Lembeh Divers House Reef Project Report

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Introduction

The House Reef Project was launched in February 2007. The aim of the project is to rehabilitate the house reef (i.e. the reef area in front of the resort) in an efficient and cost-effective way, with the view to applying the best techniques to neighbouring areas to improve the overall reef condition in this part of the Lembeh Strait. It can be considered a testing ground for reef rehabilitation and restoration techniques, with a focus on finding realistic and pragmatic approaches to dealing with the impacts and conditions encountered both locally within the vicinity of the house reef, and within the broader region.

Artificial reef structure	Installation date
Reef-balls	May 2003
Concrete blocks	April-June 2003
Biorock	December 2007
Wreck	December 2007
Rock pile	Unknown
Oil barrel	Unknown
Water cooler	December 2007

Table 1: Installation dates of the various artificial reef structures on the house reef.

Since its inception, the project has concentrated mainly on the installation and maintenance of a variety of artificial reef structures (Table 1), and the associated maintenance. Due to the time scale required to assess the viability of any reef rehabilitation/restoration technique, the outlook at present is to place more artificial reef structures to give them ample time to attract marine growth, alongside the routine maintenance that needs doing.

This report outlines the current status of the house reef project, summarises the project work performed between 19th September – 28th October 2008, and makes recommendations for possible future work to be done. The report is likely more detailed than those before, with the intention of providing a consolidated core of useful information about all the relevant issues to future volunteers working on the project, rather than just focusing on the details of artificial reef installations. The aim is to provide a more centralised document to enable new volunteers to become informed and ready to work productively on the house reef as quickly as possible.

Status of the house reef on arrival (late September 2008)

Natural reef

The house reef hosts a reasonably wide variety of coral species at a range of depths (to about 20m), including reef-building species such as massive *Porites* spp. and *Diploastrea heliopora*, and fast-growing branching *Acropora* species. Alongside these is an abundance of invertebrate life, and algal cover, although the focus of the project is on the corals. The Southern side of the house reef is comparatively well inhabited by corals, but in the shallows there are a lot of broken fragments of the more fragile branching corals, so the area has evidently been exposed to significant physical impacts, most likely a mixture of storm damage and boat traffic. However, the diversity of species evident in the area should provide an ample source of larvae to assist in natural settlement of new corals to other areas of the house reef, including artificial reef installations. Deeper than about 20m there are few corals evident, most likely associated with the low light levels at these depths due to suspended sediment in the water column.

As with most other sites in Lembeh Strait, the house reef is prone to collect a lot of man-made by-products, such as plastic bottles/bags, glass bottles, etc. There is little that can be done directly on the house reef to help this situation, as it requires adequate infrastructure to process the collected waste, along with widespread education of the need to conserve the whole area's marine ecosystem, so this is a longer term goal.

Shortly after arrival I sighted dead fish across parts of the house reef, presumably the result of local fishing practices, with the carcasses either being left over from fishing in the local vicinity, or brought by the currents to the house reef. While this probably doesn't pose any great impact to the house reef, the widespread removal of large numbers of reef-associated species does limit the opportunity for attracting them to the area. However, as with the man-made waste situation (plastics, etc.), it is unlikely that anything can be done to mitigate this, at least in the short term.

Biorock installations

There are three Biorock installations in place on the house reef (Figure 1), each made of industrial rebar steel welded into a square mesh pattern, and shaped differently:

- **Tunnel** – a three-armed tunnel with arc-shaped cross-section, laid in a square U-shape; this is the shallowest installation.
- **Pagoda** – a complex pagoda-style design with difficult access to the central bars; this installation has by far the greatest (and most uneven) mineral deposits.
- **Dome** (or "Blob") – a leaning hemispherical shaped dome; this is the largest and deepest installation, with a (small) access hole in the top.

Figure 1: Photographs of the three Biorock installations: tunnel, pagoda, and dome respectively.

Currently the Biorock installations are "unofficial", meaning that Biorock Inc. (www.biorock.net) and/or the Global Coral Reef Alliance (GCRA, www.globalcoral.org) have not officially sanctioned the installations. As a result there are some outstanding questions about how best to maintain them, although the current guidelines seem sufficient for many aspects of ongoing maintenance. The long-term aim for these installations is to have them assessed to make them official, which should help to provide support by way of further information that can maximise their productivity.

