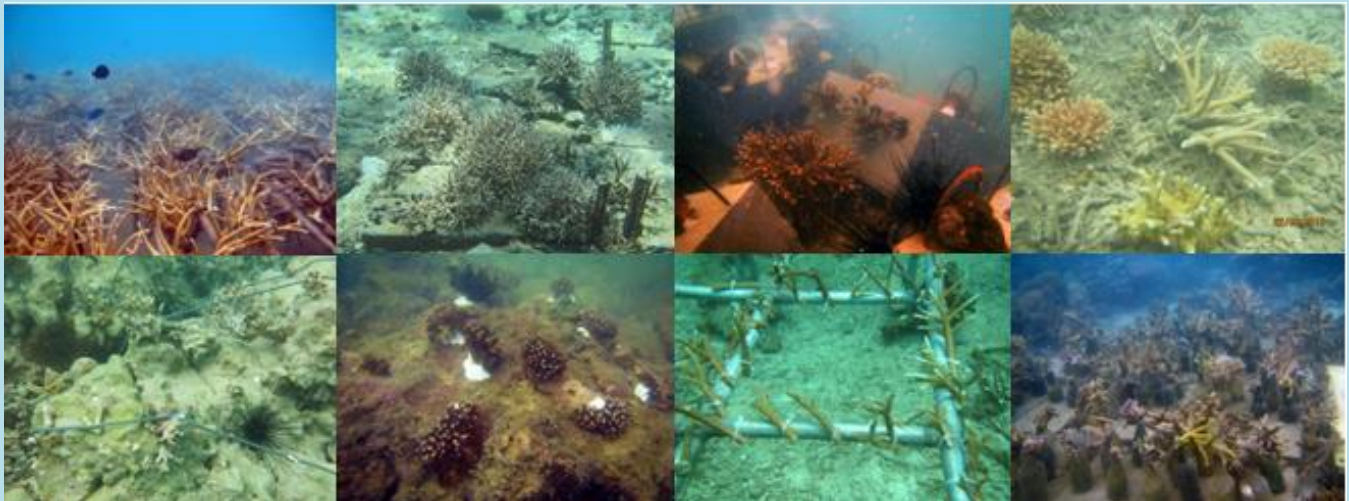




Reef Rehabilitation Experiments Edition 2: *A Review of Various Approaches*



Reef Check Malaysia

Saving Our Reefs
Research, Education, Conservation

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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 95 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 at www.reefcheck.org.my/reports-downloads/annual-survey-reports). In the last ten years RCM has trained over 780 divers to conduct reef surveys at over 200 permanent monitoring sites on coral reefs around Peninsular and 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 Pangkor, Perhentian, Tioman, Sibu and Mantanani islands to involve local communities in coral reef management. Since 2010, 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, Reef Check Malaysia was approached by a group of snorkelling guides from Pangkor Island who were concerned about the condition of 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 snorkelling guides asked if Reef Check Malaysia could help to improve the sites, and we agreed to try. Thus began our first experiment in coral reef rehabilitation. Since then, we have tried many designs at different locations, 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 updates an earlier edition, reviews our 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.

As part of initiatives to conserve remaining coral reefs in Malaysia, in 2010 Reef Check Malaysia embarked upon a series of reef rehabilitation experiments, starting in Pangkor Island. In 2011, RCM extended the project to Tioman and Perhentian Islands, and Redang and Mantanani Islands in 2012.

Reef rehabilitation is the act of partially replacing the 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 attempting to rehabilitate coral reefs 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 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. Diagram 1 is a guideline that can be used to determine the suitability of a proposed restoration project.

Designs

The approach to restoration used by Reef Check Malaysia focuses on creating a “mini-ecosystem”, in which individual coral fragments (nubbins) are planted together to form a mini-ecosystem, rather than transplanted as widely spread individual coral nubbins.

During our initial reef rehabilitation projects using our first nursery design (PVC plastic pipe frame), coral fragments (nubbins) were kept in a nursery stage for 1-2 years before transfer to final transplant site (rehabilitation site). We believed this approach would allow nubbins time to rest, recover (from stresses produced during the process of gathering and attaching them to the frame) and grow before further disturbance resulting from final transplantation, thus increasing their chances of their survival. As a result, we chose PVC pipe over cement for the nursery, because it is low cost, readily available, easy to cut and assemble and lightweight (therefore easy to deploy and move from nursery to rehabilitation site). We also believed PVC pipe would be a suitable surface onto which new corals would recruit because of its relatively inert characteristics.

However, we have learned from experience that:

- PVC plastic pipe is not a good material for reef rehabilitation projects, and
- Moving corals from nursery site to rehabilitation site is not a good approach.

These findings (discussed in more detail in the following sections) have been incorporated into on-going projects. In subsequent designs we no longer use PVC plastic pipe frames. Further, the rehabilitation site is selected as the work site from the beginning of the project; where once the

nursery structures would be deployed and nubbins subsequently transplanted, any structures are located permanently and will not be moved around. The different designs that we have experimented with and the results obtained are discussed in the following sections.

