Development of a Coral Reef Restoration Framework: A Maldivian Case Study

by

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Abstract

The observed coral reef decline has prompted alternative protection measures beyond traditional conservation efforts. Restoration can be used to reverse reef degradation and has been practiced around the world, particularly in developing countries where livelihoods rely on the ecosystems, such as the Maldives. As an atoll nation with more oceanic territory than terrestrial territory, the country’s vulnerability to increased development and unprecedented environmental changes requires effective coral reef management. A literature review was conducted to develop a restoration framework, based on common coral reef restoration practices, which can be used by Maldivian reef managers and others to prioritize restoration methods and to involve team members from several sectors. Specifically, the framework can be used by the Maldives to support inclusion of passive restoration options, sector integration, and local engagement to promote the country’s efforts in coral reef protection.
Introduction

Restoration, defined by the Society of Ecological Restoration as ‘the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed’ (SER 2004), includes various strategies. Restoration can focus on a particular species, ecosystem function, or ecosystem service (Ehrenfeld 2000). The terms ‘rehabilitation’, ‘reclamation’, and ‘remediation’ are all commonly interchanged with restoration, yet may differ in definition and in their ultimate goals. Rehabilitation aims to improve the ecosystem from a degraded state (Choi 2007), while reclamation, common with mined lands, involves repairing a system from an undesirable condition for aesthetic, safety, or multiple land use purposes (Higgs 2003; SER 2004). Remediation works to fix system damage, but not necessarily in order to recover ecological integrity (Higgs 2003). Many different actions may constitute as restoration and resources should be devoted to the development of effective projects for the sake of environmental protection (Hobbs and Norton 1996).

While the practice of restoration has existed for decades, particularly with plant ecology, the field of restoration ecology is relatively new (Young et al. 2005). Much focus of restoration efforts has been devoted to terrestrial ecosystems, including forests, grasslands, and inland riverine systems. Restoration efforts have targeted wetlands for decades (Zedler and Langis 1991; Zedler 2000; Acreman et al. 2007), and have since turned to mangrove stands, sea grass beds, and most recently coral reefs (Ellison 2000; Precht et al. 2001; Edwards and Gomez 2007; Bastyan and Cambridge 2008), in an attempt to counteract the noted coral reef decline throughout the world’s oceans.

Communities reliant on reefs for sustenance and livelihoods are particularly keen on protection of reef related resources, yet often lack the resources to provide effective management. The Maldives are a prime example of such a country. As a nation of more oceanic territory than terrestrial territory (Naseer 1997), the Maldives requires healthy marine ecosystems and sustainable use of their resources. The country recognizes this and is working towards the development of effective coral protection and restoration efforts. With recognition of their vulnerability to increased development and unprecedented environmental conditions, the Maldives has enacted policies in an attempt to protect coral reefs, but with the observed coral reef decline, the country now supports restoration as a means to protect these valued ecosystems.

However, with the lack of consolidated information on coral reef restoration efforts, there are a wide variety of techniques used worldwide, all with varying indicators of success, complicating the
determination of a ‘best’ practice. Restoration is experimental and a multitude of methodologies have been used in an attempt to recover coral reefs damaged by natural and anthropogenic threats (Young 2000; Abelson 2006). Attempts to generalize restoration techniques prove complex due to the site-specificity of each project (Hilderbrand et al. 2005). While existing research may not be able to offer a one-size-fits-all restoration solution, common practices may still be studied in order to better understand how the field of coral reef restoration can inform future management decisions.

In order to ensure effective restoration projects, a framework is necessary to provide context and guidelines for managers (Hobbs and Harris 2001; Abelson 2006). The understanding that restoration actions must be based on the best available information (Hobbs and Harris 2001), coupled with the lack of consolidated coral reef restoration specific information, necessitates a push for the assimilation of details in a way that is useful to managers. To address this need, a literature review was conducted to gather coral reef restoration project details with the purpose of informing a framework to be used by coral reef managers, particularly in the Maldives, used as a representative small island developing nation reliant on its reefs.

**Background**

*Restoration as an Ecosystem Management Tool*

Restoration requires a number of components in order to succeed. First, the success of a project is largely based on the goals that are initially set forth by project managers and relevant stakeholders (Higgs 1997). The goals must be clear, practical, achievable, and address the ultimate objective of the project, whether it is to return an ecosystem’s function or services, or recover lost biodiversity (Hobbs and Norton 1996; Hobbs and Harris 2001). The goals may take into account social or economic needs, including providing educational outreach or income to a local community, but must also be flexible to account for unpredictability in nature (Cairns 1993; Choi 2007). Success of restoration is measured by criteria delineated prior to project commencement, which are highly dependent on the goals set forth by project managers (Hobbs and Harris 2001).

Secondly, restoration must recognize the dynamic behavior of the natural world (Hobbs and Harris 2001). Each site varies in processes and environmental conditions and no two restoration projects will be precisely the same (Hobbs and Norton 1996; Hildebrand et al. 2005). Because of this dynamic nature, project managers must acquaint themselves with adaptive management (Choi et al. 2008). Finally,
projects must devote resources to monitoring, through which success criteria are evaluated, progress can be assessed, and changes in project trajectories can be addressed, if necessary (Hobbs and Norton 1996; Thom 2000).

Despite the increased popularity of restoration as a means to counteract human impact on ecosystems, the practice endures a number of limitations. Systems must be well understood prior to development of restoration projects in order to use cost effective methods. Due to the dynamic nature of ecosystems, it may not be feasible to recover a historical condition; ecosystems have changed in the past and will continue to change into the future (Hobbs 2007). While historical contexts and known baselines should be considered, restoration projects should also aim to establish a community or system that will survive in projected future conditions (Choi 2007). This proves problematic for restoration efforts targeting systems vulnerable to global climate change and other unpredictable and unprecedented environmental conditions. Also, restoration is a highly experimental field, and there often exists a schism between restoration ‘the science’ and restoration ‘the practice’, which results in frequent disagreement on best practices (Palmer at al. 1997; Lunt 2001). The noted absence of specific project information often results from research team’s unwillingness to share data and results, as well as restoration practitioner’s hesitancy in revealing any project mistakes or failures (Kondolf 1995; Lake 2001). What project details do exist is often unconsolidated and difficult to locate (Zedler 2000).

Restoration should be used when conservation efforts fall short or at least in conjunction with protection measures (Dobson et al. 1997; Young 2000; Hobbs and Harris 2001). Due to the high expenses of restoration, it is more cost effective to invest in the protection of valuable ecosystems than to attempt to recover them (Holl and Howarth 2000; Hobbs and Harris 2001; Aronson et al. 2006). If a system is not likely to recover naturally, managers must then consider applying passive or active measures, or perhaps a combination of both.