On arrival all three Biorock structures had a significant layer of filamentous algal cover (Figure 2a) over the base layer of calcium carbonate deposit, which was at times being grazed by herbivorous fish species (e.g. parrotfish, surgeonfish), but not sufficiently to prevent the algal build up. Lower parts of each structure had (and will continue to have) coarse grade sediment cover. Assuming that only coral fragments with some remaining living tissue were attached, coral transplant mortality was mostly restricted to partial mortality, although some entirely dead fragments were also found and subsequently removed. A number of naturally settled scleractinian (hard) coral larvae were found on each of the installations, particularly the tunnel. The reasons for this preference of structure are unclear, although being the shallowest of the installations it may allow better access to light for the newly settled corals to gain energy via photosynthesis. While visual identification is difficult, the majority seem to be *Acropora* and *Pocillopora* species. There were small areas of both colonial and encrusting ascidian species and encrusting sponge species, each of which could spread rapidly to out-compete coral transplants. The central pagoda installation appears to have developed increased (and more uneven) mineral deposits compared to the other installations, although the reasons for this are not clear (perhaps shape/complexity or anode positioning). The power supply to the installations on arrival was set at 6V/25A DC, with on/off cycles delivering power between 06:00-16:00, and 19:00-03:00.

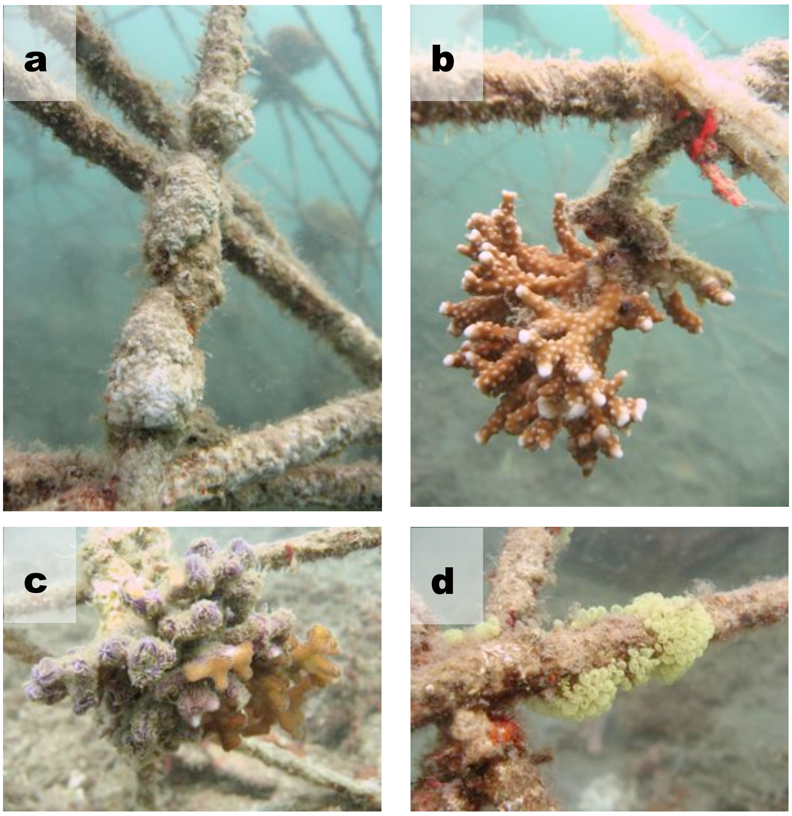

Figure 2: Close-up photos of Biorock dome installation, showing calcium carbonate accretion on the metal frame (a), algal growth over a dislodged coral fragment (b), encrusting sponge overgrowing a coral fragment (c), and colonial ascidian and algal growth on metal frame (d).

Concrete block installations

Figure 3: Photo of one of the larger and more stable concrete block installations, showing coral fragment transplants, and various other types of marine growth.

The concrete block installations (aka "fish houses") are scattered over a large area, from within the Biorock dome, heading North to near the mandarinfish dive site, generally between approximately 7-15m in depth. Some of the installations, particularly the smaller ones, appear unstable and close to toppling. The majority of the installations had a significant layer of coarse sediment cover. Nonetheless there was evidence of some coral settlement, with juvenile colonies starting to become established on some of the blocks. Two of the installations had large quantities of macroalgal growth on them, to the extent that coral larvae settlement would be very unlikely. They are located next to a natural reef area that also has high macroalgal cover, and while there are herbivorous damselfish resident in the area, their actions seem insufficient to maintain the algal growth in check, and these installations are unlikely to attract significant coral growth in their current state. One of the installations has significant coverage of an encrusting ascidian, which appears sufficiently virulent to out-compete at least some of the coral transplants so far.

Reef-ball installations

Figure 4: Photo of one of the reef-ball installations, showing good growth of *Acropora* corals.