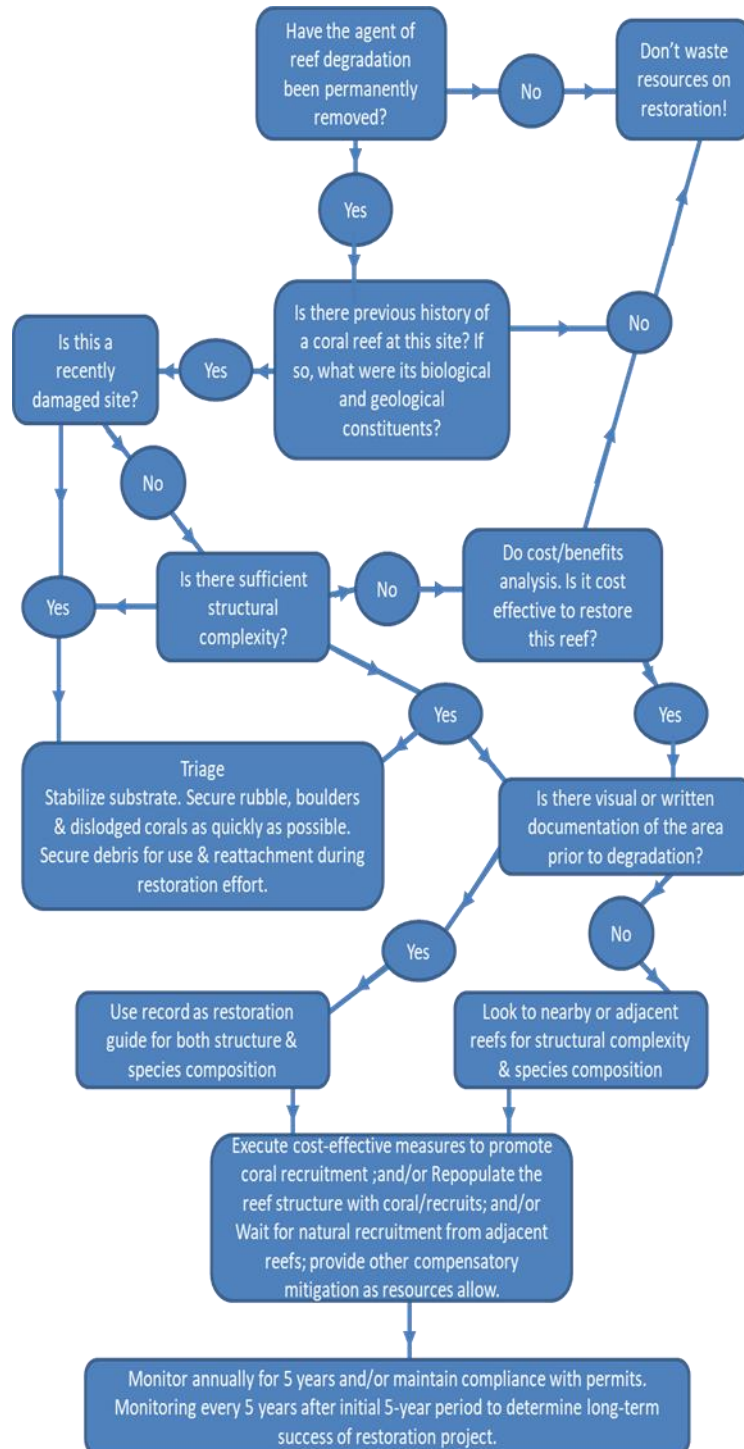


Diagram 1: Guideline to determine the suitability of a proposed restoration project (Precht & Robbart 2006)

Site Selection: Donor & Rehabilitation

A rehabilitation site needs to be identified. As mentioned earlier, coral reef restoration is the return of an ecosystem to a close approximation of its condition prior to disturbance, therefore rehabilitation sites chosen by Reef Check Malaysia comprise degraded reef areas damaged by natural or human impacts.

Coral fragments used for the reef rehabilitation project are “opportunity corals” – live broken coral fragments from the surrounding reefs. 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 any living coral would die. These nubbins are demonstrably more successful than those gathered from a more distant donor site, with both survival and growth rates 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), hence grow more rapidly.

Therefore the donor site should be reefs within 50m of the rehabilitation site. Opportunity corals are collected regardless of growth form and species (for diversity and to mimic existing reefs) but should be approximately hand (palm) size (to increase survivability).

Maintenance and monitoring

Maintenance and monitoring are a vital part of the reef rehabilitation project.

Maintenance uses simple methods such as brushes to clear silt and algae from the nursery structure, 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. Regular maintenance is important to ensure corals and the structures are in good condition. Initially maintenance is required 2-3 times per week, reducing in regularity as nubbins attach and become established.

Monitoring must be conducted regularly to assess the progress of the reef rehabilitation and to demonstrate whether the design of the project is a success. It also allows us to document findings and observations which are crucial for future reference. After installation, monitoring should ideally be conducted monthly for six months and thereafter quarterly.

Field Trials

Design 1: PVC Plastic Pipe Frame

Reef Check Malaysia's first reef rehabilitation design was a matrix of PVC plastic pipes measuring approximately 80cm X 45cm in size and 30cm in height (Figure 1a and b). The frames were arranged in rows and the legs were supported by angle iron rods of 60cm length with 30cm length of the rod anchored into seabed to provide stability and prevent movement (Figure 2).