Restoration activities tend to fall into three broad categories: no action, passive, and active. Performing no restoration action is typically the easiest option, yet may not achieve project goals and is often not considered by managers as an appropriate approach (Hobbs and Harris 2001). Passive restoration addresses the removal of the damage source (McIver and Starr 2001; Morrison and Lindell 2011), whereas active restoration necessitates direct human intervention (Holl and Aide 2010). Passive restoration may take a considerably longer amount of time to achieve project goals, and may not be suitable for human’s need for immediate gratification. Active restoration may cause more harm than
good, but the more damaged a system is, the more active restoration may be necessary in order to obtain recovery (Holl and Aide 2010).

These approaches have been used on a variety of damaged ecosystems, but have been observed increasingly on coastal and marine ecosystems, including coral reefs.

*Coral Reefs*

Coral species exist throughout the world’s oceans, but their distribution is limited by their need for particular environmental qualities, such as specific sea surface water temperatures, salinities, water clarity, and depth (Kleypas et al. 1999; Moore 2001; De’ath and Fabricius 2010). Such environmental conditions exist along the equator, which explains the high abundance of coral species in tropical seascapes. The hermatypic (reef building) coral species associated with the warm, clear waters of the tropics house a significant amount of the ocean’s biodiversity, and display high levels of productivity (Odum and Odum 1955; Connell 1978). Despite making up a small percent of ocean area, reefs are located along the coasts of over 100 countries (Spalding and Grenfell 1997; Moberg and Folke 1999; Edwards and Gomez 2007).

Reef ecosystems, perceived as incredibly valuable to both economists and biologists, offer a multitude of ecosystem services. Coral reefs serve as a habitat for fish and invertebrate species important to commercial and recreational fisheries; an estimated one quarter to one third of the world’s fish species are observed on reefs (McAllister 1991; Roberts et al. 1998). These fisheries contribute an estimated 25% of the catch in developing countries, serving as a large source of protein and income particularly in the Caribbean and Indian Ocean (Roberts et al. 1998; Reaser et al. 2000). In Asia, coral reefs provide an estimated one quarter of the annual total fish catch and protein to approximately one billion people (UNEP 2006). Reefs also buffer coastlines from erosion, storms, and related inundation events (Reaser et al. 2000; UNEP-WCMC 2006). Many nations rely on coral reefs for services beyond protein supply, including economy stimulation and maintaining livelihoods, including the atoll nation, the Maldives.

Unfortunately, due to increased anthropogenic impacts and natural disturbances, coral reefs worldwide, and specifically in the Maldives, are in a perilous position (Clark and Edwards 1994; Pandolfi et al. 2003). Conservation efforts, including the creation of marine protected areas, have attempted to protect coral reef ecosystems (Mora et al. 2006; Bottema and Bush 2012), but despite best efforts, corals still face decline. As coastal populations and related development increases around the world, it is expected that
coral reef decline will continue. While there is no substitute for ecosystem conservation, restoration can be used in conjunction with environmental protection measures to prevent the loss of ecosystems and related services (Hobbs and Harris 2001; Abelson 2006).

*The Maldives: A Country-Wide Reliance on Coral Reefs*

The Maldives, situated off of the West coast of India and Sri Lanka, is comprised of an estimated 1,190 islands, forming 26 atolls (Naseer 1997). These atolls consist of coral rubble and sand, and fringing reefs surround each of the islands. Per Darwin’s initial reasoning (Darwin 1909), atolls form as a result of coral settlement and fringing reef formation around a volcano or oceanic island. Eventually, the volcano subsides, while the ring of coral remains, continually building up on top of itself. Sand and sediment accumulates, which results in islands of coral rubble and sediment surrounding a lagoon. The Maldives, literally built on its coral (Clark and Edwards 1994; Zahir et al. 2010), are undoubtedly dependent on and attribute their very existence to the ecosystems. Beyond the geological importance of coral to the country, the Maldives’ two greatest industries, tourism and fisheries (Naseer 1997), depend on the health of the ecosystems.

Long heralded for its crystalline blue waters, the Maldives attracts divers and snorkelers from around the world. Tourism first began in the 1970’s and today over 100 resorts and hotels host international guests (Ministry of Tourism Arts and Culture A, B 2011). Over 700,000 tourists visited the islands in 2010 (after a lull due to the Christmas tsunami in 2004 and in 2009 due to the international economic crisis), contributing over 30% to the country’s GDP since 2006 (Ministry of Tourism Arts and Culture C 2011). A required tax per guest at each resort, hotel, guest house, and vessel contributes an estimated 30% to the country’s tourism revenue, as well (Ministry of Tourism Arts and Culture C 2011). Due to the prevalence of resorts and hotels, the tourism industry provides a large source of employment for locals. Regulations set forth by the Ministry of Tourism insist that at least 50% of the staff at resorts be locals (Laurel Maldives 2008).

The long practiced fishing techniques depend on the reef ecosystems as well. Maldivian subsistence fishing bears huge cultural importance; the fishing trade passed down through generations involves pole and line with live bait or small cast nets off of the shore or from traditional fishing boats, also known as dhonis. More technologically advanced methods are not allowed within the 200 mile economic exclusion zone (Prince 2010). While reef fish are not typically consumed directly, they are used as bait for the primary target of most Maldivian fishing operations, the tuna.
Despite the recognized importance of the coral reef ecosystems to the economy and culture of the Maldives, localized anthropogenic threats, such as overfishing, blast fishing, dredging, coral mining, and coral collection have the potential to decimate reefs, resulting in degraded frameworks and inhospitable conditions for related reef species. Increased development led to the practice of coral mining, which involved destroying reef heads to rubble used for construction material (Clark and Edwards 1994). The coral rubble cannot restore itself, and can often cause more damage as it is caught up in the water column by waves and storms and knocked into living reefs. Similarly, because of increased demands in reef fisheries for the tourism and commercial fishery industries (Nickerson and Maniku 1996) and exotic fish for the aquarium trade (Edwards and Shepherd 1992), many fishermen turned to unsustainable fishing behavior that have affected the reef community structure and composition (Sluka 2000).

Coral reefs are also affected by natural events such as storms and wave action, as well as events that are seemingly natural but may be linked to humans, including global climate change, disease, and over-predation by Crown of Thorns starfish (*Acanthaster placi*). The Maldivian reefs suffer from natural disturbances, namely global climate change. In 1998, increased sea surface temperatures brought by the El Nino caused mass bleaching events throughout the Indian Ocean (Zahir 2000). The Maldives attributes most of their coral damage to this sole event (AusAID 2005). The weakened state of the ecosystems has affected the resiliency of the coral. Storms also can damage reefs, though the tsunami in 2004 appeared not to have had significant impact on coral cover or ecosystem biodiversity (AusAID 2005).

