Reef Rehabilitation Experiments:
A Review of Results & Lessons Learned

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About Reef Check

Reef Check is the world's largest international coral reef monitoring programme involving volunteer recreational divers and marine scientists. First carried out on a large scale in 1997, it provided the first solid evidence that coral reefs have been damaged on a global scale. The survey raised the awareness of scientists, governments, politicians and the general public about the value of coral reefs, threats to their health and solutions to coral reef problems. Reef Check is now active in over 82 countries and territories throughout the world

About Reef Check Malaysia

Reef Check Malaysia (RCM) was registered in Malaysia as a non-profit company in 2007, and since then has established an annual survey programme to assess the health of coral reefs around Malaysia (reports are available for download from the website: www.reefcheck.org.my). In the last five years RCM has trained over 350 divers to conduct reef surveys at permanent monitoring sites on coral reefs off the East coast of Peninsular Malaysia and at sites around East Malaysia. RCM is also active in education and awareness programmes, and has a long term education programme for schools. In addition, we have been working with stakeholders in the Perhentian islands and in Pangkor to involve local communities in coral reef management. More recently, RCM has established several Reef Rehabilitation programmes, contributing to our understanding of coral reef ecology, and providing an ideal vehicle to educate local populations, businesses and tourists on the value of coral reefs and how human activities are damaging them

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Foreword

In late 2009, we were approached by a group of snorkelling guides from Pangkor island, who were concerned about their snorkelling sites. Development, tourists and climate change have all taken their toll, and today snorkelling sites around Pangkor are in poor condition, the guides' livelihoods at risk.

The guides asked if we could help to improve the sites, and we agreed to try. Thus began our initial experiments in coral reef rehabilitation. Since then, we have faced numerous challenges – and we have had our successes. Many lessons have been learned, and we have incorporated these into our approach and methodology, as part of a process of continual improvement.

This document reviews the various installations and presents the results at each, highlighting the lessons learned to date. Our aim is to assist others who are considering reef rehabilitation programmes to avoid the mistakes we made, and to benefit from our experience.

Introduction

Coral reefs are a valuable ecological and economic resource, providing a breeding and feeding ground for a third of marine organisms, as well as providing food and livelihoods for millions of people around South East Asia.

Unfortunately, a variety of human impacts are damaging coral reefs, degrading their capability to continue to provide the range of ecosystem services on which so many people rely. Coral reefs in Malaysia are no exception to these problems.

As part of initiatives to conserve remaining coral reefs in Malaysia, in 2010 Reef Check Malaysia (RCM) embarked upon a series of reef rehabilitation experiments. RCM's very first reef rehabilitation project started in Pangkor, together with reef scientist Kee Alfian Abd Adzis from National University of Malaysia. In 2011, RCM extended the project to Tioman and to Perhentian and Redang in 2012.

Reef rehabilitation is the act of partially or, more rarely, fully replacing structural or functional characteristics of an ecosystem that have been diminished or lost, or the substitution of alternative qualities or characteristics than those originally present with the proviso that they have more social, economic or ecological value than existed in the disturbed or degraded state (Edward, 2010).

Although it is widely accepted that protection should remain the focus of management efforts due to the high cost of reef rehabilitation projects, there is nonetheless a growing body of research (Chou et al, 2009, CRTR) suggesting that rehabilitation can contribute to at least slowing the rate of decline and at best increasing coral cover, with recovery of the associated ecosystem.

It is important to note, however, that there is no point rehabilitating coral reef unless the local stressors that were the original reason for the decline are addressed. Reef rehabilitation should therefore go hand in hand with rigorous management.

Methodology

Introduction

Coral reef restoration is defined as "the return of an ecosystem to a close approximation of its condition prior to disturbance" (Precht & Robbart 2006). It is important to understand that this activity needs to be looked at in the context of the wider landscape, whereby the restoration activity is integrated as a part of the existing ecosystem, and not creating a new one.

Knowledge of the ecological dynamics of the coral reef ecosystem is needed to properly plan and design the restoration activities. An implicit assumption that all methods of restoration and rehabilitation are universal will be the downfall of any restoration and rehabilitation project (Precht & Robbart 2006).

The design of the restoration methodology for a particular area will depend on the existing environment *prior* to disturbances. This can be achieved by having past documentation or interviews with local communities. A general survey of the adjacent reefs will also provide vital information on the original condition and species composition. It is important to note, however, that there is no point rehabilitating coral reef unless the local stressors that were the original reason for the decline are addressed. This restoration activity should therefore go hand in hand with rigorous management. Figure 1 is a guideline that can be used to determine the suitability of a proposed restoration project.

Coral Nursery

The approach to restoration described here focuses on creating a "mini-ecosystem", in which individual nubbins are grouped into a certain number to form a mini-ecosystem, rather than transplanted as individual coral nubbins.

The process of gathering nubbins stresses the corals, weakening them and reducing the chances of their survival if transplanted straight to a new site. Keeping nubbins in a nursery stage for six months to one year before transfer to the final transplant site (rehabilitation site) allows the nubbins time to rest, recover and grow. The nursery should be in a location where it can easily be serviced, to control silt and algae, enhancing chances of survival and growth rates. It also allows for monitoring so that data can be collected on success rates.

The nursery is constructed from plastic (PVC) pipe, of the type commonly used for water distribution. This material was selected for the following reasons:

- It is low cost
- It is readily available
- It is easy to cut and assemble
- It is lightweight and therefore easy to deploy
- It is relatively inert and a suitable surface onto which new corals will recruit