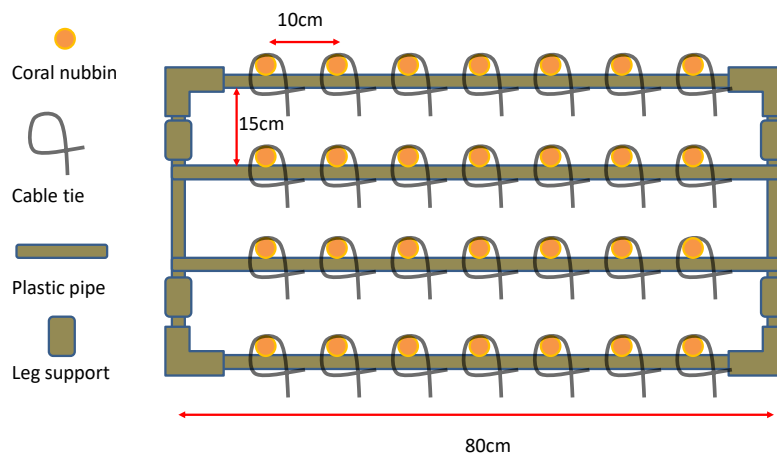


Figure 1a: Top view of the frame design

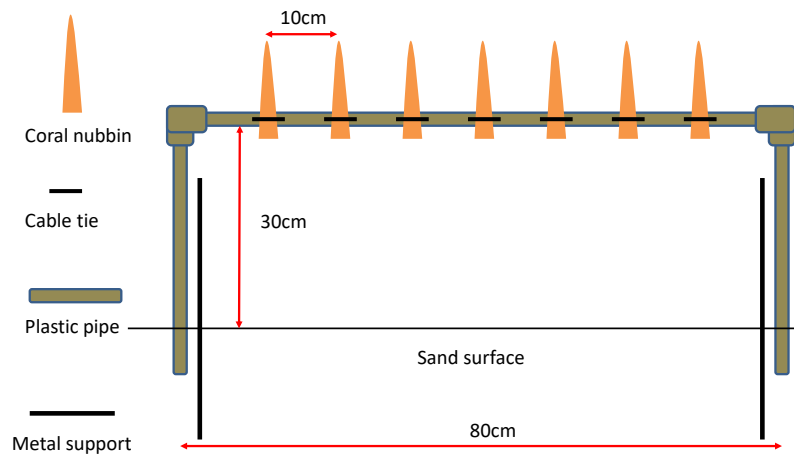


Figure 1b: Front view of the frame design

The frames were deployed at depths around 5-7m, adjacent to the edge of nearby reefs. We subsequently learned to locate the frames further away to avoid damsel fish, which aggressively defend their territory, preventing other fish from colonising the nurseries and discouraging algae grazers, resulting in excessive algae growth on the frames.

“Opportunity corals”, live broken coral fragments (regardless of growth form and species) above palm size were collected from the surrounding reefs (within 50m of the nursery site) and secured to the frames using cable ties (Figure 2). Exposure of nubbins to sunlight and air was avoided at all times by carrying out the whole process underwater.

During the first two months, the frames 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. Cleaning and maintenance were then reduced to once per month. Monitoring was conducted monthly to assess survival and growth rates.



Figure 2: Frames arranged in rows, with opportunity corals secured to frame with cable tie

After 1-2 years, depending on the readiness of the corals, the rows of frames were gathered together (Figure 3) and tied next to each other, creating a new reef of approximately 100m² at the rehabilitation site (Figure 4). Frames were tied together using fishing line (Figure 5) and all of the legs of the frames located at the periphery of the “new reef” area were secured with angle iron rods (Figure 6). This process is taxing because the frame is heavy after the corals have grown in size. Some corals from one frame are interlocking with corals from the next frame, creating more difficulties and complexities during relocation. The corals also inevitably will be stressed during the process.



Figure 3: Rows of frames were gathered together



Figure 4: Each frame was tied to one another using fishing line



Figure 5: A “new reef” of approximately 100m² at the rehabilitation site was created when all of the frames were gathered together and tied to each other



Figure 6: All legs of the frames at the edge of the “new reef” area were secured with angle iron

The cost of this design is low, approximately RM60 per nursery unit. However, it is only suitable for use in sheltered areas with very mild currents. The design is not good at withstanding strong currents and areas of the seabed with a lot of sand movement; strong current breaks the frame and sand

movement causes the frame to fall over. The PVC pipes are also easily damaged, for example by boat anchors and tree trunks. Once the PVC pipes are damaged, whether by natural or human impacts, pieces of broken PVC pipes are scattered around the reefs and some get washed up onto the shore, leaving behind a lot of plastic debris on the reefs and along the shore.

Contrary to expectations, PVC plastic pipes are not good at attracting coral recruits. On the other hand, in areas with high nutrient levels and near to damsel fish territory, the PVC plastic pipes attract extensive algae growth, as well as bio-fouling organisms such as bivalves and tunicates which often out-compete coral growth. As a result, high maintenance is required in order to ensure survivability of corals.

Despite these weaknesses, we have experienced considerable success using PVC frames to grow nubbins and create small reef areas. However, it is a labour intensive approach. Figure 7 shows pictures of selected reef rehabilitation sites.



Figure 7: Rehabilitation site using PVC plastic pipe frame

Design 2: Concrete Block

In Pangkor, which has strong currents, concrete blocks were used to replace the PVC frames as nursery structures in two locations – the original transplant site at Pulau Mentagor and adjacent to the resort jetty itself.

The blocks measure 50cm X 50cm x 30cm and have 16 holes in the surface for coral planting and four side-to-side channels to allow currents to flow through without disturbing the block, which also provide fish habitat (Figure 8). The concrete blocks were made using a special mixture of Pulverised Fuel Ash (PFA) that enhances the durability of concrete and its ability to resist seawater chloride attack. PFA is a substitute material for normal concrete mixture which makes it 'green cement'. Four handles were incorporated into the top of the blocks for lifting and handling purposes and at the bottom four corners of the concrete block metal rods of 60cm length were inserted with 30cm length sticking out to penetrate the substrate and eliminate movement on the seabed (Figure 8). The concrete blocks were deployed at 5-7m depth on coral rubble area using a barge.