There are 21 "reef-balls" located on the house reef, grouped into two main clusters of eight and ten, along with three singles elsewhere. Each reef-ball is a hollow hemisphere with a hole in the top, and various holes located on the sides, giving a large surface area onto which corals (and other marine life) may settle, while also stabilising the substrate and providing shelter for other marine life. The reef-balls are made from a modified cement recipe (unsure of exact details), probably with a coarse grade of sand to help provide a textural surface with greater area. Cement is an alkaline material, and as such could help to prohibit settlement and growth in normal circumstances, so the reef-balls have been treated to neutralise the surface alkalinity.

Comparing the reef-balls here to others at a more pristine site located further South at Ratatotok, those on the house reef appear to be working as well as could be expected given length of time they have been in the water, combined with the prevailing environmental conditions. All reef-balls show signs of some coarse sedimentation, but due to their shape this cannot accumulate substantially. Most show signs of some coral settlement, and while growth is comparatively slow compared to similar installations in other areas, this is likely due to water quality affecting the light levels available for photosynthesis. Of the artificial reef installations on the house reef, these currently seem to be providing the greatest benefit.

Wreck

Figure 5: Photo of the wreck in the deeper waters of the house reef.

A small boat (~12m long) has been sunk onto the sand substrate in approximately 26m depth. The wreck has not been in place long enough to develop any substantial marine growth, although there is evidence of some small wood-boring organisms, some limited coral and bryozoan settlement, and both filamentous algal cover and sediment cover. Small shoals of sweetlips (*Plectorhincus* sp.) aggregate close to the wreck, along with small numbers of batfish (*Platax* sp.), a few small pufferfish (*Canthigaster valentini*), etc. Two "squid lines" are in place just off each end of the wreck, with the aim to have squid lay eggs on them. Currently there is no indication of any squid activity, but they show the expected levels of marine growth, including algae, sponge, ascidian, and bryozoan activity. Given the depth of the wreck, the levels of growth are entirely as expected, and it is recommended to simply leave it as it stands.

Miscellaneous

There are currently three other artificial reef installations in place, with varying degrees of potential. Without knowing their installation dates their comparative utility cannot be assessed, but currently none of them have any significant coral settlement on them.

Rock pile A small pile of rocks has been aggregated in the shallows on the South side of the house reef, and while the date of creation is not known, the lack of settlement indicates that it is a fairly recent addition. On top of the pile has been placed a small colony of massive *Porites*, which is still in good health. Given its shallow depth and that is it surrounded by stable substrate, it does not appear to be exposed to significant coarse grade sedimentation, although this should be monitored periodically. Rock piles such as this have been identified as useful artificial reef structures (Fox, 2005; Fox et al., 2005), and it is recommended to simply leave this rock pile alone and let nature take its course.

Oil barrel An old metal oil barrel has been submerged on the reef at a depth of ~13m (on the Southern route). The metal has all-over surface corrosion, and holes in some places indicating corrosion right through. However, it has attracted very little marine growth, and despite being open at one end is not obviously being used as a shelter. Without knowing the history of the oil barrel it cannot be reliably assessed for beneficial/detrimental effects, but both the barrel and the neighbouring reef should be monitored closely for changes.

Water dispenser A metal water dispenser has been set in a concrete base and sunk to the South of the Biorock installations. It has accumulated a biofilm, but no significant settlement has occurred. The most likely reason for this is the smooth surface, which is not conducive to coral settlement. Additionally there is a layer of paint covering the metal, which helps contribute to the persistence of the smooth surface. To assist in coral settlement, it is advisable to remove the layer of paint and roughen the metal surface. For this procedure it should be removed from the water to an area where the potentially environmentally toxic effects of the paint removal will not impact either reef or rainforest ecosystems.

Assessment of current rehabilitation/restoration efforts

Overview

In my view the key steps to rehabilitating the house reef are:

- Identifying the factors that caused the reef's decline from its natural state
- Identifying the factors that are preventing the natural recovery of the reef
- Implementing procedures that allow for cost-effective, natural reef rehabilitation.

Due to lack of information, the factors that caused the reef's decline are not explicitly known, but likely related to:

- Boat traffic during construction of the resort.
- Run-off of construction materials during resort & dive centre construction.

These factors alone are relatively short-lived stresses to the reef, but when combined with more persistent environmental stressors they are likely to have contributed to its decline. The persistent environmental stressors are likely related to:

- Fine sedimentation caused by run-off from land.
- Eutrophication[*] and sedimentation from neighbouring villages (located either side of resort), possibly due to poor sewage treatment.
- Slow-to-degrade man-made waste sourced from local villages and brought into the bay by currents (e.g. plastic bags/bottles/etc.).