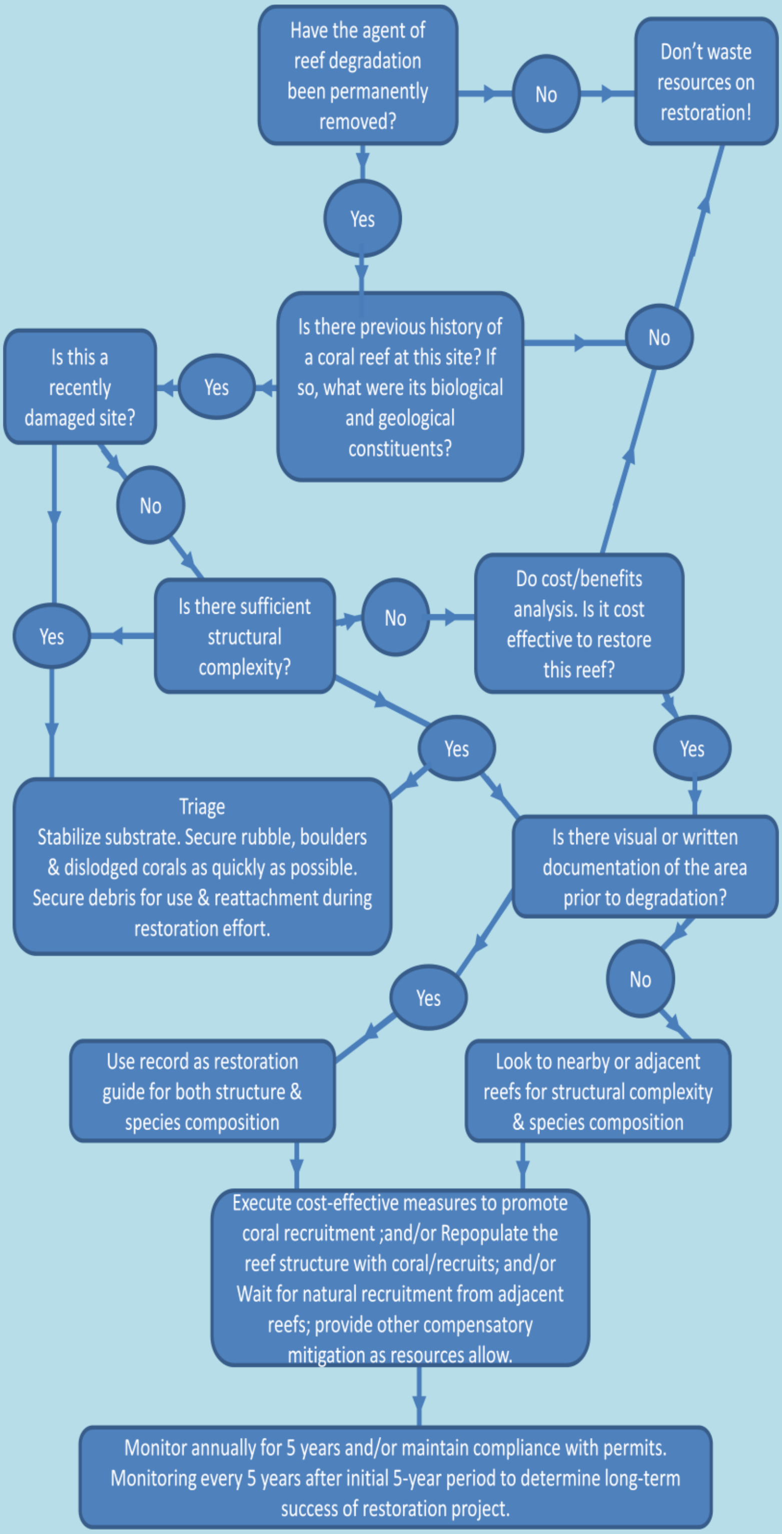


Figure 1: Guideline to determine the suitability of a proposed restoration project (Precht & Robbart 2006)

This material is therefore considered to be ideal for use in community-based restoration programmes. Other possible options include cement and metal bars, both of which release some chemicals into the water and are more expensive and heavier, thus more difficult to use in practice.

Once ready, the nursery can be transplanted as a whole mini-ecosystem to the proposed rehabilitation site.

Water Quality

Baseline water quality data must be established for the donor, nursery and rehabilitation sites. Parameters to be recorded are:

- water temperature
- salinity
- pH
- turbidity
- chlorophyll
- light intensity.

Site Selection: Donor, Nursery & Rehabilitation

A donor site needs to be identified. It is suggested that branching (*Acropora* spp) corals are used for the initial stages of rehabilitation, with other growth forms of corals being used in later stages. This step is needed to quickly establish the habitat for rehabilitation, in which this branching coral will provide the first micro-habitat, its high growth rates being a plus. Branching corals of the family Pocilloporidae and Acroporidae are categorized as opportunistic species that have the ability to settle in many locations (Lam 2003). It is strongly suggested to use only dominant species of corals as these are likely to be much stronger and more resilient (Gomez et al. 2010).

The nursery site should have similar conditions to donor and rehabilitation sites, and should provide for easy access, for maintenance and monitoring purposes.

For general information about suitable areas for rehabilitation, consultations with the local communities and local dive operators should be conducted.

Further general surveys then need to be conducted at suggested sites to assess individual site suitability for the proposed rehabilitation activities. Basic physical parameters (salinity, Dissolved Oxygen, temperature, turbidity, etc) and sediment characteristics will also need to be determined and assessed. The distance and accessibility of the proposed sites also need to be taken into consideration. This is important for later monitoring and maintenance of the corals.

Transplanting Method

The objective of this project is to rehabilitate a badly damage reef. The concept of this rehabilitation is to create a mini-ecosystem by transplanting corals to a secure and solid platform. It is recommended that all material used is submerged underwater for 4-7 days, or until a layer of transparent algae is formed. This is to ensure the materials used do not leach chemicals that will affect the recovery and growth process of the nubbins.

Once all pre-setup activities have been conducted, nubbins will be collected and kept in individual ziploc bags to avoid abrasion. The collection activities should be supervised by an individual with suitable training or experience. Nubbins must be collected carefully, by suitably qualified, experienced and trained divers, to minimise handling of the nubbins and avoid damaging the donor reef ecosystem. Once the pre-determined number of nubbins has been collected, they must be transported as quickly as possible to the nursery site, minimizing exposure to sunlight and elevated temperature, and they must not be allowed to dry out.

Once transported to the nursery site, nubbins will be attached to the nursery platform. The attachment of the nubbins will be conducted underwater at the chosen site. The nubbins will be tied to the PVC frame using a cable tie. After a few months, each nubbin will start to overgrow the cable tie and establish itself by building calcium carbonate cement around it and also onto the PVC.

Maintenance and monitoring

Maintenance of the nursery must be conducted. Initially this must be conducted twice a week, reducing in frequency as the nursery becomes established.

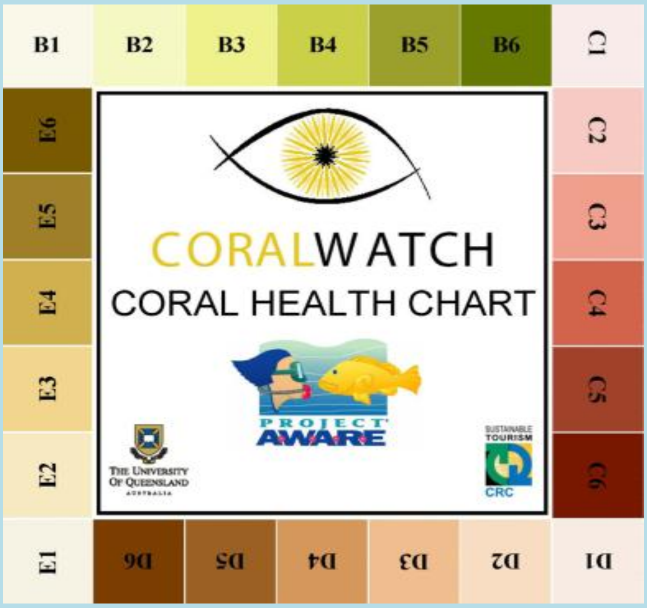


Figure 2: The coral health chart will be used to assess the progress of the coral nubbins.