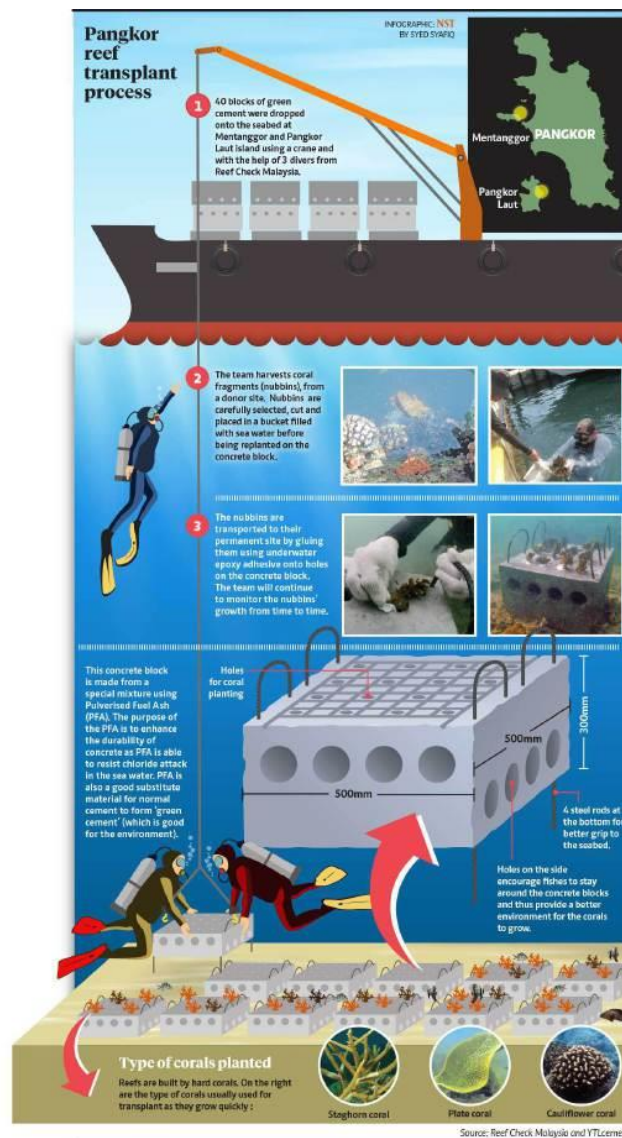


Figure 8: Graphics detailing the design of block, materials and deployment.

“Opportunity corals”, live broken coral fragments (regardless of growth form and species) above palm size were collected from the surrounding reefs (reefs within 50m of the nursery site) and the resort jetty. They were secured to the concrete blocks using underwater epoxy (Figure 9). 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. Monitoring and maintenance were conducted every 3 months to assess survival and growth rate.

The heavy weight of the concrete block (approximately 120kg) has proven very good at withstanding the strong currents in the area. The materials used to make the concrete blocks are very good at attracting coral recruits (Figure 10) and the holes in the sides of the blocks successfully attract fish, sea cucumbers and sea urchins, which make good use of the holes as shelter (Figure 11). The concrete blocks require low maintenance as they attract very slight algae growth. Pictures of the reef rehabilitation site are shown in Figure 12.

The cost of this nursery design is very high. The special mixture of PFA cannot be easily obtained from ordinary hardware suppliers thus the blocks need to be manufactured by cement companies. The heavy weight of the concrete blocks requires truck, crane and barge with crane for transportation and deployment. Although the heavy weight of the blocks is good to secure them to the bottom, it can be an issue if the blocks need to be moved. The underwater epoxy used to secure the coral nubbins onto the blocks is very expensive, not easily obtained and takes time to harden, thus coral nubbins can easily get dislodged before setting.

This said, we have achieved some success in those installations which have used concrete blocks as the nursery substrate. Additional work needs to be done in different areas to further test this approach.

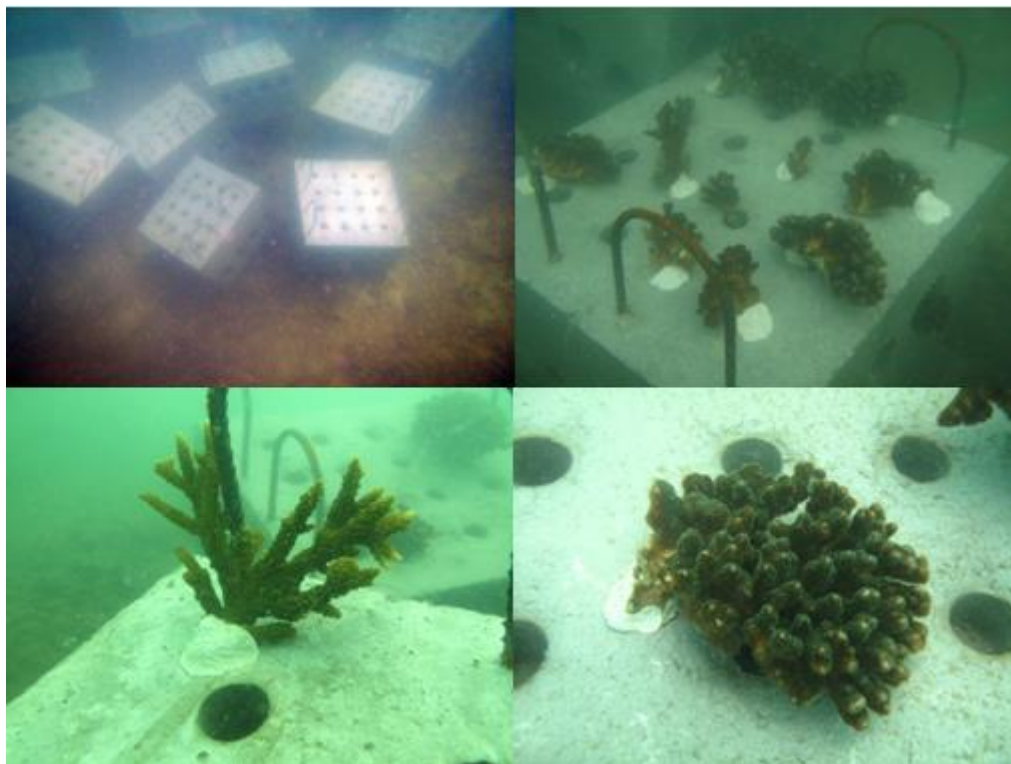


Figure 9: Photos showing new blocks deployed on coral rubbles area with coral nubbins planted using underwater epoxy (white coloured patch).