In the absence of any detailed knowledge about the state of the reef before its decline, the efforts should ideally focus around *rehabilitation* (in which changes are made to allow a natural reef growth and recovery) as opposed to *restoration* (in which efforts are made to restore the reef to its state before the decline). Larval supply of corals to the area is adequate to allow natural seeding of both natural substrate and artificial reef installations without recourse to large-scale transplantation of corals. Transplanted corals generally have a worse survival rate than naturally growing corals

[*] Eutrophication refers to nutrient enrichment of the water due to run-off from land, causing increased algal growth and a subsequent decrease in dissolved oxygen levels in the water, leading to a reduced ability to sustain animal life.

(Edwards and Clark, 1998), and while the Biorock installations are purported to increase transplant success, without further information to obtain maximal productivity from them, rehabilitation is almost certainly best achieved using passive substrate stabilisers and enhancers.

None of the current artificial reef installations can truly act as a rigorous experiment in their current state, due to a lack of a scientific control for each of them, along with a lack of reliable historical data about them. For example, a powered Biorock installation could have a control of an un-powered identical frame nearby, both of which receive similar coral transplants. In light of this lack of controls, most of the experimentation on the house reef can be at best qualitative and subjective. For all future installations it makes sense to install and monitor appropriate experimental controls where possible.

Natural reef

Two factors are likely to limit natural larval settlement in some areas, particularly on Northern side of the bay. Firstly, many coral outcrops in this area are covered with large amounts of macroalgae (e.g. *Padina* sp.); secondly, in the slightly deeper water (17m+) there is a substantial rubble zone with very little coral cover. While there is likely to be some seasonal variation of macroalgal cover, it is also a possible indication of elevated nutrient loading of the water in this area. This may be the case across the whole bay, or if it's isolated to this area it could be due to localised current/eddies near the Northern corner of the bay. For the rubble zone, the currents can keep the substrate moving which likely prevents successful settlement.

Biorock installations

Biorock installations are claimed to provide three main benefits (Sabater and Yap, 2002):

1. The electric field enabling mineral accretion may cause precipitated carbonates to attach directly to coral transplant skeletons.
2. There is enrichment of dissolved $CaCO_3$ the water in the vicinity of the coral transplants, enhancing natural calcification.
3. The electric field aids corals' energy production, leaving excess energy for possible growth enhancement.

These claims do not seem to have been rigorously tested scientifically, but there are reports of increased growth rates of coral transplants in documentation from the Biorock/GCRA websites. Some research has been done, leading to a few conclusions for practical implementation. Biorock has been found help to increase the survival of transplanted coral fragments, provided they are securely attached to the substrate (Sabater and Yap, 2002). Also, the increased concentration of ions in the water column due to the electric field is limited to a range of a few millimetres from the Biorock substrate (i.e. the metal frame cathode), such that any other benefits resulting from the electric field are only realised within this range (Sabater and Yap, 2002).

The implications are important in terms of how the Biorock installations are maintained. Firstly, the power supplied to the installations needs to be appropriate to produce accretion of $CaCO_3$ (aragonite) rather than other mineral salts that do not facilitate coral attachment and growth. According to the currently available documentation this requires a sufficiently low power to produce a majority of calcium carbonate deposition, although no equipment is available to test either the power reaching the installations or the composition of the mineral deposits, so much of this is guesswork. After repeated examinations of the structures to identify bubble formation due to electrolysis, the power supply was reduced to 6V/20A for the same time period as originally set on arrival. Bubbles are still produced on all installations, indicating that electrolysis continues. However, for best results it is advisable to get the installations assessed by Biorock/GCRA and seek advice.

Efforts to date seem to have focused on transplantation of predominantly fast-growing *Acropora* species, the aim presumably being to increase coral cover on the installations as fast as possible. However, such species generally have poor survival rates compared to the slower growing massive coral species (Edwards and Clark, 1998), which are also the predominant reef-building corals. As a result, it would seem beneficial to increase the proportion of these reef-building coral transplants to the Biorock installations. Continued transplanting of fast-growing species is also recommended, with an emphasis on species that have naturally higher fragmentation rates. Transplant survival is also associated with coral fragment size (Clark and Edwards, 1999; Edwards and Clark, 1998), so in general the larger the fragment transplanted, the better its chances of survival.

Unrelated, but in support of this change, observations were made of some transplanted coral fragments being partially eaten by corallivores, both at the individual polyp level (e.g. butterflyfish) and at the multi-polyp level (e.g. triggerfish), particularly the branching *Acropora* species. As these branching species comprise a greater proportion of such predators' diets (Pratchett, 2005), a shift away towards more reef-building species mitigates this loss to predators a little.

Considering transplant location, the current locations of the transplants are fairly well spaced, which could either be due to deliberate thought or to aesthetic values. This practice should continue, as different species (and even different individuals of the same species) have different competitive abilities, so each transplant should be given sufficient space into which to grow. Failure to give adequate space forces corals to compete with other before they have reached a reasonable size (and associated energy production), making them more likely to die.

