ARTICLE

doi: 10.1111/emr.12590

Effectiveness of coral (Bilbunna) relocation as a mitigation strategy for pipeline construction at Hayman Island, Great Barrier Reef

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Summary Coral reef management techniques such as relocation and transplantation are increasingly implemented in the context of increasing coastal development and a global decline of coral reefs over the last 30 years. A 170 m submarine desalination pipeline was constructed in 2020 to discharge wastewater from the desalination plant for Hayman Island resort, Whitsundays, Queensland, Australia. Pre-construction site assessments were conducted indicating a healthy, diverse and recovering coral community between intertidal and 12 m depth in the proposed route of the pipeline. Mitigation options included the selection of a pipeline route that minimised impact on coral, and relocation and transplantation of hard corals. Two hundred and four corals comprising 35 species from 15 genera, with estimated sizes ranging from small (less than 2 kg) to extra large (over 50 kg), were relocated from the pipeline footprint to a similar nearby site. The estimated total weight of relocated corals was 873–2850 kg. The most common species transplanted were Hump Coral (*Porites lutea*) (27%), Lesser Star Coral (*Goniastrea aspera*) (8.3%) and Starflower Coral (*Astreopora ocellata*) (7.8%). Individual coral survivorship and growth was monitored at zero, one, six, 12 and 24 months. After 24 months total coral survival was 77.5%. The survivorship of relocated coral exceeded the mean for global coral restoration projects and was deemed successful by the regulator. To assist benchmarking of future coral relocation projects we propose a standard of below 50% as poor, 50–60% as below average, over 60% as acceptable and over 80% coral survival at two years as excellent.

Key words: *Bilbunna, construction, coral reef, marine protected area, survival, transplantation.*

Introduction

Minimising damage from marine construction activities involving dredging, marinas, moorings, or pipelines in and around coral reefs is a priority for sustainable development (Rezai *et al*. 1999; Roberts *et al*. 2010; Kenny *et al*. 2012; Rodgers *et al*. 2017; CCWA 2021). Management measures including planning, environmental impact assessment, avoidance, minimisation and compensation have been used with varying degrees of success (Kotb 2016; Buckee & Blout 2021). Pipeline installations are often responsible for loss of habitats in the area covered by their route (Wilson 2015; Richardson *et al*. 2017). Currently, the longest undersea pipeline is the Nord Stream which runs for 1224 km through the Baltic Sea and there are over 18,000 miles of decommissioned pipelines in the Gulf of Mexico (Giltz 2021).

Maximising environmental outcomes is critical for management of high use and high value ecosystems and species such as marine protected areas and coral reefs (GBRMPA 2017; Jacob *et al*. 2020). Coral reef restoration and management techniques are in ever-increasing demand due to increasing coastal development and global decline of coral reefs in the last several decades (Edwards & Gomez 2007; Edwards 2010; Vaughan 2021). Coral relocation has been established as an appropriate mitigation and restoration technique in select cases, particularly where corals are scheduled for destruction (Rodgers *et al*. 2017). However, coral relocation can be expensive with an extreme example being a project associated with a cruise ship terminal in the Cayman Islands estimated at $12 million (Korbee *et al*. 2015).

The comprehensive collection, transportation and relocation of benthic

Implications for Managers

- Planning, relocation and monitoring costs for corals were approximately 4% of project infrastructure costs.
- Overall survival of translocated coral was 94.6% after 12 months and 77.5% after two years.
- Due to changes and challenges in visual identification of coral species, we suggest that coral genera offers a more accurate categorisation for practitioners and managers.
- There is no standard for measuring success of coral relocation and restoration and we propose alignment with international ecological restoration standards (McDonald *et al*. 2016) with Specific Measurable Achievable Realistic Timely (SMART) tiered goals: below 50% as poor, 50–60% as below average, over 60% as acceptable and over 80% coral survival at two years as excellent.

communities is a poorly documented topic in the scientific literature (Liñán-Rico *et al*. 2020). There have been several coral relocation projects associated with construction of pipelines and they are generally reported in non-peer reviewed literature (Anonymous 2007; Monkivitch 2008; Seguin *et al*. 2008; Kenny *et al*. 2012; Deb & McCarthy 2015; Targeted News Service 2015; PMG 2019) with several exceptions (Wilson 2015; Kotb 2016; Rodgers *et al*. 2017; McLean *et al*. 2021). Massive corals are considered more suited to relocation than other growth forms because they are less likely to be damaged in transit (Ammar *et al*. 2013). Mitigation and restoration may reduce environmental impacts, but these techniques have rarely been tested in the marine environment for massive corals (Boström-Einarsson *et al*. 2020). There have also been several companies and projects that have damaged coral or failed to monitor or relocate coral (Fleshler 2004; Hurtibise 2018; Surkes 2020).

Environmental impact assessments (EIA), and associated monitoring is generally required to confirm that projects meet agreed levels of impact and that the predictions of impacts developed in the EIA process have been accurate (Sheaves *et al*. 2016). To date there is no standard methodology for establishing success of coral restoration or relocation programs, although many projects use coral survival and health as a proxy for success (Boström-Einarsson *et al*. 2020). Guidance suggests metrics should be established that demonstrate changes or success based on the objectives of a project (Goergen *et al*. 2020).

The developer Mulpha Pty Ltd engaged environmental consultants ERM, GHD, Environment Pacific and Reef Ecologic for the environmental planning of a desalination pipeline in the Great Barrier Reef Marine Park (Environment Pacific 2018; ERM 2020) and associated coral transplantation and monitoring (Reef Ecologic 2020a, 2020b). Reef Ecologic undertook assessment and relocation activities in November 2020 with the aim to mitigate the effects of the pipeline installation. The monitoring program aimed to measure survival of relocated coral colonies. This Article (i) outlines the process undertaken to mitigate the environmental impacts associated with the installation of the pipeline, (ii) provides the overall survival of relocated corals at the relocation site; and (iii) discusses lessons learnt, limitations and advice for stakeholders involved in reef restoration as a mitigation strategy.