While the Maldivian government provides legal protection to its reefs via various environmental policies (Table 1), it is limited in their capabilities to properly monitor and restore their reefs. With only three full-time staff and limited funds (approximately $3700), the Marine Research Centre is responsible for monitoring the entirety of the Maldivian reefs (Marine Research Centre 2011). While the government

<table>
<thead>
<tr>
<th>Policy</th>
<th>Governing Body</th>
<th>Relation to Coral</th>
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<tbody>
<tr>
<td><em>Fisheries Law (5/87)</em></td>
<td>Ministry of Fisheries and Agriculture</td>
<td>Prohibition of exportation, collection, and exploitation of several coral species</td>
</tr>
<tr>
<td><em>Environmental Protection and Preservation Act (4/93)</em></td>
<td>Ministry of Housing and Environment</td>
<td>Requires EIA/EIS for any project that could potentially damage the environment. Act also empowers MOHE to identify and designate marine protected areas. Regulates sand and coral mining on house reefs and atoll rim reefs.</td>
</tr>
<tr>
<td><em>Tourism Act (Law no. 2/99)</em></td>
<td>Ministry of Tourism Arts and Culture</td>
<td>Regulates dive centers and vessels and promotes sustainable tourism development.</td>
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</tbody>
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Table 1. Maldivian policies regarding coral reef protection.
aims to develop an effective monitoring program, there lacks a baseline understanding of the reef systems prior to the bleaching events of 1998 due to the country’s lack of scientific support and capabilities, especially for islands far out of reach of the capital island, Male (AusAID 2005).

**Project Objectives**

While there are sources of information detailing coral reef threats and management efforts (e.g. marine protected areas), there is no apparent database of detailed, consolidated information on restoration projects. Most peer-reviewed articles reference country specific projects, but there is little reference to a large-scale, international analysis of reef restoration efforts. In order to better understand the field of coral reef restoration and to consolidate available information from projects around the world, a literature review was conducted in peer-reviewed and grey literature.

To consolidate and summarize common coral reef restoration practices in order to inform a framework for Maldivian managers, four questions served as primary objectives:

1. Where are reef restoration projects occurring?
2. Who is involved in the restoration projects (e.g. government agencies, NGO’s, for-profit organizations and companies)?
3. What threats are responsible for coral damage at restoration sites?
4. How are reef restoration projects conducted (i.e. what methods are used)?

Cases specific to the Maldives were used to study coral reef restoration efforts in an area with minimal resources, yet a dire need for healthy coral reefs. The information from both reviews was used to inform a framework for coral reef managers in the Maldives involved in restoration development and implementation.

**Methods**

*Literature Review Data Collection*

A literature review was conducted in Google, Google Scholar, and Web of Science. Due to the inconsistent definition, words used interchangeably with ‘restoration’ were searched as well. Queries were as follows:
Queries then targeted 30 specific countries (e.g. ‘coral reef, restoration, Maldives’) with the highest measured coral reef area as provided by the World Atlas of Coral Reefs (Spalding et al. 2001). Primary literature was initially searched via Google Scholar and Web of Science. However, due to the limited information available from peer-reviewed journals, queries were directed to gray literature as provided by Google. Gray literature information sources, including conference proceedings, project reports, news articles, promotional information for companies and organizations via websites, blogs, and multi-media such as YouTube videos (Figure 1, Appendix), were explored, following websites to further projects, partners, restoration references, and sites. Only sources with information regarding at least three of the four objectives were included. Projects were not included if they:

- Performed mitigation (i.e. in the face of a known, future threat such as dredging, corals were removed from the site of impact);
- Suggested primary project objectives other than coral reef restoration (e.g. restoring fishery stocks, addressing shoreline erosion);
- Referred to projects to be conducted in the future.

**Literature Review Summary**

Project details that addressed each objective were input to an Excel database. The database was manually coded to explore the data. Due to the multi-responses for three of the four objective questions, information was classified into commonly listed themes observed in the literature. Frequencies were tallied and percentages calculated. Case studies specific to the Maldives were included in the broad-scale database, but were also examined in more detail.

**Statistical Analysis**

Chi square tests were used to determine statistical significant relationships between the variables as follows:
- Methods used between geographical regions
- Participants between geographical regions
- Threats between geographical regions
- Methods used between threat types

The null hypothesis was set to no statistical difference implying that the distribution of methods, participants and threats around the world was random. Likewise, the null hypothesis indicates that the methods implemented did not vary significantly by threat type.

Framework Development

A general restoration framework was developed based on general restoration ecology primary literature, restoration plans for various ecosystems, and conversations with practitioners. Information from the broad scale literature review, as well as the cases specific to the Maldives, was used to develop this framework further for use by Maldivian reef managers.

Results

The literature review resulted in 202 unique coral reef restoration projects, including 10 projects specific to the Maldives.

Literature Review Summary

Objective 1: Where is restoration occurring?
Fifty-three countries were found to have reef restoration efforts. The countries were classified into five geographical regions (Table 1, Appendix). Most projects were found in the Caribbean and Latin America region (n = 65; Figure 1), followed by the Indian Ocean (n = 47), Coral Triangle (n = 45), and Pacific Ocean (n = 32). The Middle East provided the least number of projects to the review (n = 13).
Objective 2: Who is involved in restoration projects? Groups involved with reef restoration projects, as listed by each of the sources, were classified in five participant types (Table 2, Appendix). Participants listed as explicit donors or financial supporters were not included. The most commonly listed project participants were non-government organizations and non-profits (n = 77; Figure 2), while locals were least likely to be involved (n = 51). Over half (53.5%) of the projects involved multiple participant types.

Objective 3: What threats are responsible for reef damage? Damage sources listed by the projects were classified into 15 common themes (Table 3, Appendix) which included anthropogenic and natural threats. The most commonly listed source of damage was climate change (n = 42; Figure 3), followed by destructive fishing techniques (n = 30), overfishing (n = 27), storms (n = 25), ship groundings (n = 21), and pollution (n = 21). Many projects listed multiple sources of damage (23.8%).

Objective 4: How is restoration
conducted? Project methods were classified into eight categories, including passive and active approaches (Table 4, Appendix). The most common methods noted were transplantation (n = 140; Figure 4) and artificial reefs (n = 106). Fifty percent of the projects used multi-techniques. For example, mineral accretion requires the use of artificial reefs and transplantation. Similarly, nursery propagation involves transplantation of the nurtured coral fragments to degraded reefs.

Maldivian Literature Review Summary

Objective 1: Where is restoration occurring? Eight of the ten projects occurred on resort islands, while the remaining two occurred on faros, or ring-shaped reefs, a geological structure unique to the country. Most of the project sites were located within the same atoll as the capital island, Male (Figure 5).

Objective 2: Who is involved in restoration projects? When compared to projects in the Indian Ocean and internationally, Maldivian projects involve predominantly for-profit companies (n = 8; Figure 6). Government involvement is minimal (n = 2) and no project mentioned participation from locals.

Figure 5. Location of Maldivian projects (indicated by red dots) observed in literature review.

Figure 6. Percentage of participant types in Maldivian projects compared to projects in Indian Ocean and internationally.
Objective 3: What threats are responsible for reef damage? Climate change was the most commonly listed threat for projects in the Maldives, in the Indian Ocean, and internationally. Eight of the ten Maldivian projects noted reef damage related to coral bleaching induced by the 1998 El Nino. Two projects listed coral mining (Figure 7), though coral mining is seen minimally elsewhere in the world.

