AN EVALUATION OF CORAL REEF RESTORATION METHODS & ARTIFICIAL REEFS

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Introduction

Coral reefs are among the most diverse and valuable ecosystems covering approximately 250,000 km^2 in tropical oceans worldwide (distribution of tropical and cold water corals shown in figure 1 below) and house more than 30% of total marine biodiversity (Ladd, Shantz, Nedimyer, & Burkepile, 2016). The coral reef marine ecosystem provides services including food security and livelihoods for hundreds of millions of people living in coastal locations in over 100 countries around the world (Edwards, 2010). They also play an important role in coastal protection creating sheltered lagoons and protecting mangrove ecosystems (NOAA - Global Perspective, 1995).

Figure 1 – A map showing the global distribution of warm and cold water coral reefs (WWF - Coral Reefs, 2016)

It is estimated that almost 20% of the global coral reefs show severe levels of degradation and a further 15% are thought to be at risk of imminent degradation (Edwards, 2010). This is mostly due to the increasing anthropogenic threats to coral reefs. Reef degradation can be divided into local and global causes. Local causes include agricultural nutrient run-off, blast fishing and over-fishing whereas more large sale global causes include increasing sea surface temperature (SST), ocean acidification, El Nino southern oscillation (ENSO) events, typhoons and tsunamis (Edwards, 2010).

The threat of typhoons will be focused on specifically as they pose the most risk for the coral reefs in Negros Oriental. Typhoons have the potential to cause severe damage and degradation to reef sites in a very short period. Coral fragments and colonies may become dislodged or completely removed, rubble, sand or silt can smother the reef blocking the sunlight it depends on. Typhoon Washi (also known as Sendong) in 2011 and Bopha (also known as Pablo) in 2012 caused catastrophic damage to the coral reefs in Negros Oriental, Philippines. As these reefs are so important in providing livelihoods for so many, it is fundamental to try and assist the reefs recovery to these inevitable typhoons.

Ecological restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed (Edwards, 2010). Restoration aims to re-establish self-sustaining and resilient ecosystems. There are many reasons why restoration may be considered including rescue of specific species, increasing diversity and to return the reef to a given state (Abelson, 2006). Due to the declining global state of coral reefs, restoration has become part of the strategy to assist reef recovery (Montoya-Maya, Smit, Burt, & Frias-Torres, 2016). There are many methods of restoration that have been attempted in various studies however the success rate of the restoration varies.

There are critical steps involved in selecting and applying a restoration program:

- First, it is important that regular monitoring of the site is undergone to understand the state of the reef.
- Next it is necessary to assess whether the stress which caused degradation is still present. This involves considering whether an effective coastal management system is in place. A coastal management system monitors the area and manages factors like agricultural pollution and overfishing to ensure the reef is protected. Without coastal management it is unlikely that a reef will respond well to active restoration unless it has very few human influences. In cases where degradation was caused by a natural or individual event, a well-managed environment could assist the recovery of the reef a long side active restoration. Many reefs show resilience to coral bleaching and mass mortality in cases where there are very few human impacts.
- Following this, restoration goals should be defined and then the planned program should be carried out. The final step involved in restoration is monitoring to examine the success and survival of the restoration. Were the goals achieved? (Edwards, 2010) (Chou, 2016)

It is possible that after degradation a coral reef may recover naturally without active restoration projects. However this process may take up to 10 years and depends on human factors influencing the reef as mentioned previously (Edwards, 2010). Bikini Atoll in the Pacific Ocean was subject to 23 nuclear explosions between 1946 and 1948 obliterating the reef. Since this, the reefs have slowly recovered and are now thriving with an extremely high fish population and coral cover. It is thought that due to the radiation risks the reef has been protected from further human impacts as tourists were too afraid to visit the area. This meant that the reef could recover naturally over the past 60 years without further implications (Webster, 2016).

This study will evaluate and review several different methods of coral reef restoration including asexual propagation and sexual propagation both with in situ and ex situ nurseries, as well as physical restoration and artificial reefs. It will also look at a range of existing organisations in South-East Asia carrying out coral reef restoration. With this information, it will be possible to create a proper protocol for Marine Conservation Philippines how to respond after imminent typhoon damage, based on successful existing restoration methods.