Methods

The project was conducted in the waters adjacent to Hayman Island, one of the 74 continental islands belonging to the Whitsunday group of islands, which forms a part of the Country of the Ngaro People. Hayman Island (whose Ngaro name we were unable to source) is a private island famous for its luxurious Hayman Island Resort built in the 1950s. In 2019, Hayman Island Resort spent $135 million to upgrade the resort, including the construction of a pipeline for discharging wastewater from a desalination system. The pipeline was proposed to be installed on the western side of the Hayman Island Resort (Fig. 1). The pipeline was designed to go over the reef flat and onto the reef slope, finishing approximately 170 m offshore at a minimum depth of 12 m of water. The pipeline was approximately 0.5 m wide with a total corridor width of between 1.6 and 3 m which include the concrete anchors and flexible concrete mats laid over the pipeline to minimise movement.

In response to an application to install a new desalination pipeline through the fringing coral reef at Hayman Island in the Great Barrier Reef, the Great Barrier Reef Marine Park Authority (GBRMPA) required a Coral Transplantation Plan that included the relocation of coral colonies that would potentially be damaged by the installation of the pipeline. Additionally, the Permit Holder was required to measure the effect of the relocation on the coral colonies' survival. GBRMPA permit conditions (Permit number #G20/44156.1) pertaining to the coral relocation included conditions requiring coral colonies be relocated to the same reef zone, similar depths, that specimens be securely attached to the substrate and that a monitoring program be established and implemented to measure the short- and medium-term effects of the relocation over a 5-year period.

Assessment of pipeline route

Initial assessment and recommendation of an indicative route for the proposed pipeline through the reef flat was conducted by Environment Pacific and GHD Group Pty Ltd in 2019, with the contractor confirming the actual route following a review of site conditions. Researchers from Reef Ecologic assessed benthic habitats using Reef Health Impact Surveys (RHIS), a quantitative method used by divers to assess reef health in a series of five-metre radius circles (Beeden *et al*. 2014). RHIS enabled reassessment of the proposed pipeline route providing an alternative

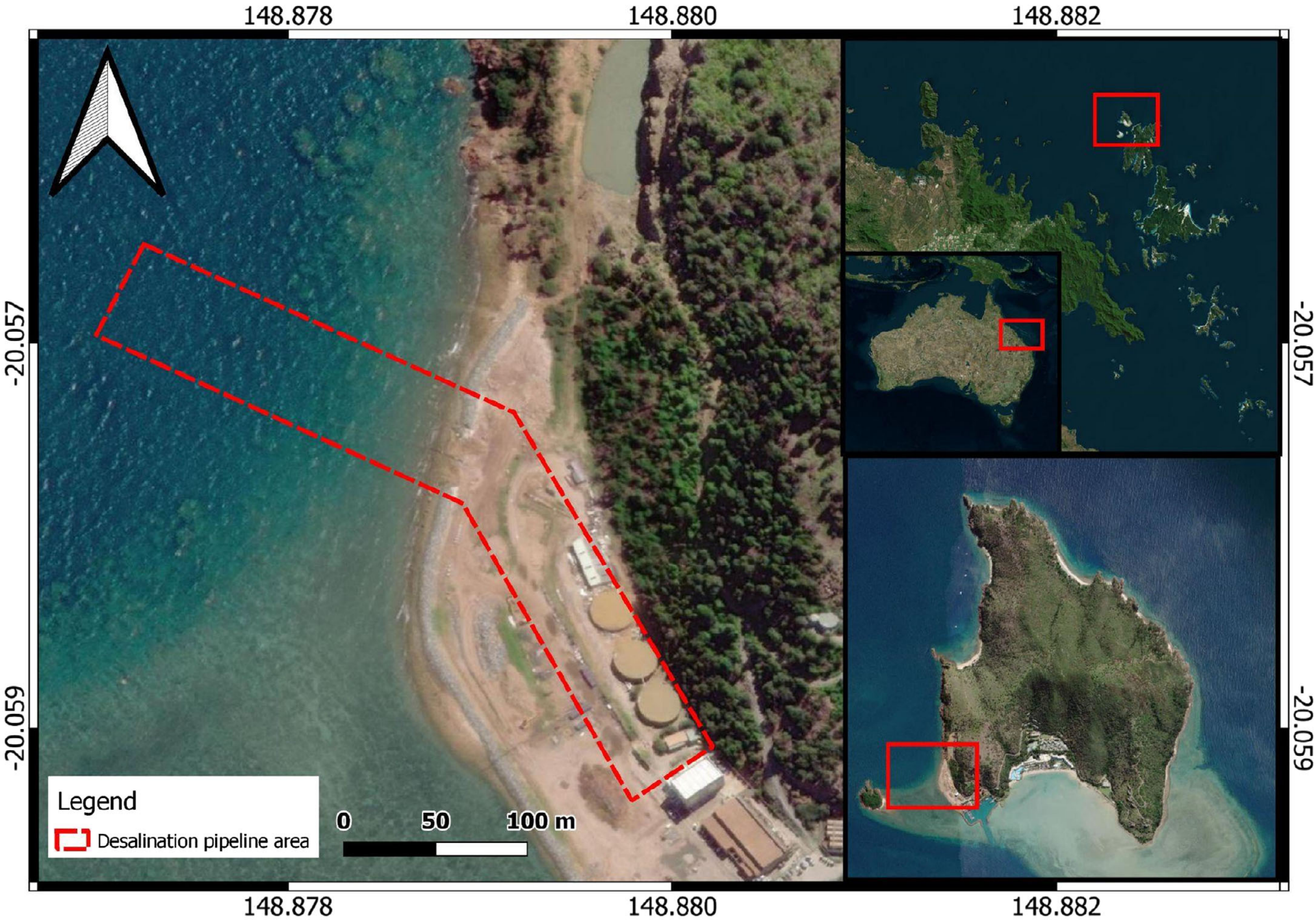

Figure 1. Proposed pipeline installation site at Hayman Island, the most northerly of the Whitsunday Islands in the Great Barrier Reef, Australia.

route through the reef flat that would result in reduced impacts to live coral colonies and require few colonies to be relocated as part of the mitigation activities (Fig. 2). We utilised three methods in Stage 1 to describe and quantify the coral distribution and abundance along the pipeline route: site mapping, point intercept transect (PIT) along the proposed pipeline route and benthic assessments to quantify coral cover and proposed coral relocation requirements (Reef Ecologic 2020a).