Figure 10: New natural coral recruits settling on the blocks



Figure 11: Sea cucumber using the hole at the side of the block as shelter



Figure 12a: Rehabilitation site using concrete cubical block

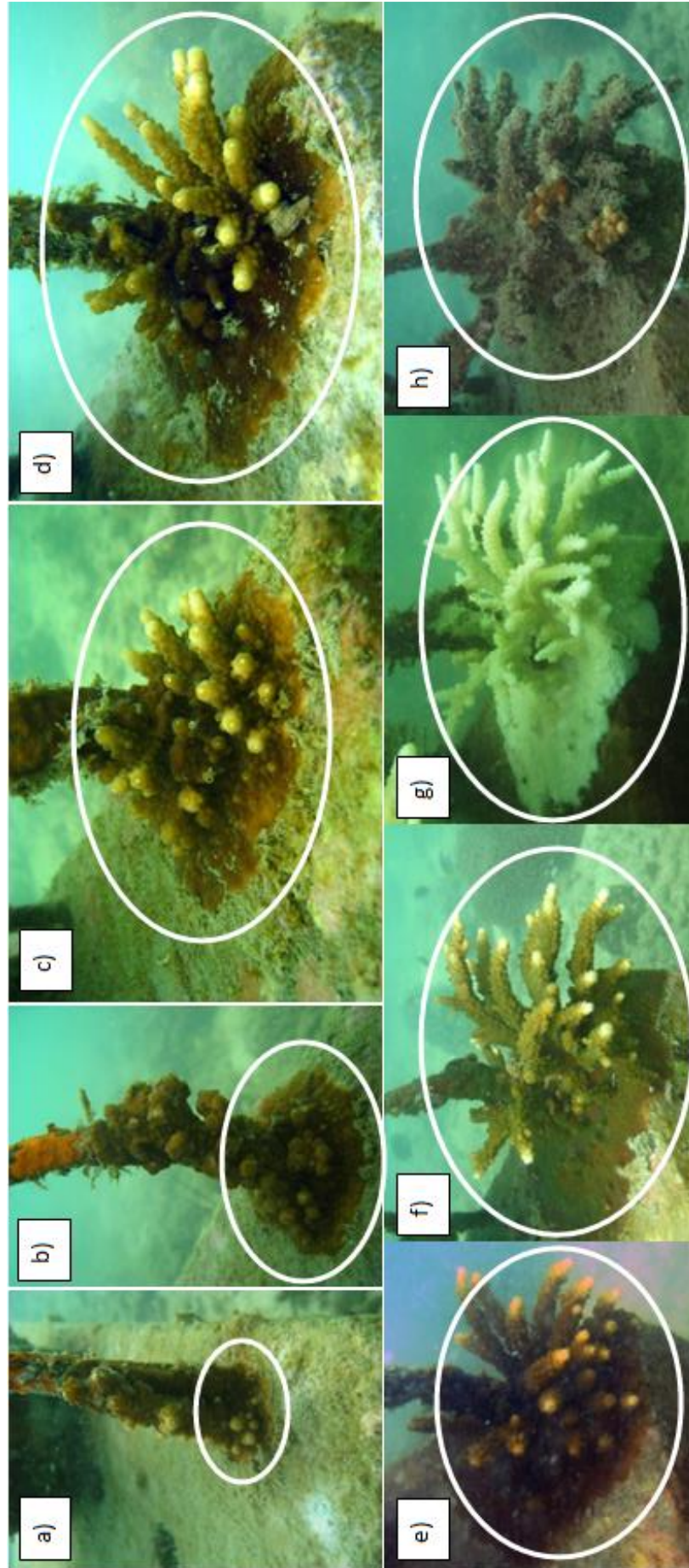


Figure 12b: Sequential photos showing progress of one of the corals since its recruitment until its death due to the bleaching event which happened in June 2016. From right: a) January 2014; b) May 2014; c) November 2014 (coral branching out); d) February 2015; e) July 2015 (secondary branching was observed); f) February 2016; g) June 2016 (100% colony bleached); h) November 2016 (90% of coral colony died and covered with silt).

Design 3: Cement Block

Cement blocks measuring 39cm X 18cm x 10cm were fabricated with eight holes on the surface for coral planting (Figure 13a, b and c). The cement blocks were made from a mixture of cement, sand and water and weigh around 1-2kg. They were deployed at 6-8m depth on damaged reefs in clusters of 10 blocks arranged closely together. At the four corners of each cluster, 60cm-long angle iron rods were anchored into the seabed (to a depth of 30cm) to prevent movement. Rocks were placed at all sides of the cluster of cement blocks to provide extra stability (Figure 14). "Opportunity corals" were collected and glued to the cement blocks using a mixture of grey and white cements and Coca-cola. Handling of nubbins was minimised during collection, transportation and re-planting. Exposure of nubbins to sunlight and air was avoided at all times by carrying out the whole process underwater. Monitoring and maintenance were conducted every month to assess survival and growth rates.

The weight of the cement block is heavy enough to withstand local currents and at the same time light enough to be transported on land, deployed and moved around underwater. The materials used to make the concrete block are very good at attracting coral recruits and require low maintenance as the blocks attract very slight algae growth. The cost of this design is very low, costing approximately RM8 per unit. All the materials used to make the cement block and glue can be easily obtained from ordinary hardware shops. Pictures of the reef rehabilitation site are shown in Figure 15.