Evaluation of coral reef restoration methods and their effectiveness

Criteria for evaluating methods

The criteria used in this study for evaluating different methods of coral reef restoration include:

- A description of the method including whether it is physical or biological restoration
- The cost of implementing and managing the method
- The time frame of implementing and managing the method

- The environmental conditions required at the degraded reef site
- On what scale, can the method be applied? e.g. sub hectare or larger scale
- Is the method carried out in situ or are there requirements for an ex situ nursery/ laboratory?
- What coral species are used in the restoration?
- Success rate/survival rate of the coral colonies? Is there evidence that this method is successful?
- Is it feasible to put in place at the Marine Conservation Philippines Marine Protected Area (MPAs) monitoring sites in Negros Oriental, Philippines?

Biological restoration

Biological restoration can use various methods involving coral growth and transplanting to assist the restoration of a coral reef.

Asexual propagation

Transplanting corals or colonies from a donor reef

Asexual propagation involves the transplanting of coral fragments or larger colonies from a donor reef site to a reef of choice, most commonly a degraded reef. It is important that the donor reef selected has similar environmental conditions (e.g. depth, exposure, salinity, temperature, water quality, substrate, sedimentation) as the degraded site. The coral fragments selected should be of reasonable size to ensure higher survival chances (Gomez & Edwards, 2007). Transplants can be taken as whole colonies either for reattachment after a disturbance (physical restoration) or if it is threatened e.g. industrial development at the site and it can be moved to a refugee site. If pruning intact parts of a coral colony it is recommended that no more than 10% of the colony is removed (Gomez & Edwards, 2007).

It is important to consider attachment tools when transplanting coral fragments onto a reef site. The use of cable ties or epoxy to stabilise the attachment of coral fragments significantly increases their chance of survival and live tissue growth over the attachment substrate can be seen within three months of transplant (Young, Schopmeyer, & Lirman, 2012). The attachment tool may vary dependant on the sites environmental conditions, for high energy environments it is most important that the corals are attached securely and will not dislodge whereas in a low energy environment corals may be secured by strategically placing between rocks and rubble (Abelson, 2006).

Corals of opportunity replanting

Asexual propagation can also involve transplanting of corals of opportunity. Corals of opportunity are coral fragments that have been detached from the reef through natural processes or unknown events such as typhoons or ship groundings (Monty, Gilliam, Banks, Stout, & Dodge, 2006).

The use of corals of opportunity is advantageous as there is minimal damage to the donor reef as the fragments have already broken off naturally. These fragments can be transplanted to degraded reefs to attempt to encourage growth. A study in Guam in 2008 (Rojas Jr, 2008) used corals of opportunity taken from a site undergoing dredging to increase the stability of a long existing rubble field. The study showed that the method was successful and that a major consideration when choosing corals of opportunity is choosing a coral with suitable morphology or that is resilient to future threats (Rojas Jr, 2008). For example, branching corals (*acroporids* and *pocilloporids*) can be used as an engineering species as they have considerably fast growth rates and therefore will quickly develop topographic complexity and provide shelter for small organisms (Edwards, 2010).

Corals of opportunity can also be used as a source of coral fragments for creating permanent or long-term nurseries.

Coral Gardening - asexual propagation using in situ/ex situ nurseries

Coral gardening is the process of collecting, growing and reattaching coral fragments at a degraded reef site.

Coral nurseries are an interim location for corals to stabilise and grow until they can be attached onto a reef. Nurseries are sometimes developed so that coral fragments are available at any time in case of a degradation event and restoration of the reef can begin immediately (Monty, Gilliam, Banks, Stout, & Dodge, 2006). Nurseries can also be used to propagate a sustainable stock of healthy and genetically diverse corals to enhance populations of endangered coral species. (Schopmeyer, 2011).

Coral nurseries can be in situ; in a sheltered sea area with similar environmental conditions to the future reef site or they can be ex situ; in aquaria development to the perfect conditions for rearing coral fragments. It is recommended that small fragments are capable of growth in an in-situ nursey whereas even smaller fragments for example <5 mm nubbins need to be grown in ex-situ nurseries where the conditions are more sheltered. However, the time frame of growing coral fragments can be very long. For example, growing 3cm nubbins to small fragments in a nursery ready for re-attachment takes approximately 9 to 12 months (Gomez & Edwards, 2007).