Pre-construction surveys determined that if the recommended pipeline route through a sand channel along the reef flat was taken, between three and 10 large (over 1 m) coral colonies would need to be relocated. However, in consultation with the construction crew prior to installation, it was revealed that the proposed pipeline was not as flexible as expected and therefore unable to bend and flex around potential obstacles on the reef flat. The addition of joints and significant bends to avoid obstacles would not only incur additional construction cost but would also result in hydraulic pressure loss. The ideal route for the pipeline installation required a more linear path (Fig. 2) than recommended resulting in two orders of magnitude more corals requiring relocation than originally proposed.

Once a final course of the pipeline was mapped, the researchers marked and moved all hard corals (>10 cm in diameter) from the pipeline's pathway (200 m long × 2 m wide and 400 m^2) (Fig. 2). Corals were detached using a hammer and chisel or large crowbar (Edwards 2010), carefully placed into 50 × 80 cm crates, transported using lift bags and towed by SCUBA divers under the water to a 10 m × 10 m (100 m^2) relocation site approximately 20–100 m away (Fig. 3). The corals remained entirely submerged during their journey to the relocation site. A total of 204 corals were relocated with the majority (88.2%) small enough to be managed by hand and placed on bare rock substrate (Fig. 3). Larger colonies (n = 20, 9.8%) required multiple divers and lift bags to move to a suitable location for reattachment while extra-large colonies (n = 4, 2%) were placed directly onto the prevailing substrate between reef rock shelves.

Relocation site

Corals were placed at the relocation site at a depth of approximately 3–5 m. Coral relocation plots were marked with

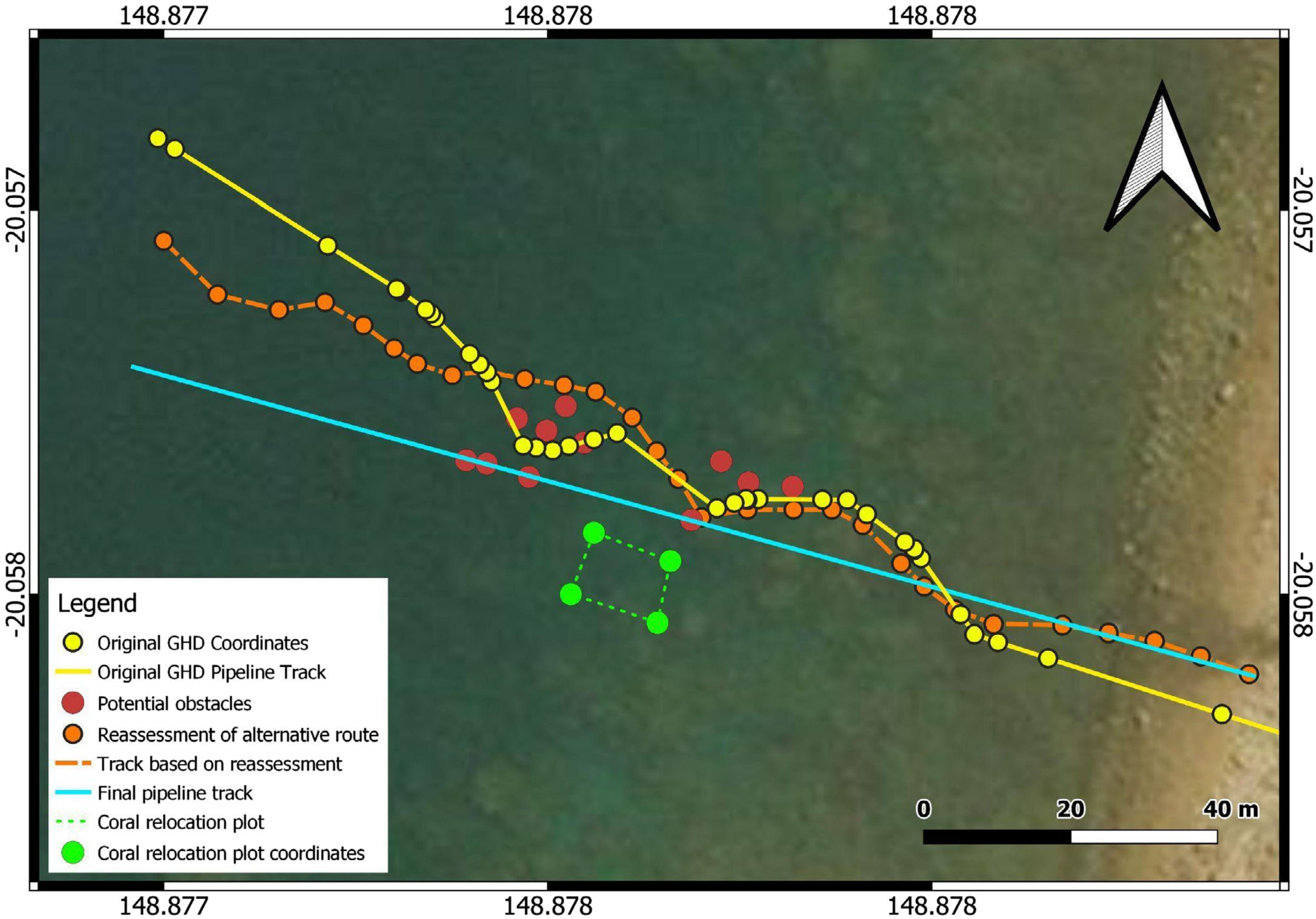

Figure 2. Proposed pipeline installation options and coral relocation plot at Hayman Island in the Great Barrier Reef. Original proposed track (solid line) and coordinates (yellow circles), potential obstacles (red circles), reassessed alternate route (in orange), and final pipeline track (in blue). The coral relocation plot (dashed lines) and its coordinates (circles) are presented in green.

subsurface buoys and documented using GPS (Fig. 2).