Maintenance will use simple methods such as brushes to clear silt and algae from the nursery frame, to avoid the build-up of silt and algae that would smother and kill the nubbins. Any encrusting organisms, such as barnacles and oysters, on or around the nubbins will need to be removed.

Monitoring must be conducted monthly to assess the progress of the nursery. Monitoring will use a coral health chart (Figure2) to assess the condition of the nubbins. The growth rate of the nubbins will also be assessed by measuring the length of a representative selection of the nubbins from the base to the tip of the nubbins. The data must be recorded and sent to the principle scientist for further evaluation.

Rehabilitation

After a period of six to 12 months, depending on survival and growth rates of nubbins, the nurseries are ready for transplant to the rehabilitation site. This methodology recommends transplanting the entire nursery (excluding legs or other supporting structure).

Additional rock and other substrate, together with other growth forms of corals, should be incorporated into the rehabilitation site so that it resembles as far as possible a natural reef. This will increase the rate of occupation by other marine organisms.

Field Trials

Phase 1: Pulau Pangkor - Pilot

Reef Check Malaysia's first reef rehabilitation project was carried out near Pangkor Island, Perak. The nursery site was established at Pulau Pangkor Laut in October 2010, and the rehabilitation site was identified as nearby Pulau Mentagor.

Nursery Design

The initial nursery design comprised four matrices of PVC plastic pipes attached to plastic pallets measuring approximately $1m^2$ (Figure 3).

Figure 3: Four matrices on a pallet

Each matrix was approximately 50cmX45cm in size, with coral holders located 15cm apart (Figure 4). Three nurseries were moored to the seabed using anchors, and suspended in the water column using floats, to a float at a constant depth of approximately 5m. Prior to establishing the nursery, site selection was conducted to ensure similar conditions at donor and nursery sites and to provide ease of accessibility for cleaning and maintenance.

Nursery Installation

Live coral fragments (nubbins) were collected from the donor site (an area of healthy reef nearby) and transported to the nursery site. Nubbins were installed into holders and secured using non-toxic plasticine. Handling of nubbins was minimised during collection, transportation and re-planting. Exposure of nubbins to sunlight and air was avoided at all times, and transport/handling time minimised. These precautions are crucial to minimise stress to the nubbins.

During this nursery stage, the nubbins were cleaned and maintained regularly (twice weekly) to keep them clear of silt and algae (that would smother and kill the nubbins) and to remove growth of other organisms that could interfere with growth of the nubbins. Monitoring was conducted monthly to assess survival and growth rates. It is of the utmost importance that maintenance and monitoring are conducted regularly, in order to ensure the success of the rehabilitation project.

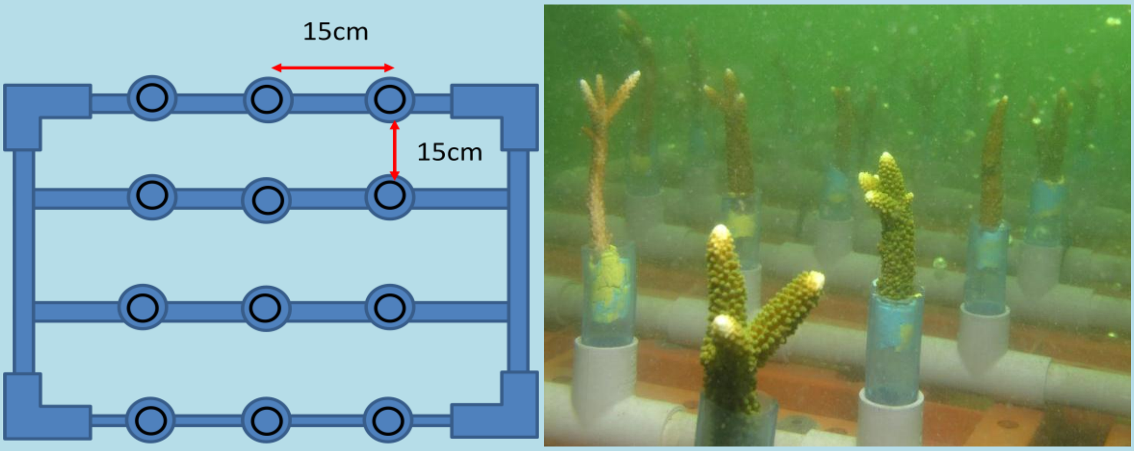


Figure 4: Matrix of PVC plastic pipes with each coral holders 15cm apart

Results

The initial survival rate of nubbins recorded was 70-75% after three months, which exceeded expectations (all data are presented in appendix 1). The nursery had also started to establish a mini-ecosystem, with small fish and various invertebrates taking up residence among the nubbins.

The condition of the nursery deteriorated during the following three months. Two problems were identified:

- The nurseries were located too close to the seabed which was silty, resulting in some nubbins being smothered
- The nurseries were situated too deep in the water, resulting in lack of sunlight penetration which corals need to produce nutrients.

Mitigation steps were taken and mortality rate was reduced. However, shortly afterward refurbishment of a jetty close to the nursery site once again caused some nubbins to die. Nevertheless, the overall results from the nursery trial were sufficiently encouraging to continue with the rehabilitation efforts.

After one year (in November 2011) the frames from the nursery were transferred to the rehabilitation site (at which time all dead nubbins were replenished). The pallets carrying the nursery frames were anchored to the bottom of a degraded reef area using steel rods.

After three months at the rehabilitation site, the survival rate of nubbins recorded was 100%. Corals showed signs of growth and numerous fish and invertebrates had taken up residence (Figure 5).

Figure 5: 100% survival rate and marine life taking up residence

Unfortunately, the design of the nursery, supported on a plastic pallet, allowed strong local currents to wash them away. A new frame design was tested, which allows currents to pass around the nursery frame without much resistance, thus reducing the chances of it being moved (Figure 6).