Objective 4: How is restoration conducted? Similar to projects in the Indian Ocean and internationally, Maldivian projects primarily utilized transplantation (n = 6) and artificial reefs (n = 6), often in conjunction with each other (Figure 8). One project mentioned mineral accretion and two projects mentioned the use of nurseries.

Statistical Analysis

The data was studied further in order to address relationships between the four objectives. Data was first summarized based on initial classifications. For ease of statistical analysis, restoration methods were reclassified as passive or active and threats were reclassified as natural (i.e. storms, waves, disease, biological disturbance, and global warming) and anthropogenic (i.e. coral collection, coral mining,
destructive fishing, development, overfishing, pollution, sedimentation, ship groundings and anchor drops, and tourism).

Passive techniques were most commonly seen in the Caribbean and Latin America region, though active techniques dominated all geographic regions (Figure 9). Transplantation was the most commonly used technique in every region, except the Coral Triangle, which was instead dominated by the use of artificial reefs. There was a statistical difference ($p = 0.007$) in the use of passive versus active reef restoration methods between geographical regions.

![Figure 9. Percentage of methods used by geographic region.](image)

All geographic regions noted involvement from all participant types (Figure 10). Locals appeared to play a small role in restoration projects. The Middle East was dominated by research and academic institutions, while such groups seemed to be less frequently involved in projects elsewhere in the world. No statistical difference was found between groups involved by geographic region ($p = 0.087$).

Ship groundings dominated the projects in the Caribbean and Latin America region (Figure 11). The Indian Ocean projects most commonly listed threat was climate change, typically manifested as coral bleaching events as a cause of coral degradation. The Middle East most frequently listed development, while the Coral Triangle was dominated by destructive fishing techniques. The Pacific Ocean had high frequencies of overfishing, storms, and climate change listed as sources of damage. No statistical difference was found between natural and anthropogenic threats by geographic region, though it is worth noting the almost significant value ($p = 0.054$).
Studying methods implemented for each damage source provided the following observations: transplantation was most commonly used for storms, ship groundings, overfishing, coral mining, tourism, development, biological disruptions, and disease (Figure 12). Projects that justified restoration because of climate change, the most commonly listed source of damage over all 202 projects, listed the use of mineral accretion most often. There was no statistical difference between methods (passive versus active) by threat type (natural versus anthropogenic; \( p = 0.573 \)).
Proposed Reef Restoration Framework

A basic framework was developed based on what is presented by general restoration ecology theory in primary literature and other ecosystem restoration plans (Figure 13). The literature review findings were used to elaborate upon these steps, as noted below (Figures 14, 15). The common practices as observed by the literature review and statistical analysis were incorporated into the framework in such a way to promote facilitated discussion and provide options that would be applicable to the development of an effective reef restoration project. The framework also served as a means to address gaps in knowledge and areas of improvement, particularly in Maldivian reef restoration efforts.

Figure 12. Percentage of methods used by threat type.

Figure 13. General restoration framework.
Framework Breakdown

1. **Site Selection** (Figure 14)

   The determination of precisely where the project site is located will inevitably influence
   the project participants and methods implemented, while setting the boundaries of the
   project. Due to the geographic separation of the islands and atolls, the location plays a
   crucial role in determining what groups would be involved with restoration efforts. For
   example, a resort island would more than likely not include locals in restoration efforts,
   whereas an inhabited island may not include a private resort company. The atoll may also
   specify political and economic justifications for project criteria that would further
   determine project participants. Ideally, geospatial analysis of the location would be used
   in order to understand where coral reefs are located relative to other marine ecosystems
   and resources, and terrestrial based impacts (e.g. sources of run off). However, it is
   recognized that developing nations, like the Maldives, would lack the resources to invest
   in such an undertaking. Restoration techniques will be dictated by the precise location of
   the coral reef on island, as sites may differ in currents, tides, and other physical
   oceanographic factors. These site-specific environmental conditions may require
   particular expertise that would further dictate participants. Specific questions to consider
   for site selection in the Maldives:
   
   a. What atoll is the island in?
   b. Where is the project located?
      i. Resort Island
      ii. Inhabited Island
      iii. Uninhabited Island
      iv. Faros (ring shaped reefs)
   c. Where on the island is the restoration going to occur?
      i. Lagoon Side
      ii. Ocean Side

2. **Build the Team** (Figure 14)

   The project participants (not necessarily financiers) will largely depend on where the
   project site is located, but will also be influenced by the damage source and methodology
   desired as some techniques may require expertise only available from particular groups.
   This team should involve a variety of experts that contribute constructively to the project
objectives. Team membership may also be dictated by funding sources. In considering possible team members, the Maldives should include:

a. For-profit companies
   i. Resort Companies
   ii. Private Consulting Companies
   iii. Marine Engineering Firms

b. Government
   i. Island/Atoll/Federal Government

c. Academic and Research Teams
   i. International Research Teams (e.g. partnerships with academic institutions or scientists from other governments)

d. NGO’s and Non-Profits
   i. Environmental Organizations – Domestic and International

e. Local Islanders

3. **Assess the Situation** (Figure 15)

   The project site should be assessed in order to understand the impact of the threat and the current state of the coral reef ecosystem. Baseline information regarding the site should be utilized, and in the case that there is none, an assessment of surrounding healthy reef, if it exists, should be conducted, acting as a nearby reference system. This can be used to determine what is necessary to restore the damaged reef site and can provide insight into undamaged system structure and function. Several environmental variables should be measured as indicators for ecosystem function and structure, but for the sake of ease on resource limited managers, a select few are noted as follows. In the case that a damage source is indirect, this environmental information should strive to identify the cause of coral reef on site. The damage source, when evident, should dictate what restoration approach should be considered (i.e. passive versus active).

a. Water Quality
   1. Salinity
   2. Sedimentation Levels
   3. Presence of Chemicals
   4. Water Temperature

b. Biodiversity
   1. Coral diversity
   2. Fish census
3. Benthic census
c. Coral Quality
   1. Coral cover
   2. Fragmented/Bleached/Diseased
d. Framework/Substrate
   1. Substrate composition
   2. Topographic complexity
   3. Consolidated versus unconsolidated substrate
e. Identify direct damage source if immediately evident

4. Define Goals and Success Criteria
   In order to establish restoration goals, all potential restoration options for a site must be considered. Attention must be paid to the site assessment findings, identified damage source, and stakeholder input, particularly project participants must be incorporated in determining the goals and success criteria. The restoration methods used will be largely influenced by the goals set forth.

5. Determine Methodology (Figure 15)
   Managers should first consider the option of no action, or natural recovery. If restoration has been deemed the most appropriate pathway, threat indications as well as the collected environmental data from the site assessment should yield potential methodologies. The method must also reflect project objectives as set forth by team members, and relevant stakeholders, as well as political, social, and economic needs and limitations as necessary. Possible methods include:
   a. Passive – necessary when the threat has not been removed or managed
   b. Active – if the threat has been managed, yet natural recovery is not an option
   c. Combination of both – if the threat must be managed and natural recovery is not an option

6. Implementation of Project
   The execution of the specified restoration plan should ensure that all team participants are working effectively together and efficiently in order to obtain the project goals on the delineated timeline.

