cover) of signs of bleaching, non-specific tissue mortality, predation scars, and diseases. During the third survey 14 months post-transplantation, also the size of each individual colony was measured, i.e., length (longest side of the coral colony on a horizontal plane in cm), width (perpendicular to length at the colony's maximum width in cm), and height (from the base of the colony to the highest point in cm). Furthermore, scaled photos were taken of each transplanted colony during the third survey for future quantification of observable growth rates and health conditions.

## Results

In total, 1,523 hard corals were relocated from five primary donor reefs to seven recipient sites. Two months after transplantation, 44 hard coral colonies (3%) were identified as dead or with over 80% loss of live tissue, and ~30 colonies showed partial damage to the tissue (>50% of surface) due to bleaching, lesions, and predation scars. Six months after the transplantation effort, 6% of all the relocated coral colonies were dead or moribund, i.e., displayed significant polyp mortality and were not likely to survive.

Just over a year after transplantation, the assessment showed that at least 1,380 hard corals had survived (1385 observed of which 5 found dead), indicating a survival rate of 91%. Note that this is a conservative value, as it is likely that not all of the surviving individual colonies were traced back 14 months post-transplantation, due to e.g. missing marking tags or by being no longer recognized as a transplanted colony.

Of the traced relocated coral colonies, 82% were in a healthy condition without observable affliction. Coral tissue ailments observed in the other transplanted colonies were classified as coral bleaching (5.8 ± 3.9%; mean ± SD), predation scars (5.1 ± 3.9%), and non-specific tissue mortality (6.1 ± 2.2%) (see Table 2). There was no significant difference in affliction between the seven recipient sites (one-way ANOVA: bleaching $p = 0.9$; predation scars $p = 0.3$; tissue mortality $p = 0.6$). Differences in type of ailments were observed between species (Fig. 3): out of eight species, five showed signs of bleaching, six were affected by predation, and six displayed non-specific tissue mortality. *Montastraea cavernosa* colonies (n=18) were not affected at all, while *Porites porites* was heavily affected (n=28; 47%), in particular by predation, and so was *Orbicella* spp. (n=299;

30%) though mainly by bleaching. The grade of ailments also differed between type of ailment and species. If coral colonies were affected, the prevalence of non-specific tissue mortality was most severe, on average 29.1±27.6% of the surface (mean±SD), compared to bleaching (5.5±4.2%) and predation (8.9±8.1%) (Table 2). In particular *Dichocoenia stokesii* (43.8±25.0% of the surface; n=4) and *Porites astreoides* (30.1±29.4% of the surface; n=61) displayed severe tissue mortality.
A full growth assessment could not be executed as size measurements were only obtained in the third monitoring survey. However, observations of obvious tissue development over the recipient substrate of some coral colonies indicate growth estimates of ~0.5-1 cm for *Porites astreoides* (n=13) and ~0.5 cm for *Orbicella* spp. (n=3) 14 months after transplantation.

**Table 2** Prevalence of coral bleaching, tissue mortality, and predation scars observed by species 14 months after transplantation