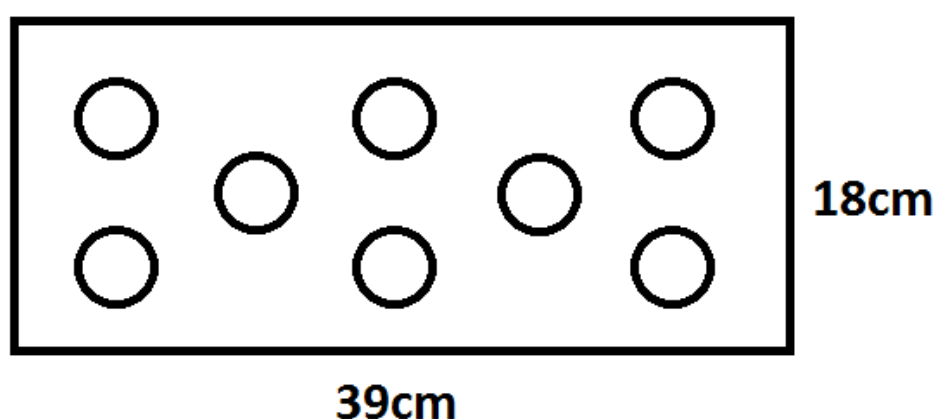


Figure 13a: Top view of the cement block design

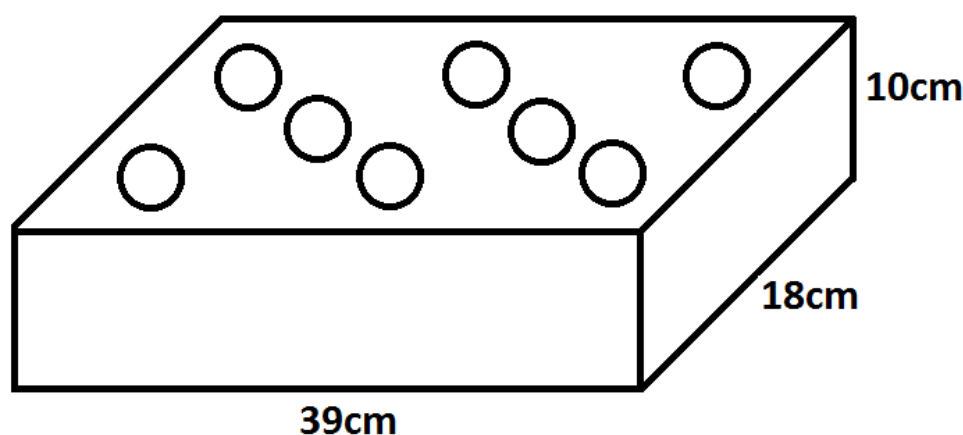


Figure 13b: Side view of the cement block design



Figure 13c: Cement block

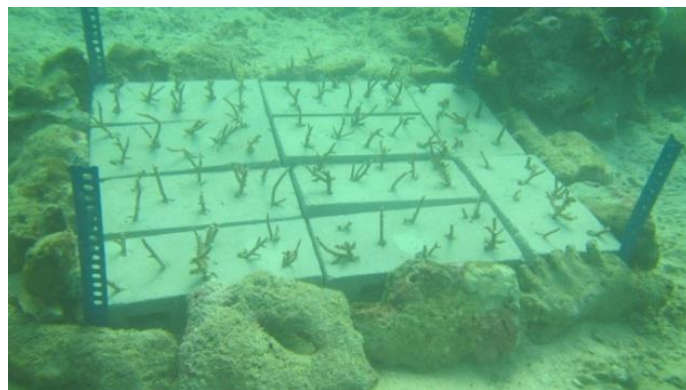


Figure 14: Cement blocks arranged closely in a cluster of 10 blocks, secured by angle iron rods and rocks

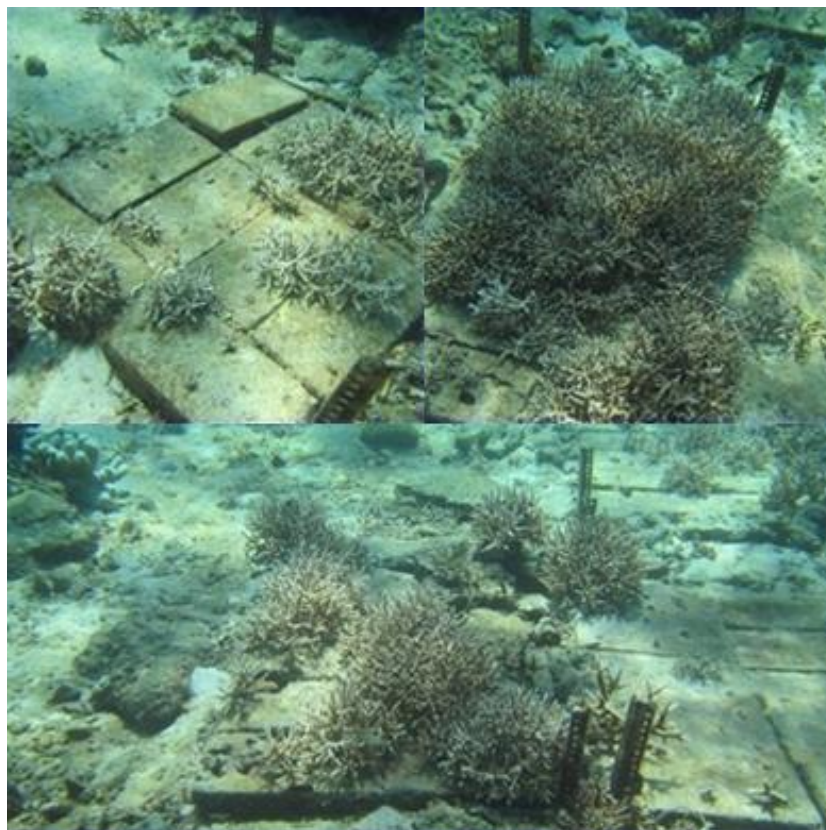


Figure 15: Rehabilitation site using cement block

Design 4: Wire Mesh

Pieces of wire mesh measuring 1m x 1m (mesh size approximately 2cm²) were deployed on areas of heavily degraded reef, mainly comprising coral rubble. The sheets of mesh were secured with U-shaped rebar spikes and cable ties. “Opportunity corals” were tied to the wire mesh with cable ties (Figure 16). Handling of nubbins was minimised during collection, transportation and re-planting. Exposure of nubbins to sunlight and air was avoided at all times by carrying out the whole process underwater.