Based on previous restoration projects, cattle tags can easily be covered by overgrowth of algae, sponges and barnacles making it difficult to find. To circumvent this, researchers laid out the coral colonies in a sequential pattern to assist with future monitoring before securely fixing to the substrate. All coral colonies were labelled with sequentially numbered cattle tags affixed beside each colony using concrete nails (Fig. 3d). Divers filled universal caulking guns with concrete which were used to deploy the adhesive mixture to attach 200 coral colonies. Portland cement was mixed with seawater at a ratio of 2.5:1 to which researchers added BondCrete Universal Bonding Agent at a ratio of 25 ml per 1 kg of cement. The concrete mixture was prepared on the vessel in 6 kg batches. Once prepared and six caulking guns, each with 1 kg capacity, were filled, they were transferred to the divers who used the mixture to fix the colonies to the hard substrate. The concrete mixture takes approximately 60 minutes to become solid but requires approximately 4–6 hours to completely cure. For this reason, fieldwork was only completed during calm weather windows to enable the coral colonies to remain stable while the adhesive cured. Additionally, during attachment, researchers took care to consider the shape of the coral colonies and the available substrate to maximise surface area in contact with the substrate for adhesion. When deploying coral colonies, it is important that individual colonies can support their own weight while curing, otherwise they may become dislodged and fall into the substrate. Four extra-large massive colonies were placed directly on the substrate without adhesive assuming their weight, morphology, and location (between reef rock shelves) would support their stability and survival.

The estimated costs of the construction and installation of the pipeline was $1 million including an estimated $400,000 for commercial diving and $38,500 for coral translocation and monitoring over a 2-year period.

Monitoring

We used common and scientific names for marine species and used the traditional name for Stony Coral 'Bilbunna' (Whitley 1936) to encourage sharing of knowledge and culture. We opportunistically photographed marine species and added images to the citizen science application *iNaturalist* to assist with identification.

Coral taxonomy for scleractinian corals is undergoing substantial changes due to new information available through genomic sequencing and DNA analyses (Shinzato *et al*. 2021). Coral specimens were identified by experts using high resolution images cross-referenced with fact sheets available at Corals of the World (www.coralsoftheworld.org). Taxonomic names for genus and species were further cross-referenced with the World Register of Marine Species (WoRMS – www.marinespecies.org) and designated based on currently accepted status. A minimum of two authors verified each identification. Genetic analysis to assist with the identification of corals was not conducted. Sequentially numbered plastic tags were nailed beside each of the 204 colonies to enable identification during ongoing monitoring.

Divers took photographs of corals and associated tags and measured the size (width and height) and estimated the weight (Small <2 kg, Medium 2–19.9 kg, Large 20–50 kg, Extra Large >50 kg) of all relocated and individually tagged and numbered coral colonies during each of four monitoring trips (Fig. 4). A number of colonies (32.8%, n = 67) were patchy in appearance with partial mortality evident on the colonies before relocation. Coral survival was assessed at five time periods over 24 months: Time 0, Time 1 (1 month), Time 2 (6 months), Time 3 (12 months) and Time 4 (24 months).

Data analysis

Statistical analyses were conducted in R-studio (version 1.4.1106, R Development Core Team, 2009) using a significance level of $P < 0.05$. We used the log rank test (Bland & Altman 2004) to compare survival rates of corals based on genus, and to test the null hypothesis of no difference in survival between two or more independent groups. We also visualised survival curves of statistically significant results using the Kaplan–Meier method (Goel *et al*. 2010). Corals with live tissue present were considered alive, regardless of partial mortality. Corals with no live tissue that were missing, or that had >90% partial mortality, as assessed through photos, were considered dead.