The current guidelines for transplanting coral fragments are not particularly rigorous, and allow for a lot of variation in individual technique. To increase the likelihood of successful transplantation, some additional recommendations have been outlined in a separate document.

Concrete block installations

In general, the taller an artificial reef structure is above the substrate the less it is affected by coarse grade sedimentation such as stirred up sand, and as a result the taller of the concrete block structures are those most likely to give good results in the long term. Many of the smaller installations are either unstable or small enough to be highly effected by such sedimentation, and would likely benefit from redesign or replacement. One way might be to consolidate the materials from more than one installation to construct a new, bigger installation. Care should be taken to minimise the likelihood of instability/toppling due to water motion.

Reef-ball installations

As with the concrete blocks, the reef-balls are subject to some coarse grade sedimentation as they are positioned on a sandy slope where silt from higher up the slope can be deposited on them. However, due to their rounded shape and the fact that the reef-balls are generally higher off the substrate than the majority of the concrete block installations, they are less affected by it. Currently the reef-balls are probably the best performing, or at least most reliably performing, of the artificial reef structures, and the best course of action for them is simply to leave them as they are.

Summary of work performed

The following summarises the work performed:

- Photo documentation of current status of Biorock installations.
- Biorock maintenance, including some new coral fragment transplantation.
- Reconstruction of one of the smaller concrete block installations that had collapsed.
- Route marker maintenance (removal of marine fouling organisms from many, but not all).
- House reef mapping.

Biorock maintenance

Routine Biorock maintenance performed includes widespread removal of potentially problematic algal growth over all three installations, and removal of problematic ascidian/sponge growth which could out-compete coral transplants. Dead colonies found on each installation were removed, and some of the current transplants were re-transplanted to provide more stable attachment. Several new transplants were performed, including several of massive *Porites* sp. to increase reef-building coral numbers.

House Reef mapping

On arrival the only map of the house reef (a painting) was considerably out of date, so I created a new one. The original idea was to create one simply as a template for a new painting to be made, but it seemed appropriate to create one also suitable for viewing within the dive centre, and that if laminated at a suitable size could also be taken underwater.

Given the numerous route markers located around the house reef, and that the key features are located close to the routes, the decision was made to base the map around the locations of those markers. The steps taken to produce the basic map of route markers will very likely be required to make updates:

1. Choose base reference marker (line in centre of wreck).
2. For each other marker, take simple measurements to locate marker (bearing/distance from reference, depth of substrate at marker).
3. Enter data into spreadsheet to calculate actual position of each marker.
4. Format chart in Excel as required to produce a figure of marker locations.
5. Import the Excel chart into Photoshop to use with map document, resize as appropriate, and edit details as required.

The equipment required to locate the markers for mapping are:

- Depth gauge
- Compass
- Underwater slate
- Waterproof measuring tape (only used once to calibrate fin kick distance)

I didn't get a chance to complete the mapping of the house reef and proposed modification to the routes, so the following items are on the list for completion:

1. Mapping of route from near Biorock to beach steps.
2. Mapping of small route looping clost to Biorock/concrete blocks.
3. Re-map some of the markers from wreck to Biorock.
4. Map markers looping around Biorock installations.
5. Map markers from Biorock back to beach steps.
6. Create short cut to long Northern route.
7. Move all spare markers to near wreck to keep them out of the way.
8. Compile printable & usable table of bearings/distances from/to all key points of interest.

Unmapped routes

There are two remaining routes that have not been mapped properly. To help make a usable map, these routes have been added to the map anyway, although the placement of the markers is guesswork, and they should ideally be mapped properly (see attached map).

Route from wreck to Biorock

Mapping of the markers on this route is complete up until the tagged marker (single cable tie between floats, #18 in spreadsheet), but East of that marker the route has been changed a bit, so it needs re-mapping.

Northern route short-cut

The route heading North from the wreck is generally considered to be too long at the moment, when considering that many divers visiting the house reef are also photographers and want to dive at a slow pace. The proposed short cut to the route removes the lowest Northward loop, so that the route from the wreck to the cluster of eight reef-balls is shortened. There are no significant features to see at present on this loop, so removing it should simply allow air divers to navigate the route more easily within a single dive, and nitrox divers to have a leisurely amble. The proposed short cut is marked on the map at the end of the document, and two underwater route markers have been tagged with a cable tie each to mark the possible end points of the short cut.

More information

I took all compass bearings to the nearest 5º, which should provide enough resolution. They were made with a UK-calibrated compass, so there's a chance they are off by a small amount, but as it is the same for all bearings taken, it doesn't matter much. Before taking any type of measurement it's worth calibrating your equipment, self, and depth:

Compass calibration should only need doing once to check how far off my compass was compared to the next used.