In most cases the costs of developing an ex situ nursery are much greater than in situ nurseries or direct transplantation. Therefore, organisations usually favour in situ nurseries or direct transplantation due to the lower expenses.

Studies have shown that the success rate of nursery growth is very high (90% survival in 6 months after reattachment), however the long-term success is relatively unknown. (Gomez & Edwards, 2007). A literature review of many existing studies involving coral transplantation indicated that fragment survival ranged anywhere between 43% to 95% during the first year of transplantation (Young, Schopmeyer, & Lirman, 2012).

Nurseries could be used to create a large strain of specific corals with certain characteristics e.g. bleaching resistant species, or a species which require little sunlight due to their high surface area. Although focusing on specific species of corals with high survival chances is encouraged, it is important to maintain a high species diversity and not lose structural complexity. In areas with high sedimentation, nurseries should be kept of the seabed to avoid smothering of corals and to improve survival chances. This can be done by using a raised mesh netting to keep the nursery away from the seafloor (Chou, 2016). Floating nurseries can be created at very low expense using rope/old fishing line with the coral fragments glued on. The ropes are held mid water column using floating buoys made from old bottles or cans (Riley, 2016).

Sufficient attachment of coral fragments from a successful nursery to a depleted reef can increase recruitment to the site and therefore establish a self-sustaining reef system that is no longer depleted (Montoya-Maya, Smit, Burt, & Frias-Torres, 2016) (Riley, 2016). The time it takes for corals to self-attach is species dependent, for example fast growing

Acropora corals will attach within one month whereas species that grow may take up to seven months (Guest, 2009).

Sexual propagation

Larvae collection

This method involves the collection of coral larvae during a broadcaster spawning event. The larvae are then reared in ex situ or in situ nursey. Larval seeding is advantageous over asexual reproduction restoration as it enhances the natural genetic diversity of corals (Meesters, Smith, & Becking, 2015). It also removes the stress and damage caused for donor reefs by eliminating the need for one (Gomez & Edwards, 2007). However, the time frame needed is substantial as the larvae must be collected during a seasonal spawning event which may only happen once a year. Once collection is made then the growth of coral from larvae to coral fragments large enough to transplant takes a long time. Mortality levels are high during the development stages as a minimal proportion of larvae collected will successfully grow to fragment size (Meesters, Smith, & Becking, 2015) This method is not often used by organisations as besides the drawbacks previously mentioned, it requires a high level of expertise to implement.

Removal of coral for spawning

This method involves removing coral colonies from the reef and placing them in aquaria until they have spawned. The larvae are collected and the coral colony is returned and reattached at its original site. The larvae are reared in either ex situ or in situ nursey until they are ready for attachment. This method can cause significant stress to the colony during both removal and reattachment *(Gomez & Edwards, 2007)*.

Physical restoration

Physical restoration is the process of rebuilding, stabilising and enhancing a reef site including the removal and stabilisation of large rubble fields or repairing the topographic complexity after major events e.g. ship groundings. Unstable rubble fields can be formed after destructive events leaving loose rubble which can further damage the reef and inhibit coral growth. Immediate action is useful to either remove loose rubble or stabilize large pieces using epoxy, however stabilising in high energy environments can be expensive and difficult and involves using flexible concrete mats or pouring concrete onto the rubble. In low energy environments stabilisation, can be achieved by simply covering the loose rubble with some limestone boulders (Gomez & Edwards, 2007).

Major physical restoration projects can become very expensive (approx. $100,000 to $1,000,000 per hectare) if civil engineering is required, therefore it is important to assess the site after the event and decide what restoration is necessary.

Minor physical restoration includes short term physical intervention to the site. For example, emergency triage after a major disturbance causing reef degradation e.g. typhoons or ship groundings. This includes small scale rubble removal, removing sand from reefs as well as reattachment of dislodged coral fragments. This can be a much more affordable process as it can be carried out with a small group of divers and only basic materials.

Stabilisation mats

Stabilisation mats are structures used to increase the stability of a reef area. There are many different designs, however the most common stabilisation mats involve cement or concrete tiles connected by rope or cables to form a mat structure. These mats can provide moderate stability during typhoons, although some minor movement has been recorded during disturbance events. As movement of stabilisation mats is not ideal, it is recommended that they should not be used in locations with strong currents or surge (Jaap, 2000).