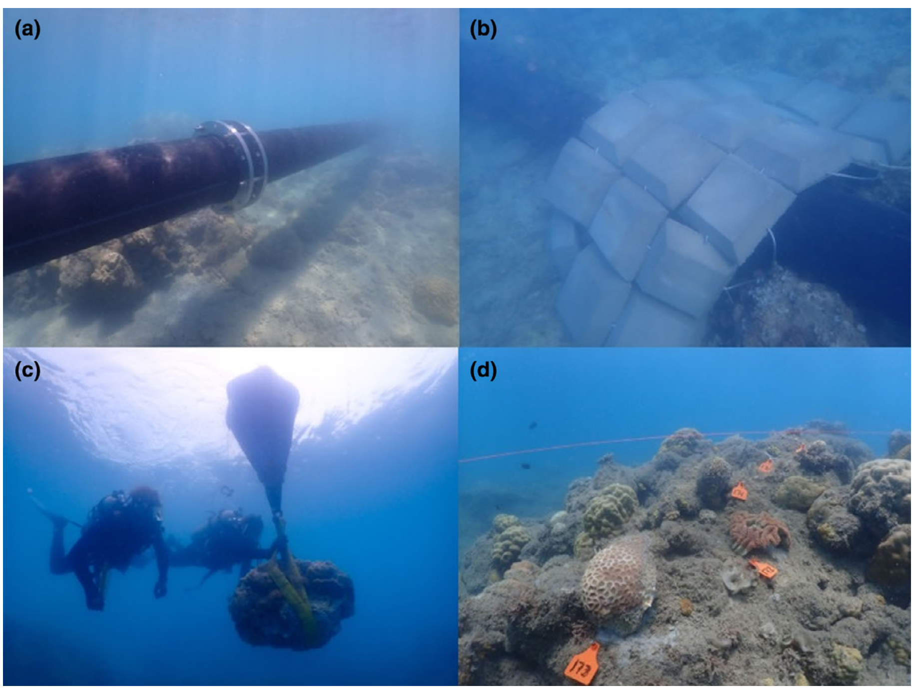

Figure 3. (a) The installed pipeline at Hayman Island in the Great Barrier Reef, (b) pipeline with concrete mats, (c) commercial divers relocating a large coral to the donor site, and (d) tagged corals at the donor site. Photographs by Gemma Molinaro.

Results

Baseline surveys

A total of 29 Reef Health Impact Surveys were conducted along the potential pipeline route, indicating substrate cover of 5.3% live coral, 5.6% macroalgae, 45.2% live rock, 24.2% rubble and 19.7% sand prior to construction. We observed four habitat types: reef flat, live coral, sand and rubble with the highest abundance of coral approximately 40–80 m from shore (Beeden *et al*. 2014; Reef Ecologic 2020a).

Relocated corals

A total of 204 hard coral colonies from 15 genera containing 34 species were moved from the pipeline-impacted reefs (donor site) to relocation reef sites. The most abundant coral genera were *Porites*, *Dipsastraea*, *Coelastrea* and *Astreopora* comprising over 72% of corals (Fig. 5). Survivorship varied from 100% for *Echinopora* 0% for *Leptoseris* and *Acathophllia* (Fig. 5).

Total coral survivorship changed over time and was excellent for the first 12 months and declined at 24 months (Table 1). However, the Log Rank Test on survivorship differed significantly between genera (x^2 = 32.4, critical value = 23.68, P = 0.002). There were differences between survivorship of coral genera. The Kaplan–Meier survivorship curve shows differences in survival probability of each coral genus after relocation (Fig. 6). Each step indicates one or more events (i.e. death). Visual inspection suggests that *Leptoseris* and *Acanthophyllia* spp. have the lowest survival probability, however this is based on only two colonies in the sample yet their low representation here may indicate poor suitability to the environmental conditions (Fig. 5). Among coral genera that have greater than 10 colonies present in the sample; *Lobophyllia* sp. (80.5%) has the highest survivorship, followed by *Porites* sp. (73.7%), *Coelastrea* sp. (72.8%), *Dipsastraea* sp. (61.4%), *Astreopora* sp. (53.8%), *Platygyra* sp. (65.9%) and *Favites* sp. (55%).

Relocated colonies were dominated by massive morphologies 95.5% (n = 195) of which 84.1% were alive after