| **Species** | **total colonies observed** | **size range (cm)** | **bleaching** | | | **non-specific tissue mortality** | | | **predation scars** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | **# coral ≤ 5% surface** | **# coral > 5% surface** | **mean % surface affected** | **# coral ≤ 5% surface** | **# coral > 5% surface** | **mean % surface affected** | **# coral ≤ 5% surface** | **# coral > 5% surface** | **mean % surface affected** |
| *Diploria labyrinthiformis* | 122 | 8-58 | 1 | | 2 | | | | | 1 | 10 |
| *Dichocoenia stokesii* | 45 | 5-21 | 2 | 1 | 5.7±4.0 | | 4 | 43.8±25.0 | 1 | | 5 |
| *Eusimilia fastigiata* | 1 | 9 | | | | | | | | | |
| *Favia fragum* | 1 | 5 | | | | | | | | | |
| *Montastraea cavernosa* | 21 | 12-47 | | | | | | | | | |
| *Orbicella* spp. | 299 | 5-58 | 54 | 11 | 5.4±3.5 | 4 | 8 | 17.5±16.9 | 12 | 2 | 5.3±2.3 |
| *Porites astreoides* | 833 | 7-61 | 16 | 3 | 5.9±6.3 | 18 | 43 | 30.1±29.4 | 32 | 24 | 10.0±9.1 |
| *Porites porites* | 28 | 7-47 | 2 | 1 | 6.7±2.9 | | 1 | 50 | 6 | 3 | 8.3±6.6 |
| *Pseudodiploria strigosa* | 18 | 10-34 | | | | | 1 | 30 | | | |
| *Siderastrea siderea* | 17 | 14-59 | | | | 1 | 1 | 27.5±31.8 | 1 | | 5 |
| **Total** | **1385** | **5-61** | **75** | **16** | **5.5±4.2** | **23** | **58** | **29.1±27.6** | **52** | **30** | **8.9±8.1** |

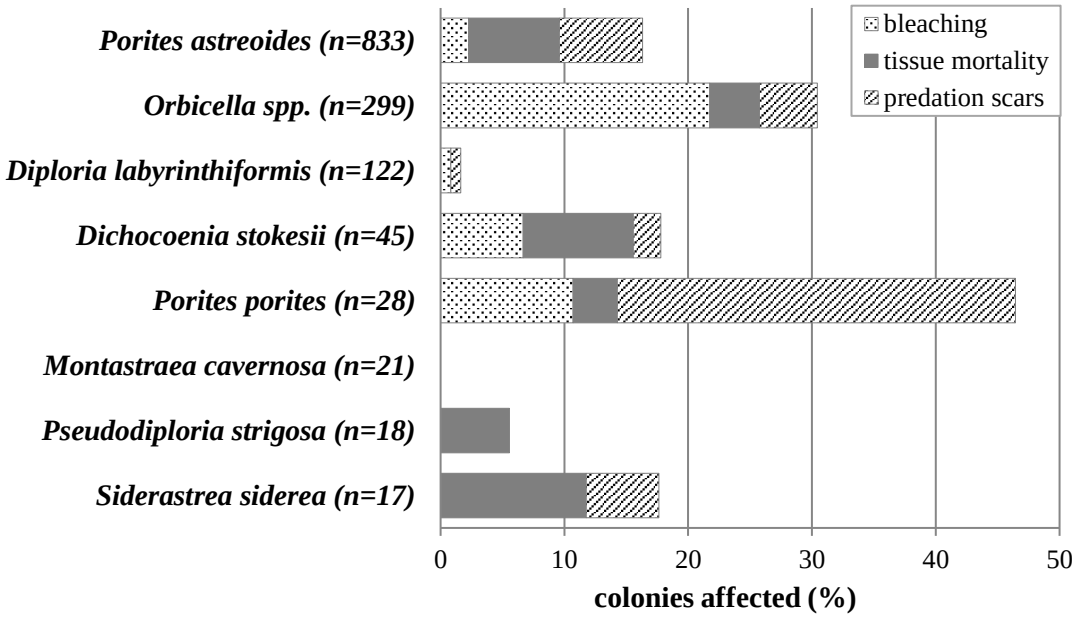


**Fig. 3** Observed ailments (bleaching, predation scars, non-specific tissue mortality) by species 14 months after transplantation