The cost of this design is low and it is good for securing and stabilising coral rubble, providing a better substrate for reef regeneration than un-consolidated, mobile rubble. However the steel wire mesh oxidises and rusts after a relatively short period of time (after 6 months) and in our trial sites the soft structure of the wire mesh broke down before the underlying coral rubble was able to cement together and stabilise. A larger diameter and tougher steel wire mesh needs to be used in order for coral rubble to stabilise and coral nubbins to attach onto the stabilised rubble before the wire mesh degrades. Pictures of the reef rehabilitation site are shown in Figure 17.



Figure 16: Opportunity corals tied to wire mesh with cable tie



Figure 17: Rehabilitation site using wire mesh

Design 5: Nylon Rope

Nylon rope of 5mm diameter was tied firmly around existing natural rock and non-living substrate, with no “slack” that would allow movement of the rope in currents. “Opportunity corals” were tied to the nylon rope with cable ties and oriented to ensure contact between the nubbin and natural rock (Figure 18) to expedite the process of corals attaching onto the rocks (Figure 19). Handling of nubbins was minimised during collection, transportation and re-planting. Exposure of nubbins to sunlight and air was avoided at all times by carrying out the whole process underwater.

The cost of this design is very low. The flexibility of the rope enables the rope to be tied around natural structures such as rock and large dead corals which are suitable structures for coral nubbins to attach onto. Coral nubbins were observed to quickly overgrow the rope and attach onto the natural structures (Figure 19). Once the coral nubbins are securely attached the excess part of the rope can be cut and removed from water. This design is very suitable in areas with a lot of bare rock or large dead corals but not in areas with high siltation as the natural structures will be fully covered with silt which will impede coral nubbins from attaching onto the structures. It is also not suitable in areas with large amounts of coral rubble because rubble is not stable and keeps moving around the seabed, preventing nubbins from attaching to, and stabilising, the substrate.

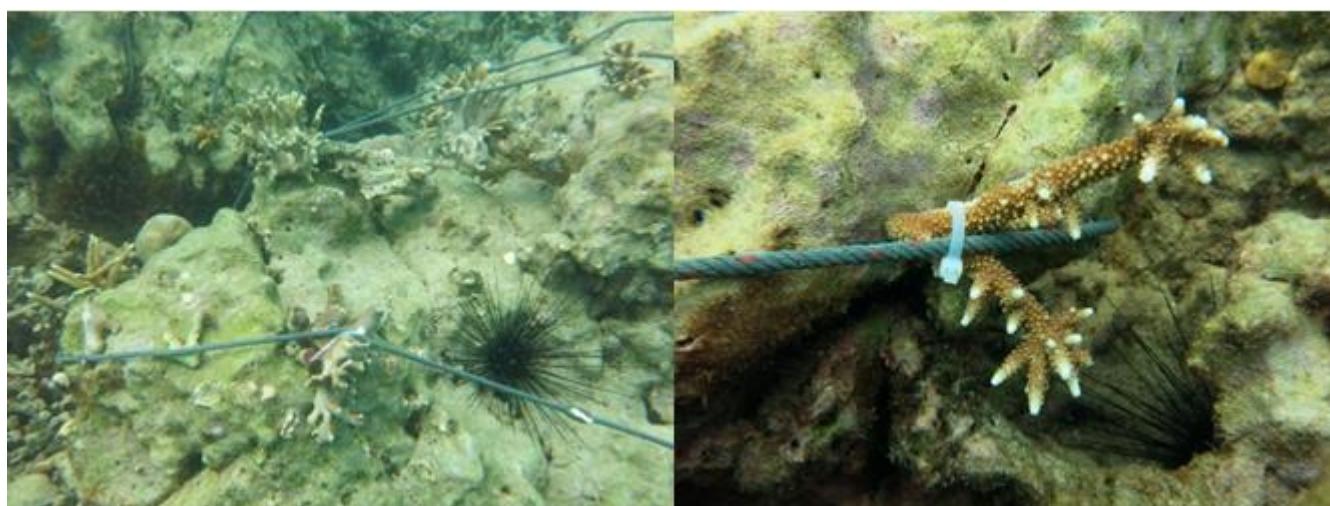


Figure 18: Nylon rope tied around existing natural rock and opportunity corals tied to the rope with cable tie

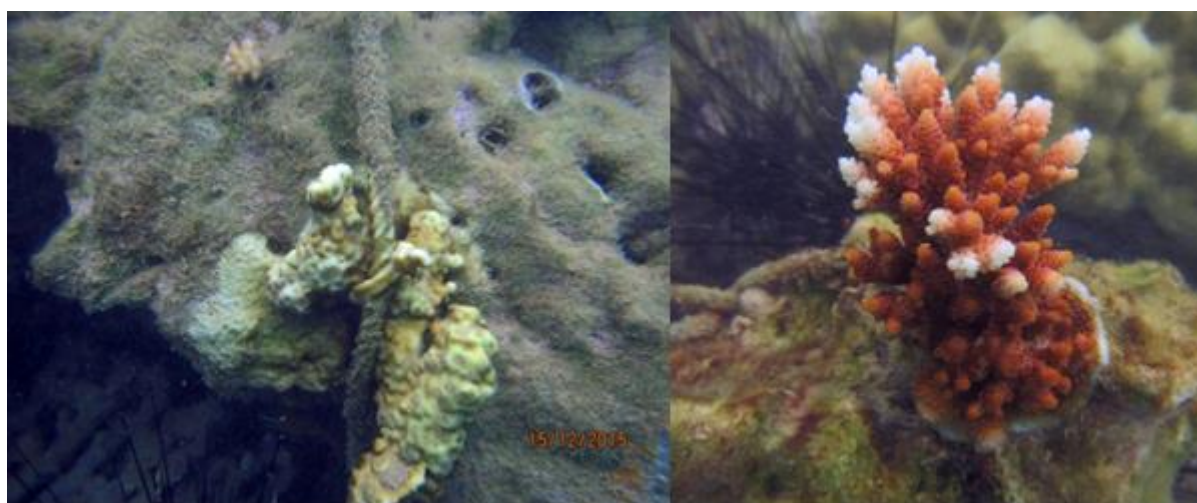


Figure 19: Corals overgrowing the rope and cable tie and attaching themselves solidly onto the rock