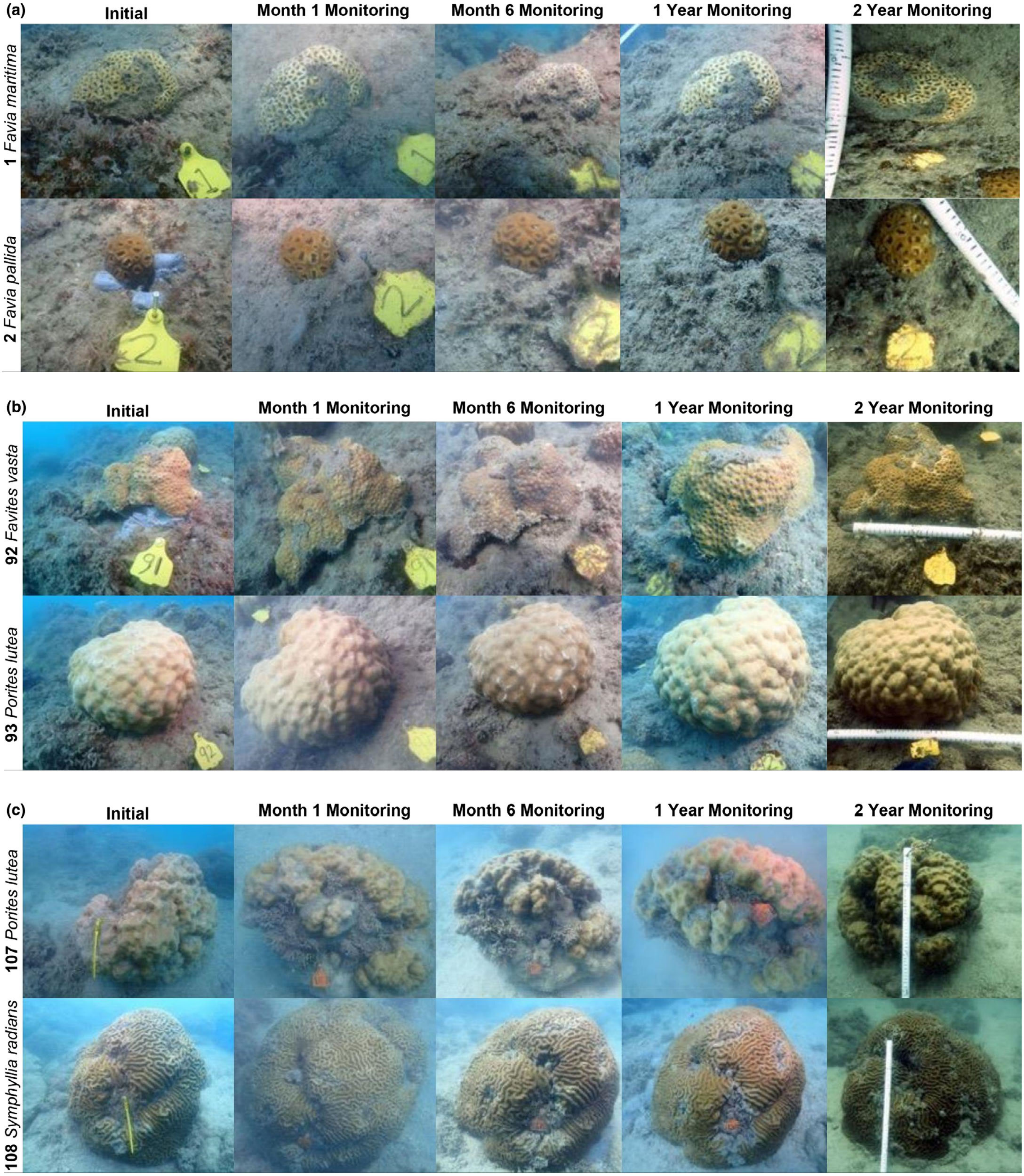

Figure 4. Photographs of selected corals at the Hayman Island pipeline relocation site with numbered tags that were classified as: (a) small, (b) medium, and (c) large that were monitored at times zero, one, six, 12 and 24 months (photographs of all 204 corals available in supplementary material). Note that a ruler was included in the photographs for the 24-month monitoring period.

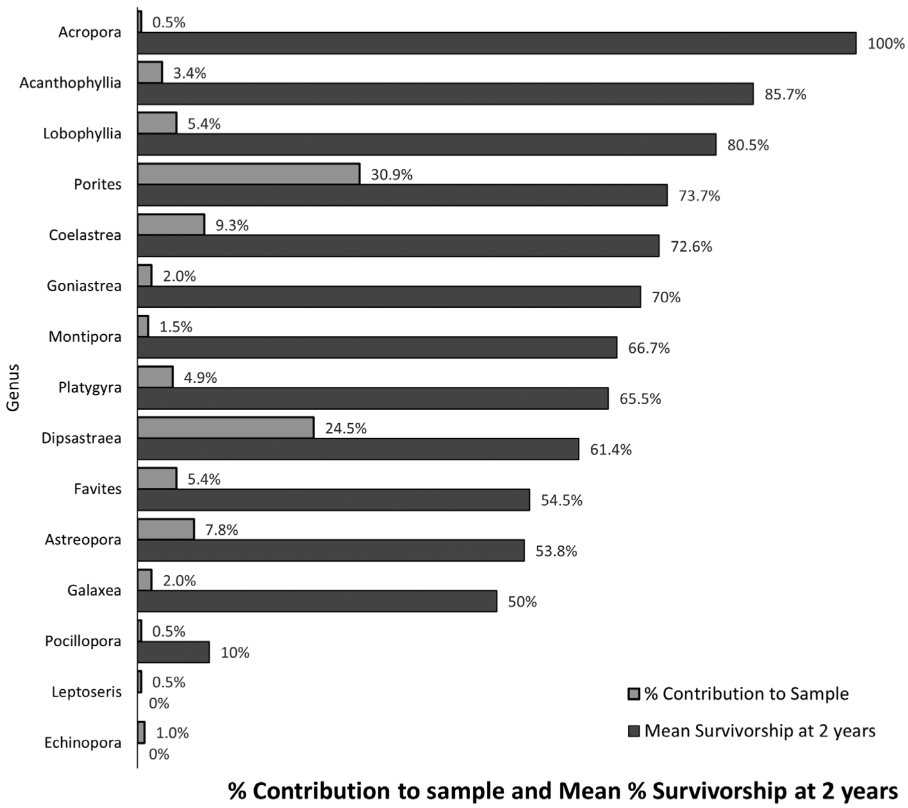

Figure 5. Diversity and proportion of coral genera that were collected and relocated at Hayman Island in the Great Barrier Reef, and their total contribution in percentage to the number of relocated colonies (light grey) and actual percent survival after 24 months in each genus (dark grey).

Table 1. Number and percentage of coral colonies at the Hayman Island pipeline relocation site surviving (≤90% partial mortality) at each monitoring timepoint (zero, one, six, 12 and 24 months)

Time (months)	Number of colonies	Survivorship (%)
0	204	100.0
1	203	99.5
6	200	98.0
12	193	94.6
24	158	77.5

24 months. Branching morphologies, consisting of *Porites* sp (n = 6), *Acropora* sp (n = 1), *Echinopora* sp. (n = 1) and *Pocillopora* sp. (n = 1) contributed the other 4.5% (n = 9) of which 44.4% were alive at the conclusion of monitoring. Of these, all of the four surviving branching colonies (*Porites* sp. [n = 2], *Pocillopora* sp. and *Acropora* sp.) showed signs of predation.

Discussion

The decline in the health of the Great Barrier Reef and cumulative anthropogenic impacts has resulted in legislation, policies, guidelines and permits to manage, mitigate and offset impacts (Monkivitch 2008; GBRMPA 2017; Jacob *et al.* 2020). Testing EIA predictions and the effectiveness of implemented mitigation measures with well-designed and consistent environmental monitoring is critical. Active coral restoration has increasingly been used as a tool to restore coral reefs at local scales, especially by the tourism industry (Boström-Einarsson *et al.* 2020; Vaughan 2021). Most coral restoration projects involve small branches or nubbins (5–15 cm and approximately 50–100 g). This research is an example of active coral relocation of small and massive corals (40–150 cm and 20–50 kg) by the construction industry associated with permit conditions for the installation of a subtidal desalination pipeline.

Scale and predicted versus actual impacts

The predicted direct spatial scale or "impact area" was 170 m long × 0.5 m wide associated with the pipeline and the predicted indirect footprint was 170 m long × 3.0 m wide associated with other infrastructure such as concrete mats. It was predicted that all corals under the direct spatial footprint of the pipeline would have 100% mortality within 1 month due to damage or shading unless they were relocated.