7. Monitor and Maintain
   Once the project has been implemented, resources must be devoted to repeatedly monitoring the system as a means to measure the defined success criteria and determine if the project has met the goals set forth. Monitoring also allows an opportunity to identify
unpredicted trajectories and gauge any negative impact the project may have on the surrounding environment. The inclusion of adaptive management strategies addresses these unforeseeable needs and issues.

The first steps can be interchanged (i.e. it may be more logical to understand the damage source before identifying what project participants to include) and are easily influenced by each other (e.g. methodology could be impacted by the damage source but also by whether the site is located on the lagoon or ocean side of an island). In the Maldives, due to the distance between islands, project participants will largely be determined by geographical location. While many projects occurred on resort islands, other island types and faros may be eligible for restoration as well, which would encourage local involvement.

Managers must also consider carefully if restoration is the most effective option for coral reef management, and whether or not natural recovery has the potential to occur. If natural recovery is not likely to occur, and restoration is deemed the most appropriate tool, historical ecosystem data should be used to develop a baseline. If such data does not exist, or managers have the resources to do so, surrounding coral reefs should be assessed to gauge the current state of a similar, ideally healthy, system. A site assessment should aim to use environmental data and ecological indices in order to understand the system and gauge the current reef condition. This information would help pinpoint the source of damage, if not immediately evident. With this information in hand, managers would be well-equipped to answer the question of how to conduct reef restoration, with either active or passive methods.

The Maldives considers climate change and coral mining their two largest threats, though based on common themes observed in the literature review, there are a number of future potential threats the country may face in light of increased development and unprecedented environmental changes. Coral mining is manageable – Maldivian policies prevent mining on house reefs – so, further passive efforts should be considered first, with active restoration used only when necessary. Climate change is a global threat and currently non-manageable. Restoration options for reefs victim to increased sea surface temperatures have two options: an active approach or no restoration at all.

Ultimately, managers must define clear goals and consider all restoration options prior to project implementation to ensure that these goals are met. Adaptive management is a crucial component to this process as ecosystems are dynamic and unpredictable events cause project trajectories to change. Managers must be prepared to re-establish project goals and methods based on these changes. Regular monitoring should be conducted to re-assess the project site, redefine goals and methods when necessary,
and determine project success. Exclusion of any of these steps may result in an ineffective project and, potentially, even more reef ecosystem damage.

Figure 14. Maldivian coral reef managers must consider the geographic location of the project site as this will indicate social, economic, political, and ecological considerations. The project site location will inevitably influence the project participants.
Figure 15. In developing a coral reef restoration project, Maldivian managers must consider first whether or not restoration is the most appropriate management tool, and whether or not natural reef recovery has the potential to occur. If restoration is deemed necessary, a site assessment must be conducted to collect environmental data that will gauge the current condition of the reef and identify the damage source, if not immediately evident. With this information in hand, managers are then suited to determine the most appropriate reef restoration method.
Discussion

Literature Review

Restoration can be an effective coral reef management tool once project information is consolidated. Understanding what is occurring in the field on a broad scale can assist site-specific needs. While peer-reviewed literature is the preferential source of reliable information in the scientific community, there is an apparent lack of primary literature on coral reef restoration. While several tendencies parsed from the literature review corroborated what has been noted in general restoration ecology peer-reviewed literature, interesting splits between what is often suggested by general restoration theory and what is actually being practiced in coral reef restoration were also revealed.

Transplantation has been noted to be the most popular technique in primary literature (Abelson 2006), which is related to its ease of undertaking and various modes of implementation. Projects from the literature review mentioned a wide variety of transplantation techniques ranging in complexity from casting storm produced fragments on to the substrate and allowing for natural attachment to removing fragments from nearby reefs and cementing nubbins to the substrate, be it natural or artificially formed.

What proves interesting in studying methodologies implemented is that mineral accretion and coral propagation via nurseries, which tend to be more complex and time-intensive procedures, are noted more commonly in developing countries than developed. This may be partially attributed to the acknowledgement by NOAA, the governing body for much of the coral reef restoration in the United States, that mineral accretion is not a peer-reviewed acceptable technique (NOAA 2010) and warrants further research before it can be implemented as an appropriate restoration method. The Global Coral Reef Alliance, the patentees of the mineral accretion technique, may have a number of reasons to invest in the Indian Ocean that cannot be explained here, which indicates the complexity of determining why particular methodologies are implemented in specific locations.

Looking to the involved parties in reef restoration efforts, the most surprising tendency is the lack of local engagement. Restoration literature generally encourages local involvement in order to foster a sense of stewardship (Seaman 2007; SER 2004). Young (2000) even notes that restoration projects are often initiated by community members. Successful restoration projects can be attributed to local engagement and knowledge (Hibbard and Karle 2002; Petts 2006) and such efforts often provide a source of income or livelihood (Aronson et al. 2006), particularly for coastal communities who are entirely reliant on the
health of their coral reefs. Another complication observed by the literature review is that project participants are not always clearly defined; some cases listed ‘project supporters’, which implies the contribution of financial assistance and no participation in the actual development or implementation of the project. Based on the available information, it was difficult to understand how cases defined project participants (i.e. one project may consider a financier as a participant, while another project may not), which may offer inaccuracies in data summaries. However, understanding sector involvement is crucial for restoration, as management plans and educational materials would be designed appropriately for each sector.

In understanding the spatial distribution of restoration efforts, it is not too surprising to find most projects along the coastlines of developing countries, as this is where much of the coral reef in the world is found. However, because many developing nations lack resources to devote to environmental protection efforts, it might be just as plausible that developed countries would offer the majority of the restoration projects, due to their financial ability to pursue such ventures. Despite the noted density of reefs in the Coral Triangle, the majority of the projects were located in the Caribbean and Latin American region. This may be largely due to the inclusion of the United States and related territories (USVI and Puerto Rico). The United States offers a legal means to pursue reef restoration by way of the National Marine Sanctuaries Act which grants NOAA authority to file financial claims on parties responsible for reef damage, typically in the form of vessel groundings (NOAA 2010). Government initiated restoration in the United States targeting ship groundings may explain why the Caribbean and Latin American region demonstrated a higher frequency of ship groundings listed as a threat.

Projects within the Indian Ocean most frequently listed climate change as the source of damage to coral reefs. It is noted throughout the literature review that the 1998 El Nino, which brought increased sea surface temperatures, led to mass bleaching events throughout the world, though reefs in the Indian Ocean were hit particularly hard. Most nations within this region attribute the El Nino to coral reef degradation, including the Maldives.

Following the El Nino in 1998, several research teams studied the effects of the disturbance on the reefs of the Maldives and, in the face of extreme levels of decline, initiated projects to return the reefs to their pre-bleaching state (Clarks and Edwards 1994; Clark and Edwards 1995; Edwards et al. 2001; Schuhmacher et al. 2005). Though the Maldives serves as a popular reef research locale, most restoration efforts have been initiated by private companies, as noted by the frequency of their participation in projects from the literature review. The minimal mention of government involvement in the Maldivian
projects further emphasizes the lack of government participation in restoration ventures and reef protection measures as evidenced by the under-supported and under-staffed Marine Research Centre.