Self-calibration needs to be done just once to determine how long your fin kicks are. Obviously this should be averaged over a reasonable distance to get measurements that don't have too much error. That said, most markers are about 4-5m apart, so error will be fairly substantial anyway, but sufficiently small for this task.

Depth calibration needs doing at the start/end (or both) of each dive to account for tidal changes. Just re-measure the depth of a marker you've already measured and note it down. Make the appropriate adjustments to the data later.

Recommendations & ideas for the future

Routine maintenance work

Route markers As already mentioned, the house reef hosts a large number of marker lines with submersed floats to demarcate routes that can be followed to assist with navigation, and to visit the key attractions. These submersed markers are rapidly and continually colonised by marine life such as sponges, ascidians, corals, oysters, barnacles, etc., many of which develop sufficient weight to sink the floats and dramatically reduce the markers' effectiveness. The larger the organism the more damage it can do (chemical boring, etc.), so regular maintenance of these markers is essential to maximise their lifespan.

Biorock Continued removal of virulent encrusting species of both ascidian and sponge is recommended across all installations (wire brush). For the pagoda, coral transplantation should probably be restricted to the outer parts of the frame, as once the corals grow larger the inside of the structure will become shaded, restricting available light for any centrally located colonies.

Photographic documentation of artificial reef installations

For long-term monitoring of the status of the artificial reef installations, it makes sense to photographically document each of the installations at regular intervals using a standardised technique. The dive centre has a rental camera currently available that can be used for this. There is currently no protocol for such photo-documentation, although photos relating to the current status of the Biorock are available alongside this document.

New artificial reef installations

The house reef still has a large rubble zone, comprising long-dead corals lying on sand. While critters such as octopus and nudibranchs can often be found in this area, coral likely cannot get a chance to settle due to water motion shifting the rubble, along with low light levels. The second of these restricts corals' growth rates, but coral growth should still be feasible given the right substrate and plenty of time. Plans are in mind to increase the numbers of artificial reef structures across the house reef, each of which is assessed below. Important criteria are:

- To stabilise the substrate to allow coral settlement.
- To provide a large, stable surface area suitable for coral settlement and growth.
- To provide refuge for non-sessile marine organisms (e.g. fish, lobster, crabs, shrimp).
- To resist coarse sedimentation.
- The aesthetic value of the structures for divers.

Reef-balls Good track record for all criteria, provided the construction materials are appropriate and the inherent alkalinity of cement is managed.

Rock piles Good support from scientific literature, addresses all criteria if tall enough, and easy to make. For the house reef project the main consideration is the ease/difficulty of sourcing appropriate rock, as the local volcanic rock may be too soft/crumbly.

Biorock Does not really stabilise the substrate, but addresses the other criteria, at least in the longer term. Lower light levels and greater distance from power source in main rubble zone might make this a less viable option. An alternative strategy might be to use the Biorock accretion technique to create artificial substrate close to a power source, then disconnect power and move the substrate to deeper water, allowing natural settlement to take place on the artificial substrate. This way the facilities can be re-used to create multiple installations, although Biorock documentation suggests that each installation would likely take about five years to "grow" enough calcium carbonate.

Miscellaneous Various old household white-goods, such as washing machines are under consideration for use as artificial reefs. Most of these items have very smooth surfaces and a layer of possibly environmentally toxic paint covering their surfaces. Without any preparation these are likely either detrimental to the environment, or at best neutral, and do not contribute aesthetically to the house reef. If realistically considered as possible artificial reef installations, careful preparation should include:

- Removal of all other potential environmental toxins/pollutants (paints, oils, lubricants, plastics, solvents, refrigerants, etc.), ensuring no similar pollution to land-based ecosystem.
- Scouring/roughening of smooth surfaces to make them suitable for coral settlement.
- Ensuring structural integrity, so that the structure remains intact when subjected to currents, storms, diver curiosity, etc.

- Ensuring structural fixing, so that the structure stabilises the substrate where it is placed, and cannot move about.

The most environmentally appropriate solution is almost certainly the use of large/tall rock piles. However, given the location and the possibly difficult task of sourcing appropriate rock, reef-balls are likely the next best option.

Artificial reef site selection

Factors to consider when choosing sites for new artificial reef installations should include:

- Larval supply (should not be a problem)
- Light levels (sufficiently shallow to allow good coral photosynthesis)
- Water motion (sufficiently deep for structure to be stable)
- Algal cover (be aware of its possible influences on the installation)

Other possible factors to consider are:

- Accessibility/convenience for any maintenance required
- Accessibility for resort divers

Addressing sedimentation

In my view one of the key issues relating to rates of coral growth on the house reef is that of sedimentation. Coarse sedimentation in the form of sand and other benthic debris is shifted by water movement and can cover corals, natural substrate, and artificial reefs, preventing natural settlement of new corals, and increasing stress and energy load for existing corals. Suspended fine sediment in the form of rainwater and waste run-off stays in the water column, decreasing light levels penetrating down through the water, in turn reducing light available to corals for photosynthesis. These effects combined with other stressors can dramatically reduce both the tolerances of existing corals to any damage or predation sustained, and can reduce the possibility of settlement.