The predicted impacts and benefits of translocating 204 corals to a 10 × 10 m area with a baseline coral cover of 5.4% were that coral would survive and that mean live coral cover would increase over time.

The number of relocated corals was 204 at Hayman Island, which is small compared to 1100 in Florida (Stephens 2007) and 2793 and 4500 in Qatar (Anonymous 2007; Deb & McCarthy 2015), 7000 coral colonies from Al-Dirreh and transplanted into Aqaba Marine Park (Kotb 2016) and 147,947 hard corals, soft coral and sponges relocated in Jamaica (Kenny *et al.* 2012). One restoration project did not count corals but estimated weight at 68,000 kg (Rodgers *et al.* 2017). The estimated total weight of relocated corals at Hayman Island was between 873 and 2850 kg.

The benthic habitat was complex and varied from intertidal sand and rubble to solitary corals and outcrops of coral reefs or "bommies" (Reef Ecologic 2020a). The initial predicted numerical impact of pipeline installation on coral was relocation of 3–10 large corals based on installation of a flexible pipeline that could be laid in sand and rubble channels and largely avoid live coral (Reef Ecologic 2020b). Due to construction processes, the pipeline installation was changed to linear and crossed over coral reefs with the mitigation involving the relocation of 25 large and extra-large corals and 179 small and medium corals. The number of corals relocated increased by up to eight times (based on large corals) and 20 times

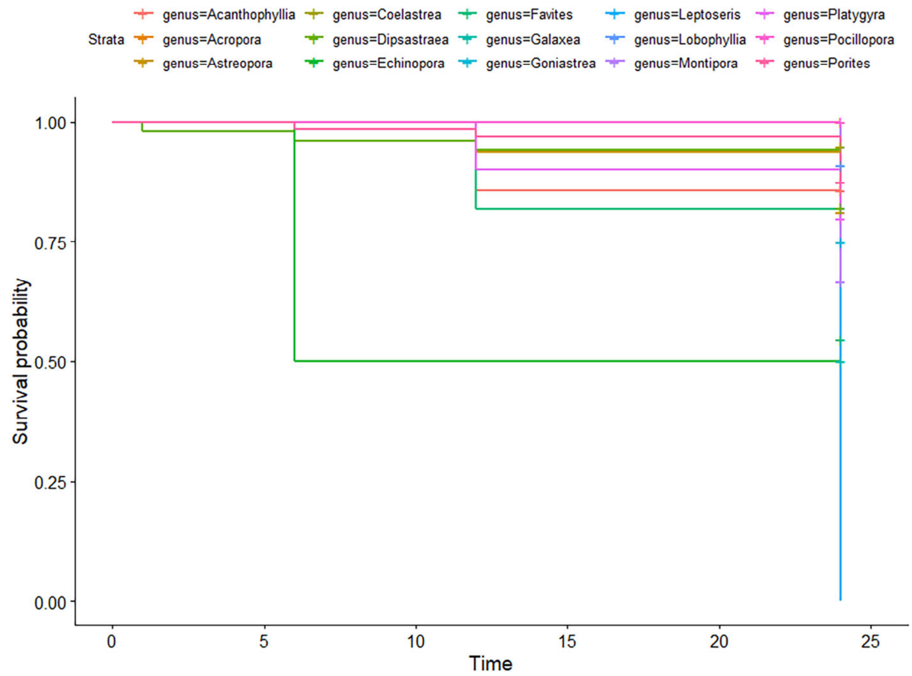

Figure 6. Kaplan–Meier survivorship probability curve for 15 genera of relocated corals at Hayman Island in the Great Barrier Reef over two years (24 months). Confidence intervals are represented by dashed lines.

(based on all corals) than initially planned. The overall temporal scale of the monitoring project is five years, and the majority of activity was focussed initially on two days of baseline surveys, five days for coral relocation and monitoring surveys at time periods of zero, one, six, 12 and 24 months. The monitoring was generally completed in one day of field work and two days of data entry and reporting. We expected to see any direct and indirect impacts of the relocated coral within 1–6 months. Any mortality after that may be due to other factors such as climate change, extreme weather, water quality, predation or other disturbances and not related to either relocation or pipeline construction (Boström-Einarsson *et al.* 2020). The costs and benefits associated with coral relocation and monitoring can be measured by legislative, economic, environmental and other indicators, for example, those identified by rights-holders such as the Ngaro Peoples and stakeholders such as tourism operators. The conditions imposed by Great Barrier Reef Marine Park Authority included "The Permit Holder must take all reasonable steps to ensure that activities carried out under this permit do not cause harm to the environment". The potential mortality of 204 live corals was deemed likely to cause harm and hence the "removal, transplantation and monitoring of relocated corals" was permitted in accordance with an approved Coral Translocation Plan. The economic costs of transplantation and monitoring were $38,500 which is less than 4% of the total project costs.

Coral diversity, morphology and survival

The relocated corals represented substantial diversity, with 15 genera comprising 34 species observed. However, coral taxonomy for scleractinian corals is currently undergoing substantial revision due to genomic sequencing and DNA analyses (Veron 2013; Shinzato *et al.* 2021) rendering field-based identification of some species of coral difficult. While every effort has been made to verify the identity of coral colonies to species level for taxonomic reference, the reality is that very few scientists can accurately identify many corals to species level in the field without access to skeletal detail or greater forensic testing capabilities. We have identified coral colonies to species level as this was required by the GBRMPA permit, however, we would recommend that future projects consider genus level identification or coral morphology for such mitigation projects. Increased resource investment to collect and test coral samples for DNA analysis could be recommended for studies with a specific taxonomic focus or for protected or threatened species.