Mats were used in a project carried out in North Dade County, Florida in 1997 to provide a stable substrate for stony corals over a sewage outfall pipe which had been exposed during a hurricane. The mats used were a fabric of 24 large concrete tiles connected by Kevlar rope. The mats were draped over the pipe to form a large protective structure. Corals were removed from the pipe and reattached to the mats using epoxy. According to the study there did not appear to be any adverse effects of removing and reattaching the corals, this may be due to the short time scale of this method (two days). Success, mortality and growth rates were monitored for two years after the transplant. The success rate was 87% and mortality 7.8% respectively. This exceeded the success and reduced the mortality rates recorded from seven neighbouring natural sites (Thornton, Dodge, Gilliam, De Victor, & Cooke, 2000).

Stabilization mats can also be made of plastic and can be used to stabilise a rubble field after destruction of a reef. For example, in a marine protected area (MPA) in Tañon Strait, Philippines a study was carried out using plastic mats to stabilise an area after blast fishing. The mats were secured over the rubble and coral transplants from a donor reef were attached. This was done either directly to the mesh using cable ties or to rock piles using cement and epoxy (Edwards, 2010).

Artificial Reefs

An artificial reef is defined as “a submerged structure placed on the seabed deliberately, to mimic some characteristics of a natural reef” (Baine, 2001). Extensive amounts of research and investment has been put into experimenting with artificial reefs, however they are not yet valued as a successful restoration and remediation approach (Abelson, 2006). Although not strictly “restoration” they can be used to assist the growth of a degraded reef providing a hard substrate for which corals can settle. There are many environmental benefits of artificial reefs including increased fish production, alternative dive site taking pressure of the natural reef, refuge for rare or endangered species, and providing nursery grounds for juvenile species (Abelson, 2006).

Artificial reefs can range from relatively small projects such as adding tyres to site to larger projects using specifically designed structures. There are many different materials that can be used for artificial reef structures including concrete, plastic, tyres, wood, shipwrecks, rope and many more (Baine, 2001). One of the most common structures designed for artificial reefs are Reef Balls™, which are concrete modules with many features including the easy mould, texture and voids or holes specifically designed to create a successful substrate for corals to attach to. There are many different sizes and styles and therefore can be used for many different objectives. Uses of reef balls include; breakwaters and shoreline protection, creating alternative dive sites for tourists to relieve pressure from a natural reef and assisting reef restoration providing a suitable substrate for coral growth (Reef Ball Foundation, 2014).

Reef Balls have been implemented globally in the creation of many artificial reefs and there are several existing studies in which these structures are used.

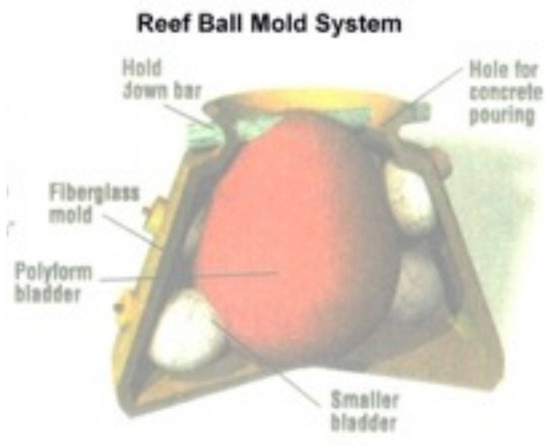

Figure 2 – An image of a Reef Ball (left) and a diagram illustrating the structure and manufacturing of Reef Balls (right) (Reef Ball Foundation, 2014).

A study by Meesters et al (2015) reviewing coral reef restoration techniques concluded that Reef Balls™ increased the level of fish biomass on a whole but the recruitment level on these structures is very low and therefore they are not ideal for restoration projects. However, a contrasting study by Bachtiar & Prayogo (2010) supported that reef ball modules can successfully be used in rehabilitating damaged coral reefs. They found that recruitment was high, although it varied a lot amongst the 30 reef ball structures installed in the study and the recruits were mostly Acropora corals (76%). They concluded that reef balls were a useful restoration tool as they provide another form of substrate for corals to settle on and can be placed in sandy areas to increase coral communities in an area where this was not possible previously. The settlement of corals on reef balls increases the habitat complexity and encourages further recruitment or coral larvae, fish species and invertebrates (Bachtiar & Prayogo, 2010).