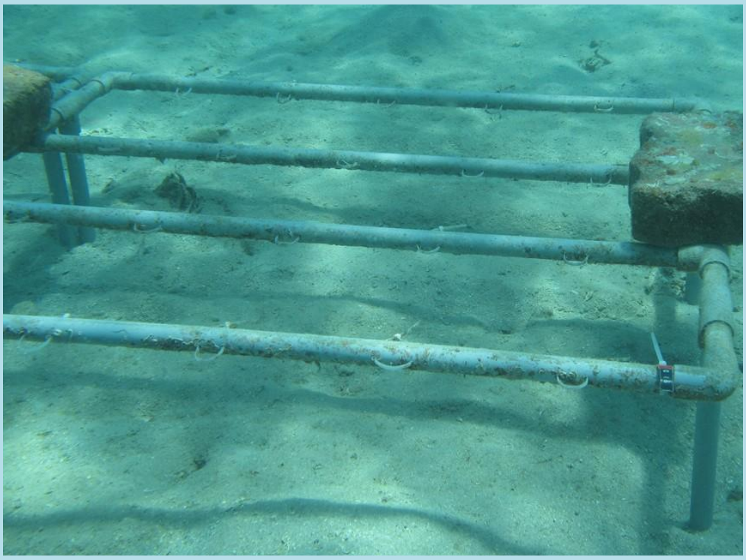


Figure 6: New frame design without the pallet.

However, even this frame design proved unsuitable for local conditions, and the new frames were also washed away.

Despite these problems with frame design and installation stability, results to date indicate that harvested nubbins will grow in the waters around Pangkor (see table 1).

Table 1: Summary of Nubbin Survival Rates, Pangkor

Location	Installation date	No Frames	Nubbin Survival (%) After:			
			3 mths	6 mths	9 mths	12 mths
Pangkor	November 2010	12	72.22	92.4	69.0	n/a

The data on nubbin survival at the first experimental site in Pangkor are inconsistent over the 12 months of the existence of the nursery, due to the need to continually replace nubbins which died as a result of various external factors.

However, lessons learned were continually incorporated into nursery management (eg., re-locating nurseries after it was learned they were too deep) and subsequent results suggest that rehabilitation efforts could play a part in improving reef sites around Pangkor, bringing benefits to the local tourist snorkelling market. Experiments continue to find a nursery structure suitable for local conditions.

Appendix 1 shows a comparison between the various rehabilitation sites.

Phase 2: Tioman (1)

Once the nursery-based approach to rehabilitation was proven, a second project site was established on Pulau Tioman, off the coast of Pahang, in June 2011.

Nursery Design

The initial nursery frame design was a matrix of pipes similar to the one used in Pangkor, with two improvements (Figure 7):

- Nubbins were secured to the frames using cable ties instead of the PVC pipes and rubber hoses originally used in Pangkor, as the latter limits the size of nubbins that can be installed. The convenience of this method led to its being incorporated into the standard methodology, and into modified designs in Pangkor.
- The frames were arranged in rows and placed on top of bricks instead of a plastic pellet, to lift them off the bottom.

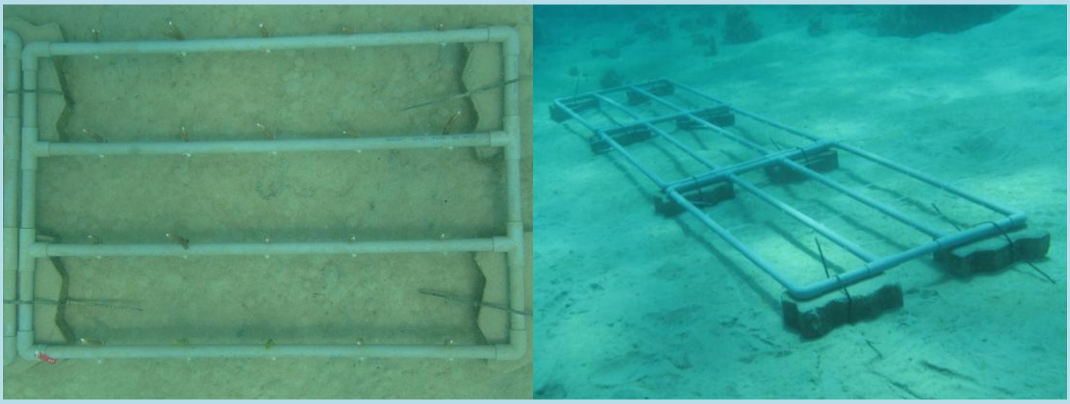


Figure 7: Matrix of PVC pipes with each length holding up to 5 nubbins secured with cable ties. Frames arranged in rows, raised on bricks.

Nursery Installation

Two locations were selected, identified closely with the nearby dive operator:

- Tekek House Reef, Kg Tekek, in front of East Divers Tioman (61 frames, June 2011)
- ABC House Reef, Kg Air Batang, in front of B&J Dive Centre (79 frames, June 2011).

Results

Figure 8: Frames were raised above the ground with legs

It was very quickly discovered that using bricks did not raise the frames high enough above the seabed. Some frames were quickly smothered by silt and others by ‘volcanoes’ of sand created by burrowing organisms. This led to high levels of mortality soon after installation. To overcome this problem, frames were raised 30cm above the seabed with legs (Figure 8) and the mortality rates recorded two weeks following the modification was almost zero.

However, because the addition of legs could only be undertaken in situ, using cable ties to attach the legs, the frames were not strong enough to withstand rough water conditions during the monsoon season later that year. As a result, some frames collapsed and some were totally submerged in the sand during monsoon, with resulting high mortality.

The frame design was therefore subsequently modified to incorporate legs into the frame itself, rather than being attached later (Figure 9). This new design is more secure, sturdier and better at withstanding strong currents. This was demonstrated in the second phase of RCM's rehabilitation project in Tioman, which saw all the frames still intact after monsoon and none collapsed.