Massive coral morphologies were dominant, representing 95.5% (n = 195) of the total sample. In contrast, a global review indicated that the coral translocation experiments use branching morphologies 59% of the time in contrast to massive morphologies which were represented 18% of the time (Boström-Einarsson *et al.* 2020). Overall survival of all coral colonies relocated at Hayman Island was very high at 95% over a 12-month period, which decreased to 77% at 24-months. The majority of genera demonstrated high survival rates with 9 of the 15 genera observed above 80% survival. This overall result was higher than the mean survival for coral restoration projects internationally at 60.9% (Bayraktarov *et al.* 2019) and 64% (Boström-Einarsson *et al.* 2020). This result was similar for survival of transplanted coral colonies at Aqaba Marine Park at 87% over a two year period (Kotb 2016). Larger corals were observed to have higher survivorship than smaller corals, possibly due to increased rates of herbivory on smaller corals (Smith *et al*. 2021).

Monitoring

The success of restoration programs is dependent on the objectives of the project (Goergen *et al*. 2020). The regulatory objectives of this project were broad and stated "The Permit Holder must take all reasonable steps to ensure that activities carried out under this permit do not cause harm to the environment", however, a "Coral Transplantation Plan" (Reef Ecologic 2020b) was required for specific detail. For this project we used coral survival and overall ongoing health to measure the success of the project. Many coral restoration or relocation projects with peer reviewed results are monitored for 12 months (Boström-Einarsson *et al*. 2020), whereas recommended monitoring to measure ecological impacts of restoration projects are recommended at 3–5 years (Goergen *et al*. 2020). To date, 24 months of monitoring has been completed with an additional assessment required by GBRMPA permit conditions to occur at five years. Assessing the survivorship of relocated corals during the first 12 months is an important time frame to see if they adjust to their new environment (Boström-Einarsson *et al*. 2020). Practical challenges such as researchers locating tags due to fouling, sedimentation and extreme weather are likely to increase over five years. In addition, linking long-term survivorship of relocated corals could be confounded by external pressures, such as coral bleaching events.

Indicators of success

The relative success of the relocation and restoration projects is difficult to estimate, mostly due to the wide range of 50 different metrics assessed to estimate the recovery (Cadier *et al*. 2020). We reiterate that there was no global standard or key performance indicator for establishing success of coral relocation programs when we commenced this study which led to uncertainty about whether success had been achieved or not. Many projects use coral survival as a proxy for success and we propose that below 50% coral survival at two years is a poor outcome, 50–60% is below average, over 60% coral survival at two years should be an acceptable outcome and over 80% coral survival at two years should be considered an excellent outcome.

Limitations

The coral mitigation and relocation project had limitations due to diverse stakeholders with different priorities and resources, including government, industry, the tourism sector, environmental consultancies, construction companies and scientists. There was considerable refinement associated with planning for the installation of the pipeline and its alignment to water depth and potential impact on corals. There were no clear standards or key performance indicators for measuring success or failure of coral relocation over time. Furthermore, it is challenging to ascertain whether or not these corals are coping with their new environment without comparing survival rates to a control site, which was beyond the scope of this project. Lastly, because we opportunistically relocated all corals that would have been damaged by the pipeline, it is difficult to assess the differences in survival based on taxonomic (e.g., genera) or morphological (e.g., coral growth forms) status with uneven sample sizes.

The coral relocation study was a small, low-impact monitoring project based on limited scale and financial resources compared to the larger construction project. The study focussed on coral survivorship and did not quantify changes in other biota such as fish or algae. However, we opportunistically recorded 69 observations of 46 species of fish, invertebrates and coral that were added to the citizen science application iNaturalist to increase knowledge of local biota. The study did not investigate water quality.

Conclusion

This project is an example of refinement undertaken by environmental practitioners in partnership with commercial divers and the Reef Authority to minimise impacts of approved developments on corals. This article aims to bridge the gap between the academic ecologist's perspective and field manager's experience working with industry partners. This study provides broad insights into the survivorship associated with the relocation and transplantation of a coral community that, without intervention, would have been destroyed under the footprint of a pipeline. Overall we found survivorship of 95% of corals after one year and of 77% after two years, higher than the global average of 64% (Boström-Einarsson *et al*. 2020). Based on a cost–benefit assessment of legal, economic and environmental factors, we recommend that a similar methodology is used to relocate corals and monitor survival over two years for future construction projects and suggest future studies also include the monitoring of a control site to compare survival of relocated corals to those at a nearby reef. Furthermore, more case studies are important to establish a global standard or key performance indicators for success of such coral relocation programs. Repositioning and displaced coral colonies can effectively aid in reef recovery in the aftermath of acute disturbances such as cyclones (McLeod *et al*. 2019). Hopefully this project sets a new precedent to mitigate some of the direct risks associated with marine construction by relocating corals to a suitable habitat.

Acknowledgements

This project was made possible due to financial and logistical support from project partners Mulpha Pty Ltd and Intercontinental Hotel Group (IHG), particularly Darren Liptrott. We acknowledge commercial divers Darren Foster, Steven Rose and Randall Glendenning from Whitsunday Mooring and Marine Construction and David Edge from David Edge Marine Contracting for their assistance with coral removal and relocation. We thank Professor Simon Robson for reviewing statistical analyses in the draft manuscript. We thank Professor Iain Gordon and Associate Professor Ian McLeod for comments on a draft manuscript. This project operated under GBRMPA Permit #G20/44156.1. We appreciate the site inspection by QPWS staff from Airlie Beach. We acknowledge the Traditional Owners of the Country in the Whitsunday region, the Ngaro People, and recognise their continuing connection to land, waters and culture. We pay our respects to their Elders past, present and emerging. We thank Traditional Owner Peter Pryor for ongoing friendship and advice on Culture. Open access publishing facilitated by James Cook University, as part of the Wiley - James Cook University agreement via the Council of Australian University Librarians.

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