There are many different forms of artificial reefs, some are specificailly designed structures and some are made from second hand materials. The costs of creating artificial reefs varies considerably depending on this, however there are both benefits and drawbacks with all types of artificial reefs, as shown below in table 1.

Table 1 – The possible benefits and drawbacks of artificial reefs (Abelson, 2006)

Benefits	**Drawbacks**
Increase in available substrates for reef organisms.	Slow development.
Increase in structural complexity.	Poor control of the community development.
Increase in settlement and recruitment.	Limited knowledge and prediction ability.
Increase in species diversity. Reduction of larval supply from natural reefs.	Reduction of larval supply from natural reefs.
Improving connectivity between sites.	Attraction of organisms from natural reefs rather than production.
Relatively easy removal in case of failure.	Possible adverse effects on neighboring natural reefs.
Instant increase in immigration of diverse reefdwelling species.	Promotion of common/dominant species.
Attractive projects that help promote public awareness.	

Organisations carrying out coral reef restoration

This section will discuss several organisations in South-East Asia already successful carrying out coral reef restoration. The questions asked and the information gathered from the organisations is as follows:

- A general description of the coral reef restoration method – physical/biological restoration.
- What costs are involved in implementing and managing the method?
- What is the time frame of implementing and managing the method?
- What environmental conditions required at the reef site?
- On what scale, can the method be applied? e.g. sub hectare or larger scale
- Is the method carried out in situ or are there requirements for an ex situ nursery/ laboratory etc.?
- Success rate/survival rate of the coral colonies? Is there evidence that this method is successful?
- What coral species are you using in the restoration project and what are the reasons for this?
- How many years has the project been running?
- Why did you choose this restoration method? What factors influenced your decision?

Organisations involved in study:

Coral Guardian in Indonesia runs many reef restoration projects involving both coral gardening and artificial reefs. The projects were set up between March 2012 and November 2013 and range in size of site from 200m^2 to 2500m^2. All projects involve multiple species of coral rather than focusing on one specific species to maintain species diversity. In total, 3570 coral fragments have been transplanted.

Nova South Eastern University in Florida have set up the Coral Nursery Initiative which aims to replenish the population of Staghorn corals. This is done using an offshore coral nursery to grow the coral fragments until they are big enough to be transplanted. Since the project began 3000 corals have been grown and it has now been expanded to a much larger scale and has an annual operations budget of over $100,000.

Reef Check Malaysia are currently running a reef restoration programme using in situ coral nurseries containing corals of opportunity which have broken off naturally from the reef and are approximately larger than palm size. They are collected within 50 metres of their new permanent homes and are not species dependant, therefore a range of species are collected maintaining the structural complexity of the reef. The nursery is monitored regularly to protect it from silt and algae build up to prevent smothering the corals. This project has been running since 2010 and has now been replicated at 13 sites across Malaysia. All sites underwent initial monitoring to assess the success and survival rates of the coral transplants. Four are still undergoing monitoring and the average success is 69.6%. Six of the sites are no longer monitored but are visually checked from time to time, the average survival rate is 70.73%. There were three initial sites used as the pilot sites for setting up the reef restoration project, donor sites were used for coral transplants. Since then, it has been found that using corals of opportunity is considerably more effective. The average survival rate of the three sites was 30.82%. Two of these sites were lost in 2013 due to a severe storm which destroyed 80% of the surrounding natural reefs.

Bolinao Coral Reef Targeted Research Program was a community based reef restoration programme carried out between 2004 and 2009. The project involved using an in-situ nursery to transplant hump corals (Porites Cylindrica) targeting dead or dying coral bommies. Approximately 200 corals were attached at three different sites and after six months 49% of the corals had successfully self-attached. This project involved a lot of community work, including lectures to teach the local community about corals and restoration as well as training for local divers and free divers on how to tend the nursery and how to attach corals. This community based approach is useful as it increases the understanding and desire to protect and restore the coral reefs into the local society.