Figure 9: New frame design with legs integrated into the frame

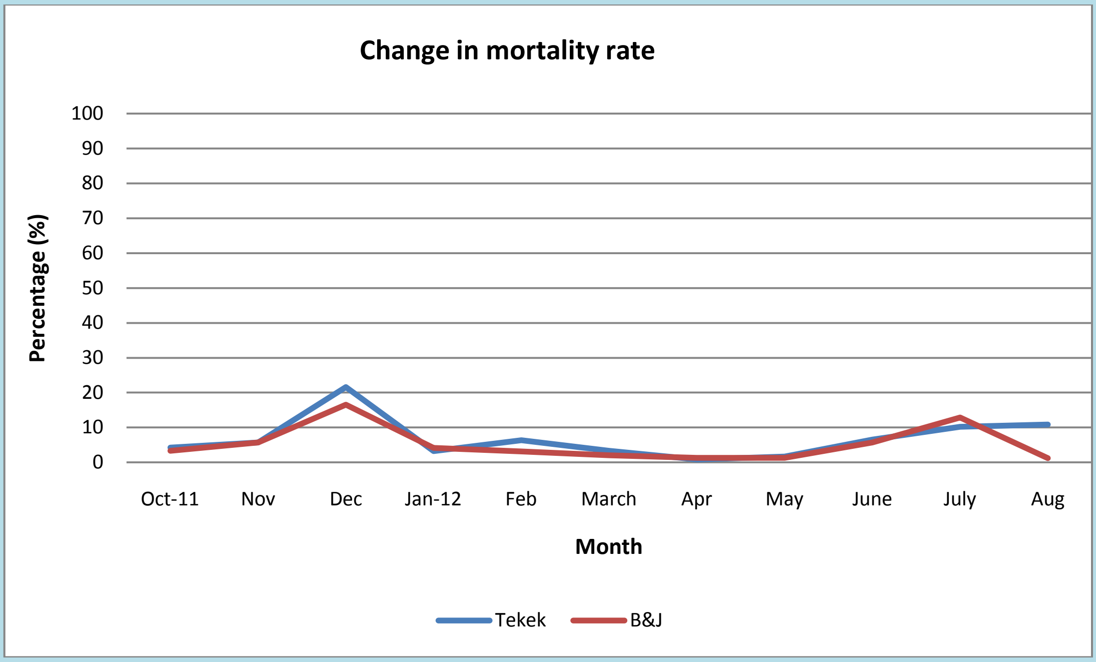
Another problem identified in the first rehabilitation project in Tioman was the impact of territorial damsel fish. Some nursery frames were located close to the edge of an existing reef, which was subsequently discovered to be too close to damsel fish territory. This fish is considered to be a "habitat engineer", creating algal 'yards' on live coral and other substrate (Figure 10) and protecting these yards against other herbivores (IUCN, 2011).

These damsel fish are recognised as being responsible for a proportion of natural coral mortality as well as retarded coral recovery (IUCN, 2011). They also caused problems during cleaning and maintenance work, attacking divers working on frames.

Frames that were affected by the damsel fish were relocated away from the damsel's territory. Although this did not completely prevent the damsel fish from using the frames to harvest their algae, it greatly reduced their impact on the frames.

Figure 10: Frames were used by territorial damsel fish to build algal 'yards'

Once these various problems had been overcome, results at these two nursery locations were better than anticipated.



Graph 1: Change in mortality rate per month

The change in mortality rate per month for nurseries at both Tekek and B&J is more or less the same throughout most of the nursery period. The big increase in the 3rd month (December) was due to the collapse of frames during the Northeast monsoon season and the relatively smaller increase in the 9th and 10th (June and July) months was due to the impact of the Southwest monsoon. Rough water conditions and heavy rain during these monsoon seasons, together with increased sedimentation and turbidity in the water column, stressed the corals and caused increased mortality. The decrease in the change of mortality rate per month at B&J after the monsoon seasons indicates that the corals were able to recover from this stress, helped by immediate repairs to the damaged frames and regular cleaning whenever the weather permitted during the monsoon seasons, and twice weekly outside monsoon seasons.

The survival rate of both nurseries at 3, 6, 9 and 12 month is shown Table 2. Appendix 1 shows a comparison between the various rehabilitation sites.

Table 2: Summary of Nubbin Survival Rates, Tioman Phase 1

Location	Installation date	No. Frames	Nubbin Survival (%) After:			
			3 mths	6 mths	9 mths	12 mths
Tekek	June 2011	61	68.4	55.6	46.6	24.3
B&J	June 2011	79	74.4	65.1	56.8	42.8

By November 2011, frames in the B&J nursery were substantially stabilised. However, mortality continued to increase at the Tekek nursery where survival was eventually very low (24%). These data reflect one of the important early lessons learned regarding nursery site selection. The site at Tekek has proven to be much more prone to silting than initially anticipated, leading to the very low nubbin survival rate. These observations have been incorporated into lessons learned and the Methodology.

Phase 3: Tioman (2) & Perhentian

The project was extended in early 2012, with new locations added in Tioman and a new site added in Pulau Perhentian. The new Nurseries incorporated all design and installation changes highlighted above plus other changes regarded as desirable, based on field experience to date and success rates.

Nursery Design

Observations of existing nursery installations suggested that by placing nubbins 15cm apart the nurseries did not resemble a natural reef. Furthermore, the time needed for individual nubbins to branch and grow towards each other to produce the networks seen in natural reefs is too long.

It was therefore decided that the distance between each nubbin should be reduced to 10cm. Diagrams of the new design, with all the necessary modifications, are shown in Figures 11 and 12.