Transplantation, nurseries, artificial reefs, and mineral accretion have all been utilized in the Maldives (Clark and Edwards 1994; Clark and Edwards 1995; Goreau et al. 2000). Of these techniques, transplantation and artificial reefs are the most frequently used at various resort islands and typically involve guest sponsorship and participation in the transplantation process. Such projects benefit the resort: not only do they engage visitors so can contribute tourism dollars, but they assist with repairing localized coral damage. Resort islands are invested in these projects, as evidenced by the marine biologists employed on the premises. These resorts offer support to marine biology departments and marine educational programs and centers on island, all as a means to offer environmental outreach to international guests. Educational programs engage the local resort staff that partakes in the projects as well. Restoration projects create jobs and economy within the resort, but also have the potential to create jobs on local islands, as evident by the case of one company, which uses locally manufactured frames for coral transplantation.

Private company involvement in Maldivian restoration most frequently occurred via resorts partnered with marine consulting firms in order to recover resort house reefs. Due to the government’s limited capability to effectively monitor the coral reefs, granting each resort authority to manage their own reef allows for more feasible reef protection and restoration, and requires minimal resource input from the government. Resort-based management appears to benefit the country as a whole, not only because the coral reef cover and species biodiversity has increased in areas where privatized restoration projects exist, but because the efforts attract press. Journalists from all over the world have traveled to the Maldives to witness the restored coral reefs with their own eyes (and cameras), further promoting the message that the country is invested in the protection of their marine resources.

With private companies at the helm, the country has the potential to effectively manage their coral reef ecosystems via localized efforts. However, the Maldives would benefit from a country-wide integrated approach that encourages involvement from all relevant stakeholders and sectors and encourages the use of passive restoration efforts in order to develop cost-effective projects.
Statistical Analysis

The only statistically significant relationship found by chi square analysis was between geographic region and restoration method, which indicates that there is a significant difference in the use of passive and active approaches between geographical regions as observed in the case studies. This would further suggest that methods are specific to each region. However, while geographic location may influence the technique used, there are a number of factors that also dictate method, including resource availability, damage source (though here the relationship was found to be non-statistically significant), spatial scale of the damage, political and social conditions, existing partnerships between project participants, amongst a plethora of other variables that were not taken into consideration with this literature review. While this statistical result proves interesting, more research would be necessary to determine what influences the use of particular reef restoration methods.

The relationship between geographic region and threat type was found to be almost significant different and warrants attention. This would suggest that anthropogenic threats are concentrated by region, while natural events are observed worldwide. For example, destructive fishing is noted particularly in the Pacific Ocean, which may be a result of the high number of subsistence fishing communities in the region. Similarly, coral mining occurs predominantly in the Maldives as a result of development pressure and the need for easily accessible construction material. However, climate change and storms are observed in restoration projects worldwide.

No other relationships were found to be statistically significant. This may be a result of the data set. It may also be a result of the number of factors that influence method utilized and which groups participate in projects. Further research is necessary to determine what drives restoration practices. This would rely on more in-depth data collection, a task limited by the lack of information that currently exists.

Framework

While the framework is intended for specific use in the Maldives, it can easily be adapted for other regions in the world that are interested in pursuing effective coral reef restoration efforts, yet lack the resources to do so. In an effort to implement successful coral reef management tools, this framework engages managers in an active decision making process that promotes careful consideration of all options prior to implementation. Coral reef restoration is still a new field and projects must be developed
deliberately so that more damage is not inflicted onto the marine ecosystems and resources are not wasted.

The framework promotes this need for careful planning by asking managers to consider if restoration is even the best option. One crucial question managers must ask is whether or not coral was present in the site initially. While it may sound counter-intuitive to create a system from scratch, many resorts in the Maldives, and elsewhere, are interested in coral reef restoration as a tourist attraction. Reefs are created in easily accessible locations to encourage use by snorkelers and divers. However, many of these ‘restoration’ projects fail due to non-conducive environmental conditions. A general rule of thumb for managers to follow is that if coral did not initially exist at the site, there is probably a good ecological reason for that. Resources should be devoted to restoring damaged reefs, not creating novel ecosystems. Furthermore, coral may have the potential for natural recovery, especially when damaged by natural events such as storms, and restoration should be used minimally in these situations.

Though statistical analysis did not reveal relationships between all of the four variables of interest, it is still likely that they influence each other through the restoration decision-making process. It was for this reason that framework steps merged into each other. With the lack of information on coral reef restoration efforts, it is difficult to determine why particular methods are selected, or why particular groups are involved in projects, but this framework does accentuate that there is some relation.

Implications and Recommendations

While there are recommendations to make for the field of coral reef restoration, including the push for consolidated information to better direct future management decisions, there are also a number of recommendations specifically for the Maldives.

This literature review emphasizes the need for a forum to share and consolidate coral reef restoration project details. While restoration is site-specific, projects can learn effective techniques from previous work. Due to the current lack of consolidated information, coral reef restoration project details are difficult to access, and it is for this reason that this literature review is acknowledged as non-exhaustive. A number of projects, particularly in developing regions, may not have the ability to promote the restoration effort on the internet. On the other hand, many companies may advertise the projects as a means to recruit investors and clients and, in doing so, limit the amount of reliable information.
Research from peer reviewed literature has the potential to assist with coral reef restoration projects, if it is assimilated properly and into a format that practitioners, some who lack a research ecology background, can understand and utilize effectively. The wide variety of techniques used in coral reef restoration necessitates further research into the implemented methodologies. While the cases in the literature review indicated eight common methods, within each of these common techniques, there are a wide variety of means of implementation. For example, artificial reefs could take the form of a Reef Ball, a wire frame, cement blocks, or PVC racks. While there is a push to develop the most cost-effective method, future research should consider what environmental factors influence success on coral restoration projects. Further analysis into project specifics, including spatial scale, cost of project, coral species used, and environmental conditions that may contribute to the success of a restoration project would benefit the field. Research should also invest in the impact of threat mitigation on coral reef ecosystems comparatively to active restoration efforts.

Monitoring efforts must also become a focal point of future restoration work. It is crucial to include monitoring into the project development in order to measure delineated project success criteria and ensure the project has no negative impacts on the surrounding environment. Continued monitoring will depend largely on available funding and staff to conduct such efforts.

For the Maldives specifically, managers are in a unique position. Coral reef management has essentially been turned over to the resort islands, which hold jurisdiction as to whether or not perform restoration or not. While coral rubble may exist as a result to former mining ventures, climate change is most commonly attributed to the country’s coral reef decline. The country has enacted several policies to address anthropogenic threats such as coral collection and mining, but lacks the ability to address increased sea surface temperatures. The small island developing nation, unfortunately, stands little chance in addressing the global climate change threat. The former president, Mohammed Nasheed, was a strong force at climate change discussions, representing the small island developing states. His presence and adamancy at the need for global climate change reform brought attention to the Maldives; however, since the ousting of the first elected president after decades of dictatorship, and the resulting political uncertainty, the country is currently in a state of limbo shifting attention from marine resource management needs.