A useful bit of information for future artificial reef installations would be to discover the height to which coarse sedimentation affects coral settlement. This needs to be performed at a variety of locations/depths across the reef, as sedimentation will vary, but this information can subsequently be used to influence the design and height of future installations.

Addressing fine sedimentation is a much larger issue, involving long-term monitoring of water turbidity, assessment of rainwater catchments, assessment of waste outflow facilities in both the resort and neighbouring villages, etc. A useful start point would be to design and initiate a sampling program to collect turbidity data (using a Secchi disc) at several points across the bay, which can be done in a standardised way by staff located on site if briefed appropriately.

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Maintenance Guidelines

Biorock maintenance

Regular maintenance performed by each volunteer should include:

- Removal of significant algae growth likely to affect natural coral larvae settlement.
- Removal of virulent encrusting sponge and colonial ascidian growth.
- Removal of dead coral fragments from metal frame.
- Transplanting of new coral fragments onto suitable sites on the metal frame, with appropriate preparation of attachment sites.

Maintenance dives often require the use of extra equipment, which the dive centre should be able to provide to volunteers, including:

- Gloves (to protect hands from cuts/scrapes/stings while working)
- Wire brush (for cleaning Biorock frame)
- Non-galvanised wire (for attaching coral fragments)
- Cable ties (useful for almost everything)
- Writing slate

Large amounts of algal growth can affect the ability of coral larvae to settle on the substrate. Established corals also need to divert energy away from growth to fight many algae, so removal of such algae can help to maintain higher levels of natural larval settlement and high growth rates of coral transplants. Removal of algae is best done with a wire brush, as some types of very well adhered. Take care to avoid brushing any of the coral fragments already in place, or any corals that have settled naturally, so look carefully for newly settled larvae (especially those only a few polyps in size).

Both encrusting sponges and colonial ascidians can grow very fast and often out-compete many coral species by smothering or boring, so they should be removed when seen to be growing unchecked. Regular maintenance should include monitoring and removal of virulent species of colonial ascidian, encrusting ascidian, and encrusting sponge (e.g. *Perophora modificata*, *Leptoclinides* sp.).

Dead coral fragments can in principal become new settlement substrate, but it makes more sense to remove the old fragments and transplant new fragments onto the metal frame to maximise the effectiveness of the electro-chemical accretion process.

Transplanting coral fragments

When transplanting new coral fragments onto the Biorock frame it makes sense to try to maximise the transplant success in every way possible.

- Select fragments comprising as much living tissue as possible.
- Select fragments with no sponge/ascidian/algae cover.
- Thoroughly clean attachment site (and nearby regions) to remove all sponge/ascidian/algae growth, even down to the metal frame if necessary.
- Attach fragments securely using non-galvanised metal wire[*], ensuring they will not move around due to water motion.

[*] Using metal wire to attach the fragments very likely has a side benefit of increasing the effective cathode area around a fragment, at least when it touches the bare metal frame at some point.

All transplants should be attached to well-cleaned Biorock substrate, with healthy live tissue held securely against either the metallic surface or to algae-free calcified deposit. Attachment site should be thoroughly cleaned/checked before attachment, and must be made securely enough that the coral fragment will not move around in the water current, as insecure attachment is known to increase fragment mortality (Bowden-Kerby, 2001). When a coral transplant has died and needs to be removed, the removal of the old transplant can sometimes pull away calcified deposits down to the metal base. As this metal base is likely to provide the fastest site of new $CaCO_3$ deposits, it is recommended to use this as a site for a new transplant while the metal is still bare (Figure 1).

Figure 1: Close-up photo of Biorock, showing where a dead coral fragment has been removed. Such a site is a good choice for a new transplant to be made, as calcium carbonate deposition (and therefore coral attachment) will be fast on the metal. Notice that the wire used to attach the coral fragment is touching the bare metal.