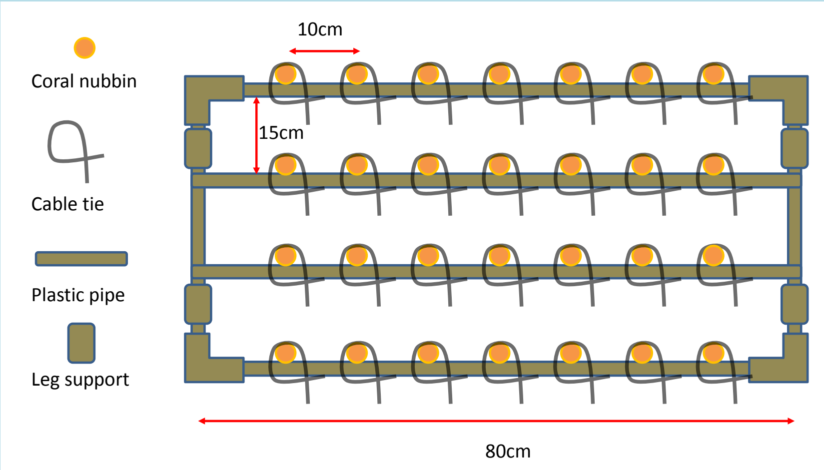


Figure 11: Top view of the frame design

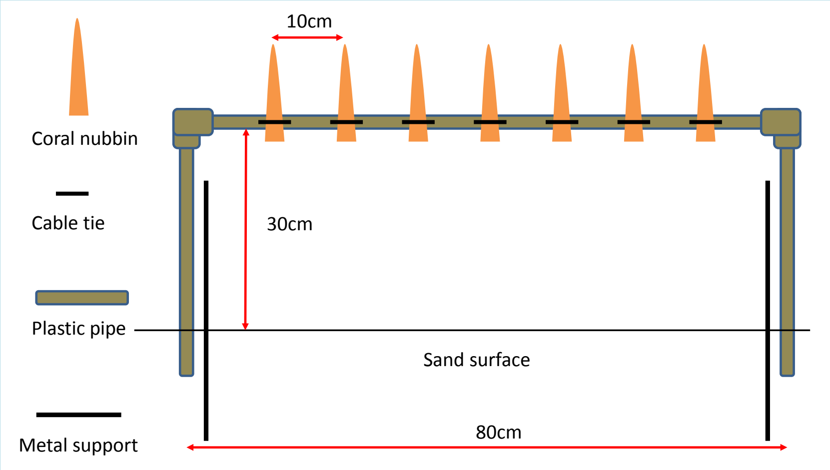


Figure 12: Front view of the frame design

A further change was to experiment with "opportunity corals", populating a few rows of the nursery frames with live broken coral fragments (regardless of growth form and species) collected from the surrounding reefs (reefs within a 50m of the nursery site). Many of these fragments were on the seabed and thus partially bleached (the side resting on the sand). Without attachment to a solid substrate, these nubbins would, over time, be abraded by natural water circulation and would die.

Nursery Installation

In Tioman, two locations in ABC House Reef were selected:

- In front of EcoDivers (40 frames, March 2012 and 30 frames, August 2012)
- In front of Nazri Resort (60 frames, April 2012)

In Perhentian, the installation was located in front of Bubbles Resort and Dive Centre (60 frames, March 2012).

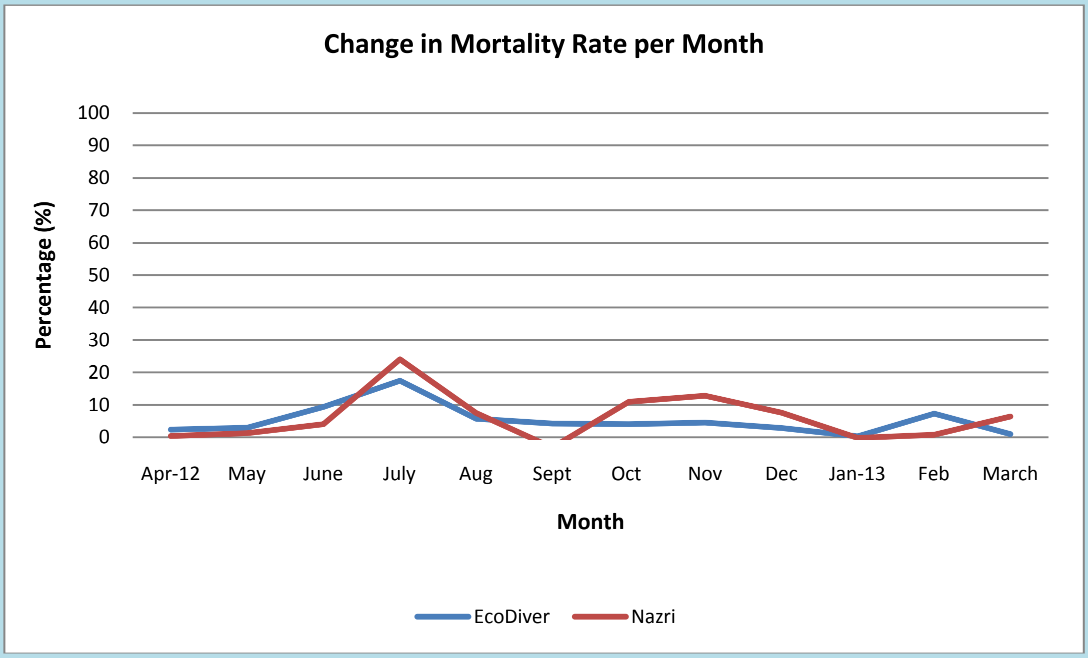
Results

Tioman

No problems were encountered with frame stability, the original design having been improved based on early experience at Tekek and B&J sites.

At the Nazri site in Tioman, survival and growth rates were much lower than other nursery locations. This site was slightly deeper than other nursery sites, close to a river mouth and more distant from surviving reef areas. As such, availability of healthy nubbins was limited and this is thought to have affected success rate. Furthermore, shortly after the installation was completed, construction started at a nearby resort, increasing siltation in the waters around the nursery. After 12 months, it was decided to abandon this site.

The change in mortality rate for the nursery at EcoDiver is similar to the Nazri site, but lower.



Graph 2: Change in mortality rate per month

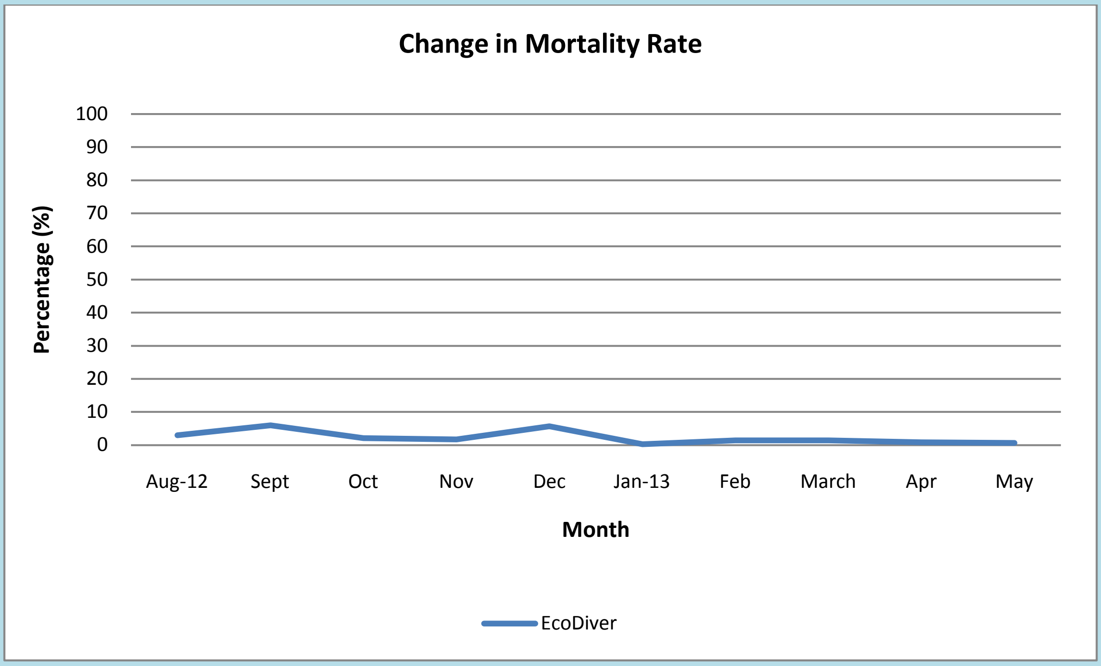
The big increase in the change of mortality rate in the 4th month (July) at both nurseries was due to the impact of the Southwest monsoon while the increase in the 7th month (October) was due to the onset of the Northeast monsoon, as reported for the earlier installations at Tioman. During both monsoon seasons, the nursery at Nazri recorded higher increases in the change of mortality rate per month. This is most likely because the nursery at Nazri was situated close to a river mouth, and therefore received a high influx of freshwater from the river during the monsoon season. This influx also caused high turbidity, both impacts leading to higher mortality rates.