Design 6: Metal Structure

The structure of the nursery is a matrix of metal frames measuring approximately 180cm x 90cm x 90cm (Figure 20). The frames were deployed at 6-8m depth. “Opportunity corals” were attached to the metal frame using cable ties (Figure 21). Handling of nubbins was minimised during collection, transportation and re-planting. Exposure of nubbins to sunlight and air was avoided at all times by carrying out the whole process underwater. The cost of this design is very high. Although the structure is heavy, the design of the frame is not good at withstanding strong currents.



Figure 20: Metal frame structure



Figure 21: Opportunity corals attached to metal frame using cable ties

Design 7: Direct Transplant using Epoxy

“Opportunity corals” were attached onto bare or “cleaned” rocks with underwater epoxy (Figure 22). Handling of nubbins was minimised during collection, transportation and re-planting. Exposure of nubbins to sunlight and air was avoided at all times.

The underwater epoxy is very expensive, not easily obtained and takes time to harden, thus nubbins can easily get dislodged before setting. The epoxy does not work well on rocks with even a very thin layer of silt. Monitoring is very difficult with this approach as it is hard to distinguish natural existing corals and planted coral nubbins after a period of time.

Pictures of nubbins transplanted using direct transplant are shown in figure 22.



Figure 22: Opportunity corals are attached onto bare rocks with underwater epoxy

Design 8: Cement Block with Old Glass Bottles

In 2015, Reef Check Malaysia was approached by Tioman Cabana to help them with a coral rehabilitation project and suggested the use of old glass bottles embedded in cement blocks. The cement blocks are approximately 50cm X 30cm x 10cm with 5 to 7 old glass bottles embedded into the block (Figure 23). Blocks were deployed at 5m depth at coral rubble patches with mild current and many herbivorous fish. “Opportunity corals” were tied to the neck of bottles with cable ties. Handling of nubbins was minimised during collection, transportation and re-planting. Exposure of nubbins to sunlight and air was avoided at all times. Monitoring and maintenance were conducted to assess survival and growth rate.

The materials used are inexpensive (around RM20 per unit) and eco-friendly and the structures are able to withstand rough water conditions during monsoon season. However the structure is heavy, making transportation on land, deployment and moving underwater difficult. A smaller concrete base would have made it lighter and thus easier to be moved around. The old glass bottles are good at attracting juvenile fish and octopus, which make good use of the bottles as shelter. Pictures of the approach are shown in Figure 24.



Figure 23: Cement block with old glass bottles



Figure 24: Rehabilitation site concrete block and old glass bottles

Summary

Since 2010, Reef Check Malaysia has been experimenting with various approaches to reef rehabilitation, as outlined above. Below is a comparison table for the different approaches that we have used.

Design	Building Cost	Ease of Deployment	Maintenance	Durability	Attraction for recruits	Ability to withstand strong currents	Environmentally friendly
PVC plastic pipe frame	Medium	Medium	High	Low	Low	Low	No
Concrete Block	High	Difficult	Low	High	High	High	Yes
Cement Block	Low	Easy	Low	High	High	High	Yes
Wire Mesh	Low	Easy	Low	Low	Low	Medium	Yes
Nylon Rope	Low	Medium	Low	Medium	Low	Medium	No
Metal Structure	High	Difficult	Low	Medium	Low	Low	Yes
Direct Transplant using Epoxy	High	Medium	Low	Low	None	Medium	Yes
Cement Block, Glass Bottles	Low	Medium	Low	High	High	High	Yes

Key Lessons Learned

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

Design

- Able to withstand rough water conditions
- Allows easy attachment of nubbins
- Not too heavy – easy to transport and deploy
- Use eco-friendly/natural materials (to avoid leaving behind man-made/unnatural debris should the structure get destroyed).

Site selection

- Adjacent to a damaged reef area
- Easily accessible to reduce costs
- Avoid fine sediment areas to limit siltation
- Avoid strong currents (if possible – depends on location)
- 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 parts of such broken corals must be removed before attaching to the frames.

Maintenance

- Regular maintenance 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.

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 challenges have been encountered (e.g. siltation, 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 growing, many natural recruits are settling on the structures, 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 and (to date) small scale 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 reef rehabilitation to improve upon the existing approach, and to test other approaches suitable to local conditions. The focus will remain on community-based, low cost approaches to rehabilitation.

We are happy to share our experiences, as contained in this brief document. If you are interested to learn more, please contact us at the address shown above.

References

- Chou, L.M., Yeemin, T., Abdul-Rahim, B.G.Y., Vo,S.T., Alino, P. & Suharsono. 2009. Coral reef restoration in the South China Sea. *Galaxea*, 11:67-74.
- Edwards, A.J. (ed.) (2010). *Reef Rehabilitation Manual*. Coral Reef Targeted Research & Capacity Building for Management Program: St Lucia, Australia. ii + 166 pp.
- Precht, W.F. & Robbart, M. 2006. Coral reef restoration: the rehabilitation of an ecosystem under siege. In. Precht, W.F.(ed.). *Coral Reef Restoration Handbook*. New York: CRC Press. Pp. 1-24.