Recommendations specific to the Maldivian restoration effort include:
Pursue Passive Restoration Efforts

When degradation sources are identified, managers should focus efforts on eliminating or, at least, managing the threat as much as possible. Research indicates that reefs are prone to severe degradation if they are chronically stressed by anthropogenic sources of damage (Nystrom et al. 2000). It is in the best interest of the Maldives to analyze and properly manage potential threats, and if possible, mitigate against possible future threats. Though legislation has been enacted to protect reefs against coral mining, collection, and exportation, the country must make a concerted effort to enforce these policies. The country is also in dire need of addressing waste management and land-use changes as a result of increased development, as both issues can be considered potential threats to coral reefs.

Expansion of Efforts

While a number of resorts currently engage in reef restoration efforts, the country could benefit from an increase in these efforts on more resort islands, as well as on other island types. Though there are a number of complications with expansion, the country would benefit from encouraging more stakeholders to participate.

Over 100 resorts and hotels operate in the Maldives but only a small number of the resorts registered in the country advertise coral reef restoration activities. Engaging a majority of these resorts in reef restoration or monitoring would further the understanding of the current state of the country’s coral reefs. However, managing companies are not necessarily based in the Maldives and upper-management may not be aware of the ecological significance of coral reefs. Great effort would be involved in communicating with every resort and hotel managing company. Some resorts may be more suited to invest resources into a coral reef program, and due to discrepancy in revenue between the various resorts and hotels, any sort of country-wide program would inevitably be voluntary. If the country is to truly benefit from the research and data collected from the resort-based restoration projects, many more resorts must be encouraged to initiate their own.

To promote engagement in reef protection efforts, social surveys should be conducted to determine why resorts have not implemented restoration projects. Resorts that publicize environmental-friendly policies (e.g. prevent plastic water bottle usage; water re-use when possible) may be more likely to invest in coral protection and restoration projects on their island. It would be beneficial to understand 1) why (or why not) resorts were driven to (not) implement such projects, 2) what in-house environmental policies they
currently abide by, and whether or not such policies are company-wide or unique to the Maldivian resort and 3) what might incentivize resorts to undertake a restoration project. Also, because resorts are scattered through the 26 atolls, many islands would collect data and conduct restoration and monitoring in areas that government teams may be unable to reach easily. Restoration via privatized efforts is much more economically feasible for the Maldivian government, benefits the environment, and is fairly easy to initiate once resorts are willing to commit to a partnership with a private company. 

While the country benefits from the privatized efforts, this limits restoration to resort islands, which only make up a small fraction of the total number of islands in the Maldives. Inhabited and uninhabited islands, as well as faros, should also be considered for restoration. A country-wide restoration network would benefit the nation as it would increase biodiversity and coral cover in localized areas.

**Sector Integration and Communication**

Integration is absolutely necessary between the resorts involved in reef restoration, as well as between the resorts, the government, and all other groups in order to develop a unified country-wide effort. For this to occur, project information and research data should be shared between resorts and with the government and other stakeholders. The encouragement of more restoration projects would only be beneficial if these resorts could interact with one another and integrate the data collected. As of now, there is little communication between resorts. Even resorts that have partnered with the same private company do not interact, nor is there any means of data sharing between resorts. Effective integration can occur via online data sharing forums and workshops between resort marine biologists.

Access between the country’s multiple resort islands is limited by distance. Because of this an online data forum would be ideal. A database, similar to Reef Check, an online resource where groups can input data into a shared database, would promote standardization in data collection. An online data sharing site, though time consuming in initial set-up, would be cost-effective and fairly easy to implement. Unfortunately, data sharing would be voluntary which may pose difficulty in recruiting entities to join. Also, private companies, particularly those invested in the tourism market, may hesitate in sharing research, and may not want to advertise failed projects, or less than perfect results.

Additionally, periodic workshops should be held for resort marine biologists. To further promote communication and data integration, periodic workshops should be conducted to educate marine biology teams on project successes and failures, as well as pertinent research and news that would assist in
managing their own projects. Inevitable difficulties arise due to the distances between islands; primary efforts would be directed at engaging resorts within atolls in discussion. With the advent of tele-presence and Skype, communication can occur even across atolls. Workshops would require more funding, but would be incredibly beneficial to the advancement of protection and restoration needs.

Through these integrative options, data would not only available to other resorts and private entities, but to the government as well. By supporting the privatized restoration efforts, the government would benefit from access to the data that is collected by the projects. Because of the current limitations of the Marine Research Centre, by allowing private entities to manage reefs, more of the country’s marine resources are protected and monitored, than if the government alone was responsible for this task. The government also can use the workshops as a forum to express management and research needs that may be addressed through localized efforts.

Local Engagement

While private and government institutions are obvious stakeholders, any future marine resource protection plan development must consider the local islanders. Currently, with restoration efforts led by resort islands, locals are limited in their involvement. If the country is to create a strong sense of stewardship of marine resources, local islanders must be engaged in the protection and restoration of their coral reefs, which means that restoration efforts should include inhabited islands. Facilitated discussion via periodic workshops regarding marine resource needs should target locals and aim to encourage marine conservation and sustainable fishing techniques particularly in the face of increased development. Encouragement of local involvement also helps to incorporate local and traditional knowledge into environmental management decision-making.

In order to integrate locals into the coral protection and restoration efforts, social surveys should be conducted to gauge 1) how knowledgeable they are of the importance of marine resources, 2) whether or not they believe that their behavior impacts coral reefs, 3) what behavior they partake in that could potentially be damaging to coral reefs, 4) whether they feel marine protected sites and/or restoration efforts are necessary, and 5) what environmental issues they are concerned about. The responses would be helpful in addressing the gap between words and action, help the government to develop future policy, and engage the locals in environmentally-based decision making while promoting environmental education outreach.
Conclusion

Though conservation should be the first consideration for coral reef protection, restoration serves as an important management tool. It is for this reason that restoration has since become a popular method to address the noted coral reef decline throughout the world’s oceans. Reef restoration has been observed throughout the world, necessitated by a variety of damage sources, both anthropological and natural. Because of the site-specific nature of restoration projects, it is nearly impossible to generalize all of the previous restoration efforts into a ‘one-size-fits-all’ recovery response. Still, projects can learn from previous restoration efforts, if such information is consolidated and made easily accessible to managers. There is some indication that the methodology used may depend on the location of the project, as well as the sectors involved and the listed sources of damage, though further research is necessary to understand what drives restoration and influences its success. Such information can inform reef restoration frameworks that direct managers in the development of an effective project. Engaging managers in a thorough decision-making process encourages progress in the field of coral reef restoration and promotes effective implementation of future programs, particularly in developing nations reliant on healthy coral reefs, including the Maldives.
Appendix

Figure 1. Literature review project source types.
Table 1. Description of classified geographical regions of literature review projects.