## Discussion

To reduce the environmental impact of infrastructural development projects, contractual requirements often include taking appropriate mitigation measures. Where coral ecosystems are threatened by marine works, one such measure is the relocation of coral colonies to recipient areas outside the direct zone of impact. As such a mitigation measure is part of the scope of a project, it is automatically limited by the boundaries of its - often short - duration. Accordingly, emphasis is generally put on the relocation effort itself, the primary objective, with little or no attention for careful monitoring and evaluation of the long term effectiveness of the measure to avoid fatal impact by marine construction activities. Occasionally, survival rates of hard corals after transplantation have been monitored, and with favourable results, e.g. in Qatar (99% survival of reattached monitored colonies after 1 year) (Kilbane et al. 2008), Yemen (91% after 1 year) (Seguin et al. 2008) and Jamaica (86% remained attached with 96% survival after 18 months) (Kenny et al. 2012). Due to low concern for monitoring and consequently financial constraints, conclusions on the survival rates are generally drawn from small subsamples (<5%) of the transplanted corals (Sequin et al. 2008; Kilbane et al. 2008). The observed survival rate in Coral Harbour (91%, 14 months after relocation) is exceptional in being based on quantitative monitoring of all individual transplanted coral colonies.

Ecologically sound management of coral transplantation should include the monitoring of survival rates, growth rates and health condition of transplants. For example, size-dependency in survival rates could guide transplantation operations as is shown with fragments (Soong and Chen 2003), and the health status is an indicator for the corals being resilient to stress caused by transplantation (Abelson 2006; Edwards and Gomez 2007). The monitoring in Coral Harbour 14 months after relocation provides a detailed quantitative baseline that includes a full size (length, width, height) and health condition (percent cover of ailments) assessment, and a scaled photo ID of each individual colony. No indication was found for size-dependent suffering from the different types of ailments, but type and grade of ailments varied strongly between coral species. It was found that some species showed no (*Montastraea cavernosa*) or very little (2%, *Diploria labyrinthiformis*) ailments, while others were severely affected (46%, *Porites porites;* 31%, *Orbicella* spp.). The shape of the two severely affected corals is branching or rather nodular, while all other transplanted species have a more massive growth structure, which might explain the observed difference in ailments. Such findings indicate that future relocation efforts require a careful design, and shape should be considered as a criterion when colonies are selected for transplantation.

The success of the coral transplantation effort in Coral Harbour, 91% survival and a general good health status after 14 months, is attributed to a combination of factors. It is likely due to the source corals being in a healthy condition, as well as to thriving and relatively untouched recipient sites with similar environmental conditions to the donor site (Edwards and Clark 1998). Transplanted corals are known to benefit from recipient sites with low pressure of human activities (Shafir et al. 2006) and survival rates may reduce when being relocated to sites with different environmental conditions (Plucer-Rosario and Randall 1987). The recipient sites in Coral Harbour mimicked the natural conditions of the donor sites, and are located far from the main population centre of the island New Providence with all its anthropogenic pressures. Furthermore, seasonal timing is important for successful transplantation (Sequin et al. 2008; Edwards and Gomez 2007), and by executing the Coral Harbour Coral Transplantation Project in the winter season, the corals were allowed to recover sufficiently from stress prior to high seawater temperatures in the summer and hurricane season. It is finally hypothesized that the transplantation techniques used, such as keeping the corals submerged using a purpose-designed transportation cage, or soaked during relocation, and carefully perfecting the cement mixture to enhance good adhesion to the substrate, further reduced the negative impacts attributed to coral transplantation.

In conclusion, the Coral Harbour Coral Transplantation Project has reduced the ecological impact of the Coral Harbour's dredging project by preserving many viable corals and associated

invertebrates through relocation. Comprehensive monitoring has resulted in a coral health database of the transplants at the colony level, allowing the evaluation of the transplantation effort, and providing the opportunity for future longer-term studies, including growth assessments. It was demonstrated that a successful coral transplantation initiative requires a well-prepared design for careful selection of viable corals and suitable recipient sites, efficient techniques to minimise stress of the corals during handling, and extensive pre- and post-transplantation monitoring to assess the relocation effort.

Edwards and Clark (1998) stressed that successful transplantation of corals should by no means be seen as a generally acceptable and easy option to legitimise coral reef habitat loss and avoid debate of other potentially better management options. Taking this at heart, the successfully applied strategy in the Coral Harbour Coral Transplantation Project may be considered promising for application in future coral relocation initiatives, as well as in the rapid establishment of thriving reef communities on new-build constructions, like breakwaters and artificial reefs.

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