The survival rate of both nurseries at 3, 6, 9 and 12 month is shown Table 3. Appendix 1 shows a comparison between the various rehabilitation sites.

Table 3: Summary of Nubbin Survival Rates, Tioman Phase 2

Location	Installation date	No. Frames	Nubbin Survival (%) After:			
			3 mths	6 mths	9 mths	12 mths
EcoDivers	Mar 2012	40	85.3	58.0	46.6	37.9
Nazri	Apr 2012	60	94.4	65.9	34.5	27.6

The second deployment at EcoDivers, constructed in August 2012, showed the lowest changes in mortality rate of all nurseries constructed to date.



Graph 3: Change in mortality rate per month

The increase in mortality rate in the 5th months (December) can be attributed to the impact of the Northeast monsoon. From the 6th month onwards, there is a clear improvement, with the change in mortality rate remaining below 1.5% per month. This nursery installation incorporated all the lessons learned from previous projects, and represents best practice to date in this location.

Survival rate at this site is correspondingly high, as shown in table 4 (see also comparison in appendix 1).

Table 4: Summary of Nubbin Survival Rates, Tioman 2

Location	Installation date	No. Frames	Nubbin Survival (%) After:			
			3 mths	6 mths	9 mths	12 mths
EcoDivers	Aug 2012	30	91.1	81.3	77.6	n/a

Perhentian

The nursery site in Perhentian was chosen partly due to the enthusiasm of the nearby resort. The site is a highly degraded reef area in front of the resort, with low coral variety and few fish. Survival rate at this site is correspondingly moderate, as shown in table 5 (see also comparison in appendix 1).

Table 5: Summary of Nubbin Survival Rates, Perhentian

Location	**Installation date**	**No. Frames**	**Nubbin Survival (%) After:**			
			3 mths	**6 mths**	**9 mths**	**12 mths**
Perhentian	Mar 2012	40	94.2	78.5	55.0	89.46

*Note: the apparent increase in nubbin survival from month 9 to month 12 is a result of the operator replacing some of the dead nubbins.

Our results and observations suggest that the abundance of a single fish species – territorial damsel fish – in this location is having a negative impact on reef regeneration. By dominating a large area of the reef, these fish deter other species from taking up residence. This reduces fish diversity, and in turn reduces coral recovery because grazers such as parrot fish are chased away from the reef area, thus increasing overall algae cover (in addition to the algal fields that the damselfish tend).

This field observation requires more detailed research because if it proves to be true, it has significant implications for reef rehabilitation efforts, for example the need to consider fish populations in site selection.

One key observation in both Tioman and Perhentian was the success of the experiment with "opportunity corals". These nubbins are demonstrably more successful than those gathered from a more distant donor site, with survival and growth rates both higher for opportunity corals. It is thought that there are two reasons for this:

- Corals collected from distant donor sites are visibly stressed by the time they are attached to coral nurseries, despite careful handling. It is thought that this is the cause of higher mortality rates among these nubbins
- Opportunity corals are precisely adapted to conditions at the nursery site (depth, salinity, water quality, temperature, etc).

Subsequent installations in the same locations adopted the practice of using opportunity corals, with the same results – higher survival and growth (see Fig 13).

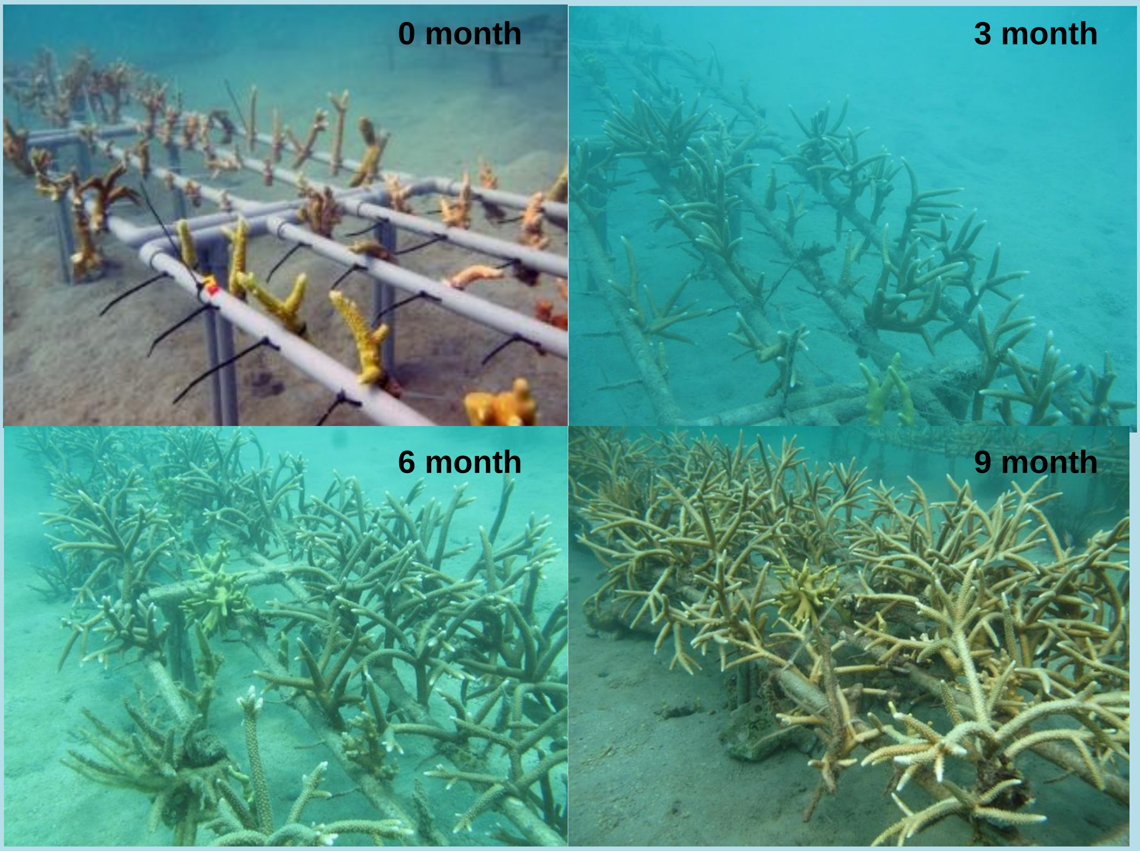


Figure 13: Nursery installation at EcoDivers using "opportunity corals", after 0, 3, 6 and 9 months

These results strongly indicate that the initiative to utilise broken coral fragments of any growth form and species is an appropriate approach to reef rehabilitation.