<table>
<thead>
<tr>
<th>Geographical Region</th>
<th>Includes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caribbean/Latin America</td>
<td>Antigua, Bahamas, Barbados, Belize, Bermuda, Bonaire, British Virgin Islands, Cayman Islands, Costa Rica, Curacao, Dominican Republic, Honduras, Jamaica, Mexico, Puerto Rico, St. Maarten, Turks and Caicos, United States (Florida), US Virgin Islands</td>
</tr>
<tr>
<td>Coral Triangle</td>
<td>Indonesia, Malaysia, Papua New Guinea, Philippines, Solomon Islands, Timor-Leste</td>
</tr>
<tr>
<td>Indian Ocean</td>
<td>India, Kenya, Maldives, Mauritius, Mayotte Island, Seychelles, South Africa, Sri Lanka, Tanzania, Thailand</td>
</tr>
<tr>
<td>Middle East</td>
<td>Egypt, Israel, Jordan, Kuwait, Oman, Qatar, Red Sea, United Arab Emirates, Yemen</td>
</tr>
<tr>
<td>Pacific Ocean</td>
<td>American Samoa, Fiji, French Polynesia, Guam, Japan, Palau, Singapore, Tuvalu, United States (Hawaii), Vanuatu, Vietnam</td>
</tr>
</tbody>
</table>

Table 2. Description of project participant classifications.

<table>
<thead>
<tr>
<th>Group Type</th>
<th>Includes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Academic and research teams</td>
<td>Universities, non-government affiliated research institutions</td>
</tr>
<tr>
<td>For-profit organizations/companies</td>
<td>Corporations, consulting firms, engineering firms</td>
</tr>
<tr>
<td>Government</td>
<td>Local/state/federal agencies</td>
</tr>
<tr>
<td>Locals</td>
<td>Community members, local businesses, service organizations, school groups, tourism associations, volunteers</td>
</tr>
<tr>
<td>Non-governmental organizations/non-profits</td>
<td>Community based and international groups</td>
</tr>
</tbody>
</table>
### Table 3. Description of threat (damage source) classifications.

<table>
<thead>
<tr>
<th>Threat Type</th>
<th>Threat Source</th>
<th>Threat Explanation</th>
<th>Noted Characteristics of Damage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Anthropogenic</strong></td>
<td>Anchor Drops</td>
<td>Anchor, anchor chains, buoys, or diving platforms that have been dropped and/or dragged on reef.</td>
<td>Substrate/framework destruction, fragmented coral</td>
</tr>
<tr>
<td></td>
<td>Coral Collection</td>
<td>Human removal of coral for aquarium trade/personal collection.</td>
<td>Fragmented coral, lack of marine diversity/abundance</td>
</tr>
<tr>
<td></td>
<td>Destructive Fishing</td>
<td>Use of dynamite or poison in order to harvest reef fish.</td>
<td>Disruption to substrate/framework, lack of marine life diversity/abundance</td>
</tr>
<tr>
<td></td>
<td>Development</td>
<td>Often associated with dredging. May also involve sedimentation as a result of terrestrial based development projects.</td>
<td>Bleaching events, framework destruction</td>
</tr>
<tr>
<td></td>
<td>Mining</td>
<td>Use of iron rebar or dynamite to break apart reefs for use as construction material.</td>
<td>Substrate/framework destruction, fragmented coral</td>
</tr>
<tr>
<td></td>
<td>Overfishing</td>
<td>Unsustainable fishing techniques on reef fisheries.</td>
<td>Lack of marine life diversity/abundance</td>
</tr>
<tr>
<td></td>
<td>Pollution</td>
<td>Waste management concerns and run-off from terrestrial systems.</td>
<td>Bleaching events</td>
</tr>
<tr>
<td></td>
<td>Ship Groundings</td>
<td>Ship or small vessel running aground on a shallow reef.</td>
<td>Evident ship present, framework destruction</td>
</tr>
<tr>
<td></td>
<td>Tourism</td>
<td>High levels of human presence. Inexperienced divers/snorkelers and related boat traffic.</td>
<td>Fragmented coral</td>
</tr>
<tr>
<td><strong>Natural</strong></td>
<td>Biological Disruption</td>
<td>Presence of invasive and/or predatory species that directly impact reef (e.g. Crown of Thorns starfish), or algal blooms.</td>
<td>Lack of marine diversity/abundance, presence of algae/invasive species/predator</td>
</tr>
<tr>
<td></td>
<td>Climate Change</td>
<td>Typically associated as ocean acidification and increased sea surface temperatures</td>
<td>Bleaching events</td>
</tr>
<tr>
<td></td>
<td>Disease</td>
<td>Examples include white band disease, black band disease,</td>
<td>Evident signs of disease, bleaching event</td>
</tr>
<tr>
<td></td>
<td>Sedimentation</td>
<td>Oft related to loose substrate, or as a result of terrestrial erosion.</td>
<td>Bleaching events, unstable substrate</td>
</tr>
<tr>
<td></td>
<td>Storms</td>
<td>Wave action and related events as a result of hurricanes, tsunamis, and typhoons.</td>
<td>Fragmented coral</td>
</tr>
<tr>
<td></td>
<td>Wave Action</td>
<td>Natural wave action and/or currents.</td>
<td>Fragmented coral</td>
</tr>
</tbody>
</table>
Table 4. Coral reef restoration method classifications.

<table>
<thead>
<tr>
<th>Approach</th>
<th>Method</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passive</td>
<td></td>
<td>Limited human intervention. Often addresses removal of damage source, but does not deal directly with the damaged coral reef.</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Active</strong></td>
</tr>
<tr>
<td></td>
<td>Artificial Reefs</td>
<td>Artificial substrate provided to encourage coral larvae recruitment or to transplant coral fragments directly to. Adds topographic complexity to sites with limited substrates. Examples include: Reef Balls, frames, plugs.</td>
</tr>
<tr>
<td></td>
<td>Biological Recruitment</td>
<td>Often seen as directing coral larvae onto a particular substrate in order to encourage growth.</td>
</tr>
<tr>
<td></td>
<td>Mineral Accretion</td>
<td>Use of electrical current to mimic the natural coral reef skeleton on a frame in order to encourage coral reef growth of transplanted fragments. Process patented by the Global Coral Reef Alliance (GCRA) as Biorock.</td>
</tr>
<tr>
<td></td>
<td>Nursery</td>
<td>Nurturing of coral fragments above water or in water nurseries. Fragments are nurtured, then often transplanted to degraded reefs.</td>
</tr>
<tr>
<td></td>
<td>Substrate Stabilization</td>
<td>Stabilizing substrate damage by filling in holes or gashes with cement that result from direct impact.</td>
</tr>
<tr>
<td></td>
<td>Transplantation</td>
<td>Fragments from a healthy reef are moved to a degraded reef. Various forms of fragment attachment to the reef are used.</td>
</tr>
<tr>
<td></td>
<td>Triage</td>
<td>Turning over coral heads. Reattachment to substrate. Often used in emergency coral restoration efforts.</td>
</tr>
</tbody>
</table>
Acknowledgements

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