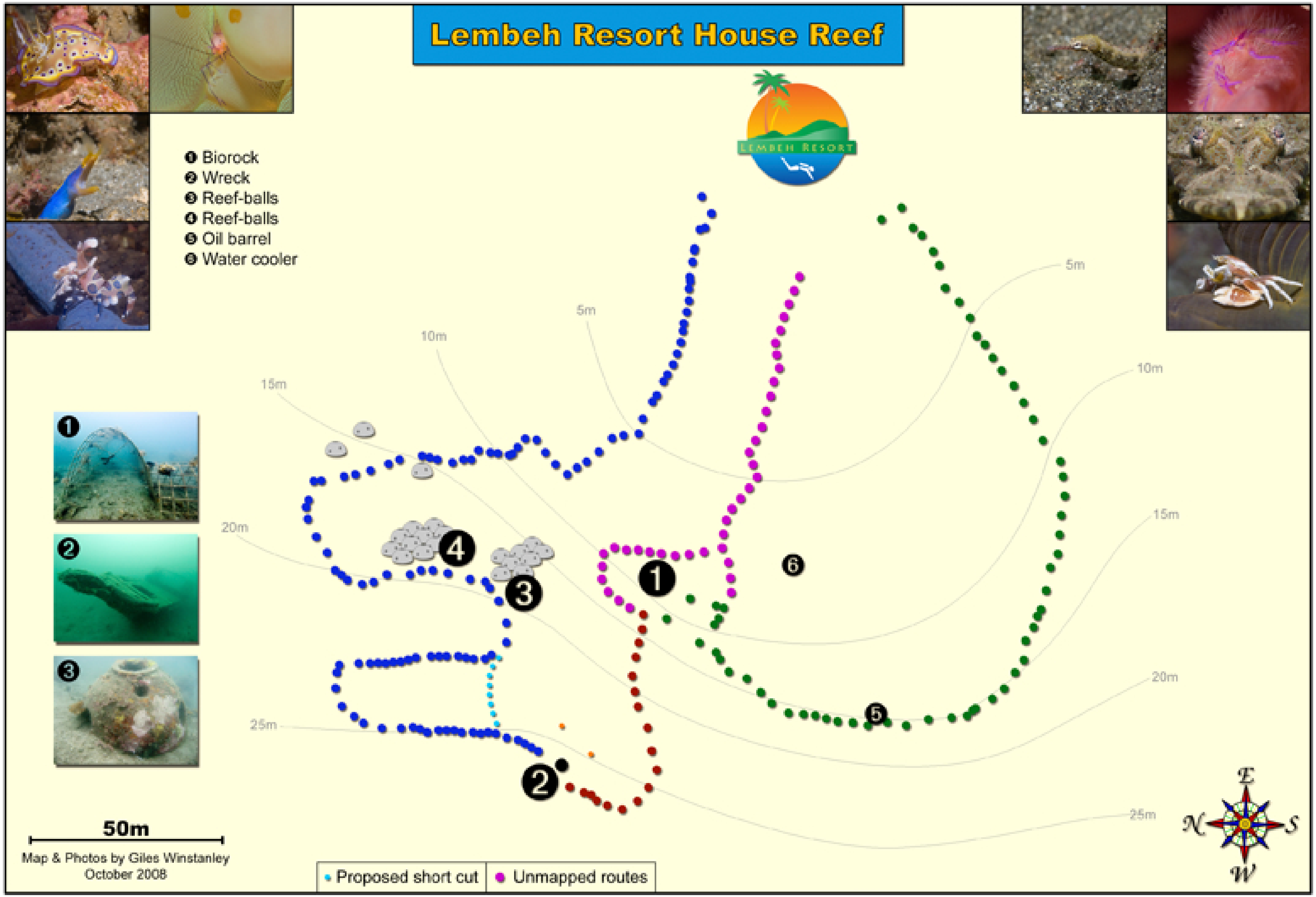
Route marker maintenance

The route markers attract marine fouling organisms, and they tend to settle and grow quickly. As a result they need regular maintenance to prevent the growth causing the markers to sink, and to prevent any boring organisms from damaging the floats. Typical fouling organisms include sponges, ascidians, corals, oysters, and barnacles. They also attract algal growth, although if it is merely filamentous algae cover, this is not such a problem, as it does not weigh down the markers, and it can help avoid other organisms settling.

To clean the route markers you will need at least the following equipment:

- Gloves (to protect hands from cuts/scrapes/stings while working)
- Dive knife (to help remove stubborn oysters/barnacles/etc.)
- Wire brush (for cleaning stubborn sponges/ascidians/algae)

Fouling organisms should be removed as thoroughly as reasonably possible from both the floats and the attached lines, being careful to damage the floats as little as possible.


Lembeh Resort House Reef
LEMBEH RESORT
❶ Biorock
❷ Wreck
❸ Reef-balls
❹ Reef-balls
❺ Oil barrel
❻ Water cooler
5m
10m
15m
20m
25m
1
2
3
4
5
6
50m
Map & Photos by Giles Winstanley
October 2008
Proposed short cut
Unmapped routes
E
N
S
W