Phase 4: Tioman (3)

The project was extended in early 2013, with additional frames in Tioman.

Nursery Design

Nursery design incorporated all modifications highlighted above, including attached legs and smaller distance between nubbins. 100% "opportunity corals" were used.

Nursery Installation

The new frames were added to the existing nursery on ABC House Reef, in front of EcoDivers (40 frames, March 2013).

Results

No problems were encountered with frame stability.

While few monitoring data were available at the time of writing, the success of "opportunity corals" noted in Phase 4 was quickly observed at this new location, with high survival and growth rates recorded within the first two months of installation. The survival rate after 3 months at this site was over 94% (see Appendix1).

This further supports earlier observations that the initiative to fill the nurseries with “opportunity corals” – broken coral fragments of any growth form and species collected locally – is appropriate. Furthermore, it adds meaning to this reef rehabilitation project by rehabilitating degraded coral reefs using local resources, reducing the amount of nubbins to be harvested from donor site and increasing the diversity at the nurseries.

Phase 5: Rehabilitation

The ultimate goal of these experiments is to rehabilitate damaged coral reefs. One of the criteria for selection of a nursery site is that it should be adjacent to a natural reef that has been affected by natural and anthropogenic impacts, to make final rehabilitation more convenient.

After 12 months of consistent monitoring (i.e. after initial design/ installation problems had been overcome) the nurseries at Tekek and B&J were considered to be in suitable condition for transplant to a final rehabilitation site.

Therefore in early 2013, the nurseries in these two locations were dismantled and the individual nursery frames were moved to nearby degraded reef areas. Nursery frames were attached to existing natural substrate using cable ties, and where necessary rocks were brought in to the area from nearby degraded reef to provide additional substrate and anchoring points. Once frames were in place, additional coral colonies were added to the mix, again using “opportunity corals”.

Four locations were selected from which photographs of the rehabilitated area would be taken monthly, to continue to monitor site development. Figure 14 shows selected initial views of the site at B&J.

Figure 14: Selected pictures of site rehabilitation at B&J, ABC House Reef, Tioman

Monitoring of the sites will continue for 24 months to assess progress of the rehabilitated area.

Key Lessons Learned

As our rehabilitation experiments have progressed, we have identified the following key lessons learned:

Frame design

- Allows currents to pass through without much resistance
- Allows easy attachment of nubbins
- Legs incorporated into the frames and supported by angle iron rods of 60cm length to provide stability and prevent movement
- Small distance between nubbins (approx. 10 cm)
- Raised above the bottom to avoid siltation/smothering.

Site selection

- Easily accessible to reduce costs
- Avoid fine sediment areas to limit siltation (consider conducting silting tests before establishing nurseries)
- Avoid strong currents (if possible – depends on location)
- Adjacent to a damaged reef area
- Far away from damsel territory.

Source of nubbins

- Broken corals (“opportunity corals”) from the reefs surrounding the nursery location as they have been found to have higher survival and growth rates; dead part of such broken corals must be removed before attaching to the frames.

Maintenance

- Regular maintenance (twice a week for at least first two months, and once a week thereafter for up to a year) to periodically remove silt, ascidians, hydroids, bivalves and algae to prevent competition with the growth of coral nubbins
- Use soft brush to avoid abrading nubbins (which themselves should NOT be cleaned).

Monitoring

- Monthly monitoring to monitor success of the project – record survival rate of nubbins and growth rate of selected nubbins.

This experience was incorporated into the third phase of the rehabilitation programme in Tioman. Encouragingly, the survival rate of the nubbins was high at 77% after 9 months of deployment. Corals at two rows of the frames were interlocking with corals from the next row and immediately at their side and forming a natural 3-dimensional reef structure (Figure 15). Extra angle irons were added to each leg to support the weight of the corals.

Figure 15: Corals forming a natural 3-D reef structure

Conclusion

Reef Check Malaysia's reef rehabilitation programme has numerous benefits beyond simply rehabilitating areas of reef, principally involvement of local communities in the project and providing numerous education and awareness opportunities.

Although numerous problems have been encountered (e.g. siltation, securing the frames to withstand bad weather conditions, high mortality rates), the lessons learned have been incorporated into subsequent phases, and results obtained continue to improve. Survival rate of nubbins is increasing, corals are overgrowing cable ties and frames in a short period of time, many natural recruits are settling on the frames, fish and invertebrates are taking up residence at the nursery and rehabilitated sites, and the corals at the nursery are growing and forming a natural 3-D reef structure.

As noted in the introduction, it is widely accepted that protection should remain the focus of management efforts due to the high cost of reef rehabilitation projects. However, it is also recognised that rehabilitation can contribute to at least slowing the rate of decline and at best increasing coral cover, with recovery of the associated ecosystem.

RCM will continue its experiments with coral nurseries and coral reef rehabilitation to improve upon the existing approach, and to test other approaches suitable to the local conditions. The focus will remain on community-based, low cost approaches to rehabilitation.

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Appendix 1

Survival rate of nursery at different sites and phase

Location	Installation date	No. Frames	Nubbin Survival (%) After:			
			3 mths	6 mths	9 mths	12 mths
Pangkor Laut Resort, Pangkor	Oct 2010	12	72.22	92.4	69.0	n/a
Pulau Mentagor, Pangkor	Nov 2011	12	100	100	43	0
Tekek, Tioman	Jun 2011	61	68.4	55.6	46.6	24.3
B&J, Tioman	Jun 2011	79	74.4	65.1	56.8	42.8
Perhentian	Mar 2012	40	94.2	78.5	55.0 *	89.46
EcoDivers, Tioman	Mar 2012	40	85.3	58	46.6	37.9
Nazri, Tioman	Apr 2012	60	94.4	65.9	34.5	27.6
EcoDivers, Tioman	Aug 2012	30	91.1	81.3	77.6	n/a

*Estimate