New Heaven Marine Conservation Programme in Koh Tao, Thailand having been carrying out coral restoration work since 2007. They have set up several in situ coral nurseries as well as artificial reefs. Their methods include mid water table and floating nurseries, fish nurseries, steel artificial reef structures, glass bottle fish/coral habitats and coral larval culturing substrates.

When setting up the nursery three main designs were used 1) sloped tables designed to hold coral trays, 2) flat tables designed to hold coral trays and 3) flat tables designed to hold coral ropes. Each table holds 2 1m x 1m trays totalling 24 trays between all sites hosted at New Heaven. The nurseries are populated using corals of opportunity collected from the nearby natural reef. No strict guidelines are in place as to which species to collect but a broad range of species are collected to maintain diversity. Corals are either attached to vinyl tubes or secured in ropes in the nurseries and are transplanted once they reach 15cm in diameter or are considered robust enough to survive on the natural reef. To secure these fragments to the reef methods included finding existing holes in the reef, drilling holes in dead corals or securing using wedges. Coral transplants secured to the artificial reef can be attached using cable ties quite easily.

At one of their main sites Ao Leuk, prior to restoration work it was 97% sand, 2% rubble and 15 hard coral cover. The only marine life found were gobies and shrimp. Now there is a wide range of fish and invertebrates including rabbitfish, parrotfish, triggerfish, scorpionfish, barracuda and much more. Data taken from the nurseries shows there was almost no mortality in the first month, after this there was a small amount of damage caused to one table by an anchor. In 2011 storms caused the sloped tables to be destroyed and corals to come out of their vinyl tubes. Later that year a crown of thorns attacked one of the nurseries. Further data were collected to assess the growth rates of the coral fragments over a period of 105 days. Fragments grew in height by 56.4%, in diameter by 48.55% and number of branches increased on average by 49.5%. This was considerably faster than corals on the natural reef.

Environmental Conditions

It is important to assess the environmental conditions at a degraded site before planning active restoration. According to the *Reef Rehabilitation Manual* by *Edwards, 2010* the main environmental conditions to consider include:

Was there a coral community in this area prior to disturbance?

It may only be possible to implement active restoration at a specific location which was previously thriving prior to the disturbance. It is unlikely that successful restoration will be possible at a site where there were no coral communities previously. A lack of coral communities in an area with no major disturbance would most likely indicate the environmental conditions do not support coral growth.

Has the water quality deteriorated since the coral degraded?

Major disturbance events such as typhoons may cause increased nutrient run off from the land as well as increased pollution. It is important to assess this and do not start some methods of active restoration e.g. propagation until the nutrient levels in the water have returned to normal.

What condition is the substrate after the disturbance?

In many cases a disturbance event may cause parts of the reef to become physically damaged and it becomes littered with loose rubble. Before considering biological restoration, the first steps of restoration should include the assessment of whether loose rubble needs to be cleared or stabilised. If rubble is not secured it may cause further damage to the reef as storms cause movement of the rubble and coral mortality may increase. Large scale physical restoration is expensive but it may be necessary to achieve successful restoration.

Has sedimentation altered since the disturbance?

A typhoon may increase the sedimentation rate causing the reef to become smothered by sand or silt. Before beginning biological restoration work, as mentioned in the previous question, it is important to assess the site and carry out any physical restoration needed including removing silt or sand from the reef.

Areas experiencing urbanization and population increase may experience sedimentation build up causing reduced visibility and sunlight penetration. A good example of this is Singapore who has experienced 60% loss of coral reefs in the last 50 years. Due to the reduced sunlight penetration, corals will only grow in a restricted, shallow area of the reef (Chou, 2016).

Is the balance between herbivorous fish and macro-algae acceptable?

It is important to monitor the abundance of herbivorous fish (e.g. parrotfish, surgeonfish, rabbitfish), macro-algae and juvenile corals (less than 5cm). If there are few herbivores at the site, this may lead to an algae bloom and no juvenile corals will grow. In this case management is needed to restore the natural balance of the reef including fisheries regulation to increase the population of herbivores and nutrient input control.

Is the site recruitment limited?

The site must have a reasonable supply of coral larvae, usually carried to the reef by currents to naturally recover from a disturbance. If the site is recruitment limited and an insignificant supply of larvae is provided, fragment transplants may accelerate recovery.

Discussion

Protocol for post-typhoon restoration

After gathering information from literature studies as well as existing coral reef restoration projects, a protocol for post-typhoon reef restoration action has been formed. This protocol is a suggestion of actions to be carried out by Marine Conservation Philippines at one of their monitoring sites.

Studies suggested that biomonitoring of the proposed site is carried out prior to any restoration is considered (Edwards, 2010) (Chou, 2016) (Reef Check Malaysia). For the MCP sites this is taken care of by continuous monitoring projects involving surveys for fish, invertebrates and substrates. It may be useful to do some additional monitoring to assess dead coral matter and broken coral fragments at the sites.

It is vital that a coastal management system is in place at the site to control human influences on the reef including pollution, sedimentation and over-fishing (Edwards, 2010). At MCPs dive sites in Negros it is unlikely that high levels of pollution and sedimentation are entering the waters as there relatively little urbanisation. The main concern would be over-fishing, by choosing a well-managed MPA as the testing site the human influences are under control.

Most existing studies involve a permanent in situ nursery close to the reef (<50m) in a sheltered environment (New Heaven, Reef Check Malaysia, Coral Guardian – selected projects, Bolinao CRTRP). This can be stocked using corals of opportunity collected from the reef site. Some studies focus mainly on one species of coral e.g. fast growing branching corals (Nova South Eastern University); however, many other studies try to keep a range of species to maintain the structural complexity of the reef and so a single species doesn't dominate and therefore alter the fish and invertebrate populations that live there.

If under unfortunate circumstances Negros is hit by another destructive typhoon it may be necessary to carry out emergency triage and rubble stabilisation. This involves a group of SCUBA divers assessing the site and removing any rubble or debris from the reefs as well as any sand or silt that may be smothering the reefs.

As part of the emergency triage corals of opportunity can be collected, any fragments of coral that have been broken off during the typhoon (over palm size/10 centimetres) can be harvested and added to the coral nursery.

Once the fragments in the nursery have grown to small colonies, they can be transplanted to the reef (the permanent site). This can be done using a small amount of epoxy or cable ties to attach the corals, it is important to make sure they are secure as self-attachment will not take place if the corals experience movement due to high energy conditions (Young, Schopmeyer, & Lirman, 2012).

It is critical to continue monitoring of the site after the restoration has been carried out to assess the success of the transplants, for example – percentage of self-attached corals after 6 months, 1 year etc (Chou, 2016) (Edwards, 2010). MCP's long term monitoring surveys will assess fish and invertebrate biomass change in the transect locations.

Protocol for artificial reefs

After gathering information on artificial reefs from literature as well as existing organisations with artificial structures it is possible to conclude that artificial reefs can be a useful tool in reef rehabilitation projects as they can create further substrate for coral settlement, increase species diversity and relieve pressure from natural reef sites. However, they may be slow to develop and have low recruitment levels as well as being effected by sedimentation in some locations (Abelson, 2006). Similar to natural reef restoration projects, it is important to consider environmental factors and carry out monitoring before implementing an artificial reef project.

Conclusion

Due to the deteriorating state of global coral reefs, restoration projects and artificial reefs are becoming increasingly important. This study has explored different methods of coral reef restoration as well as artificial reefs hopefully to increase our understanding of what is possible at Marine Conservation Philippines. The section below will discuss the suggestions for further study following on from this research.

Further study

This study has provided a basic evaluation of reef restoration, there are other areas of study that need to be understood to implement this at MCP.

To set up a coral nursery at one of the MCP monitoring sites, further research is needed on:

- Species selection – how to maintain species diversity when collecting coral fragments?
- Nursery design – how to physically build the nursery? What materials are needed? Where should it be located?
- Location selection – which site to use? (Consider environmental factors)

A secondary project would be to build an artificial reef at one of the MCP monitoring sites, further research is needed on:

- Is it possible to collaborate with the local municipality on the creation on artificial reefs for fishing benefits and to reduce pressures on natural reefs?
- Do any local dive resorts wish to create an artificial reef project as a new dive site for tourism benefits and to reduce pressures on natural reefs?
- What design features should be implemented?
- Location selection – which site to use? (Consider environmental factors)

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